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Johnson Space Center

Research and Technology
Annual Report 1990

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Johnson Space Center

Research and Technology

Annual Report 1990

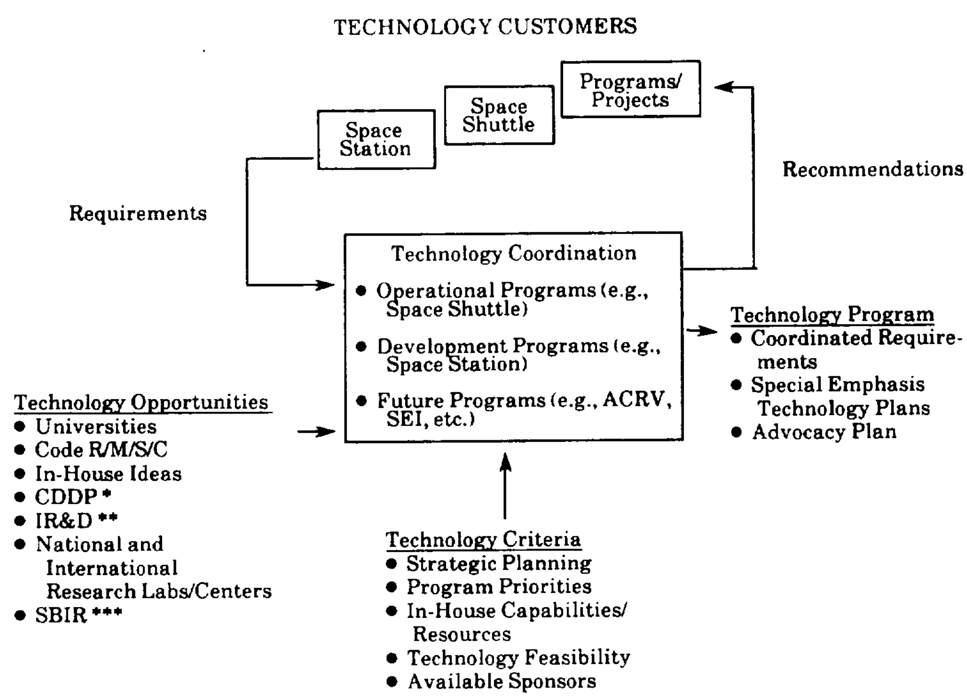
March 1991

Prepared by
New Initiatives Office
Lyndon B. Johnson Space Center
Houston, Texas

INTRODUCTION

The roles and missions of the Johnson Space Center (JSC) include significant portions of the Agency's Space Shuttle, Space Station Freedom, Space Exploration Initiative, and Science and Technology Programs. In particular, the Center has unique capabilities in program management, space operations, lunar and planetary geoscience, and all aspects of human presence in space. The success of JSC, in major part, can be attributed to the unique facilities that have evolved in support of the Agency programs and to the depth and breadth of expertise provided by the Center personnel. Although JSC is considered a NASA development center, its involvement in research and technology (R&T) programs continues to be crucial from two aspects: (1) training and development of highly qualified employees able to specify and monitor the development, testing, and operations of complex space systems, and (2) providing systems ensuring safety of humans in space and cost-effective mission operations. In view of this, JSC is conducting significant space-related R&T development in accordance with its roles and mission.

In an effort to streamline the R&T planning and management process during the past year, JSC has implemented the strategy shown on the following chart:



*CDDP = Center Director's Discretionary Program **IR&D = Internal Research and Development
***SBIR = Small Business Innovation Research

This process continues to be beneficial in the identification of R&T thrusts which are deemed important for the Agency's programs, as well as those essential to support the roles and missions of JSC. Over the year 1990, JSC has communicated

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R&T thrusts identified through this process to NASA Headquarters by means of RTOP submissions and working groups/committees in which JSC participates. This interaction has resulted in a focused and prioritized implementation of JSC R&T efforts. In the future, we anticipate providing comprehensive inputs to the Agency programs and plans, as well as developing interdependent programs with other NASA centers, government agencies, educational and research institutions, and industry.

The Johnson Space Center Research and Technology (R&T) Report is published to highlight the Center activities during the past year. This report serves to communicate within and outside the Agency our significant R&T efforts, as well as to inform Headquarters' R&T program managers and their constituents of the significant accomplishments that have promise in future Agency programs. While not inclusive of all R&T efforts, the report represents a comprehensive summary of JSC's activities with the corresponding technology focal points identified in the Index.

The JSC R&T annual report is organized in four sections:

- The Life Sciences Section provides a review of the broad range of applied medical programs in support of life sciences and human presence in space. These projects represent substantial commitment on the part of JSC to provide excellent support for the Agency's long range plans, including lunar outpost and manned missions to Mars.

- The Solar System Sciences Section contains a sampling of the projects in support of human exploration of the solar system. This R&T effort deals with the characteristics, origin, and evolution of the debris, terrestrial planets, asteroids, and satellites (the rocky objects located in the solar system). In addition, the research on the practical use of the planetary resources to support and maintain human presence and expansion into the solar system is covered.

- The Space Transportation Technology Section dwells on the projects that support human systems and space operations associated with the Agency's transportation infrastructure. The JSC has made significant progress in the design and development of human spacecraft and associated technologies in support of the Agency's advanced operations. Closed-loop life support systems will be necessary for the Agency's long range programs. The JSC efforts in support of this vital Agency goal are included in this section.

- The Space Systems Technology Section encompasses technical areas which include human factors/man-machine cooperation, extravehicular activity; control and guidance; materials and structure, automation and robotics; on-orbit assembly and construction; servicing; life support; propulsion; power; thermal, and communications and tracking. The technology dimensions cover those considered evolutionary and emerging, as well as the mission-driven ones. The JSC has made outstanding contributions in the software simulations of hardware systems and functions and human-machine interfaces, which have become invaluable tools in the specification and prediction of systems level performance.

This report was developed under the guidance of the Chief Technologist, New Initiatives Office, and represents a coordinated endeavor with JSC line organizations, most notably the Administration, Information Systems, Space and Life Sciences, and Engineering Directorates. The schedule for this report represents a formidable challenge, as most of the work had to be performed during the months of December 1990 and January of this year. The authors of the individual reports are therefore commended for their timely efforts. Personnel listed below have coordinated the technical inputs in specific sections and written summaries for their respective sections. Detailed questions may be directed to me, the section coordinators, or the principal investigators listed in the index.

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Life Sciences

Summary

Life Sciences

The NASA Johnson Space Center (JSC) conducts a broad range of applied medical programs in support of Life Sciences goals. These goals ensure the health and performance of humans in space, first by characterizing the medical consequences of spaceflight, and second by developing research and technology programs focused on validating countermeasures for biomedical problems precipitated by spaceflight exposure. A further goal is to exploit the unique properties of space environment as a means of increasing and improving fundamental knowledge in medicine and biology.

The Extended Duration Orbiter Medical Program, which endeavors to protect the space crews' ability to perform egress, entry, and landing after lengthy Space Shuttle flights, is well under way. NASA, contractor, and advisor teams in the areas of environmental health, biomedicine, cardiovascular medicine, exercise, muscle, and neurophysiology are implementing studies to develop and test flight countermeasures and countermeasure hardware.

Defining the requirements for Space Station Freedom continues as the Station design evolves. Medical hardware for the crew health care subsystem is under development. Microbiologists are developing an automated system to detect, count, and identify microorganisms in environmental and clinical specimens in space and to test their sensitivity to antimicrobial agents. Some prototype instruments for testing air and water quality have been flown onboard the Space Shuttle. Toxicologists are working with the National Research Council to establish new limits for both short-term and long-term exposure to potential atmospheric contaminants.

Work continues on developing and evaluating techniques and hardware for Freedom's Health Maintenance Facility, including provision of respiratory and surgical support for injured crewmembers, inhalational drug delivery systems, and production of sterile intravenous fluids from potable water onboard Freedom.

For research at the cellular level, the Biotechnology Program continues to develop its fully automated cell culture system. This system has been designed to simulate some of the fluid-mechanical conditions of microgravity; it also can be used in microgravity for raising high-fidelity tissue models and other applications. *In vitro* biochemical studies are under way to understand the functioning of the blood-brain barrier in response to microgravity-induced fluid shifts.

Physiological studies in fiscal year 1990 have included evaluations of a new drug and an alternative drug-delivery system for preventing or ameliorating motion sickness; development of a method for determining nutritional (caloric) requirements for humans during space travel; exploration of how exposure to microgravity affects postural equilibrium; and evaluation of how exercise affects later performance during extravehicular activities.

The following sections describe these and other research and technology efforts in the Life Sciences area.

Life Sciences

Significant Tasks

Ventilator Function in Hyperbaric Conditions

TM: Charles W. Lloyd, Pharm. D./SD2
PI: William T. Norfleet, M.D./SD2
Joey B. Boyce, M.D./SD2
Reference LS 1

Respiratory support for one injured crewmember onboard Space Station Freedom is required in three areas:

- At the Health Maintenance Facility (HMF),
- Within a transport vehicle, and
- Within the Hyperbaric Airlock [HAL].

This paper reports on a study that sought to obtain performance data for an HMF-type ventilator (Siemens Servo 900C) and a transport-type ventilator (AutoVent 2000) in a hyperbaric environment. The objective was to determine set versus delivered expired-minute volume (V(dot)E), breathing frequency (f), and tidal volume (Vt).

Experiments were performed in a multiplace chamber complex. Data were collected at ambient pressures of 1.0, 2.8, and, in the case of the 900C, 6.0 atmospheres absolute pressure (ATA). Air was supplied to the ventilators at 50 psi above ambient chamber pressure. The 900C was arranged to deliver gas from the inspiratory limb into a 2-liter anesthesia bag, then into the expiratory limb of the ventilator, and, finally, through the ventilator gas exhaust into a gas collection system. The AutoVent was configured to exhaust directly into the gas collection device; all sources of gas leakage from the patient valve assembly were occluded. Gas delivered by the ventilators was collected into a 10-liter Ohio rolling seal spirometer. Output of a potentiometer connected to the spirometer was recorded by a Grass polygraph located outside the chamber. Measurements of V(dot)E, Vt, and f were determined by examination of the polygraph tracings. Calibration of the gas-monitoring system was accomplished before each round of data collection with a 2-liter volumetric syringe. The following settings were maintained on the 900C throughout experimentation: Working Pressure = 80 cm H_2O, Mode = Volume Control, Inspiratory Time = 33 percent, Inspiratory Pause = 10 percent, PEEP = 0 cm H_2O, Trigger Sensitivity = −20 cm H_2O, and Inspiratory Pressure Level = 0 cm H_2O. This device was enclosed in a nitrogen-purged Lexan box for prevention of electrical fires. The setting, Tidal Volume = 1200 mL, was maintained on the AutoVent throughout experimentation.

Data concerning V(dot)E delivered by the 900C are shown in figure 1. Operating the 900C involves setting first the V(dot)E, then the f; Vt is implicit from these settings. The abscissa in figure 1 displays set f. Delivered f was very close to set f (data not shown). The left-most bar of each group of bars relates set V(dot)E. Delivered V(dot)E data at each of three ambient pressures are grouped to the right of each "SET" bar. The group of data labeled "Max" was obtained when the 900C was set to deliver

- A V(dot)E = 99 L/min, and
- A tidal volume (via adjustment of f) that resulted in a peak inspiratory pressure (PIP) of 40 cm H_2O.

These settings forced the ventilator to deliver as much gas as possible. As can be seen in this figure, delivered V(dot)E was very close to set V(dot)E at 1 ATA, but it fell short at raised ambient pressures. The 2.8 ATA produced over 20 L/min. Data derived from the AutoVent are displayed in a similar manner in figure 2. Set and delivered V(dot)E were approximately equal at 1 ATA, but performance dropped off at 2.8 ATA to an extent somewhat greater than that of the 900C. Figure 3 is of greater clinical significance. Again, the unit performed well at 1 ATA but suffered significant degradations of performance at 2.8 ATA. A maximal Vt of less than 400 mL was maintained, a figure which is inadequate for ventilation of a 70-kg adult. In view of these data, tests of this ventilator at 6 ATA were not deemed worthwhile.

The Siemens Servo 900C uses a servo feedback design to adjust the operation of scissor valves to maintain set ventilatory parameters. A pneumotachograph in the gas circuit provides this feedback. Because pneumotachographs are sensitive to changes in gas density, it is not surprising that the 900C performance varied with ambient pressure. Despite this limitation, the overall unit performance would permit adequate ventilation of a 70-kg adult under most clinical circumstances at ambient pressures of at least 6 ATA. The experimental design imposed a severe load on the 900C through the use of a 2-liter anesthesia bag as the "test lung." The PIPs of 50 cm H_2O were observed. Despite this simulation of poor pulmonary compliance, the unit delivered gas in close approximation to set parameters during experiments at 1 ATA. This supports the contention that degradations in performance seen at raised ambient pressures also would have been seen if less severe pulmonary disease had been simulated.

In this study, extensive precautions were taken to prevent an electrical fire induced by the 900C. Although the ventilator provided adequate gas delivery, this device is not ideal for use in hyperbaric conditions. The AutoVent 2000 is a compact, powerful ventilator which delivered gas in close approximation to set parameters at 1 ATA. Its performance in hyperbaric conditions was inadequate, probably as a result of the inherent design of this constant flow, time-cycled pneumatic system conditions. The AutoVent 2000 is a compact, powerful ventilator which delivered gas in close approximation to set parameters at 1 ATA. Its performance in hyperbaric conditions was inadequate, probably as a result of the inherent design of this constant flow, time-cycled pneumatic system.

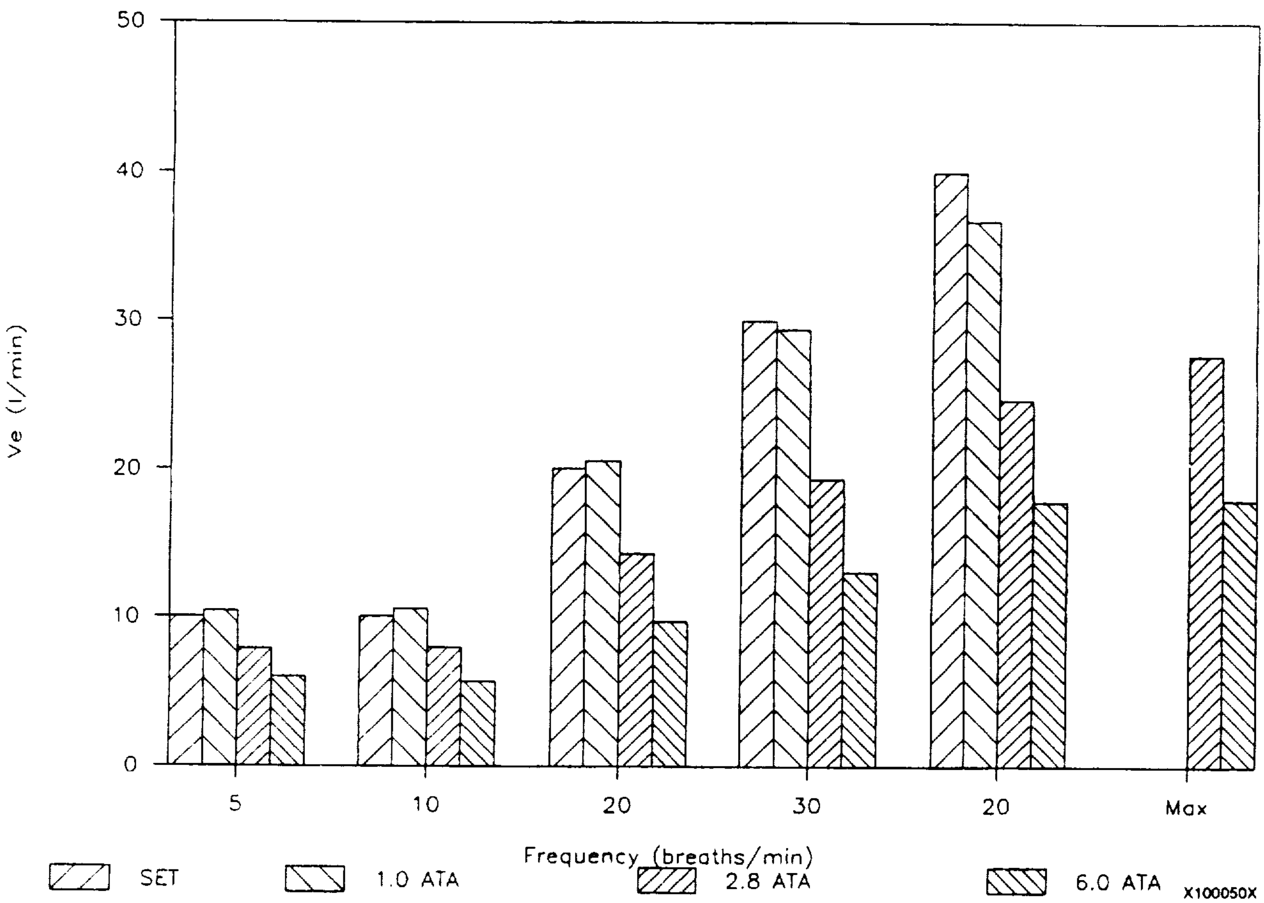

Figure 1. Minute ventilation volume using the Siemens 900C ventilator.

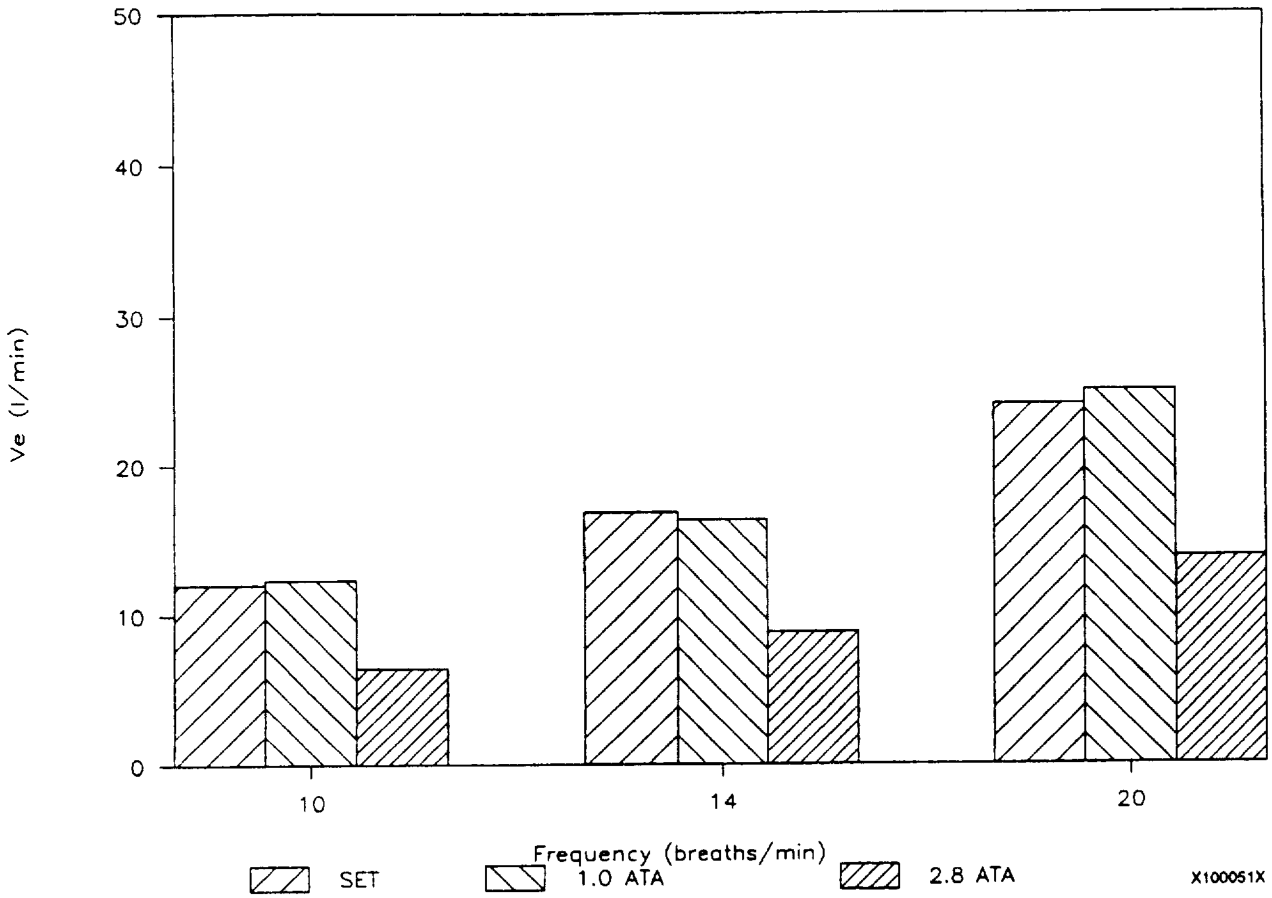

Figure 2. Minute ventilation using the AutoVent 2000 ventilator.

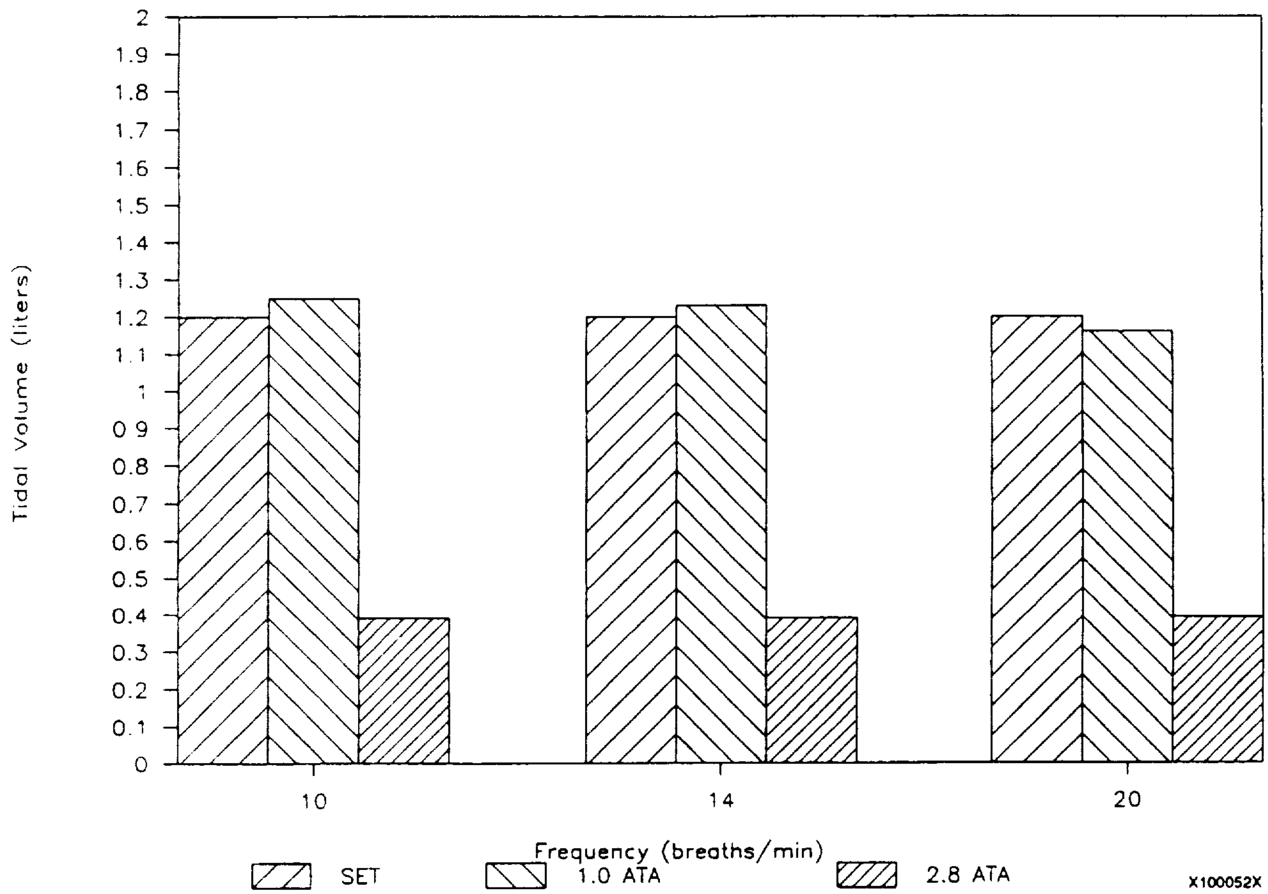

Figure 3. Tidal volume using the AutoVent 2000 ventilator.

Phase I Evaluation of Aerosolized Medications During Parabolic Flight

TM: Charles W. Lloyd, Pharm. D./SD2
PI: Charles W. Lloyd, Pharm. D./SD2
William J. Martin, Pharm. D./St. John Hospital; Detroit, Mich.
John Gosbee, M.D./SD2
Reference LS 2

Onboard Space Station Freedom (SSF), an extensive inventory of pharmaceuticals, including aerosolized medications, will support the Crew Health Care System medical functions. Regarding aerosolized medications, inhalation devices are an efficient and minimally invasive method for delivering drug products to the respiratory tract and, in some cases, to systemic circulation. These drug products are in either an aerosolized liquid or suspension and may be delivered by

- Standard spray bottle,
- Pump spray bottle, and/or
- Pressurized spray bottle.

The concern with aerosol devices is that they may not consistently deliver the manufacturer's preset dosage (i.e., inhalation, puff, nozzle actuation) in zero-g conditions. To better characterize the effects microgravity may have on these products and to determine if they would be a viable means for delivering drug products on SSF, they were tested during parabolic flight onboard the KC-135 aircraft.

The goal of this evaluation was to determine visually if an aerosolizing device is an acceptable method of drug delivery in a zero-g environment. The experiment was designed to compare patterns of spray dispersion under control one-g and zero-g conditions. Part of the experiment consisted of an attempt to determine the total volume of drug product available when used in a zero-g environment.

The experiment was performed inside an acrylic glove box (see figure) to ensure the safety of the investigators during parabolic flight. The procedures were initially run in a one-g setting to determine the appropriate setup for the high-speed filming. During one-g testing, it was determined that all products were position-dependent. In each case, the device failed to function properly within several actuations of the devices. The drug products were selected based on device function:

- Afrin® (standard spray bottle)
- Nostril® (pump spray bottle)
- Cetacaine®, Ventolin® (pressurized spray bottle)

During the first set of 10 parabolas, each of the half-full containers was used, and the spray dispersion was filmed. In all cases, at least three actuations of the device were filmed. The Cetacaine® spray device appeared to function normally, and the spray stream remained continuous throughout each actuation. During parabolas six and seven, the Ventolin® inhaler was filmed with no notable failures. The pump spray container was evaluated early and late during parabolas eight and nine. The operator stated that the device appeared to fail when the fluid shifted up into the neck of the bottle. The failure was characterized as occurring sporadically and late in the parabola.

Starting with parabola three of the second set, the full containers were used in the order outlined above. Each device was filmed early in the first parabola and late during the second parabola. All devices, except the standard spray bottle, appeared to function without failure. When the standard spray bottle was used, it was actuated with the nozzle tip pointing either slightly upward or outward, with the tip level to the base of the glove box. This device appeared to function properly in an intermittent fashion. Three types of spray patterns were noted throughout the flight:

- Normal mist spray which forms a v-pattern as the spray leaves the nozzle. This usually occurred when the device was nearly full and the nozzle tip was pointed upward.

- A simple narrow stream of liquid. This occurred if the nozzle tip was pointed outward, level with the base of the glove box. It appeared to occur when fluid moved up into the neck of the bottle.

- Slight bubbling and little or no fluid. This occurred more as the bottle was used.

During the last set of parabolas, it was assumed that all of the containers were nearly empty, and the Cetacaine® and Ventolin® inhalers continued to function without a failure.

The volume of fluid in the partially filled containers was believed to represent normal overfill. The residual volume of the full containers suggested

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that there was insufficient flight time to use properly the entire contents of these devices.

After reviewing the film and photographs, it was determined that pressurized aerosol containers appeared to function better than either the standard squeeze-type or pump-type bottles. It was reported in the biomedical findings of the Apollo Program that the standard squeeze-type dropper bottle did not function well; however, no comments were made regarding the other type of aerosol bottles evaluated in this experiment.

During future parabolic flight evaluations of aerosols, it is recommended that a more accurate measure of the device function be required. Clear containers should be used to better characterize the effects of zero-g on the fluids in these containers.

Enclosed work space for zero-g evaluation of aerosols.

On-Orbit Formulation of Intravenous Fluids

TM: Charles W. Lloyd, Pharm. D./SD2
PI: Gerald J. Creager/SD2
Charles W. Lloyd, Pharm. D./SD2
J. Ogle /Baxter Healthcare
Reference LS 3

Intravenous (IV) fluid administration is a fundamental aspect of terrestrial medicine and is expected to remain a valuable adjunct in spaceborne practice. The IV fluids represent a bulky, heavy cargo if carried to space in the terrestrial form. In conjunction with the design of the Space Station Freedom (SSF) Health Maintenance Facility, NASA is developing a technique to produce sterile IV fluids using potable SSF water and sterile concentrates that conform to the United States Pharmacopoeia Volume XXI (USPXXI) and the National Formulary Volume XVI.

Potable water is purified, using either conventional or new technologies: a passive column purification system which removes macroscopic particulates, organic compounds, ionic species, and endotoxins; a reverse osmosis system with membrane filtration; or an ion chelation technology. A submicron filter is utilized in all systems to provide sterilization immediately prior to introduction into the final container (bag).

The IV fluid formulation has been studied extensively to determine the best method to use in microgravity. Evaluations of powder mixing and dissolution, packaging, sterility, and ease of use were undertaken. The options included powders and concentrates in the final container, concentrates added to a container of sterile water, dissolution of powders with sterile water and reintroduction of the additive, in-line ("flow-thru") dissolution and mixing of powders prior to the bag, and flow-thru mixing of liquid concentrates.

The system selected accomplishes fluid formulation, utilizing in-line mixing of liquid concentrates. This system was selected because of the relative ease of handling for the operator, simplification of sterility and sterility assurance, and simplification of the final container design. In addition, concerns about the dissolution of powders without external mixing devices or increased temperatures caused redirection to liquid concentrates for this process. The water purifier output, which meets USPXXI standards for water for injection, is routed through a series of plastic tubes containing the concentrate for the desired IV fluid. The tubes are packaged in a serpentine pattern that promotes nonturbulent flow within the package, improving mixing of the concentrate with the purified water. A final sterilizing filter of 0.22 micron mean pore size is interposed between the formulation package and the final container. Although this filter does not provide for removal of viruses, this was considered an acceptable program risk. Terminal mixing occurs within the bag caused by the fluid flow. The IV bag filling is terminated by volume limiting within a fabric containment garment. The volume of the garment is sized to 1 liter. The system is shown in the first figure. The next figure shows the formulation packages for 5 percent dextrose and 0.9 percent sodium chloride.

The mass and volume required for storage of this system is reduced significantly when compared to the volume of a conventional bag (1 liter) of IV solution. The typical IV formulation package requires less than 100 ml volume and has a mass of less than 150 grams, including packaging. The (empty) IV bag masses 100 grams and requires ~65 ml volume. The mass and volume of the water purification system are dependent on the final design selected, but will be less than 10 liters volume and 15 kg mass, with a capacity to produce over 200 liters total purified water for formulation of IV fluids.

In designing the system for spaceflight use, particular attention was paid to the problem of liquid spills in microgravity. An innovative use of valved connectors was proposed to reduce the possibility of inadvertent leakage from the various components of the system on orbit. Standard 1/8-turn threaded plastic connectors ("Luer-locks") equipped with pressure-actuated valves were incorporated onto the IV bags to provide dripless connections. This design differs from the terrestrial IV bag in that the Earth-based application utilizes a sharp spike to connect the tubing that carries the fluid from the IV bag to the patient.

The system developed for IV fluid formulation in microgravity is an innovative response to the requirements placed on technology for use onboard the SSF.

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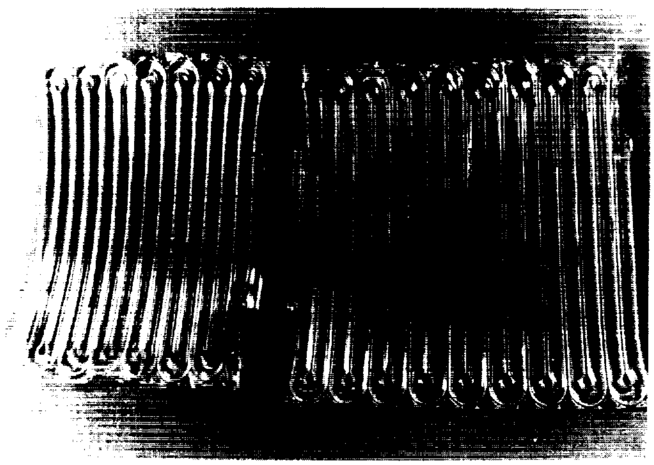
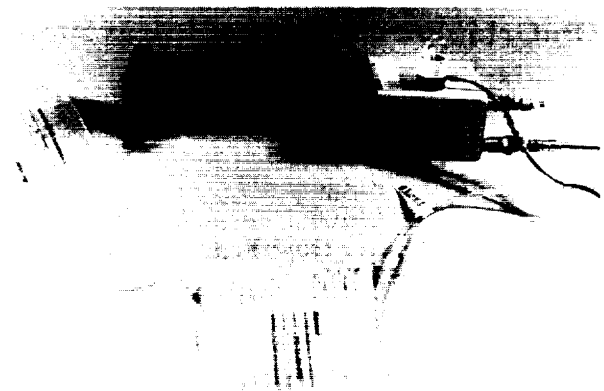


Prototype inflight IV fluid system.



Liquid concentrates for use in fluid formulation.

Development of a Surgical Support System for Space Station Freedom

TM: Roger D. Billica, M.D./SD2
PI: Roger D. Billica, M.D./SD2
Frank T. Eichstadt/MDSSC
Reference LS 4

Human surgery has yet to be performed during spaceflight. However, with increasing man-hours in space, prolonged mission duration, and expanded activities, including construction tasks, the need for surgical capabilities is inevitable. The Health Maintenance Facility being developed for Space Station Freedom is planned to contain a level of surgical capability that can handle minor surgical needs such as repair of lacerations and management of trauma. It is hoped that the experience gained in developing and using this facility will prepare the way for more extensive surgical capabilities for future space exploration.

The first phases of investigation into surgical requirements and facilities have focused on the basic needs of medical restraint, patient and surgeon preparation (such as creating a sterile operating field, patient draping, gloving, and gowning), lighting, and instrumentation. With the design of a functional medical restraint system (MRS), it has been found that most of the other functions required to perform minor surgery can be done simply and effectively in zero-g with minimal modification to Earth-based practices.

The exception to this reliance on traditional methodology has been in the area of hemostasis (control of bleeding and prevention of fluid loss) and maintenance of a clear field-of-view for the surgeon. Zero-g presents unique challenges in areas of fluid behavior that seriously affect the surgeon's ability to provide hemostasis and maintain a sterile and clear field. Many of the procedures used for these tasks on Earth rely upon gravity.

Therefore, in addition to providing the usual surgical equipment, instruments, and supplies, a stepwise approach is proposed for providing the needed support system for conducting surgery in microgravity. This surgical support system consists of a modular three-tier approach that provides adaptable methods for conducting a variety of surgical procedures. The levels, or tiers, of support employed for any given procedure would depend on the complexity of the procedure and the degree of hemostasis and fluid control anticipated.

Tier 1 consists of the MRS, surgical preparatory materials to create a sterile field, local surgical drapes (adhesive), instrument restraint tray, and local suction capability. This tier would provide capability for most minor procedures such as repair of small lacerations. Limited amounts of bleeding and fluid loss can be managed easily through the use of local absorbent barriers (gauze, etc.) and local suction. This is very similar to traditional medical practice found in any clinic or emergency room.

Tier 2 is accomplished through the addition of a laminar flow/particle containment device to Tier 1 (first figure). This device has been tested in KC-135 parabolic flight and functions to contain errant fluid droplets, particles, and cautery fumes that may be created in more complicated procedures or dental operations. It also assists in preventing environmental contamination from affecting the operative site.

Tier 3 provides a clear, inclusive chamber that surrounds the operative area defined by Tiers 1 and 2 (second figure). This surgical canopy concept has been tested in KC-135 parabolic flight and is undergoing further design development. It provides surgeon and equipment access to the surgical field while maintaining a control zone to keep environmental contaminants out of the sterile field. It also assists in preventing blood, fluids, or infectious material from escaping into the Space Station environment. It would be utilized in the most complex procedures where vigorous fluid loss or arterial bleeding is anticipated or in instances of infected wounds or need for wound irrigation.

Laminar flow/particle containment device being used in simulated surgery during KC-135 flight. Directional laminar airflow originates from under the instrument tray (left). Suction collection occurs through funnel trap (right). Handheld local suction also is employed (center).

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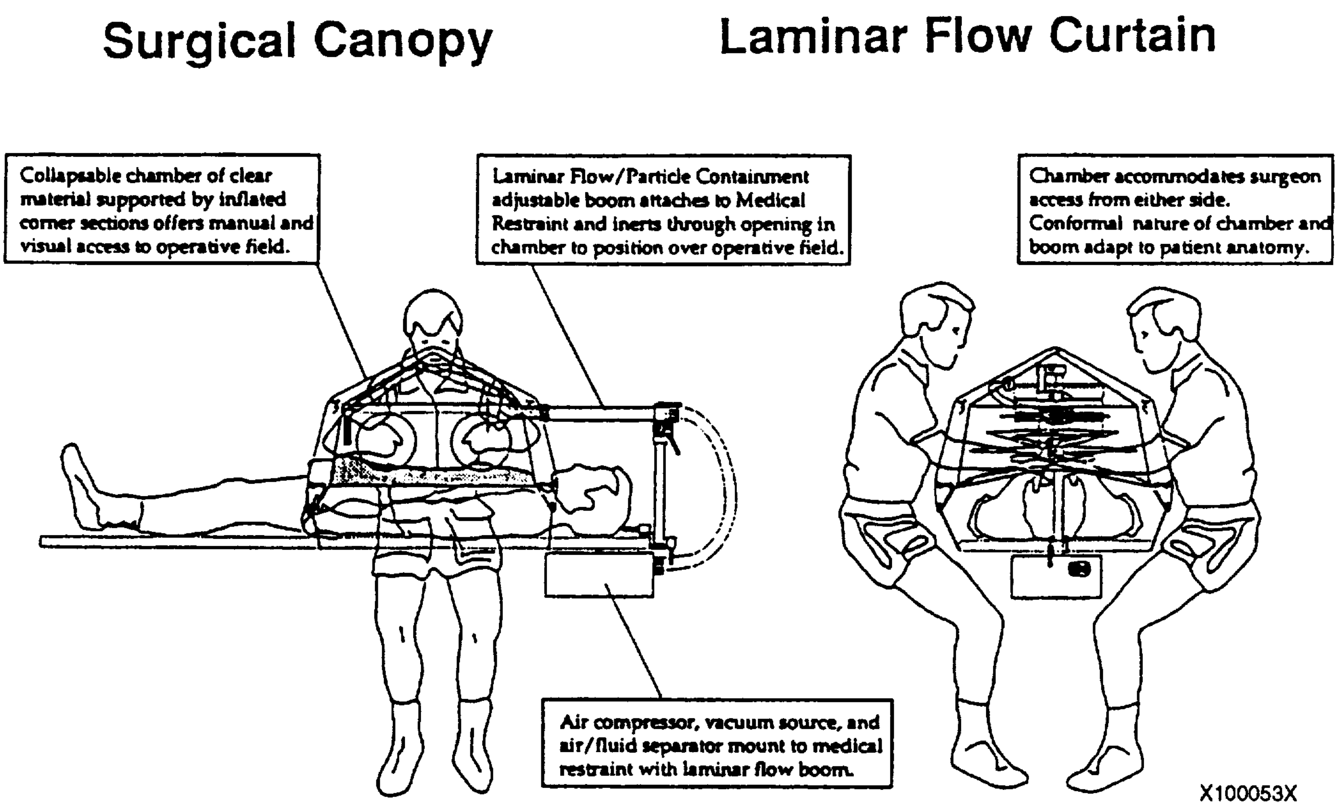

Surgical canopy allows controlled access to sterile operating field while providing laminar flow and suction.

Venipuncture and Indwelling Intravenous Infusion Access During Zero-Gravity Flight

TM: Joey B. Boyce, M.D./SD2
PI: Debra L. Krupa, R.N./SD2
Gerald J. Creager/SD2
Joey B. Boyce, M.D./SD2
Reference LS 5

The properties of fluids and the function of an intravenous (IV) administration set have been investigated in the development of health care delivery capabilities for space travel, although venipuncture and successive administration of IV fluids into a human had not been demonstrated successfully. It was hypothesized that there might be potential changes to procedures followed in one-g for the successful completion of this process.

A flight experiment onboard the NASA KC-135 aircraft was performed to test the difficulty of securing an IV catheter in zero-g flight, evaluation of procedural techniques for training the Crew Medical Officer (CMO), and selection of appropriate hardware and supplies for use in space. The IV placement was accomplished on one human subject by two separate Crew Medical Officers (CMOs), and the complete fluid administration system was activated to measure system performance. Procedures were performed only during zero-g to maintain appropriate evaluation of the process. Two successful venipunctures were executed, with the IV pump experiencing intermittent failure to function on the second administration.

In determining the difficulties associated with IV access in a microgravity environment, it was found that the technical skill required of the CMO does not differ from that for one-g. Most critical for successful completion are the proper placement and restraint of the CMO and patient, organization of the supplies and equipment, and placement of materials within easy reach. The venipuncture itself is highly dependent upon the current technical skill of the CMO for successful completion.

Evaluation of the various methods of securing an IV catheter and attached tubing for infusion showed that the techniques used in one-g before transporting a patient are appropriate for use in the microgravity setting. Unrestrained, free-floating tubing should not create a problem except in cases of sterile field or with excessive patient movement. Assessment of the various materials available for securing an indwelling IV catheter led to the recommendation to use transparent transpore tape, which is easily torn to preferred size and shape for application, is easily removed, and maintains appropriate adhesive properties.

Verification of the integrated fluid therapy administration system was completed as predicted with the system functioning well from end to end. The two major difficulties encountered during flight were

- Priming the fluid administration tubing with the fluid bag, and
- A mechanical problem with the pump on the second insertion attempt.

After catheter insertion, the pump functioned well with continuous instillation of fluid during various movements of the patient's extremity. The pump and administration set were easily installed, programmed, and activated. The CMO preference was the only difference noted in catheter usage. The guidewire, closed-system catheter appeared to contain all fluids well. The angiocatheter did not contain the drainage of insertion fluids; however, it was easily prevented with CMO technique.

Several recommendations for further investigation evolved during this test:

- A method should be developed for collection and management of the numerous small tip/cap covers on the ends of tubing and fluid bags.
- Velcro or another measure for securing the fluid bag to the pump should be made available.
- Difficulty in purging the fluid bag into the tubing should be investigated further to discover the cause, and this information should be used in the design of all future bags/tubing for space travel.
- Stable restraint of the CMO is essential for successful completion of this procedure.
- Placement of audio or other switches on the posterior of the pump should be removed from the design of the pump. Failure during the second insertion was discovered to be related to pressure against the audio switch when the pump was secured to the aircraft.
- Additional investigation of packaging content and access to the numerous small items required for indwelling venous catheter insertion should be made in one-g prior to performance on the Space Shuttle mission.

- Excellent functioning of the guidewire catheter in fluid containment for IV access suggests a strong preference for consideration on Space Station.
- Training of the CMO in this skill can be accomplished easily in one-g. However, this skill is ideal for instruction in microgravity, as it integrates numerous concerns for patient positioning, CMO restraint, supply access, fluid containment, equipment activation, and waste management of all types (wet, dry, and sharp).

Placement of an IV catheter in microgravity is easily accomplished by someone who is well trained and current in the skill. The procedure is a representative task of one very likely to occur on the Space Station and would be easily utilized for microgravity training for the CMO prior to flight. This will provide the crew with a solid perspective on the integration of procedures in zero-g, and can be easily accomplished within the restraints imposed by parabolic flight. Such a process utilizes understanding of techniques required for CMO restraint, equipment access and utilization, supply management, waste disposal, fluid containment, troubleshooting, human-machine interface, and patient positioning.

Priming the IV administration set by forcing fluid through the tubing.

Starting an IV onboard the KC-135.

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Effectiveness of Intranasal Scopolamine in Normal Subjects

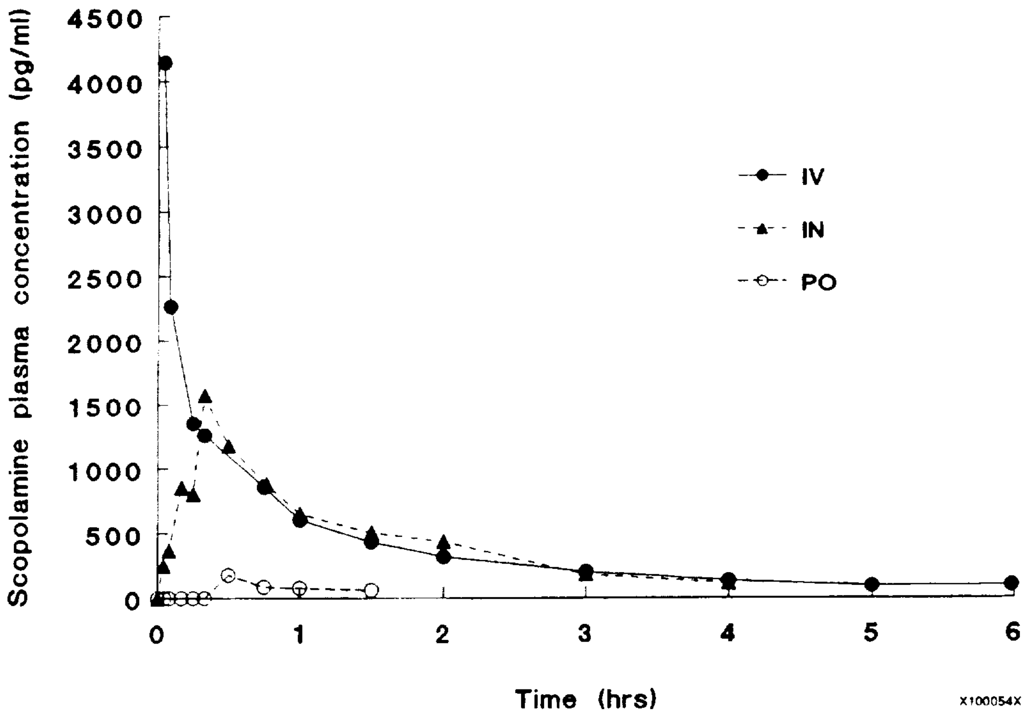
TM: Nitza M. Cintron, Ph.D./SD4
PI: Lakshmi Putcha, Ph.D./SD4
Robert P. Hunter, M.S./SD4
Cecilia Parise, B.S./SD4
Karen Tietze, Ph.D./Philadelphia College of Pharmacy and Science
Reference LS 6

The therapeutic effect of a drug is a function of its intrinsic activity and its bioavailability in the body. Bioavailability, in turn, is affected by the route of administration. While intravenous (IV) administration of a drug provides instantaneous availability, it is not always possible to administer medications by this route during spaceflight because of technical and operational constraints, as well as the greater risk of toxic effects from high concentrations of potent drugs. Many drugs achieve good systemic bioavailability after intranasal administration. This route would be particularly appropriate for use in spaceflight, where crewmembers can easily self-administer drugs such as scopolamine that require a relatively small dose for biological activity.

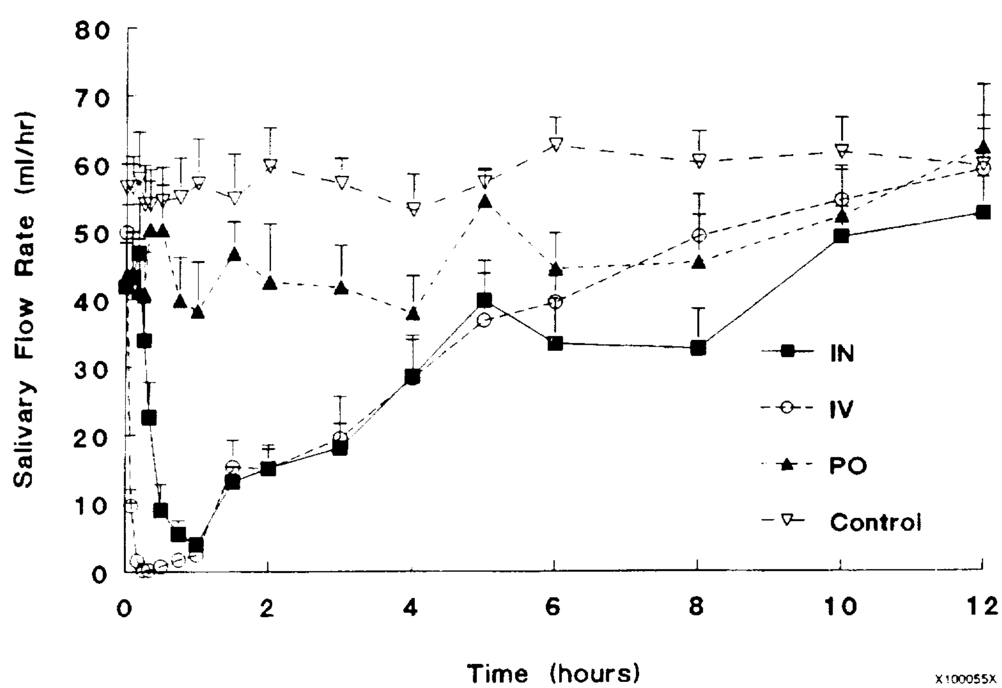
Scopolamine is administered orally (PO) for the control of space motion sickness. Earlier studies conducted in our laboratory indicated that absorption of oral scopolamine is highly variable among subjects, that oral doses are metabolized presystemically by the liver, and that less than 25 percent of an oral dose is bioavailable. As an alternative to the oral form, we developed an intranasal (IN) dosage form and tested its effectiveness by observing the degree of suppression of salivary flow rate, which is an indicator of the pharmacodynamic effect of the drug.

Scopolamine (0.4 mg) was IV, IN, or PO administered to 12 healthy male subjects. Serial blood and saliva samples were then collected for 12 hours, and urine for 24 hours, after dosing. Samples were analyzed for scopolamine concentration using combined reverse-phase liquid chromatography and a competitive receptor-binding assay. The time course of the pharmacodynamic effect of the drug was determined by calculating salivary flow rate (SFR) as a function of time. Plasma concentrations of scopolamine after IN and PO administration showed that the drug is absorbed rapidly and reaches peak concentrations 19 to 40 minutes after administration by these routes (first figure). However, the availability of an oral dose was quite low compared to the IN dose (7.9 percent PO versus 69 percent IN in one subject). The concentration over time corresponded well to salivary flow rate over time in all subjects (second figure). The relative effectiveness (reduction in SFR) of the three dosage forms was estimated from the area under the effect-time curve [AUC] after IV, IN, and PO administration as percent suppression of SFR compared to the control. The IN suppressed SFR similarly to IV (57 percent and 59 percent, respectively). The PO, in contrast, produced only 24 percent suppression. This indicates that an IN scopolamine dose will be as effective as an IV dose. Bioavailability of the IN dose calculated from plasma concentration data (0.82) and from SFR data (0.89) were in good agreement. In contrast, preliminary analyses show that less than 10 percent of the PO dose was bioavailable.

This study suggests that IN administration of scopolamine may prove to be a noninvasive, fast, and effective treatment for motion sickness and for other disorders requiring anticholinergic therapy. This route of administration provides an alternative for administering other drugs with low systemic availability associated with gastrointestinal stability or first-pass metabolism. Intranasal administration of operationally useful medications holds great promise for future space medical operations, since it eliminates the impracticality of parenteral dosage forms and the unreliability of some oral dosage forms during flight.



Representative plasma concentration profiles of scopolamine after administration of 0.4 mg does to normal subjects.



Salivary profiles after administration of 0.4 mg dose of scopolamine to normal subjects.

Development of a Card Filler Module for the Automated Microbiology System II

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Saroj K. Mishra, Ph.D.
Joyce A. Skweres, MTASCP, M.S/SD4
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Reference LS 7

Extended duration manned spaceflight presents a novel set of environmental conditions in which microorganisms will interact with spacecraft and crewmembers. The potential effects of this interaction include fouling of the environmental control system; degrading of spacecraft structural components such as seals, adhesives, and electronic circuits; producing toxic/noxious metabolic by-products; and causing invasive or allergic disease in crewmembers. The control of microorganisms in terrestrial or spaceflight environments involves several capabilities: detection, enumeration, identification, and, in the case of pathogens from clinical specimens, antimicrobial sensitivity testing. Conventional procedures for analysis of microbial samples require technical skill, many supplies, and take days to weeks to perform. Many of these procedures are unsuitable for use in a spaceflight situation owing to constraints on storage space, crew time, and equipment availability.

During the past decade, numerous advances have been made toward the automation of microbial detection, enumeration, identification, and antimicrobial sensitivity testing procedures. After numerous literature searches and market surveys, the AutoMicrobic System manufactured by VITEK Systems was selected for further evaluation. During 1987, a collaborative effort between the NASA Johnson Space Center (JSC) and VITEK Systems, Inc., resulted in a unit known as the Automated Microbiology System II (AMS II), a miniaturized version that would fit into a Space Shuttle middeck locker.

The AMS II system as proposed for Space Station Freedom (SSF) is composed of three units: the card filler module, the reader incubator, and the reader-incubator computer. In a preliminary effort to produce a flight-compatible version of the AMS II, a reader-incubator module has been developed. In 1990, the NASA JSC Microbiology Laboratory has focused on developing the card filler module and testing it in microgravity. A prototype has been developed (as seen in the first figure) and preliminary tests have been completed successfully in the laboratory and during brief periods of simulated microgravity onboard NASA's KC-135 aircraft.

During KC-135 parabolic flights, it was noted that the introduction of small bubbles during the fill cycle does not interfere with the identification of microorganisms if the bubbles adhere to the sides of the plastic chamber. However, larger bubbles can interfere if they obstruct the optical path, necessitating further evaluation and refinement of the card-filling mechanism during longer periods of microgravity. To achieve this objective, we plan to test the card filler module during the Space Transportation System flight STS-44 mission in mid-1991 as a development test objective.

The efficiency of two card-filling mechanisms will be evaluated: an automatic vacuum pump contained within the card filler module, and a hand-operated vacuum pump for use during power failure. Using both of these filling mechanisms, two types of test cards will be inoculated with a colored saline solution to avoid on-orbit use of viable organisms. A nonseptumized card will be inoculated using the automated vacuum chamber by means of a test tube/transfer tube assembly designed to contain the fluid during vacuum inoculation. A septumized card will also be inoculated using the Sample Receiving Card Loading Device (SRCLD). The SRCLD will enable containment and transfer of inoculum fluid by means of injection by needle. The transfer assembly and the SRCLD each have been modified for optimal fluid transfer within the parameters conferred by a microgravity environment. Each fluid transfer system and card-filling mechanism will be evaluated under microgravity conditions for near bubble-free card fill. Ground-based evaluation of each card fill will be accomplished by analyzing photographic and voice-recordings from the astronauts during card-filling.

Evaluation of the AMS II card filler module under prolonged microgravity conditions will allow optimization of this equipment for use during extended-duration spaceflight. Perfection of the card filler module, an essential component of the AMS II for SSF, will be a major achievement in facilitating crew health maintenance and environmental monitoring.

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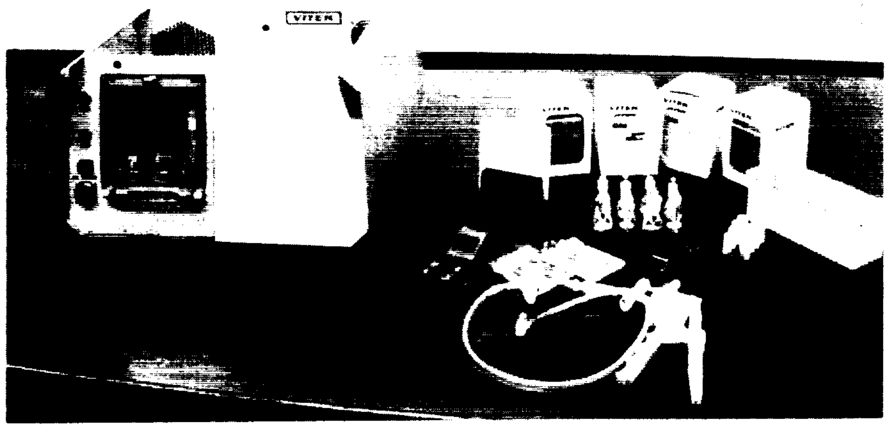

Prototype card filler module for use with the AMS II.

Determining Energy (Caloric) Requirements in Space

TM: Helen W. Lane, Ph. D./SD4
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Richard A. Socki/SN2/LESC
Dale A. Schoeller, Ph.D./ Dept Medicine, University of Chicago
Reference LS 8

Studies of energy utilization (calories) by crewmembers during Skylab flights suggested that living in space requires at least as much energy as does living on Earth. However, the relative roles of energy expenditure at rest and in exercise during flight have yet to be examined .

The Nutritional Biochemistry Laboratory and the Stable Isotope Mass Spectrometry Laboratory are developing a state-of-the-art method to determine energy expenditures by individual crewmembers. This method involves the use of water labeled with two stable (nonradioactive) isotopes of hydrogen (^{2}H, deuterium) and oxygen (^{18}O, "heavy oxygen"). Both isotopes occur naturally and are nontoxic at the levels used. Subjects drink a small amount of the labeled water, and the labels are traced in their saliva and urine over a period of days. The rate of disappearance of ^{18}O is used to calculate CO_2 production, with a correction for water turnover (calculated from the disappearance of ^{2}H). The corrected CO_2 value is converted to energy expenditure in calories. At the NASA Johnson Space Center, the ratios of hydrogen to deuterium (H/D) and ^{16}O to ^{18}O are determined using the Finnigan MAT 251 stable isotope mass spectrometer (fig. 1). Analytical capabilities to purify H/D and ^{16}O/^{18}O from biological samples (urine, saliva) are being developed and validated. Vacuum extraction and purification lines have been developed and are now being tested with known laboratory standards.

Although this method has been used successfully in normal human populations and hospital patients, it has not been used in space medicine research. In order to adapt this method to spaceflight, parameters unique to spaceflight must be evaluated. One such parameter is the level of ^{2}H and ^{18}O found in the potable water produced by the Orbiter's fuel cells (fig. 2). Hydrogen and oxygen reservoirs supply the fuel cell, which generates water as a by-product of power generated. We are analyzing the isotopic composition of the hydrogen and oxygen supplied to the fuel cells and the resultant composition of the fuel cell potable water as a function of time throughout a mission.

Data from the few Space Shuttle missions studied to date are depicted in figure 3. The dotted lines represent ^{2}H and ^{18}O content in the gas tanks from the Space Transportation System (STS) flight STS-35; the data points represent labels found in the fuel-cell-produced water from three earlier missions. In addition, STS-32 service water (water brought to the Space Shuttle before launch) had an isotopic composition similar to meteoric precipitation in Florida. Water produced by the fuel cells on both STS-28 and STS-33 was isotopically enriched relative to the starting composition on STS-35. The extensive enrichment of the STS-34 water may be due to evaporation before analysis. The cause of this enrichment is unknown; however, analysis of samples from a single flight, including the hydrogen and oxygen supplied to the fuel cells and the water produced by the fuel cells, will indicate whether the enrichment results from fuel cell reactions. Once the source of enrichment is identified, the isotopic composition of Orbiter-produced fuel-cell water might be predicted simply by analyzing the fuel-cell gases prelaunch. This would allow more accurate assessment of the amount of isotopes being consumed by crewmembers, which, in turn, would improve the accuracy of the doubly labeled water method for determining energy expenditure.

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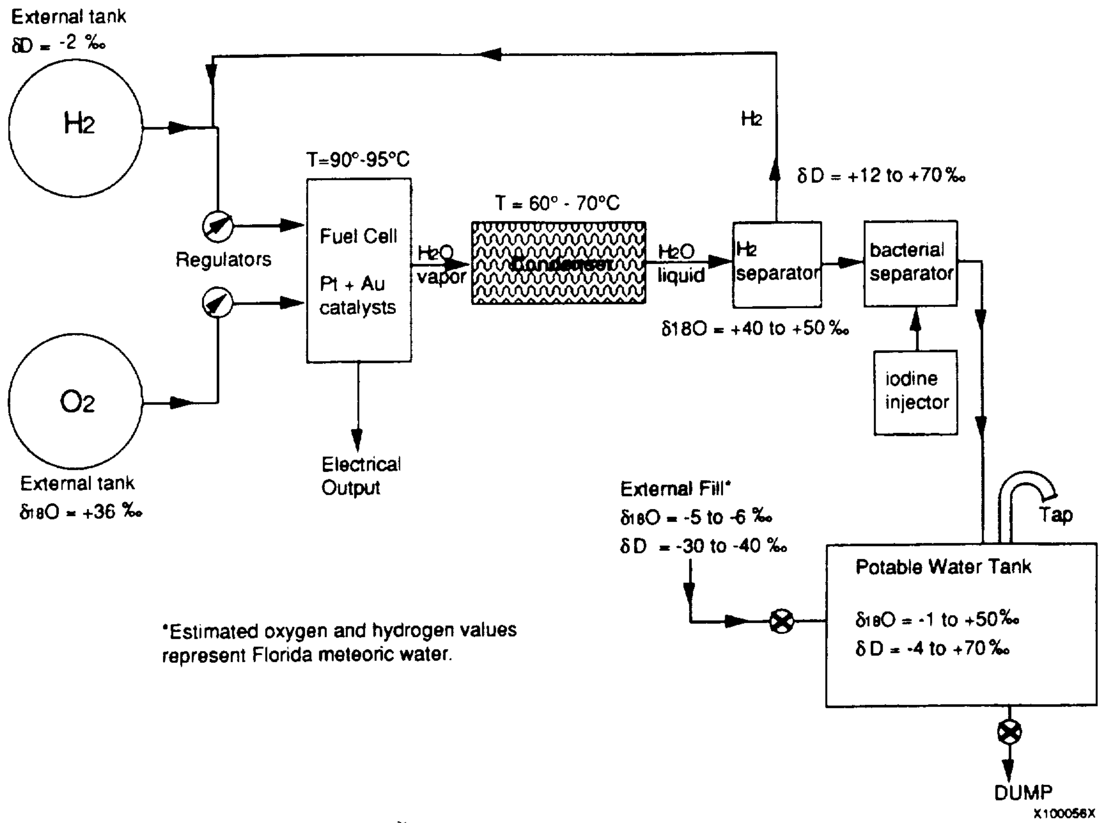
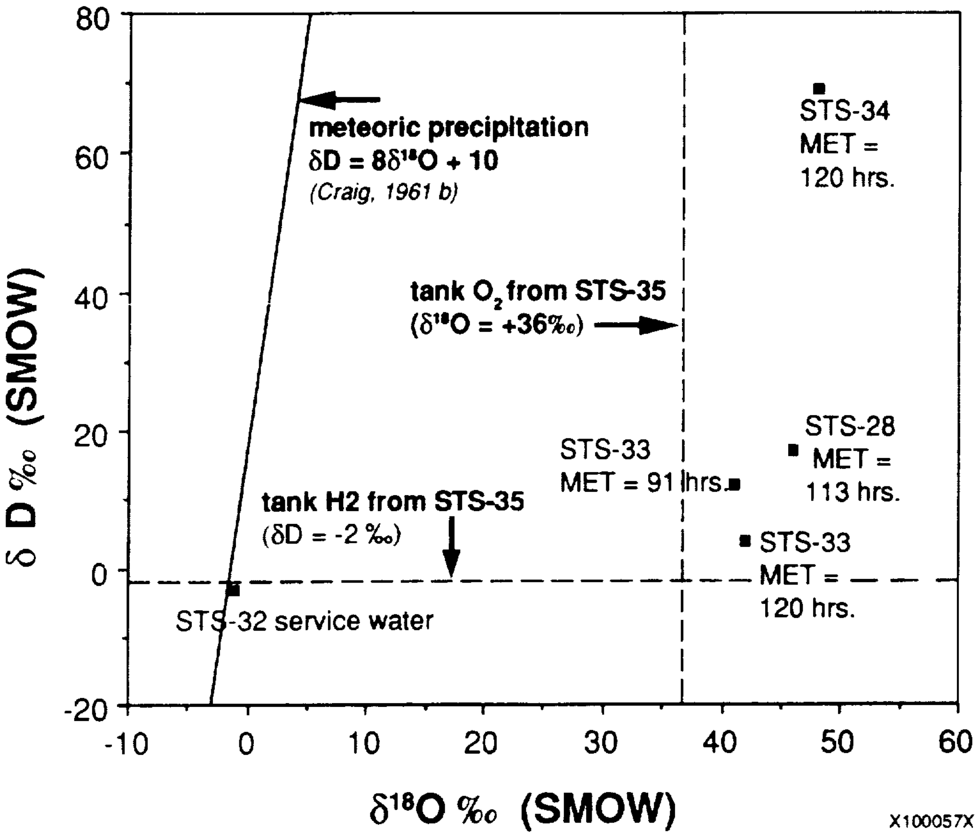
The Finnigan MAT 251 stable isotope mass spectrometer.



Production of Space Shuttle fuel cell water.



Enrichment of water on Space Shuttle missions.

A Combustion Products Analyzer for Contingency Use During Thermodegradation Events on Spacecraft

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Thomas F. Limero, Ph.D./SD4
Steve Beck/SD4
Raymond C. Cromer/Enterra
Steve Summerfield/Enterra
Reference LS 9

As mission length and the number and complexity of payload experiments increase, so does the probability of thermodegradation contingencies (e.g., fire, chemical release, and/or smoke from overheated components or burning materials). When thermodegradation occurs onboard a spacecraft, potentially hazardous levels of toxic gases could be released into the internal atmosphere. Therefore, it is imperative that a means be provided to assess the quality of the air following such an event and to monitor the effectiveness of decontamination efforts. The information collected by such instrumentation would be used to help determine when the crew can safely remove their breathing apparatus.

Space Shuttle experience has clearly demonstrated the likelihood of thermodegradation even during relatively short missions. During Space Transportation System (STS) flight STS-6, wiring behind a panel became overheated, producing noticeable odor in the cabin and ultimately resulting in fusion of the wires. On STS-28, ~2 cm of a teleprinter cable were completely burned before the circuit shut down. Most recently, on STS-35, two digital display units failed, releasing the odors of burned electronics into the cabin of the Space Shuttle. In all cases, the crews suffered no apparent ill effects; however, this possibility must be addressed for future missions.

An instrument to be flown on every mission must be small, lightweight, compact, easy to use, reliable, portable, and consume little power. These features were incorporated into the combustion products analyzer (CPA), which was developed by Enterra Instrumentation Technologies under the guidance of the Toxicology Laboratory at the NASA Johnson Space Center. The CPA monitors four gases that are the most hazardous compounds likely to be released during thermodegradation of synthetic materials: hydrogen fluoride, hydrogen chloride, hydrogen cyanide, and carbon monoxide. The levels of these compounds serve as markers to assist toxicologists in determining when the atmosphere is safe for the crew to breathe following a thermodegradation event.

The CPA (shown in the figure) has four electrochemical sensors, one for each gas, a pump to pull air over the sensors, and an alarm that sounds if levels exceed a preset maximum. The electrochemical sensors of the CPAs are unique in their size and zero-g compatibility. The immobilized electrolytes in each sensor permit the instrument to function in space and eliminate the possibility of electrolyte leaks. The sample inlet system of the CPA is equipped with a particulate filter that prevents clogging from airborne particulate matter. Other features include a digital readout that displays gas concentrations and various warning signals (low battery, low flow) that can be conveyed to the crew. The instrument can be set to scan the concentrations of all four gases, or it can monitor one gas continuously.

As shown in the figure, the CPA is a compact, portable instrument that uses minimal power (~30 hours per battery set). Preliminary evaluations of the CPA have been encouraging; tests in a combustion atmosphere are planned for the future. Development efforts include adding a data logger and a microprocessor to provide more signal-processing capability. The same attributes that make the CPA ideal for use on spacecraft will also be valuable in commercial markets, such as for instruments to be used by firemen entering burning or smoldering buildings.

The combustion products analyzer.

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Ion Mobility Spectrometry: A Key to Real-Time Monitoring of Volatile Organic Compounds

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Gary Eiceman, Ph.D./New Mexico State University
John Brokenshire, Ph.D./Graseby Analytical, Watford, U.K.
Alan Rhodes/Graseby Analytical
Ed Overton, Ph.D./Louisiana State University
Reference LS 10

During manned spaceflight missions, the capability of identifying and quantifying airborne compounds is required in the event of a chemical spill, thermodegradation, or other accidental contamination of the spacecraft atmosphere. At present, archival sampling of the internal atmosphere with subsequent ground-based analysis is the only means available for determining spacecraft air quality; however, ion mobility spectrometry (IMS) is a promising technology that could be used to automatically identify small amounts of the complex atmospheric mixtures that would be found in spacecraft atmospheres during contingencies as described above.

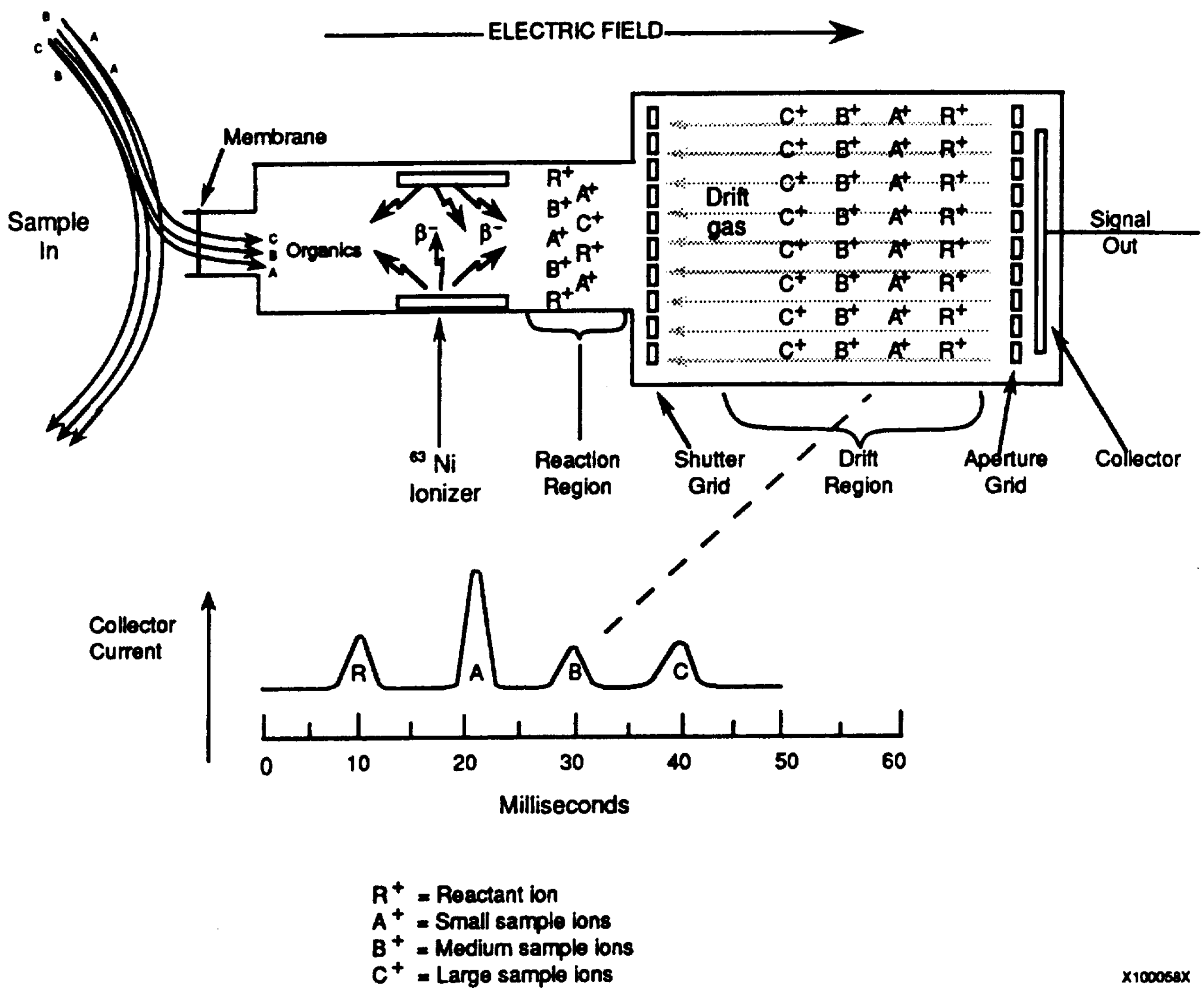
Our experience with archival samples and crew comments from past missions has provided ample evidence of the need for real-time detection, identification, and quantitation of volatile organic compounds (VOCs) during flight. As an example, on STS-35, the failure of two digital display units released a pungent odor into the cabin atmosphere; however, there was no way to identify the compounds causing the odor. The increasing mission length envisioned for the extended duration Orbiter, coupled with the greater complexity and number of experiments projected in this program, further highlight the necessity of onboard device(s) that can detect, identify, and quantify VOC contamination in the cabin. Such devices must be small (less than a single middeck Space Shuttle locker), lightweight, easy to operate, must consume little power, and be capable of analyzing samples from remote locations.

Instruments that can detect total hydrocarbon concentration are relatively small and portable, but they have disadvantages such as unresponsiveness to freons. Gas chromatography/mass spectrometry (GC/MS) is currently the primary candidate for air sample analysis onboard spacecraft. Unfortunately, GC/MS instrumentation is large, heavy, requires much power, is complicated to operate, and needs frequent maintenance. Many of these limitations stem from the vacuum system in the analyzer region. In contrast, a Volatile Organic Detector and Analyzer (VODA) based on GC/IMS will be able to meet the dual function of detection and identification/ quantitation. And, because the VODA is small, it can fit into a single middeck Space Shuttle locker.

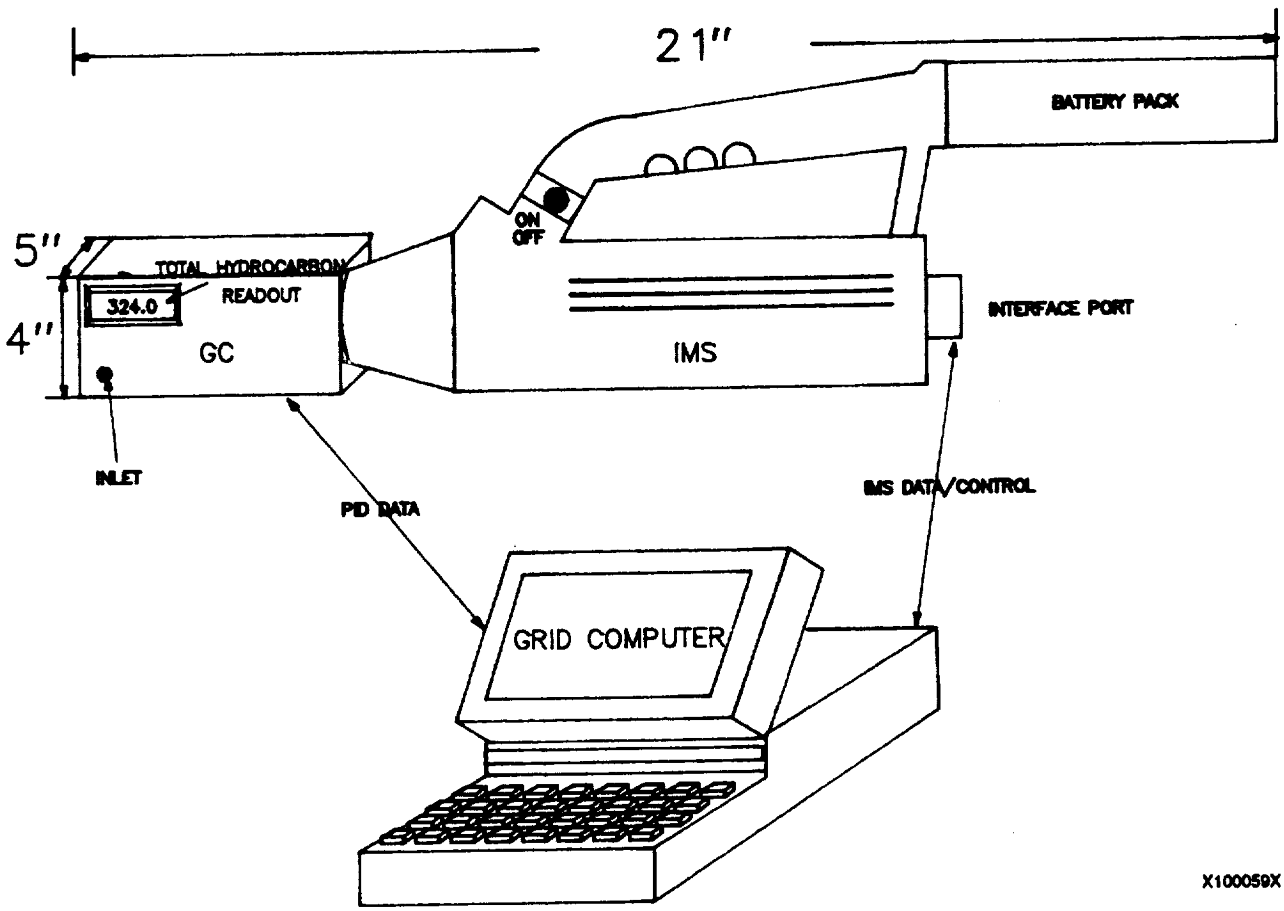
The principle of ion mobility spectrometry, the cornerstone of the VODA, is illustrated in the first figure. An air sample passes into the ionization region, where ionized dopant molecules transfer a charge to the sample molecules. The ionized sample molecules are then pulsed into a "drift region" where the faster molecules traverse the gradient electric field faster than larger molecules, thus providing separation and a means of compound identification. Selectivity or universality of response can be achieved by careful selection of the dopant gas. Operation at atmospheric pressure is the major advantage of the IMS, which eliminates the need for a vacuum system.

Although GC/IMS has been considered promising for some time, technical limitations have prevented use of the system for air quality analysis. Under the guidance of scientists at the NASA Johnson Space Center, a team of experts has been assembled in the technical areas of IMS (Graseby Analytical), sampling and gas chromatography (Louisiana State University), and data management and testing (New Mexico State University). This team is currently constructing a breadboard GC/IMS for later development of a VODA. The retention-time data generated by the GC and the mobility spectra generated by the IMS provide the means for the VODA to identify each compound in a complex mixture. The VODA (second figure) is being designed to function in a total hydrocarbon mode in which the sample enters directly into the ionization region, and the total VOC level is measured by monitoring the magnitude of the reactant ion peak. The VODA can also operate in the identification and quantitation mode, in which the preconcentrated sample is separated on a GC before entering the ionization region. In the latter configuration, compounds reaching the IMS detector would be automatically identified by comparison to reference spectra stored in the IMS computer.

The goal of this effort, a small, sensitive, and reliable chemical analyzer for VOCs, should find immediate applications in NASA programs such as the Space Station and the Space Exploration Initiative. This technology could be transferred easily to waste-site monitoring, industrial monitoring, and occupational hygiene, where small portable instruments that can detect and quantitate a range of VOCs could fill the void that now exists in these fields.



Operating principle of the IMS.



Volatile organic detector and analyzer.

Sample Collection Device for Rapid Immunological Identification of Group A Strep

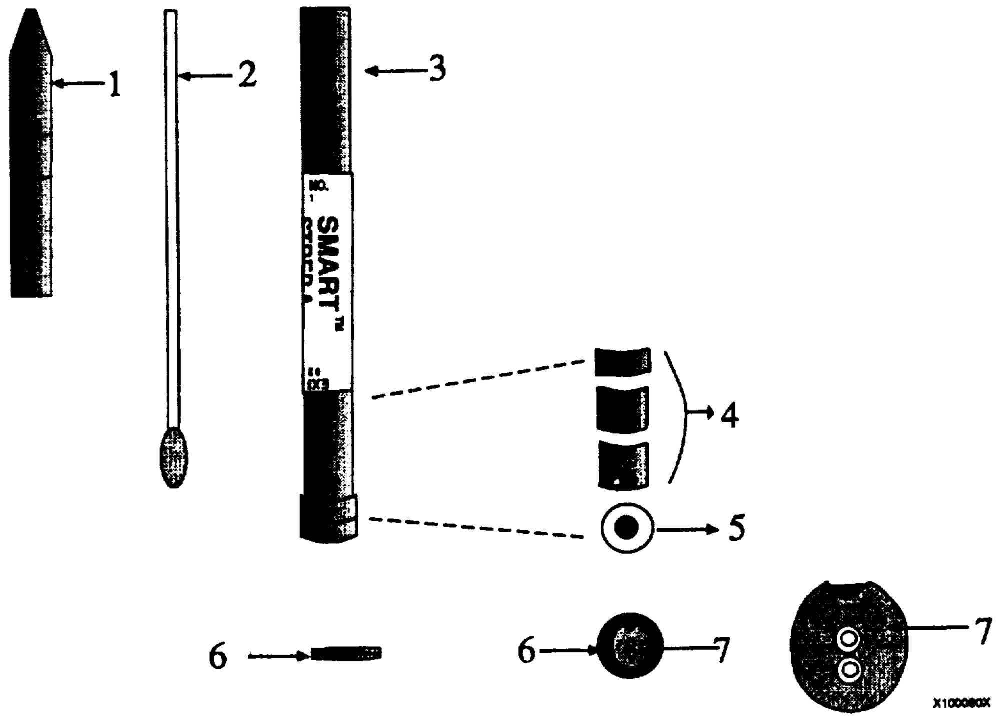
TM: Clarence F. Sams, Ph.D./SD4
PI: David Bernstein/New Horizons Diagnostics
Reference LS 11

Long-duration space missions will require an onboard capability for identification of microorganisms in biological and environmental samples. This capability will be necessary for medical support of flight crews and for monitoring recycled water systems and the closed spacecraft environment. Current methods require numerous reagents, sample transfers, and washing steps that are impractical in microgravity and complicate the control of waste and resources. In addition, many tests require skilled operators and complex diagnostic equipment. Using immunochemistry-based diagnostics has simplified the identification of some organisms considerably. These tests are based on antibody recognition of specific target organisms and the subsequent development of a visual signal. While these techniques offer specificity and ease of use, they usually require several transfer and washing steps and are of limited utility in a spacecraft environment. A series of self-contained microbial test kits based on immunolabeling technology are currently being designed under a Small Business Innovative Research grant. This report summarizes preliminary results using this simple device to identify group A streptococci.

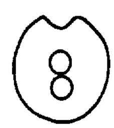
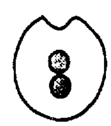
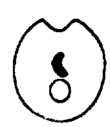
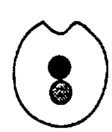
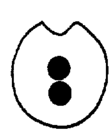
The test device consists of a cylindrical plastic housing that encloses a series of compartments separated by frangible seals (see first figure). At one end of the housing is a plastic end-cap that contains a dacron-tipped swab. The swab is used to take a medical sample or to swab a site suspected of microbial contamination. The swab is then slipped back into the housing and pushed through the seals, reacting with the reagents. The contents are mixed by rotating the assembly inside the housing. All liquids are absorbed by the swab, eliminating potential contamination of the outside environment. After the required incubation time, the applicator is pushed through the next seal to contact the base of the device. The reagent mix diffuses through a filter onto a membrane, which concentrates the appropriate components and generates a visual marker for positive identification (second figure). A control spot is included to permit assessment of the validity of the test and aid in interpretation. A positive test generates a colored spot, and the control spot is clear or slightly stained.

The test is based on the use of colloidal gold-labeled antibodies to specific components of the target organism. The labeled antibodies specifically recognize these components (antigens) and bind to them with great affinity. After the incubation period, the resulting antibody/antigen complex is drawn through a filter to remove particulates and concentrate on a capture membrane. The capture membrane contains a second antibody bound to the membrane that binds the antibody/antigen complex but does not bind free antibody. The binding to the capture-membrane antibody concentrates the colloidal gold-coupled antibody/antigen complex, which produces a red spot. The control membrane contains no membrane-bound antibody and permits free diffusion of the antibody/antigen complex through the membrane. This spot then serves as a control for the nonspecific background. Initial trials with this system for group A streptococci have provided positive identifications of $< 5 \times 10^6$ organisms in only 7 minutes.

This technology provides a simple and rapid test for identifying microorganisms. This self-contained test can be performed by unskilled personnel and requires no complex analytical equipment. Current plans include configuring the device for shelf-life at room temperature for up to 1 year, making this technology applicable to operations in remote or primitive field sites of all types. Further development includes expanding the device's repertoire of detectable organisms, including viruses, as well as the presence of bacterial toxins or other biological compounds.



Exploded view of the rapid-detection device. The components are: (1) end-cap, (2) dacron swab, (3) housing, (4) reagent compartments separated by frangible seals, (5) filter, and (6) removable end cap with (7) capture membrane. An expanded view of the capture membrane shows the control and test spots.

If the test spot reaction is...	And the control spot reaction is...		Then the result is...
Absent	Absent or weak		Negative
Weak	Weak		Negative
Weak	Absent		Weak Positive
Moderate to strong	Absent or weak		Positive
Weak to strong	Moderate to strong		Inconclusive/ repeat test

X100061X

Key for interpreting test results.

Endothelin Production by Blood-Brain Barrier Endothelial Cells

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PI: Peggy A. Whitson, Ph.D./SD4
M. Helen Huls /SD4
Yu-Ming Chen, Ph.D. /SD4
Reference LS 12

Exposing humans to microgravity produces a number of physiological changes, including a redistribution of the fluids from the extremities to the thorax and head. The body responds to this fluid shift via a number of endocrine mechanisms, many of which are not well understood. The blood-brain barrier (BBB) is composed of specialized endothelial cells with characteristic structural features that severely limit access to the brain of the components in circulation. The characteristics of the BBB and the function it performs are modulated by the presence of glial cells. For instance, the formation of the tight intercellular junctions are known to be induced by the presence of the neighboring glial cells. The exact mechanisms by which these cells modulate the cells composing the BBB are not precisely known. The integrity/functionality of the BBB may be altered during the dramatic fluid shift that occurs in microgravity. Using an *in vitro* model system, it is possible to examine the mechanisms involved in the complex regulation of BBB function.

Endothelins (ETs) are a family of peptides, originally isolated from medium conditioned by vascular endothelial cells, and are the most potent vasoconstrictors known. A better understanding of the mechanisms regulating ET production will provide beneficial data in understanding the potential role of this hormone in the dramatic fluid redistribution that occurs with spaceflight. At least four distinct endothelins have been identified, including ET 1, ET 2, ET 3, and vasoactive intestinal contractor [VIC]. Common structural characteristics of these peptides include

- The presence of two disulfide bonds forming a polar, charged loop, and
- Similar sequences.

Changes in the loop structure or the carboxy-terminal residues of endothelins significantly reduce their biologic activity. The ET 1 is produced by vascular endothelial cells, while ET 3 has been isolated from brain tissues. A number of autoradiographic or immunoassay studies have identified ET binding sites in various regions of the brain. The production of ETs can be modulated by thrombin, calcium ionophore, angiotensin, arginine-vasopressin, and epinephrine. This study was initiated to characterize the immunoreactive that ET secreted from BBB endothelial cells and determine whether glial cells modulate ET production by these cells.

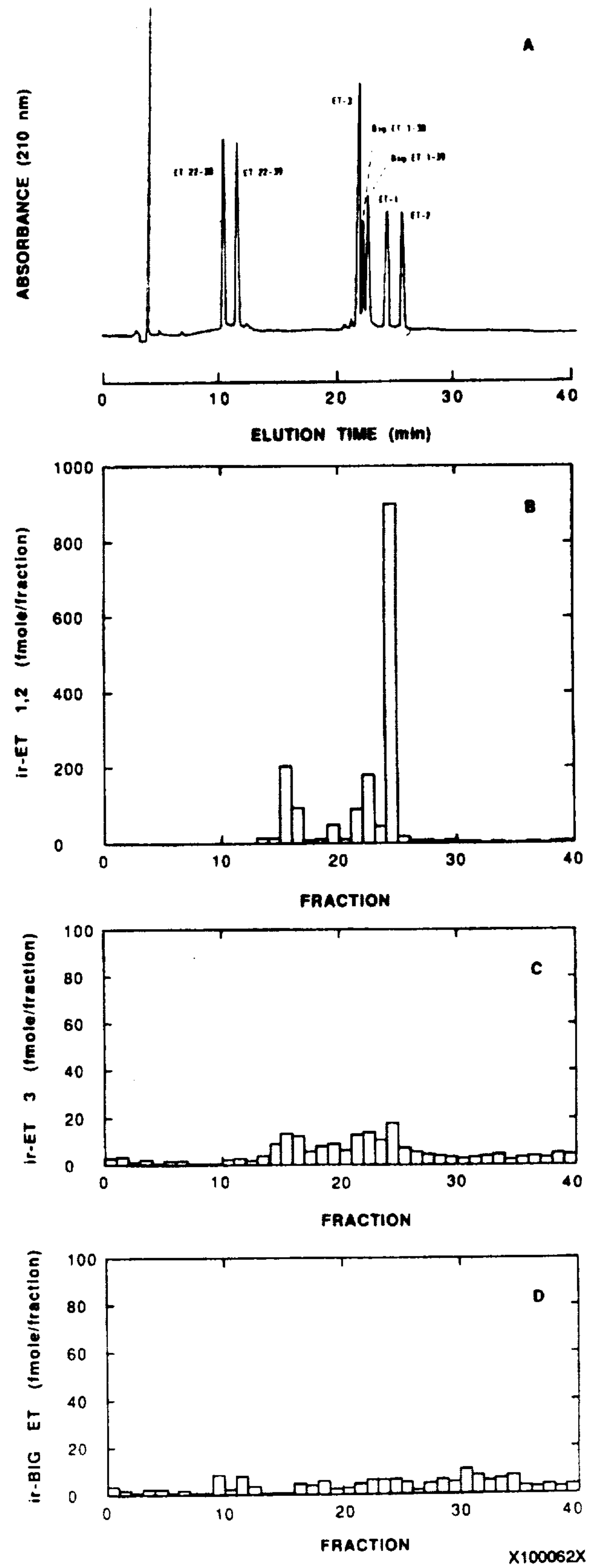
We characterized the immunoreactive endothelin (ir-ET) produced by primary BBB endothelial cells in a 2-step process. First, HPLC was used to separate cell products by hydrophobicity and size. Next, three antibodies were used to identify the specific types of ET. Figure 1 illustrates the HPLC elution profile of standards for ET 1, ET 2, ET 3, the precursor peptides big ET [1-38] and big ET [1-39], and the ET fragments ET [22-38] and ET [22-39], which are generated from cleavage of the precursor peptides. Panels B-D depict the immunoassay results of the HPLC-fractionated medium using antibodies specific for ET 1 and 2, ET 3, and big ET, respectively. The majority of the ir-ET was detected with the antibody that recognizes both E D 1 and E D 2. However, the elution time of the peak corresponded to ET 1. The ET 3 levels were 1/40 of the comparable ET 1 values (panels B and C) and suggest that the ir-ET 3 detected represents anti-ET 3 antibody binding nonspecifically to ET 1. In addition, ir-big ET (panel D) did not appear to bind specifically in any of the HPLC fractions. Thus, these data indicate that the majority of the ir-ET detected in BBB endothelial cell medium corresponds to ET 1.

In the second part of the study, we added medium containing glial cell products to the BBB endothelial cells to examine the glial cell effect on ET production. We found that the presence of glial cell products decreased ET production. Figure 2 illustrates a 47 percent and a 67 percent decrease in ET production after 6 or 24 hours of treatment with glial cell products as compared to control medium. These data suggest that glial cells may play a regulatory role in modulating ET production in brain microvessel endothelial cells. Thus, ET production by the BBB endothelial cells and the resultant modulation of vasoconstriction in the vasculature may be under the influence of glial cells.

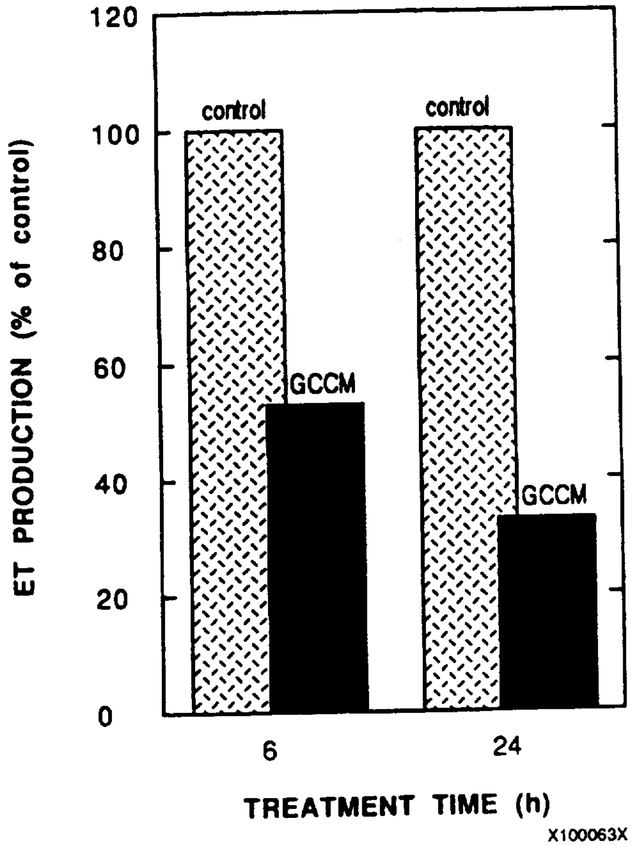
Conclusions from these studies include the following:

- Primary cultures of bovine BBB endothelial cells release ET 1 into the medium.
- Glial cell products caused a decrease in the release of ET from BBB endothelial cells.

These data suggest that this *in vitro* culture system may be valuable in understanding the mechanisms by which ET production in brain endothelial cells is regulated. Further study of these regulatory mechanisms will clarify information concerning brain physiology and contribute to our understanding of the altered physiological conditions induced by spaceflight.



HPLC Characterization of endothelin-like immunoreactivity: A linear (40 min) gradient of 20-60 percent acetonitrile in 0.1 percent trifluoroacetic acid was maintained at a flow rate of 1 ml/min for the separation of the ET peptides. Panel A illustrates the elution profile of the synthetic standards ET 1, ET 2, ET 3, big ET [1-38], big ET [1-39], and ET fragments [22-38] and [22-39]. Panel B shows the ET immunoreactivity of an antibody that detects ET 1 and 2. One fraction contained 900 fmole of ir-ET and corresponded to the ET 1 synthetic standard, eluting at 24 min. Panels C and D depict the ET immunoreactivity using antibodies that detect primarily ET 3 or big ET, respectively. No definitive peaks were observed with either antibody (note the difference in scale from Panel B).



ET production following treatment of BBB endothelial cells with glial cell products (GCCM): GCCM was prepared over a 48-hour period. The GCCM was then supplemented with serum, glucose, glutamine, and the pH readjusted. This medium containing glial cell products and the control-conditioned medium were sterile-filtered and added to the endothelial cells. Duplicate cells were assayed for ET immunoreactivity after 6 or 24 hours. The GCCM not exposed to the endothelial cells was also assayed to eliminate possible interference from the medium. This figure depicts the ET production after 6 and 24 hours of GCCM treatment (filled bars) relative to the control (hatched bars) at each time. A 47 percent decrease and a 67 percent decrease in fmole ET produced/million cells after 6 and 24 hours, respectively, was noted.

Johnson Space Center Biotechnology: Cell Culture Process

TM: Glenn F. Spaulding, M.D./SD4
PI: David A. Wolf, M.D./CB
Ray P. Schwarz/SD4
Reference LS 13

Current microgravity cell culture techniques are unable to facilitate growth beyond 24 hours due to a lack of metabolic support. Mass transfer and maintenance of nutrient support in concert with metabolic waste removal is of paramount importance for sustained cell growth beyond 24 hours. If metabolic parameters are not monitored and maintained, artifactual results are likely to occur as a function of metabolic stress leading to ambiguous or misleading results.

The NASA Johnson Space Center (JSC) advanced ground-based bioreactor system (fig. 1), with full metabolic support, has been developed as a core facility to stimulate academic and industrial development of microgravity. Ground-based growth in the JSC bioreactors will become an important first step for investigators to further the biological applications of microgravity, especially in the areas of tissue growth, viral culture, therapeutics development, and human organ transplant.

The JSC has advanced cell culture technologies in the vital areas of growth/differentiation, metabolic support, and shear reduction, through its development of an integrated closed-loop culture system (fig. 2). Hardware configuration centers around independent subsystems, closed-loop controlled with master-slave multiprocessing. The four essential elements are a bioreactor vessel for cellular containment; a flow injection analyzer for nutrient mixing and analysis (fig. 3); a gas control loop for partial pressures support (fig. 4); and a processing control computer for supervision, data acquisition, and data storage (fig. 5).

A key feature in emulating microgravity is the reduction of destructive shear forces. Concentric cylinders rotating at low revolutions per minute alleviate most of the shear adversities while maintaining nutrient perfusion; the core cylinder provides for nutrient dispersion. Metabolic by-products flow into the main loop and through the flow injection analyzer. Housed in the analyzer subsystem are pH and reference electrodes for acid/base adjustments, an oxygen electrode for O_2 regulation, and a glucose-monitoring unit. Glucose is measured by the ortho-toluidine method, utilizing a specialized spectrometer. Oxygen is regulated directly, while pressures of CO_2 and N_2 are interpolated for regulation. Integrated support is mediated via a standard bus master-slave multiprocessing. Each processor functions independently, the master computer facilitating data transfer, acquisition, and storage. Inherent to the system is high-fault tolerance. Once sterilized using standard ethylene oxide sterilization methods, the JSC bioreactor becomes a fully automated cell culture system.

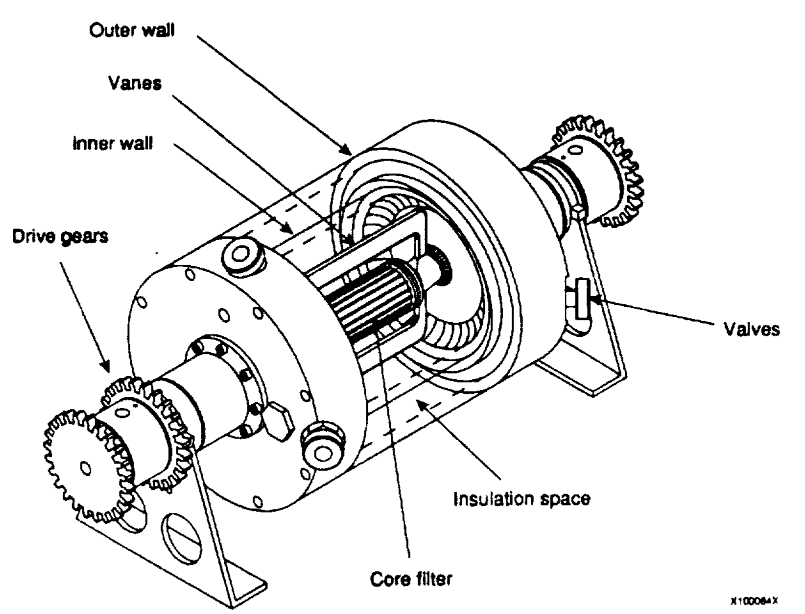


Figure 1. The JSC rotating wall perfused bioreactor vessel.

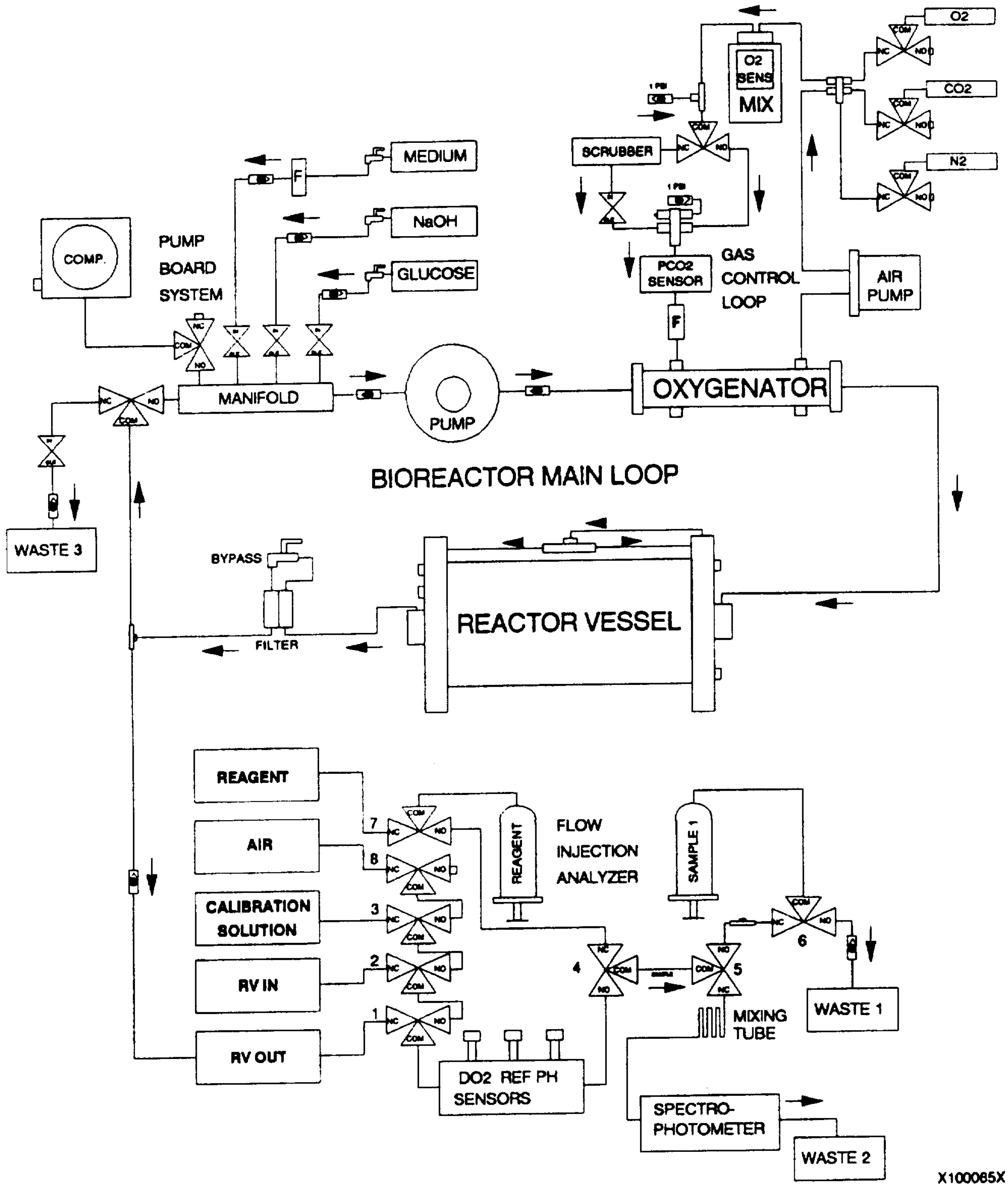


Figure 2. Plumbing diagram for a closed-loop culture system.

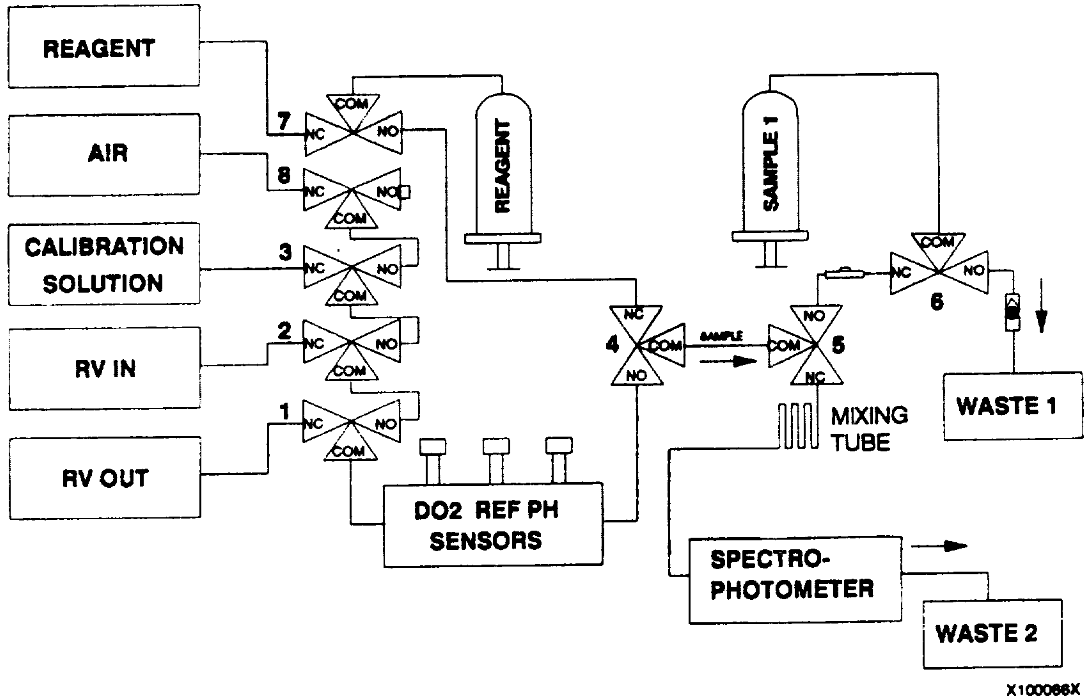


Figure 3. Flow injection analyzer.

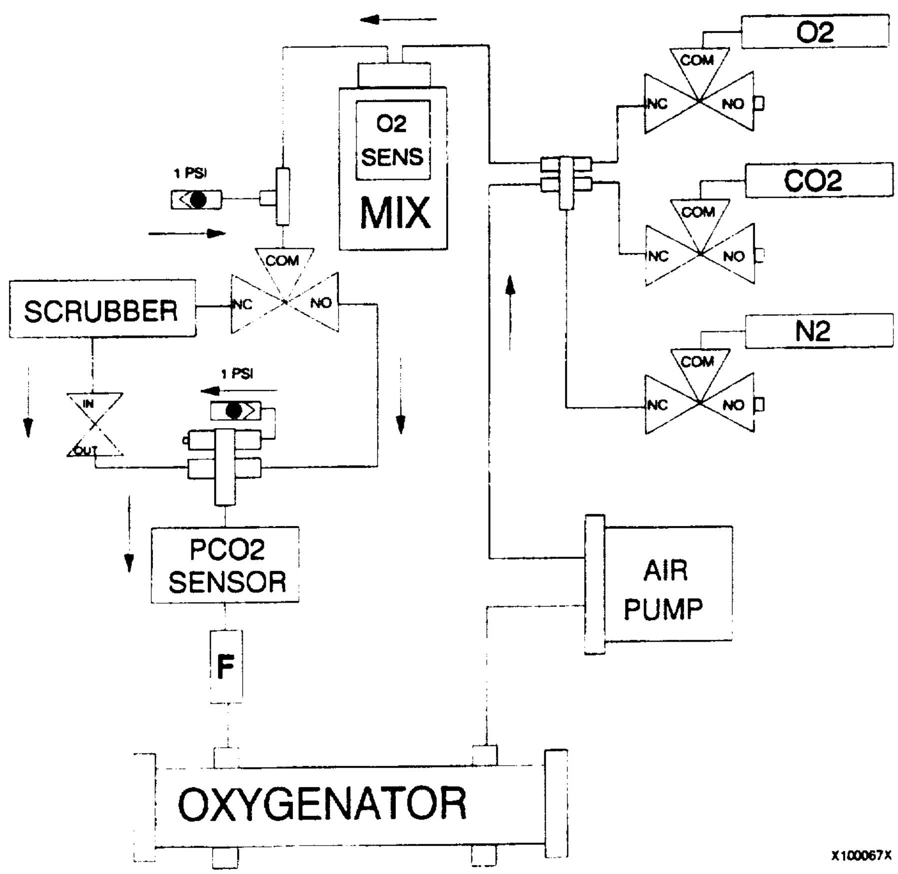


Figure 4. Gas control loop.

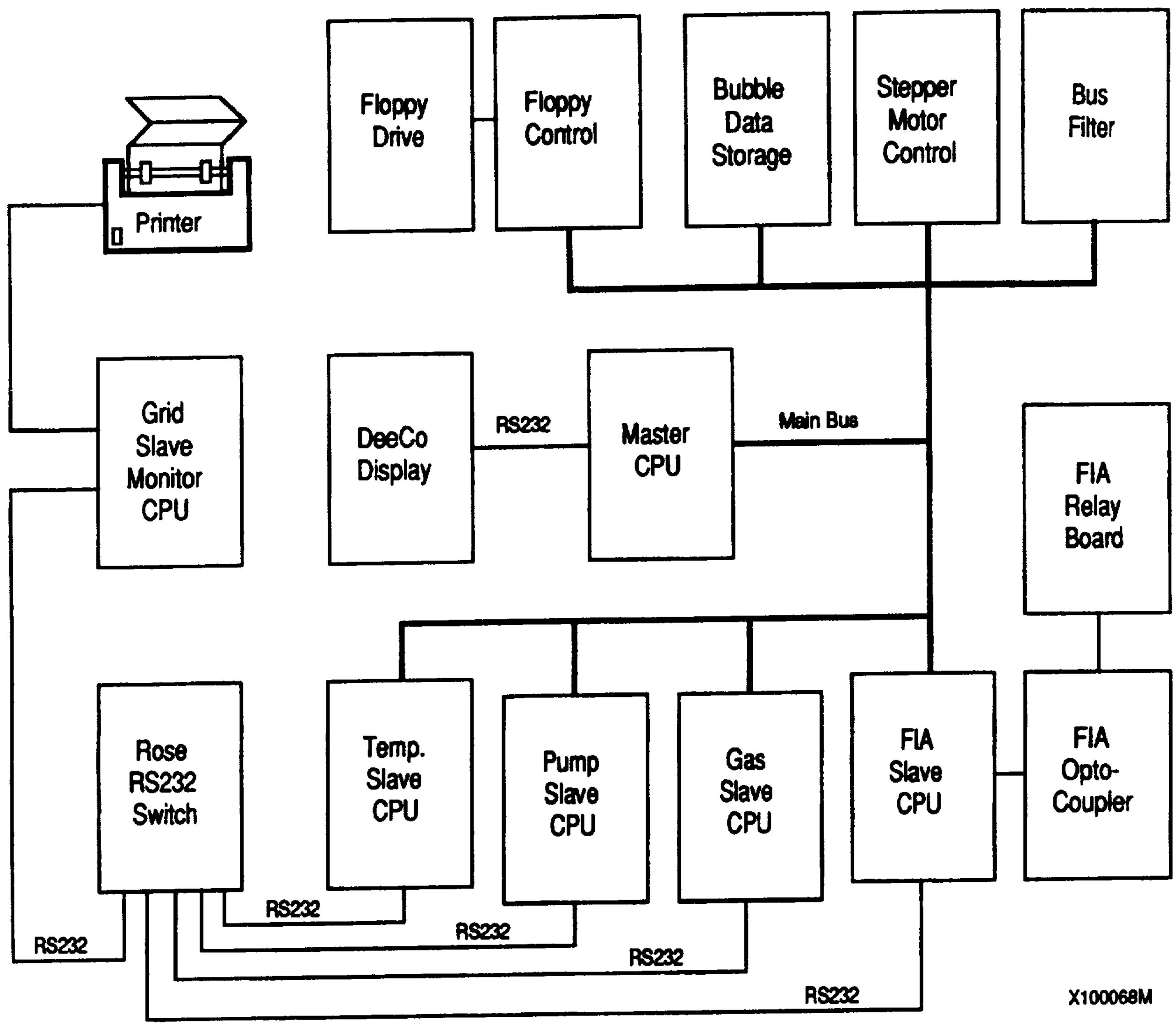


Figure 5. Process-control computer.

Telemicrobiology: A Ground-Based System to Perform Microbiology Tasks in Extraterrestrial Human Habitats

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Reference LS 14

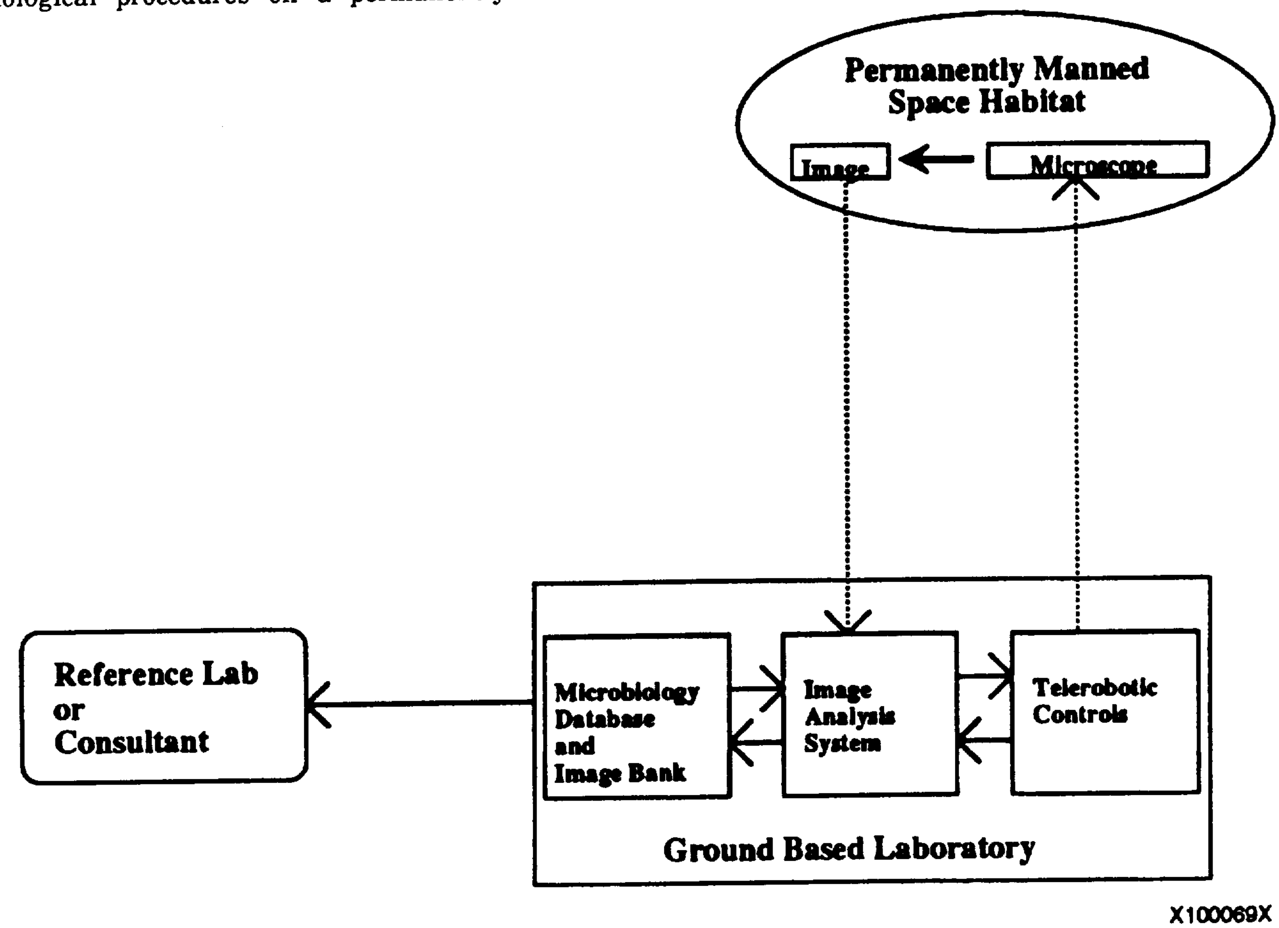
Establishing a permanently manned orbiting or stationary base is an essential prerequisite to the success of space exploration initiatives. Extraterrestrial human habitats such as Space Station Freedom, a lunar base, or a colony on Mars undoubtedly will have closed environmental systems. Continual habitation, crew exchange, docking of resupply vehicles, and the presence of biological experiments and experimental plants and animals onboard will contribute to the microbial load in these closed environments. The unique ability of microorganisms to adapt rapidly to environmental changes could affect missions in many ways. Although only a small number of microorganisms are known to cause serious diseases in humans with normal immune systems, the list of potential pathogens becomes almost endless if the exposed population is immunologically compromised. The available evidence suggests that human immunocompetence may be adversely affected during long-duration missions. Prolonged exposure to large numbers of microbial propagules in a confined area may also provoke serious allergic reactions. Furthermore, uncontrolled microbial growth could lead to colonization and destruction of a wide range of materials through the process of biodegradation and pollution of the internal environment through the production of toxic metabolic byproducts.

Because of the finite capacity of the environmental control system for removal of potentially harmful microorganisms, it is imperative to monitor the number and type of microorganisms present in the environment regularly. Currently available methods require growing microorganisms on various culture media. The final qualitative and quantitative assessments are made when the colonies are fully developed; several sets of subcultures on selective/differential media may be required for specific identification. These procedures are quite acceptable if supplies are plentiful and the tasks are performed by trained microbiologists; however, they could be hazardous if performed by amateurs. Thus, in view of limited work space, supplies, expertise, and crew time, it would be highly desirable to shift the bulk of the workload to a ground-based microbiology laboratory.

Telemicroscopy provides a means of achieving this goal. Until recently, it would have been hard to imagine that Earth-based microbiologists could operate a microscope located in a distant planetary base, examine a specimen, and relay a diagnosis. Telemicrobiology, which encompasses modern telecommunication electronics, telerobotics, and classical microbiology, makes it possible now to operate a microscope from a distance of several thousand miles. The telemicrobiology system can be divided into two subsystems, the distant and base units. The distant unit consists of a telerobotic-compatible, multifunctional, advanced research microscope fitted with a computer-controlled high-resolution camera. The base unit consists of an image analysis and enhancement system that includes high-quality video monitors, an image database, and a telerobotic control system (see figure).

Corabi Telemetrics and the NASA Johnson Space Center Microbiology Laboratory have jointly evaluated the Corabi system for telepathology for its potential for use during long-term manned space missions, specifically, to provide accurate, timely evaluation of environmental and clinical specimens. For environmental specimens (e.g., air or water), a known volume of the sample will be passed through a 0.2 micron (pore size) membrane filter. The membrane will be treated with microbe-enhancing reagents and mounted on a microscope slide. Similarly, wet mounts or stained smears can be prepared from surface samples, pure cultures, or clinical specimens such as throat swabs, blood, or any other body fluid. The prepared slide will be placed on the mechanical stage of the microscope by a crewmember, and the digitized image will be downlinked to a ground-based microbiology laboratory. Using the telerobotic system, scientists at the base unit can focus on the specimen, move the mechanical stage, change the objective, and thus evaluate the entire slide. The digitized image can also be relayed to other centers or reference labs for real-time consultations. Using an image analysis system, cellular parameters such as size, shape, area, cell wall type, cytoplasm ratio, and number of cells, collectively or within a defined group, can be determined. The image is stored in a memory bank that can be preprogrammed with images of commonly encountered microorganisms or other cellular features. The computer can automatically match the image in question with the descriptions of species stored in its memory, and assist in presumptive identification. The image also could be recalled for analysis or further consultations at a later date.

The feasibility of performing standard microbiological procedures on a permanently manned orbiting or stationary base will be limited by the availability of space, supplies, expertise, and time. These procedures are critical, and suitable alternatives must be found to ensure the health and safety of the crewmembers. Telemicrobiology offers a possible solution that combines the best available communications and microscopic technology to give crewmembers access to ground-based expertise.



Telemicrobiology network.

Analysis of Eye, Head, and Body Movement During Locomotion

TM: Millard F. Reschke, Ph.D./SD5
PI: Jacob J. Bloomberg, Ph.D./SD5
Deborah Harm, Ph.D./SD5
Brian T. Peters/SD5
Reference LS 15

The Neuroscience Research Laboratory at the NASA Johnson Space Center conducts investigations of human sensory-motor adaptation to microgravity. Astronauts adapt to the microgravity environment of spaceflight by reinterpreting the relationship between sensory input and motor output. However, this neural recalibration is inappropriate for a terrestrial one-g environment, leading to inappropriate postural, gait, and ocular responses upon return to Earth. Astronauts returning from Space Shuttle missions have experienced postural and gait instabilities and illusionary self and surround motion during head movement.

A new series of experiments has been initiated that investigates how head, body, and gaze stability are affected by exposure to spaceflight. These investigations are operationally significant, as it is imperative to determine if sensory-motor adaptation to microgravity affects the ability of astronauts to escape from the Space Shuttle during emergency conditions. The objectives of current research are to characterize microgravity-induced alterations in astronaut head and body movement along with gaze stability during walking, running, and jumping – tasks that are relevant to egress from the Space Shuttle. These studies will aid the development of countermeasures that will reduce the impact of these sensory-motor modifications.

A video-based motion analyzing system developed by Motion Analysis Corporation (Santa Rosa, Calif.) is being used to measure and analyze head and body movement during walking, running, and jumping tasks. This system tracks passive spherical retroreflective targets (shown in the first figure) placed on the head and body and can analyze their interrelationships producing a 3-dimensional biomechanical assessment of head and body movement.

Data are collected using a series of video cameras. The video signal from each of the cameras is fed to a video processor where the outlines of the various targets are extracted and passed to the system host computer for analysis. The system consists of four video cameras, a Sun SPARC computer workstation, a video processor, four VCRs, video monitors, a 32-channel Analog Data Acquisition System, and associated analysis software.

The parameters being measured by this system include

- Linear and angular acceleration, velocity, and displacement of the head, shoulders, hips, knees, ankles, and feet;
- Angular movement of the head with respect to space and the rest of the body;
- Predominant frequency of head movement; and
- Bearing of all body target movements relative to a reference target on the head.

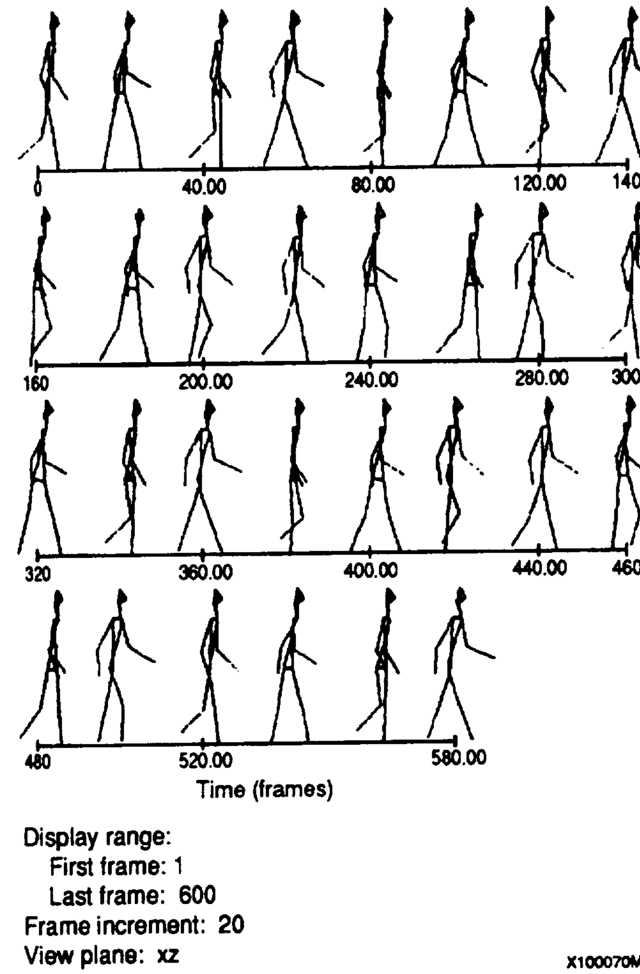
This system can track the 3-dimensional position of any of the body targets to within 0.5 mm.

The major advantage of this method of data collection is that it is noninvasive. It requires no encumbering measuring devices attached to the legs, torso, or head, thus allowing subjects to perform locomotion tasks in as natural a manner as possible. In addition, this system is capable of providing near real-time data reduction and analysis, permitting quick turnaround from testing to presentation of results.

The video motion analysis system can also be used to record ocular target acquisition performance during walking and running. This is achieved using a small head-mounted camera that records eye movement. In this case, eye movement is calculated by tracking the center of the pupil.

Alternatively, for supporting studies, a magnetic scleral search coil system will be used to record eye movements. With this system, a subject is surrounded by an electromagnetic field that induces a voltage in a small coil embedded in a contact lens. The voltage is proportional to the area of the coil perpendicular to the magnetic field. This system is extremely accurate (+ 0.5 deg), does not have a shifting baseline and gain, and can be used to record eye movements in three dimensions (horizontal, vertical, and torsional).

Video analysis of reflective targets placed on the head and body produce a 3-dimensional assessment of movement.



A computer reconstruction of human locomotion.

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The Effect of In-flight Exercise on Decompression Sickness During Extravehicular Activities

TM: James M. Waligora, M. S./SD5
PI: K. Vasantha Kumar, M. D./National Research Council
James M. Waligora, M.S./SD5
Reference LS 16

The primary objective of this study was to examine the effect of exercise undertaken prior to decompression on the incidence of altitude decompression sickness (DCS). The effect of such exercise is unknown and is crucial in prescribing inflight exercise for astronauts on long-duration space missions without increasing the hazard of DCS during extravehicular activities (EVA).

The study was designed as a two-period, crossover trial where each individual was tested twice at altitude. The experimental run required the subjects to exercise at their predetermined, individual anaerobic threshold levels for 30 minutes each day (see figure), and the control run required no exercise or physical activity for a period of 3 days prior to altitude exposure. On the fourth day (under both runs), the subjects were exposed to an altitude of ~6 400 m (21 000 ft., 6.5 psi) in the hypobaric chamber without prior denitrogenation. At altitude, they exercised for 3 hours, simulating an EVA while breathing 100 percent oxygen (second figure). They were monitored for circulating microbubbles by precordial Doppler device and also for symptoms of DCS. The two runs were separated by a period of 2 weeks or more. The order of administration of the two runs was randomized, where approximately half of the subjects were given control run first, exercise run second; and the other half were given exercise run first, control run second.

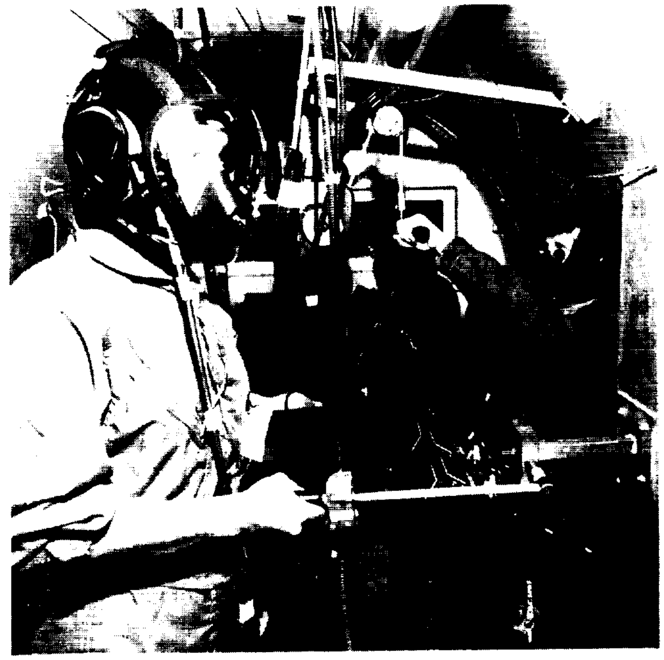
Out of 78 exposures (39 pairs of runs), there were 15 cases of DCS – all being type I pain-only bends. Within the crossover design, no residual or carryover effects between the two periods were detected. The occurrence of DCS was as below:

	Symptoms	No Symptoms
Control	7	32
Prior Exercise	8	31

Tests for treatment effects based on untied responses showed $p = 0.56$, for both symptoms and microbubbles. We also examined the data using sequential analysis techniques. The skew sequential design for detecting 10 percent excess preference under the experimental run, with $p = 0.05$ (one-sided) and power of 95 percent, also showed there was no difference between the two treatments.

In summary, no significant differences were detected between preexposure exercise and control with reference to DCS (both symptoms and microbubbles). However, these results are limited by the amount of exercise (30 minutes at anaerobic threshold each day $\times$ 3 days) and time interval between exercise and exposure (16 to 20 hours) in this study. Under the crossover trial, no statistically significant differences on DCS were observed within subjects due to prior exercise.

Test subject performing exercise on the treadmill at anaerobic threshold level with cardiopulmonary monitoring.



Two test subjects performing exercise simulating EVAs (foreground), while a third subject is being monitored for circulating microbubbles with the precordial Doppler device inside the hypobaric chamber.

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Dynamic Posturography Laboratory

TM: Millard F. Reschke, Ph.D./SD5
PI: Millard F. Reschke, Ph.D./SD5
William Paloski, Ph.D./SD5
Reference LS 17

A laboratory for the study of postural equilibrium control in astronaut and normative test subjects has been established at the NASA Johnson Space Center. Control of postural equilibrium is normally maintained through central nervous system integration of sensory inputs from the visual, vestibular, and proprioceptive systems. During spaceflight, however, these systems adapt to the microgravity environment, and, upon return to the terrestrial environment, a period of neurosensory readaptation to one-g must occur before normal postural equilibrium control returns.

The primary purpose of the Dynamic Posturography Laboratory is to obtain quantitative data regarding the magnitudes, time constants, and dependence on specific mission-related activities of these effects in order to assess accurately the degree to which inflight alterations in postural equilibrium control may affect postflight crew operations. These data will be used to guide development of countermeasures designed to offset any untoward effects of neurosensory adaptation during extended-duration missions. Secondary purposes for this laboratory include testing normative subjects to establish comparative databases for astronaut studies, evaluating the efficacy of Preflight Adaptation Trainer protocols, and developing quantitative models of postural equilibrium control.

All subject testing in the Dynamic Posturography Laboratory is performed using a modified version of the Equitest posture platform system developed by Neurocom International for clinical diagnosis of disorders in balance control. The Equitest system consists of a computer-controlled, motor-driven dual footplate capable of both rotational and translation movements, and a computer-controlled, motor-driven visual surround capable of rotational movements about the subject's ankles. Force transducers located beneath the dual footplate are used to monitor and record the subject's weight distribution and reaction torques during standard postural equilibrium testing.

As a means of improving the sensitivity of the posture platform system to subtle changes in postural equilibrium control, the Equitest system has been modified to monitor and record

- The EMG activity of the medial gastrocnemius, tibialis anterior, hamstrings, quadriceps, paraspinals, and rectus abdominus muscle groups; and
- Dynamic changes in hip position, shoulder position, and head angular velocity.

The Equitest system computer provides automated movement coordination and sensory organization test procedures. A typical Dynamic Posturography Laboratory test session consists of four movement coordination tests followed by six sensory organization tests.

In the movement coordination tests, the subject is presented with four types of sudden support surface perturbations, each repeated either three or five times in succession. The support surface perturbations include forward and backward translations (maximum translation = 7 cm), and toes up and toes down rotations (maximum tilt angle = 10°). The translations are repeated three times in succession, and the rotations are repeated five times in succession. During these tests, the rapid support surface perturbations provide stepwise external stimuli to the subject's posture control system. The dynamic postural responses of the subject to this sudden perturbation are monitored and recorded for a 2.5-sec period following the perturbation.

In the sensory organization tests, the subject attempts to maintain upright postural equilibrium control, while the footplate, the visual surround, or both are driven to tilt in response to the subject's normal postural sway. This "sway-referencing" has the effect of nulling ankle proprioceptive or visual feedback, thereby distorting the subject's posture control sensory inputs. The following six sensory conditions are each repeated three times in random order:

- Normal vision, fixed support surface
- Absent vision (eyes closed), fixed support surface
- Sway-reference vision, fixed support surface
- Normal vision, sway-reference support surface
- Absent vision (eyes closed), sway-reference support surface
- Sway-reference vision, sway-reference support surface

During these tests, the dynamic postural actions of the subject are monitored and recorded for 20-sec periods, while the subject attempts to maintain a stable, upright stance under normal and abnormal sensory input conditions.

A series of parameters is routinely derived from each of the movement coordination and sensory organization test procedures in order to evaluate the performance of the subject. Among the parameters routinely derived for the movement coordination tests are

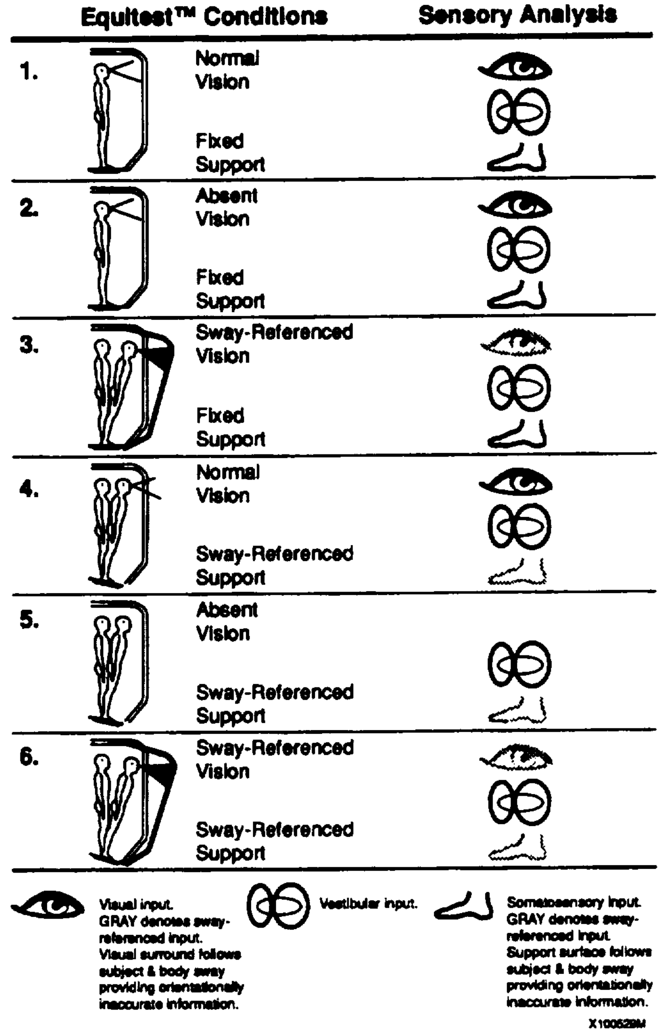
- Static and dynamic symmetries;
- Force and EMG latencies;
- Sway, strength, and EMG amplitudes; and
- Adaptation and strategy.

Among the parameters routinely derived for the sensory organization tests are

- Sway amplitudes,
- Strategy, and
- Equilibrium.

Studies performed in the Dynamic Posturography Laboratory should provide the quantitative data required to accurately assess the degree to which inflight neurosensory adaptations may affect postflight postural equilibrium control, and to guide development of countermeasures designed to offset any untoward effects of this adaptation on postflight crew operations.

The modified Equitest posture platform system.



The modified Equitest posture platform system.

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Effect of Prolonged Lower Body Negative Pressure and Saline Ingestion on Plasma Volume During Bed Rest

TM: Suzanne Fortney, Ph.D./SD5
PI: Suzanne Fortney, Ph.D./SD5
Nitza Cintron, Ph.D./ SD4
Reference LS 18

Hyatt and West, *Aviat. Space Environ. Med.* 48, 1977, reported that a 4-hour exposure to a mild level (−30 mm Hg) of lower body negative pressure (LBNP) and ingestion of 1 liter of an isotonic solution will restore plasma volume and improve orthostatic responses after 7 days of simulated spaceflight (bed rest). The purpose of this study was to determine whether their protocol may be shortened to 2 hours and still expand plasma volume during bed rest. We proposed that LBNP redistributes body fluids from the thoracic region of the body to the lower body. This may result in an increase in the secretion of antidiuretic hormone (ADH) and aldosterone (ALD). Increased levels of ADH and ALD cause fluid and electrolyte retention, and this may be the mechanism for the plasma volume expansion.

Ten men (25–40 years old) participated in this study. The protocol involved a crossover design with the subjects randomly assigned to groups A and B. Each subject was exposed to one 4-hour and one 2-hour LBNP/saline treatment, with group A (n = 5) exposed to the 4-hour treatment first and the 2-hour treatment second, and group B (n = 5) exposed to the 2-hour treatment first and the 4-hour treatment second. During each treatment, subjects were exposed to a continuous negative pressure of −30 mm Hg, and they ingested 1 liter of isotonic saline between exposure minutes 30 and 90. Each subject underwent a 13-day, 6° head-down bed rest. Throughout bed rest, fluid, salt, and food intake were maintained at 2500 ml of rehydration fluid/day, 4 grams of salt/day, and 2500 Kcal/day. Twenty-four-hour urine collections were obtained, from which volume, electrolytes, ADH, and ALD concentrations were measured.

Blood volume was calculated as the sum of red cell volume (RCV) and plasma volume (PV) measurements taken at the beginning and on the last day of bed rest. The RCV was determined with ^{51}chromium sulfate, and PV was determined with ^{125}iodinated human serum albumin. The PV was calculated for each bed rest day from the daily RCVd (RCVd = pre-bed rest RCV minus the accumulative loss of red cells due to daily blood draws) and the daily hematocrit value; where PV = [RCVd/(hct/ 100)] − RCVd.

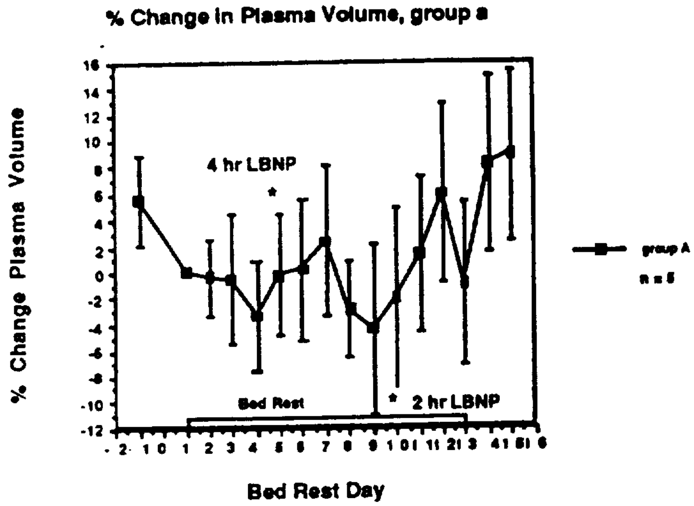
The changes in PV determined from each morning blood sample are shown in figure 1 for Group A and in figure 2 for Group B.

The effect of the LBNP and saline ingestion treatments on PV and endocrine responses is shown in figure 3.

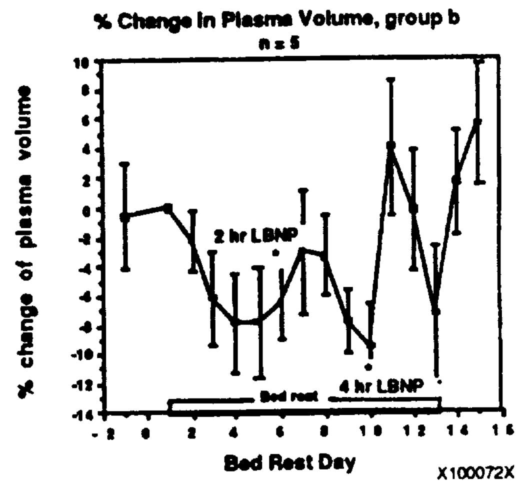
We conclude that both 2-hour and 4-hour LBNP exposures during bed rest effectively increase PV for at least 24 hours, and this expansion may be related to an increased secretion of ADH and ALD.

Variable	PreBR	Pre 4hr	Post 4hr	Pre 2hr	Post 2hr
PV (ml)	3157(161)	*2918(132)	3144(173)	*2987(131)	3109(146)
UV (ml)	2506(250)	2538(155)	+2923(111)	2258(162)	+2788(191)
ADH (ng)	136(33)	114(15)	+177(26)	93(18)	+155(42)
ALD (ng)	16(4)	*35(4)	+*54(5)	*37(7)	+*46(7)

*** = Different from pre-bed rest, P < 0.05.**
+ = Different from pretreatment (pre 4 hr or pre 2 hr), P < 0.05.



Percent change in plasma volume (Group A) (n = 5).



Percent change in plasma volume (Group B) (n = 5).

An Intelligent Microscope Imaging System (IMIS)

TM: Gerald R. Taylor, Ph.D./SD5
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Norwood Hunter/ SD5
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Reference LS 19

Microscopic analysis of biological and nonbiological specimens will be a critical need of some investigators with experiments onboard Space Station Freedom (SSF). Disciplines such as Materials Processing, Plant and Animal Research, Human Research, Environmental Monitoring, Health Care, and Biological Processing have a diversity of microscope requirements. Limitations in crew time available for conducting experiments, space, power, and mission duration have necessitated creative approaches to the way experiments will be conducted onboard SSF. To compensate for these constraints, experiments should be as automated as possible.

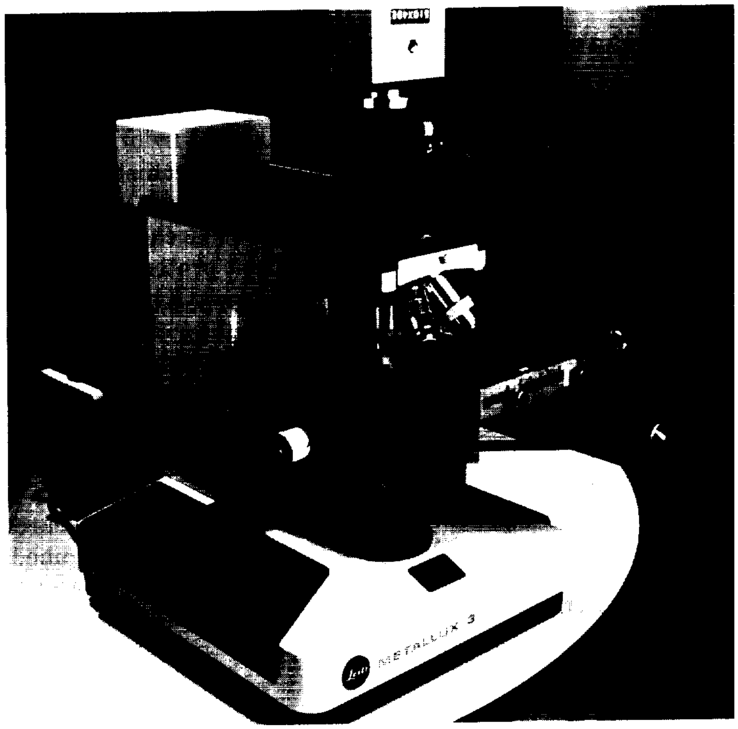
In the past, microscopy in space was conducted manually by the crewmember with observations being recorded in notes, drawings, or photographs. Today, three additional modes of microscopy are available for use in space. These are Remote Coaching, Remote Control, and Automation. Remote Coaching requires manual operation of the microscope with instructions given by two-way audio/video transmission during critical phases of the experiment. In the Remote mode, the Principal Investigator controls the microscope from the ground. The Automated mode employs artificial intelligence to control microscope functions and is the only mode that can be operated in the other modes as well.

The Technology Innovation Facility [TIF] at the NASA Johnson Space Center (JSC) has developed a functioning ground-based prototype Intelligent Microscope Imaging System (IMIS) (see figure) to address the unique demands of microscopy in space. These include accommodation of multiple users, multiple requirements, reduced crew time, and restrictive data/instruction transmission capability. The system is composed of an Automatic Metaphase Finder (AMF), a device that locates cells in the second stage of cell division (metaphase), during which the chromosomes are arranged in the equatorial plane of the spindle prior to separation. The other components of the system include a digitizing camera and an Image Processing Facility. The IMIS is also interfaced between the development laboratory to remote workstations located in the Scientific Monitoring Area at the JSC and Science Support area in Hangar L at the Kennedy Space Center (KSC). The system is designed so that only preliminary initialization and setup tasks require human interaction. Once the specimen slide is manually loaded onto the AMF and the system is initialized, the IMIS scans the slide for metaphase spreads. Chromosomes in metaphase were selected as the model for this development, because it has been reported that chromosomes are altered during spaceflight; therefore, the IMIS could be used as a biological radiation dosimeter. After the entire slide is interrogated, each spread is relocated and digitized, and the images are stored or transmitted to a remote workstation.

To demonstrate the IMIS telescience capability, a unit located in its parent laboratory 2 miles from the JSC in Houston was successfully activated and commanded from remote workstations located at the JSC and the KSC in Florida. The IMIS automatically located, digitized, and transmitted images of metaphase spreads. Transmitted images were received by the remote workstations and found to be of diagnostic quality.

Implementing systems like the IMIS will expedite the automation of experiments in space and allow ground-based investigators to control and interact with inflight diagnostic systems. This will greatly minimize the impact of reduced crew size and crew time on Space Station experiments.

Development has begun on the next generation of the IMIS. This system will incorporate the latest advances in robotics and artificial intelligence and will be completely automated.



A prototype IMIS.

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Pharmacological Countermeasures to Space Motion Sickness

TM: Millard F. Reschke, Ph.D./SD5
PI: Randall Lee Kohl, Ph.D., F.C.P./National Research Council
Millard F. Reschke, Ph.D./SD5
Reference LS 20

Drugs selective for tissues, including the central nervous system, that respond to arginine-vasopressin (AVP) were tested for their ability to prevent space motion sickness. A specific drug originally developed by SmithKline Beecham and designated SK & F 100273 was given to squirrel monkeys prior to stressful motion stimuli. SK & F 100273 (see figure) is a potent and highly specific antagonist of vasopressin receptors of the V1 subtype. A dose of 200-240 mcg IV 30 minutes prior to motion prevented emesis and dramatically reduced symptomatology (table). A second compound called SK & F 103561 was given to two monkeys at a lower dose of 100 mcg prior to testing. This drug, another potent V1 antagonist, also significantly delayed or prevented emesis.

This research has lead to the successful granting of patent protection by the United States Patent Office to Lewis Kinter of SmithKline Beecham and Randall Kohl for the indications of motion sickness, nausea, and emesis. Efforts from prior years had established that individual human susceptibility to motion was correlated with nausea-induced levels of AVP. Present year testing of specific drugs that target the vasopressinergic system was a logical extension of this prior research. These findings aim to solve one of NASA's biomedical problems with orbital flight, namely, the occurrence of nausea and emesis during the first 3 days of flight.

PREVENTION OF EMESIS AND MOTION SICKNESS SYMPTOMATOLOGY IN SQUIRREL MONKEYS FOLLOWING INTRAVENOUS $d(CH_2)_5Tyr(Me)AVP$, A VASOPRESSIN (V1) ANTAGONIST

	Motion Sickness Rating[1]			Latency to Emesis (min.)		
Monkey	Predrug[2]	On Drug[3]	Postdrug[4]	Predrug	On Drug	Postdrug
1	22.8	3	17	36.3	60+	40.0
2	20.6	2	18	32.2	60+	50.2
3	21.4	4	24	38.3	60+	45.5
4	21.6	5	22	26.4	60+	38.5
Mean	21.6	3.5	20.2	33.3	60+[5]	43.6
SEM	0.4	0.6	1.6	2.6	—	2.7

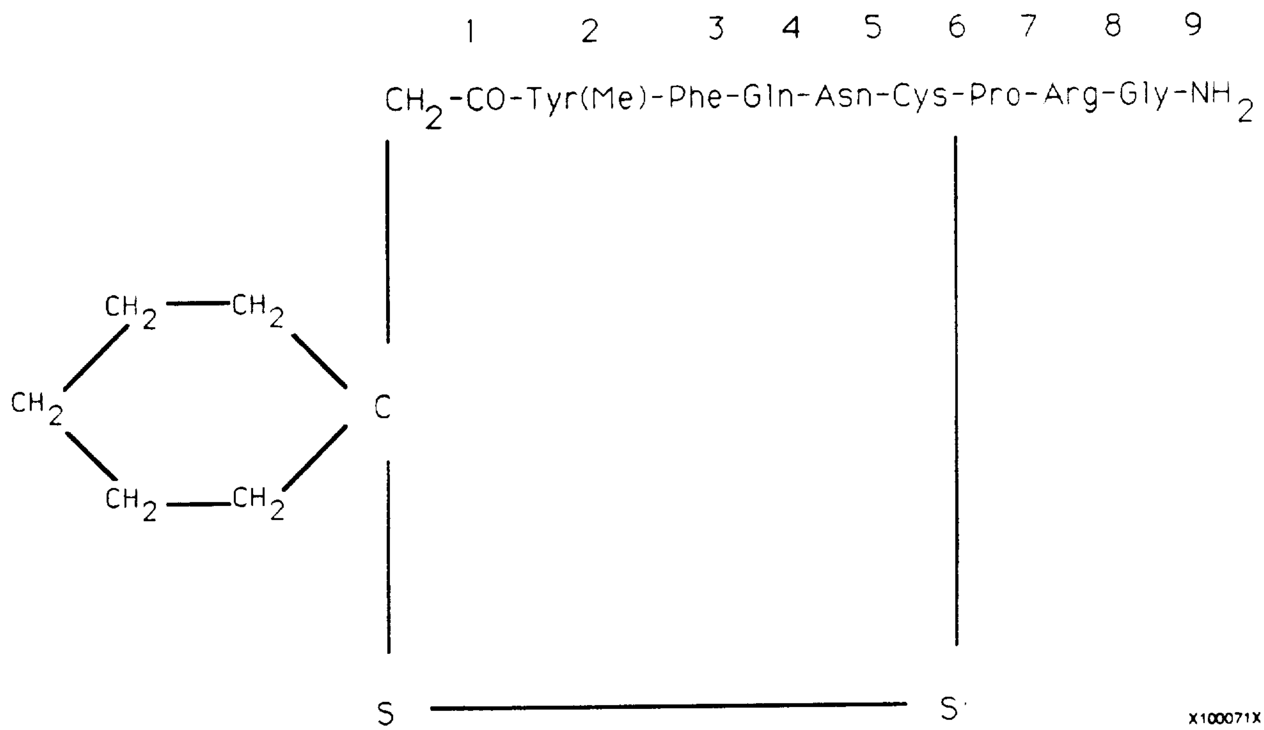
[1] Maximum symptom score is 31

[2] Motion sickness rating on tests given up to 2 years prior to drug test, 5 repetitions

[3] 200-240 mcg $d(CH_2)_5Tyr(Me)AVP$, IV, into each squirrel monkey (~800-1000 g weight) 30 minutes prior to stressor test

[4] Test repeated ~2 weeks later without drug

[5] Testing was terminated after 60 minutes



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Chemical structure of SK & F 100273, also commonly known as $d(CH_2)_5Tyr(Me)AVP$ or the "Manning Compound." Chemically, it is [1 - (beta-mercapto-beta, beta-cylopentamethylene propionic acid), 2-(0-methyl) tyrosine, 8-Arginine] vasopressin.

Computer-Predicted Human Strength

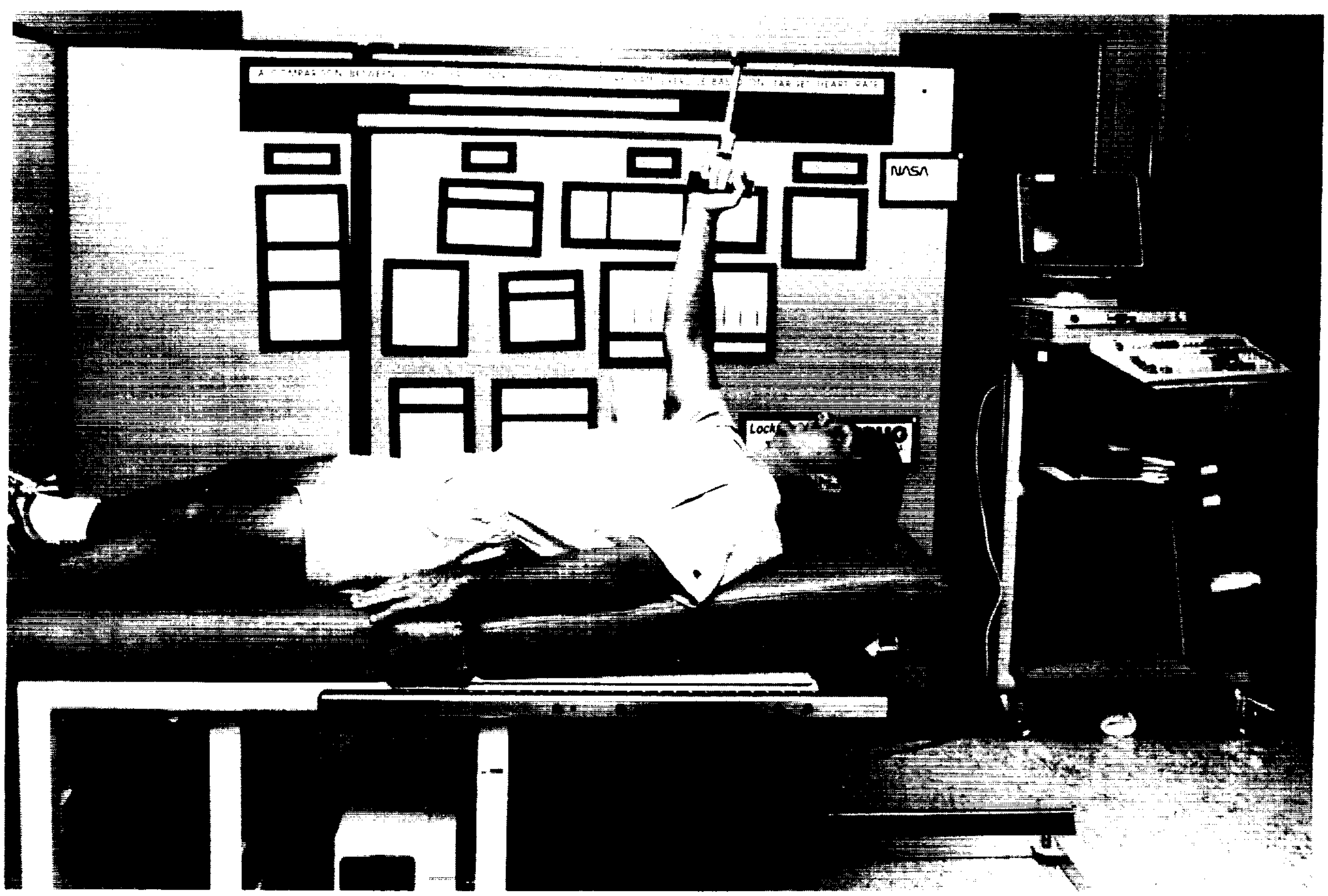
PI: Barbara Woolford/SP34
Abhilash Pandya/C95
Reference LS 21

In order to plan operations and design equipment for use in zero-g or on planetary surfaces, knowledge of human strength in those environments is essential. It is also exceedingly difficult to collect directly, and, when that becomes possible, the knowledge will already be needed.

In an effort to provide this knowledge, a man-modeling program called JACK [not an acronym] is being extended to provide predictions of human strength in varying situations. The first phase of this development project is under way. Single joint strength data were collected from 15 individuals. Also, compound motions where several joints operate together were collected. The intent is to predict the compound motion strength from the individual joint strengths. The data were collected at the University of Texas Medical Branch and analyzed in the Anthropometry and Biomechanics Laboratory at the NASA Johnson Space Center (JSC).

The data for each of the single joints in the arm were examined and fit to a polynomial equation and stored in JACK's database. A search and interpolation routine was written to locate the strength of any joint for any angle for any velocity of rotation. The simulated compound task was pushing and pulling on a ratchet wrench. This required inputs from all joints. Vector addition was used to calculate the end effector (hand) force.

This simple algorithm gave the right shape curve, with the maximum force occurring at the proper place in the wrench motion, but also gave values significantly lower than those measured. This is due to interaction between the joint angles and to extreme sensitivity to starting position. Video tapes are being analyzed to get the correct data for the starting position as measured. The investigators are conferring with a biomechanist on the interaction of joint forces for the arm. Additional data will be collected in the JSC Anthropometry and Biomechanics Laboratory and transferred to JACK.



Strength data collection using an LIDO dynamometer.

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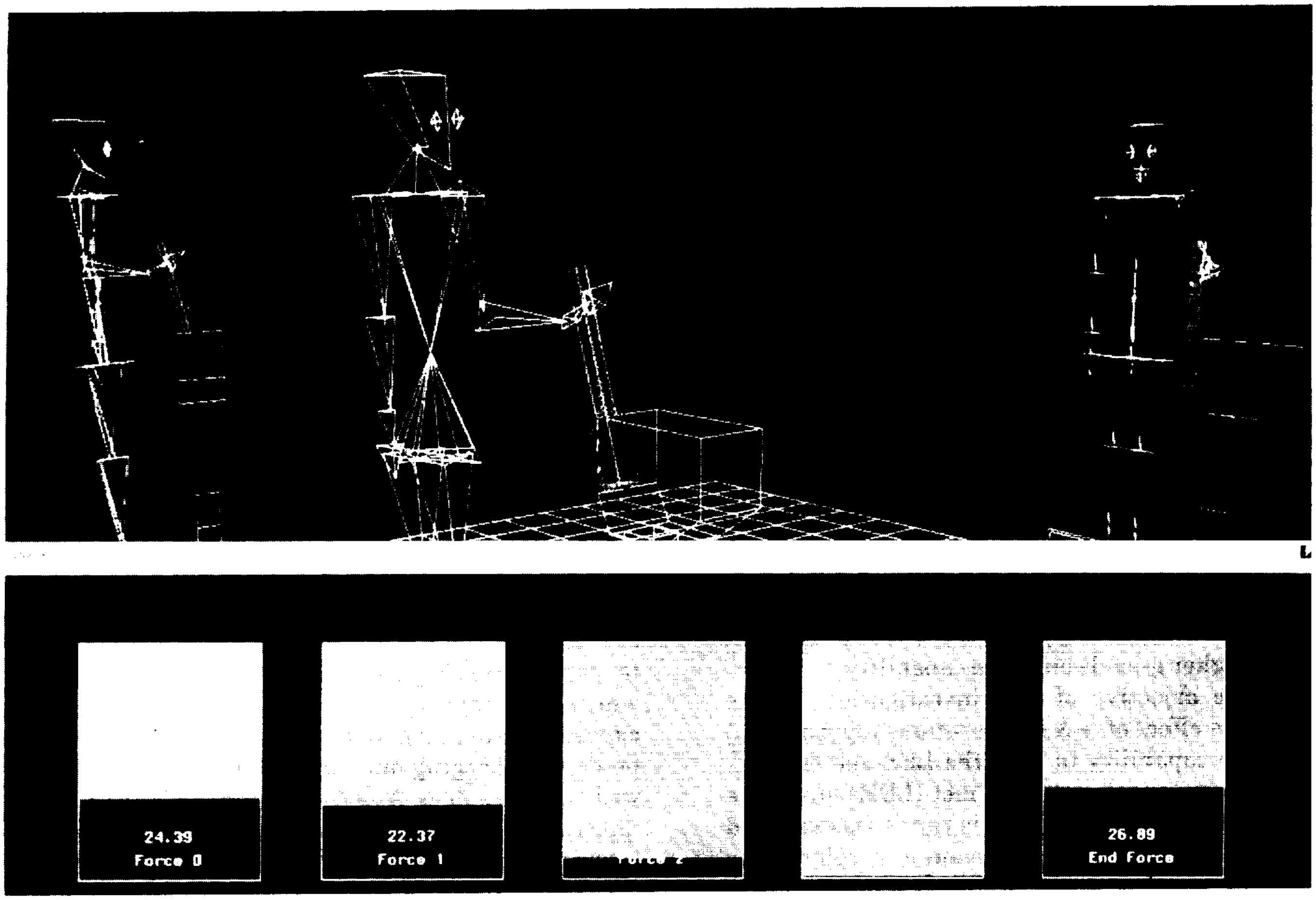

Body in JACK pushing ratchet wrench with individual joints and end-effector joint shown as bar graphs at bottom.

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Overhead and Forward Reach Capability During Exposure to +X Accelerations

PI: J.P. Bagian M.D., P.E./CB
L.E. Schafer, M.S.E. /C95
Reference LS 22

Crew performance under varying g-loads during spaceflight has received only cursory attention in the past. To date, no truly quantitative reach study in which actual crew equipment is worn and Shuttle seat/restraint systems are used has been conducted. This lack of reach performance data raised a number of questions regarding the use of simulators in ground-based training for Space Shuttle missions, the impact of the current Shuttle launch escape suit (LES) on crew reach capability, and the effect of sequentially higher g-loads on reach capability.

The objective of this investigation was to study the effect of +X accelerations (eyeball's in) on reach capability in both the LES and the pre-*Challenger* launch entry helmet (LEH) ensemble over a range of 1 to 6g's. This range was selected because it covered the spectrum of accelerations seen in current space operations (e.g., Space Shuttle) as well as anticipated future operations (e.g., Assured Crew Return Vehicle (ACRV)). Seven veteran astronauts and four Brooks Air Force Base (AFB) airmen participated in the study. The subjects performed standardized reach sweeps during each g-load in the Brooks AFB centrifuge. These sweeps were recorded using photogrammetric techniques and analyzed using 3-dimensional motion analysis.

The analysis of the LES 1 and 3g sweeps indicated that Shuttle crews in training can expect to maintain all of the overhead reach capability evident in good simulator runs and suffer only moderate degradation in forward reach performance during the launch phase of an actual Shuttle mission. Although the absolute difference was small, the LES provided less reach capability that did its predecessor, the LEH. Finally, an analysis of reach sweeps performed during consecutive +X 1 to 6g loads indicated that crew tasks requiring limb movement can be performed confidently during accelerations of up to 4g in the forward direction and 5g in the overhead direction. However, in actual practice, the speed of required response and potential fatigue effects must be considered.

Since these data are handled and stored digitally, they are fully transferable. Because of this portability factor, in future studies our data will be used to predict reach performance in any environment where the subjects use the same equipment and are exposed to similar g-loads. Currently, we are in the process of merging our measured reach information with the Graphics Analysis Facility (GRAF) Space Shuttle cockpit model. This will allow us to find the intersection of these two databases and determine the actual panel positions reachable by a specific subject. Other applications of these data include predicting reach performance during ACRV operations, evaluating future flight suit configurations against these baseline data, and combining crew anthropometric measurements with the GRAF model to determine if new ground-based training procedures are feasible.

Layout of reach capability test in the Brooks AFB centrifuge gondola. The subject is wearing an LES and is strapped to an actual Shuttle flight seat in the launch position.

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Solar System Sciences

Summary

Solar System Sciences

NASA is investigating several space initiatives which, it is hoped, will enhance our understanding of the Earth upon which we live and which will support the eventual human exploration of our solar system. These include (1) a fundamental space research program in Earth orbit, and (2) a planetary exploration program with goals that include the establishment of a lunar outpost and, eventually, a human mission to Mars. Solar system research at the Johnson Space Center (JSC) supports development of concepts that ultimately will foster the science and technology necessary to enable these initiatives. In the Solar System Exploration Division, research is conducted on several aspects of these emerging fields of study. This includes work on the space radiation environment, as well as on the characteristics, origin, and evolution of planets, asteroids, and satellites in our solar system. It also includes research into the practical uses of the resources of these planets to support and maintain human expansion into the solar system. It has been conducted by

- Analyses of planetary materials;
- Experimental simulation of planetary conditions and processes;
- Remote sensing observations;
- Theoretical modeling of analytical, experimental, and observational data; and
- Theoretical study of the Earth and solar system and their interaction with the rest of the universe.

Such research at JSC in Solar System Sciences is necessarily broad and far-reaching. In previous years, for example, ground-based telescopic observations of the Moon, Mercury, and asteroids were published. Rather than repeat some of that work which is still continuing, new results during fiscal year FY 1990 in other complementary disciplines will be described.

The following, which is not comprehensive, is a brief discussion of some of this research.

Lunar Sample Research

At JSC, the curatorship and study of extraterrestrial materials, including lunar samples, meteorites, and cosmic dust particles, is heavily emphasized in solar system study. These extraterrestrial materials provide the only samples with which to investigate directly the origin and evolution of the Earth's planetary system directly. The lunar samples collected as part of the Apollo program are curated at JSC and distributed worldwide to scientists at many institutions for research purposes. Research at JSC on these lunar samples has contributed new results to the understanding of accretion of planetesimals and differentiation processes of the Moon and other planetary bodies.

Cosmic Dust Research

Recent return of the Long-Duration Exposure Facility (LDEF) after years in Earth orbit has added considerably to NASA's lunar and Antarctic meteorite collections. The LDEF dust and particulate collector contains significant information regarding the Earth's space operations environment.

The JSC investigations were only preliminary in FY 1990, but new understanding of long-duration exposure in space is forthcoming. The LDEF cosmic dust particles are considered 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 will provide insight into the origin and evolution of the solar system. At JSC, scientists also maintain a collection of stratospheric dust acquired by NASA aircraft equipped with special cosmic dust collectors during flights through the Earth's upper atmosphere.

New methods of cosmic dust sample collection and preparation to minimize contamination are under development. Such methods enable detailed laboratory analyses of the cosmic dust particles and provide valuable insight with which to develop cosmic dust collection facilities in space.

In-Situ Resource Utilization

Detailed study of the lunar rocks and soils provides insight into the potential for planetary resource extraction. Use of *in situ* lunar resources, for example, has the potential for establishing the feasibility of, and increasing the long-term viability of, a manned lunar outpost. It also could reduce the cost of such a project. These studies provide information which aids in the design of unmanned and manned lunar missions, with the goal of establishing a manned lunar outpost and eventually conducting a manned Mars mission.

In FY 1990, new methods in the extraction of oxygen from lunar regolith were devised.

Life Support System Research

Proposed NASA space missions to the Moon and, possibly, to Mars are very long-duration missions. To minimize costly resupply missions from the Earth, essential consumables must be regenerated by the life support system. All water and air must be reused, and food must be produced in some fashion. 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. An example of this work is synthetic soils for lunar base agriculture.

In this vein, new results in lunar base agriculture were obtained at JSC during FY 1990.

Windows for Earth Observation

Although one of the principal justifications for space exploration is the remote observation of the Earth, not enough attention has been paid to the spacecraft windows used in space. Investigations by JSC have begun to define the scientific requirements for optical measurements made through windows from the "shirt-sleeves" environment of a manned spacecraft. The focus is upon Earth orbital observations, but the intent is to establish a stable, long-term window configuration that supports the operational environment of even a surface outpost such as the proposed lunar base.

New window requirements were obtained during FY 1990, and new configurations are emerging.

Planetary Sample Missions

Future exploration initiatives include unmanned missions which analyze the surface of a planet and, possibly, return a suite of samples to Earth for intensive laboratory examination. Surface landers on remote planetary objects require compact 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. *In situ* sample analysis and preservation 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.

Therefore, scientists at JSC have studied in FY 1990 several such remote surface analyzers of planetary geologic material.

Orbital Debris

With the lengthening mission duration of some flights, such as the planned Space Station Freedom and Extended Duration Orbiter, increased attention has been paid to the amount of orbital debris in Earth orbit. 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 international 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 comprehensive radar systems capable of measuring debris in such a size range have been developed so that a statistically valid database can be assembled. Additional models are being built to characterize the debris environment more accurately. Ground-based telescopic observations by JSC scientists have extended the radar data considerably. These optical measurements are still under investigation, but they already have contributed to the definition of requirements for a complementary radar-optical observation system of the orbital debris environment.

Hypervelocity impact studies of orbital debris also are conducted at JSC. This research is concerned with determining efficient shielding techniques for long-duration spacecraft missions. New results in multishock impact simulation reinforce a long-held belief that multilayered shielding may be the answer for long-duration space exposure.

Cosmic Geochemistry

No understanding of the Earth would be complete without a satisfactory story recounting its origin and thermal history in our solar system. Scientists at JSC, more than those at any other NASA center, are deeply involved in the geochemical analysis of planetary origin and evolution. This consists of serious study of fundamental constituents in cosmogony, the relics of which comprise cosmic dust, meteorites, asteroids, and comets. No more volatile a topic exists in planetary geochemistry than the thermal history of our own Moon, and JSC research addresses even some of the most controversial aspects of disputing orthodox ideas. This work, confronting such simple objects as an Antarctic or lunar meteorite, could one day alter our very theories of the Earth and Moon as constant companions.

Solar System Sciences

Significant Tasks

Sample Acquisition, Analysis, and Preservation

PI: Doug Blanchard/SN
Doug Ming/SN14
Judy Allton/C23
Reference SSS 1

Sample acquisition, analysis, and preservation (SAAP) is an element of the Exploration Technology Program (ETP), which is intended to define and develop technologies that will enable NASA to implement the Space Exploration Initiative (SEI) efficiently under the existing monetary and technological constraints. The following is an attempt to describe this program, and to relate some of its accomplishments in fiscal year 1990 (FY 1990).

The goal of SAAP is to develop critical technologies required for automated *in situ* analysis and to return to Earth scientifically valuable specimens from planetary surfaces (e.g., Moon, Mars), comets, and asteroids. An example of a mission that would utilize SAAP technology is the proposed Mars Rover Sample Return (MRSR) mission. This mission, which includes a surface rover, will provide a wealth of information about Mars and will increase our understanding of the origin and evolution of terrestrial planets. The mission also will set the stage for the human exploration of Mars. The major goal of the MRSR mission is to collect and return several kilograms of rocks, soils, and sediments from Mars. It will be necessary to select carefully a diverse suite of samples and to preserve their chemical and physical integrity during the collection process and the return trip to Earth. Also, it will be desirable to include a variety of instruments on the rover/lander to conduct *in situ* measurements to supplement or replace information that might be lost from degraded samples during the return trip. Although MRSR is the most publicized mission, SAAP technology will also address other possible unmanned and manned missions associated with SEI in which extraterrestrial material is to be acquired, analyzed and preserved (e.g., unmanned lunar sample return, lunar outpost, Mars outpost, comet and/or asteroid sample return).

The SAAP ETP (formerly Pathfinder) is managed by the NASA Jet Propulsion Laboratory. The NASA Johnson Space Center (JSC) is the primary participating center. The SAAP program addresses four areas for technology development:

- Methods for site and sample selection;
- Techniques for obtaining samples;
- Techniques for performing physical, mineralogical, and chemical analysis; and
- Methods for preserving and containing samples without contamination.

Of these four, JSC is responsible for the development of techniques for performing chemical, mineralogical, and physical analyses as well as methods for preserving and containing samples.

Technology developed for performing sample analysis (one of the JSC tasks) will be extremely helpful in choosing a wide variety of samples for a return trip. Even though extreme care will be taken to return samples in their natural state, it is possible that some samples may degrade during the return trip. Therefore, it is important to have instruments on the rover/lander that will measure properties of the samples which may be altered or lost during the return trip. The objectives of this task are to

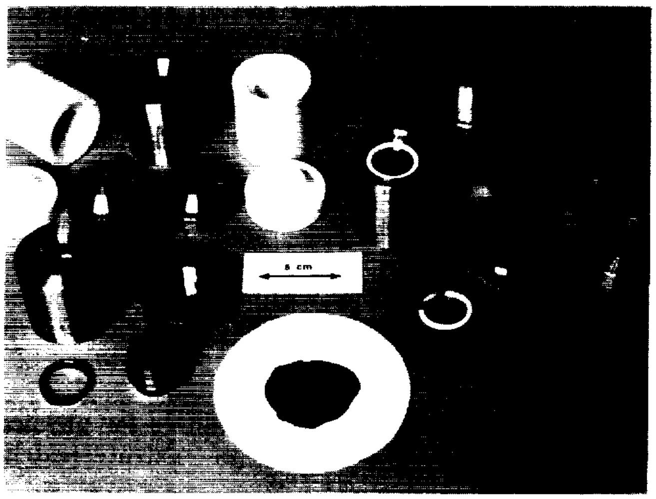
- Develop strategies and procedures for physical and chemical analyses of extraterrestrial material,
- Identify and develop technologies that will enable instruments to perform a variety of *in situ* measurements on a planetary surface, and
- Develop and demonstrate technologies that prepare and deliver samples for analysis and that do not cross contaminate between samples.

To date, relevant instruments for sample analysis of extraterrestrial materials have been identified and reported (Sample Acquisition, Analysis, and Preservation Instrument Technology Workshop, JSC). This report also assessed the technology level for each instrument with respect to its use in SAAP. Several high-priority instruments were identified as requiring technology development including

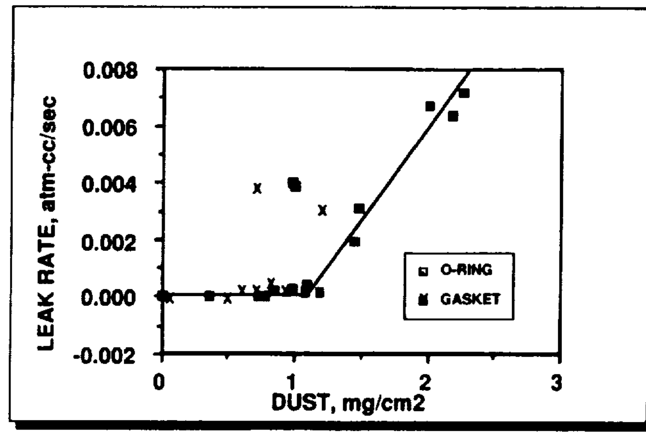
- A high-temperature differential scanning calorimeter to measure sample mineralogy,
- A gas chromatograph/mass spectrometer to measure the contents of gases (e.g., atmosphere, regolith),
- An X-ray diffraction/X-ray fluorescence unit to determine sample mineralogy and chemistry, and
- A full-imaging spectrometer that would provide spectral data for mineralogical analysis and sample selection.

A number of other technology areas requiring development also were identified.

One of the greatest challenges of a sample return mission is to package samples so they will remain pristine and unchanged during the return trip to Earth. Containment and preservation of samples for return trips is one of the four major areas requiring technology development for SAAP. The JSC is responsible for the identification and development of such technologies, and containers and seals have been fabricated as well as tested (see first figure). Quantitative data on the effect of small dust-sized particles on Teflon container seals at room temperature have been determined in FY 1990 (see second figure), and subsequent experiments at martian surface temperatures are planned for FY 1991.



Atmospheric tight containers will be essential to preserve returned samples from planetary surfaces, comets, and/or asteroids in their natural state.



Leak rate of container as a function of concentration of dust coating o-rings and gaskets at room temperature (25°C).

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Lunar Base Agriculture: Synthetic Soils for Plant Growth

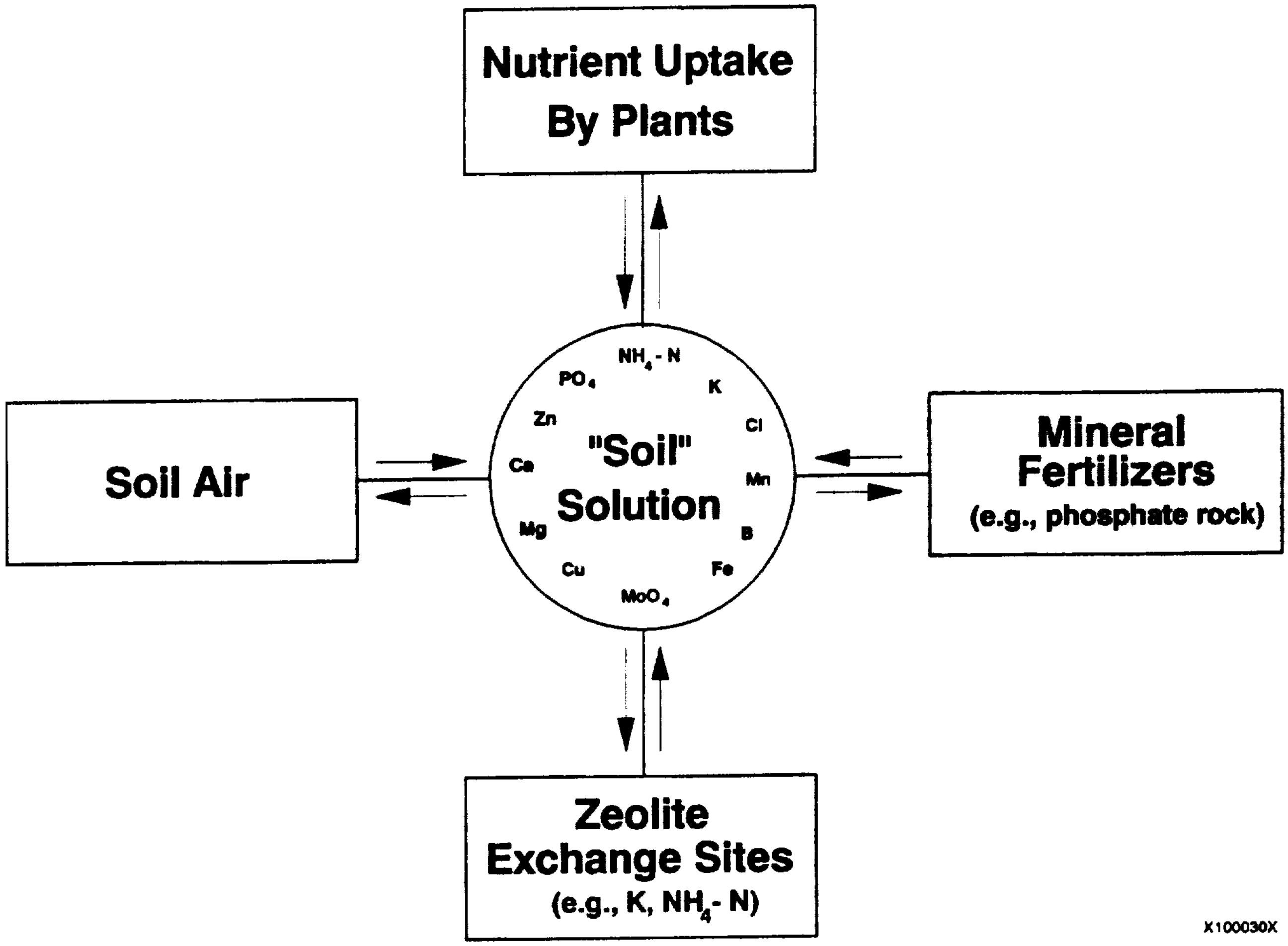
PI: Doug Ming/SN14
Don Henninger/EC3
Reference SSS 2

Several critical, near-term technologies need to be developed to meet the challenges of NASA's proposed Space Exploration Initiative. Regenerative Life Support Systems (RLSSs) have been identified as one of these technology areas that requires development, and the following discusses some accomplishments during 1990. These systems are necessary to establish long-term, self-sufficient outposts on the Moon and Mars.

The RLSS will regenerate air, water, and wastes and will generate food for humans. Plants are considered the most likely candidates for food production at lunar and martian outposts. Several systems exist in which to grow plants; e.g., hydroponics, aeroponics, and solid-support substrates. Most of the plant growth research in RLSS has been aimed toward hydroponic systems. Solid-support substrates that slowly release essential growth elements to the plant also may be viable plant growth systems; however, these systems require further research before a decision can be made as to which plant growth system will be best suited for planetary base agriculture.

Highly productive, synthetic soils are being considered as solid-support substrates for plant growth at lunar/Mars outposts. One such system currently being studied is zeoponics – i.e., the growth of plants in zeolite mineral substrates. Zeolites are crystalline, hydrated minerals that contain loosely bound ions (e.g., Ca, K, Mg) within their crystal structures. Zeolites have the capability to exchange some of their constituent ions freely with ions in solution without changing their structural framework. Zeoponics is defined as the cultivation of plants in zeolite mineral substrates that contain essential, plant-growth nutrients. These plant-growth nutrients are released slowly into "soil" solution where they become available for plant uptake. A zeoponics system is illustrated in the figure 1. The goal of this research is to develop zeoponic systems wherein all plant-growth nutrients are supplied by the plant-growth medium for many growth seasons with only the addition of water.

To date, wheat plants have been successfully grown in zeoponic substrates (figure 2). These substrates have adequately supplied several of the macronutrients, including nitrogen, phosphorous, potassium, and calcium. Particular attention has been directed to the characterization of the zeoponic substrate after plant growth experiments. Only small amounts of these elements have been depleted from the zeoponic substrate during multiple growing seasons (figure 3). Because a large portion of these elements are still present in the substrate, it is probable that these substrates will support a number of future crops without fertilization. These results are encouraging for the development of zeoponic systems which supply plant growth nutrients for many growth seasons with just the addition of water.



Dynamic equilibria for a zeoponic system. Plant growth nutrients are slowly released from zeolite minerals and other mineral phases, e.g., apatite a phosphate rock. The reactions in soil solution (i.e., nutrient release) should (theoretically) be driven towards the root-soil interface by the uptake of nutrients by the plant.

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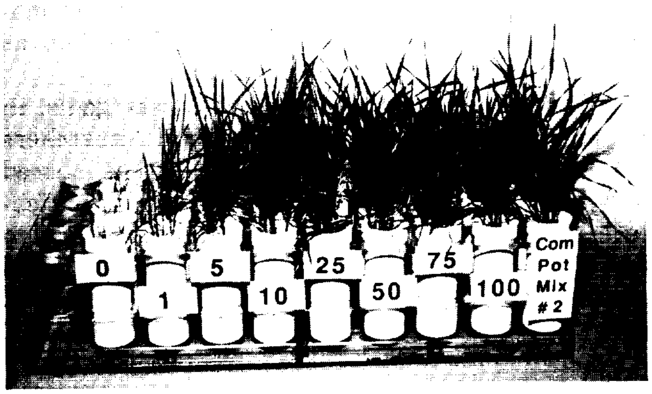
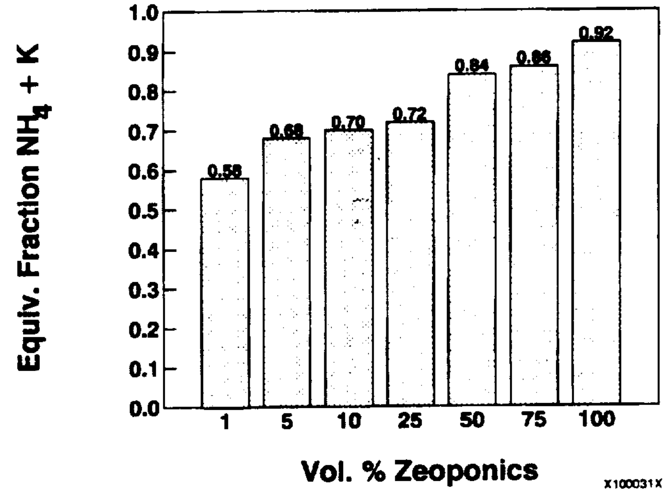


Wheat plants have been successfully grown in zeoponic systems in controlled environment plant-growth chambers. The zeoponic system consisted of varying amounts of zeolite/phosphate rock and inert quartz sand mixture. Wheat plants had a favorable response in zeoponic systems consisting of 25 to 100 percent zeolite/phosphate rock compared to other zeolite/phosphate rock treatments and control experiments of commercial potting soil. After 225 days of plant growth, wheat yields (dry matter weight) were higher in zeoponic systems with approximately 100 percent zeolite/phosphate rock mixtures.



Over 90 percent of the original potassium and ammonium-nitrogen remained in the 100 percent zeoponic system after continuously growing wheat for 225 days. Zeoponic systems with only 1 percent by volume zeolite (99 vol. percent inert sand) had over 50 percent of the original ammonium-nitrogen and potassium remaining in the zeoponics substrate. These data suggest that zeoponic systems will slowly release plant growth nutrients for many growing seasons with only the addition of water.

The Long-Duration Exposure Facility (LDEF) Satellite: New Data on Cosmic Dust and Spacecraft Debris

PI: Michael Zolensky/SN21
Reference SSS 3

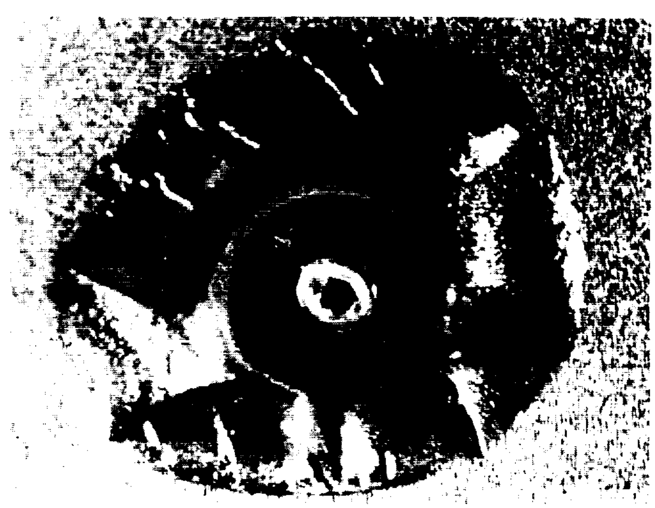
After nearly 6 years in space, the Long-Duration Exposure Facility (LDEF) was returned to Earth by the Space Shuttle *Columbia* in January 1990. It reveals a wealth of new data regarding the nature of cosmic dust and spacecraft debris which have undergone preliminary analysis.

As originally envisioned, LDEF was intended to be a bus-sized collector for cosmic dust and space debris particulates. However, as the project matured and as NASA grew to realize the potential hazard posed to spacecraft by space environmental factors, other critical science and engineering objectives were added. By its launch date in 1984, the mandate of the LDEF mission was to sense and record the nature of the total environment in low-Earth orbit, where most spacefaring operations occur. The effects of cosmic dust and space debris impacts, solar and galactic radiation, oxygen erosion (the destruction of materials through collisions with oxygen present in the Earth's upper atmosphere), the relative vacuum of space, and other space-related phenomena are recorded on the more than 10 000 test specimens flown on LDEF. These test specimens are now being studied by more than 300 investigators representing 7 NASA centers, 21 universities, 33 private companies, 9 department of Defense laboratories, and 8 foreign countries.

Since the LDEF was gravity stabilized, the same end of the 30-ft-long cylinder always faced the Earth, the same side always faced in the direction of orbital travel, and the opposite side always faced in the backwards (or trailing) direction. Therefore, careful examination of dust impact features, which are observed in abundance all over the satellite, will enable us to decipher the composition, velocity, and travel direction of each impacting dust grain. This painstaking work will help to reveal, for the first time, potential sources of cometary and asteroidal dust particles. Such particles are predicted to retain the clearest record of the birth and early evolution of our solar system. In addition, the threat to spacecraft from these dust grains and particulate spacecraft debris can be evaluated. Therefore, an analysis of the LDEF is expected to provide critical information for the design of future spacecraft as well as possible insight into the Earth's origin.

Taking the first steps towards these goals, in the spring of 1990 a dedicated group of researchers led by Johnson Space Center (JSC) scientists labored to document all 5000 of the largest dust-impact features on the entire LDEF satellite. This work had to be completed before the satellite was dismantled and scattered to laboratories all over the world. Results from the survey of the aluminum frame of the LDEF are shown in the relative impact frequency on the 12 LDEF frame sides.

With this preliminary work now successfully completed, coordinated detailed analyses have been initiated by space scientists in their laboratories. These studies include compositional and isotopic analyses of dust remnants discovered within and about impact features, as well as the investigation of damage to space-exposed materials induced by impacting dust, solar and galactic radiation, and oxygen erosion. To facilitate these and future analyses of LDEF test samples, many critical pieces of the LDEF have been curated at the JSC. These space-exposed surfaces take their place beside the lunar, Antarctic meteorite, and stratospheric dust collections as a valuable resource for research on solar and planetary origins.



An impact feature on a Teflon thermal insulation blanket. This feature has a small (0.5 mm) penetration hole surrounded by a large (1 cm) zone of disrupted Teflon.

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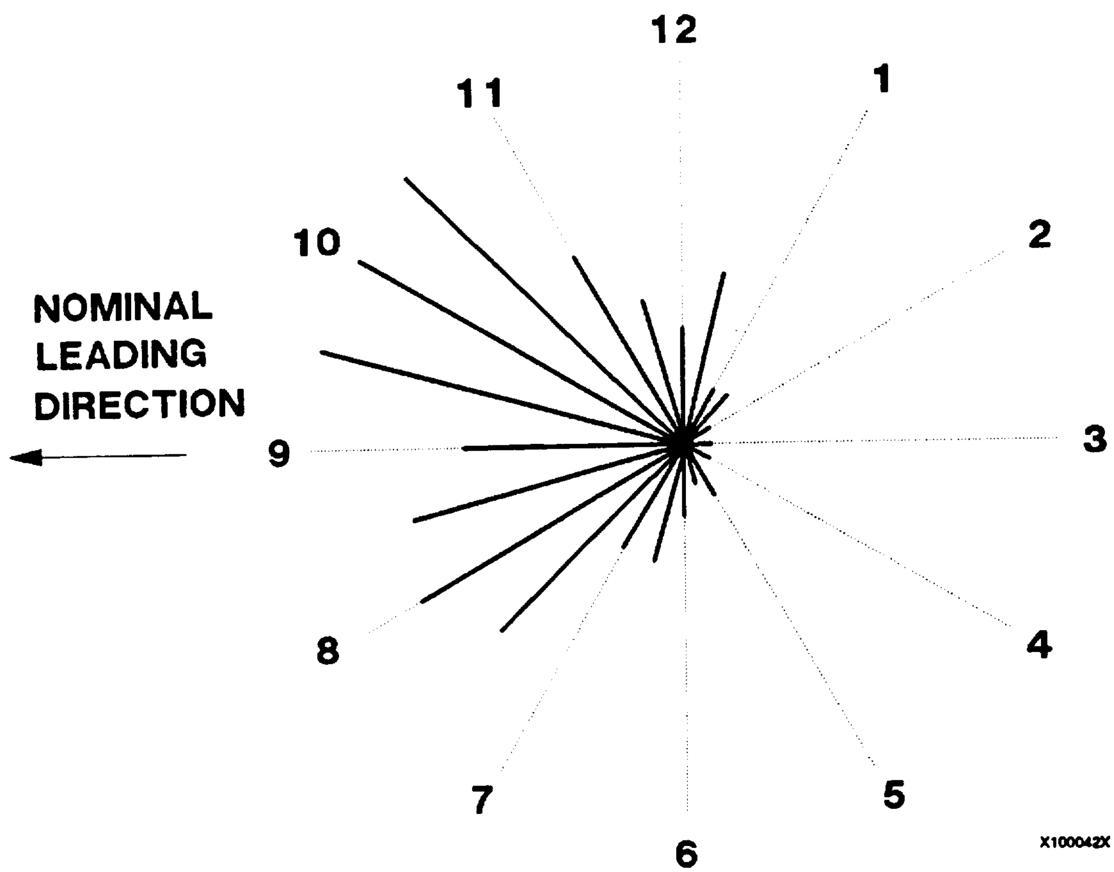


The relative impact frequency observed for the 12 LDEF frame sides and their intermediate facing directions. Side 9 is the nominal forward-facing direction, Side 3 is the rear-facing direction. The length of the heavy lines indicates the magnitude of the relative impact frequency in each direction. These results confirm that the forward-facing directions of spacecraft will require far greater shielding from meteoroids and debris than rear-facing directions.

Manned Observation Technologies: Optical-Quality Windows for Space Station Freedom and Beyond

PI: David L. Amsbury/SN15
Reference SSS 4

Imagery, both photographic and electronic, obtained from the pressurized volume of Space Station Freedom (SSF) will be vital to maintenance and operations tasks and will complement images of the Earth and its environmental systems obtained from unmanned satellites in different orbits. Earth images will be important for scientific studies of the Earth and its natural systems, for technological development of new remote-sensing devices and procedures, for education, and for participation in space exploration by the world's citizens. Good viewing requires good windows. Most of the fiscal year 1990 (FY 1990) effort of the Manned Observation Technologies Experiment was devoted to obtaining a consensus of window requirements for the Space Station; a brief description of the results follows.

Previous Station design specified two classes of windows: "general viewing," similar to the present Orbiter overhead windows; and "scientific viewing," which had somewhat higher optical quality. Specifications for the two window types were not stated in terms that were parallel and readily compared, so it was difficult to make rational scientific and engineering decisions about them. In some respects, both classifications were ambiguous.

A concerted effort, led by the program investigator, has focused government-wide attention on this question. Astronauts have demonstrated their ability to obtain excellent, striking, and scientifically valuable photographs through Space Shuttle Orbiter windows, which have properties similar to the planned Space Station "general viewing" windows. These photographs are obtained using handheld cameras mounted with lenses in the 50-250mm focal-length range. There are scientific and technical reasons for viewing Earth

- At longer focal lengths,
- Using larger-aperture optical systems, and
- In a broader portion of the electromagnetic spectrum.

Such investigations are precluded from the pressurized volume of the Orbiter cabin and would also be precluded from the Space Station unless window capabilities are increased significantly.

Optical systems having apertures of 5 to 7 in. are commercially available for use on handheld cameras and electronic imaging systems. The "general viewing" window quality causes significant degradation of image properties (fig. 1). The previously-specified "scientific" windows would be better, but still far from the cost-effective state-of-the-art in spacecraft window design. Studies during FY 1990 at the Johnson Space Center (JSC), the Marshall Space Flight Center, and by the Aerospace Corporation under contract to the U.S. Department of Defense (DOD), showed that a total window (multiple-pane) wavefront deviation of no more than 1/10 of a light wavelength (at 632.8 nm) over any 16.5 cm aperture within the clear viewing area is achievable, and practical, for all Space Station windows. This optical quality can be achieved by fabrication from fused silica blanks that incorporate very few flaws, plus careful attention to surface finish. A benefit of the new design is increased safety. The more homogeneous the material and the smoother the surface polish, the stronger the pane.

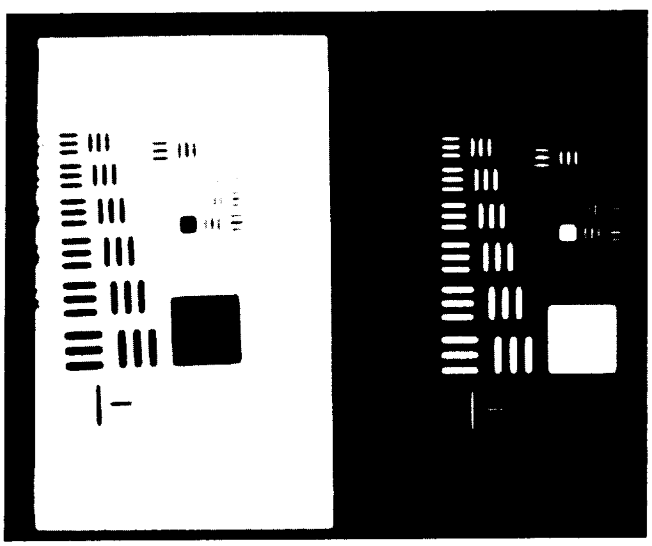
Visual protection from short ultraviolet (UV) radiation is required for each spacecraft window when there is any possibility of direct sunlight penetrating the window. The UV-protective coatings on Space Shuttle windows (fig. 2) and those planned for Space Station also cut out radiation in the near-infrared (IR). There is a substantial amount of information in the reflected infrared (0.7 to 1.5 µm), mostly about distribution of various vegetation types, and about vegetation vigor, but also about many different terrestrial features. Transmission through the fused quartz panes now proposed for the Space Station will be substantial, both in the IR and UV (fig. 3). The new design provides crew protection by removable panes, either inside or outside of the spacecraft, so scientific and technical observations both in the IR and UV may be performed at a crewmember's discretion.

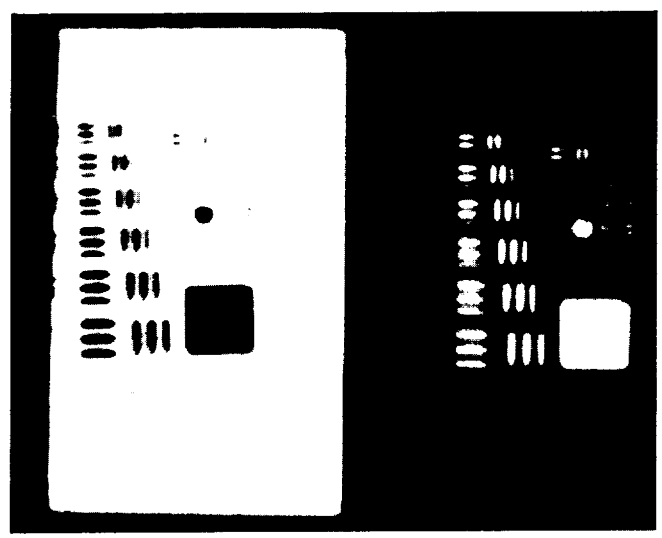
Window size obviously is a major consideration in spacecraft module design, as well as in the potential usefulness of a window system. Extensive discussions with NASA scientists and technicians, non-NASA scientists in several Earth-science disciplines, representatives of commercial interests, and representatives of the DOD reached a consensus that a 20-in., circular, clear-viewing aperture is the minimum required for the types of observations, and the potential viewing devices, that will be used on the SSF. A 20-in. clear aperture requires a window system about 24 in. in diameter; this is about the maximum that can be accommodated within the present structural design of the habitation module, the laboratory module, or a hatch position on a resource node. A round window has inherent strength; this shape provides a common design for windows in several possible positions, which is a savings in design, fabrication, and maintenance costs. For trapezoidal windows, such as those proposed for cupolas, the new specifications provide for common optical properties within a clear viewing aperture "...as large as is consistent with the shape of the window and the structural mounting requirements."

The consensus among potential scientific and technical users of Space Station windows is that high-optical quality, unobstructed viewing to the horizon is necessary in all directions from the spacecraft. Oblique-viewing activities continuing from current Space Shuttle flight tests will include study of variations in ocean surface roughness seen in sunlight, polarized reflectance from surfaces and within the atmosphere, bidirectional reflectance of vegetation and other materials, and oblique study of 3-dimensional features such as weather systems, dust and smoke plumes, and geological structures.

The simplest design to accommodate the scientific and technical viewing need is the use of windows in a nadir-mounted cupola. The spacecraft configuration planned through FY 1990 does provide one nadir-viewing cupola, but studies by the Astronaut Office predict extensive use of this cupola for operations and spacecraft maintenance activities. These activities would severely limit potential time for Earth viewing as well as limit the types of Earth-viewing equipment that could be set up in a window system for extended periods of time. Studies by the Manned Systems Division (SP4) at the JSC showed that some of the viewing directions could be accommodated by mounting round window systems in a combination of various modules, including the laboratory module, habitation module, and resource nodes.

Studies continue on viewing opportunities versus spacecraft operational considerations and costs, as the NASA spacecraft design evolves.





An optical test of a Space Shuttle overhead window was performed at the Corning Laboratory by Karen Scott of Aerospace Corporation under contract to the DOD. "General Viewing Windows" proposed for SSF have similar properties to the Space Shuttle Orbiter windows. These photographs illustrate the best focus obtained using a 5-in. aperture Celestron telescope mounted to a Nikon camera back. (a) No window in the optical path. (b) Three-pane window in the optical path, illustrating image degradation as recorded by a diffraction-limited system.

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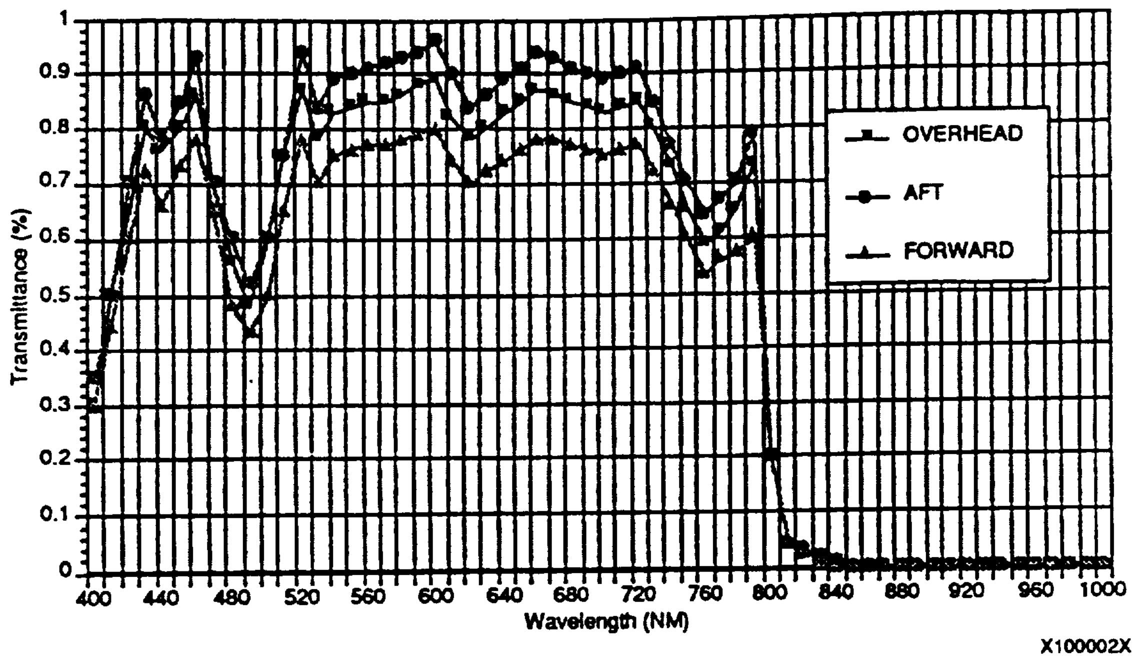
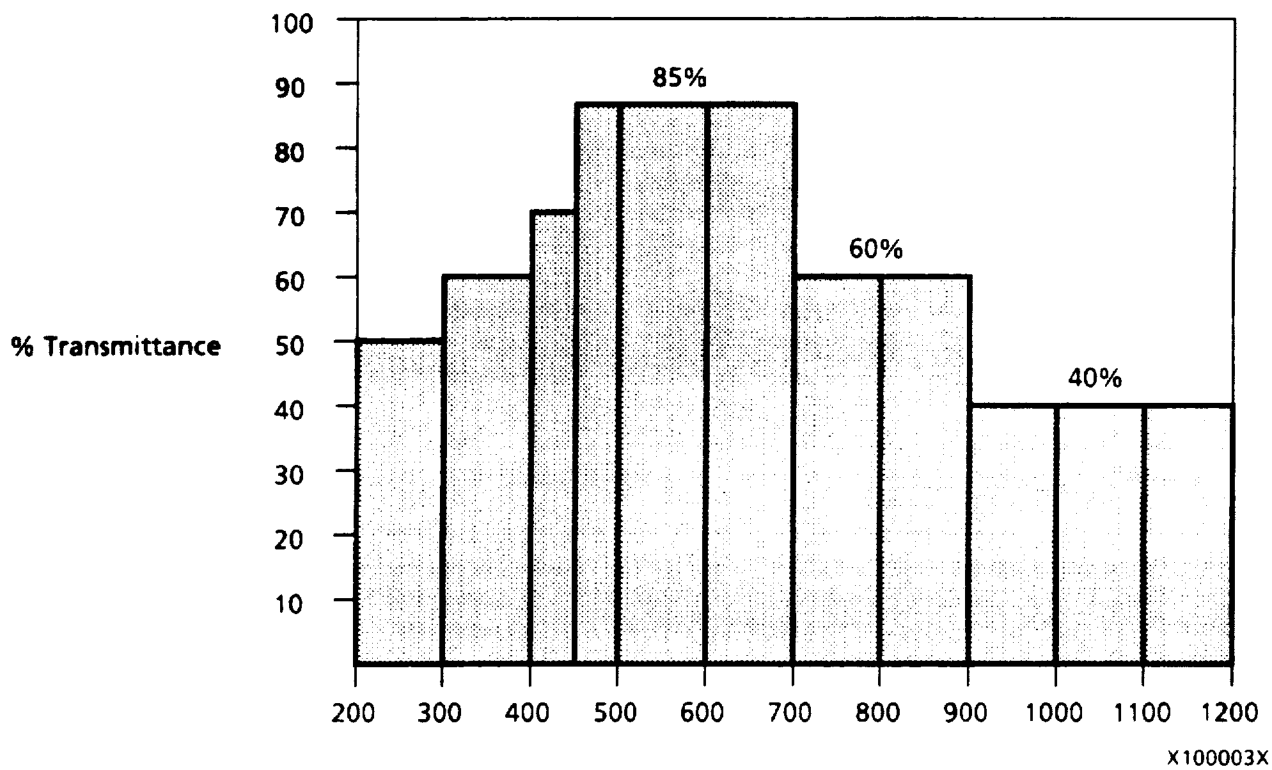


Spectral transmission of the present Orbiter windows. The coating used to protect crewmember's vision from UV radiation also cuts out near-IR radiation longer than about 800 nm. Solar radiation in the 700-1500 nm band, when reflected from vegetation and other terrestrial surfaces, contains a great deal of information on plant-type distribution and vegetation vigor.



Spectral transmission of uncoated fused-quartz panes to be used in SSF window systems. Scientific and technical studies at wavelengths shorter than and longer than visible wavelengths will be possible using windows made from this material. Crew protection from harmful UV radiation will be accomplished using transparent panels that are removable at the crewmember's discretion.

Optical Observation of Orbital Debris

PI: Karl G. Henize/SN3
Andrew E. Potter/SN3
John Stanley/SN3
Christine A. O'Neill/SN3
Reference SSS 5

The possibility that Space Station Freedom and other important spacecraft might be severely damaged by impact with orbital debris is a matter of growing concern. The Orbital Debris Group at the NASA Johnson Space Center (JSC) is specifically evaluating orbiting debris in terms of amount, size range, rate of growth, and the hazard it poses to spacecraft now and in the future.

Efforts to measure the amount of orbital debris concentrate on the diameter range from 1 to 100 cm. Data in the 1 to 10 cm range are essentially nonexistent and, although the Space Command radars provide data in the 10 to 100 cm range, it has been found that these data are incomplete. The Orbital Debris Group employs both optical telescopes and radar to obtain statistical data in these size ranges. This report describes the optical studies.

Telescopes from which optical data have been gathered are summarized in the table following along with appropriate acronyms for this work.

The Ground-based Electro-optical Deep Space Surveillance [GEODSS] system telescopes have provided the most extensive data to date. A total of 81 hours of data have been processed and show 622 satellite crossings. The sensor, an Ebsicon large-format vidicon tube with one stage of intensification, intercepts a field of 1.6×1.2 deg on a side.

These tapes are screened and measured at JSC. The time, rate, and direction of each satellite event allow detailed identification with known objects in the Space Command Catalog (SCC). The diameter of each object may be calculated from its brightness and an assumed mean albedo (reflectivity). These optical diameters may then be compared with the radar-derived diameters for objects on the SCC to confirm or adjust the assumed mean albedo. The mean albedo found by this method has a surprisingly low value of 0.08.

It is suspected, but not fully confirmed, that mean albedo varies among the various debris swarms that have resulted from the breakup of individual rockets and satellites. This may give a clue as to the cause of such breakups in those cases where the cause is unknown. Such information is important in preventing future breakups. The mean albedo also is important as a parameter which is required to convert optical brightness to diameter for those objects not found in the SCC. This datum makes it possible to evaluate the completeness of the SCC as a function of particle diameter. The results are shown in the first figure. Here, it is clear that, for diameters of 1 m and greater, the SCC is essentially complete but that, for smaller diameters, the completeness gradually diminishes with size until, in the 10 to 20 cm range, we find the SCC is only 30 percent complete. Over all diameters, the optically-derived number of debris particles down to a limit of 10 cm is twice the number found in the SCC.

The charge coupled device debris telescope (CCDDT) and the LENZAR are portable telescopes used by JSC staff to observe specific debris groups to study mean albedo, phase angle effects, and tumble rates. The CCDDT, which uses a charge coupled device (CCD) sensor, was especially designed for this work and has replaced the LENZAR. The CCD detector has greater sensitivity, stability, and accuracy than the vidicon sensors, and, when used in the time delay integration (TDI) mode, can reach to very small particle diameters considering the telescope aperture.

In the TDI mode, the CCD chip is rotated so that the pixel columns line up roughly with the expected motion of the satellite image, and the electron bins are read out along the columns at a rate adjusted to equal the motion of the image. Thus, satellite photons are concentrated on only a few pixels, and very faint objects may be detected.

If the satellite is expected to be of more than minimal brightness, the chip rotation is intentionally misaligned by a few degrees so the images will drift over several columns. The resulting short streak gives a light curve from which the tumble period of the object may be determined. An example of the TDI image of a tumbling satellite is shown in the second figure.

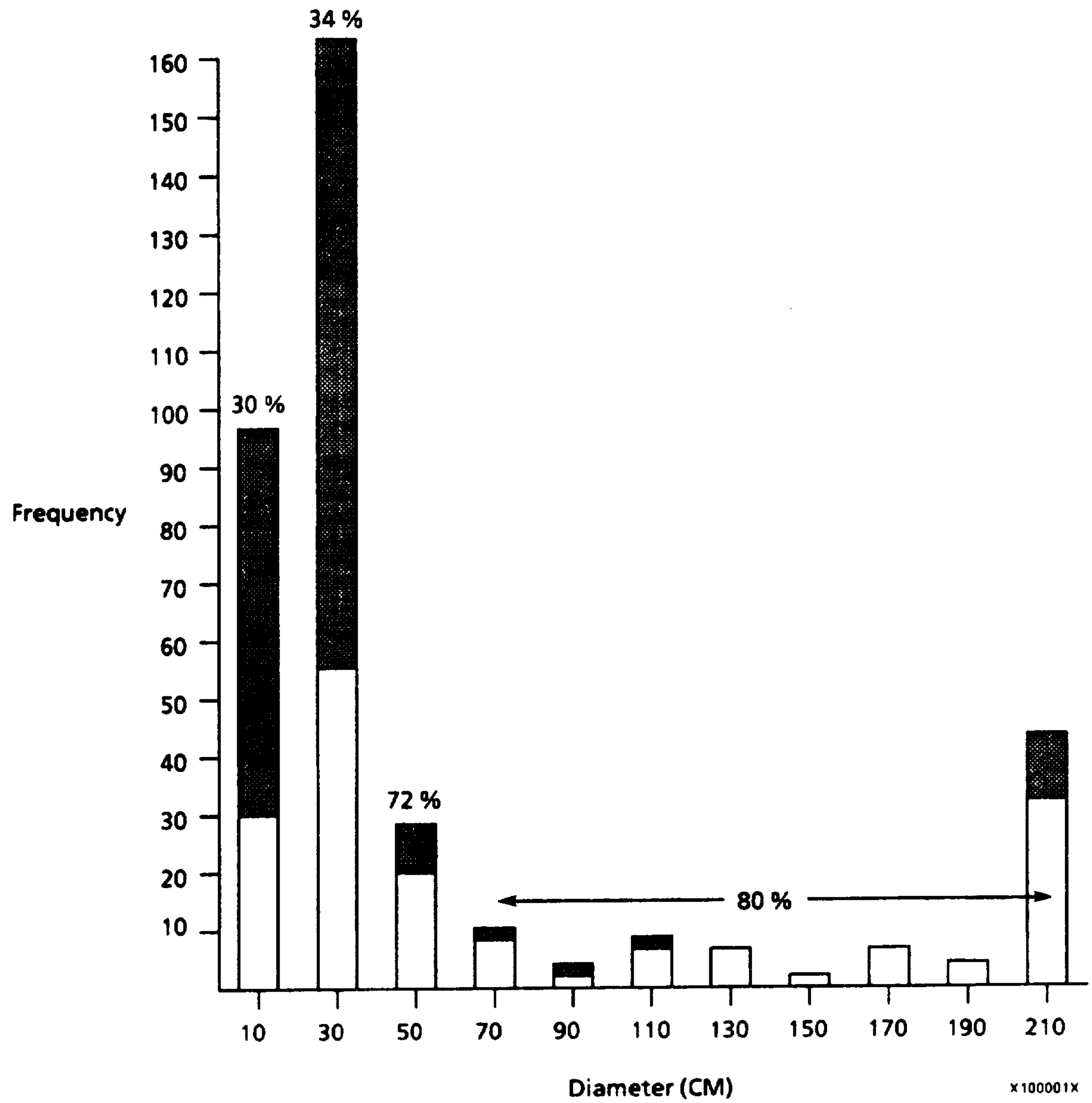
The CCDDT data are still being analyzed. However, one of the preliminary results is a measure of the brightness increase found for objects as they move from a solar phase angle of 90° (analogous to a first quarter Moon) to a solar phase of 60° (analogous to the Moon's being between first quarter and full). The derived value, 1.4, is considerably lower than the value of 1.9 given by the up-to-now accepted Lambert phase function. Since the phase function is also a factor in converting brightness to diameter, this result should give improved statistical results in future diameter calculations. The experience gained in operating CCD detectors is expected to lead to their use in much larger telescopes designed to detect debris particles in the 1 to 10 cm range. One such telescope currently under study is a low-cost mercury mirror telescope with an aperture of 3 m. This telescope would be capable of detecting debris particles as small as 2 cm diameter.

OPTICAL TELESCOPES USED TO OBSERVE ORBITAL DEBRIS

Telescope *	Location	Aperture (cm)	F/	Sensor	LIM Mag (static)	LIM Diam (cm)**
ETS	Socorro, NM	79	5.0	Vidicon	16.5	8
GEODSS	Maui, Ha. Diego Garcia	100	2.2	Vidicon	16.0	10
SOI	New Brunswick	61	16.0	Photomult.		
CCDDT	(Portable)	32	1.3	CCD	14.5	10
LENZAR	(Portable)	22	1.3	Vidicon	12.5	70

* – ETS denotes the Experimental Test System operated by the MIT Lincoln Labs; GEODSS denotes the Ground-based Electro-optical Deep Space Surveillance system operated by the U.S. Space Command; SOI denotes the space object identification telescope operated by the Canadian Air Force; CCDDT denotes the charge coupled device debris telescope operated by the NASA Johnson Space Center (JSC); and LENZAR denotes a low-light-level vidicon sensor built by the Lenzar Corporation and used by JSC.

** – The quoted diameter is for an albedo of 0.1 and a distance of 400 km.



The frequency of objects as a function of diameter. The objects identified in the SCC are indicated by "I" and objects not found in the SCC are indicated by "N." The numbers give the ratio of the identified to the total objects; i.e., the completeness factor for the SCC. The non-catalog objects with diameters greater than 1 m are probably objects in the classified "analyst satellite" list to which we do not have access.

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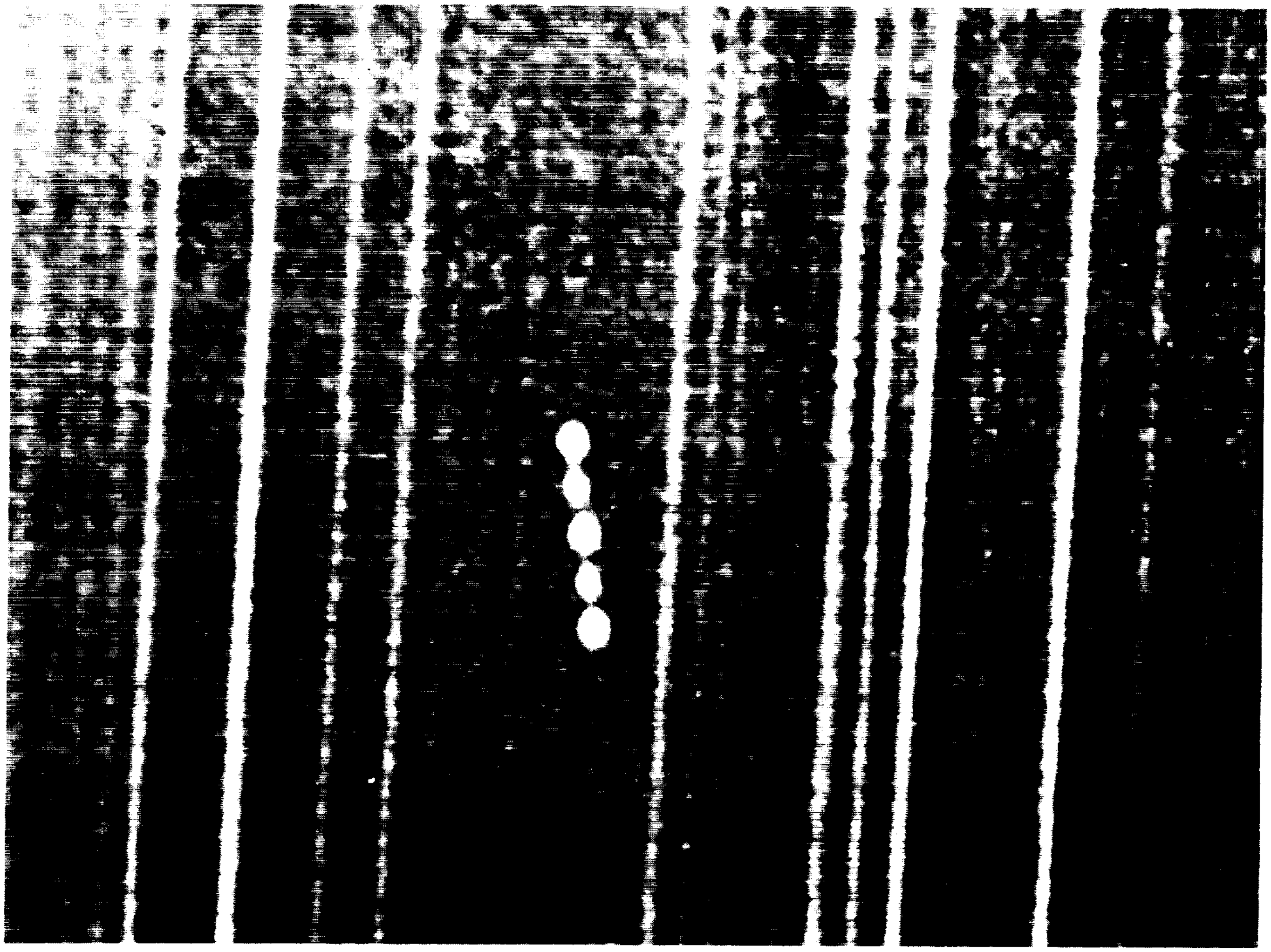

A sample satellite image taken in the TDI mode. Background stars appear as long streaks, while the satellite image is a short trail. The periodic brightness fluctuation indicates that the object

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Orbital Debris Radar Measurements

PI: Eugene G. Stansbery/SN3
John F. Stanley/SN3
Reference SSS 6

The objective of the Orbital Debris Radar Measurements Project at the NASA Johnson Space Center is to characterize the orbital debris environment for debris sizes down to 1 cm diameter at Space Station altitudes using high-power, short-wavelength radars. The effort includes collecting, analyzing, and interpreting radar data, and modeling the relationship between the number of debris objects detected by the radar as well as the actual or true population of debris in orbit.

This project has made extensive use of the existing Haystack radar (shown in the cutaway figure) in the near term to collect data to support the Space Station shielding requirements definition. Haystack, located near Boston, Mass., can detect ~1 cm diameter objects at altitudes of 500 km and with inclinations down to 28° by pointing south at an elevation angle of 10° above the horizon. In the long-term, data from the ground-based radar X-band, currently in the development stage, or some other near-equatorial radar will be used to monitor the orbital debris environment in low-Earth orbit and determine its distribution in size, altitude, inclination, and eccentricity.

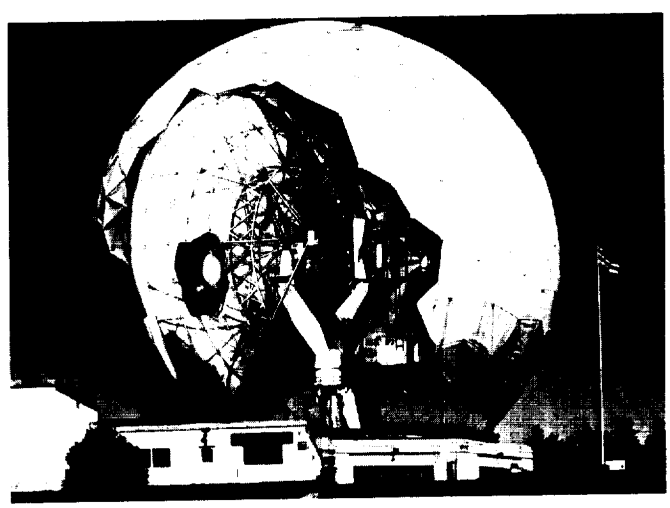
The Haystack radar collects orbital debris data by "parking" the radar beam so that debris will randomly pass through the beam and be detected. This operational mode is different from the normal Haystack tracking mode. Normal calibration techniques developed for tracking are not sufficient for calibration of "beam park" operations. New calibration techniques have been developed and implemented on Haystack appropriate for measurement of the orbital debris flux. Approximately 200 hours of orbital debris data at Haystack were collected in October to December 1990. An additional 1000 hours of data will be collected during the remainder of fiscal year 1991 (FY 1991).

The radio energy reflected from an object is characterized by the object's radar cross section (RCS) and scintillation characteristics. The RCS does not have a 1:1 relationship with physical size, however. Instead, RCS and scintillation are functions of the object's shape, material composition, orientation in the radar beam, and object size-to-radar wavelength ratio. It is impossible to determine these parameters absolutely for any individual on-orbit debris object with a single radar measurement.

Therefore, it is necessary to develop a statistical relationship of object size and shape with RCS and scintillation. This task has three main thrusts: to model numerically the RCS of small, irregularly shaped objects; to measure the RCS of known objects from ground breakup tests under controlled conditions at an RCS measurement range; and to make simultaneous measurements at different wavelengths of orbiting debris objects.

Accomplishments during FY 1990 include 11 simulated debris objects which have been measured at RCS ranges operated by Systems Planning Corporation and by the Houston Advanced Research Center with an additional 31 objects to be measured in FY 1991. Over 100 on-orbit debris objects and intact satellites were tracked simultaneously using the four radars operating at the Kiernan Reentry Measurements Site located on Kwajalein Atoll (seen in the second figure) in an experiment conducted in October 1990. Nineteen of these objects were tracked simultaneously with an optical telescope.

Future prospects also avail themselves. The relationship between the flux of orbital debris objects detected by an individual radar and the actual or true flux that passes through the radar beam becomes more complicated as the radar signal strength returned from an object approaches the background noise level of the radar. A radar performance model is being developed which will predict probability of detection and false alarm rate for debris using the detection criteria used by the radar and the statistical RCS versus physical size and scintillation relationships discussed above.



Cutaway drawing of the Haystack radome showing the 30 m diameter radar dish. Along with orbital debris measurements, Haystack also is used for radio astronomy and radar imaging of satellites.

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Photograph of the Kiernan Reentry Measurement Site located on Kwajalein Atoll. The site has four radars which operate at six separate wavelengths ranging from 193 to 1 cm.

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Hypervelocity Impact (HVI) Effects on Materials

PI: Eric L. Christiansen/SN3
Reference SSS 7

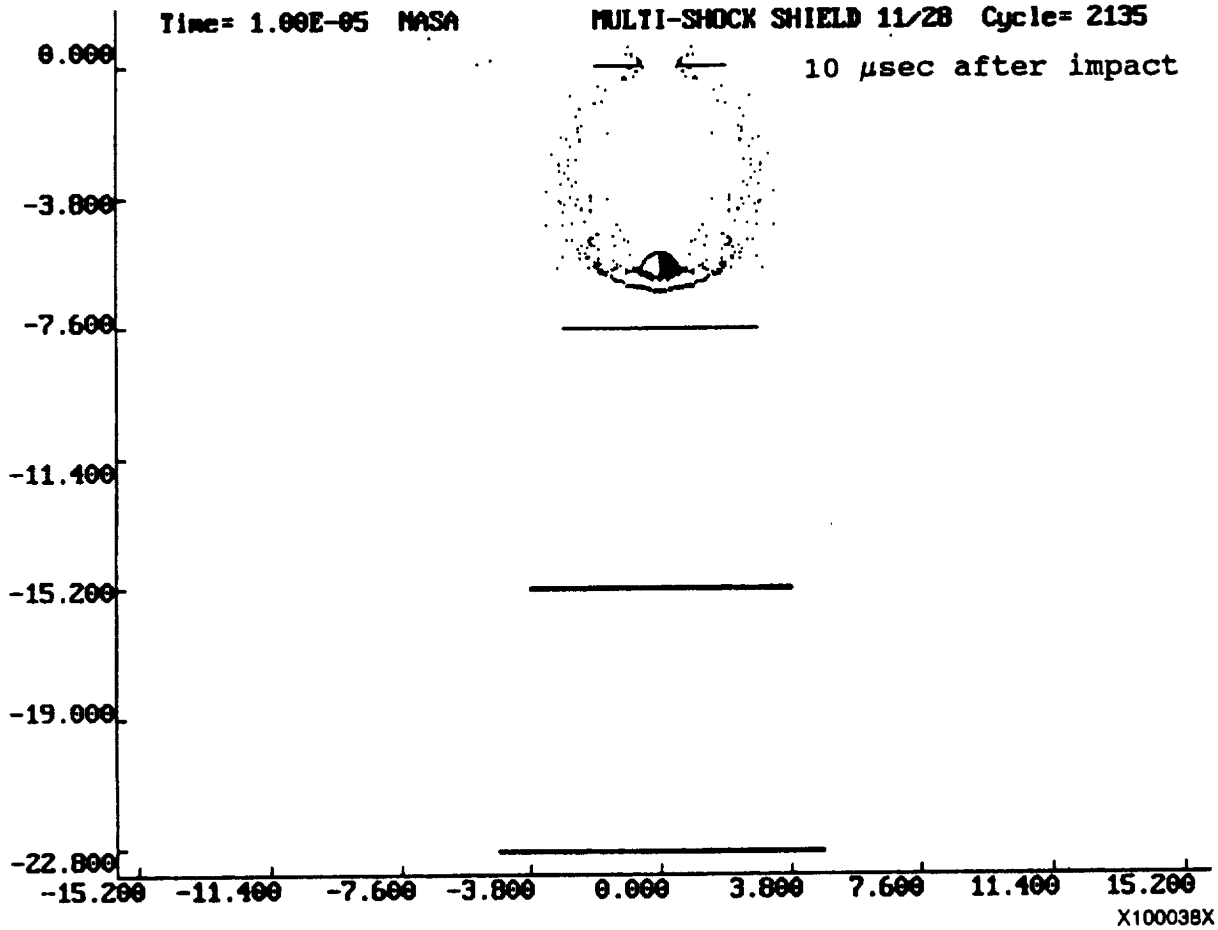
Meteoroids historically have been a spacecraft design consideration. On the other hand, orbital debris is a new and growing threat to spacecraft and structures in low-Earth orbit. Debris and meteoroid relative impact velocities range up to 15 and 72 km/sec, respectively. Efficient techniques for protecting large, long-duration space assets from orbital debris and meteoroid impacts are mandatory because conventional shielding approaches, such as the two-sheet "Whipple" shield, require a substantial weight penalty.

Development of advanced shielding materials and concepts has been the subject of an intensive research effort. Primary objectives of this effort are to reduce shielding weight and increase protection capability. Other important considerations are to minimize generation of secondary debris produced by hypervelocity impact (HVI) on shield surfaces, and to provide capability to increment (or "augment") shielding protection over time.

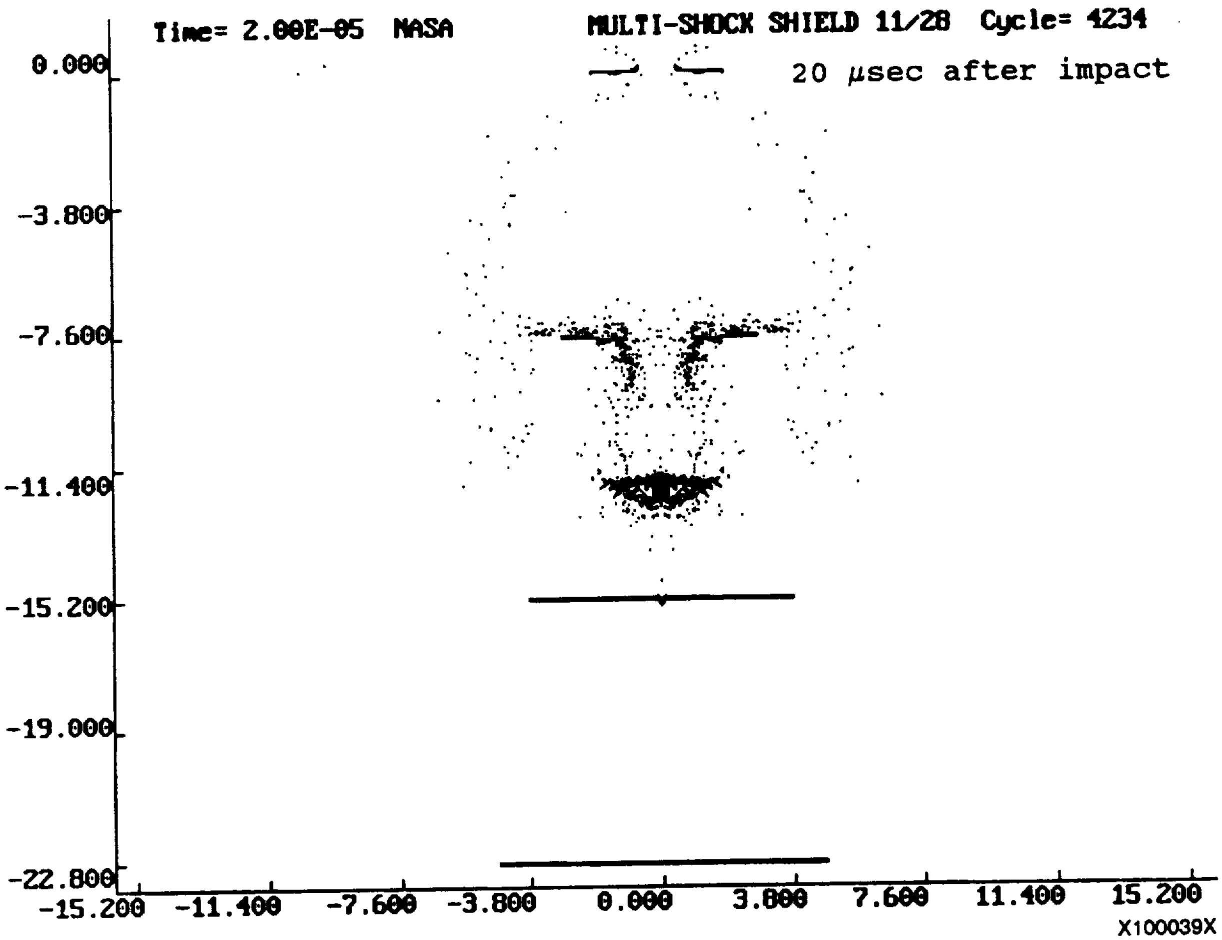
Weight reductions of 50 percent compared to conventional Whipple shields have been demonstrated in impact tests at the NASA Johnson Space Center (JSC) Hypervelocity Impact Research Laboratory for several advanced shield concepts. Two concepts – the multishock (MS) shield and the mesh double-bumper (MDB) shield – show particular promise in laboratory testing. However, current HVI facilities are limited to test velocities of less than 9 km/sec.

Accomplishments in fiscal year 1990 include an assessment of shield performance over the full range of expected impact conditions, which must be accomplished before on-orbit application. Mathematical models have been developed for predicting performance of the MS and MDB shields beyond test conditions. These models predict that the MS and MDB shielding concepts will be more efficient than the conventional Whipple shield under all impact conditions.

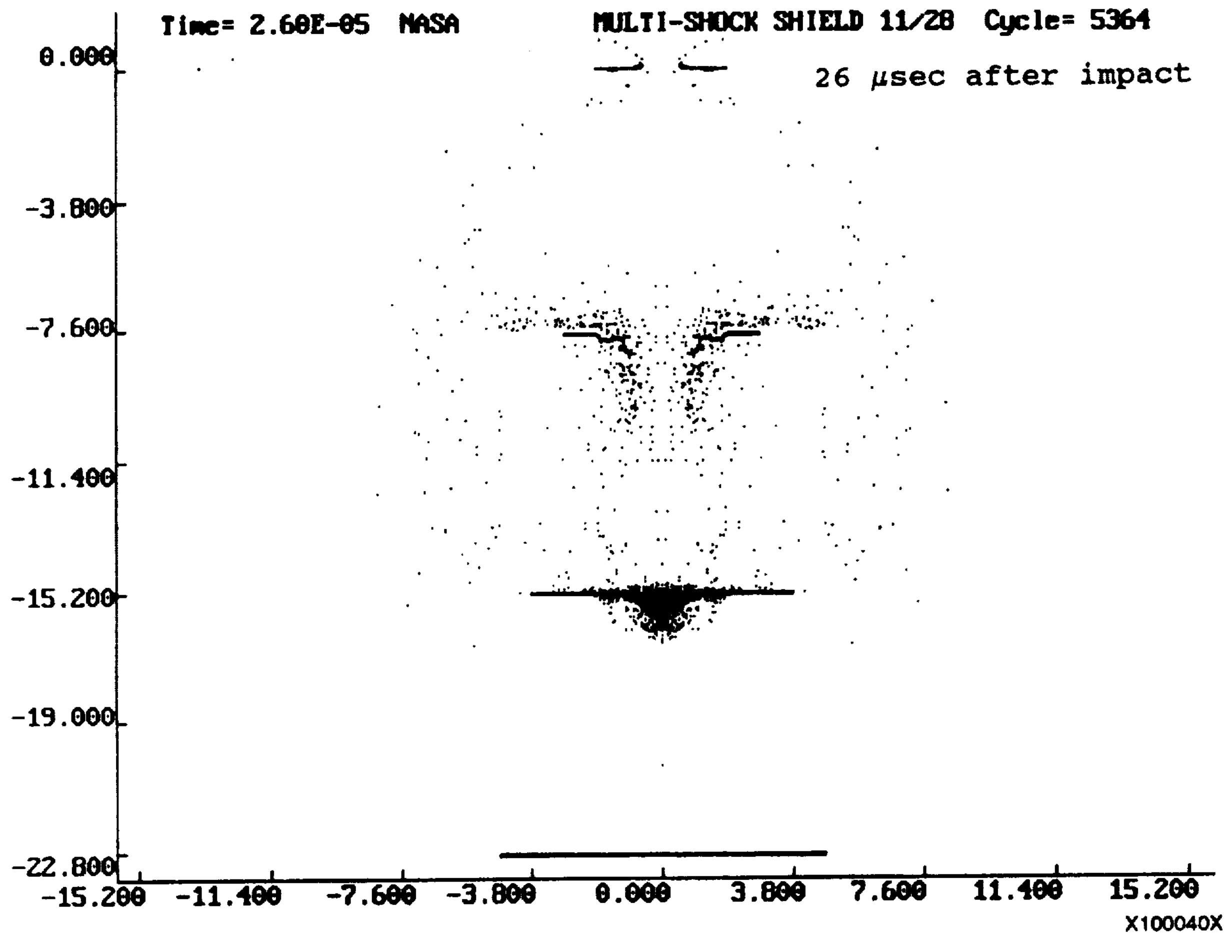
To verify protection capability beyond test conditions, additional computer analysis using finite-element hydrocode models is in progress at JSC. An example of hydrocode simulation during 1990 for an HVI on an MS shield is shown in the figure.



Simulation results for a 1-cm aluminum projectile impacting an aluminum MS shield at 6.5 km/sec.



Simulation results for a 1-cm aluminum projectile Impacting an aluminum MS shield at 6.5 km/sec.



Simulation results for a 1-cm aluminum projectile impacting an aluminum MS shield at 6.5 km/sec.

Lunar Meteorites

PI: Marilyn M. Lindstrom/SN2
Reference SSS 8

The discovery of the first lunar meteorites (ALHA91005) in 1982 was of major importance to both lunar science and meteoritics. It was the first meteorite from a known parent body, and it provided new information from a random site on the lunar surface to supplement the results of Apollo and lunar missions. In the past 8 years, a total of 11 meteorites of undoubted lunar origin have been discovered; all are housed in the United States and Japanese Antarctic meteorite collections. The past year has been particularly exciting, marked with the discovery of the largest lunar meteorite, anorthositic breccia (MAC88105), from the lunar highlands and of four basaltic meteorites from the lunar mare.

MAC881-5 (first figure) and its companion meteorite MAC881-4 have been studied by an international consortium led by the Johnson Space Center (JSC) Antarctic Meteorite Curator. The samples are anorthositic polymict breccias similar in many respects to the first five lunar meteorites. All aspects of the petrology, bulk composition, and isotopic characteristics (except cosmic-ray exposure histories) are similar to those of some lunar breccias from Apollo 16 and Luna 20, the only sample return missions which visited typical lunar highlands.

MAC88105 and other anorthositic lunar meteorites are plagioclase-rich, complex breccias which contain fragments of glass, minerals, highland rocks of several different types, and rare mare basalts. Their bulk compositions reflect their plagioclase-rich character. They are Ca- and Al-rich and Ma- and K-poor rocks with moderately low and variable Fe and Mg. Compatible trace elements strongly support a lunar origin. Like lunar samples, Mn is low and the Fe/Mn ratio falls on the Earth-Moon trend. Incompatible element concentrations are low compared to Apollo polymict breccias, indicating a very small KREEP (potassium, rare-earth elements, and phosphorus) component, but MAC88105 has the highest REE (rare-earth elements) of anorthositic lunar meteorites. Isotopic characteristics also are indicative of a lunar origin. Oxygen isotope composition falls on the Earth-Moon trend. Radiogenic isotopes yield crystallization ages of 3.9 to 4.0 billion years, typical of lunar polymict breccias. Noble gas isotopes suggest a solar wind contribution, while cosmogenic nuclides indicate complex exposure histories, both on the Moon and in space.

We also have studied two of the basaltic lunar meteorites discovered in 1990 – EE87521 (second figure) and Y793274 – both of which are basaltic breccias. The other two basaltic meteorites – Asuka 31 and Y793169 – are coarse-grained mare gabbros which have been announced but not studied in detail. The two basaltic breccias have complex textures but are dominated by mafic minerals, olivine, and pyroxene with subordinant plagioclase. Their mineral and bulk compositions are very similar to those of lunar very low titanium (VLT) basalts from Apollo 17 and Luna 24 except that they have higher incompatible element concentrations, which may reflect a small amount of KREEP component. We have shown that Y793274 is a mixture of highlands rocks with 75 percent magnesian VLT basalt like that at Apollo 17, while EE87521 is essentially pure ferroan VLT basalt like that at Luna 24. The markedly different basalt components and large distance between sample locations make it unlikely that the two analyzed basaltic meteorites were from the same impact.

The table is a summary of the 11 lunar meteorites. Samples thought to be paired – i.e., to represent the same meteorite (e.g., MAC881-4 and MAC881-5), or at least to be from the same impact – are given on the same line. Thus, the seven anorthositic lunar meteorites reduce to just four meteorites, while the four basaltic lunar meteorites are all distinct.

Studies of lunar meteorites and Apollo-Luna samples are aimed at understanding the nature and evolution of the lunar crust. The lunar meteorites are assumed to be random samples from several sites, while the Apollo samples were carefully selected samples from specific sites. A comparison of the lunar meteorites to results of the Apollo-Luna missions leads to important contradictions. The 50-50 proportions of anorthositic-basaltic lunar meteorites contrasts strongly with the 83-17 distribution of anorthositic-basaltic terrains derived from Apollo photogeologic mapping. The VLT basalt is the dominant basalt type in lunar meteorites, yet it is common only at the Luna 24 site, just one of the nine sites visited.

Resolution of these contradictions requires more data and may mean that one of our fundamental assumptions is wrong. We may be misled by the statistics of small numbers of lunar meteorites, or the lunar meteorites may not be random samples from several sites but may represent only a couple of impacts. Conversely, the results of Apollo-Luna missions may not be representative of the lunar crust, since they were collected from an area representing less than 5 percent of the lunar surface. More studies of lunar meteorites would be helpful in resolving these contradictions, but the ultimate answer lies in a renewed exploration of the Moon, both by more detailed global remote sensing and detailed geologic exploration. Understanding the surface of the Moon is important for planning a lunar outpost, and studies of lunar meteorites are contributing new information on the nature of the lunar crust.

Lunar Meteorites

Discovery	Location/Number	Classification/Weight g	
1982	Allan Hills 81005	anorthositic breccia	31
1984	Yamato 791197	anorthositic breccia	52
1985-87	Yamato 82192/ 3/86032	anorthositic breccia	37/27/ 648
1987*	Yamato 793274	basaltic breccia	9
1989	MacAlpine Hills 88104/5	anorthositic breccia	61/662
1989**	Elephant Moraine 87521	basaltic breccia	31
1990	Asuka 31	mare gabbro	442
1990*	Yamato 793169	mare gabbro	6

* Y793274 was classified as a lunar anorthositic regolith breccia in 1987, but was found to be a basalt-rich breccia in 1990.

** EE87521 and Y793169 originally were classified as eucrites.

Meteorite MAC881-5.

Two basaltic lunar meteorites – EE87521 and Y793274.

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The Angrite Meteorites: New Insights

PI: J. H. Jones/SN2
Reference SSS 9

The following is a result of some NASA Johnson Space Center (JSC) research on angrite meteorites. The angrite meteorites are enigmatic. Angrites are very rare "basaltic" meteorites (basalts are rocks that crystallized from a melt – a process described as igneous) that have unusual chemistries and primitive isotopic signatures. In fact, only three occurrences of angrites are known. The first known angrite, Angra dos Reis (a meteorite from Brazil, abbreviated as AdoR), does not closely resemble the other two angrites that were found in Antarctica; and, in many ways, the Antarctic angrites do not resemble each other. However, all angrites contain silicate minerals – pyroxene, olivine, and anorthite – whose composition is similar in all three angrites.

What is the origin of these strange rocks, and how are they related to each other? Are angrites truly rare in the solar system. or should we expect angrite compositions to be relatively common?

We will summarize here some of the new and interesting results that have emerged from the study of angrites. To anticipate our conclusions, we suggest that angrites are not so strange as was once thought. It may even be that we should expect to find angrite basalts on a common basis as we continue to explore the mysteries of the asteroid belt.

The first concerted effort to understand (what at that time was) the only angrite was made in the mid-1970's by Klaus Keil (U. of New Mexico; presently, U. of Hawaii), who organized a consortium effort (the AdoRables) to decipher the history of AdoR. Two major conclusions of the AdoRables were that

- AdoR was a nearly monomineralic pyroxene cumulate; i.e., a concentrated collection of pyroxenes that crystallized from a melt (Marty Prinz and collaborators, U. of New Mexico; see figure); and
- The $^{87}Sr/^{86}Sr$ isotopic ratio at the time of this crystallization event was the lowest ever measured for an igneous rock (Gerald Wasserburg and collaborators, Caltech).

The significance of a low Sr isotopic ratio is that ^{87}Sr is produced continually by ^{87}Rb, a radioactive element that decays to ^{87}Sr with a 50 billion year half life. The older the rock, the less ^{87}Sr there was at the time the rock crystallized and the lower the $^{87}Sr/^{86}Sr$ ratio at that time. Thus, as a result of this intense consortium study, AdoR was viewed as an accumulation of crystals from a basaltic liquid that was very old – about 4.6 billion years old, the age of the solar system.

Not all these data fit this standard model for AdoR. In 1981, John Jones (then at Caltech) noted that pyroxene efficiently excluded uranium but that AdoR was comparatively uranium-rich. Jones suggested that AdoR originally contained significant amounts of trapped silicate melt between the pyroxene crystals, implicitly assuming that subsequent heating had erased any easily recognizable traces of this trapped liquid. In 1989, Allan Treiman (Boston U.) took this notion one step further and suggested that trapped melt could be a major component of the pyroxene itself. If Treiman's model is true, distinguishing between the original pyroxene crystals and the trapped liquid might be difficult. A variety of experiments by Treiman, Gary Lofgren (NASA/JSC), and Ed Stolper (Caltech) indicated that this was a possible interpretation.

Another model for the origin of angrites was announced by Marty Prinz (American Museum of Natural History) in 1988. Prinz noted that the compositions of the pyroxenes in AdoR (which are rich in Al and Ti and are dubbed fassaitic) resembled those in refractory Ca-, Al-rich inclusions in some carbonaceous chondrites (chondrites are primitive meteorites unaffected by igneous processes). Prinz felt that the characteristics of AdoR were best explained if the parent material were rich in these refractory inclusions which were later melted. Prinz viewed the angrites not as planetary differentiates but as primitive matter that was only one or two steps removed from the beginning of the solar system.

Thus, by the end of the 1980's, a number of models for the origin of angrites had been put forth. Even if no real consensus had been reached, the complexity of AdoR's past had been recognized and there was a need to choose between competing models.

The Antarctic ice sheets are a veritable treasure trove for meteoriticists. By the late 1980's, two more angrites had been discovered in Antarctica. They were grouped with AdoR, not because they were identical (far from it; see figure), but because the chemical composition of the minerals in these rocks resembled that in AdoR. Instead of being monomineralic fassaitic pyroxene, the first new angrite, LEW86010, was comprised of subequal amounts of fassaitic pyroxene, Ca-rich olivine, and anorthite. Ca-rich olivine is also a minor component of AdoR, but anorthite in AdoR is very rare (if present at all). Thus, the mineral compositions generally agreed even if their proportions did not. Like AdoR, LEW86010 also had very primitive Sr isotopic ratios and, more importantly, its oxygen isotopic composition agreed with that of AdoR.

This last observation is important because, for the last 15 years, meteoriticists have used the ratios of the isotopes of oxygen to help classify meteorites. This work is primarily carried out by Bob Clayton (U. of Chicago). If two meteorites appear to be related, the first major test applied is that of oxygen isotopes. If the meteorites are indeed related, their oxygen signatures should be similar. This is the case for the angrites that were subjected to that test.

The newest member of the angrite clan is LEW87051. Unlike the other angrites, it is rich in olivine. LEW87051 contains many crystals of olivine set in a ground mass of crystals that is chemically similar to the bulk composition of LEW86010. Oxygen isotope taxonomy has not been performed yet on this sample, so, technically, LEW87051 is a "probable" angrite. Interestingly, the oxygen isotopic composition of the angrites is indistinguishable from that of the eucrites, another group of igneous meteorites.

What have we learned from these new angrite finds? First, more isotopic work has been done and several investigators [e.g., Larry Nyquist (NASA/JSC) and Gunther Lugmair (U. of California, San Diego), and their collaborators] have discovered that the initial strontium isotopic composition of the angrites, while still low, is not as primitive as was once thought and is indistinguishable from that of the eucrites.

Second, Gordon McKay (NASA/JSC), Gislaine Crozaz (Washington U.), and their colleagues have found that LEW86010 formed under relatively oxidizing conditions. Eu is an element that can change its chemical behavior, depending upon how oxidizing the ambient conditions are. McKay and Crozaz, comparing detailed laboratory experiments with ion microprobe analyses of LEW86010, have used the chemistry of Eu to define the conditions under which angrites crystallized. In comparison to eucrites, angrites crystallized under conditions about 100 times more oxidizing.

We hope we have conveyed the idea that angrites are odd – distinctly odd. No other igneous meteorites have fassaitic pyroxene as a major component or Ca-rich olivine. Such rocks are extremely rare on Earth and are not known at all on the Moon. Where do these strange rocks come from, and how did they form? The new angrites and, perhaps, AdoR as well seem to represent liquid compositions. How were these melts generated?

One possible resolution to the origin of angrites has come from experimental work at JSC. Amy Jurewicz, Dave Mittlefehldt, and I have performed partial melting experiments on a carbonaceous chondrite. This series of experiments was performed at a constant temperature (1200°C) but at different redox conditions. The more reducing experiments (with Fe metal present) were intended to mimic the conditions under which eucrites formed. The more oxidizing conditions were intended to reproduce approximately the redox conditions inferred for angrites by McKay and Crozaz. The results were surprising. At reducing conditions, the melts resembled eucrites. At oxidizing conditions, the melts were similar to angrites. Except for the Fe/Mg ratio (which can vary from planet to planet), the melts produced in our most oxidizing experiments were extremely similar in chemical composition to LEW86010. Additionally, the olivines left behind in the melting process were enriched in Ca and resembled the olivines in olivine-rich LEW87051. Apparently, by simply changing the redox conditions, it is possible to produce eucrite-like basalts and angrite-like basalts on the same planet. Perhaps this observation can explain some of the isotopic similarities between eucrites and angrites.

As we have continually emphasized, angrites are rare. However, carbonaceous chondrites such as Allende are not so rare, and several varieties are known. Based on our experiments, partial melting events on carbonaceous chondrite parent bodies are just as likely to produce angritic basalts as eucritic basalts. Consequently, we suspect that angrites may not be as rare in the solar system as we once believed. When we eventually explore the asteroid belt and document its geological variety, we suspect that angrites will be a prominent component of the igneous rocks there. The sooner our prediction can be tested, the better.

The angrite meteorite, Angra dos Reis (AdoR), grouped with two other angrites found in Antarctica in the 1980's. Marty Prinz and collaborators, University of New Mexico, part of a consortium effort to decipher AdoR.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Europium in Mare Basalts: Support for a Global Lunar Magma Ocean?

PI: Gordon McKay/SN2
Reference SSS 10

Experimentation in geochemistry is incomplete without a satisfactory story or theoretical model recounting the origin and history of the Earth and its Moon. That this story is still incomplete is a focus of Johnson Space Center (JSC) research, one version of which is the following result of reassessing orthodox opinion about the Earth's nearest neighbor.

One dramatic scientific result of the Apollo Program was the discovery of evidence suggesting that the early Moon was largely or completely molten. According to this hypothesis, the surface of the Moon once consisted of an incandescent "ocean" of red-hot silicate melt, or magma. As this magma ocean cooled, minerals began to crystallize, much like ice forming in a freezing pond. Some minerals, such as the Ca-Al silicate called plagioclase, were lighter than the magma. Like ice, these minerals floated to the surface to form "rockbergs" which eventually coalesced to form the lunar crust. Other minerals, such as the Fe-Mg silicates olivine and pyroxene, were denser than the magma. Like stones dropped into a pond, these minerals sank to the bottom of the magma ocean to accumulate in a thick layer called the lunar mantle. These basic elements of the magma-ocean hypothesis are illustrated schematically in figure 1.

According to the hypothesis, later reheating and melting of the olivine and pyroxene in the lunar mantle produced Fe-rich molten lavas. These lavas migrated upward and erupted through huge systems of fissures to flood low-lying areas of the lunar surface. The lavas solidified to form broad, dark plains over much of the nearside of the Moon; these plains are the dark areas on the face of the Moon visible to us with the naked eye. They are called "maria" or seas, and their rocks are called "mare" basalts.

Support for the magma-ocean hypothesis comes from the seemingly arcane study of a group of chemically-related elements called the rare-earth elements. These elements have two felicitous properties which make them diagnostic of certain geochemical processes. First, their chemical behavior is so similar that most of the rare earths are not easily separated from one another by common geological and geochemical processes. Hence, their relative abundances in most materials are similar to those in primitive, unprocessed solar system material (such as chondritic meteorites). Second, there is a fortunate exception to the above generalization. The chemical behavior of one of these elements, europium (Eu), is different from the others under certain conditions, so that the abundance of Eu in a rock or mineral relative to the other rare-earth elements holds clues to the processes that have affected that rock or mineral.

Crystallization of plagioclase from a magma is one process that greatly affects relative Eu abundances. Plagioclase has a much greater affinity for Eu than for any other rare-earth element. Hence, crystallization of plagioclase from a magma will preferentially extract Eu from that magma; the plagioclase will be enriched in Eu relative to the other rare earths, and the magma will be depleted.

Until recently, most geochemists believed that the minerals olivine and pyroxene would not preferentially exclude or include Eu, so that crystallization of these minerals should not change the abundance of Eu relative to the other rare earths in a crystallizing magma. Minerals lacking a strong affinity for or aversion to Eu will have the same ratio of Eu to the other rare earths as the magma from which those minerals crystallized. Moreover, any lava formed by the subsequent remelting of such minerals will inherit the ratio that typified the original magma.

This understanding of the behavior of the rare earths during crystallization of a magma is one of the cornerstones of the lunar magma-ocean theory. The mare-basalt lavas were depleted in Eu relative to the other rare earths. Experimental melting studies have established that these lavas formed by melting of olivine and pyroxene in the lunar mantle. Thus, the olivine and pyroxene in the lunar mantle must also be depleted in Eu. How did this depletion arise? According to the magma-ocean theory, it arose because crystallization of plagioclase in a magma ocean and flotation of this plagioclase into the crust forming at the top of the ocean removed Eu from the magma and enriched it in the crust. The olivine and pyroxene of the lunar mantle subsequently crystallized from the Eu-depleted magma, inheriting its depletion. This depletion, in turn, was passed along to the mare basalt lavas formed by later remelting of the olivine and pyroxene.

This scenario is particularly appealing because it ties together the rare-earth abundances in mare basalts and in the rocks of the lunar crust in a single, simple theory. Thus, the complementary depletion of Eu in the mare basalts and enrichment in the rocks of the lunar crust (fig. 2) was a fundamental observation that led to the magma-ocean hypothesis. This hypothesis is currently widely accepted among lunar scientists. Occasionally, however, a few have questioned the theory, and some have proposed that early melting on the Moon was never "oceanic" in scale.

The most recent outbreak of this differing point of view came from scientists at the South Dakota School of Mines. Using a new, ultra-sensitive technique for measuring rare-earth element abundances in individual mineral grains, they noted that pyroxene showed a surprisingly large depletion in Eu relative to the other rare-earth elements. They suggested that this depletion was due to a previously unrecognized tendency of pyroxene to exclude Eu, and further suggested that the Eu depletion of the mare basalt lavas was not inherited from an Eu-depleted magma ocean after all, but instead was produced as a result of this intrinsic property of pyroxene.

Geochemists commonly quantify a mineral's affinity for, or aversion to, a given element in terms of mineral/melt partition coefficients. A partition coefficient is simply the concentration of an element in a mineral divided by the concentration of the element in the silicate liquid from which the mineral crystallized. If the partition coefficients for two different elements in a mineral are the same, that mineral has no tendency to exclude or include one of the elements relative to the other, and the ratio of the two elements should be the same in the mineral as in the magma from which it crystallized. Partition coefficients can be used in mathematical "models" or calculations to simulate crystallization of the magma ocean or melting of mantle rocks. Using these models, the hypothesis of magma-ocean crystallization and remelting of the lunar mantle to form mare basalt lavas can be tested.

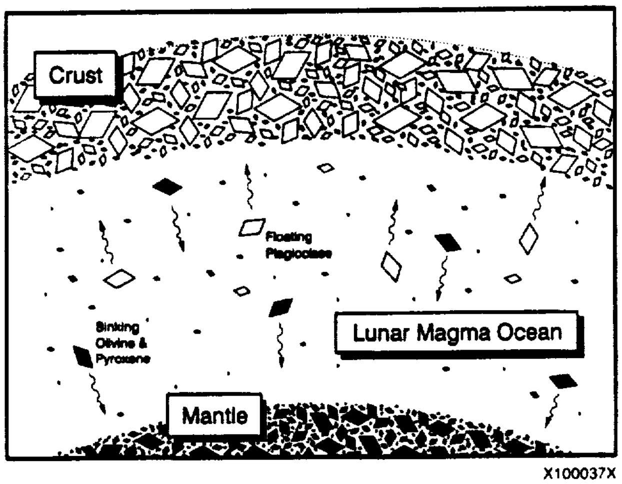
Using pyroxene/melt partition coefficients derived from their analyses or rare-earth elements in individual pyroxene grains in mare basalts, the South Dakota School of Mines scientists developed a model of magma-ocean crystallization and subsequent remelting of the lunar mantle. Their model produced lava compositions having relative Eu depletions similar to those of the real mare lavas, without the necessity of removing plagioclase before the olivine and pyroxene of the mantle had crystallized. If this model were to survive scientific scrutiny, it would weaken one of the fundamental arguments supporting the magma-ocean hypothesis.

A potential flaw in their arguments is that the South Dakota scientists could not prove that the Eu depletion they measured in mare basalt pyroxene was a result of the intrinsic ability of pyroxene to discriminate between Eu and other rare earths, as opposed to reflecting a preexisting Eu depletion in the magma from which the pyroxene crystallized. Using partition coefficients derived from other studies, scientists from Indiana University produced a mathematical model similar to that of the South Dakota group – except that the calculated basalt compositions had much smaller Eu depletions than were actually observed in mare basalts. Hence, the Indiana scientists concluded that removal of plagioclase prior to the crystallization of the olivine and pyroxene in the lunar mantle was in fact necessary to match the mare-basalt Eu depletion, thus supporting the magma-ocean hypothesis.

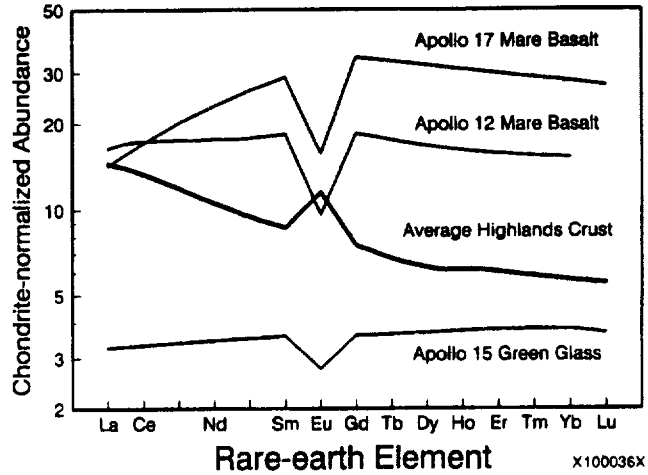
Controversy hinged on exactly how strongly pyroxene can exclude Eu relative to the other rare earths. In most studies that have addressed this question, workers have relied on decade-old values for pyroxene partition coefficients, particularly values measured in rock-melting experiments by workers at the University of Oregon. Those measurements indicated little tendency for pyroxene to exclude Eu preferentially. However, experimental and analytical techniques have improved considerably in recent years, raising the possibility that new measurements might resolve this controversy. Therefore, we recently remeasured pyroxene/melt partition coefficients. Our JSC results (fig. 3) showed that, as suggested by the South Dakota group, pyroxene does indeed have a significant capacity to exclude Eu relative to the other rare earths.

However, the origin of the Eu anomaly in mare basalts is still unsettled. Using our new pyroxene partition coefficients, the Indiana group recomputed their earlier models. If they allowed no plagioclase removal prior to crystallization of olivine and pyroxene, they could indeed match the Eu depletion observed in the natural basalts, but only by starting with unreasonably high overall rare-earth abundances in the magma ocean. If there were prior plagioclase removal, their calculations were able to produce rare-earth abundances similar to those observed in mare basalts using a reasonable starting composition for the magma ocean. But the only way they could match the rare-earth element abundances in natural basalts with no prior plagioclase removal and reasonable magma-ocean initial rare-earth abundances, was to use pyroxene partition coefficients much different from the ones we measured.

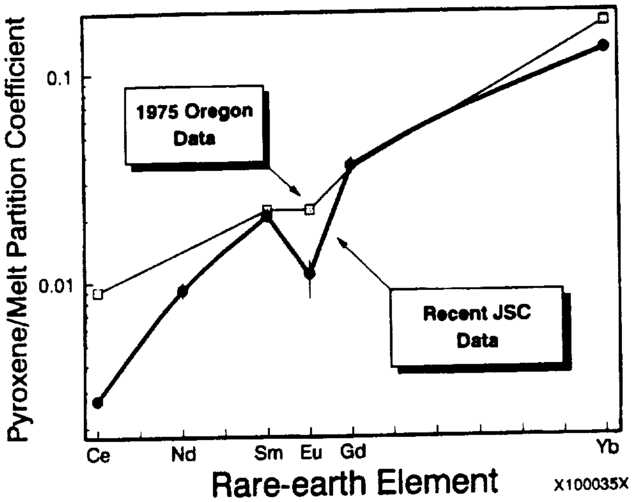
Could the actual partition coefficient values in the lunar mantle be similar to those required by the Indiana model? Possibly. Our experiments were done at low pressure, whereas the lunar mantle minerals crystallized and remelted at high pressure, deep within the interior of the Moon. The effect of pressure on partition coefficients is not yet known, but must be studied before the final chapter in this story can be written. We are beginning such a study. In the meantime, it appears that the magma-ocean hypothesis, including the requirement for crystallization of plagioclase prior to crystallization of the minerals of the lunar mantle, is still intact.



Schematic cross section of the early Moon, illustrating basic aspects of the magma-ocean hypothesis. According to this hypothesis, the outer part of the early Moon consisted of a global "ocean" of red-hot silicate melt, or magma. As this magma cooled, minerals crystallized. Light minerals, especially plagioclase, floated to the top of the ocean to form the lunar crust, while dense minerals, such as olivine and pyroxene, sank to the bottom of the ocean to form the mantle.



Rare-earth element abundances in three lunar mare basalts and in the average lunar highlands crust composition. (Apollo 15 Green Glass is an especially primitive form of mare basaltic lava, found as small glass beads which scientists think were formed by rapid cooling of lava droplets in incandescent "fire fountains".) Abundances of rare earths have been normalized to chondritic meteorites to produce "smooth" patterns for elements other than Eu. The rare earths are plotted in order of increasing atomic number because, except for Eu, their chemical properties correlate smoothly with their atomic number. The "bump" at Eu in highlands crust abundance pattern is an Eu enrichment caused by the accumulation of plagioclase through flotation during the formation of the lunar crust. This bump is matched by a complementary "dip" or Eu depletion for the mare basalt samples. The traditional interpretation of this depletion is that is was inherited from the depletion of Eu in the magma ocean due to crystallization and flotation of plagioclase to form the highlands crust. These complementary Eu enrichments and depletions are one of the major lines of evidence supporting the magma-ocean hypothesis.



Rare-earth element partition coefficient patterns for pyroxene. Partition coefficients indicate the relative tendency of elements to be incorporated in a mineral crystallizing from a silicate melt. Partition coefficients for closely related elements, such as the rare earths, are often plotted together in diagrams such as this so that any systematic behavior or pattern in their partitioning behavior will be evident. Both partition coefficient patterns in this diagram indicate that pyroxene has a tendency to incorporate rare earths on the right side of the diagram (those with higher atomic number) to a greater extent than those on the left, a trait long known to geochemists. The older partition coefficient pattern measured by University of Oregon scientists indicated little capacity for pyroxene to separate Eu from the adjacent elements in the diagram. However, the newer pattern, from our recent work, shows a pronounced "dip" at Eu, indicating that pyroxene has a much larger tendency to discriminate between Eu and neighboring rare-earth elements than was formerly believed. Implications of this tendency for the magma-ocean hypothesis are discussed in the text.

Space Transportation Technology

Summary

Space Transportation Technology

Activities conducted at the Johnson Space Center (JSC) which address Space Transportation Technology are predominantly sponsored by the Advanced Program Development Division within the Office of Space Flight. The objectives of these efforts are focused toward increasing the operability and capability of the Space Shuttle, developing an architecture and technology base for future human transportation systems, and evolving the technologies associated with space servicing.

The research and technology (R&T) accomplishments in fiscal year 1990 (FY 1990) included significant enhancements to the operational systems supporting the Space Shuttle, as well as continued progress in developing the systems and critical technologies needed to enable permanent human presence in space. Technical progress at JSC was demonstrated in numerous technology areas, including spaceflight systems, training, computer simulation, expert systems, guidance and control, communication and tracking, and on-orbit operations. These technologies are essential for the development and operation of safe and reliable human transportation systems that will be required to support the NASA objectives for Space Station Freedom (SSF) and future planetary exploration programs. The paragraphs that follow highlight specific technology accomplishments in FY 1990 and discuss the continuing studies that provide direction for other R&T activity. Reports on selected tasks follow this summary and are intended to illustrate the diversity of technologies under investigation.

Advanced Operations

Flight operation systems in the Mission Control Center (MCC) have been one focus of technoogy applications at JSC directed toward increasing efficiency and reducing cost. Dramatic improvements in the ability of flight controllers to monitor their onboard systems have been realized through implementation of the Real Time Data System (RTDS). The RTDS project has established a low cost telemetry monitoring capability which provides real-time Shuttle data to flight controllers in the form of color graphical displays. Developed by combining commercial telemetry processors and UNIX-based workstations with expert system technology, the RTDS has demonstrated substantial reductions in data analysis processing time along with notably enhanced analysis capabilities. Other improvements to the MCC capabilities are in work under the Flight-to-Flight Data Overlay project. Scheduled to be operational in early FY 1993, the software developed from this project will provide flight controllers with timely access to data from all previous missions along with the ability to overlay signatures from previous flights with the current flight to aid system performance evaluations. Presently, only data from the last flight is readily accessible. Definition of the project's requirements and development of the framework for the Flight-to-Flight Overlay user interface were completed during the past year.

Voice recognition technology for computer control applications in space was successfully demonstrated during FY 1990. The Voice Command System (VCS) Flight Experiment, flown aboard STS-41, enabled two astronauts to control the Orbiter's closed-circuit television system using verbal commands. The benefits of VCS technology lie in the potential to reduce crew workloads and increase crew productivity on future programs by removing the need for tactile computer control of selected systems.

The development and application of expert system technology to meet the challenges of low cost and efficient space operations has continued to be a significant R&T focus at JSC. Training is a major activity at all NASA operational centers and has high associated costs. The JSC is continuing its development of workstation-based, Intelligent Computer-Aided Training (ICAT) systems which apply artificial intelligence and other advanced technologies toward the goal of reducing on-the-job training requirements. During FY 1990, two new ICAT systems were brought to operational status: the Main Propulsion Pneumatics (MPP) system for training of Shuttle test engineers at Kennedy Space Center and the Instrument Pointing System (IPS) for training of mission and payload specialists. Progress was also made in implementing knowledge acquisition tools in a general purpose ICAT architecture. This development environment will aid trainers in creating specific ICAT applications in the future by integrating tools for knowledge acquisition, interface development, knowledge-base editing, and adaptive trainee modeling.

Future space missions will require increasing levels of autonomy in order to achieve effective performance in an environment of complex operations. To address this need, JSC is investigating the application of expert system technology to the automated control of space vehicles and associated systems. Development of the Rendezvous Expert System (REX) has provided a test bed in which Shuttle crews and flight controllers can evaluate modes of rendezvous operations, ranging from computer-aided manual execution of procedures to fully autonomous rendezvous operations. The ability of the REX guidance algorithms to properly control both nominal and off-nominal approach trajectories was established during the past year, and enhancements to the REX terminal guidance were completed. The JSC is also emphasizing development of modular fuzzy logic algorithms for adaptive control and operational decision-making applications. Studies at the Center have shown that fuzzy logic technology has robust capability in interpreting imprecise measurements and generating appropriate guidance and control decisions. Noteworthy accomplishments include integration of attitude control algorithms in simulations of Shuttle proximity operations, testing of a fuzzy logic trajectory controller for surface rover applications, and preliminary development of an intelligent sensor system that can identify objects in space and track them continuously. Such systems will be invaluable for traffic management and proximity operations of the Shuttle around the SSF and for future application to robotic systems.

Software development is a schedule driver in the construction of complex systems. Reducing the high development and maintenance costs of such systems while improving their quality is the goal of the ongoing Advanced Software Development Workstation (ASDW) Project. The ASDW utilizes knowledge-based technology with a high level graphical interface to enable reusable software applications to be easily developed by engineers. Activity during FY 1990 has been focused on redesign of the user interface to take advantage of enhanced system capabilities.

In additional to the emphasis placed on knowledge-based technology applications during the past FY, some basic expert system R&T activities were also conducted. The current version of the "C" Language Integrated Production System (CLIPS), software developed at JSC for creating expert systems, received enhancements that include new procedural programming capabilities. Progress was also made in generating guidelines and standardized tools for the development of cooperative expert systems and for general verification and validation of knowledge-based systems.

With the advent of space-based assembly, maintenance, and planetary exploration operations, the accurate simulation of space vehicle and robotic system performance has become an increasingly critical technology. To address the need for more flexible simulation capabilities, the Logistics and Operations Integration Requirements Project has focused attention on specific simulation techniques pertinent to space-based robotic technologies. A significant product of this activity is the Robotics Software Testbed (RST) simulation system that has been developed for rapid prototyping, algorithm verification, and sustaining engineering analysis of robotic systems performance. Engineering graphics is another technology having direct application to vehicle and robotic simulations. New technology in the area of network-based graphics servers has led to the development of the Tree Display Manager (TDM) which provides users with graphical manipulation and object collision detection capabilities. The TDM is now being utilized in Space Station assembly analysis as well as in robotic, tether, and Shuttle simulations.

Among the key technologies promising more efficient operability for next generation launch systems is autonomous guidance. Implementation of onboard autonomous guidance systems will provide future vehicles with the capability of responding in real time to changing flight conditions through the use of advanced algorithms, flight computers, and sensing devices. Emphasis of these studies during FY 1990 was directed at evaluation of potential guidance algorithms and advanced sensing devices. The FY 1991 activity will be refocused toward providing near-term improvements to the Shuttle abort guidance algorithms.

Advanced Transportation

Advanced transportation studies at JSC continue their previous directions in evaluating potential Shuttle technology enhancements and addressing the human transportation requirements associated with Space Station Freedom operations and the lunar and Mars exploration objectives.

The JSC has initiated a program to upgrade the current Orbiter Fuel Cell Powerplant (FCP) to provide extended life and higher power density. With extended endurance capability, the advanced FCP will have the potential of reducing launch processing turnaround times. Its increased power capability also offers the opportunity to replace the Orbiter's existing hydraulic actuator systems with electromechanical actuator systems for potential cost reduction and increased reliability. Successful testing of a full-scale single cell during FY 1990 has demonstrated the advanced FCP performance objectives. Plans are now being drawn to build and test a four-cell FCP. Continued work to evaluate an uprated Shuttle Orbital Maneuvering System (OMS) engine has included successful completion of engine testing under simulated altitude conditions at the White Sands Test Facility. This engine, which is a pump-fed version of the current pressure-fed OMS engine, has the potential to increase the Shuttle altitude and payload capability. It may also have application as a main engine on future space transfer vehicles and upper stages, in which storable propellants (nitrogen tetroxide and monomethylhydrazine) are desirable.

The Space Shuttle Evolution Study furnishes the strategy for ensuring that the Space Shuttle remains a reliable and effective system into the next century for manned transportation to and from low-Earth orbit. Previous work has established plans for evolving or modifying the Shuttle to achieve increased safety, reduced costs, and increased capability. During FY 1990, emphasis was directed toward the study of several crew escape system concepts for possible implementation to the Shuttle Orbiter. The primary objectives of these studies were to identify escape system requirements and to assess the corresponding Orbiter impacts and program costs. A study investigating Crew Escape Module (CEM) concepts, which enable escape during any phase of mission operations, concluded that implementation of a CEM is feasible but that the required redesign of the Orbiter forward fuselage and overall program costs would be extensive. A second study was begun to quantify the necessary Orbiter modifications for incorporation of other crew escape systems employing ejection or extraction seats. These escape concepts offer the potential to significantly expand the present Orbiter crew escape envelope. Impact assessments verified the feasibility of integrating either escape concept into the Shuttle Orbiter but concluded that significant redesign of the crew module and forward fuselage would be necessary. Work will continue in FY 1991 to quantify Shuttle performance impacts and to estimate program costs and schedule.

In support of the safety objectives for SSF, work has continued on the Assured Crew Return Vehicle (ACRV) Project. The ACRV is under design to fulfill the vital need for safe transport from SSF at any time in the event of emergency. Phase A accomplishments last year included the validation of ACRV mission and system requirements and the development of alternative ACRV design concepts and life-cycle cost estimates. Significant progress was also made in defining an integrated ACRV operations concept aimed at reducing costs. The Personnel Launch System (PLS) Study continued to investigate a new system to provide alternative means of human transport to low-Earth orbit (LEO). This JSC effort is directed at defining a low lift-to-drag ratio, recoverable PLS concept for delivery of personnel with little or no cargo. Detailed conceptual design and analysis studies have been completed which included definition of all spacecraft systems and evaluation of launch and escape system requirements. Future plans have been identified to evaluate several reference PLS configurations in the area of manufacturing, launch vehicle integration, and operational efficiency. The potential uses of the PLS include Space Station crew rotation, delivery of lunar and planetary crews to LEO, rescue missions, and orbital servicing.

Space Servicing

Space servicing is an emerging technology which has historically been limited to those functions and operations which could be performed by humans. The development and application of new technologies to improve the capability, efficiency, and autonomy of space-based servicing is vital to cost-effective space operations. Toward this goal, JSC has been engaged in efforts to develop improved techniques and systems to facilitate functions such as communications, tracking, rendezvous, docking, robotic manipulation, and fluid resupply.

An alternative system for providing communication between the Shuttle Orbiter crew cabin and payload bay underwent testing last year in preparation for a 1991 flight demonstration on STS-43. This system, which creates a fiber-optic link by transmitting optical information through the Orbiter window, will allow payload specialists to communicate with their payload independent of the Orbiter system.

The JSC is developing and evaluating systems which will assist in future docking and berthing operations of the Shuttle and Space Station. One such system evaluated during FY 1990 was a passive fiber-optic alignment aid. This optical system provides natural images to the operator during docking operations and is under investigation as an alternative targeting method. Test evaluations of the sensing capability of the system have been performed, and work will continue to complete the design of an operational system. Another important system under development is the Laser Docking Sensor (LDS). A study conducted in FY 1990 concluded that the performance objectives for the LDS system could be met using existing technology, with moderate costs. A test facility also was developed to assist in verifying LDS performance. After cancellation of a planned LDS flight demonstration, efforts have now been refocused on proposing LDS flight hardware to support Shuttle and SSF rendezvous and docking operations. Development of LDS systems that can provide accurate spacecraft relative position, attitude, and approach rates also will contribute to enabling more autonomous rendezvous and docking capabilities in the future.

As space servicing operations become more commonplace, applications of robotic systems will increase. These systems will require the capability to sense their environment in order to conduct effective and autonomous operations. Image-based tracking techniques are being investigated as a means to provide this needed robotic vision capability. Progress was made in FY 1990 in the development of image-based systems that utilize video cameras, 3-D imaging laser radar, and image processors to supply the information required for robotic operations. Potential applications for image-based systems include tracking of free-floating objects in the vicinity of the SSF and sensing capability for an extravehicular activity (EVA) retriever.

On-orbit refueling of propellants is another key area of serving technology being addressed. The JSC is developing tanker concepts and the required coupling hardware to enable resupply of both storable and cryogenic propellants. Hardware tests and evaluations were in work during FY 1990 to qualify a superfluid helium coupling and a storable fluid coupling. The superfluid helium coupling is scheduled for on-orbit evaluation during a 1993 flight experiment that will simulate a satellite servicing operation.

Space Transportation Technology

Significant Tasks

Real-Time Data System

TM: Troy A. Heindel/DF24
Reference STT 1

The Mission Control Center (MCC) has served as the seat of the United States manned space operations since the Gemini program. Through the years, this facility has undergone little change in the tools and technologies available to the operators who work there. While the facility has served NASA well for the Gemini, Apollo, and Shuttle programs, its resident tools and technologies are considered outdated and insufficient to meet the more demanding needs of a continuously operating Space Station. Many consider the MCC to be an ideal proving ground for the new computer-based technologies that will be essential to making the Space Station Control Center a safe and cost-effective operations facility.

Begun in 1987 with the goal of improving the quality of Space Shuttle flight decision making, the Real-Time Data System project has expanded to provide real-time data and rule-based expert systems technology to eight flight control disciplines including the Flight Director. By utilizing commercial off-the-shelf hardware and software and the latest advances in software engineering, this project has been able to establish a low-cost telemetry monitoring capability that is independent of existing operational systems.

Commercially available telemetry processors and UNIX-based workstations were chosen to minimize development costs and maximize overall system flexibility. Because UNIX is not a real-time computer operating system, innovative techniques had to be developed to ensure time-homogeneous acquisition of Space Shuttle telemetry data. By utilizing UNIX real-time extensions such as memory lock, continguous file input/output, process prioritization, and an elastic ring buffer, time-homogeneous real-time data are provided to flight controllers monitoring applications.

Real-time data analysis applications are expressed in traditional C programs as well as in non-traditional real-time expert systems. The latest computer programming techniques such as object-oriented programming, rule- and procedure-based expert systems, and distributed systems were incorporated into the design by integrating a commercial expert system package into the developer tool set. Through use of this software tool, flight controllers were able to develop and test complex monitoring applications quickly. This system of data acquisition and software tools represents the most sophisticated development and run-time capabilities available in any manned space operations facility.

Operated by flight controllers around the clock during six Space Shuttle missions in 1990, these systems have enabled a significant improvement in the ability of flight controllers to monitor their onboard systems by providing real-time spacecraft data to knowledge-based systems which display results in an easy-to-understand color graphics format. A computer application called Main Engine monitors pressures and temperatures of main engines during ascent, carries out complex data analysis tasks every second, and provides results to BOOSTER flight controllers 4 seconds faster than their traditional mainframe-based displays. An animated 3-dimensional graphics representation of the Shuttle's remote manipulator system (RMS) is driven by real-time data and enables the RMS flight controllers to visualize the arm as it is moving without a video downlink, determining whether the arm is moving in a way which might impact the Orbiter. An application called Jet Control monitors the availability of the RCS maneuvering jets and can tell the Guidance, Navigation, and Control Officer in seconds facts about the Shuttle's control capability which used to take over 20 minutes to obtain. The Flight Director now has a system which collects real-time wind data from the landing sites, computes crosswind components automatically, and displays results in easy-to-read graphics format, thereby reducing the amount of verbal communication necessary between himself and the Weather Officer.

Unanticipated benefits of this task have proven to be almost as important as the task itself. Flight controllers now have the capability to expose themselves to many different types of failures which they previously had to wait for during integrated simulations which take place in the MCC with the entire flight team of over 50 people. This task has also demonstrated that the use of expert system tools can reduce the development and maintenance cost of these knowledge-based systems by up to 40 percent over standard programming methodologies.

These dramatic improvements in the operational tools of Space Shuttle flight controllers are made possible largely due to the great increase in speed and reduction in cost of computer workstations coupled with the sophistication and reliability of commercial software packages. The revelation of this activity has been in realizing the great promise of commercially available hardware and software, and in working diligently to provide the glue to stick the various components together.

Flight-to-Flight Overlay of Shuttle Mission Data

PI: Linda A. Perrine/DF72
Reference STT 2

The objective of this project is to provide flight controllers quick access to all previous Shuttle mission flight data and to locate particular signatures which have occurred on past missions that may be relevant to the current mission being supported. Currently, flight controllers have fairly timely access to previous mission data from the current flight only (referred to as near real-time (NRT) data). The process of reviewing and plotting previous flight data involves support from Flight Support Host technicians who must locate the previous mission's Orbiter Data Reduction Center (ODRC) magnetic tapes, load these tapes into the NRT system, and search for the time period desired by the flight controller. This process has required 6 to 12 hours to turn around one request on previous missions and is not conducive to evaluating failures in real time. The Environmental, Emergency, and Consumables Manager flight control discipline heavily relies on previous mission data to evaluate current mission systems performance, and has developed the concept of having access to all previous mission flight data on an optical disk system with the ability to overlay signatures from previous flights with the current flight. At the time this project was conceived (December 1988), it was an undeveloped technology to be explored. In May 1989, a new, larger scale task had been developed to rehost the current ODRC magnetic tapes to an optical disk-based host which would provide support to the Johnson Space Center/Engineering and Mission Operations. Once the ODRC rehost was defined and funded, the Flight-to-Flight Overlay project decided to forego storage of data on its own optical disk system and concentrate instead on a graphical user interface for gathering and displaying ODRC-retrieved data to the flight controller.

The Flight-to-Flight Overlay project got underway on 1 March 1990 with enough funding to support two programmers. Level A requirements were defined and a 3-month prototyping period produced the framework for the Flight-to-Flight user interface. Project requirements include the use of a commercial off-the-shelf data base package (we will be using ORACLE) to store pertinent mission event times which can be accessed in the course of building a request for previous mission data. In other words, the flight controller can ask for a given set of parameters for Space Transportation System (STS) 41-D, 51-A, or 61-B, or STS-30 from orbital maneuvering system-1 ignition to payload bay door opening without having to know the exact time of these events on selected missions. The data base also stores information such as attitude time line, anomaly reports, crew size, vehicle number, specific line replaceable unit serial numbers, etc. The database is easily expandable and will be expanded to accommodate other disciplines' interests in the early part of 1991.

The plotting software will then be able to overlay all parameters from these missions or easily allow the user to select which parameters are desired to be overlaid, one mission on top of the next. This allows for significant improvement in failure analysis for certain types of signatures which flight controllers currently have no ability to perform other than by viewing separate plots of mission data on paper. One other significant improvement to reviewing previous mission data which is being added by this project will be to initiate a search through one or more previous missions for certain types of events: a given parameter tripping a user-specified limit; or a parameter-changing state (0 to 1); etc. This alleviates the user having to know exactly when or whether a certain type of signature occurred.

To date, the Flight-to-Flight Overlay project is scheduled to begin simulation and, eventually, mission support starting in February 1991. After the first software release, the next stage will be to develop an ODRC emulator with an Intergraph-provided optical disk jukebox. This will allow thorough testing of the software prior to ODRC coming on-line in September 1992. The project also is proposing connections to the Intergraph jukebox for the developers of the ODRC software so they may work with representative mission data in the planned format and with planned ODRC interfaces before the real system is on-line. The Intergraph jukebox is only a temporary unit which will be removed at the time of the ODRC system being made available.

Voice Command System Flight Experiment

PI: George A. Salazar/EE22
Reference STT 3

Future space programs, such as the Space Station or Lunar/Mars exploration, will require the crew to operate several spacecraft computer systems on a daily basis. Hundreds of manual switches associated with these systems will reside within the vehicle. This tactile form of control will require the crew to be next to the computer panel when using the system. Furthermore, the crewmember must remember the function of each switch. Duties such as checkout of the station structure and performing on-orbit experiments will consume a lot of astronaut time when using these traditional tactile control panels. For example, manipulating a robot arm while simultaneously controlling the closed circuit television (CCTV) system will place high demands on the astronaut. The astronaut must stop the control of the arm each time he wants to adjust or select the cameras or monitors. This disrupts the robot motion, diverts the astronaut's visual attention, and distracts his mental concentration, thus increasing his workload.

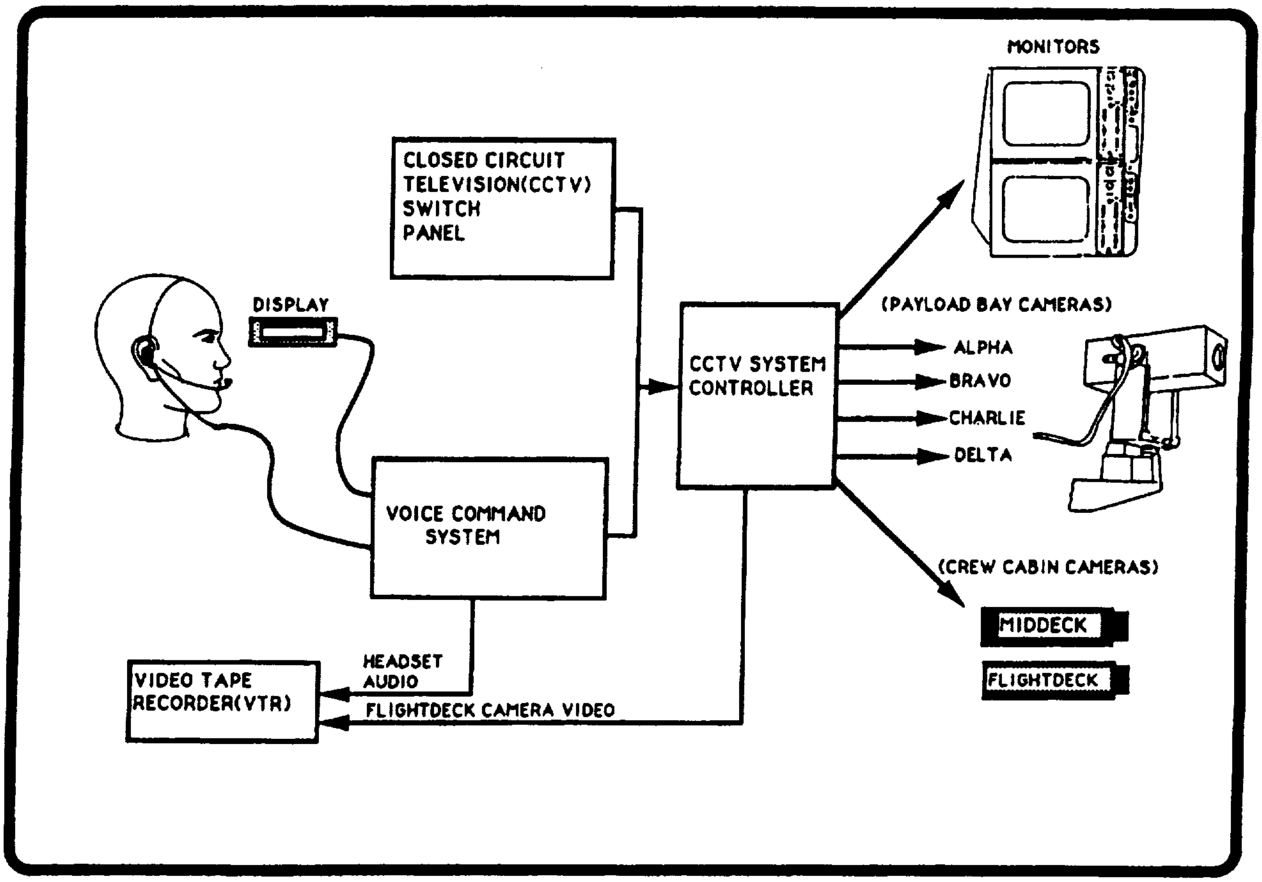
Consider the use of a voice interface to a computer. A voice interface offers the opportunity of interacting with computers using the human's most natural form of communications - speech. By simply using a microphone, the astronaut would communicate with the computer without physically being located near the control panel or requiring a lighted room. For robot control, the astronaut would keep his hands and eyes on controlling the robot arm while using his voice to control the CCTV system. Inventory control, vehicle inspections, experiment reporting, and computer-screen page call-ups are just a few potential applications of voice recognition technology for space programs where improvement in crew productivity would occur.

To investigate the potential use of this type of computer input for space applications, an experiment was successfully flown on Space Transportation System-41 in October 1990. The experiment, the voice command system (VCS), was used to control the Orbiter's CCTV system by voice. It was the first time that voice recognition technology flew in space.

The VCS allowed two astronauts to operate select CCTV functions by using a microphone input and verbally issuing commands such as "camera alpha," "monitor one," or "zoom in." The VCS recognized spoken commands and operated the appropriate controls to the CCTV system. The experiment consisted of the VCS control panel located directly below the CCTV switch panel, a display unit for VCS status feedback, and interconnecting cables between it and the Orbiter. The VCS ground training required the astronauts to create personalized voice prints of each command word. These voice prints were stored in the VCS memory and used both for training and for on-orbit mission tasks.

To ensure experiment success, several technical and training obstacles were overcome. The VCS specifications called for the CCTV system to operate regardless of the VCS power state, either on or off. To meet this specification, a unique isolation interface was designed and developed. This interface worked flawlessly during the experiment. False commands were prohibited from reaching the CCTV system. Command word selection and test methods were developed that ensured the words chosen were robust enough to minimize false commands getting through the VCS. Mission test data show this objective was met. Training techniques and methods for the astronauts were developed that simulated the Orbiter environment. This was important to ensure experiment success. Astronaut comments indicated that the training received was excellent, giving them a high degree of confidence in the VCS.

Two astronauts used the system on flight days 2, 3, and 4. Mission specialist 1's performance on the VCS was virtually 100 percent throughout the 3 days. Performance for mission specialist 2 was initially poor the first day; however, by the third day, he obtained almost 100 percent recognition. Post-flight astronaut comments about the VCS were favorable. The astronauts believe that the VCS is a technology that would benefit the Shuttle for control input and that the VCS should fly again to refine the system.



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Voice Command System flight experiment overview.

Voice Command System flight demonstration.

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Intelligent Computer-aided Training (ICAT)

PI: Robert T. Savely /PT4
Dr. R. Bowen Loftin
Reference STT 4

Training of NASA astronauts, flight controllers, and other ground support personnel historically has required extensive on-the-job training in order for individuals to acquire the knowledge and skills necessary for acceptable performance and/or certification. Current flight rates and the loss of experienced personnel to retirement and transfer 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 large-scale, physical simulators. By integrating expert systems technology with training methodologies, such systems can significantly reduce the amount of on-the-job training necessary to achieve acceptable levels of performance. As the first figure illustrates, the Johnson Space Center (JSC) ICAT approach also brings to bear on the training process other advanced technologies, such as speech recognition/generation to simulate better operational environments, cognitive modeling to provide truly adaptive training, qualitative simulations to produce more efficient and maintainable simulations, and state-of-the-art software technologies (e.g., object-oriented programming and X-Windows) to enhance programming productivity and software portability.

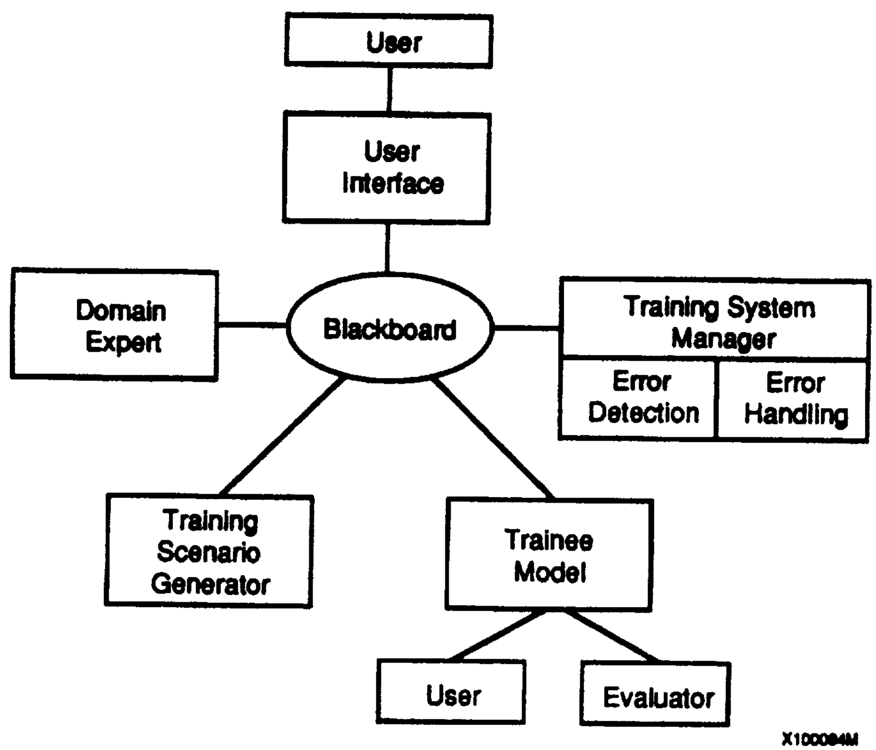
To deliver sophisticated and individualized training, ICAT systems model the behavior of both experts and novices in the performance of a complex task. In addition, the expertise of a trainer is modeled and used to determine the feedback given in response to trainee errors and to design increasingly challenging simulations to meet training goals. Thus, the efforts of both an expert in the task and an expert trainer are applied simultaneously to each trainee. Such systems offer increased efficiency and reduced cost in training and provide uniform and verifiable training, enhancing safety and the probability of mission success.

During fiscal year 1990 (FY 1990), the Payload-Assist Module Deploy Intelligent Computer-aided Training (PD/ICAT) system was rehosted to the Masscomp computer at the request of the Mission Operations Directorate. Initial phases of two additional ICAT systems also were completed. The Main Propulsion Pneumatics (MPP) ICAT system, under development for the Kennedy Space Center, achieved the capability of training Space Shuttle test engineers in the Operations and Maintenance Instruction procedures for activation and deactivation of the 750 psi helium system. Progress has been made in extending this system to train engineers in the troubleshooting techniques employed to detect and correct problems with the MPP system. The Instrument Pointing System (IPS) ICAT system, supported by the Marshall Space Flight Center, also reached Phase I operational status. This phase supports training mission and payload specialists in the activation, deactivation, and initial pointing of the IPS as used on the Astro-1 mission. Further extension of this system to address final pointing and operation of the Hopkins Ultraviolet Telescope is now under way.

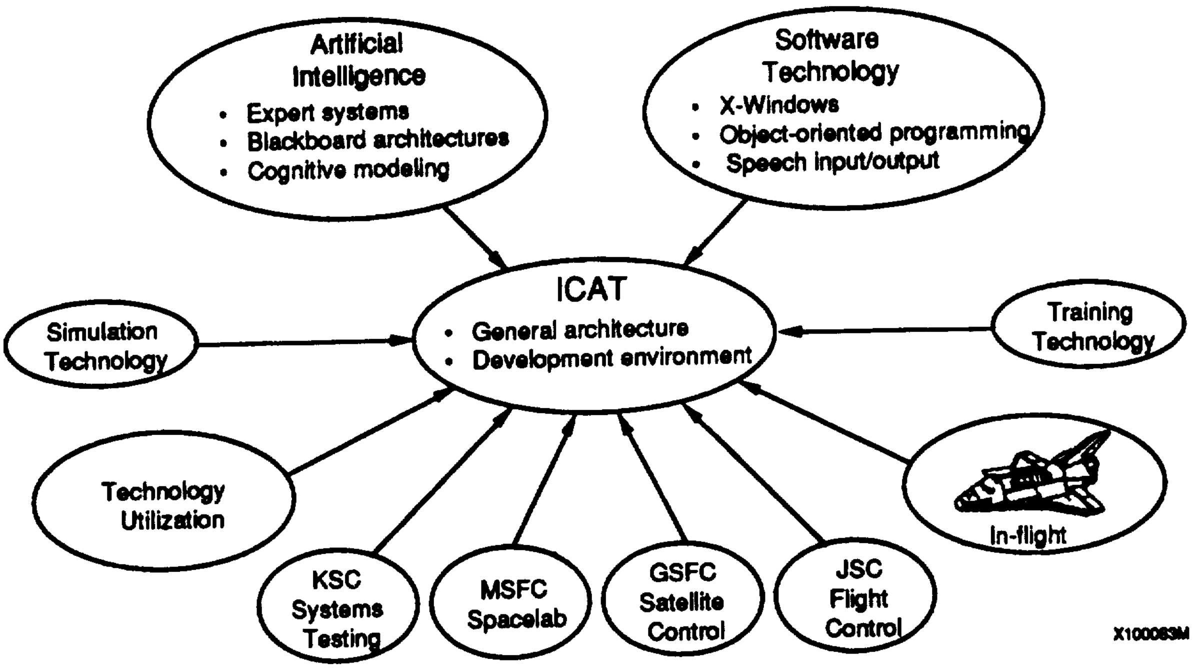
Work also has been completed on the general ICAT architecture. This architecture is designed to segregate domain-independent portions of the ICAT system and to facilitate the adaptation of the architecture to new applications. As shown in the second figure, this architecture consists of four cooperating expert systems (domain expert, training session manager error detector, training session manager error handler, and training scenario generator) that interact through a common blackboard. The domain expert encodes, in rules, the procedures used by experienced personnel to carry out complex tasks. This expert system supports multiple approaches to task performance and problem solving and includes a knowledge of the most common errors made by novices. The two systems comprising the training session manager compare the actions of trainees to those of the domain expert and, when errors are noted, decide how best to inform and remediate the trainee. This latter activity is accomplished by using the model created for each individual trainee to determine the optimal response to a given error. Finally, the training scenario generator draws on the system's training goals, the trainee model, and the knowledge of experienced trainers to create new and ever more challenging simulations for each trainee. The success of the general ICAT architecture is demonstrated by its use at the Goddard Space Flight Center, to develop a prototype system for training personnel in satellite operations, and at the Houston offices of McDonnell Douglas Space Systems Company, to build an ICAT system for the Space Station Freedom thermal control system. A patent application for this general architecture has been submitted by the JSC.

The long-term goal of this project is to facilitate the use of the ICAT architecture by trainers in both the governmental and commercial sectors through the creation of a general-purpose development environment for ICAT systems – a suite of software tools to aid trainers in adapting the architecture to build specific applications. This development environment ultimately will consist of integrated tools for knowledge acquisition, interface development, knowledge-base editing, and adaptive trainee modeling. During FY 1990, evaluation of knowledge acquisition tools was completed and requirements were developed for a tool suitable for the ICAT domain. Work was begun to implement the knowledge acquisition tool in Windows 3.0 and C for delivery in FY 1991. The requirements for a user interface development tool also were completed, in preliminary form, and production of a prototype is planned for FY 1991. By FY 1993, the development environment will be transferred to other NASA centers for final testing through actual application development.

In summary, a robust and extensible "core" architecture for ICAT systems has been achieved, and work is well along in the creation of software tools to make the use of this architecture in the building of new applications efficient and effective.



ICAT systems integrate diverse technology, providing effective and efficient training to many NASA operations.



The general ICAT architecture consists of multiple expert systems and data structures that communicate via a common blackboard.

Computer-Aided Scheduling System: COMPASS

PI: Ervin Grice/PT4
Reference STT 5

Effective use of the Space Transportation System (STS) and the future Space Station Freedom requires careful scheduling of many program elements. Scheduling is a difficult, error-prone process, and unexpected events or changing requirements 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 an interactive scheduling system which allows human schedulers to interact with a computer-aided scheduling process. Users can define, edit, and modify all elements of a schedule while the computer performs those detailed computations that guarantee the feasibility and quality of the schedule. The Computer-Aided Scheduling System (COMPASS) is being developed to meet these requirements. It provides the ability to schedule critical activities interactively while providing a full spectrum of automatic scheduling and editing capabilities.

The COMPASS is based on requirements generated at a NASA workshop on planning and scheduling held at the Jet Propulsion Laboratory in 1986. It 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 commands, and saves the resulting schedule in a data file where it can be retrieved for later publication or modification and revision. 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 required resources. The user can schedule activities one at a time to control the resulting product or command the computer to schedule everything automatically without human intervention.

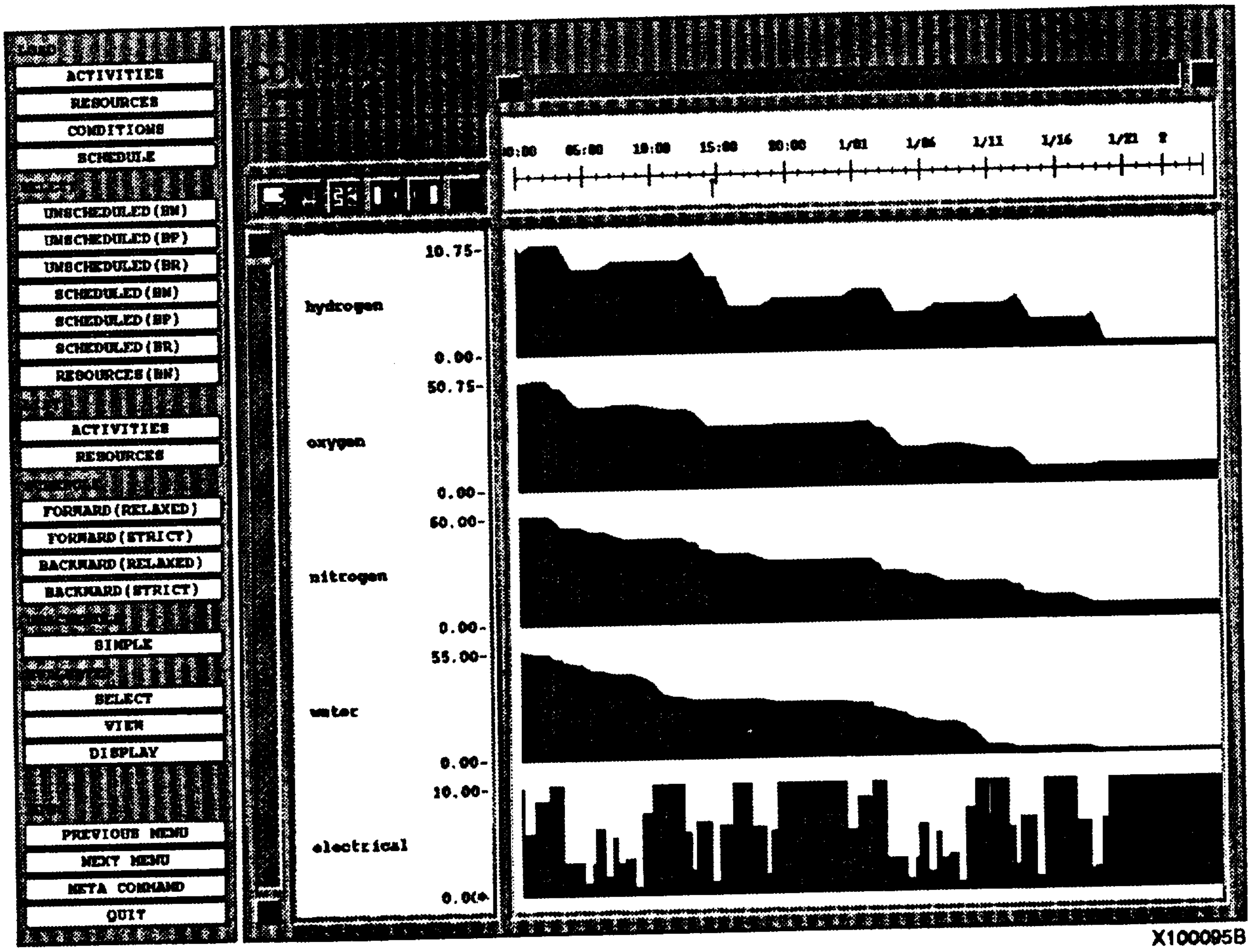
The COMPASS is suitable for a wide range of problems including activity and project scheduling. It has the capabilities necessary for plan creation in advance of execution time, plan revision prior to execution time, and plan revision at execution time in response to failures and delays. The COMPASS can be used to manage a variety of activities subject to timing constraints, ordering constraints, and the availability of resources. It also can be used to manage a wide range of resources These resources may be used then returned by an activity (such as tools), consumed by an activity (such as propellant), or produced/resupplied by an activity (such as water).

The user may customize the external activity representation to meet the needs of the application. A value and penalty may be associated with each activity that allows for "scoring" of schedules. Preferred as well as required intervals of time are provided which more accurately schedule the activity as desired. The COMPASS also allows the user to model the environment using boolean conditions and ensures that activities are scheduled only when specified conditions are met.

Finally, COMPASS provides a utility for evaluating a schedule. Given a schedule, it displays any activity that violates its constraints and describes which constraints are being violated. This allows the user to evaluate preexisting schedules and to verify that such schedules respect all of their constraints.

The COMPASS is written in Ada and supports two interfaces. An X-Windows interface provides a mouse-driven graphics interface. For those systems which do not support the X Windowing System, an ASCII interface is available. The COMPASS was designed for portability and currently runs on Sun3/Sun4, SunSPARC, Apollo, PS2 (the ASCII version only), RS6000, and VAX machines.

The COMPASS is being developed on an incremental basis. The first step was to capture basic generic scheduling technology in a library of routines. This version is currently available through COSMIC. During the last year, a number of new commands and features were added to make COMPASS more robust for a variety of scheduling problems. The 1990 development work focused on functionality and performance. Boolean constraints, temporal constraints, and preferences were added to the activity representation to support more complex scheduling applications. Performance was carefully analyzed and critical routines were rewritten so the time required for input, output, and scheduling operations was reduced by a factor of three. The user interface was enhanced with support for iconification, relocation, and resizing of the application window, with improved methods for scrolling the Gantt chart and resource profile windows, and with a scrollable menu of scheduling commands. Future plans are to develop an editor that will allow the user to edit resource and activity data interactively. A uniform user interface will be developed to support multiple platforms, and a report generator will be added so the output from COMPASS may be presented in a customized format. Finally, further enhancements to the base algorithms, data structures, and the user interface will be added to increase support of traditional critical path project scheduling, resource constrained scheduling, and facilities scheduling.



Computer-aided Scheduling System display.

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Expert System for Crew Procedures Execution

PI: H. K. Hiers/ER2
Reference STT 6

The objective of this project is to investigate the application of expert system technology to the execution of crew procedures performed during Shuttle rendezvous operations. Initiated in fiscal year 1987 (FY 1987), this work has resulted in the development of the Rendezvous Expert System (REX). The credibility of REX is enhanced by its operation in a realistic environment provided by the systems engineering simulator (SES), a major real-time engineering simulator at the Johnson Space Center. The SES is used extensively for Shuttle on-orbit procedures development and crew familiarization, as well as for the engineering evaluation of advanced concepts. The REX, integrated with the SES on-orbit simulation, provides a testbed in which crewmembers and flight controllers may evaluate rendezvous concepts ranging from computer-aided manual execution of procedures to fully autonomous modes of operation.

In the first phase of REX development, the concept of a crew "advisor" was implemented. This early prototype had four basic functions:

- In place of the printed rendezvous procedures in the Flight Data File document, REX presented the applicable procedures on a cathode ray tube (CRT) display, highlighting the next recommended step to be performed by the crew.
- The REX evaluated telemetry from the SES for immediate confirmation that the recommended step was performed by the crew.
- The REX continuously monitored the status of navigation and rendezvous sensors and, upon detection of a problem, recommended contingency actions.
- The REX provided a dynamic CRT plot of Shuttle/target relative motion and the predicted path of the Shuttle subsequent to orbital maneuvering subsystem/reaction control subsystem thruster burns.

The FY 1990 additions to REX deal with the terminal phase of a rendezvous mission, proximity operations, during which the Shuttle makes its final approach to the target. In this phase, as the crewmember maneuvers the Shuttle near the target by deflections of the translation hand controller (THC), considerations of minimum fuel usage and minimum plume impingement on the target are of concern. To support this rendezvous phase, a sophisticated crew interface has been provided which displays, in a compact grouping of "windows," information pertinent to the final approach. Additionally, crew distraction from visual observation of the target is minimized by use of a Votrax speech synthesizer for REX's recommendations to the crew. Two modes of operation are available during this phase: (1) the ADVISORY mode (also called the MONITOR mode), in which REX recommends THC commands for execution by the crew; and (2) the CONTROL mode, in which REX runs in automated mode through docking by sending the required digital autopilot pulse commands directly to the SES for execution.

Both operation modes are supported by guidance controllers for Shuttle final approaches along the V-bar (direction of target's orbital motion) and R-bar (perpendicular to direction of target's orbital motion), as well as by a controller for stationkeeping which maintains the Shuttle at a desired position with respect to the target during the final approach.

The REX terminal guidance is based on modified Clohessy-Wiltshire (CW) linear equations of relative motion. The algorithm guides the Shuttle (or prompts crew actions, in the case of the MONITOR mode) from the last rendezvous midcourse maneuver (MC4) through docking with Space Station Freedom. The uniqueness of this algorithm is that it allows us to use the CW equations to fly a line-of-sight V-bar or R-bar in the final approach docking phase. The algorithm is made of two parts, in and out of plane, and can be used for stationkeeping during final approaches. The REX simulation runs with SES perfect navigation data indicating the precision obtainable with this guidance scheme (typically 6 in. or less of error during the docking phase). This accuracy meets the tentative contact condition specifications for the docking mast being proposed for the Shuttle and Space Station.

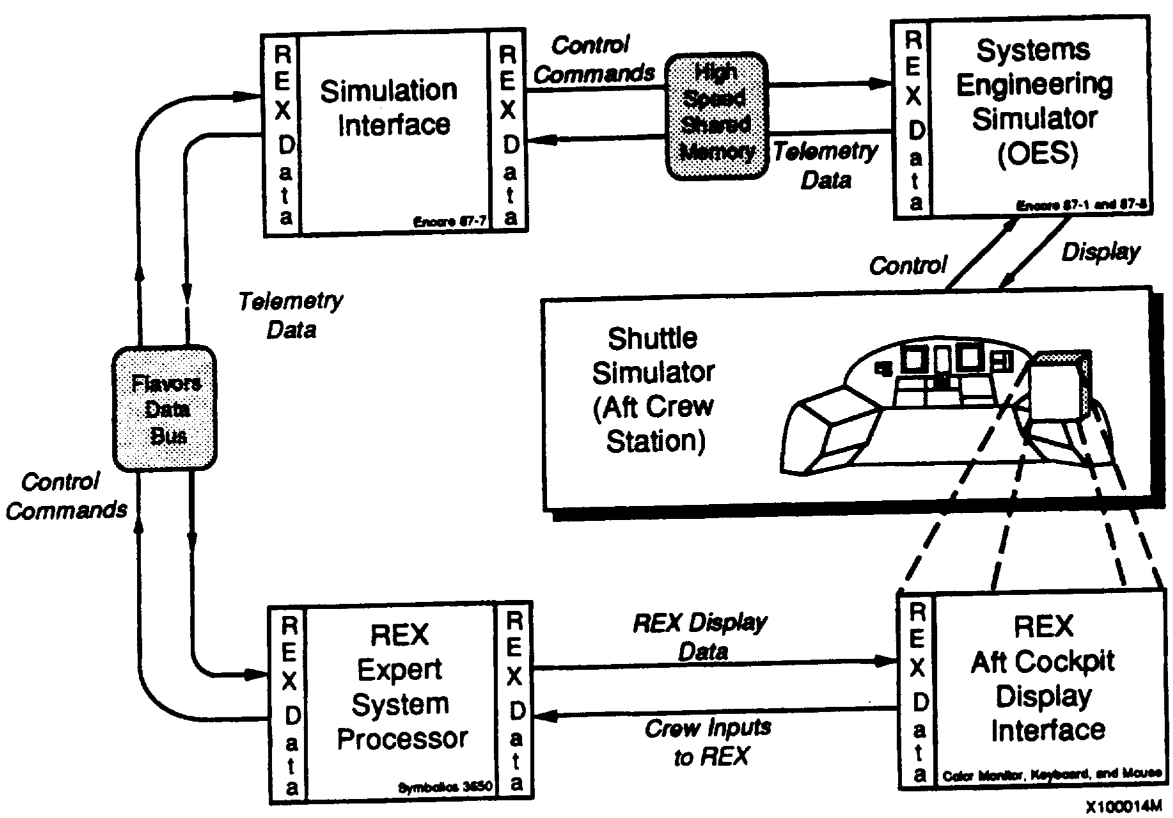
At year's end, some testing of REX with the SES laser docking sensor math model integrated with a slightly modified Shuttle navigation system had been accomplished successfully. Modifications include the addition of the target docking port location in the rendezvous navigation, the addition of process noise to the Shuttle navigation Kalman filter for system stability, and the reduction of navigation errors to the lowest possible level during the docking phase. This activity, which tests the algorithm in a more realistic navigation environment, seems to indicate that, with an accurate laser docking sensor and a properly integrated and tuned navigation filter, automated docking of the Shuttle to the Space Station Freedom is feasible.

The ability of REX's guidance algorithms to handle properly both nominal and off-nominal approach trajectories was established in numerous simulation runs with the SES and with trajectory analysis software developed for a personal computer (pc). The pc software proved a highly valuable alternative to the SES during the checkout phase in that considerable testing was accomplished without use of costly SES time.

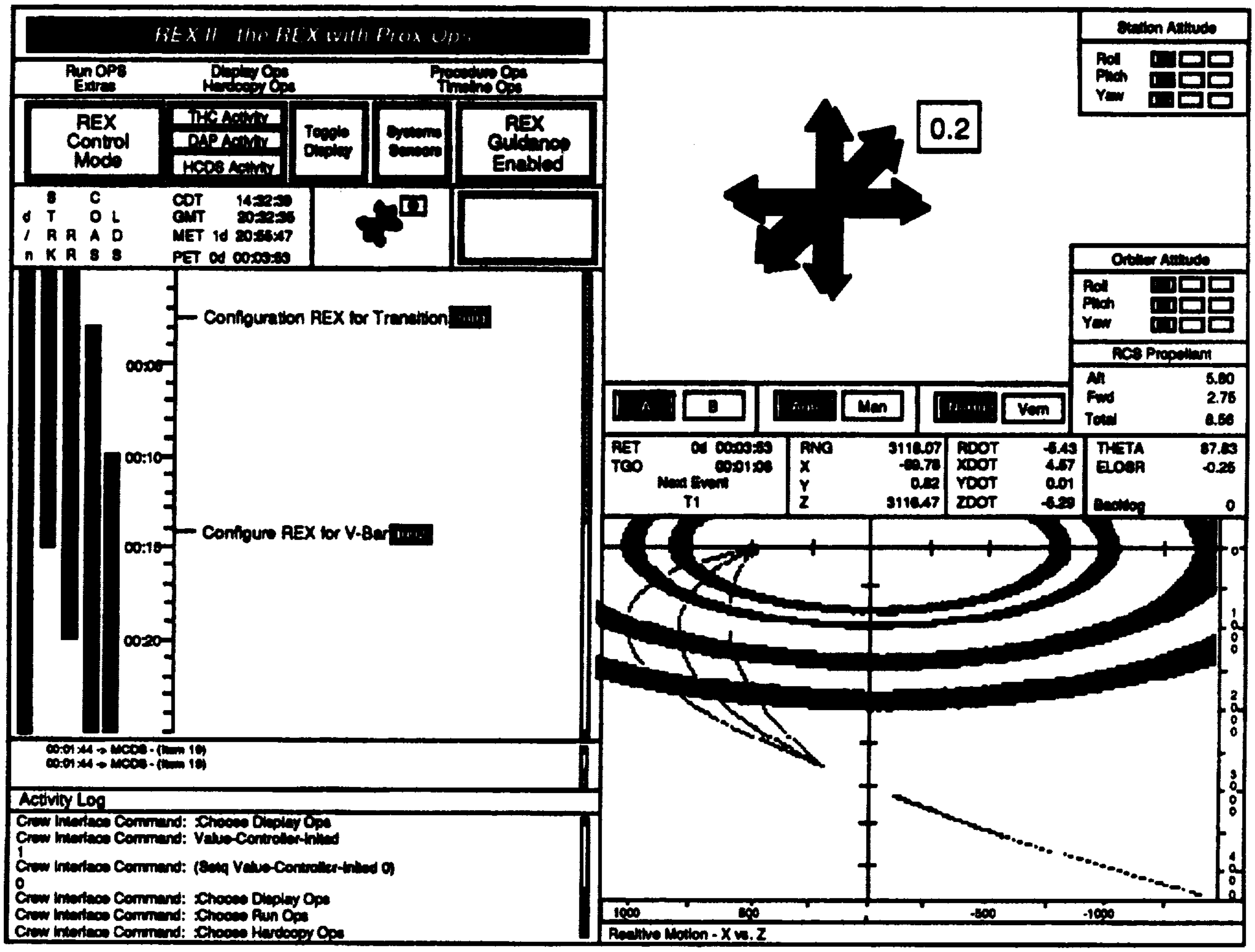
The REX resides in a Symbolics, Inc. 3650 processor interfaced with the SES Gould computers via a high-speed Flavors Technology, Inc. data communications medium. The crew interface consists of a color CRT monitor and a mouse control device installed in the SES aft cockpit – the crew station that duplicates the Shuttle aft cockpit controls.

The REX software is implemented in a mix of conventional and artificial intelligence languages. Guidance controllers are written in the conventional C language, while procedure management functions are written in Lisp, and navigation/rendezvous sensor health monitoring functions are implemented in the JOSHUA expert system shell.

The current REX, designed as a Shuttle-based system, addresses the needs of the Shuttle crew. Some REX features and processes also have application to a ground-based system for flight controllers. Funding has been received and plans are being formulated for porting elements of REX software to a ground-based environment with the addition of features tailored to the needs of flight controllers in the Mission Control Center.



REX architecture.



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REX architecture.

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Fuzzy Logic for Adaptive Control and Operational Decision Making

PI: Robert N. Lea / PT4
Reference STT 7

Future space missions will require autonomy as well as high operational efficiency to ensure effective performance. Studies at the Johnson Space Center (JSC) have shown that fuzzy logic technology is powerful and robust in interpreting imprecise measurements and generating appropriate control decisions in expert systems applications. The JSC has set objectives of developing applications of fuzzy logic to the control of space vehicles and remote manipulator systems, and to develop an adaptive logic design to create more robust fuzzy controllers. Fuzzy logic algorithms for relative motion and attitude control, developed over the last 2 years, have been integrated into a complete 6 degree of freedom simulation for Shuttle proximity operations. Based on experience gained from these efforts, motion control algorithms that include obstacle avoidance have been developed for a mobile robot and are being tested in a software simulation. A concept of an intelligent sensor system that can identify objects and track them continuously while learning from its environment has been developed. Such systems will support traffic management and proximity operations of the Shuttle around the Space Station Freedom. Further studies have been initialized for developing an adaptive controller by integrating a neural learning system developed at Ames Research Center (ARC) with JSC's fuzzy Shuttle controller to study its usefulness in docking operations.

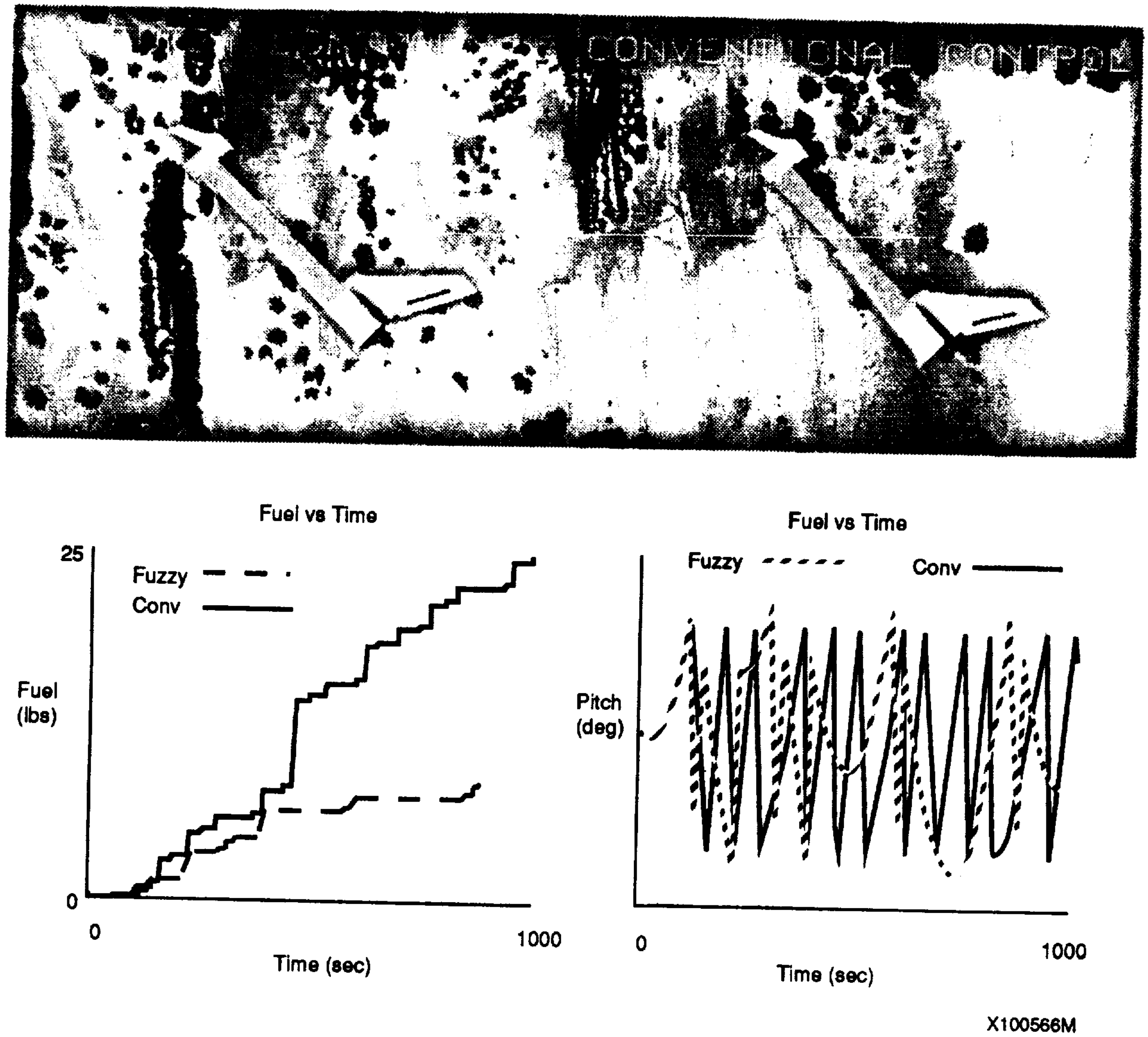
A crucial problem in space operations is guidance and collision avoidance of space vehicles and robotic arms in their respective zones and work spaces. As an initial effort, the problem of control and collision avoidance of a surface vehicle or rover as it maneuvers through a field of obstacles was considered. In moving from one point to another, it will be necessary to avoid obstacles which cannot be identified prior to the mission. A fuzzy logic approach to trajectory control has been developed that allows the rover to avoid these hazards as it traverses required paths to accomplish its mission. The fuzzy trajectory controller receives the goal or target point from the planner, uses X and Y position errors as well as orientation errors in the control system frame, and sends steering angle and velocity commands to the rover. The fuzzy rule base containing 112 rules for the controller has been designed to drive the rover towards the target point while it corrects the orientation error.

The fuzzy trajectory controller for the rover simulation has been tested on several cases. Preliminary results have shown that the trajectory controller can reach the target position within 0.25 m and attitude within 0.45 deg. It is believed that these inaccuracies can be reduced by tuning the membership functions to better represent the input and output variables. Results of activities in this project have shown that the fuzzy approach provides a control system that can be modified and tested easily and gives very good results.

A concept for a Camera Tracking System (CTS) has been developed, and fuzzy logic based rules have been developed and coded to perform the task of tracking an object. The fuzzy controller receives the object's position in terms of pixel location in the camera field of view and range from a laser range finder. Commands for the pan and tilt gimble drives are generated using the rule base with 35 fuzzy rules. Detailed plans are being developed for testing the concept in a software simulation prior to implementing it into a hardware laboratory that integrates cameras, lasers, computers, and movable objects for tracking. The concept of the CTS was presented at the 8th International Congress of Cybernetics and Systems in June 1990. This concept can be expanded easily to include object identification, a caution and warning system for collision avoidance. and extravehicular activity monitoring tasks.

A concept for the integration of a neural learning system developed at ARC with the fuzzy Shuttle controller developed at JSC has been developed, and the plan has been presented at the IEEE Symposium on Intelligent Control in September 1990. This system will be applied to a Shuttle docking problem as soon as the necessary interfaces are defined and built.

The main objective of fiscal year 1990 activities has been to utilize fuzzy logic for adaptive control and decision making and to increase autonomy in orbital operations. Greater autonomy desired for future space operations will result in a higher level of operational efficiency. The approach taken has been to develop modular fuzzy logic based control systems that can be upscaled for greater autonomy in an integrated environment. The initial step has been to develop a software controller that can be integrated with hardware at an appropriate level. As the activities progress, detailed testing will be performed to verify implementation and integration of hardware and software components. Preliminary results promise a very successful utilization of fuzzy logic in autonomous orbital operations.



Comparison of fuzzy and conventional control for Shuttle attitude.

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Advanced Software Development Workstation (ASDW)

PI: Ernest M. Fridge III/PT4
Charles L. Pitman/PT4
Reference STT 8

The National Aeronautics and Space Administration (NASA) has many complex software systems that contain hundreds of thousands, or in some cases millions, of lines of code. The development and maintenance costs of such complex information systems are very high. The challenging goal of Computer-Aided Software Engineering (CASE) is to reduce the cost of large, complex software systems while improving their quality. The objective of the CASE research and development being performed under the Advanced Software Development Workstation (ASDW) project is to provide productivity enhancements that will realize this goal and thus benefit a broad range of NASA programs, such as the Software Support Environment, the Space Station Control Center, and the Flight Analysis and Design System (FADS) which is used to support the Space Shuttle and the Space Station Freedom.

The ASDW CASE research and development effort is applying knowledge-based technology (sometimes called expert system technology) to all phases of software development and maintenance life cycle (except system testing). The ASDW project consists of three subtasks: (1) the Parts Composition System (PCS), sometimes called Access or Bauhaus, (2) the Engineering Script Language (ESL), and (3) the Framework Programmable Integration Platform (FPP). Together, these subtasks seek to develop:

- A knowledge-based system (the PCS) with a high-level graph interface (the ESL) that allows reusable software applications to be developed easily and operated by engineers with a minimum of programming experience,

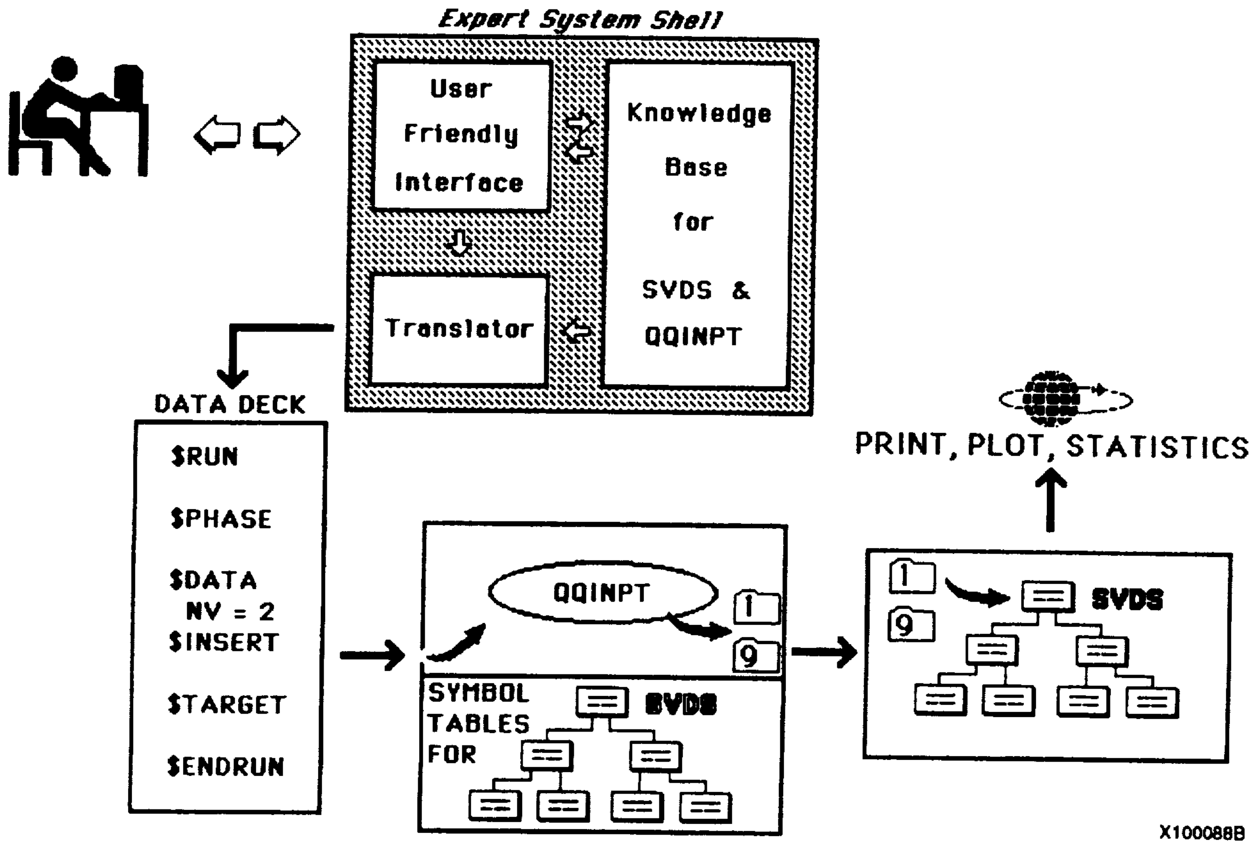
- A knowledge-based tool (the Framework parts of the FPP) to aid all software system users and managers in the selection and use of integrated CASE methodologies and tools for the various situations and roles that they encounter in their work, and

- A realistic and useful method (the Integration parts of the FPP) allowing knowledge-based integration of CASE tools that span the entire software life cycle.

In fiscal year 1990 (FY 1990), the ASDW graphical user interface (GUI) system was replaced and made more portable with the migration to X-Windows and the Goddard Space Flight Center's TAE+. In response to initial field tests, the ASDW user interface was completely redesigned to take greater advantage of the new GUI's capabilities. The document defining the ESL also was delivered in FY 1990. It contains the language definition, graph interface specification, rules for automatically translating the application graphs to a high-order language (such as Ada, C, or Fortran), and the menu interface for integration with the PCS. The "Concept of Operations" and "Requirements" documents for the FPP also were delivered in FY 1990.

Currently, the ASDW supports the reuse of software and data. The reuse of data, supported by knowledge-based assistance, provides an opportunity for significant productivity enhancement in the operation of complex computer programs. For example, extensive user time often is required for preparing and debugging input data to very large trajectory simulation programs. In FY 1990, as a test case for the ASDW, a knowledge base was developed for an Intelligent User Interface (IUI) that aids the user (generally an aerospace engineer) in the data-set-up for Ground Simulation (GNDSIM), a Space Vehicle Dynamics Simulation (SVDS) application (see figure). The IUI is inserted as a new layer between the user and the input "data deck." Previously, the user had to set up a data deck (which may contain hundreds of data sets) with a line editor, and submit it to the Generalized Input Processor (QQINPT), and then to the SVDS itself which ran the trajectory simulation and generated the output. With the new IUI layer, the user interacts with a user-friendly graphical interface instead of a line editor, and the data deck is automatically translated into QQINPT format. Thus, the user sees the input data in a well-organized, natural language style. Access to online context-sensitive help is available by pointing and clicking. The knowledge base also contains information about the GNDSIM variables and constraints, which allows potential data deck errors to be prevented (or detected and reported) before the data deck is submitted to be run. This will reduce the number of unproductive runs made. Initial user reaction to the IUI for GNDSIM/SVDS has been very positive, and it will be undergoing further user testing in January 1991.

The IUI for GNDSIM has demonstrated the usefulness of applying knowledge-based technology to making complex software easier to operate. The total ASDW project is continuing its efforts to bring the best CASE technology to NASA to make the complex information systems required for space exploration easier to develop and maintain.



Intelligent user interface for SVDS.

C Language Integrated Production System (CLIPS)

PI: Gary Riley/PT4
Reference STT 9

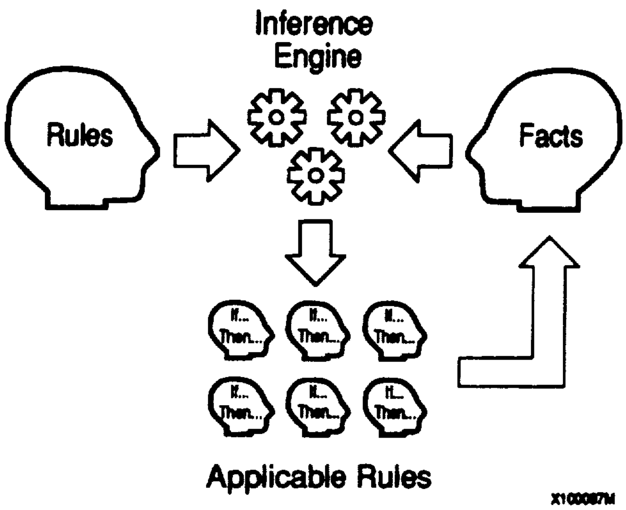
Expert systems are computer programs which emulate human expertise in well-defined problem domains. The potential payoff from expert systems is high: valuable expertise can be captured and preserved, repetitive and/or mundane tasks requiring human expertise can be automated, and uniformity can be applied in decision-making processes. Since the early 1970's, expert system technology has been pursued aggressively by researchers and, since the early 1980's, both government and commercial application developers have given expert systems considerable attention as well. An entire industry has grown to support the development of specialized software tools that can greatly reduce the effort and cost involved in developing an expert system.

Despite the wide variety of software and hardware products available, expert systems have generally failed to make a major impact in application environments. In part, this failure was caused by a lack of options for deploying expert system applications within conventional computing environments. To solve this problem, the Johnson Space Center (JSC) developed the C Language Integrated Production System (CLIPS) which was designed specifically to address several requirements: the ability to run on a wide variety of conventional hardware platforms, the ability to be integrated with and embedded within conventional software, and low-cost development and delivery options. At the time of its development, CLIPS was one of the few tools that was written in C and capable of running on a wide variety of conventional platforms. Since the initial development of CLIPS, a version of CLIPS written completely in Ada, CLIPS/Ada, also has been developed.

The primary method of representing knowledge in CLIPS is a rule. Rules are used to represent heuristics, or "rules of thumb," which specify a set of actions to be performed for a given situation. A rule is composed of an "if" portion and a "then" portion. The if portion of a rule is a series of patterns that specifies the facts (or data) which cause the rule to be applicable. The process of matching facts to patterns is called pattern matching. The CLIPS provides a mechanism, the inference engine, that automatically matches facts against patterns and determines which rules are applicable. The then portion of a rule is the set of actions to be executed when the rule is applicable. The actions of applicable rules are executed when the CLIPS inference engine is instructed to begin execution. The inference engine selects a rule and then the actions of the selected rule are executed (which may affect the list of applicable rules by adding or removing facts). The inference engine then selects another rule and executes its actions. This process continues until no applicable rules remain.

The CLIPS is a continually evolving product. The primary focus of effort in fiscal year 1990 has been towards the development of the next release of CLIPS, version 5.0, which is scheduled for release in January 1991. In addition to enhancements to the rule-based programming capabilities of CLIPS, version 5.0 also includes support for procedural and object-oriented programming. The new procedural programming capabilities allow global variables and functions for use by a CLIPS program to be defined directly within CLIPS, bypassing much of the need to write procedural code in a language such as C, Fortran, or Ada. The new object-oriented programming capabilities allow data and procedures to be coupled closely within objects – the procedures for manipulating an object's data are part of the object. In contrast, data and procedures usually are defined separately in procedural languages – the programmer defines data structures and then procedures that operate on the data structures. Benefits of object-oriented programming include modularity and reusability (since new objects can be defined in terms of existing objects).

Although CLIPS originally was developed by NASA to create aerospace-related expert systems, it has been put to widespread use in a number of fields. The CLIPS has been made available to the general public for a nominal fee through the Computer Software Management and Information Center, the distribution point for NASA software. The current release of CLIPS, version 4.3, is being used by over 3000 users throughout the public and private sector. At the first CLIPS Conference held at JSC in August 1990, over 80 papers were presented by representatives of the government, industry, and academia on a diverse range of topics. Because the CLIPS source code is readily available, numerous groups have saved man-years of development time by using CLIPS as the basis for their own expert system tools. In general, the development of CLIPS has helped to improve the ability to deliver expert system technology throughout the public and private sectors for a wide range of applications and diverse computing environments.



Execution of a rule-based program.

Cooperating Expert Systems

PI: Chris Culbert/PT4
Reference STT 10

Knowledge-based system technologies have successfully bridged the growing gap between low-level control systems and human control in narrow applications. Although only a few have been integrated into the domain of spacecraft operations, many applied research projects have shown that knowledge-based systems can provide human workload relief and are able to perform routine operations for individual spacecraft subsystems. However, true integration cannot be achieved simply by attaching a knowledge-based controller to every subsystem. As demonstrated by current ground mission control operations, communication and cooperation among controllers is a mandatory requirement for a robust control organization. Coordination among knowledge-based, human, or heterogeneous controllers requires a body of design and implementation guidelines that are still under development.

The purpose of this project is to define and develop guidelines, methodologies, and tools for distributed cooperating systems, and to apply them to develop and deliver distributed and cooperative systems tools to interested customers.

Although cooperation can be achieved in many different ways, there are two primary architectures for cooperation: hierarchies and peer committees. Each approach has its own advantages and disadvantages. On the positive side, a hierarchical organization provides centralized locations with which to define overall system behavior. It also provides a natural partition to organize knowledge that is relevant to two or more systems simultaneously. It simplifies the human-machine interface. However, on the negative side, a hierarchical organization also is a single point of failure and a potential communications bottleneck. A hierarchical pyramid of agents might waste resources in vertical communications and subsequent processing. For a peer committee organization, the advantages include providing flexibility for reconfiguration under changing mission requirements and for evolutionary development during a spacecraft's life cycle. It can function as a hierarchy if necessary. However, a peer committee organization might lack the ability to guarantee reasonable upper bounds in decision-making processing and waste resources in unending goal refinement.

Prior to fiscal year 1990 (FY 1990), two expert systems were developed that could be used to evaluate cooperative, distributed systems issues. During FY 1990, these systems were put into a distributed, cooperative testbed which focused on evaluating a hierarchical organization of cooperating expert systems. Peer committee approaches will be evaluated in future work. In the current prototype running on the testbed, two agents manage the control system itself, making sure that all agents are running as expected, balancing loads on platforms, and starting failed agents. Two other agents monitor and control spacecraft subsystems, namely a Shuttle-like reaction subsystem and a Shuttle-like electrical distribution subsystem. A system manager coordinates the two by applying diverse strategies to manage conflicts between the two controller's goals and coordinating their activities. Finally, a "Murphy" agent is charged with generating malfunctions within the simulators.

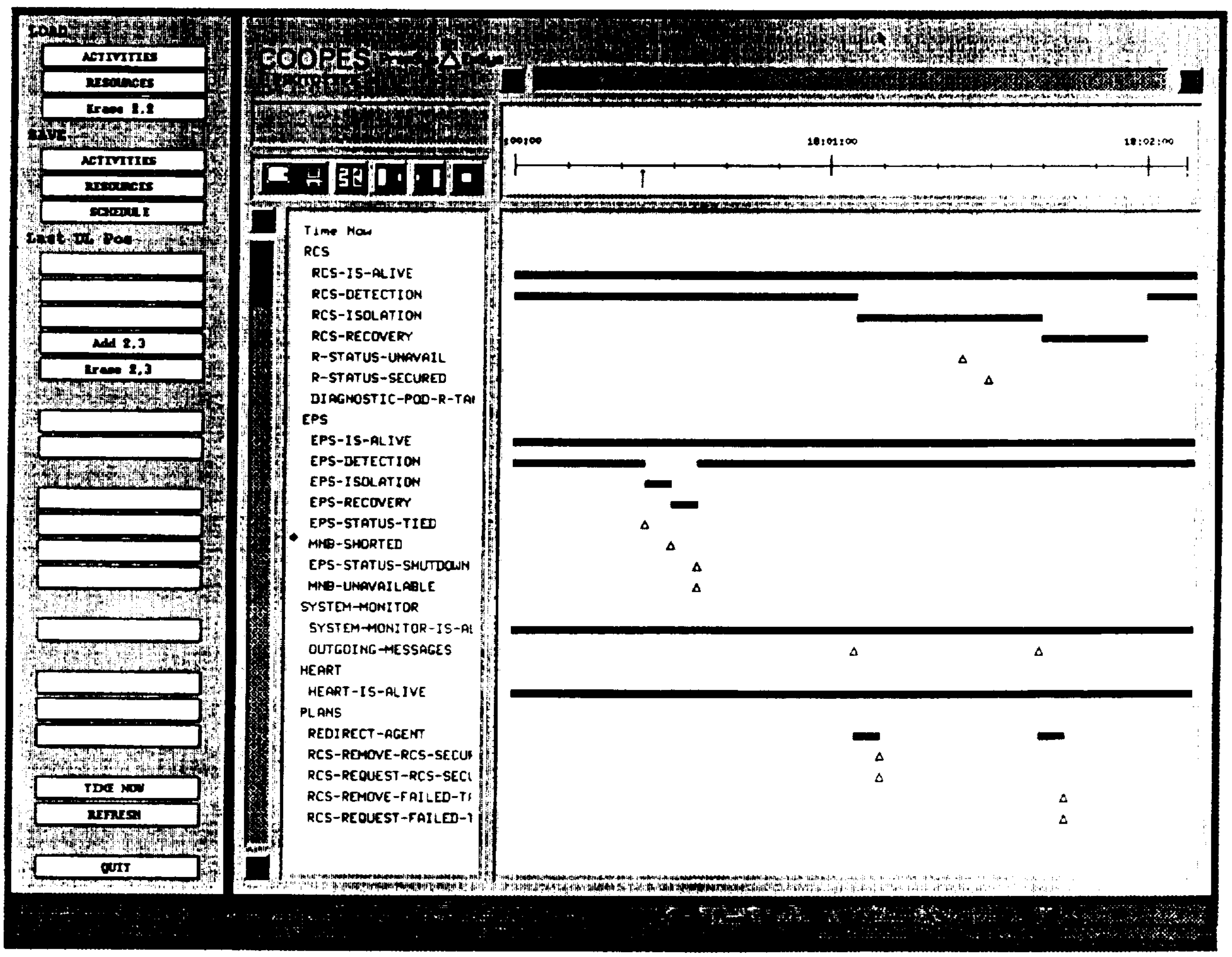
The prototype's human interface combines a physical description of the monitored subsystem's status and an abstract presentation of the cooperative module's reasoning paths. The latter interface is based on a scheduling interface which ideally supports the display of activities and resources on a time line (see figure). A system configurator graphically supports the operation of the whole testbed, including allocation of agents and tasks to machines, redirection of displays to alternate machines, message routing to the agents, and monitoring and control during operations.

All the agents and operating system functions except the System Monitor are implemented using C and CLIPS on UNIX. The System Monitor currently is implemented with an object-oriented programming tool that runs on Sun Lisp. It will be ported to CLIPS 5.0, which supports objects. The testbed should run on a wide variety of UNIX workstations and has been tested on multiple Sun 3, Sun Sparc, Masscomp, and NeXT workstations.

Based on the results of FY 1990 work (experience gained developing the current testbed), many important issues can begin to be addressed. Agent intelligence can be measured practically in terms of external decision rates. Agent domain intelligence versus organizational intelligence can be measured in terms of a coupling coefficient involving average message length, message rate, amount of computation, and agent decision rate. The amount of computation is divided between external decisions and actions and cooperative operations. Only external decisions contribute directly to the efficiency of the overall system. The single factor which most influences cooperation is communications delays and reliability. Delays prevent coordinated actions from occurring in situations where fast response is a requirement. Reliability issues prevent agents from reaching common knowledge of important facts. Such constraints do favor hierarchical architectures, especially in uncontrolled, open computer networks.

Capitalizing on the lessons learned from the prototype, a distributed platform is being designed for the COMPuter Aided Scheduling System (COMPASS) scheduler itself called DIStributed COoperative Resource Scheduling (DISCORS). Distribution will allow coordinated generation of schedules during replanning from different locations. Future development increments will include heuristic approaches to increase the quality of generated schedules by taking into account the potential synergies and conflicts inherent in distributed scheduling. Generic packages also are defining for organizations which need tools to distribute their applications.

Future work for FY 1991 and FY 1992 will focus on developing and evaluating peer committee approaches to cooperation. The eventual result of this work will be documents that provide guidelines for the implementation of distributed or cooperative systems and tools which support the use of distributed processing in a wide variety of NASA application domains.



Cooperating Expert Systems system manager display.

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Knowledge-Based System (KBS) Verification and Validation

PI: Chris Culbert/PT4
Reference STT 11

Knowledge-based systems (KBSs) are in general use in a wide variety of domains. As reliance on these types of systems grows, the need to assess their quality and validity reaches critical importance. As with any software, the reliability of a KBS can be attributed directly to the application of disciplined programming and testing practices throughout the life cycle. However, essential differences exist between conventional software and KBSs, both in construction and use. Identifying how these differences affect the verification and validation (V&V) process and the development of techniques to handle them is the basis of work in this field.

Much of the work in KBS V&V has focused on developing conceptual approaches and postulating different techniques for performing some or all aspects of V&V on various types of KBSs or Expert Systems. Very little work in this field has demonstrated the usefulness of proposed techniques on operational KBS. More importantly, since effective V&V must be applied throughout the life cycle, almost no case study work has been done in applying disciplined software V&V principles throughout the development of an operational KBS. The long-term goal of the project is to develop guidelines, standards, tools, and techniques for V&V of all KBS applications which may be used in the Space Station Freedom Program or other NASA programs. As a precursor to determining the applicability or usefulness of many of the proposed KBS V&V techniques, it is important to develop an understanding of what V&V practices are commonly in use today and how proposed techniques can improve upon those practices.

It has been widely claimed that few expert systems are subjected to the same level of V&V that conventional software routinely undergoes. Little or no documentation exists which describes the problems associated with KBS V&V from the developer or user's point of view. During fiscal year 1990, the Johnson Space Center and their support contractor, IBM, developed a survey to begin documenting the experiences and problems KBS developers have encountered in performing V&V on their systems and relating those problems to the kinds of issues KBS V&V researchers consider important. The results of the survey and selected follow up interviews suggested a number of specific conclusions and directions for further work in this field based upon the kinds of problems that developers really have encountered in developing and verifying expert systems. Recommendations resulting from the survey include: to develop specific requirements for KBS V&V, recommend a specific life cycle for KBS development, develop techniques for addressing problems of readability and modularity of KBS code, develop criteria for classifying expert systems by their intended use and relate those classifications to specific V&V activities, and develop better techniques for applying configuration management to KBS. Many of these problems will require additional work before solutions will be readily available. The analysis of the survey and interviews and the subsequent recommendations will serve as a valuable reference for directing future KBS V&V research into those areas that are of the most value to KBS developers and users. In addition, managers of KBS development projects can learn from these results to structure life-cycle approaches for KBS development which are more likely to lead to high-quality application software.

In future work, these issues and problems will be evaluated in terms of the needs of those NASA programs which can readily use KBS technology, such as the Space Station Freedom and the Space Transportation System. This will help to determine which issues are most likely to impact the eventual use of KBS. Of particular interest will be determining how well existing NASA software quality requirements address these issues and what changes will be required to ensure highly reliable KBS. Finally, specific programs and practices which improve the quality of KBS used in NASA programs will be defined and put in place.

Logistics and Operations Integration Requirements

PI: Les Quiocho/ER3
Reference STT 12

The advent of space-based robotic operations such as assembly, maintenance, and planetary exploration presents a serious need to predict the motion of manipulator systems and to analyze their performance realistically. In a space-based environment where experimental flight data are limited severely, numerical and graphical simulation is becoming an increasingly important tool to depict these real-world systems accurately. Despite this, current simulation designs are limited in that the capabilities generally are applied to a particular robotic system rather than to a variety of robotic systems. Moreover, due to the complexity of the underlying mathematical models, few of these simulations have exhibited the performance necessary to provide quick-turnaround analyses. Furthermore, robotic simulation packages have not been conducive to the addition of newly developed models, often requiring time-consuming integration efforts, thus delaying the algorithm development process. In order to overcome these current simulation design limitations, the primary objectives of this project have been to support research and development of real-time and non-real-time simulation techniques pertaining to space-based robotic technologies. Specific technologies investigated included simulation architecture design, rigid-body dynamics, kinematically redundant arm control, coordinated multiple arm control, task space collision avoidance and path planning, and systems integration (with applications targeting an orbital environment). In addition to providing internal support at the NASA Johnson Space Center (JSC) through newly developed algorithms and computing techniques, this project involved interfacing with external organizations such as area universities and Small Business Innovative Research contractors to promote, share, and integrate their robotics capabilities as well as to initiate hardware/software implementations for proof-of-concept demonstrations.

Significant accomplishments of this project during fiscal year 1990 include

a. A Robotics Software Testbed (RST) simulation architecture designed specifically for rapid prototyping, algorithm verification, and sustaining engineering analyses of robotic systems performance consistent with typical operational constraints. Key features of the system include

   - Generalized discrete time simulation executive or main program with automatic code generation for high-level job scheduling;
   - Generalized input/output processing with automatic code generation for low-level data input and output processing; and
   - Modular, reusable, and data-driven components via well-defined component interface specifications.

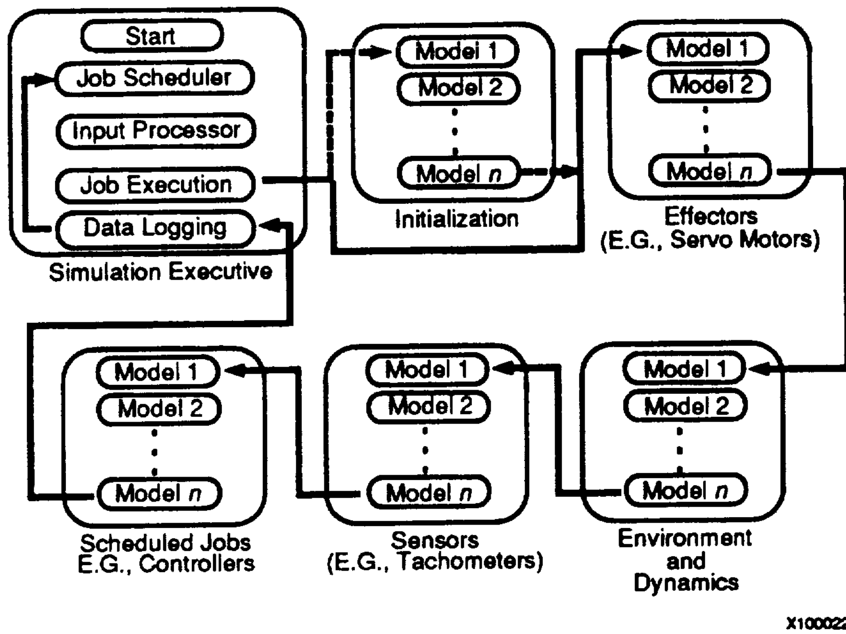
   Substantial benefits were demonstrated by the RST architecture and include the following:

   - Large-scale use of automatic code generation principles eliminates the most tedious and complicated programming tasks of the simulation development process and allow a developer to concentrate on math modeling and algorithm prototyping;
   - A library of system models (e.g., generalized servo mechanism model or multibody dynamics) can be reused for a variety of robotic systems; and
   - Data-driven components require no code changes nor any recompilation to conduct parametric analysis.

b. Development and implementation of an open kinematic chain dynamic model using the RST simulation architecture. Unlike terrestrial applications in which the base of a manipulator remains stationary or fixed, space manipulators must account for free-floating bases and payloads. A method for obtaining the differential equations of motion for this spatial system was performed based on classical mechanics. The resultant dynamics formulation was documented as a JSC technical report.

c. Implementation and analysis of resolved rate and torque control schemes for space-based kinematically redundant manipulators. Results based on a manipulator simulation consisting of free-end rigid-body and motor dynamics, motor and joint stiction/friction, gearbox backlash, and Space Station remote manipulator system type configuration parameters were used to evaluate the performance of resolved rate and torque control. Once again, the RST simulation architecture provided an ideal software environment for developing these control and motor models.

The simulation executive of the RST architecture has found practical application as the prototype executive for the JSC Automation and Robotics Division's new manipulator dynamics simulation tool for non-real-time and real-time analyses. In addition to the executive, the manipulator dynamics model is being utilized within this new software tool. Overall, the project has demonstrated successfully the viability of applying new simulation techniques to complex robotic problems.



Robotics software testbed simulation architecture.

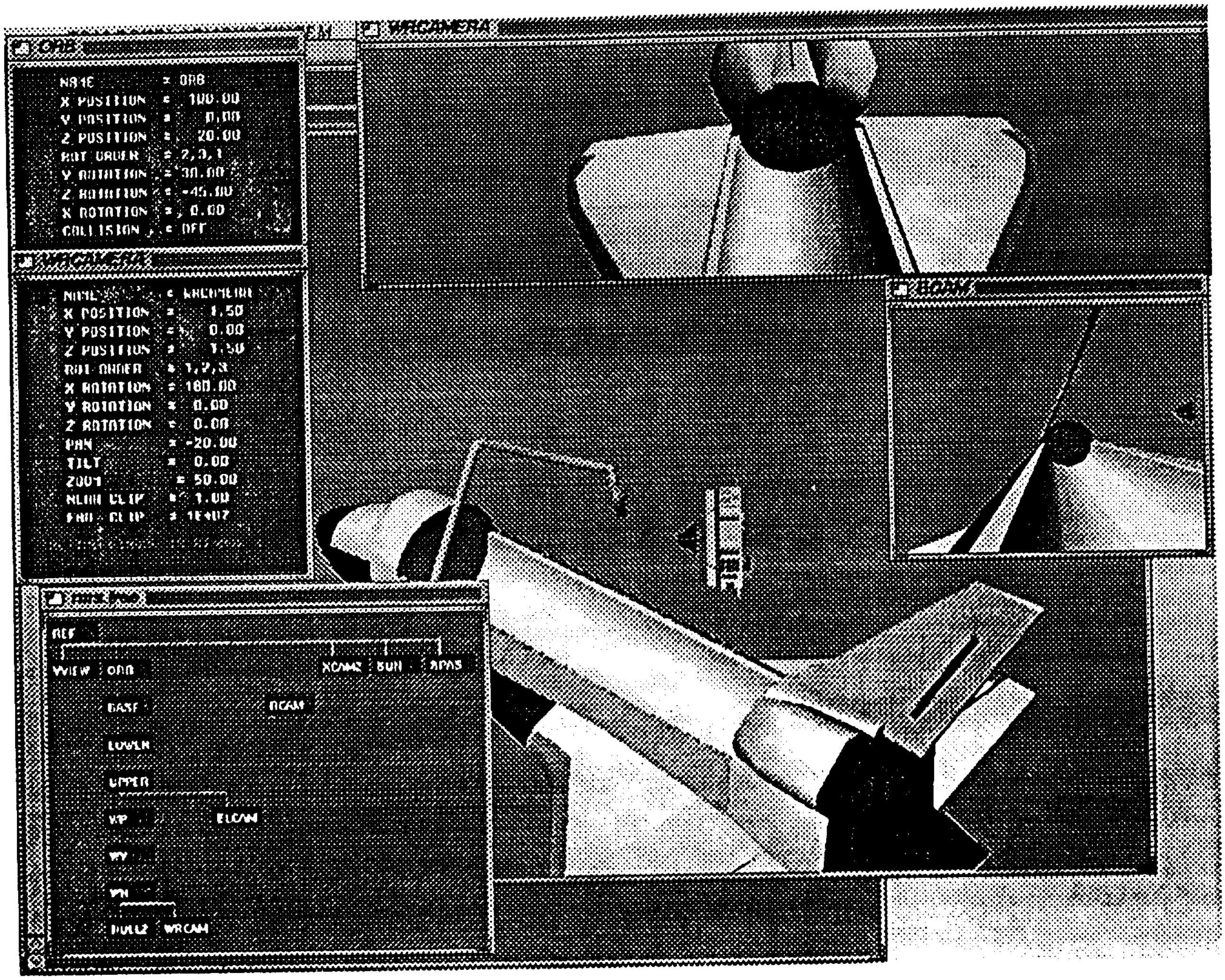
Development of Advanced Graphics Lab Applications

PI: Mike Goza/ER42
Reference STT 13

The primary tool developed under this Research and Technology Objectives and Plans (RTOP) is the Tree Display Manager (TDM) - a network-based graphics server that responds to user-client requests. This multifunction tool is being utilized by ~50 users in the areas of Space Station assembly analysis and robotic, tether, and Shuttle simulations. The TDM provides new technology in the area of application-based networked graphics servers. This technology is becoming more important as more scientific and engineering applications require visualization as an analysis tool. The TDM is the first step to providing users with graphical functions that can be integrated into applications easily. An example is the manipulator tool, MAGIK, which currently is being utilized for Space Station assembly studies. This simulation can execute on a computer that is networked to TDM on another system, thus resulting in improved simulation performance and efficient computer system utilization. The TDM functions include tree operations to allow users to manipulate graphical structures to add, move, delete, or archive. Multiple camera views are displayed with perspective or in the orthographic mode while the autocam function positions a camera to view a selected object automatically and then tracks the object. The TDM utilizes collision detection to determine collisions among objects, which is important for robotic applications. Other TDM features include generation of trails that display the trajectory of an object, plots that display simulation data in plot format, overlays, and multiple windows to display various camera views.

The TDM also has been developed to function as a graphics server for the Johnson Space Center Research and Engineering stereo helmet system. This system offsets the left eye image from the right eye image for true 3-dimensional depth perception. The 3-dimensional tracking mechanism synchronizes real-time image generation to head motion for a 360° field of vision. The resulting sensation can be compared with being "immersed" or "projected" into the simulated scene. The helmet utilizes a Polhemus 3-dimensional tracker coupled with camcorder displays and currently is being integrated into two SGI VGX210 systems that will provide ~1 000 000 polygons/channel performance capability. The SGI systems also will enable more realistic scene generation capability due to enhancements such as real-time texture mapping and anti-aliasing. In addition, this high-performance helmet system will incorporate TDM results in new technology that can be applied to engineering simulation, remote telepresence, and crew training. This technology also will have applications outside of NASA including medical imaging, environmental engineering, and robotics.

This RTOP continues to provide high-level, cost-effective graphical tool development that is being applied across many engineering and scientific disciplines. As the user community continues to expand, these tools also will continue to be enhanced to provide this essential engineering graphics technology. In addition, several universities also are utilizing TDM. The benefits to NASA are a significant reduction in user training, an increase in engineering productivity, and associated cost reductions.



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RMS simulation utilizing TDM graphics server.

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Autonomous Guidance

PI: Gene McSwain/EG2
Reference STT 14

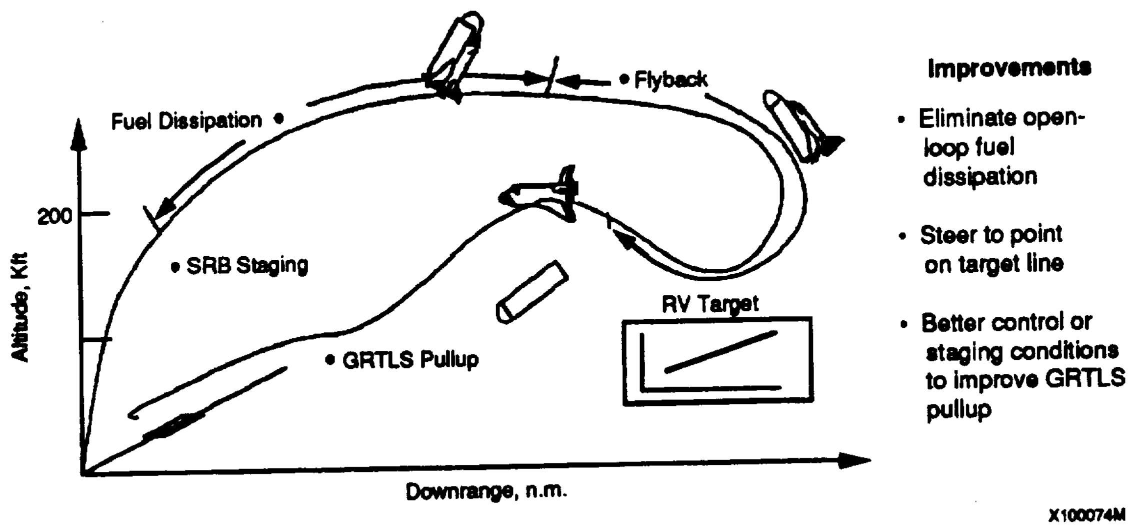
The focus of this Research and Technology Objectives and Plans (RTOP) in 1990 was to investigate technologies needed for an autonomous onboard guidance system for use on future launch vehicles. Ideally, this system would be capable of responding in real time to changing flight conditions through the use of advanced guidance algorithms, flight computers, and sensing devices (i.e., wind and angle-of-attack sensors). Implementation of such a system would greatly increase launch probability and safety while significantly reducing operations costs.

As part of a study to investigate potential onboard algorithms, the Sequential Gradient/Restoration Algorithm (SeGRAm) was enhanced significantly. The SeGRAm is a calculus of variations optimization program which provides insight into the optimal control profiles for a wide array of trajectories, vehicles, and performance indices. Since it performs functional optimization, SeGRAm can assist in identifying potential guidance schemes. This program was tested through a series of ascent trajectory studies on a reference Space Transportation System (STS) evolution vehicle. The SeGRAm determined the optimal control profiles for the nominal ascent of an advanced vehicle powered by liquid boosters. This included staging, (3g) acceleration limiting, and a simple drag model as well as inequality limits on dynamic pressure. Although this algorithm shows promise for future launch vehicles, its direct near-term application to the Shuttle is limited due to the substantial computational requirements. The use of this algorithm in advanced computers using parallel processors was demonstrated, but not to the fidelity required by the Shuttle due to the over-constrained nature of the first-stage trajectory and the difficulty in modeling these constraints.

The use of advanced sensing devices also was investigated. In particular, a laser-radar (LIDAR) wind profiling system was researched as part of the Bridging RTOP. The LIDAR is a laser anemometer system which uses laser pulses to measure wind velocity profiles accurately over a long range in a short time. Studies conducted during this fiscal year have concentrated on using a ground-based system and defining the requirements of such a system. Two separate devices were tracked concurrently: a 10.6 mm wavelength CO_2 system out of the Marshall Space Flight Center and a 1.06mm wavelength solid-state Nd:YAG system supported by the Langley Research Center. It was decided that the relative merits of the two systems would be evaluated through demonstrations at the launch and/or landing sites. Preliminary findings indicate that the main benefits of these systems to the current STS program lie in the reduction of operations costs and logistical complexity. Further efforts will concentrate on achieving these goals.

Another study was conducted to determine what effects relaxing or eliminating first-stage trajectory constraints would have on the current Shuttle ascent. As mentioned earlier, the first-stage ascent trajectory for the Shuttle is highly constrained. In particular, the vehicle is required to fly within envelopes of dynamic pressure (q), angle of attack (a), and the products of dynamic pressure with angle of attack (qa) and angle of sideslip (qb). The implementation of an advanced guidance algorithm coupled with sensors, such as those discussed above, may result in the relaxation of these constraints. A LIDAR system would allow relaxation of the dynamic pressure constraints due to a reduction in the measurement uncertainty of the wind used in the ascent trajectory design. This results in increased performance at main engine cutoff. However, the increase is only slightly beyond that attainable by the implementation of the Day of Launch I-Load Update Phase II (DOLILU II) which uses a prelaunch measured wind in the design process. The upper limit on possible performance gain was determined by designing a trajectory with the constraints on q, a, qa, and qb eliminated. Actual elimination of these constraints would require several hardware changes in addition to an advanced guidance algorithm and sensing devices. The results showed that increases on the order of 3000 lbs were possible. However, this gain is small when compared to the cost and feasibility of incorporating the necessary changes. There is, therefore, little to be gained in terms of performance by implementing first-stage guidance improvements beyond DOLILU II. Based on these conclusions, the focus of the RTOP has changed for fiscal year 1991.

The focus will now be directed toward providing guidance improvements with applications in the near term. Specifically, improvements will be made to the abort guidance algorithms with a strong emphasis on the return to launch site (RTLS) abort. Algorithms will be developed to make the RTLS trajectory more benign and adaptable, thus increasing flight safety. Preliminary work is under way in the evaluation of possible guidance schemes such as open or closed loop out-of-plane fuel dissipation and bilinear tangent steering. In addition, SeGRAm is being used to determine the optimal trajectory given the desired final conditions and trajectory constraints. Currently, the Shuttle employs a mass optimal trajectory whereas in most cases RTLS is not performance critical. Furthermore, flight design for RTLS is time intensive, requiring a great deal of analysis and verification. The new algorithms to be developed offer the potential of reducing operations costs by eliminating a large portion of the flight design effort required in addition to improving flight safety.



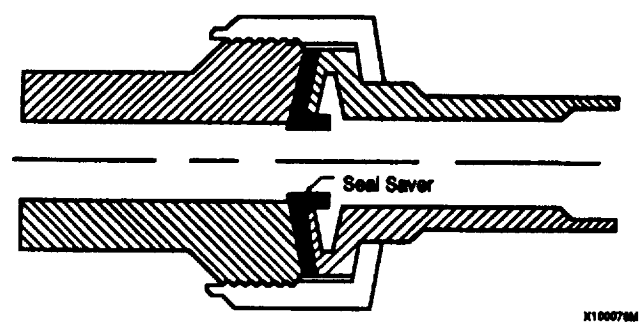
Return to launch site abort.

Dynatube Insert Development and Test Program

PI: Karla Fulton/EP4
Reference STT 15

Currently, several hundred Dynatube mechanical fittings are used in numerous fluid systems on each Space Transportation System (STS) Orbiter. These fittings reduce the maintenance time and risks for fluid systems requiring periodic component servicing and replacement. The Dynatube fitting utilizes a metal-to-metal seal that has been extremely reliable but can be scratched by either abuse or through numerous disassembly and reassembly cycles. Damaged fittings presently are repaired either by polishing the fitting surfaces or cutting the fitting out of the system and installing a new fitting. Both of these repair methods are time consuming, involve significant system preparation (especially for systems containing toxic or corrosive fluids), and risk possibly contaminating the fluid system with particulates. For repairing fluid systems, especially when the schedule is critical, a more flexible repair method is desirable.

Soft inserts between the Dynatube fitting sealing surfaces previously have been used to correct leakage due to scratches but are not certified for use on the STS and in some cases are not compatible with STS fluids. This in-house NASA Johnson Space Center (JSC) program evaluated the use of Teflon-coated and gold-plated 304L stainless steel as possible repairs for STS Earth-storable propellant use. These inserts were designed with a self-centering lip to permit ease of installation and avoid protrusion into the flow path. The figure indicates the Dynatube fitting and sealing insert configuration. Development testing of the sealing insert was performed at the JSC Thermochemical Test Area in 1990. An initial leak rate greater than 10^{-3} sccs of He was established for all six assembled Dynatube fitting test articles without sealing inserts. The testing phases consisted of initial assembly with the inserts, thermal cycling, vibration, and post-test cold flow checks. After each phase of testing was completed, the test articles were leak checked. A leak rate less than 10^{-4} sccs of He was considered acceptable. Cold flow leak checks were performed 18 weeks after Dynatube insert installations. The gold-plated sealing inserts were unsuccessful in repairing any of the leaking test articles. The Teflon-coated inserts, however, were successful in repairing all six test articles in which they were installed. Final leak rates of the Teflon-coated inserts were less than 10^{-7} sccs of He. The Teflon-coated inserts are being pursued as a practical means of repairing STS Dynatube fittings, and plans for qualification testing and flight certification of the inserts are in work.



Seal saver installation in Dynatube fitting.

Electromechanical Orbiter Fuel Cell Program

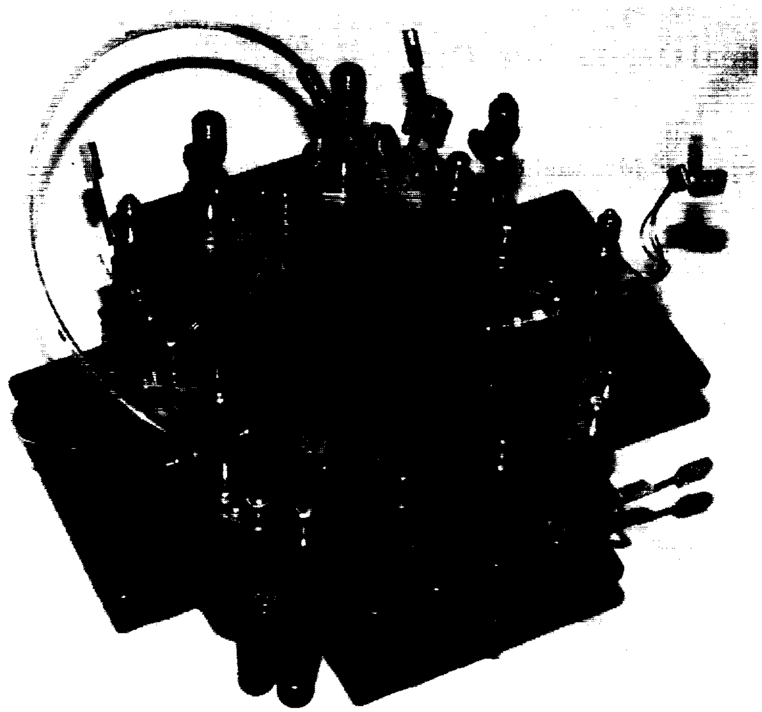
PI: Nanette M. Faget and Michael Le/EP5
Reference STT 16

It has been proposed to replace the existing hydraulic actuator system on the Space Shuttle with an electromechanical actuator (EMA) system to improve safety and reduce costs. The Space Transportation System's recent flight manifest indicates 12 Shuttle flights in 1993 with a future flight rate goal of 14 flights a year by the mid-1990's to support the assembly of Space Station Freedom. An Orbiter fuel cell power plant (FCP) with a longer life than its current 2000 hours would contribute to reducing turnaround time for launch processing operations. Moreover, an FCP with higher power density would allow the replacement of the auxiliary power unit (APU) and hydraulic actuators with electrical motor-driven EMAs for the Space Shuttle. An EMA system has the potential of being safer and more reliable than an APU/hydraulic system.

The NASA Johnson Space Center (JSC) has initiated a program with international fuel cells to upgrade the current Orbiter FCP using improvements developed for the Strategic Defense Initiative (SDI) program. The SDI program has mission requirements similar to those of NASA but requires a higher power FCP with low launch weight. The NASA JSC sought to take advantage of SDI technology in developing an FCP to meet the higher power and longer life requirements of the Orbiter EMA program. The advanced cell has improved durability so that the overhaul frequency will be reduced, thus providing logistics cost savings. The higher power density of the advanced cell will provide more power to the Orbiter payload as well as provide the power required by the EMAs.

The objective of the program was to demonstrate the endurance capability of an advanced technology alkaline fuel cell at Orbiter conditions of 180 °F and 60 psia with periodic higher power operation to 1500 W/ft^2 at a cell temperature of 250° F. The secondary objectives of the program were to develop an FCP with a cell-specific weight of less than 1.5 lbs/kW and with a life of 10 000 hours. To achieve the lower weight and the 10 000-hour life, the present cell frame and matrix, which are both susceptible to corrosion, were replaced with a polyetheretherketone frame and a potassium titanate/asbestos matrix. It is estimated that the higher power density FCP will provide significant weight savings such that four 60 kW FCPs of the advanced configuration will weigh the same as the current Orbiter's three 12 kW FCPs.

A full-scale single cell was built and tested for 2000 hours with virtually no degradation in performance. Intermittent operation at high current densities to meet the EMA power requirements had no effect on the cell's performance when it was returned to normal Orbiter operating loads. Two subscale single cells were tested to demonstrate the materials compatibility of the potassium titanate/asbestos matrix to verify that corrosion would not limit the life of the cell. A mockup composite frame with an Ni insert, which represents a lighter weight separator plate, also was built and delivered to NASA JSC. Based on the successful results of the full-scale single cell test, plans are being made to build and test a 4-cell stack. This will lead to a multiyear effort to design and build a long-life, high power density FCP for several advanced Orbiter applications.



Test setup of full-scale advanced single cell.

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Uprated Orbital Maneuvering System (OMS) Engine

PI: Richard J. Schoenberg/EP4
Reference STT 17

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 Space Transportation System, including increased Shuttle Orbiter payload and altitude capability and a high-performance, man-rated engine for upper stage applications.

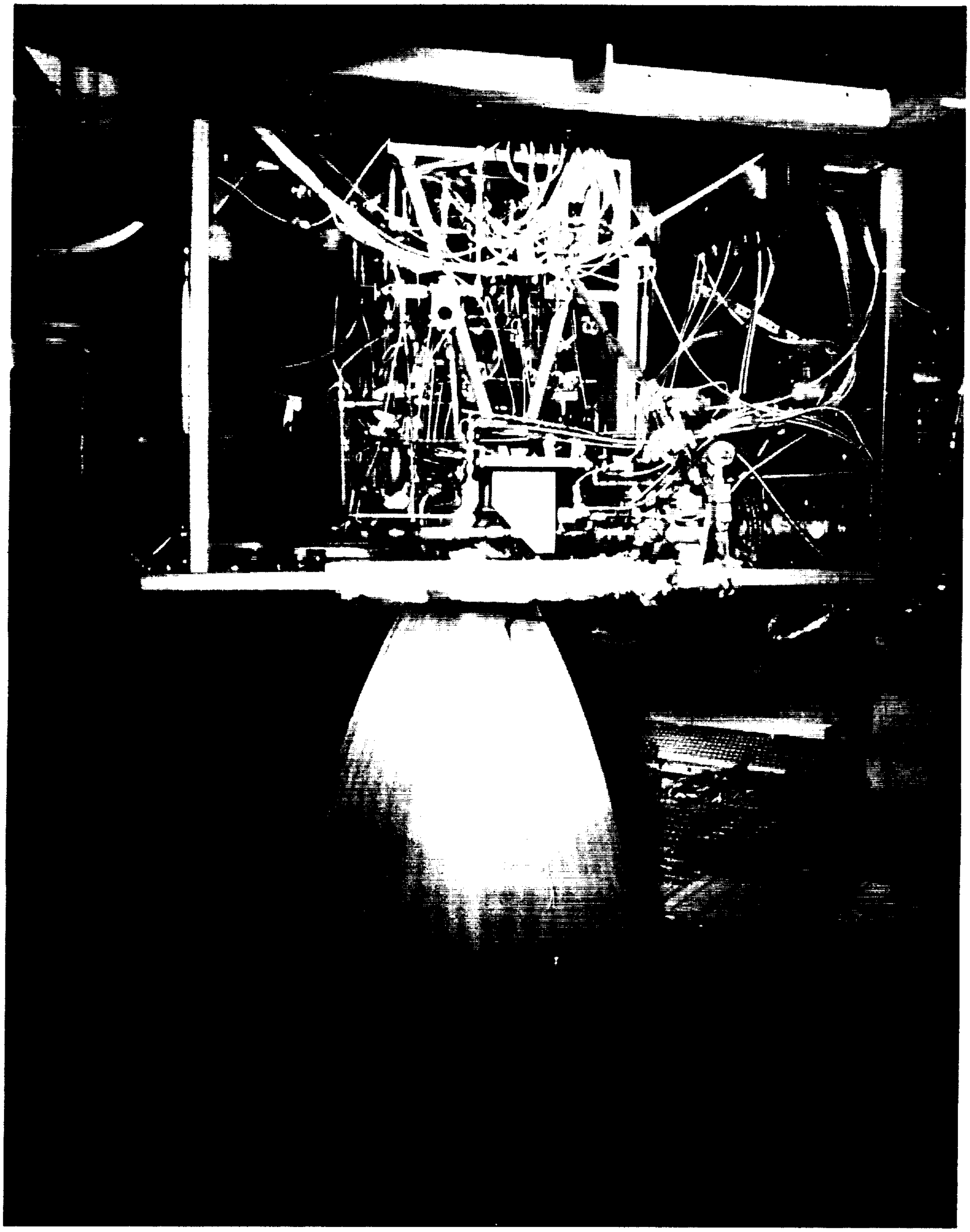
The uprated OME (UOME) has the potential to significantly increase Shuttle mission manifesting and operational flexibility. The improved OMS performance increases the Shuttle payload lift capability by up to 1300 lbs. This type of increase significantly helps to regain much of the Shuttle lift capability lost due to recent hardware and operational modifications. It also provides a 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 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 n. mi. can be achieved. If the UOME could have been made available for Hubble Space Telescope 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 6 000 lbs is near optimum for satellite delivery to geosynchronous Earth orbit, 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 objectives of the UOME advanced development program are 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 at Aerojet.

During FY 1990, the additional components required to allow engine testing at simulated altitude conditions were fabricated and assembled. These components included a turbine exhaust line, nozzle coolant manifold, and a nozzle adapter. An altitude test program was completed successfully at the NASA White Sands Test Facility. Testing was performed at the Shuttle optimum mixture ratio of 1.65 and also at a 1.95 mixture ratio which is optimum for an upper-stage application. The accompanying photograph shows an altitude test firing of the UOME. The test program was extremely successful. The engine performance at both mixture ratios was as expected, and there was good correlation to analytically predicted performance as well as the previous sea-level test program results. The review of altitude test data was begun in FY 1990. Plans for FY 1991 include completion of altitude test data review and an engine design update to incorporate lessons learned and potential areas of improvement.



Altitude test firing of the UOME.

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Shuttle Evolution Phase II Crew Escape Study

TM: Kevin C. Templin/ET2
Steve Nagel/CB
Reference STT 18

In 1987, a study was conducted to examine more capable crew escape concepts for possible Orbiter implementation. This study utilized personnel from the NASA Johnson Space Center as well as national experts on escape systems from the Naval Air Development Center, the NASA Langley Research Center, and various industry consultants. The results of this study were as follows:

- Pod or capsule escape from the Orbiter is impractical due to weight and center of gravity (c.g) limitations (assuming that the external geometry is not changed).
- Ejection seats and seated extraction appear to be feasible for retrofit and provide escape opportunities for a broad range of failure conditions.

The viability of any escape system proposed for use in a Shuttle Orbiter depends to a large extent upon the magnitude, complexity, and cost of the required modifications to the Orbiter. In an effort to quantify some of the necessary modifications for incorporation of a more capable escape system into an Orbiter, one ejection seat and one extraction seat concept were selected as candidate escape systems for further study. The Systems Engineering Division and the Orbiter & GFE Projects Office, along with Rockwell International - Space Systems Division performed this feasibility assessment. The scope of the 1990 assessment was limited to defining cost, schedule, Orbiter structural, pyrotechnic, and avionics impacts.

The candidate ejection seat concept will provide escape capability for up to eight crewmembers. All eight crewmembers will exit the vehicle through an opening in the top of the Orbiter. An industry survey identified three ejection seats which have similar size and capability. The McDonnell Douglas Advanced Concept Ejection Seat (ACES) II was used in this study as representative of current state-of-the-art ejection seat technology.

Many ejection seats are qualified to typically provide escape capability during flight phases where velocities do not exceed 600 knots equivalent air speed (KEAS). A nominal Shuttle ascent trajectory does not exceed this limit. The Shuttle ascent escape envelope is limited by the requirement that crewmembers must not pass through engine exhaust plumes. The escape envelope with the use of ejection seats extends from the pad to 50 000 feet and beyond on ascent. The ascent escape envelope will be interrupted between 9 000 and 29 000 feet if the center Space Shuttle Main Engine (SSME#1) is not shut down during the escape sequence. Evaluation of a worst case scenario using a 95 percentile crewmember revealed that, due to dynamic pressure (Q) in this ascent altitude range, the trajectory of the seated crewmember will pass through the plume of SSME#1. Envelope limitations were determined by analysis of engine plume geometry data and ejection seat trajectory profiles across the flight conditions of nominal ascent. The descent escape envelope starts at 50 000 feet and continues through rollout. The 50 000 foot limit for both ascent and descent indicates the current tested capability of an open ejection seat. Additional performance is available from the ejection seat; however, additional flight testing is required to ascertain the maximum altitude at which the ejection seat can be used.

It will be necessary to rearrange the Orbiter crew module/forward fuselage to integrate the proposed ejection seat concept. The airlock, currently located inside the crew module must be relocated to the payload bay, cantilevered off of the Xo 576 bulkhead. The aft flight deck floor must be removed to allow three sets of rails to be installed. The rails will be connected on the middeck floor and will travel upward to the crew module ceiling on the flight deck. Avionics impacts include the rerouting of cables which currently pass through the portions of the crew module ceiling and forward fuselage that are to be pyrotechnically removed as part of the escape sequence. Environmental control impacts may result if the vacuum duct configuration is changed. The cabin recirculation system will require redesign if this happens. Additional structure will be required in both the crew cabin and the forward fuselage to beef up areas surrounding openings and to carry loads introduced by the ejection seat system. Crew module fittings used to attach the crew module to the forward fuselage may require redesign if the 30 000 pound design load specification is exceeded by installation of the ejection seats. The ejection seats are heavier than the current seats flown during Shuttle missions and will add weight in the crew cabin. The eight person ejection seat concept will add approximately 2 700 pounds to the Orbiter and produce an Orbiter c.g. shift of 5 inches toward the front of the vehicle.

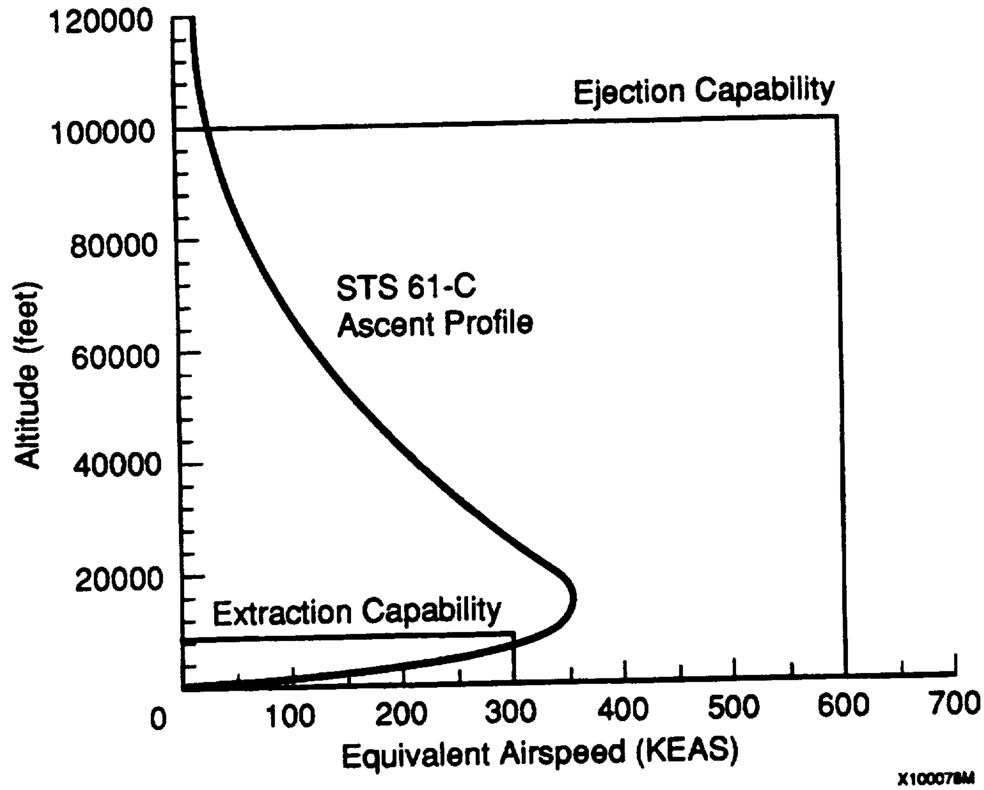
The candidate extraction seat concept will provide escape capability for seven crewmembers. The extraction seat method of crew escape is not limited to seven crewmembers; however, eight person extraction methods will require Orbiter modifications similar to those of the eight person ejection seat concept. Five crewmembers on the flight deck will be extracted out of the top of the vehicle while two crewmembers on the middeck will extract from the side hatch opening. An example extraction seat for this study is a product of Upco. Seated extraction differs from ejection seat escape in that the crewmember is extracted via a body harness which is connected to an extraction rocket by a lanyard. Rather than being pushed out of the vehicle, as is the case with an ejection seat rocket, the extraction rocket pulls the crewmember out of the vehicle. The extraction rocket is expelled from the vehicle by compressed gas, the lanyard is pulled taut, the extraction rocket is ignited and the crewmember is pulled from his/her seat. The extraction concept also is considerably lighter than the ejection seat concept.

Extraction seats offer a smaller escape envelope than do ejection seats. Extraction seats are limited to use where velocities do not exceed 300 KEAS. This restriction is necessary to ensure that the extraction rocket is not forced back by the air flow around the Orbiter to a point where the rocket will make contact with the Orbiter and prevent the extraction of the crewmember. Typical Shuttle ascent trajectories exceed 300 KEAS. Also, the ascent escape envelope using extraction seats is limited by the requirement that crewmembers not pass through engine exhaust plumes. The ascent escape envelope for the extraction seat method opens just after liftoff and ends at 3 500 feet with SSME#1 operating. Crewmembers will pass through the SSME#1 plume if it is operating. The ascent envelope extends to 10 000 feet with SSME#1 shut down. The descent escape envelope opens at 25 000 feet and continues to 300 feet of altitude. Pad and rollout escape may be available to the crewmembers on the flight deck only. Higher descent escape may be available but, as with the ejection seats, additional testing is required to confirm any additional capability.

The Orbiter impacts for the candidate extraction concept are less severe than for the selected ejection concept. The airlock must still be relocated to the payload bay. Overhead openings must be pyrotechnically cut in the top of the vehicle but the openings will be smaller than with the ejection seat concept. Horizontally mounted rails must be installed in the middeck which will lead to some redesign of the waste collection system. The seven person extraction seat concept will add approximately 1 500 pounds to the Orbiter. The resulting c.g. shift will be 2 inches forward.

This impacts assessment concluded that both escape systems appear feasible for integration into an Orbiter but would require significant redesign of the crew module and forward fuselage. Industry experts agree that the two candidate seats are acceptable system elements in the concepts identified and that the Orbiter can accommodate the modifications necessary to implement either concept. The estimated costs and schedule for incorporating either escape concept are expected by study completion in early 1991. While weight impacts are estimated to be less than 3 000 pounds, the c.g. impacts of the two concepts could limit Orbiter payload capability.

Ejection and extraction seats offer the prospect of providing a significant expansion to the Orbiter crew escape envelope. However, before either seat concept can be recommended for implementation, further studies are required to fully understand the operational impacts (e.g., weight-to-orbit, payload bay volume), risks (e.g., handling ejection/extraction seats on orbit), and costs associated with such an implementation. These must be weighed against the escape envelope expansion that will be provided to completely understand the practicality of undertaking the modifications which will be necessary for the Orbiter.



Typical STS ascent profile and regions of escape system applicability.

Shuttle Evolution Crew Escape Module (CEM) Study

TM: Kevin C. Templin/ET2
Reference STT 19

Manned spacecraft travel through a changing and hostile environment in which subsystem failures can lead to the loss of a vehicle and the crew inside. The systems required to provide crew escape during all phases of a spacecraft's flight envelope are complex and expensive. A study was performed to define the top level requirements for a crew escape module (CEM). The system impacts, necessary to make the Orbiter/CEM vehicle a viable system, were defined.

In FY 1990, the NASA Johnson Space Center completed engineering analyses of escape module concepts that provide escape for the entire Space Transportation System Orbiter flight envelope. The CEM was designed to accommodate 10 crewmembers (2 pilots and 8 Space Station crewmembers). The study included design reference data which show the effects of integrating a CEM into a Block II Orbiter. For this study, a Block II Orbiter was defined as an Orbiter modified to include a CEM. An effort was made to keep changes to the Orbiter to a minimum in order to take advantage of the current Orbiter design.

Three CEM concepts were initially considered: a modified version of the current crew cabin, a double deck blunt body module, and an extended flight deck module. The extended flight deck CEM was selected for further development during the study based on its potential to meet the requirement to provide escape capability throughout the Orbiter's flight envelope. In order to place ten crewmembers on the same deck, the flight deck had to be extended 5 feet into the payload bay. Subsystem requirements for the CEM were determined and wherever possible, Orbiter subsystems were relocated for use within the CEM. Transferred subsystems were redesigned for dual purpose use as both Orbiter subsystems nominally and as CEM subsystems when required. Systems within this category include three of the five general purpose computers (GPC), the cabin air filtration system, and parts of the Orbiter's communications and tracking equipment. Two solid rocket motors were sized to propel the CEM. The motors required thrust vectoring for attitude control. The separation motors will be used to de-orbit the CEM for on-orbit aborts. The separation motors were sized to meet but not exceed, the physiological limits of 9 g's +Gx and/or 5 g's +Gz. These limits would allow the crew to remain conscious through the sequence of events starting with escape initiation. The separation motors were sized to develop a combined thrust of 161 405 pounds. A reaction control system (RCS) was included to provide onorbit and deorbit control and stability augmentation. Power for the CEM was provided by lithium-bromine complex (Li-BCX) DD-cell batteries.

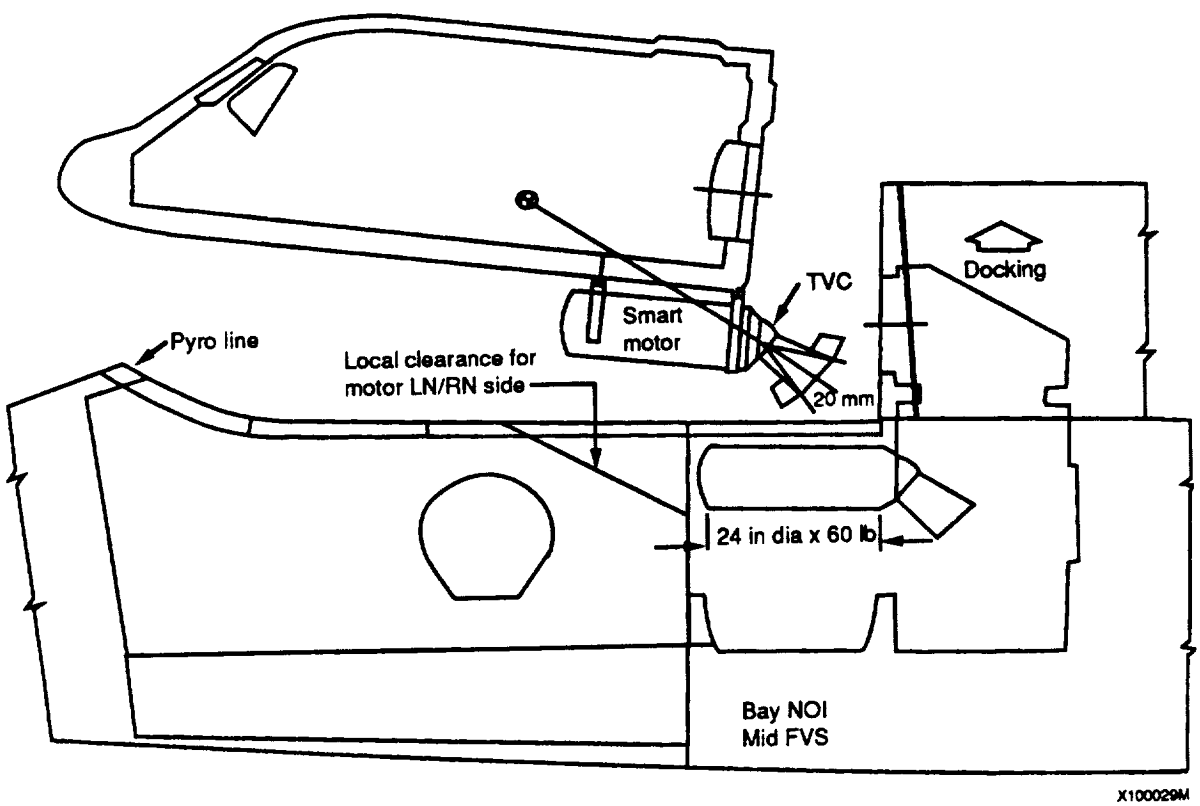
In order to ensure proper attitude control and provide for the possibility of incapacitated crewmembers, a closed-loop flight control system was envisioned for the CEM. Navigation would be accomplished with the use of horizon scanners, a global positioning system, two inertial navigation systems (INSs), and onboard computers. An INS/GPC/RCS system is used for active attitude control. Landing and recovery could either be accomplished with a parachute and retro rocket system or a drogue parachute and extraction seat system. The total weight of the CEM would be in the 25 000 pound range. This represents an addition of 15 000 pounds to the current Orbiter.

New designs would be required for the two new modules - the CEM and the middeck volume. In order to integrate the CEM into the Orbiter, additional structure would be required to accommodate the two pressure vessels. There would be minimal impact on the forward fuselage frames. Structure between the nose and main landing gear would require detailed redesign of skin and stringers. Nose landing gear and back-up structure also must be redesigned. The radial load would increase 10 percent, based on a maximum landing weight of 256 000 pounds.

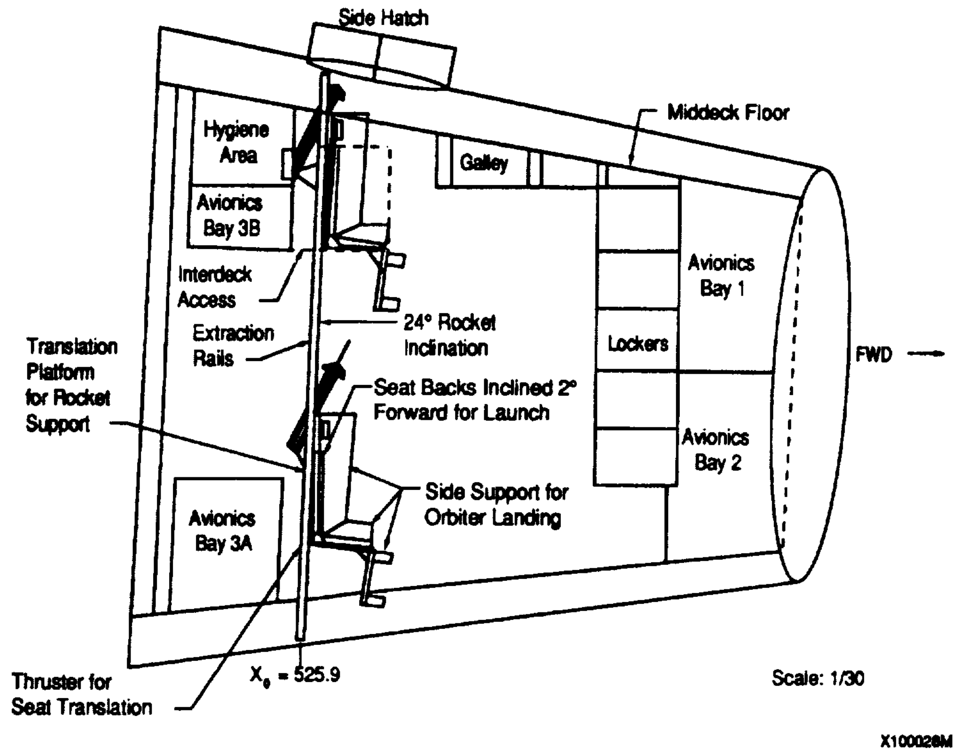
The addition of 15 000 lbs at station Xo = 576 inches would shift the Orbiter forward X center of gravity (c.g.) to the Xo = 1043.5 inches, representing a c.g. shift of 33.2 inches. The result of this forward c.g. movement would be the loss of pitch control authority for velocities above Mach 3. Possible solutions to counteract the forward c.g. problem were analyzed. Three modifications were deemed feasible: increasing the elevon size, repositioning the wings forward, or adding canards. Increased elevon would be achieved by adding an elevon chord rearward. Elevon center of pressure moves aft with increasing chord size. This would increase elevon moment arm. For the 33.2-inch c.g. shift, the elevon area would have to be increased by 74 percent. Elevon hinge moments and wing loads would increase significantly. The resulting increase in the theoretical wing area would be 425 square feet. Orbiter wing loading at landing would be 82 percent of baseline. The second option to maintain static pitch margin with the forward c.g. shift called for the wings to be moved forward. In order to provide the Orbiter/CEM vehicle with the same pitch control margin that existing Orbiters have, the wings would need to be moved 90.7 inches forward. This would require a complete redesign of the Orbiter mid-fuselage. The final option proposed the addition of canards to the Orbiter. With large inherent moment arm, canards are efficient at accommodating forward c.g. For the 33.2 inch c.g. shift, the required canard area would be 168 square feet. The total theoretical lift area for the wing plus canard combination would be 3 162 square feet. The resulting wing loading with a canard would be reduced 8 percent from the baseline. The Orbiter forward fuselage would require redesign to accommodate additional loads.

After considering the Orbiter impacts of each of the proposed pitch control solutions, elevon resizing emerged as the most promising option. Elevon resizing presents the most modest changes of the three options. The elevons must be redesigned, the number of actuators must be increased by one per elevon, and the rear spar and hinges adjacent to hinge supports also will require redesign. The additional elevon area would allow for reduced landing wing loading which can be used to reduce landing speed and lower the landing angle of attack.

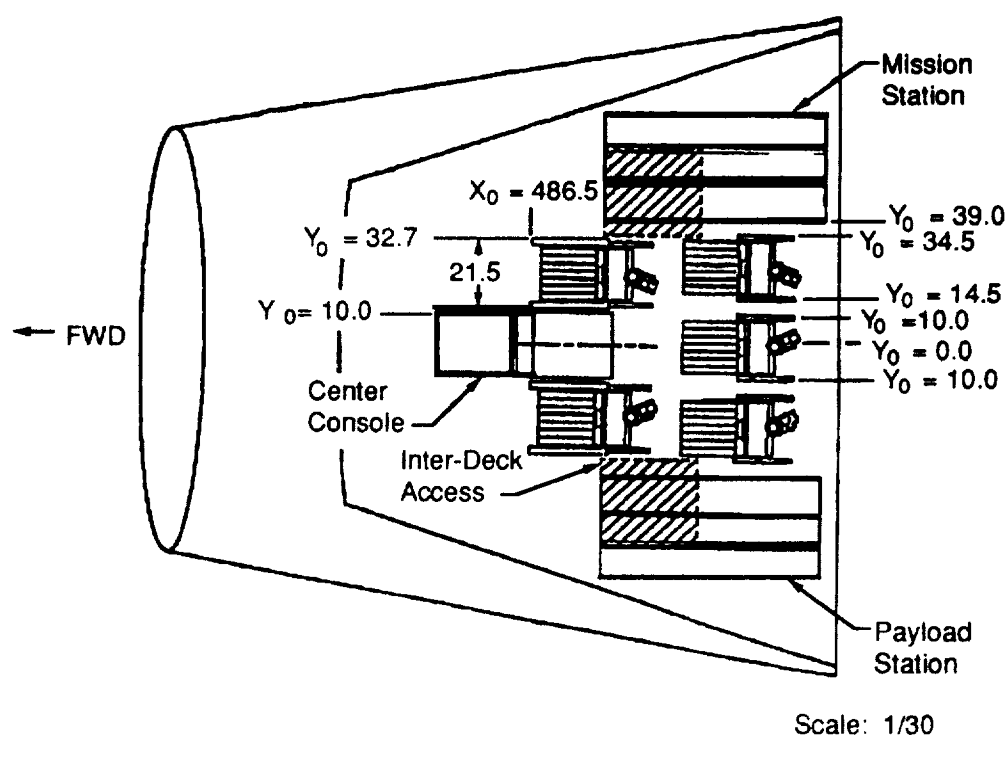
Rough order of magnitude cost estimates put the price for each CEM at $3 billion. The cost to redesign and certify the Orbiter would be $5 billion. The study indicated that a CEM and Orbiter integration are feasible. However, major redesign of the forward fuselage as well as associated costs, not only of Orbiter redesign but also of CEM design, development, and testing would make such an integration impractical. Retest and recertification of the Orbiter/CEM vehicle would also be required.



The CEM concept.



The CEM concept.



The CEM concept.

Assured Crew Return Vehicle (ACRV)

PI: Jerry Craig/IA13
Reference STT 20

In fiscal year 1990 (FY 1990), the Assured Crew Return Vehicle (ACRV) Project was in Phase A, focusing on the validation of ACRV mission and system requirements to meet them.

NASA validated the missions of the ACRV system, which are to evacuate

- A seriously injured/ill crewmember from Space Station Freedom (SSF) to a ground-based care facility,
- SSF in the event it becomes uninhabitable, and
- SSF in the event Space Shuttle flights are interrupted.

System performance requirements previously derived by NASA from these three missions were then validated. Requirements validation focused on the areas of medical constraints to protect an injured/ill crewmember, emergency activation conditions, and SSF interfaces. The issues were considered by an interdisciplinary NASA team including the crew, safety, medical, operations, design, and other technical specialties.

In the medical area, preliminary analysis indicated that an ACRV designed for water landing can meet the Apollo Block-II impact g crew limits of 15, 10, and 8.5 g's in the crew body x, y, and z axes, respectively. Other medical requirements included crew orientation constraints after landing and total mission time from the SSF to a ground-based medical facility.

Contingency operations studies identified the reasonable minimum pressures at which the ACRV might be activated during an SSF decompression scenario as well as the time constraints on returning to normal pressure. The capability to isolate the crew inside the ACRV in 3 minutes was assessed.

Building on in-house work concepts performed at the Johnson Space Center (JSC), Kennedy Space Center (KSC), and Langley Research Center, two ACRV prime contractors participated in a Requirements Validation and Concept Definition Study (Phase A'). Beyond supporting NASA in validating and refining the ACRV system requirements, this study identified and compared design and operational concepts for the end-to-end ACRV system and developed preliminary life cycle cost (LCC) estimates.

Following the competitive submission and evaluation of bidder proposals in the autumn of 1989, Lockheed Missiles & Space Company, Sunnyvale, Calif., and Rockwell International, Downey, Calif., were selected as the two prime contractors. Their contracts began on 2 April 1990. Also in FY 1990, Eagle Technical Services was selected as the ACRV Technical and Management Support contractor. The prime contractors began developing independent design solutions to NASA's functional requirements. Generally, the contractors found that a number of simple design solutions can satisfy the requirements.

To facilitate evaluation of contractor-proposed design concepts, NASA studied a low lift-to-drag capsule capable of returning 8 persons and providing up to 24 hours of on-orbit loiter. The dry mass of the capsule was 9000 lbs and that of the required external service module was 3600 lbs. The gross masses (including the crew) were 11 600 and 4400 lbs, respectively. A preliminary in-house landing accuracy analysis also was completed. The project endorsed the concept of basing two 8-person vehicles at SSF with a spare on the ground.

The design philosophy of ACRV is to apply existing technology and avoid new technology development. The recovery system most likely can use an Apollo-type parachute technology. Likewise, it was shown that the Space Shuttle's surface insulation tile technology will suffice as a thermal protection system for ACRV reentry.

The most significant design challenge identified was for a vertical land-landing system which must meet the medical impact-g constraints for an ill or injured crewmember. Approaches under consideration included parachute/retro-rocket systems combined with impact-attenuation struts. Air-bag-type systems were examined but appear to present problems for landing in high-wind situations.

During FY 1990, NASA made significant progress towards defining an integrated ACRV operations concept based on embedded operations. Given the infrequent and unexpected nature of ACRV missions, this concept proposes that the full spectrum of ground, mission support, and flight operations utilize existing facilities, personnel, processes, and other resources as a means of reducing costs.

Major concept features include

- Streamlined prelaunch processing at KSC
- Launch and delivery of the ACRV as a passive payload
- Use of "generic" products for ACRV mission operations
- Initial mission support by the on-duty control center team

- Reliance on existing United States and international search, rescue, and medical resources
- Use of the SSF-integrated logistics system

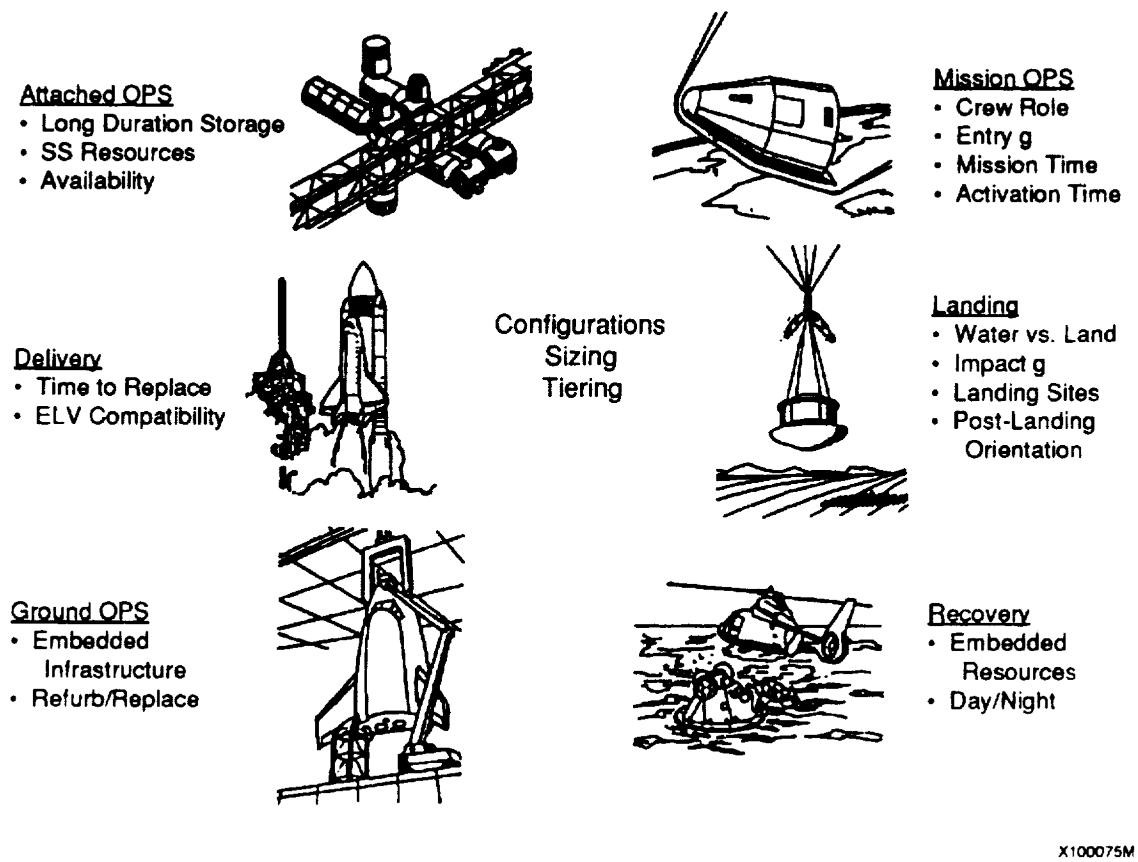
NASA found that essential control center functions could be limited to selecting landing sites, coordinating with search and rescue forces, and providing medical support. Specialized functions (e.g., on-orbit maintenance, subsystem troubleshooting, training, and vehicle recovery support) could be accommodated by cross-trained individuals from similar disciplines.

The NASA operations team integrated operations concepts and plans for each ACRV mission phase into a continuous flow. These analyses identified candidate requirements, contributed to the contractors' design concept work, and enhanced the accuracy of preliminary cost estimates.

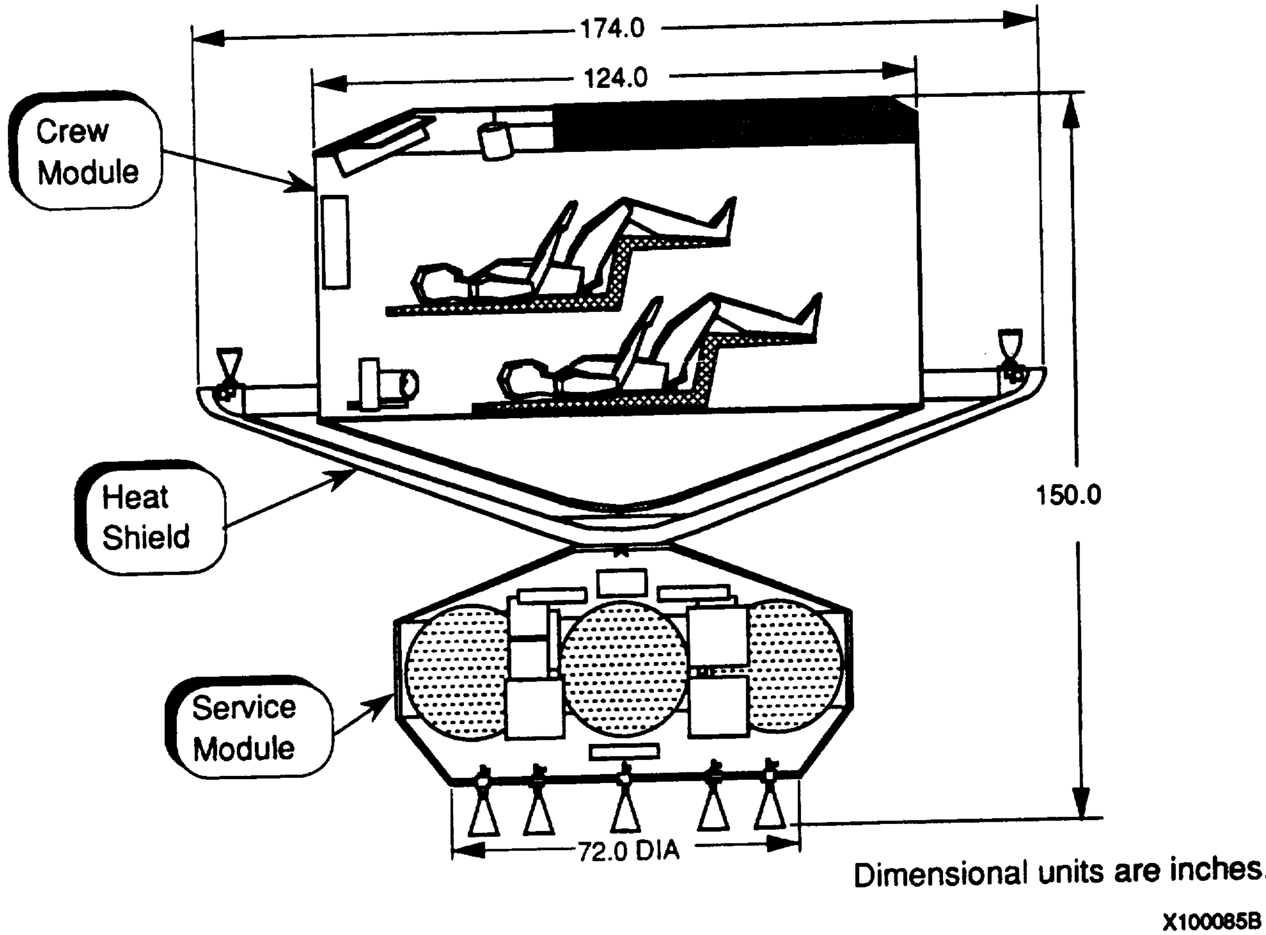
NASA continued to refine total LCC estimates for the ACRV system including design, development, test, and engineering, production, and operations-phase costs. Each prime contractor developed LCC estimates for various design alternatives that compared favorably with in-house estimates. The studies showed that parachute-landing vehicles with minimal crossrange capability are the least expensive to develop. Lifting bodies with moderate crossrange and runway-landing capability were shown to cost significantly more.

Supporting definition activities also were performed in FY 1990 at JSC, KSC, and the Department of Defense, including ACRV ingress simulations performed in a simulated weightless environment on the NASA KC135 aircraft. Analyses of ACRV landing opportunities were completed and candidate landing sites identified. Ground operations studies contributed to the operations concept work.

In FY 1990, the project developed systems for managing and protecting the two prime contractors' competition-sensitive data. It also developed a local area network-based information management system to organize and provide access to ACRV data, initiated a configuration management system to control requirements, maintained programmatic strategies to support the SSF Program, and developed project schedule and action tracking systems.



The ACRV system requirements issues were at the focus of technical activity in FY1990.



Although competing contractors will select their best design solutions, NASA developed this ACRV concept as a baseline for analysis.

Personnel Launch System (PLS)

PI: Andrew Petro/ET2
Reference STT 21

The purpose of the Personnel Launch System (PLS) study was to generate the information needed to assess the potential advantages of a people-only launch and recovery system as a future space transportation alternative. The PLS is intended to be a relatively simple, safe, and efficient means of transporting people to low-Earth orbit. Candidate designs for the PLS spacecraft include simple capsules, biconic shapes, lifting bodies, and winged gliders. The PLS concepts will be compared to evolutionary derivatives of the Space Shuttle and new designs for multi-purpose launch systems.

The first phase of PLS studies concentrated on defining ground rules and reference missions and performing overall system trade studies. A reference concept also was developed. This work was begun in-house and was supplemented by a contracted design study. Based on trade studies and other analyses, it was determined that the PLS should be a reusable spacecraft, one that would be delivered to orbit by an expendable, liquid-propellant launch vehicle and recovered on land. The selected spacecraft capacity is eight passengers plus a crew of two.

A series of simple spacecraft shapes were studied to determine their aerodynamic performance and stability characteristics. The spacecraft shapes that were studied include the Viking heat shield, blunt and pointed Discoverer, Apollo, and five types of biconics. Lift-to-drag ratios, trim angles-of-attack, and stability margins were determined. An additional study was completed to analyze the sensitivity of the selected biconic shape to length variation.

The spacecraft reference concept developed in the in-house design study has a biconic shape with a slightly flattened bottom. The biconic shape was selected because, in comparison to other simple shapes, its entry crossrange capability is higher and entry deceleration forces and heating loads are lower. Also, it is very efficient volumetrically. Practically all subsystems, including on-orbit propulsion, are housed in a module at the aft end of the spacecraft. The spacecraft is recovered by means of a parafoil; which is a deployable, steerable lifting surface. The launch escape system consists of several solid rockets housed in the launch vehicle adapter.

Numerous ascent trajectories for the PLS were analyzed using the Titan 3, an adaptation of the Shuttle liquid rocket booster, and a version of the Advanced Launch System. For purposes of comparison, several types of launch vehicles were designed specifically for the PLS mission.

The original reference insertion orbit for PLS was 100 by 50 n. mi. This orbit was found to result in booster impacts on land masses, so a parametric study was performed to determine a more desirable insertion orbit. It was found that reducing the insertion perigee to 40 n. mi. eliminated the impact problem without reducing overall launch performance.

An in-house study was begun to examine the fundamental performance and flight mechanics aspects of air launching. The trade study covered launch velocities from zero to Mach 3 and altitudes from zero to 75 000 feet.

A detailed study of launch escape systems was completed and system parameters were determined to provide for safe separation and recovery of the spacecraft following descent on conventional parachutes or a parafoil. This work included some in-depth analysis of the aerodynamic performance of a parafoil and an investigation into the flotation characteristics of the spacecraft.

Entry trajectories were generated for maximum crossrange and maximum heating conditions. The trajectory results were used to design a reusable thermal protection system. Recovery on land was found to be a significant engineering challenge. Parachutes are a proven approach, but drift due to wind will make tumbling after impact a constant concern. The selected design is a parafoil with a large nose skid and aft airbags for impact attenuation. Using a parafoil, the spacecraft can fly into the wind for a more controlled landing, but parafoils require additional development for large scale applications.

The conceptual design included a definition of all spacecraft systems including life support, tracking, communications, displays, controls, avionics, propulsion, and personnel accommodations. The onboard power requirements profile was generated for a typical mission and the power system was sized accordingly. A heat generation profile also was determined, and the thermal control system was designed for worst-case conditions.

A detailed weight breakdown was developed for the conceptual design. Working with cost analysts, complexity and other factors were defined for each spacecraft component. The cost factors and weight breakdown were used to develop a detailed life cycle cost estimate including vehicle development and operations for the 30-year program.

The reference concept developed in the contracted study also has a biconic shape. The contractor performed extensive trade studies of capacity, reusability, landing mode, landing precision, and spacecraft autonomy. In subsystem trade studies, numerous propellant combinations were considered in an effort to find the least hazardous option. Many innovative launch escape system options were studied. The selected system is an expendable, high-thrust liquid rocket which uses propellant from the orbital maneuvering system rather than a separate source.

Areas were identified where additional technology development would be beneficial. The operational use of a parafoil will require continued development and testing. There is also a need for propulsion and attitude control systems that use less-hazardous propellants and generate less-contaminating exhaust products. Additional development of existing concepts for low-maintenance power, life support, and thermal control systems is also needed.

Future plans include continued conceptual design activities in an effort to define four representative spacecraft types. Reference designs for a simple capsule and a winged glider will be added to the biconic and lifting body designs already generated. The four spacecraft configurations will be evaluated in the areas of manufacturing, launch vehicle integration, and operational efficiency. A concentrated effort will be made to understand the implications of operations in subsystem design. This multi-discipline design activity will be aided by the construction of a detailed scale model of a representative spacecraft. Studies of launch options also will continue.

PLS recovery concept.

Optical Communication Through the Shuttle Window (OCTW)

PI: J. L. Prather/EE6
Reference STT 22

In January 1987, NASA Headquarters funded a 3-year program to design and develop an alternative communications link between the crew cabin and payload bay on the Orbiter. This innovative system will allow payload specialists to communicate with their particular payload independently of the Orbiter system and also will increase the potential bandwidth for communicating between the crew cabin and the payload bay without penetrating the payload bay bulkhead. Fiber optics will be utilized in this system to achieve these goals. Optical fibers, transmission mediums for light, will guide light that is modulated with the appropriate electrical test signals to the cabin side of the aft window. There, the light (with the information stored in its intensity levels) will shine through the window and be received on the payload bay side of the window by a fiber that will guide the light to a box in the payload bay that will act as a repeater station for the test signals. On leaving the payload bay box, the light will return to the Optical Communication through the Shuttle Window (OCTW) crew cabin box, again via fiber-optic cable and the aft window. This box will evaluate the integrity of the optical link. Two subsystems will be a part of the OCTW system: a 200-mbps emitter coupled logic digital link and a video link. The system is manifested for flight in June 1991 on the Space Transportation System (STS) flight STS-43. The experiment will be operated four times during the mission to evaluate system performance in different vehicle attitudes, including bay to the Sun and bay to space. It is hoped that successful completion of the experiment will lead to incorporation of the technique as an optional service to future payloads.

Project accomplishments in fiscal year 1990 have included the following:

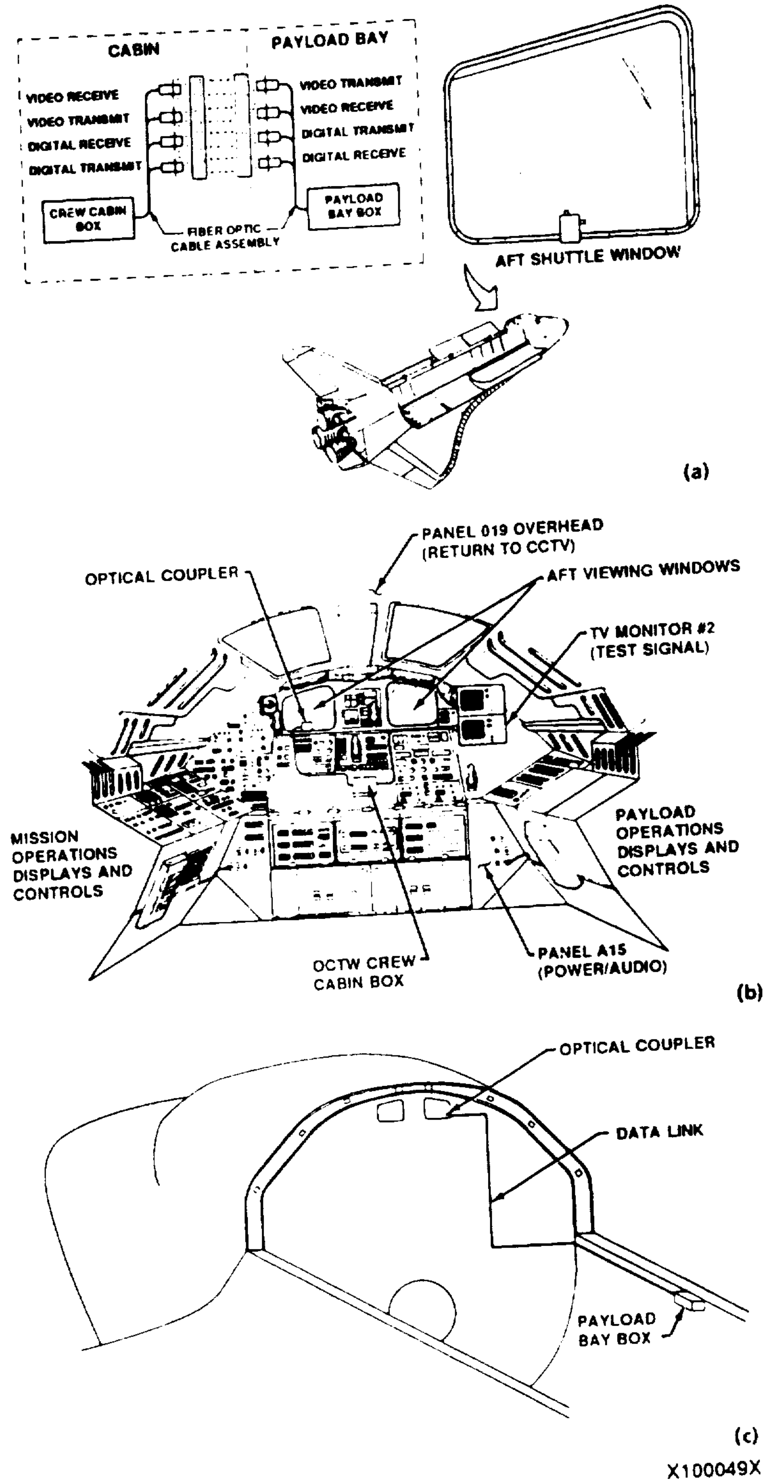
a. Flight hardware was developed and successfully tested. Tests included system performance verification, qualification for acceptance vibration, qualification for acceptance thermal, acceptance vibration, and acceptance thermal, bench shock handling, and electromagnetic interference/electromagnetic compatibility tests.

b. Modifications to the flight hardware were made due to a failure that occurred during qualification testing. A component was supplied by the vendor that was not intended to survive a space environment. Analysis was done to determine the part was unnecessary, and it was removed.

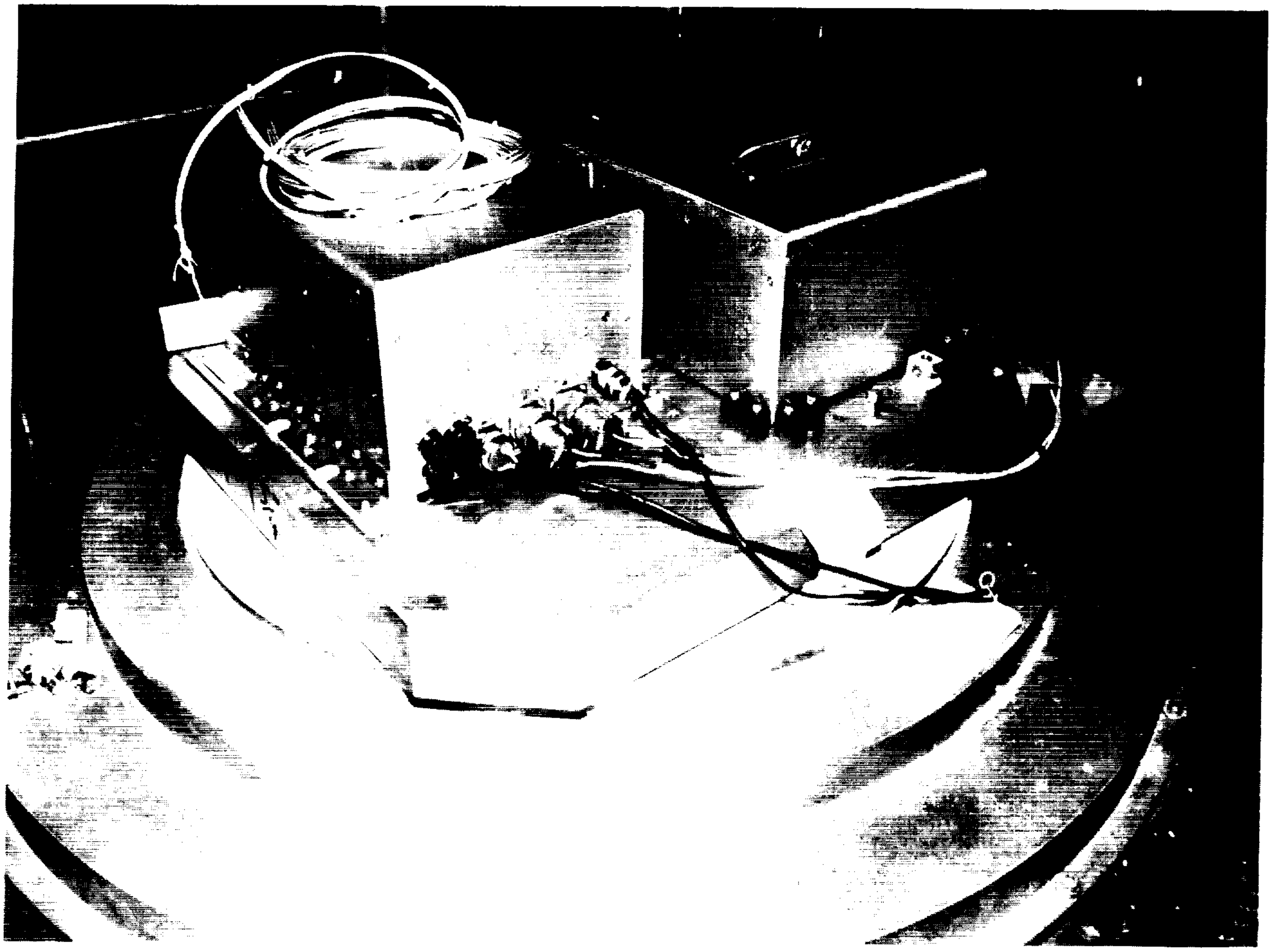
c. The Phase II flight safety review was completed, and the Phase III flight safety data package was submitted.

d. The Phase II ground safety review was completed and the Phase III ground safety review was submitted.

e. Various Payload Integration Plan annexes were completed, including the Flight Operations Support annex, the Middeck Interface Control Document, the Cargo Systems Manual, the Payload Systems Data and Malfunction Manual, the Payload Data Package annex, the Flight Planning annex (Parts I and II), and the Payload Verification Requirements annex.



Optical communications through the Shuttle window.



OCTW cabin and payload bay hardware.

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Visual Docking Aids

PI: Richard D. Juday/EE6
Reference STT 23

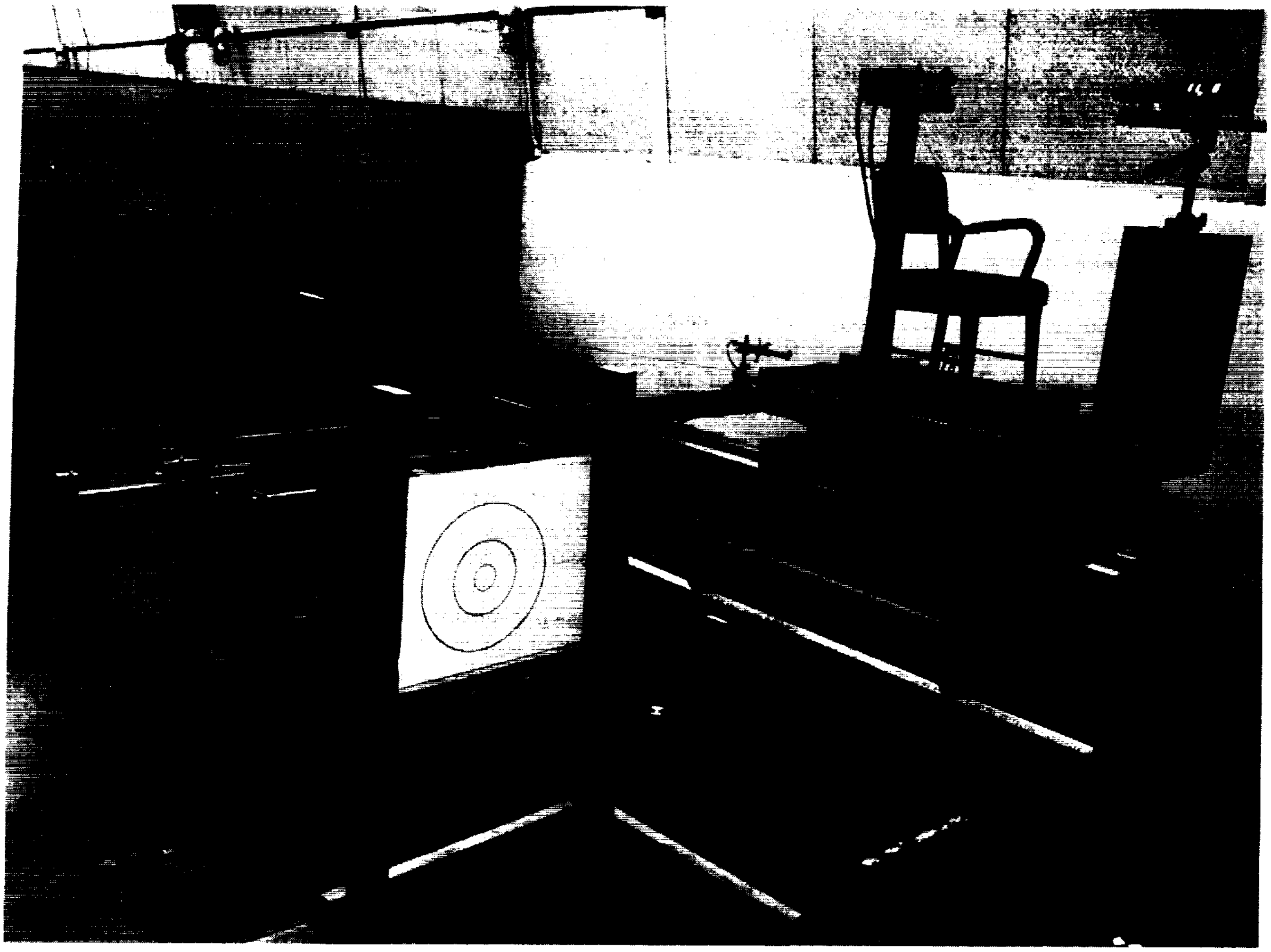
Simulations done in the Shuttle Avionics Integration Laboratory (SAIL) have shown there is a potential problem in docking the Shuttle and Space Station. Stacked translation dispersions at time of contact will require a 1-ft capture radius ability of the docking ports. Substantial reductions in cost, weight, and volume (applying to each flight of the Shuttle 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 would be to use a port-mounted television camera with cathode ray tube (CRT) display to the crewmember doing the docking. The crew, however, wish to have a backup method. To this end, JSC thoroughly evaluated one of several previously identified alternative docking target methods this year. It is a coherent fiber optic imaging bundle used as a periscope. The National Space Transportation System Integration Office funded the investigation.

"Berthing" recently has been given considerable attention. In berthing, the remote manipulator system (the remotely controlled arm on the Shuttle) is used to grasp a fixture on the Space Station and then the two vehicles are drawn into soft dock. "Docking" continues as the initial direct hard contact between docking port mechanisms on the Shuttle and Station. The fiber optic periscope technique is applicable to berthing as well as to docking.

The fiber optic periscope system has two major strong points. First, it is entirely passive. It has no electronics at all. For crew convenience, an optical television tap might be inserted, but the fundamental passive quality remains. Since it works quite well in laboratory ambient lighting, we expect it to operate in the Shuttle cargo bay's ambient lighting. Second, it achieves its precision by presenting a natural image to the operator; one does not infer position from secondary sources such as the appearance of an offset docking target.

We quote results for the effort in terms of the three major contributors to dispersion in the two-vehicle relative alignment. These are sensing, systematic, and control errors. Sensing error is where we can make a contribution. Systematic error is a translational bias misalignment resulting from Shuttle/Station relative rotational misalignment. Control error arises even if the pilot has perfect knowledge of the actual misalignment. We can reduce sensing error to a small fraction of an inch. Lateral sensitivity is the important parameter while docking motion occurs along the line of sight. We obtained test results with a full scale motion base simulator. It was about a twentieth of an inch at contact distance, with a less than one-inch systematic error resulting from typical attitude-hold deadband and the tentative placement of the fiber optic system. Using a prototype stereo setup with two fiber bundles at 8 inch separation, the range differentiating ability was better than one-inch at 5 feet and 2 inches at 20 feet.

In the coming year, we will develop this idea further. We will engineer the through-hull penetration of the fiber optic image cable, put typical components through environmental testing, and complete the design of a flyable system.



Fiber-optic alignment aid test setup.

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Laser Docking Sensor (LDS) Flight Demonstration

PI: J. L. Prather/EE6
Reference STT 24

A laser docking sensor (LDS) is being developed to aid future spacecraft docking, stationkeeping, and berthing operations with passive vehicles, as well as enable automated docking by more accurately determining the relative spacecraft position, attitude, and rates between docking vehicles. A flight experiment was being developed to verify system performance under actual working conditions in a space environment. The flight experiment was terminated in December 1990 due to the reallocation of funds from the sponsoring organization. Efforts are now focused on proposing flight hardware to support Orbiter to Station rendezvous and docking/berthing. If approved, hardware could be needed as early as 1994 to support the beginning of Station assembly in 1995. In fiscal year 1990, a Phase A/B study was performed by McDonnell Douglas Space Systems Company to determine potential systems designs and costs to support tracking at 100 n. mi. The results show the performance goals (listed in the table above) could be met using existing technology with moderate cost and technical risks.

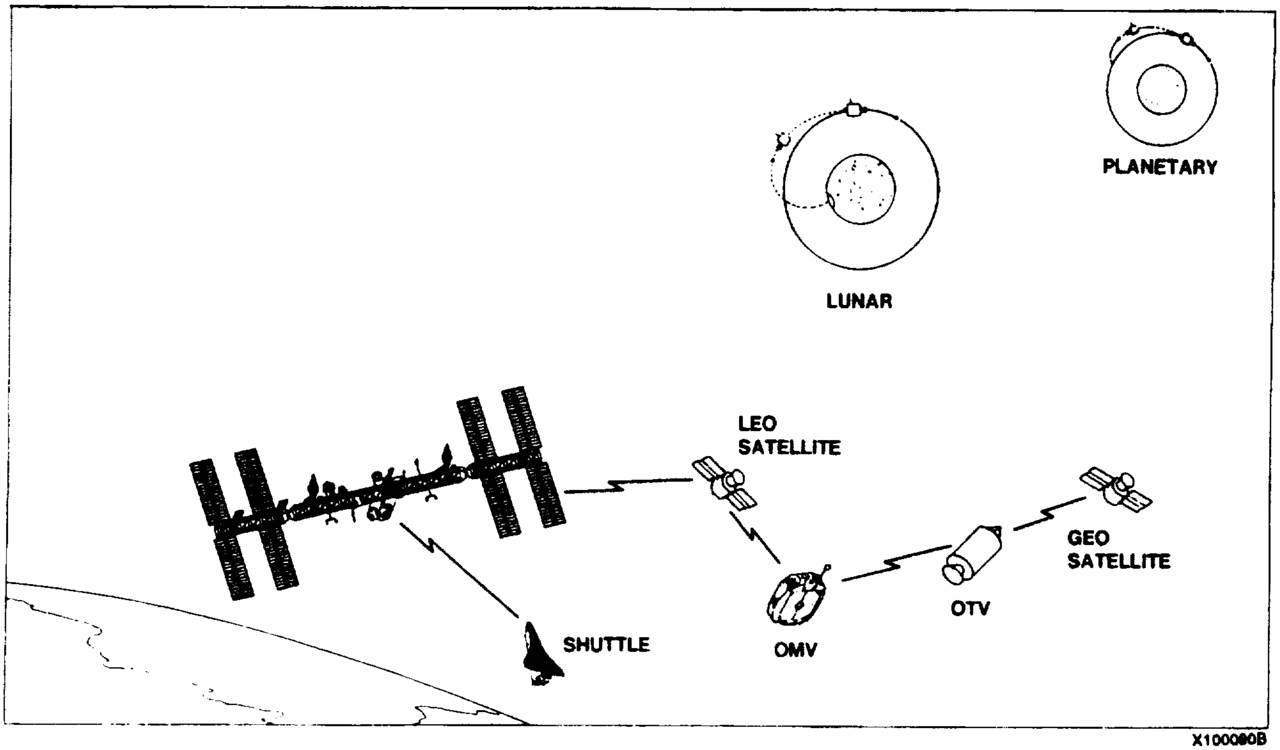
A candidate system uses a pulsed Nd:YLF laser combined with high-speed time-of-flight ranging to obtain range and range rate data, a ratiometric quad cell to obtain bearing data, a two-axis scanner for search, acquisition, and tracking, and a charge coupled device camera with video processing for attitude information. The video camera also can be used as a short-range backup to provide range and bearing information.

In addition, an in-house test facility was developed that will assist in verifying the performance parameters of the LDS hardware. The heart of the facility consists of a 6-degree-of-freedom (6-DOF) target positioner. The 6-DOF consists of a sensor and target positioning gimbals and a 12 m granite rail. The sensor gimbal uses two servo-motor rotary stages to provide azimuth (AZ) and elevation (EL) angle measurements over ranges of ±45 deg at maximum rates of 40 deg/sec and an accuracy of 0.002 deg. The sensor gimbal is attached to an air-bearing table which rides on the granite rail and is stepper-motor driven at a maximum rate of 0.5 m/s with an accuracy of ±5 u/m. The target gimbal assembly consists of three servo-motor rotary stages to provide yaw, pitch, and roll accuracies and rates equal to those of the sensor gimbal system except for roll, which has a maximum angular rate of 10 deg/sec.

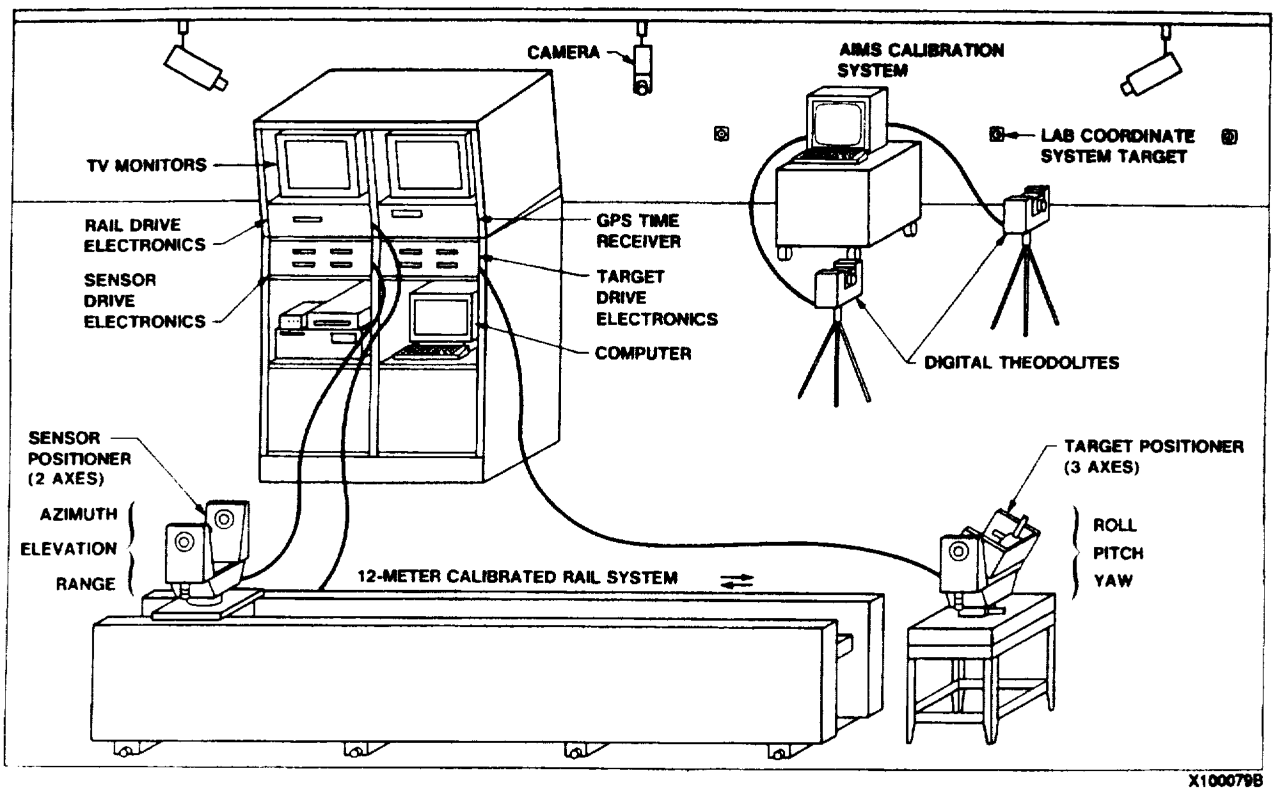
Laser Docking Sensor Performance Specifications

Parameter	Limit	Accuracy (u + 3s)
Range (R):	30 mm – 185 km	$\pm(0.015 \text{ OR } 0.03R)$ m
Range Rate:	±6 m/sec	$\pm(0.003 \text{ OR } 0.009R^{1/3})$ m/sec
Bearing Angle: (AZ and EL)	±10°	$\pm 0.183/(R^{1/3})°$ for $R \leq 305$ m ±0.15° for $R > 305$ m
Bearing Angle Rate:	±1°	$\pm 0.086/(R^{1/2})$ deg/sec for $R \leq 305$ m ±0.009 deg/sec for $R > 305$ m
Attitude: (Pitch and Yaw)	±45°	±0.9°
Attitude (Roll):	±180°	±0.9°
Attitude Rate:	±6 deg/sec	±0.03 deg/sec

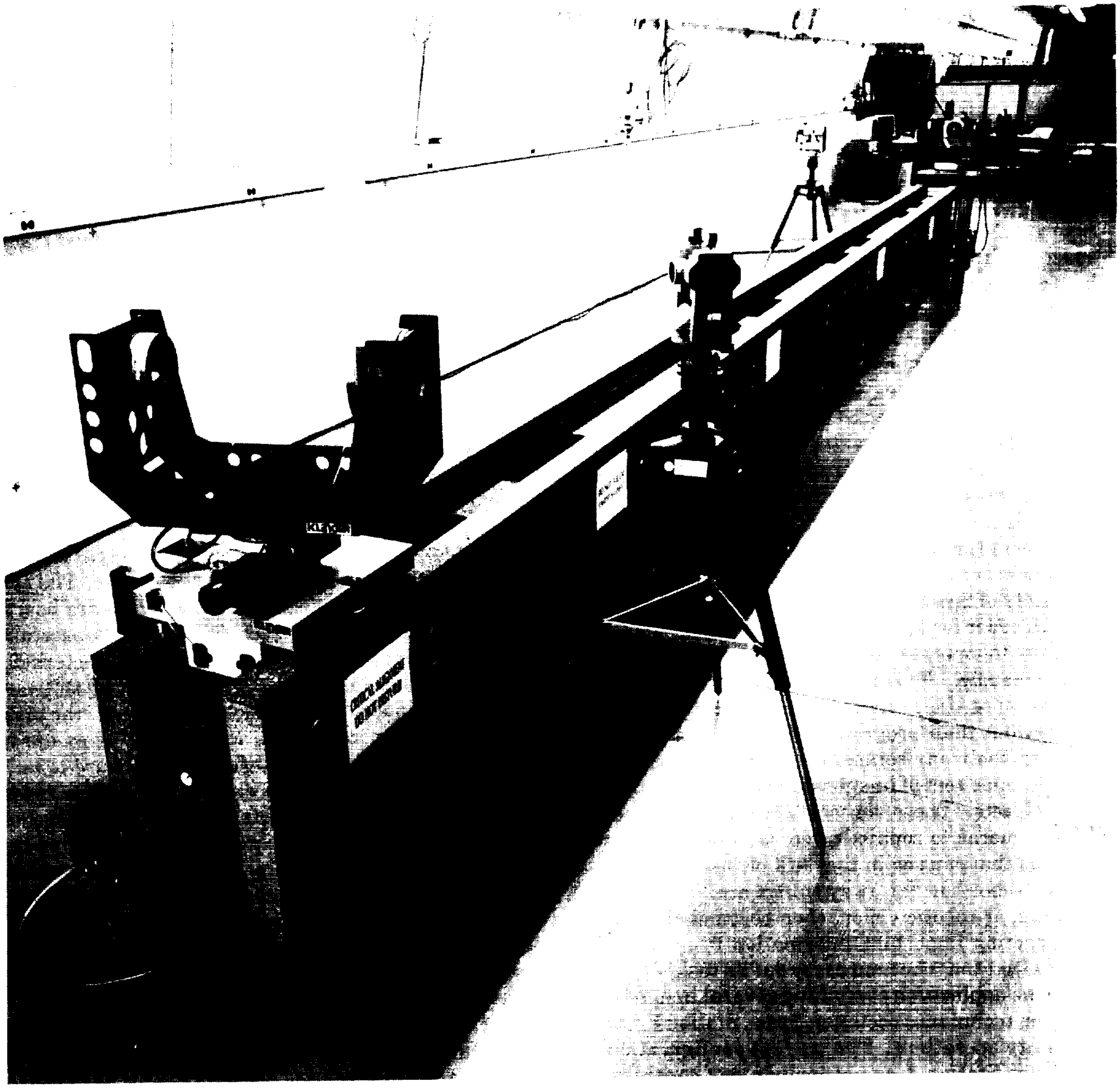
The attitude measurement and accuracies are for ranges ≤ 30 m.
R = range in m; s = standard deviation of error (random); u = mean error (bias).



Laser docking sensor applications.



The 6-DOF facility.



The 6-DOF facility 12 m calibrated rail system.

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Image-Based Tracking Systems Development

PI: Tim Fisher/EE6
Richard Juday/EE6
Reference STT 25

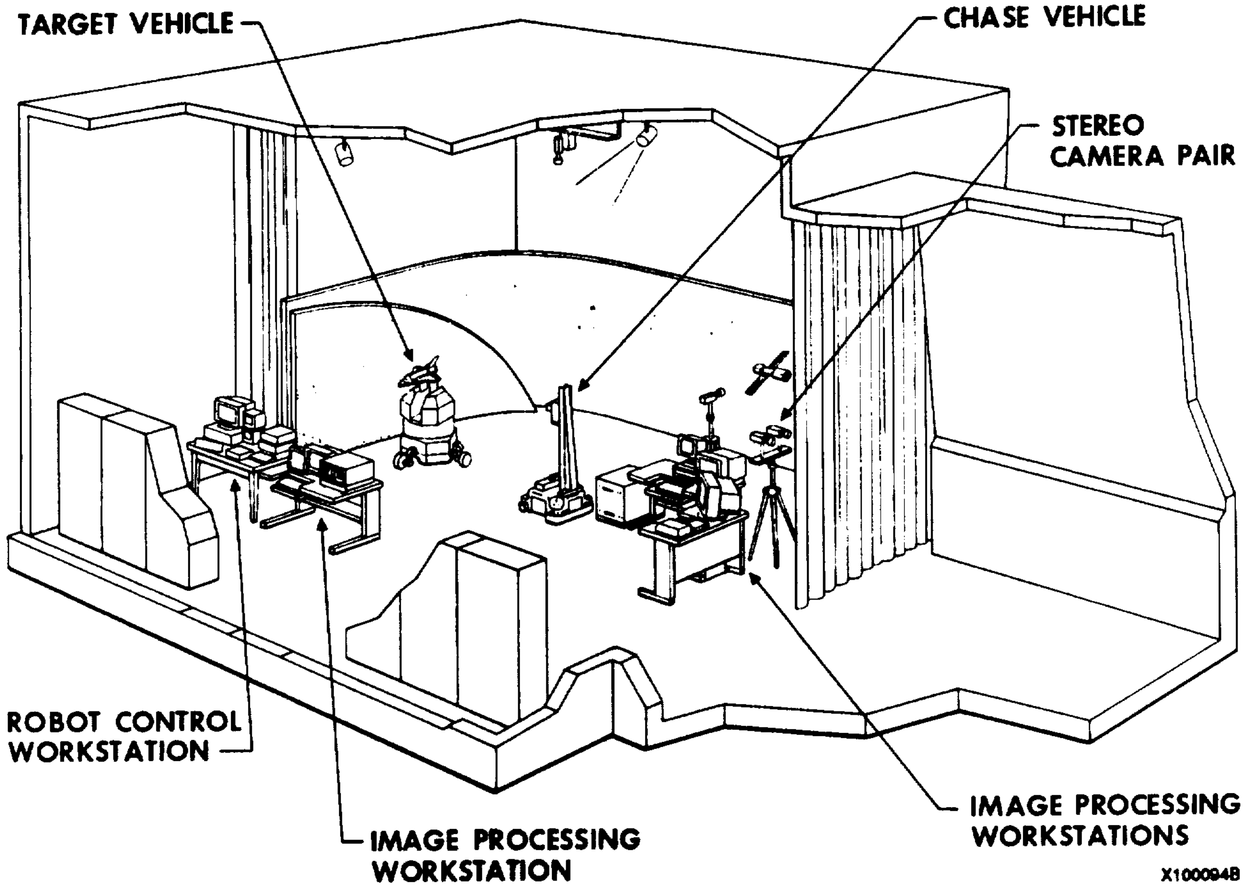
As NASA begins operating routinely in the space environment, it will rely more and more on robots and remote manipulators to ease the work load of its astronauts. For example, a robotic arm can recognize and grapple a disabled satellite automatically, thus relieving the astronauts of this task. Robots also can be used to accomplish tasks that either cannot be done by, or are too dangerous for, astronauts. Examples include docking autonomous vehicles above the martian surface and retrieving objects that are floating away from the Space Station. In the first case, it is impossible for an astronaut to be available to perform the task. In the second case, it would be too dangerous for an astronaut to venture so far from the safety of Space Station Freedom (SSF).

In order for the robots to do their job, they must be able to operate either autonomously or semi-autonomously. This means that the robots must be able to sense their environment and act accordingly to carry out their programming. One way for robots to sense their environment is through sensors that provide some sort of image which the robot can use to "see" objects. These sensors can range from simple video cameras to sophisticated sensors like infrared cameras that can see in the dark or laser radars that tell the robot how far away things are. Image-based tracking, or robotic vision, then becomes the science of extracting important information from these images so that the robot can carry out its task.

One application combining several image-based tracking techniques occurs in Space Station Freedom proximity operations. The current configuration for the Space Station does not include any capability to track objects or loose objects in its vicinity. For example, the Space Station does not have any way to track the position of an astronaut on extravehicular activity (EVA) accurately or to keep track of free-floating robots in the area. Since there are no tracking sensors onboard the Space Station *per se*, video cameras are the only available sensors for supplying the required information. The JSC has defined a multiuser, multi-access, image-processing system for the Space Station which is capable of providing tracking parameters using the SSF video cameras. The system can use two or more Space Station cameras to get stereo-depth information or can use more sophisticated image-processing techniques to subtract static Earth, Moon, or Space Station structure backgrounds from the image to track only the moving objects in the image. These capabilities will be demonstrated in 1991 in our image-based tracking testbed.

Another application for image-based tracking techniques is the EVA Retriever (EVAR). The EVAR is designed to retrieve loose objects in the Space Station environment and to act as an astronaut helper. The EVAR uses a combination of video cameras and a 3-dimensional imaging laser radar as its imaging sensors. During 1990, a video tracking system was built which will recognize and track moving objects. This system uses only a binary video image, one in which each pixel is either white or black. Objects in such an image lose their interior detail and appear as "blobs" in the image. The system is built around a special set of hardware boards called an APA-512 board set. The APA-512 accepts a binary image and calculates area parameters for each of the blobs in the image. The tracking software then uses some of the parameters to classify the blobs as either being in a known target class or as unrecognized targets. The classification software is built around a neural network classifier that can recognize three classes of targets: astronauts, wrenches, and Orbiter replacement units. The software can recognize the targets at any range and rotation angle about the line of sight, but not as the objects rotate out of plane. The software also can track objects as they move through obstructions (in front of or behind another blob). Currently, the EVAR image-based tracking system is being upgraded to use a Kalman filter to track targets through occlusions when the targets have nonlinear trajectories and to track objects as they rotate out of plane.

Other approaches to image-based tracking are being pursued by JSC, which has gained national and international recognition for its work in the area of optical correlation techniques for full 6 degree of freedom object recognition and tracking. The center also is engaged in investigating the use of alternate coordinate systems for images to improve the computation of tracking and object recognition information.



Fiber-optic alignment aid test setup.

Superfluid Helium Orbital Resupply Coupling

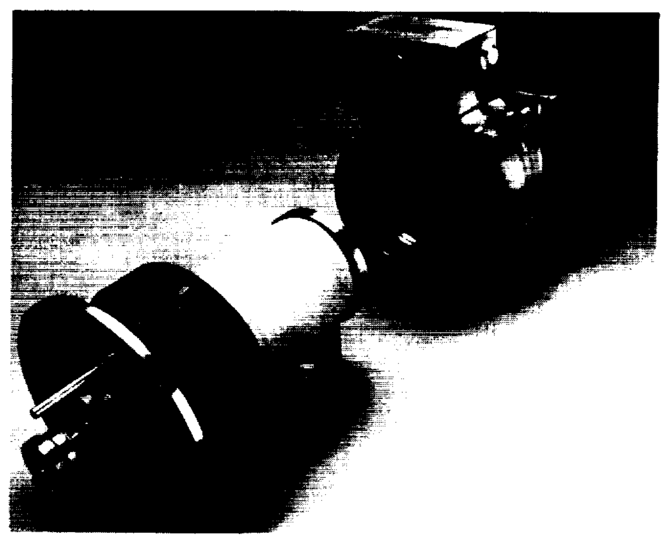
PI: Richard J. Schoenberg/EP4
Reference STT 26

Orbital consumables replenishment provides an attractive method of 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 currently is under way at JSC on the development of both Earth-storable and superfluid helium (He II) tankers.

The objective of this effort is to develop a coupling for the transfer of He II in zero-g. The coupling was designed for use on the Superfluid Helium On-Orbit Transfer (SHOOT) flight experiment. The SHOOT is managed by the Goddard Space Flight Center and is designed to simulate a satellite servicing operation. It currently is manifested for the Space Transportation System flight STS-54, scheduled to fly in January 1993.

The coupling is designed to minimize heat leak (under 1.0 W) to maximize the amount of fluid transferred. Due to the supercryogenic nature of He II (a 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, as well as be readily modifiable for automatic operation. The coupling may be subsequently incorporated into He II flight systems such as the Superfluid Helium Tanker, the Space Infrared Telescope Facility, and the Particle Astrophysics Magnetic Facility. Moog Space Products has been under contract to JSC since 1987 for the design and development of the He II coupling.

The effort in fiscal year 1990 (FY 1990) focused on demonstrating applicable technologies through the design, fabrication, and assembly of development level hardware. Accomplishments during FY1990 included testing of critical subassemblies such as thermal isolation jackets and the cryogenic seals. These tests were performed to gain confidence in the coupling design at the subassembly level. The first of two development level couplings was assembled in FY 1990. The accompanying photograph shows the completed coupling hardware. Fixtures required for ambient and cryogenic testing also were completed. Acceptance level testing of the first unit was begun. Initial results show good hardware performance for mechanical cycling and leakage. The test program will be accomplished in two phases: ambient testing will be performed by Moog; cryogenic testing will be performed by Ball Aerospace. Results from both ambient and cryogenic testing will be used to evaluate coupling performance to ensure compliance with hardware specification requirements. Plans for FY1991 include completion of the acceptance testing on the first development unit, and assembly and testing of the second development unit.



First development He II coupling.

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Automatic Storable Fluid Resupply Coupling

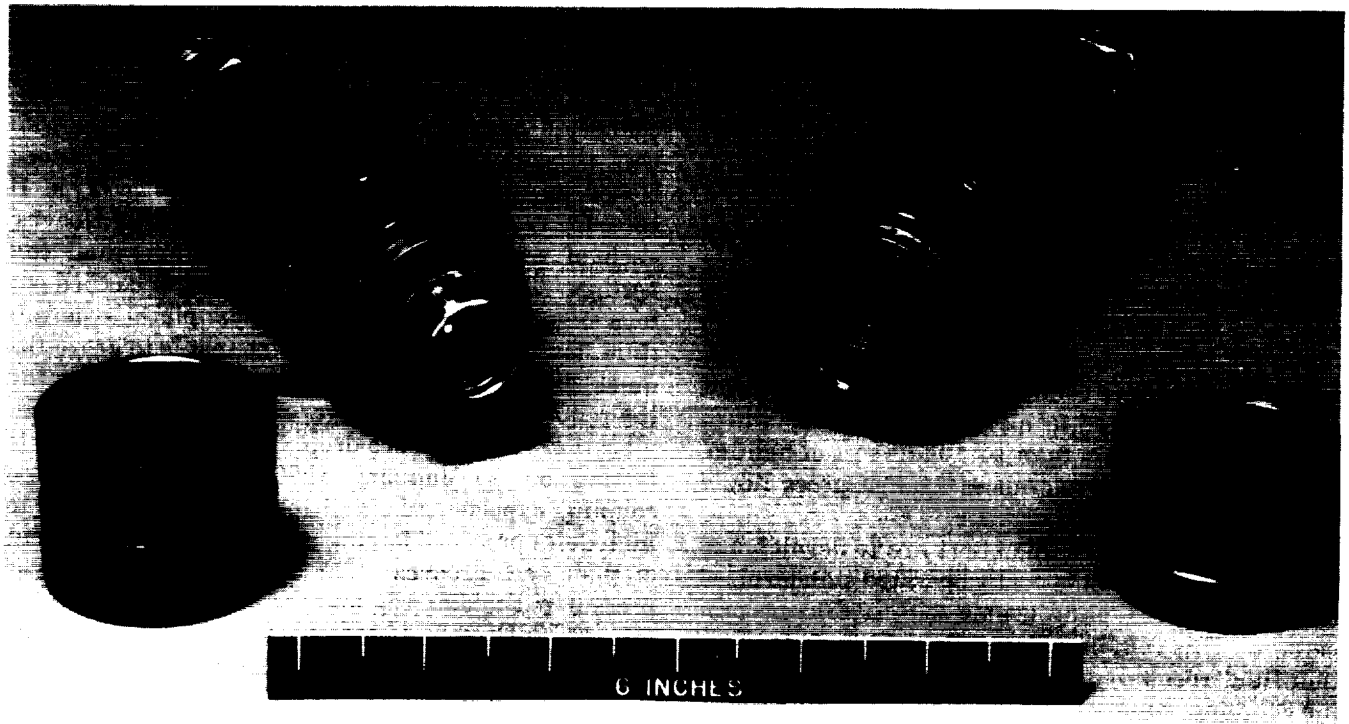
PI: Mark S. Falls/EP4
Reference STT 27

An automatically operated coupling is a key system element for future fluid resupply operations between tankers and spacecraft. The coupling consists of a tanker half (Type I) and a spacecraft half (Type II). When the two halves are engaged, they provide an interface connection between a spacecraft and a supply tanker to allow fluid transfer which limits leakage to less than $1 \times 10E{-6}$ sccs of helium, providing two fault tolerances against gross liquid leakage.

The objectives of this effort are to develop and flight certify an automatically operated standardized fluid resupply coupling usable with hydrazine propellant. This coupling also will apply to Space Station fluid resupply. With modified seal materials, the coupling would also apply to bipropellants (monomethylhydrazine and nitrogen tetroxide) resupply of spacecraft propulsion systems. The coupling will be designed for actuation by a separate interface mechanism that will be capable of actuating several fluid and electrical couplings simultaneously. The design will incorporate the necessary redundancy features to comply with safety requirements for performing resupply operations in the Orbiter payload bay and at other on-orbit locations. This coupling would become a standard component to be provided to spacecraft anticipating fluid resupply by the Space Transportation System.

The in-house activity performed at the Johnson Space Center (JSC) in fiscal year 1990 (FY 1990) involved the test evaluation of a technology coupling developed by Fairchild Control Systems (FCS) to assess current disconnect capabilities for Space Station and for satellite servicing. This technology coupling consists of two coupling halves: the Type I and the Type II. Each coupling half is self-sealing in the disconnected position. There are two series-independent poppets in the Type I, each of which is loaded closed by an individual coil spring. The Type II contains two closure elements in the form of sleeves, each of which is loaded closed by individual coil springs. The operation of the coupling is carried out by a simple push-pull motion (carrier plate) to permit fluid flow. The significance of the test is to prove the quick disconnect coupling to be capable of meeting the requirements of leakage, spillage, misalignment, vibration, and pressure drop. During pressure cycle testing on 23 January 1990, the poppet design coupling experienced a multiple O-ring failure due to high delta pressure forcing several of the O-rings out of their seal grooves. The Type I half (male) was pressurized to 590 psig and the Type II half (female) was pressurized to 100 psig when the failure occurred. The failure mode was duplicated at FCS where it was determined that a design flaw in the seal groove initiated the O-ring failure. Fairchild Control Systems rectified the problem by molding redesigned seals in place into modified seal grooves for positive retention. The refurbished coupling was returned to JSC in late June 1990 to undergo further testing. Tests will include helium leak checks, proof pressure, surge pressure, vibration, delta pressure versus flow rate, engagement cycling, pressure and temperature cycling, and disengaging in a vacuum. The effort in FY 1991 will continue to test and evaluate FCS's poppet design coupling for on-orbit resupply.

The results of FCS's coupling evaluation consolidated with Moog's ball design coupling assessment completed in FY 1989 will be factored into the total set of design requirements for the coupling development and certification program.



Fairchild's automatic storable fluid resupply coupling.

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Space Systems Technology

Summary

Space Systems Technology

The Space Systems Technology section includes many diverse technical disciplines, including Thermal Control, Life Support, Extravehicular Activity, Human Factors/Man Machine Integration, Communications and Tracking, Guidance, Navigation, and Control, Aerodynamics, Aerothermodynamics, Computation Fluid Dynamics, Data Processing Hardware/Software, Propulsion and Power, Automation and Robotics, Structures and Materials, Computation Science, and Information Systems.

These research and technology categories represent current Johnson Space Center (JSC) efforts which are focused on NASA's long-range strategic goals and objectives associated with existing and emerging programs and the new technologies they require. They support endeavors such as Space Shuttle/Orbiter enhancement and evolution, Space Station Freedom (SSF) initial deployment and evolution, Earth orbit operations; advanced space vehicles, and the Space Exploration Initiative (SEI) with lunar, Mars, and interplanetary missions. Excellent progress has been demonstrated in these various discipline areas in support of the ongoing and evolving programs in the past year.

In the areas of thermal control and heat rejection, significant progress and innovative approaches have been defined and tested which will increase overall heat rejection efficiency with significant mass savings over existing systems. Emphasis is being placed on evolved SSF, Space Transfer Vehicles, Planetary Surface Systems, and Extravehicular Mobility Systems. In the area of Life Support research, emphasis has been placed on regenerative physico/chemical and biological systems technologies that facilitate water reclamation, air revitalization, waste processing, and food production. This results in greater recovery of consumables and reduced resupply requirements. Significant progress has been made in innovative approaches to these technology areas and defining the critical development and integrated testbeds. In the area of extravehicular activity (EVA) development, emphasis has been placed on advanced suit and portable life support systems in the areas of enhanced and extended space suit mobility, dexterity, candidate materials abrasion resistance to planetary dust, and lightweight materials development. Significant mass reduction with improved mobility and dexterity is required for lunar and Mars extravehicular mobility units (EMUs) over the Apollo and Shuttle technologies employed.

Future manned vehicles and SSF will require intelligent design of the interface between human beings and the machines, computers, and workstations which they employ. Significant research progress has been made in the Human Factors/Man Machine engineering areas in SSF procedures, format, display developments, intelligent computer systems monitoring (nominal and fault detection) of SSF Thermal Control Systems, Shuttle Payload Deploy and Retrieval Systems, SSF hand controller commonality evaluations for remote manipulators, dexterous manipulators, and free-flyer applications. Optimal work surface evaluations and neutral body positions were examined using the PLAID graphics system and KC-135 flights. Significant accomplishments were also made in SSF hatch viewport size evaluations, SSF cupola window evaluations for normal viewing and/or higher quality optical windows for scientific observations, and EVA speech recognition enhancement studies.

In the Communications and Tracking areas, significant photonics research technologies are being developed to support autonomous rendezvous, docking, navigation, hazard detection and avoidance, and techniques for autonomous landing systems. Optical correlation, filtering, image processing, pattern recognition, and tracking technologies are being pursued. These technologies will enhance and/or enable the autonomous rendezvous, docking, and landing flight objectives which are critical to the SEI while enhancing the SSF evolution with improved operability. Emphasis is focused on processing speed, light efficiency, low power, high-space bandwidth product per volume optimization for various laser, laser radar (LADAR), and lidar technical approaches. Innovative research in small, lightweight system applications for Ku-band low-profile antenna, miniaturized ultrahigh frequency (UHF) matrix switches, and high-temperature superconductivity applications for microwave antennas is being developed with promising results from the past year.

In the Guidance, Navigation, Control, and Aeronautics technical discipline, significant accomplishments were made in the autonomous rendezvous and docking areas with an initial development of an off-line graphical playback of a predetermined rendezvous and proximity operations trajectory. Plans were developed for an interactive simulation to be added along with buildup to an in-house demonstration of an integrated docking sensor and docking mechanisms. Surveys of various sensor technologies were studied and are continuing. In support of the Personal Launch System (PLS) studies, a lifting body concept proposed by Langley Research Center (LaRC) was integrated into the Shuttle Engineering Simulator (SES) with modifications to the Shuttle guidance, flight control, aerodynamics, and software modeling. Initial results of the approach and landing simulations indicate the need for a higher lift-to-drag ratio (L/D). Revised aerodynamic data have been furnished by LaRC, and an additional simulation is planned in the coming year. Large flexible space structures like Space Station present significant technology challenges. Significant progress has been made in advanced theory, reaction control pulse modulation techniques, self-tuning adaptive control, and frequency-based localization sensing health monitoring. Innovative techniques were developed to study laser-induced fluorescence and spectroscopic diagnostics of the arc jet plume flow to support aerobrake heating predictions and gas recombination theories.

Research and technology emphasis in the Propulsion area has been on SSF hydrazine thrusters, gaseous oxygen/hydrogen workhorse thrusters, on-orbit compressor technology development, generic fluid transfer computer program development/applications, and waste gas systems material compatibility studies. Significant accomplishments were made in fiscal year 1990 to support SSF design reviews and concept selections, and to maintain on-orbit maintenance and servicing evolution pathways. These technology development areas also have applicability to advanced man spacecraft studies including PLS, Assured Crew Return Vehicle (ACRV), and the SEI mission objectives.

The Automation and Robotics disciplines continue focused research and technology development in direct support of SSF, enhanced Space Shuttle remote manipulator system (RMS) and other on-board systems and enabling efforts for a large number of the SEI mission objectives. The focus on SSF is developing various expert systems for performing fault diagnosis and system recovery in managing large complex systems. Automated systems should lower operations costs, increase flexibility, improve reliability, increase productivity and feasibility of autonomous space vehicles, and reduce hazards to humans. Robotic efforts have focused on the addition of force torque control sensors to Shuttle RMS, fault tolerant manipulator joint mechanism and controls, and automated robotic assembly of large space structures. Very good progress was made in these areas in defining the requirements, conceptual designs, engineering modeling and simulation, testbed development, and demonstrations. The manned exploration of the Moon and Mars and the associated unmanned precursor missions will require the capability to land a spacecraft safely, accurately, and autonomously. A conceptual design of an onboard hazard detection sensor was developed along with a simulation of the sensor and the associated image processing in the laboratory.

Since SSF will be required to perform usefully over an extended 30-year lifetime, advances in materials and structures are needed. Research into long-life protective coatings and materials resistant to atomic oxygen effects and space debris is a primary focus. The returned samples from the Long Duration Exposure Facility (LDEF) are being examined in a number of laboratories. The JSC has been working closely with Los Alamos National Laboratory with their unique facility capabilities and our in-house facilities to develop coatings/materials that are resistant to space environment. These efforts will continue over the next several years. The Experimental Investigations of Spacecraft Glow (ESIG) contractor, Lockheed Palo Alto Research laboratory was selected for Phase C/D. Experiment definitions, flight objectives, sensor definitions, and design were initiated. The Aeroassist Flight Experiment (AFE) continues to make excellent progress with completion of the preliminary design on the aerobrake assembly, thermal protection system, and base flow heating experiments. Mechanical, structural, thermal protection, and electrical designs are proceeding on schedule. With revised Computational Fluid Dynamics (CFD) modeling, instrument locations studies have been determined. A Critical Design Review (CDR) was planned for early 1991 to finalize all the designs and to release final production drawings. Space assembly and operations require sophisticated techniques and reliable positioning and joining methods. A multisegment robot prototype system was designed, fabricated, and tested successfully. Robotic assembly of an aerobrake thermal protection system (TPS) was investigated to determine problems and method of installation. Innovative design concepts and robotic methods were successfully demonstrated.

In the software technology development discipline, research studies are being focused on identifying, evaluating, and developing software technologies for use in NASA information systems in support of space systems development and operations. The software technologies that have been evaluated and/or developed include: Computer-Aided Software Engineering (CASE) tools and concepts, expert systems, fuzzy logic, neural networks, genetic algorithms, machine vision, parallel processing, cooperative knowledge-based systems architectures, verification and validation tools development, Intelligent Computer-Aided Training (ICAT), and speech recognition and synthesis.

A number of innovative research approaches are being pursued with simulation tools using RMS models, C language integrated production system (CLIPS) with fuzzy logic, space transportation analysis and intelligent space systems, a phoneme-based speech recognition system for use in high-stress, moderate-noise environments, and autonomous docking using machine vision. Supporting research studies conducted in-house have developed tools for developing expert systems, software development costs, an automated library, and a number of neural network development tools; e.g., NETS, STNN, and NNETS. The primary focus on these research activities is to develop highly reliable, extremely fast, human-like computational reasoning and decision-making systems to speed up simulation, enhance training, provide faster data retrieval, enhance productivity, and lower operational support costs for ground/flight operations. There has been extensive spinoff from this activity government-wide and in the private sector; e.g., CLIPS is being used by over 3000 users in these areas.

Space Systems Technology

Significant Tasks

Rotating Bubble Membrane Radiator for Spacecraft Waste Heat

PI: John Thornborrow/EC2
Reference SST 1

Spacecraft designed to support human life must be well insulated from the environment to prevent large swings in habitat temperature. Consequently, heat generated by humans and electrical equipment quickly builds up, causing the internal temperature to increase. Waste heat must be rejected to deep space to maintain habitat conditions. This task is performed by the active thermal control system (ATCS) which acquires heat from the habitats, transports heat to the rejection site, and rejects waste heat to deep space. A vital component of this system is the heat-rejection device that transfers waste heat from the transfer loop to deep space. The current Space Station Freedom heat-rejection device is a flow-through condensing radiator. Vapor from the transport loop enters the radiator from a manifold on one side. As the vapor travels through the radiator, heat is rejected to deep space and the fluid condenses to a liquid state. The liquid working fluid is then collected at the exit manifold and returned to the transport loop. The heat rejection section is ~60 percent of the total ATCS mass and has an area density of ~8 kg/m^2.

Significant mass savings to the entire system can be achieved by developing a lightweight heat-rejection device that is resistant to hypervelocity impacts. The rotating bubble membrane radiator offers such advantages. Use of the rotating bubble membrane radiator would decrease the heat rejection system mass by more than 50 percent with heat rejection densities of less than 4 kg/m^2. The use of fabric composite materials also makes it highly resistant to puncture by foreign projectiles.

The radiator skin consists of a thin metal liner 2–5 mil (0.002–0.005 in.) thick surrounded by a 10 mil (0.010 in.) thick ceramic fabric overbraid which acts as the pressure boundary. The ceramic fabric material, which has been demonstrated to be highly resistant to hypervelocity impacts, is very lightweight and has good heat transfer properties. The result is a strong, lightweight heat-rejection device that is one-third the mass of current heat pipe radiator systems.

As shown in the first figure, the rotating bubble membrane radiator employs a rotating, spherical, radiating surface at the center of which is housed a two-phase nozzle. Vaporized working fluid is ejected by the nozzle into the radiator envelope. As the working fluid condenses on the inner surface, liquid is moved by centrifugal forces to the sphere equator where it is collected and pumped back through the cycle. Heat released by this condensation process is conducted through the thickness of the sphere and radiated to space.

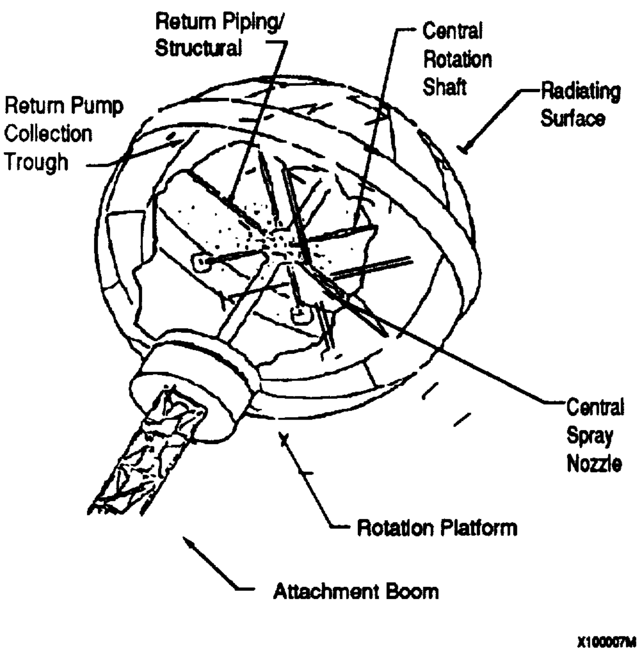
The rotating bubble membrane radiator is an efficient heat-rejection device because it combines the advantages of two-phase flow, high fin efficiency, and a spherical or ovoid shape which maximizes surface area per unit mass. The rotating bubble membrane radiator is gravity-insensitive due to the spherical surface and, because of the flexible nature of the material being considered for use, also is stopped easily.

Several efforts were performed in fiscal year 1990 to develop a prototype ground test article. Material compatibility tests were performed to verify the integrity of liner materials with potential working fluids. Liner materials such as titanium, aluminum, stainless steel, and copper were tested with acetone, methanol, water, and ammonia as the working fluid. These tests succeeded in providing a full matrix of results for many possible liner/working fluid combinations.

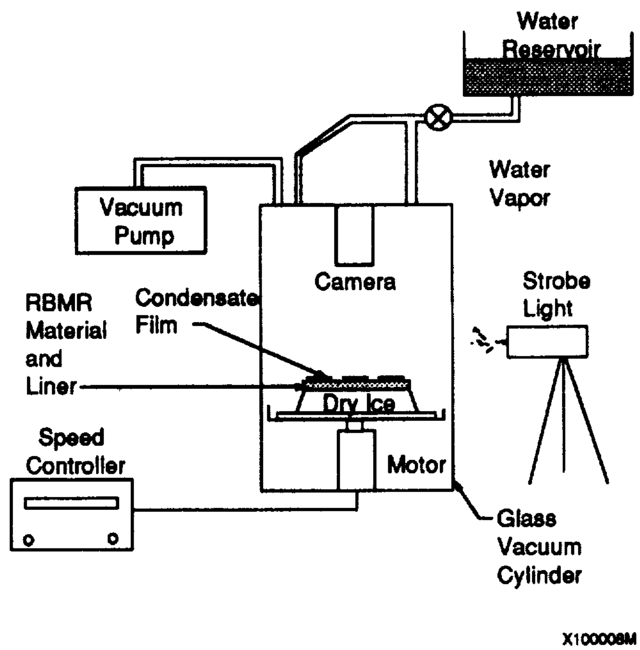
Hypervelocity impact tests also were performed to demonstrate the impact integrity of the fabric composite materials. Coupons of 4×4 in. ceramic fabric materials were tested with a titanium liner. A 2 mg aluminum projectile with a 1/16 in. diameter was shot at the test sample at 7 km/sec. Some damage was sustained in three out of four test shots, but far fewer than are normally demonstrated with a similar aluminum sample. Analysis shows that the fabric composite will be completely able to resist impact from 0.001 mg projectiles striking at speeds of up to 20 km/sec. Similar aluminum radiators would fail to stop such projectiles.

A fluid dynamics and heat transfer test rig also was designed and fabricated. The test apparatus, shown in the second figure, consists of a glass vacuum chamber and rotating test article platform. Instrumentation and viewing equipment also are present to record working fluid condensation on the heat transfer surface. The purpose of the test rig is to demonstrate the fluid flow and heat transfer characteristics of the thin film across representative liner and backing materials. Of particular interest are flow velocities, instabilities, laminar-turbulent transitions, temperature profiles, and heat rejection. The test results will be used to verify the rotating bubble membrane radiator heat transfer prediction model and to update the sizing model for this system. These tasks affect system development directly, but technology associated with the project also has potential uses in micrometeoroid shielding and fluid transfer and storage. The fabric composite is lightweight and highly resistant to foreign object penetration; it thus could be used for spacecraft debris shielding. A few layers of fabric composite materials would be lighter and much more effective at shielding against impacts than standard metal bumpers. Moreover, as the system is essentially a large fluid pressure vessel, the technology also is applicable to lightweight piping and fluid storage systems.

In summary, the rotating bubble membrane radiator combines the advantages of high-efficiency heat transfer mechanisms and state-of-the-art materials to yield a durable, lightweight alternative to current heat-rejection devices.



Rotating bubble membrane radiator concept.



Rotating bubble membrane radiator concept 1-G test facility.

High Heat Flux Thin Film Condenser for Spacecraft Thermal Management

PI: John Thornborrow/EC2
Reference SST 2

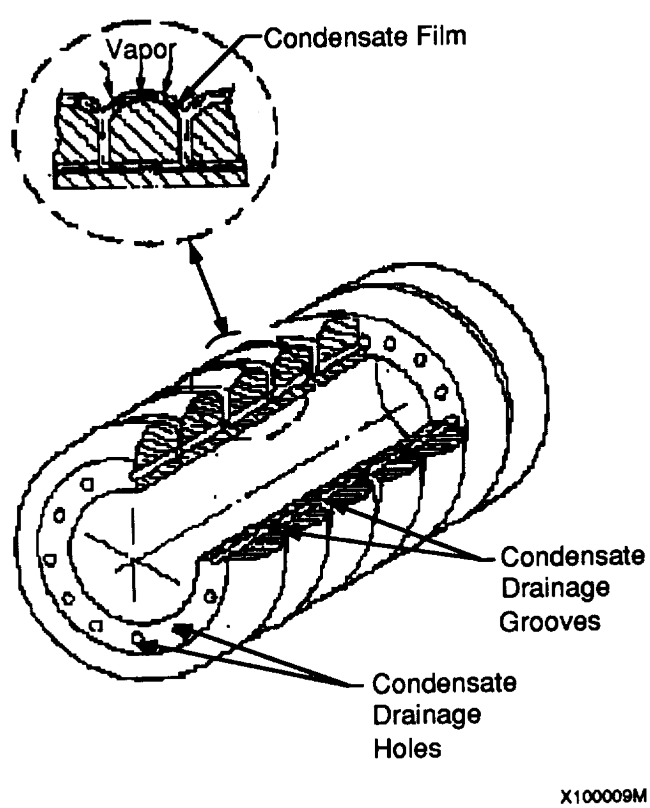
Early spacecraft, such as the Apollo lunar module, operated on 500 W of power and supported a 2-man crew for only a few days. The Space Station Freedom will require up to 75 kW of power, support a minimum crew of four, and operate continuously. As spacecraft become more complex, the active thermal control system (ATCS) also must grow to accommodate these increased requirements. To maintain the minimum possible mass of a thermal system, high heat flux components must be developed. These components must transfer more heat over much smaller areas, thus keeping their mass and volume at a minimum. Creare, Inc., has developed a prototype of a high heat flux condenser that has significant advantages over current designs.

The thin film condenser is a high heat flux two-phase condenser designed to exceed the performance of the Space Station baseline. The condenser design employs fins based on the Gregorig groove, an optimized surface that maximizes the transfer of liquid from the condensing surface into the liquid removal grooves. As depicted in the figure, the heat transfer surface is a collection of fins separated by liquid removal grooves. Each fin has a varying radius of curvature that creates a pressure gradient in the liquid film. This pressure gradient causes the fluid to flow from high-pressure areas at the surface peaks to low-pressure areas in the surface valleys. This continual movement of fluid assures that the thin film will be maintained across the condensing surface and that the condensation process will continue at a high heat flux level with a very low temperature drop.

The thin film condenser is designed to operate at high heat transfer coefficients which allow the design to be very compact and operate with low temperature drops across heat transfer boundaries. Utilizing capillary forces to maintain thin film heat transfer allows the condenser to operate with low pressure drops on both the liquid and vapor sides.

A thin film condenser prototype was fabricated in fiscal year 1990. The condenser fin sleeve was assembled by stacking individual fins (of concentric rings) together and aligning the drainage holes to form drainage passages. The stack was then heat-pressed together until the rings were joined permanently. The condenser sleeve was then integrated into the casing to form the assembled unit. The condenser was tested using alcohol as a working fluid to verify the unit operation. These tests were run successfully; their results verified the expected performance. Using alcohol as a working fluid, the condenser achieved a heat transfer coefficient of 4 W/cm^2-°C with a subcooling temperature of 1° C. The condenser will be tested soon using ammonia as the working fluid to establish a direct comparison with the Space Station requirement. The condenser unit was designed to exceed the Space Station heat exchanger baseline, which now requires the transfer of 2 kW of heat with a temperature drop of $<$ 3° C and a heat transfer coefficient of $>$ 9 W/cm^2-°C using ammonia as a working fluid. The performance of the prototype condenser using ammonia as a working fluid is expected to easily exceed current Space Station requirements.

As spacecraft evolve, they should support more biomass and accommodate ever-increasing power levels. Similarly, the ATCS will be required to reject the ever-increasing waste heat generated within the spacecraft. High heat flux thermal control components such as the thin film condenser will be essential to minimize the mass of the ATCS and to provide spacecraft users with efficient heat rejection.



Low film resistance condenser concept.

Investigation of Long-Term Stability in Metal Hydrides

PI: Patricia A. Petete/EC2
Reference SST 3

Future missions to the Moon and Mars will require the use of a heat pump to reject moderate temperature habitat waste heat during the hot lunar day. Metal hydride heat pumps offer a regenerable alternative to current heat pump technology and have been under investigation for the past few years. Metal hydride heat pumps operate on the principle of absorption and desorption of hydrogen, which are endothermic and exothermic reactions, between two hydride containers (fig. 1). These chemical heat pumps elevate the moderate temperature waste heat to enable rejection to the warmer environment without the power penalty associated with vapor-compression type heat pumps. High-temperature waste heat from a power source is utilized to regenerate the heat pump.

Experimental evidence has shown that raw materials from manufacturing metal hydrides are abundant in lunar minerals such as ilmenite. Ilmenite contains iron and titanium in the correct proportions to manufacture iron-titanium (FeTi), an alloy that reacts with hydrogen to form $FeTiH_2$. If oxygen is to be produced from ilmenite, the mining, beneficiation, and some of the energy and processing required to manufacture FeTi could be written off against oxygen production. FeTi would thus be a by-product, gained through a marginal expenditure of energy. The point of relevance to future NASA missions is that hydrides may not need to be transported from the Earth.

Since the contract start date of 1 September 1989, this effort has focused on investigating the effects of long-term rapid cycling and thermal aging on metal hydride performance. Hydrogen Consultants, Inc., has designed and developed a rapid cycle test apparatus (fig. 2) that allows for cycle times of 360 sec and enables visual observation of the absorption/desorption process. Numerous samples of lanthinum-nickel ($LaNi_5$), lanthinum-gadalinium-nickel ($La_{0.9}Gd_{0.1}Ni_5$), and vanadium hydrides have been exposed to a rapid cycle process. Samples of these hydrided alloys were also sent to the University of Nevada, Reno, for X-ray diffraction testing. Initial results show a change in the a- and c-directions of the lattice structure of vanadium hydrides when cycled from 1000 to 4000 times. Results of $LaNi_5$ cycling (fig. 3) indicate much less degradation of this hydride than originally was expected. However, it does appear as if thermal aging could play an important role in reduced performance of $LaNi_5$.

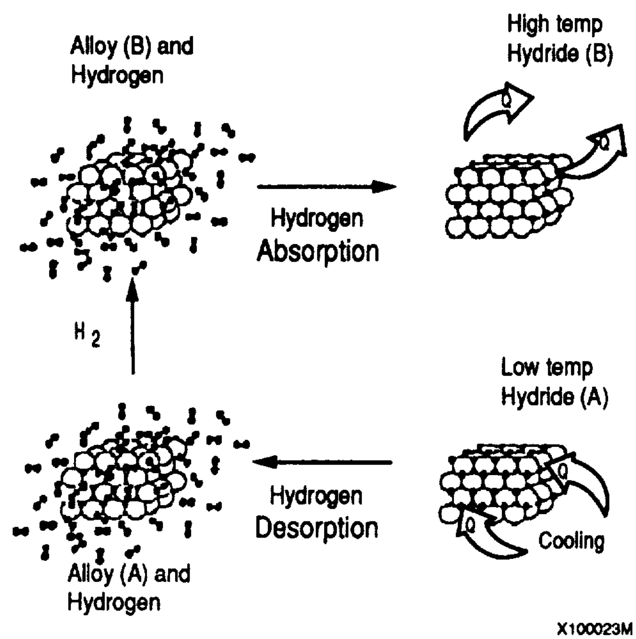


Figure 1. Metal hydride heat pump operations.

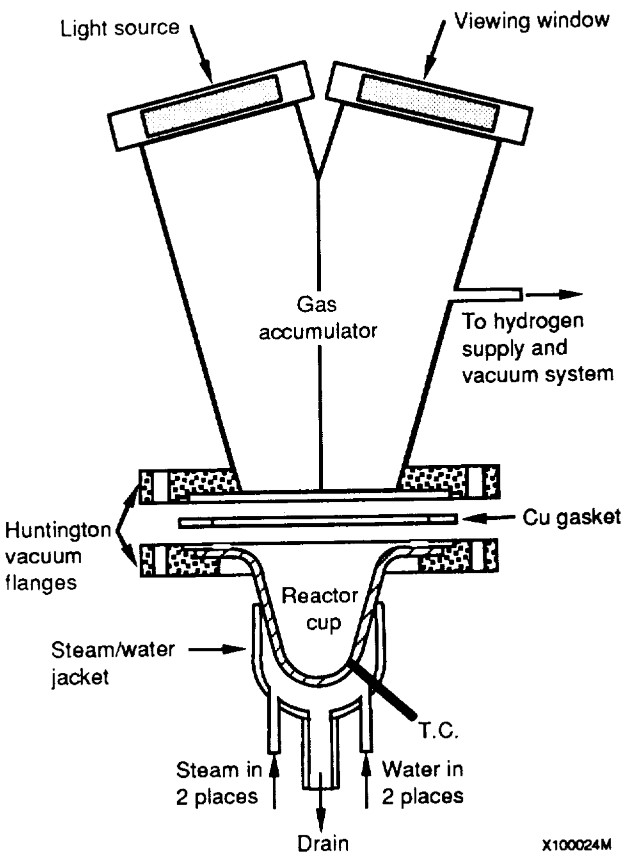


Figure 2. Rapid cycle test apparatus.

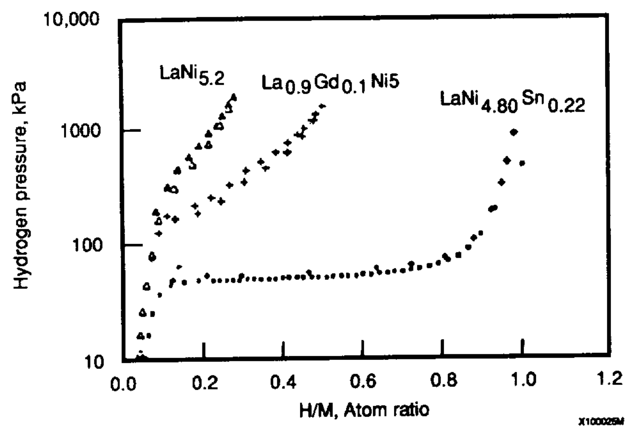


Figure 3. Results of $LaNi_5$ cycling.

Fundamental Process Enhancements in Electrochemical CO_2 Removal

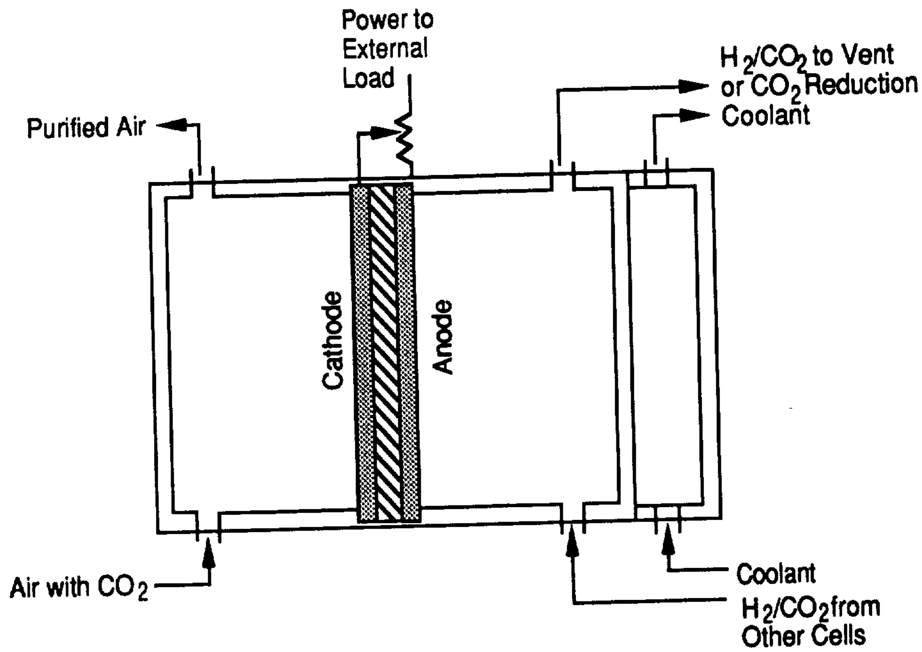
PI: Mariann F. Brown/EC3
Reference SST 4

The objectives of this program are to identify and develop improvements in electrochemical carbon dioxide (CO_2) removal technology. The electrochemical CO_2 removal technology developed to date employs two reactions to transfer CO_2 from the process cabin air across a basic pH electrolyte matrix resulting in high-purity CO_2 at the opposite electrode of an electrochemical cell. A fuel cell reaction combining oxygen (O_2) and hydrogen (H_2) to form water (H_2O) produces the driving force to maintain the chemical reaction of CO_2 with hydroxyl ions (OH^-) to form carbonate ($CO_3^=$) and bicarbonate (HCO_3^-) ions. Similar to the reactions in an H_2/O_2 fuel cell, the transfer reactions are thermodynamically spontaneous, and useful power is generated by the process. The same process can be carried out without the supply of H_2; however, these reactions are not spontaneous, and power must be supplied. Schematics depicting both processes are shown in the figures. The "with H_2" approach has been the most developed process to date. Part of the thrust of the current research is to better develop the "without H_2" process because of the safety concerns of H_2.

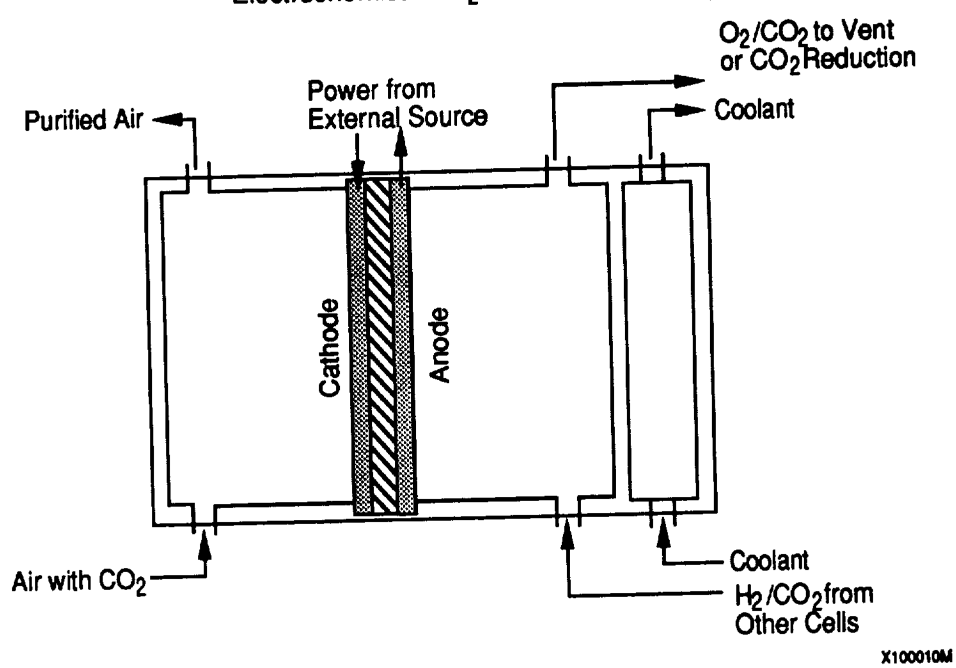
Phase I of this program was completed in February 1990. The Phase I tasks included a literature survey to identify candidate process improvements, laboratory-scale investigations of candidates for each cell component (e.g., electrode, matrix, electrolyte, etc.), and single-cell studies of various combinations of cell components. The single-cell studies included baseline materials and the most promising materials identified during laboratory tests. Cells for operation with H_2, without H_2, and dual operation (a cell capable of operation with or without H_2) were investigated. Several areas were identified where changes from the baseline cell configuration led to improvements in the process. Accomplishments of the program to date include improvement of the electrode structure of the air cathode for both processes (with and without H_2). Specific improvements are higher CO_2 transfer (5-20 percent) and improved cell voltage (50-80 mV) over previously developed systems. In addition, the identifcation and development of the anode electrocatalyst and its substrate material for the without-H_2 process were accomplished.

A 1-year Phase II multicell development effort began early in 1990. The design and fabrication of a multicell unit for CO_2 removal without H_2 also have been completed. Included in the design effort was a test apparatus design to test the multicell CO_2 removal cell in conjunction with an electrochemical O_2 separator. This type of electrochemical system could be used to control the atmospheric levels of O_2 and CO_2 between adjacent crew and plant habitats on a planetary base. Testing of the multicell unit will take place in 1991.

Electrochemical CO_2 Removal with H_2



Electrochemical CO_2 Removal without H_2



Electromechanical CO_2 removal (H_2 variable).

Engineering Analysis of Regenerative Life Support Systems with a Process Simulator

PI: Marybeth A. Edeen/EC7
Reference SST 5

The current Space Shuttle life support system requires water, oxygen, nitrogen, lithium hydroxide, and other consumables which are launched with the vehicle and either are returned to Earth used or are dumped in space. The weight of these consumables is reasonable for short-duration missions but, for longer missions, their weight becomes excessive. Therefore, Space Station as well as future manned lunar and martian bases will require life support systems which reclaim useful material from the waste products generated by the crew. The two major processes include air revitalization, which removes carbon dioxide (CO_2) and water vapor and generates oxygen for the crew, and water reclamation, which purifies waste water and humidity condensate so it can be reused for hygiene or potable water. Modeling of these processes is important in determining the thermodynamic and chemical feasibility of the subsystems and the interactions between the various subsystems.

In fiscal year (FY) 1990, Aspen/Plus – a process simulation tool which analyzes chemical engineering unit operations – has been used to model numerous air-revitalization subsystems and to develop integrated models of three complete systems. In general, the subsystem models are comprehensive and accurately reflect the inputs and outputs from a given subsystem but do not contain detailed information about specific kinetics that occur within the subsystem. For example, the Bosch reactor – which reduces carbon dioxide (CO_2) into water for electrolysis – is modeled as a free-energy minimization reactor in which CO_2 is converted to water and carbon via the overall reaction

$$CO_2\,(g) + 2\,H_2\,(g) \rightarrow C\,(s) + 2H_2O\,(l)$$

In the simulation, the hydrogen (H_2) to CO_2 ratio in the feed is maintained at 2:1. Single pass conversion is less than 10 percent and is based on the free energy minimization of the reactants and products at the reactor conditions. In reality, the reaction is a two-step process in which kinetics determine the composition in the reactor at any time. The comprehensive model is sufficiently detailed to determine system-level interactions because the inputs and outputs are accurate even if the kinetics are ignored. A list of the models completed to date is shown in the table below.

Three integrated system-level models also have been completed in FY 1990 for simulation of the air revitalization system. The first model is the Space Station Freedom air revitalization configuration which is used for the baseline. The second integrated model is an air revitalization system which utilizes biological systems for CO_2 reduction. The biological system is treated as a boundary condition and includes an extra heat exchanger to account for removal of water vapor generated by the plants. The final integrated model utilizes *in situ* resources from the martian atmosphere to allow for partial reduction of CO_2 to carbon monoxide and oxygen.

PROCESS SIMULATION MODELS COMPLETED IN FISCAL YEAR 1990

- Trace Contaminant Removal Subsystem
- CO_2 Removal Subsystems
  - Regenerative Adsorption
  - Non-regenerative Adsorption
  - Electrochemical CO_2 Concentrator
  - Membrane-Based CO_2 Removal
- Temperature/Humidity Control Subsystems
  - Condensing Heat Exchanger
  - Noncondensing Heat Exchanger
  - Regenerative Moisture Adsorption
  - Membrane-Based Water Removal
- CO_2 Reduction Subsystems
  - Bosch CO_2 Reduction
  - Sabatier CO_2 Reduction
  - Advanced Carbon Reduction Reactor
  - Partial Reduction Reactor
- Water Electrolysis Subsystems
  - Static Feed Electrolysis
  - Solid Polymer Electrolysis
- Gas Leakage and Makeup Subsystems
  - Cryogenic Gas Storage/Supply
  - Hydrazine Decomposition
  - Supercritical Gas Storage/Supply

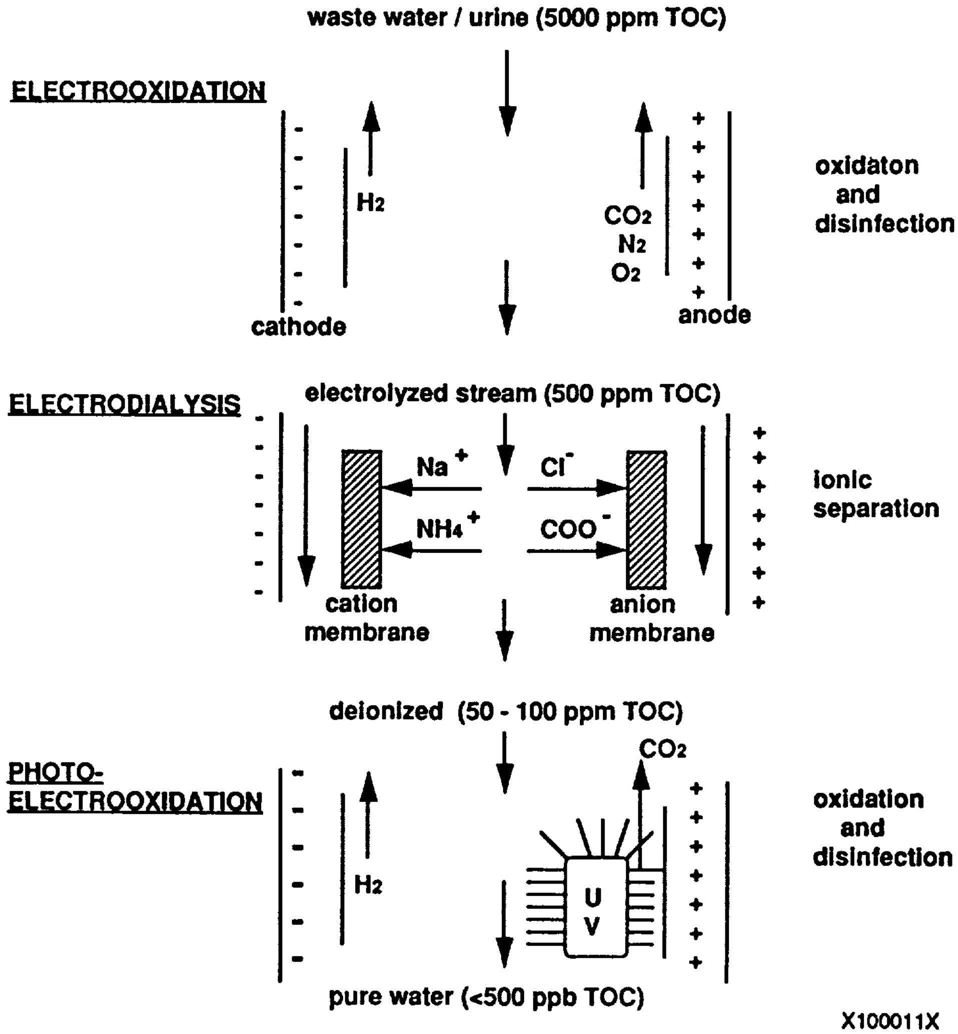
Electrochemical Water Recovery System for Treatment of Waste Waters

PI: Charles E. Verostko/EC3
Reference SST 6

Future manned missions to explore the solar system will require extensive regeneration of consumables. Controlled regenerative processes that eliminate expendable chemicals and hardware components and provide longevity, reliability, and safety are essential to mission success. The water reclamation systems baselined for Space Station Freedom utilize chemical expendables and in-line pasteurization (250° C) for pretreatment, and expendable multifiltration sorption beds with residual disinfection for post-treatment. Replacing these expendables with reliable regenerative processes is important for manned planetary exploration. Processes providing potable and hygiene water free of organic impurities (< 500 ppb total organic carbon (TOC)) and no detectable microbial contamination are required. *In situ* disinfection and direct removal of organic impurities in crew-use waters are required. Recent research completed on a Small Business Innovative Research Phase I contract has demonstrated the feasibility of selecting electrochemical technologies for purifying waste waters for reuse while eliminating the requirement for pre- and post-treatment expendables and in-line pasteurization.

The electrochemical water recovery system (shown in figure) consists of an electrooxidation (electrolysis) process that provides oxidation and disinfection; electrodialysis for separating the anionic and cationic impurities into a brine with > 90 percent of the water recovered; and photoelectrooxidation provides oxidation and disinfection for final polishing of the reclaimed water prior to reuse. The electrooxidation voltage potential is 2 to 4 V and the current is 1 to 3 A. The electrolysis process is discontinued when oxidation of inorganic ions (Cl^-) is detected. Processing then continues with electrodialysis. The organic/inorganic anionic and cationic impurities are separated in an electric field through a potential gradient across anionic and cationic membranes where the ionic species are concentrated into a brine, and the effluent water organic impurity level is reduced to 50 to 100 ppm TOC. The post-treatment (photoelectrooxidation) starts, and the organic impurities are oxidized to levels < 500 ppb, and the reclaimed water is disinfected.

The research accomplished demonstrates a potential electrochemical water recovery system that requires no pre- and post-treatment chemical and multifiltration expendables. Power consumption is estimated to be ~150 Whr/lb of reclaimed water.



Electrochemical water recovery system for treatment of waste waters for reuse.

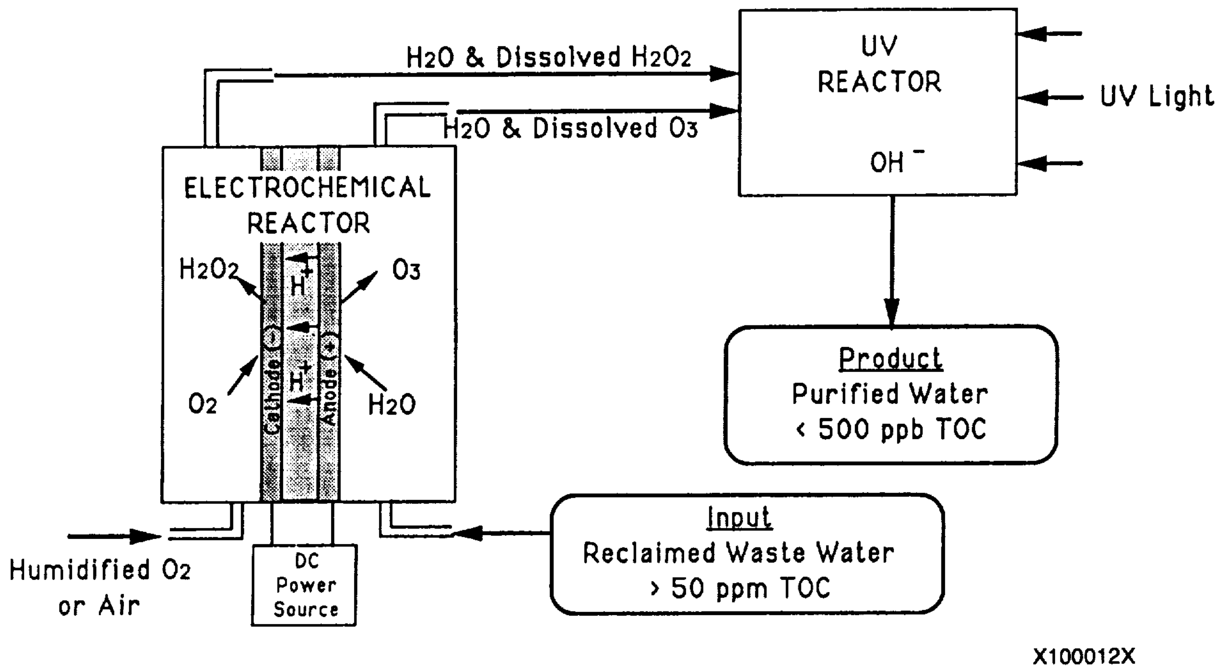
Proton Exchange Membrane-Based Electrolyzer for Water Reclamation Post-Treatment

PI: Charles E. Verostko/EC3
Reference SST 7

The current water reclamation systems baselined for Space Station Freedom utilize expendable multifiltration sorption beds with residual disinfection for post-treatment (i.e., final polishing) of reclaimed waters. Recent research demonstrated the feasibility of using a ultraviolet (UV) proton exchange membrane-based electrolyzer to remove residual organic impurities at concentrations as high as 50 ppm total organic carbon (TOC) to levels < 500 ppb while also providing disinfection. The process technology (see figure), neither requires nor produces chemical or component hardware expendables, such as sorption beds.

The technology incorporates the use of a proton exchange membrane as the electrolyte medium between the anode and cathode. As reclaimed water flows through the electrochemical cell, a small fraction of water is oxidized at the anode to both ozone (O_3) and protons (H^+). The protons generated at the anode are transported by ion exchange across the membrane to the cathode to combine with oxygen as it is reduced to form hydrogen peroxide (H_2O_2). Both the H_2O_2 and O_3 are powerful oxidants of residual organic impurities in reclaimed waters and also are powerful disinfectants for destroying microbial contamination. During initial feasibility evaluation tests, UV light irradiation coupled with the electrochemical generation of oxidants (O_3 and H_2O_2) was found to enhance the oxidation of organic impurities. Testing included evaluating the effectiveness of the process to oxidize organic impurities common to reclaimed waste waters (e.g., urine distillates, wash water permeates, and humidity condensates) at concentrations of 50 to 100 ppm TOC in water. Process disinfection features also were examined by the inoculation of microbial cultures into the test water. For these tests, the TOC impurity content was reduced from > 50 ppm to < 500 ppb. Rapid disinfection of microbial contamination (i.e., *Escherichia coli* and *Staphylococcus epidermitis*) was also produced.

The benefits of this system are *in situ* disinfection; direct and efficient removal of residual organics; elimination of expendables; and no moving parts. Expendables such as sorption bed filters, catalyst beds, and chemicals will have much higher penalties for planetary exploration missions. Expendables required for post-treatment to meet potable water requirements for a crew of four with Space Station Freedom technology are estimated to be ~300 lbs/year and 1000 lbs for hygiene water. A follow-on development in 1991 will include parametric testing, design, development, fabrication, and delivery of a breadboard UV proton exchange membrane-based electrochemical water reclamation post-treatment system.



UV Proton exchange membrane electrolyzer water post treatment system schematic.

Lunar/Mars Candidate Extravehicular Activity Materials Dust and Abrasion Resistance Test

PI: Joseph J. Kosmo/EC6
Reference SST 8

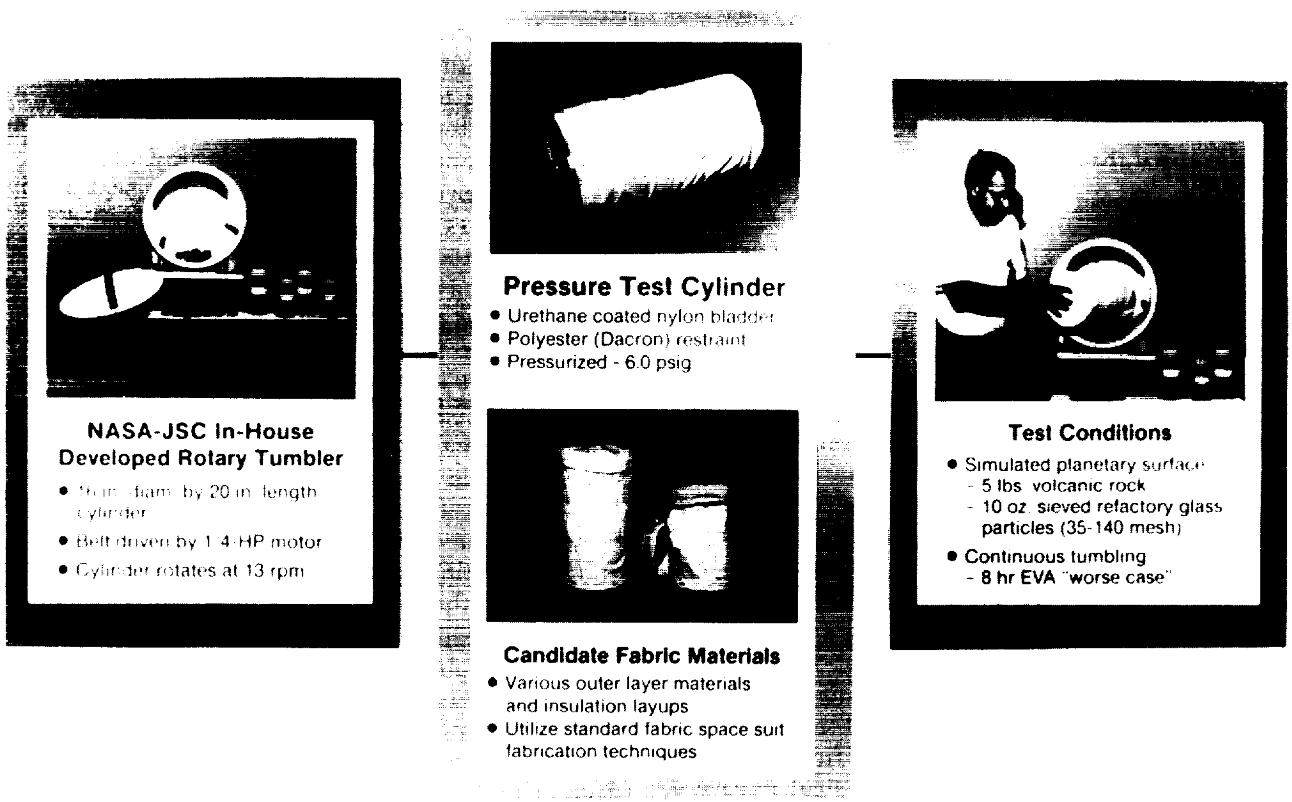
The presence of sharp rocks and dust particles on the lunar and martian surfaces represents a significant challenge to future planetary extravehicular activities (EVAs) in support of extended exploration missions and long-duration stay times beyond those encountered on Apollo missions. Rough surface terrain features – e.g., dust on the Moon and Mars and additional windborne dust in the martian atmosphere – will result in extreme abrasion conditions including deposition of dust on operational systems. Approaches must be developed to provide both abrasion resistance and dust protection as well as to remove dust contamination from space suits so their performance will not be compromised.

Consideration of various space suit abrasion resistance, dust protection, and removal techniques indicates that the selection of a specific design approach will be influenced by the physical nature of the planetary surface and the materials and construction features of the space suit assembly. Experience gained during the Apollo Program showed that, for short-term EVA periods, a majority of the heavier dust particle concentrations could be removed simply by brushing excess dust from the outer surface of the space suit. However, finer grained particles became embedded in the woven fabric outer layer of the thermal/micrometeoroid garment. Dust did not adhere to smooth surfaces or coated fabric areas to the extent seen on exposed woven fabric structures.

Preliminary laboratory tests were conducted to screen the suitability of various "off-the-shelf" selected materials for abrasion and dust resistance. Candidate materials were evaluated for potential application as outer cover layers for future planetary space suits. The abrasion method chosen was a variation of a standard industry test method, but modified to use flat-fabric-to-flat-fabric rubbing rather than the standard flexing bar. This was accomplished by clamping one layer of fabric to the lower surface of the upper stationary plate of a Stoll Universal Wear Test Machine while a second piece of fabric was clamped to the upper surface of the lower reciprocating table. The lower fabric element was deemed the test specimen. This lower specimen moved back and forth on the reciprocating table. To simulate wear conditions under actual use, the upper test plate was dead loaded between 2 and 8 lbs to increase contact pressure on the test specimen; and, finally, a measured amount of simulated lunar soil was sprinkled over the test fabric at the beginning of each test. Preliminary results indicated that, of the material test samples, the Orthofabric and Teflon film-laminated Goretex fabrics appear to be the most abrasion resistant of the candidates evaluated. However, it should be pointed out that comparisons made between materials as a result of a particular laboratory abrasion test are not necessarily the same as those stemming from other test methods more representative of the "as used" condition.

As a result, in-house efforts were performed at the NASA/Johnson Space Center Crew and Thermal Systems Division, Advanced Space Suit Development Laboratory to continue investigating candidate abrasion-resistant space suit materials. The objective of this in-house activity was to provide a test methodology to establish a more realistic exercise to determine comparative abrasion wear characteristics between various candidate fabrics. The developed abrasion test method incorporates a large rotary drum tumbler to induce wear in various fabric test cylinder elements representative of what might be experienced during long-term planetary surface extravehicular excursions. The in-house fabricated tumbler incorporates a large, belt-driven rotary drum turning at 13 rotations per minute into which are placed various size- and shape-simulated planetary surface rocks and abrasive dust particles together with individual fabric test elements. Fabric test elements composed of selected materials were fabricated utilizing standard space suit construction techniques.

Currently, seven fabric test cylinders have been constructed and are undergoing tests. Results of this series of test activities will be used to establish space suit baseline requirements and a design protocol for application to the Exploration Technology Program.



Lunar/Mars candidate extravehicular activities materials dust and abrasion resistance test.

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Human-Computer Interaction Laboratory - Applied Research

PI: Marianne Rudisill, Ph.D./SP34
Reference SST 9

The Human-Computer Interaction Laboratory's (HCIL's) applied research program emphasizes the importance of effective communication between humans and computer systems. The laboratory uses the results from this research to

- Develop human-computer interface (HCI) guidelines, requirements, and standards;
- Design and evaluate HCIs for space systems; and
- Evaluate HCI design techniques.

The HCIL currently is investigating interfaces for use on the Space Shuttle and Space Station Freedom (SSF).

The HCIL continues to expand its research program on the electronic display of procedures. A software system was developed to display a variety of prototype procedures created by the HCIL and other NASA laboratories. An experiment is being conducted to determine which procedure formats (e.g., flowcharts and checklists) are best suited for different types of procedures (e.g., nominal and malfunction). The results of this experiment will be used by the Mission Operations Directorate at the Johnson Space Center (JSC) to define guidelines for displaying SSF procedures.

Research is being conducted on a number of questions concerning interaction with intelligent computer systems (e.g., expert systems). A series of experiments investigated users' performance in identifying faults in spacecraft systems (e.g., the thermal control system). These experiments showed that fault identification can be improved by allocating the selection of information to an expert system. The advantage was greatest in graphical display formats and under heavy processing loads. An experiment is now being developed to examine whether reliance on an expert system results in users forgetting important information about the underlying spacecraft system. The HCIL research on interfaces to intelligent systems was applied in a collaborative project with the Engineering Directorate (NASA/JSC). In this project, HCIL personnel helped to redesign an intelligent interface that will be used by Shuttle flight controllers (for the payload deployment and retrieval system).

Another HCIL research program is focusing on information-coding techniques that can improve how information is presented in computer displays. A review of information-coding techniques is under way. This will be used to develop guidelines for information coding in displays emphasizing human processing capabilities and the specification of tasks and data types. A series of experiments was conducted about the use of color coding as an aid to identifying information in a computer display. While user performance was shown to improve with task familiarity, color coding did not result in any performance enhancement in identification tasks.

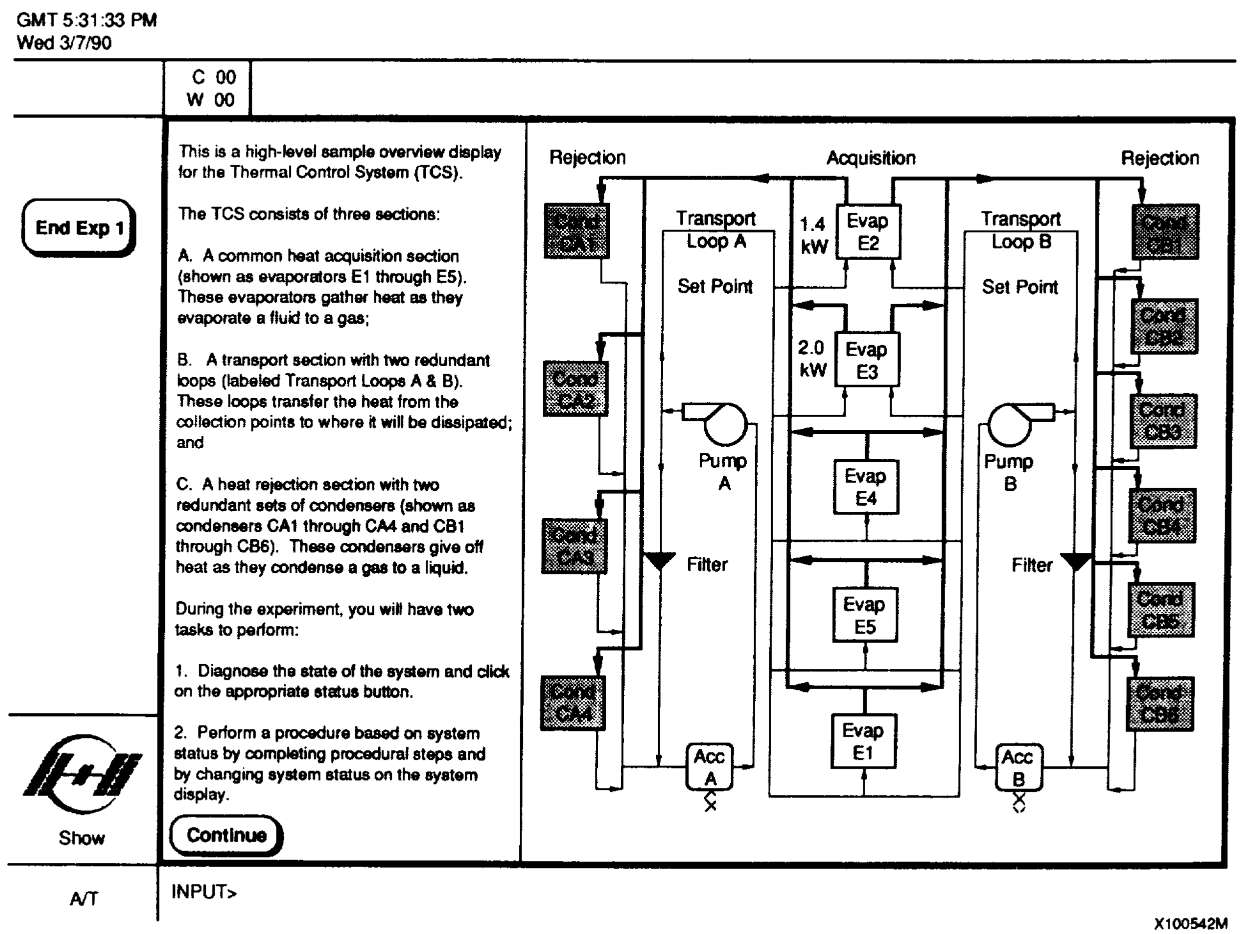


Figure 1. Subject introduction for procedures experiment showing overview and schematic of space-based thermal control system (TCS).

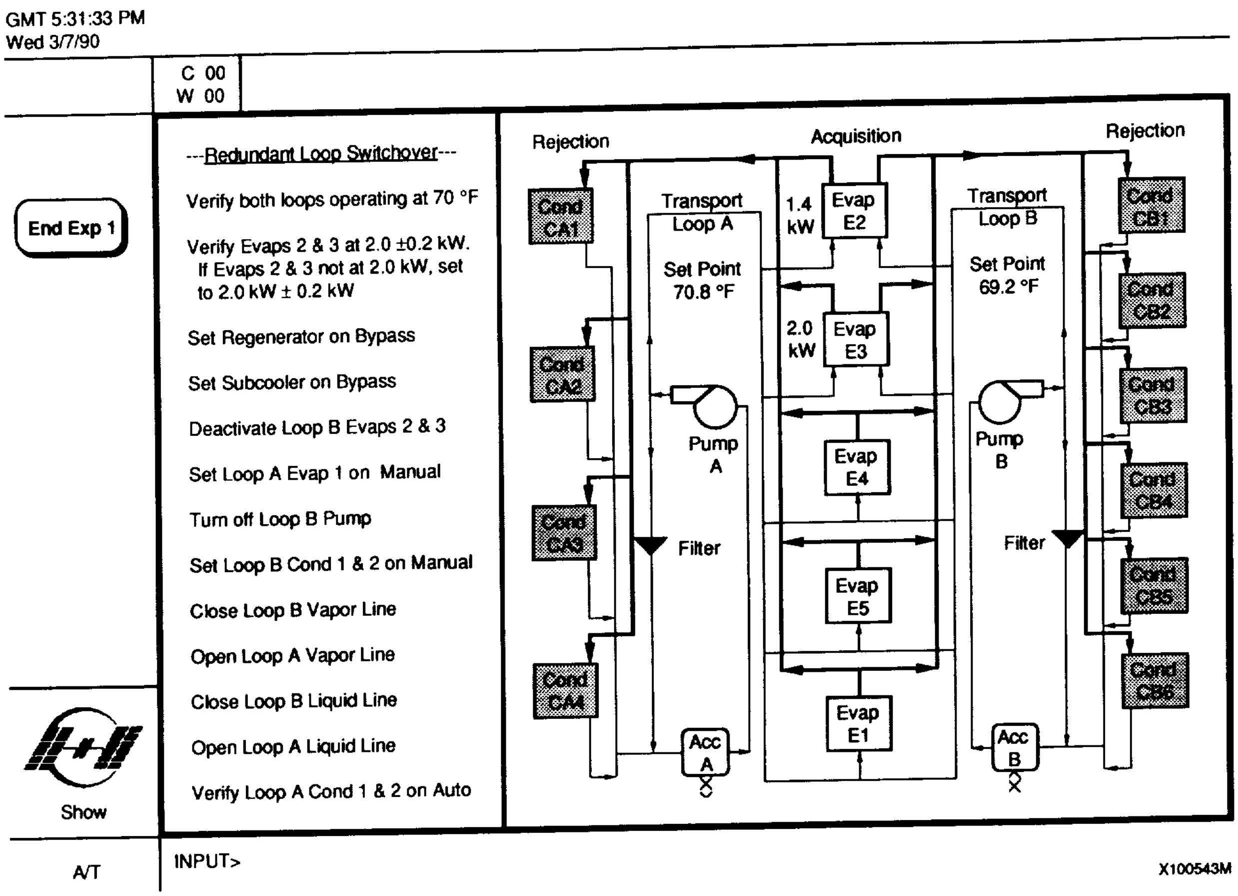


Figure 2. Subjects perform the displayed procedure by interacting directly with procedure text and manipulating TCS schematic objects.

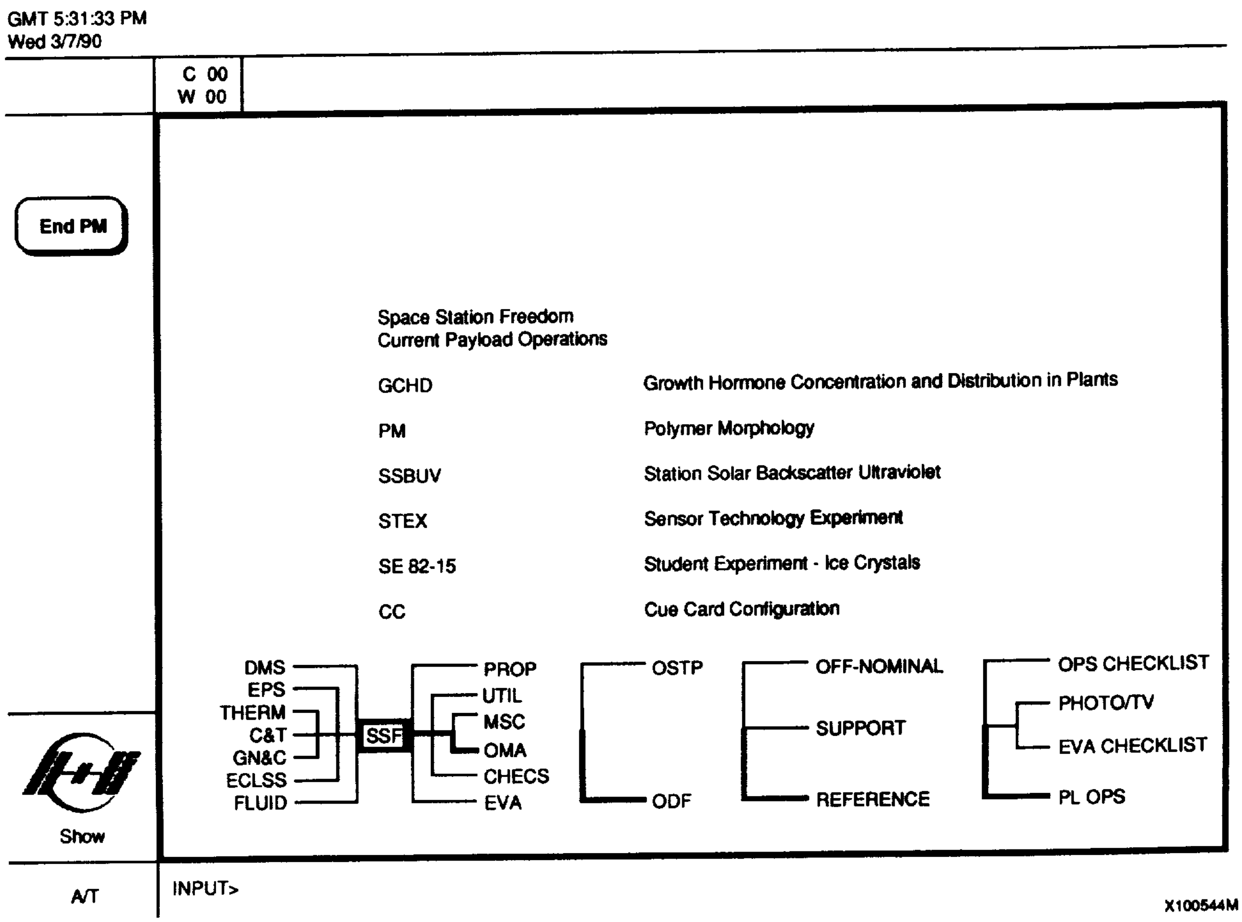


Figure 3. SSF interface navigation tool prototype display for access to electronic procedures.

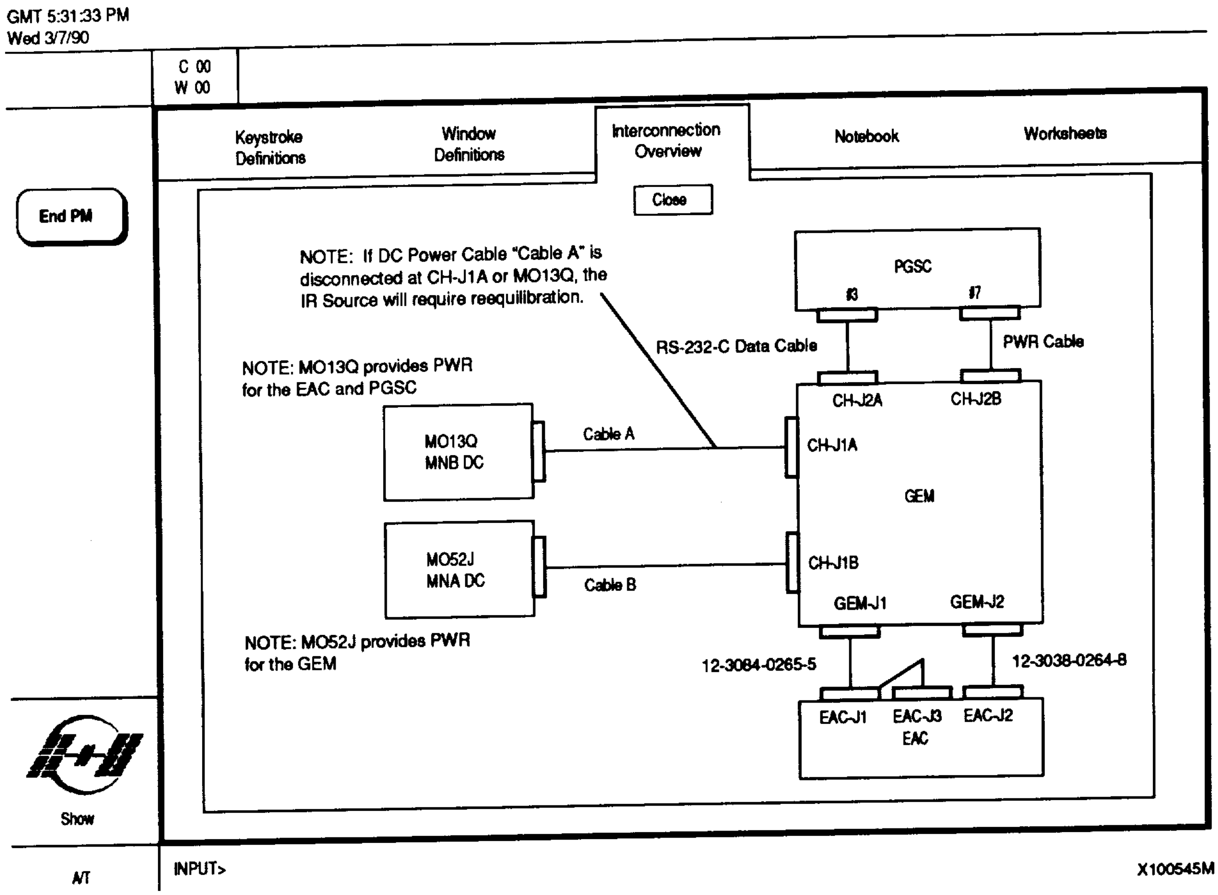


Figure 4. Procedure reference item menu is displayed at the top of screen workspace; schematic of polymer morphology payload wiring has been selected by crewmember and displayed.

Human-Computer Interaction Laboratory – Multitasking Research

PI: Marianne Rudisill, Ph.D./SP34
Reference SST 10

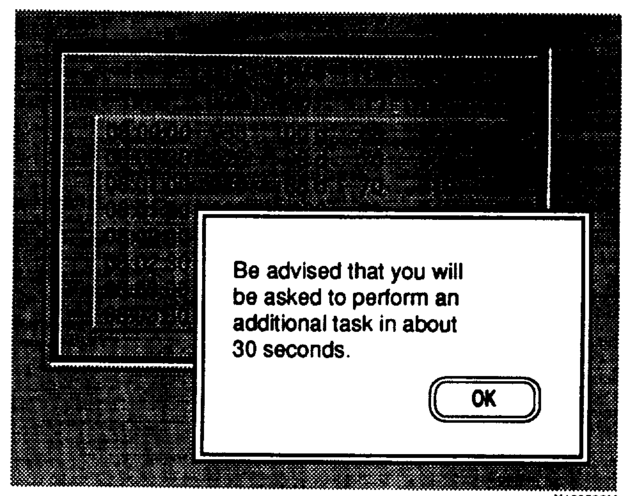
The Human-Computer Interaction Laboratory's (HCIL's) research program emphasizes the importance of effective communication between humans and computer systems. Research results apply to a wide variety of space-related computer systems, from the Space Shuttle to lunar/Mars missions. Specific products of the HCIL include

- Human-computer interface (HCI) guidelines, requirements, and standards;
- Designs and evaluations of HCIs for space systems; and
- Evaluations of HCI design techniques.

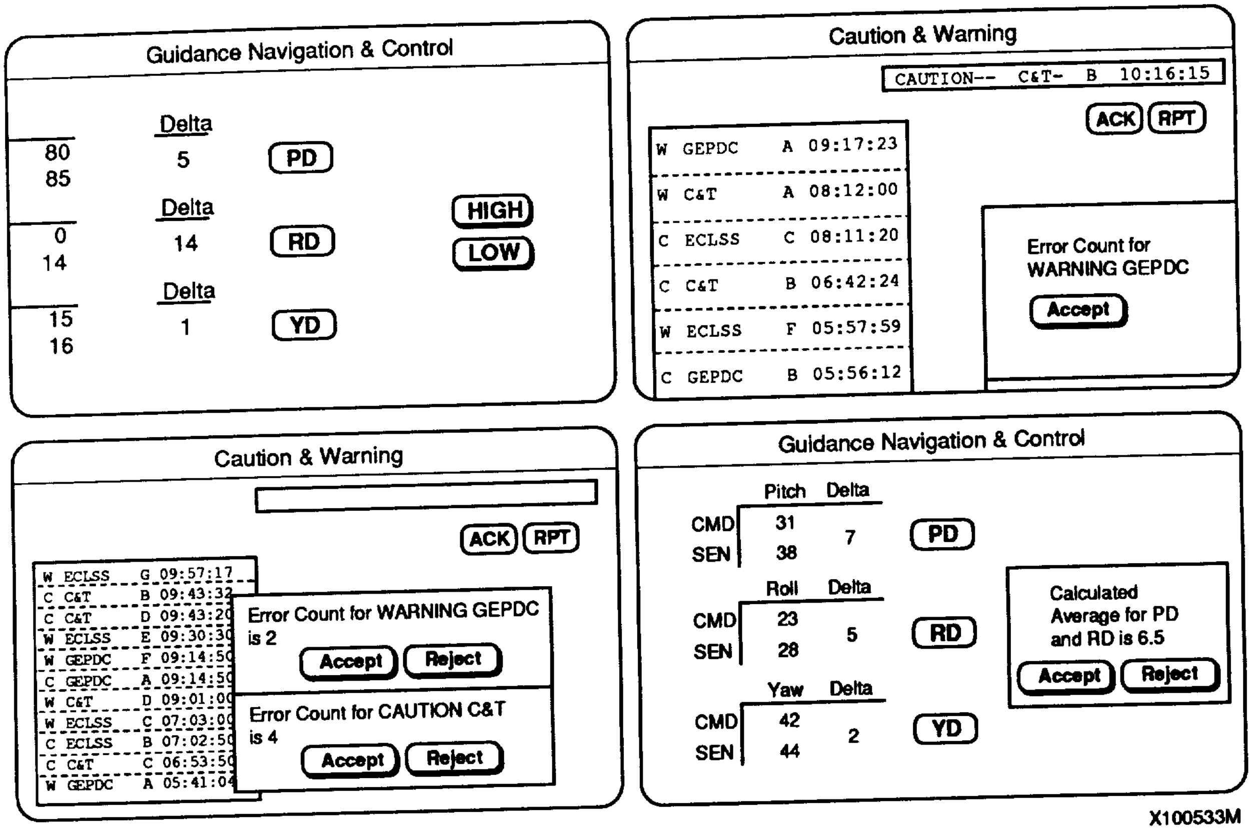
A major area of HCIL research concerns user performance in a multitasking environment. Many advanced spacecraft, as well as other environments, involve user monitoring and interaction with complex systems where multiple pieces of information are provided simultaneously and interruptions are frequent. Two research projects are focusing on how to assist the user in dealing with multitasking environments.

The first project is investigating the cognitive load on the user performing multiple tasks simultaneously, and how best to design the HCI to minimize this load. A current experiment focuses on the importance of various window-management techniques (e.g., resizing, moving, overlapping) for users performing various numbers of simultaneous tasks in a multiwindow environment. Experiment subjects are provided with varying degrees of window-management capabilities and perform either one, two, or four tasks simultaneously. This issue is vital to future systems such as Space Station since windowing capabilities are expensive to provide onboard and the overall benefit of these capabilities is questionable. The extensive detail of data collected in this experiment (which, in addition to automated on-line recording of time-stamped keystrokes, includes recording of time-stamped videotape) also will provide a precise picture of how humans interact in a multitasking environment.

The second project is investigating the effect of interruptions on users. An experiment was conducted to determine whether a user's performance on a primary task was affected by the similarity and priority of an interrupting task. Results showed that highly similar interrupters interfered with primary task performance more than did dissimilar interrupters. However, high-priority interrupters (where users had to discontinue the primary task without warning) did not degrade performance any more than did low-priority tasks (where a warning was available). These findings suggest that, when computer tasks must be interrupted, any aspects of the interfaces that emphasize the dissimilarity of primary and interrupting tasks will improve user performance. The HCIL is designing further experiments on interruptions in multitasking environments as well as observational studies of multitasking in space applications (e.g., flight controllers).



During the primary task, the participant is given either a warning or is not given a warning about an interrupting task.



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Subjects were required to perform four independent space-related tasks simultaneously that were displayed either in tiled window mode (as shown) or in overlapped window mode.

Human-Computer Interaction Laboratory – Pathfinder Research

PI: Marianne Rudisill, Ph.D./SP34
Reference SST 11

The Human-Computer Interaction Laboratory's (HCIL's) research program emphasizes the importance of effective communication between humans and computer systems. The HCIL Pathfinder research focuses on applied human-computer interface (HCI) issues of importance beyond Space Station Freedom. Results from this research will be used to

- Develop HCI guidelines, requirements, and standards;
- Design and evaluate HCIs for space systems; and
- Evaluate HCI design techniques.

A major focus of HCIL Pathfinder research is the evaluation of HCI design techniques. Such techniques are necessary to enable HCI designers to consider the needs of users when developing the complex computer interfaces that will be used on advanced space missions. The HCIL has conducted an extensive literature review of a new interface design technique – analytical models. This review suggests that analytical models (e.g., the [goals, operators, methods, and selection rules] GOMS model) show promise in helping designers generate and evaluate preliminary HCI designs. However, practical issues, such as the time it takes to develop models, must be considered before such models can be used in real design organizations.

Another project is evaluating the knowledge-elicitation and -acquisition techniques that allow an interface designer to assess the task domain knowledge of an expert (e.g., a flight controller). This assessment of task knowledge is an important part of the early phase of HCI design. An experiment is being conducted to compare the effectiveness of four knowledge-elicitation techniques; i.e., verbal protocols, psychological scaling, structured interviews, and linear decision techniques.

In a third project focusing on HCI design, the HCIL is helping to organize a workshop – the *Human-Computer Interface Design: Success Cases, Emerging Methods, and Real-World Context* workshop – that will be held in July 1991. This workshop will unite developers of interface design techniques and HCI design practitioners (designers and their managers) to discuss the opportunities and problems of implementing improved HCI design techniques in complex organizations. The workshop's proceedings will be published in an edited book.

In addition to evaluating HCI design techniques, HCIL Pathfinder research also has focused on forecasting the information technologies and crew tasks that will be part of long-duration space missions (e.g., a manned Mars mission). A literature review of articles on future trends in information technology has been conducted, and abstracts of these articles have been entered in a computer-based Advanced Information Technologies database. Primary task analyses have been performed for a number of crew tasks on long-duration missions that will involve information technology. A detailed task analysis is under way for one such task (planning planetary exploration routes); and it is projected that HCI techniques to support this type of crew task will be explored in future laboratory work.

Concept Maintenance Workbench – Work Surface Evaluation

PI: Frances Mount/SP34
Jason Beierle/C95
Reference SST 12

It has been stated that the objective in human factors is to fit the workplace/task to the human. Good human factors design incorporates this objective with the knowledge of human capabilities to optimize the human-machine interface.

Much knowledge is now available for workplace design in the confines of a "normal" Earthbound design; the influence of gravity on the fit and function of a workstation as well as the ability to apply force is not of tantamount concern. However, in zero-g, the common design principles that take advantage of gravity now become apparent. Comfortable, relaxed body postures as well as the ability to apply force change a good deal in space.

During Skylab missions in the weightlessness of space, it was noted that the crew naturally adopted a relaxed body posture that differed from a normal one-g posture. In Skylab, the crew worked and lived in larger volumes than in previous U.S. manned spacecraft. Thus, zero-g design knowledge was not available for Skylab. Basically, the Skylab design accommodated either the one-g sitting or standing posture. Neutral (relaxed) body posture (NBP) has been described as neither sitting nor standing but as falling somewhere in between. Skylab Experience Bulletin No. 17 (*Neutral Body Posture In Zero-G*) states: "It was realized that fitting the workstation to the crew population would influence comfort, physical well-being, and output efficiency."

Complaints from the Skylab crew included:

- It was difficult to lean forward and fatiguing to hold position.
- It was difficult to sit in a chair.
- The most sensitive angle is that of the body and upper leg. Closing this angle caused tension in the body that was described as "having partially completed a one-g sit-up and then having to hold that posture."

The concept of an angled work surface was proposed to address the difficulties itemized above. The Space Station maintenance workstation design is of interest for meeting these unique design requirements. The workstation is to be a high-capability workstation for simple to fairly complex and time-intensive diagnostics and repairs.

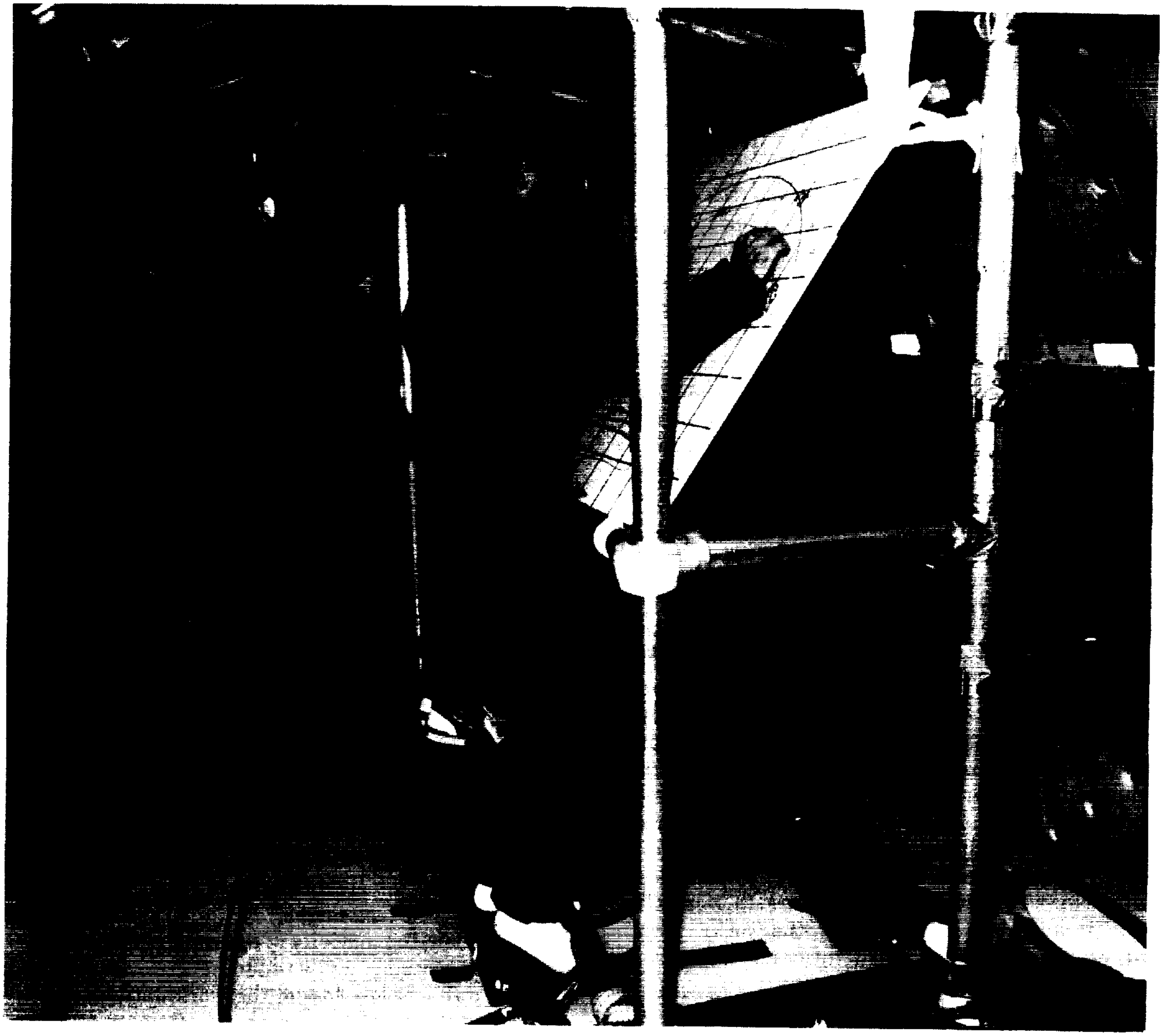
Objectives of the work surface evaluation were

- To compare work surface angles during simulated zero-g in KC-135 aircraft for accommodation of NBP as related to fit, feel, and reach accessibility.
- Based on KC-135 study, to determine an optimal work surface elevation.
- Using PLAID (a man-modeling computer program) reach envelopes, to verify KC-135 analysis (effect of elevation) by comparing optimal work surface elevation against a proposed standard (horizontal) work surface design.
- To package results in a presentation format for timely input to the proposed design.

Six work surface positions from zero (horizontal) to 65° were analyzed during the KC-135 test flight. Data acquisition included an in-flight recording of each distance at each work surface elevation, a post-test debriefing, and a dedicated and portable video. An optimal work surface position of 4° was determined based upon maximum extended reach across the work surface, minimal bending at the waist, and good visibility of an orbital replaceable unit mounted on the work surface.

Next, the PLAID graphics system at the NASA Johnson Space Center was utilized to show reach envelopes of anthropometric figures in relation to the changing work surface angles At the optimal work surface position, the majority of the work surface was shown to be accessible while in the NBP; however, at the horizontal position, less of the work surface was accessible in the NBP. Increasing the figures' depth of reach across the horizontal work surface resulted in bending at the waist.

Although reach accessibility to all portions of the work surface was of major interest, the importance of accessibility of other workbench surfaces and volumes was illustrated in this analysis. This becomes meaningful when attention is given to the reach accessibility of workbench displays, controls, drawers, floating items, etc. For any of these considerations, the raised work surface configuration seems to offer a more usable design for accommodating the operator in a zero-g environment.



Maintenance workstation – work surface mockup onboard the KC-135.

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Hatch Viewport Size and Its Impact on Viewing on Space Station Freedom

PI: Frances Mount/SP34
Boyd Morrison/C95
Reference SST 13

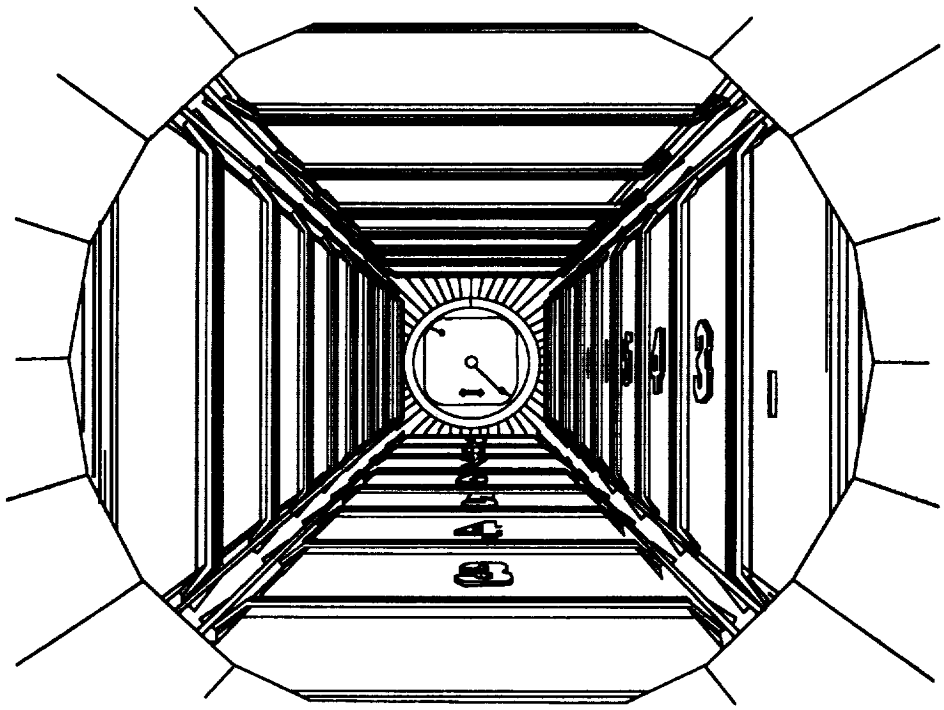
Hatch viewports are deemed necessary for the safety of crewmembers onboard Space Station Freedom and are required by program documents. Viewports can aid astronauts in the inspection of Space Station modules from the exterior in the event of a module depressurization or power loss. Before reentering a module following a fire, a crewmember can inspect from the exterior for potential hazards such as residual fire, smoke, or exposed arcing electrical wires. Other possible uses of the viewports might be viewing of pressurized element berthing alignment guides for connecting modules, contingency viewing of extravehicular crewmembers during a space walk, and communications via hand signals with an extravehicular astronaut who has a disabled radio.

While the consensus is that hatch viewports are necessary, reduction of the viewport diameter is a tempting way to reduce weight during Space Station reconfiguration. This was first proposed by replacing the glass viewport with a "fish-eye" lens similar to peepholes found on apartment front doors to obtain wide-angle views of the module from the exterior. The lens would have only 2 in. diameters, while the current hatch viewport has an 8-in. viewing diameter. This would save weight, but it has some serious drawbacks. Wide-angle lenses are not reversible, thereby requiring that one lens look in each direction for viewing from both sides. Peepholes offer a distorted view of objects, even when the object is near the peephole. Beyond 2 ft, the "fish-eye" lens is unable to focus at all. For this reason, a crewmember cannot look through two hatches simultaneously. Moreover, one's eye must be close to the peephole for viewing, which makes use of the viewport impossible for a crewmember wearing a space suit.

Another means of saving weight is to use the same glass specifications for the current viewport but to reduce the viewport diameter. The proposed reductions are to diameters of 6, 4, and 2 in. Studies conducted in the Man-Systems Division at the NASA Johnson Space Center have shown that, for viewing into a module, the minimum diameter for a hatch viewport should be 6 in., with the current 8-in. diameter being optimal. These studies were conducted using a 3-dimensional computer modeling tool containing the dimensions of the baselined Space Station configuration. Analyses included simulated views of the interior of a module through hatch viewports of various sizes using the computer modeling tool. Additionally, an independent geometrical analysis of line-of-sight views through viewports was performed. Both analyses agreed with each other.

Studies simulated views seen by both a crewmember in a pressurized environment and a spacesuited crewmember. The crewmember was assumed to be constrained to a position directly in front of the viewport while looking into a well-lighted module. In both circumstances, views through the 6-in. diameter viewport were significantly better than through the 4- and 2-in. diameter hatches. Other arguments for 6-in. diameter viewports include: the ability for depth perception, which is lost with the smaller diameter viewports; and the ability to look through the viewport into a module during a power failure while simultaneously using a flashlight, which is awkward or impossible with the smaller viewports.

Future studies will be undertaken to determine whether current viewports can meet the needs of the Space Station after module restructuring.



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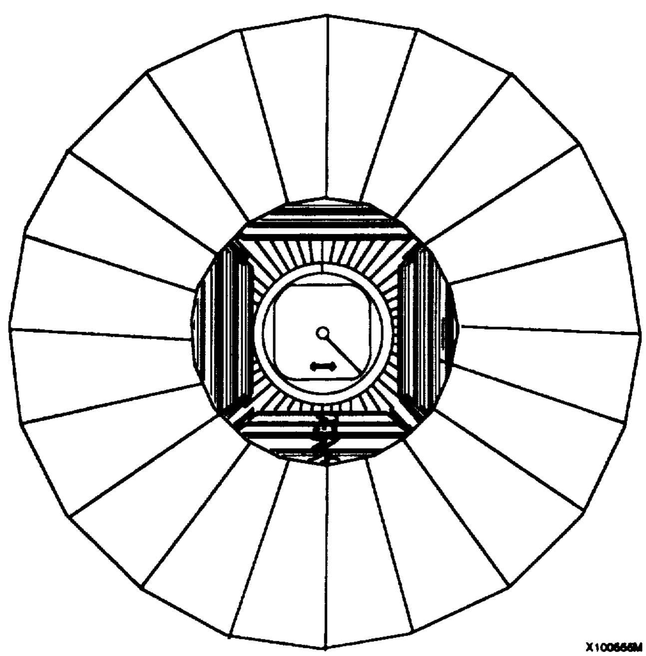
View into module through closed node hatch 6-in. diameter viewport **located at hatch center; eyepoint set back** 3 in. from glass surface.



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View into module through closed node hatch 2-in. diameter viewport located at hatch center; eyepoint set back 3 in. from glass surface.

Derivation of Space Station Window Viewing Locations

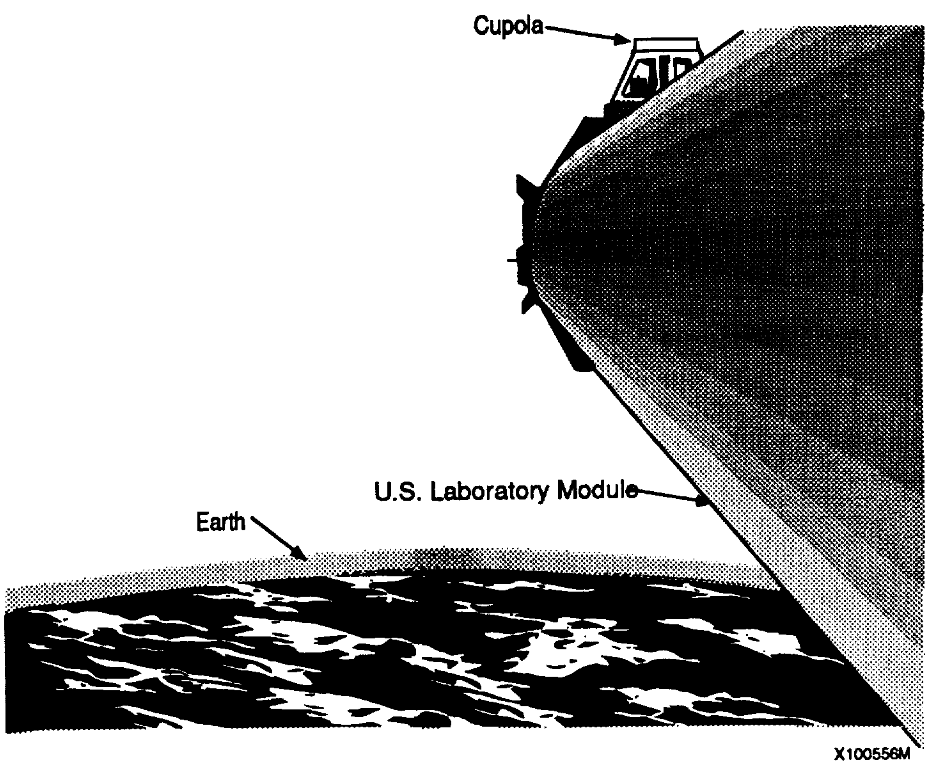
PI: Frances Mount/SP34
Boyd Morrison/C95
Reference SST 14

The potential exists for scientific and technical viewing to be accomplished through windows on Space Station Freedom. While high-optical quality windows have not yet been baselined in the Space Station, studies have been done in the Man-Systems Division at the Johnson Space Center to determine the optimum viewing locations meeting the scientific users' needs and conforming to structural requirements. All viewing studies were done using the Graphics Analysis Facility (GRAF), a 3-dimensional computer modeling tool containing the dimensions of the baselined Space Station configuration.

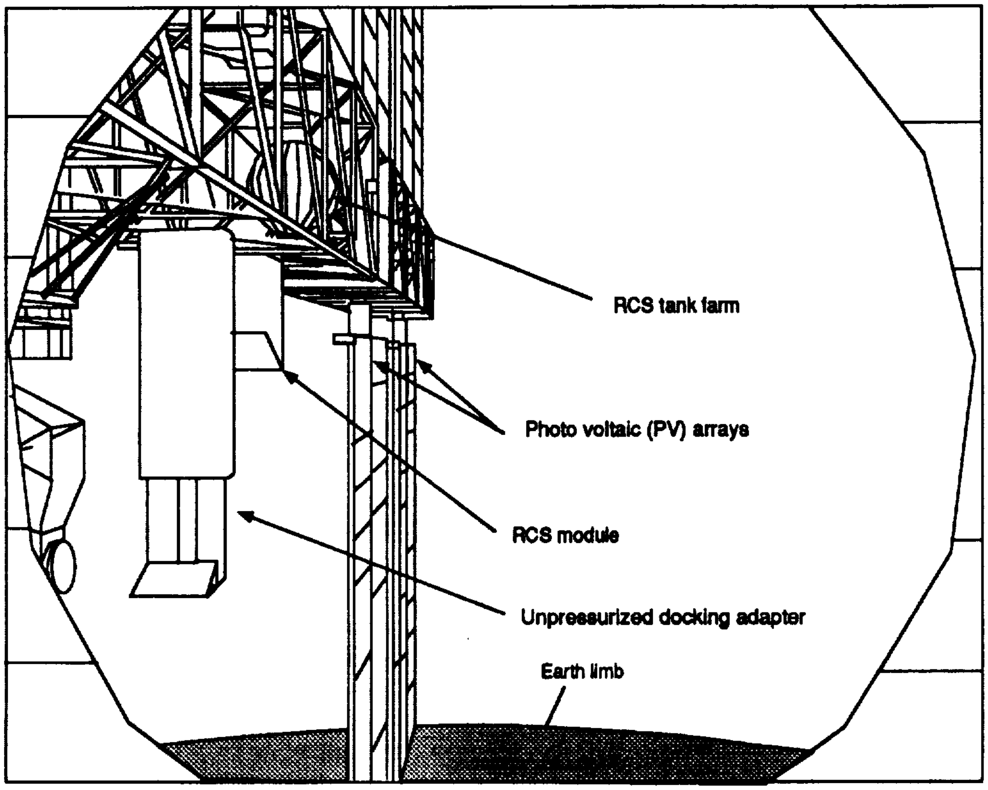
Scientific users require viewing in the nadir or Earth-facing direction and also in all directions along the horizon. The simplest design to accommodate the users' needs would be a nadir-mounted cupola attached to a node. As it is configured now, the Space Station is equipped with a nadir cupola. However, the operational activities already taking place in this cupola preclude scientific use. As no other node is available on the nadir side for placement of a cupola, it was determined that a dedicated user cupola placed on the port side of the Space Station would satisfy user requirements. This could be accomplished by using an already designed cupola with higher quality windows or designing a cupola especially equipped for scientific operations. Viewing needs in the starboard direction could be met by a window in a starboard hatch.

The cupola option would be the most desirable in terms of viewing and meeting the needs of the scientific community. But cost considerations reduce the appeal of a dedicated scientific user cupola. Therefore, sites were selected in the Space Station, outside of the habitability module, that make use of current window design and conform to user needs. After structural considerations and previously occupied rack locations were taken into account, locations in the laboratory module and resource nodes suitable for window placement were identified by analysis. Views were generated in the GRAF from the selected positions to confirm that window placement would meet the scientific users' requirements for viewing.

Future studies will use information about the reconfigured Space Station Freedom and plot the optimum viewing locations available within such a station.



View of Earth horizon from a dedicated user cupola located on the port side of Space Station Freedom.



View of the Earth horizon from a Space Station Freedom laboratory module port window.

The Role of Perturbed Sensory Feedback in Space Remote Manipulation Tasks – Preliminary Guidelines

PI: A. Jay Legendre/SP34
Reference SST 15

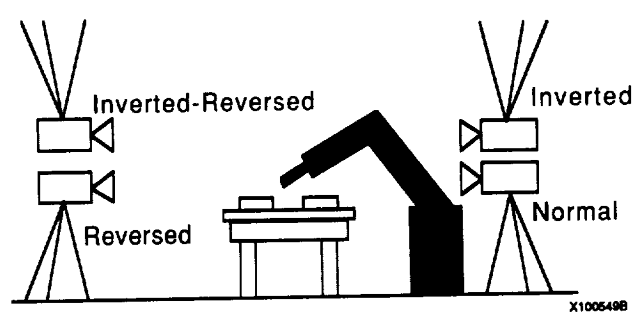
Remotely operated systems (e.g., manipulators, cameras, free-flyers) will be used heavily for the assembly, maintenance, and servicing of NASA's extant as well as future spacecraft and installations. The visual system may be the single most important source of sensory information for the operator of the various remotely operated systems that will be used. Cameras often will provide the primary mode of visual feedback to the operator concerning manipulator position, orientation, and rate of movement. Perturbed sensory feedback is defined here as a disturbance or transformation in the normal pattern of sensory feedback (e.g., visually reversed, inverted, inverted/reversed).

This report details a preliminary investigation of the use of perturbed visual feedback during the performance of remote manipulation tasks. Four test subjects with prior dexterous remote manipulation experience performed a remote manipulation task in the Remote Operator Interaction Laboratory at NASA's Johnson Space Center while exposed to the following camera-viewing conditions (refer to first figure): "normal" or zero-degree displacement, reversed, inverted/reversed, and inverted. Performance and subjective data were collected from each test subject.

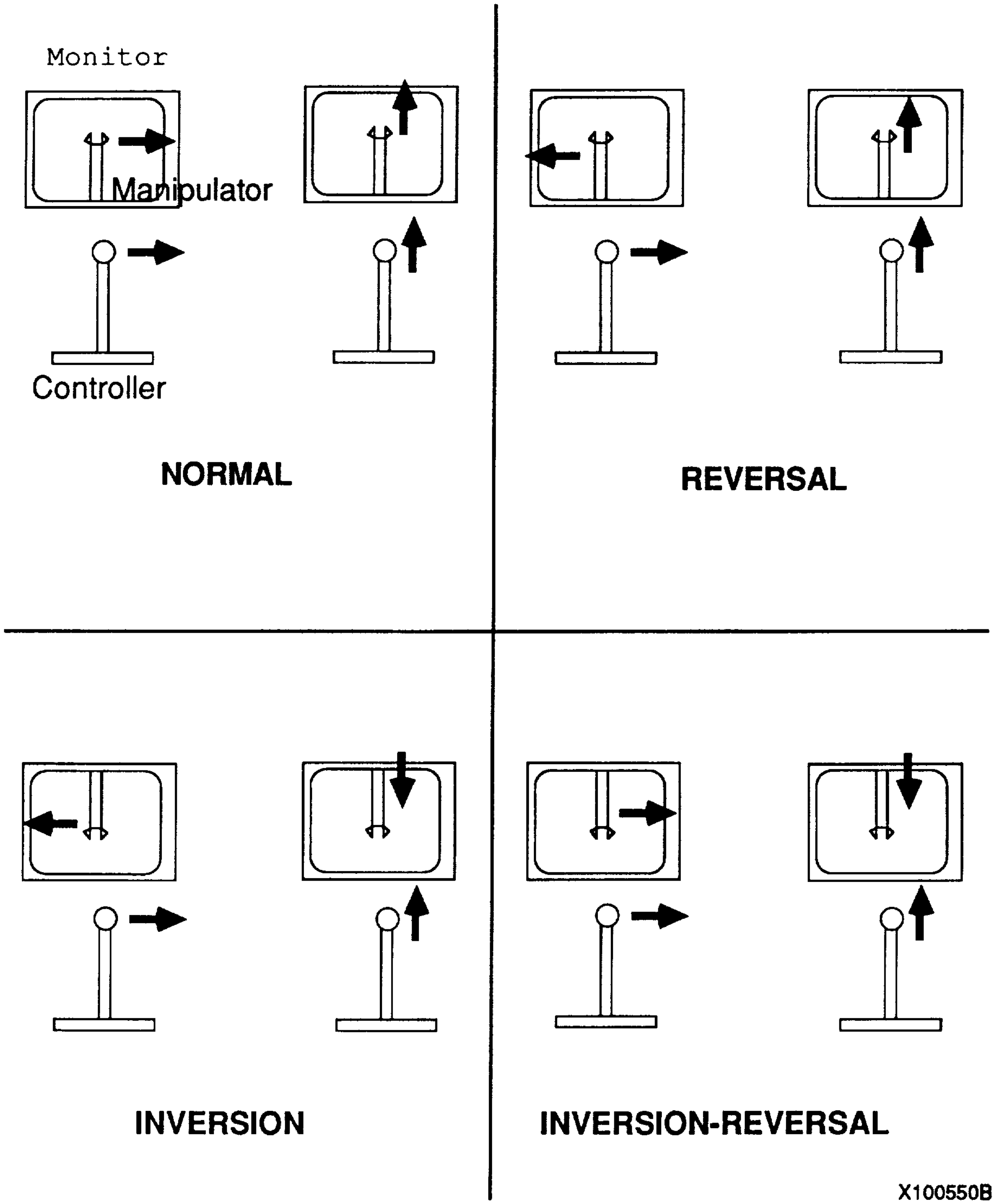
The first objective of this study was to determine how various types of visually perturbed feedback differentially affect the performance of various types of remote manipulation tasks. Data analysis revealed that all perturbed viewing conditions were significantly worse in performance time than the normal viewing condition data, although statistical analysis did not reveal significant differences between the perturbed viewing conditions. The second figure illustrates the inconsistency between hand controller movements and viewed manipulator movements on a monitor with respect to the different perturbed viewing conditions.

The next objective accomplished was to determine if test subjects exhibited any adaptive strategies which would allow them to perform remote manipulation tasks more efficiently while exposed to perturbed visual feedback. The following adaptive strategies were gathered from the test subjects: use movement of hand controller as a reference point, not the movement of the manipulator on the screen; position grippers in front of and behind object to be grappled, then lightly make contact with the end effector, to help ensure a clean grapple; use shadows at the remote worksite to serve as a guide; and move the manipulator arm away from the task piece area and move around in all axes to determine the type of perturbed visual feedback before attempting remote manipulation tasks,

The final objective was to use the data collected and analyzed during this investigation to formulate the following set of preliminary guidelines: use perturbed visual feedback as little as possible; provide information on camera placement and orientation; train operators to perform tasks under perturbed viewing conditions; use a "camera-oriented" rather than "manipulator-oriented" control mode; maximize visual cues provided to the operator (e.g., position of task pieces with respect to the end effector), markings at the remote task site, use of shadows; and consider the type of task, or types of functions, that need to be performed since performance of critical tasks requiring a high level of precision perhaps should be avoided, if possible. This preliminary list should in no way be construed as complete. More testing will be conducted so that all aspects related to this critical issue can be researched thoroughly.



Camera viewing conditions used.



Viewed manipulator movements with respect to controller movements per camera viewing conditions.

Space Station Hand Controller Commonality Tests

PI: Dean G. Jensen, Ph.D./SP34
Gregory C. Blackburn/EK54
Reference SST 16

A variety of dexterous robots, crane-type remote manipulator systems (RMSs), and free-flyers will be controlled by the Space Station Freedom crew. Six different hand controller configurations have been proposed for crewmembers to control these devices. The Man-Systems Division of the Johnson Space Center (JSC) was asked to determine the appropriate level of commonality for Space Station hand controllers. A hand controller evaluation process was conducted which included representatives from the international Space Station robotics systems, the hand controller providers, and the JSC test facilities.

The hand controllers evaluated in this study consisted of the Space Shuttle Type Two (one rotation and one translation) three-axis hand controllers (or 2×3-degree-of-freedom (DOF)) rate controllers, a Canadian CAE 6-DOF rate hand controller, a Honeywell 6-DOF hand controller (capable of rate, position, and force-reflection modes), the National Space Development Agency of Japan/Toshiba hand controller (also capable of rate, position, and force-reflection modes), a modified Martin Marietta/Kraft mini-master controller (capable of rate and position modes), a commercial off-the-shelf Kraft mini-master controller (used only for force-reflection node), and a Schilling Omega mini-master controller (capable of rate, position, and force-reflection nodes).

Four JSC facilities were used by astronauts and other experienced subjects to test hand controllers for RMSs, dexterous manipulator, and free-flyer applications. The JSC Systems Engineering Simulator cupola provided dynamic simulations of an RMS logistics module transfer task and a free-flyer docking task. The JSC Displays and Controls Laboratory provided kinematic simulations of joint RMS/flight telerobotic servicer (a dexterous manipulator) orbital replacement unit (ORU) changeout tasks. The Man-Systems Remote Operator Interface Laboratory provided a hardware simulation of three dexterous manipulator tasks – an ORU (dual-peg) changeout task, a quick-disconnect task, and a thermal blanket task. The Man-Systems mockups were used for hand controller volumetric tests in the Orbiter full fuselage trainer, the Space Station cupola, and the Space Station command and control workstation.

The hand controller commonality participants and the JSC facilities and resources together made possible a hand controller study which compared more tasks, modes, and hand controllers than any previous study. This study also was unique in that it addressed space-based applications exclusively. Nine crewmembers with varying experience collectively spent over 200 hours, and 20 experienced noncrew subjects collectively spent over 270 hours testing the six different hand controllers in the four JSC facilities. Various objective (e.g., task completion time, hand controller inputs, etc.) and subjective (questionnaires addressing mental workload, physical discomfort, acceptability, etc.) measures were taken after the completion of each task with each hand controller.

Results indicated that the 2×3-DOF configuration which is similar to that of the current Space Shuttle most consistently ranked highest for both crew and noncrew objective and subjective measures across the tasks. It also was found that dexterous manipulator tasks were performed more quickly with rate modes than with position modes and that there was no evidence that force reflection to the hand controller facilitated performance across tasks.

These results indicate that a single hand controller configuration is best suited for crewmembers for all Space Station applications. Implementing these recommendations results in power, weight, volume, cost, and crew training savings for the Space Station Freedom Program as well as increased crew productivity on orbit.

Space Station Freedom Fluid Coupling Tasks – An Evaluation of Their Space Operational Compatibility

PI: A. Jay Legendre/SP34
Reference SST 17

The development of Space Station Freedom (SSF) tasks that are compatible with both telerobotic and extravehicular activity (EVA) is necessary to ensure successful day-to-day operations. One task that is likely to be routine onboard SSF will be the changeout of various quick-disconnect fluid couplings. Such fluid couplings will allow on-orbit resupply of various liquids and gases; e.g., propellants, pressurants, and coolants.

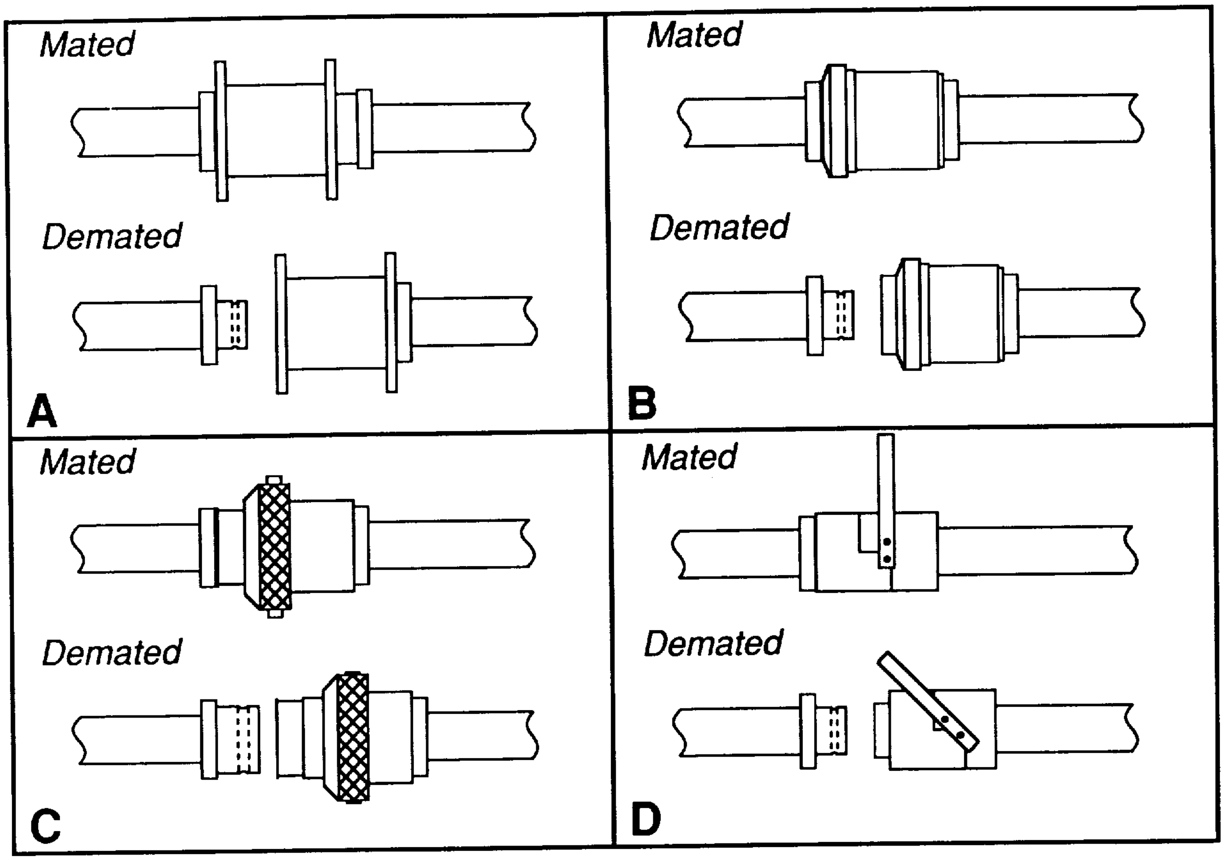
At present, many quick-disconnect coupling designs exist which allow quick mating and demating by the extravehicular astronaut. Since it is likely that telerobots will be assigned these activities as well, the compatibility of the couplings to the telerobot must be altered. In response, Symetrics Inc., a custom fluid coupling manufacturer, has developed quick-disconnect fluid couplings designed to be compatible with both modes of operation. These iteratively designed couplings are the result of feedback from various laboratories dedicated to research in telerobotics and remote manipulation. The result is a coupling modified from an existing design with certain characteristics enhanced to improve telerobotic compatibility.

To assist in resolving design issues, the Remote Operator Interaction Laboratory (ROIL) at NASA's Johnson Space Center performed an investigation evaluating the custom coupling as well as the three standard fluid coupling designs illustrated in the figure. Participants in the evaluation operated the couplings both telerobotically and manually (manual operation of the couplings was performed to include a reasonable approximation of EVA performance).

The results of the investigation were that custom coupling not only operated faster but was generally preferred over the other couplings. During the course of this investigation, certain guidelines were derived regarding further work into improving telerobotic/EVA compatibility. These not only pertain to fluid couplings, but also may apply onboard SSF whenever compatibility between the telerobot and the EVA astronaut is critical. The recommendations are

- That the complete redesign of hardware may not be necessary to improve telerobotic/EVA compatibility. Modifying existing designs may optimize the effort.
- To enhance both telerobotic and EVA operation, hardware should operate as logically as possible – i.e., complex operations should be avoided. Robust grapple points and straightforward operational procedures should be stressed.
- With respect to fluid couplings in particular, a common interface should be implemented across all coupling points onboard SSF to reduce the likelihood of implementing an incorrect operational procedure.

The ROIL will continue working with fluid quick-disconnector manufacturers. Further guidelines will be developed as new quick-disconnector designs become available for evaluation.



Schematic diagrams of the four couplings evaluated in this study. Coupling A was the customized fluid connector in this evaluation

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Schematic diagrams of the four couplings evaluated in this study. Coupling A was the customized fluid connector in this evaluation.

Extravehicular Activity (EVA) Speech Recognition

PI: Barbara Woolford/SP34
Jose Marmo/EC5
Charles Sheperd/C95
Reference SST 18

A series of three tests was performed to determine the usefulness and reliability of voice recognition for extravehicular activity (EVA) applications.

The tests used a Macintosh computer and a Voice Navigator speech recognition device. This system reported the word recognized from the current vocabulary, if any, and also a confidence level and an amplitude level. These levels are critical for real-world application of the system.

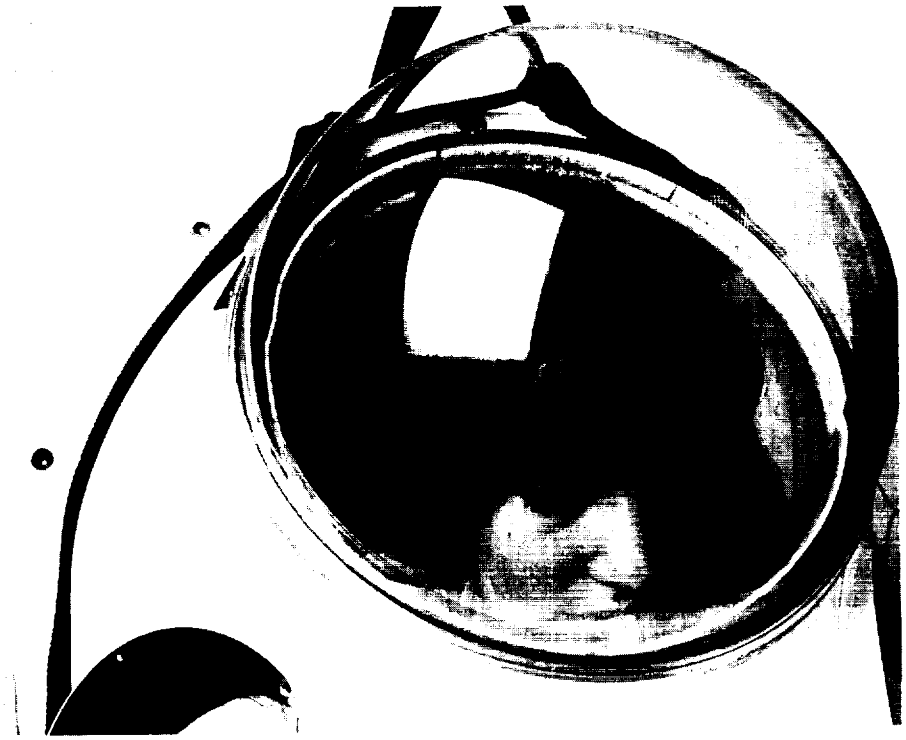
The first test was with shirtsleeved subjects. They trained the Voice Navigator to recognize an 8-word vocabulary and then went to recognition mode. Two basic conditions were run: accuracy of recognition, where the subject was presented with the word to say, a word which the subject tried to have the recognition device recognize; and false alarm rate, where the subject performed another task during which extraneous conversation was carried on and measures of false positives were collected. A false positive is a case where the voice recognizer reports a match when, in fact, the subject did not say the word reported.

Results from the first test led to concern for the high rate of false positives - i.e., 1 error per 20 seconds of speech. The recognition rate was high, however. Data were studied to see if raising the required confidence level for a recognition would decrease the false positives. In fact, this *post hoc* analysis indicated that it did.

The second experiment was carried out in an EVA helmet and hard upper torso with air flow to produce a realistic sound environment. The subjects again trained the voice recognizer in several different modes, using noise canceling microphones in varying positions. This time, the subject read a 2-page transcript of an actual EVA conversation as well as performed recognition tests. Confidence levels for recognition were set at high levels. This reduced the insertion error, or false positive, rate to less than 0.1 errors per minute and maintained the correct recognition rate at 95.7 percent.

The third experiment used suit-certified subjects in a Mark III Zero-Prebreathe suit. Training again was carried out, and confidence levels were set. It was found that confidence levels alone led to a zero insertion error rate and decreased the correct recognition rate to 88.5 percent. To correct this problem, it was determined that both amplitude information and confidence level must be used. When reanalyzed with a suitable, subject-dependent amplitude level, the false recognition rate was maintained near zero while the correct recognition rate approached 95 percent.

This research shows that voice command is a viable option for use in EVA suits to permit hand-free operation of electronic cuff checklists, helmet-mounted displays, or other EVA equipment.



Microphone placement in helmet of HUT.

Subject reading EVA transcript during Phase II test. Macintosh controls experiment.

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Computer-Aided 3-Dimensional (CAT) Stowage

PI: L. W. Lew/SP33
Reference SST 19

Although stowage is not a glamorous or highly visible system, it is essential for maintaining the order of Space Station consumables and loose items. Storing thousands of unique items is a major challenge for Space Station engineers. Effective packaging of items ranging from telephone-booth-size subsystem components to pens and pencils for accessibility, stowability, and handling is a goal that has never been encountered before in U.S. manned spaceflight.

The limited and highly valued onboard stowage space must be used in a manner to obtain the maximum efficiency while providing adequate protection and restraint. For the Space Shuttle Program, much of the stowage volume (as much as 50 percent) was lost to the packaging material alone when sensitive and fragile equipment was stowed. However, the need to provide vibration and shock protection during launch and landing dictated such protective measures.

Space Station stowage requirements will be somewhat different since only the pressurized logistics module will make routine round-trips to orbit. Unique concepts are needed for "launch only" protection and for zero-g restraint on orbit. Optimum packaging schemes must be developed for transporting items to and from orbit, in their designated stowage area, and at their use location.

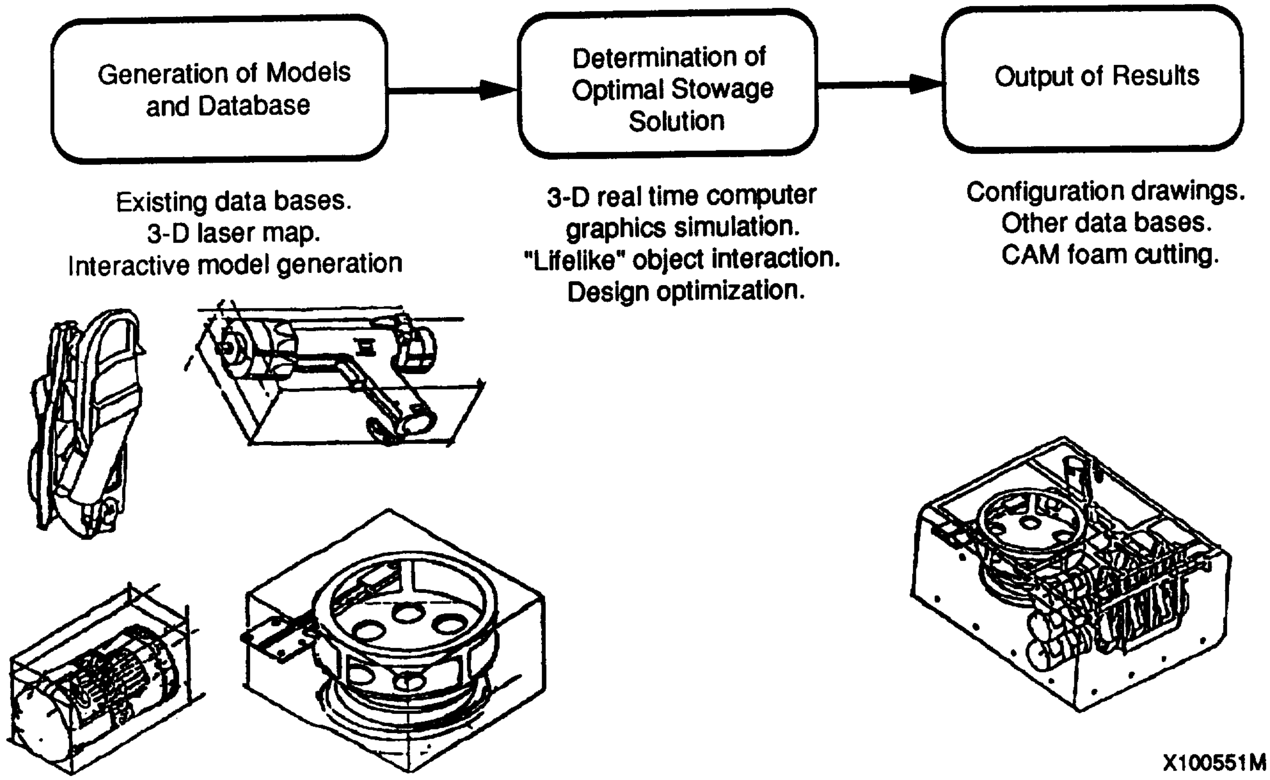
Eliminating any unnecessary stowage inefficiencies must be accomplished. It is imperative that loose item stowage requirements are met without sacrificing crew productivity.

The current approach to determine the packaging scheme of the Space Shuttle Orbiter stowage trays is done manually. From this, a somewhat high probability exists that some stowage attributes/criteria are not met and possible redundancies are incorporated inadvertently. For Space Station, this would be unacceptable when the cost of transporting items is over $5000 per pound.

In order to improve the stowage proficiency, a Small Business Innovative Research (SBIR) Phase I project using 3-dimensional computer graphics with optimization software to solve Space Station stowage was pursued. The study revealed that existing computer-aided software is well suited to solving complex stowage problems.

A Phase II SBIR project is under way to develop a turnkey system which will combine several existing technologies into a unique and innovative tool for solving stowage problems. The turnkey system will consist of a powerful computer graphics workstation environment and customized version of software to

- Quickly find optimal stowage solutions of objects in stowage trays by generating computer models of objects to be stowed or select models from a previously generated database and interactively packing them into stowage trays.
- Permit 3-dimensional computer models to be translated and rotated in real time.
- Display models in line or solid shaded image mode.
- Display interferences or closest proximity distances from objects.
- Simulate compressible or deformable objects; e.g., clothing, coils of cable, etc.
- Permit interfaces with other useful tools including the laser mapping system for model generation, PLAID for model sharing, and a numerical-controlled milling device for cutting foam packing material.
- Generate spreadsheets which contain object listings in their respective stowage trays and racks.
- Generate configuration drawings from computer models automatically.



Computer-aided storage process.

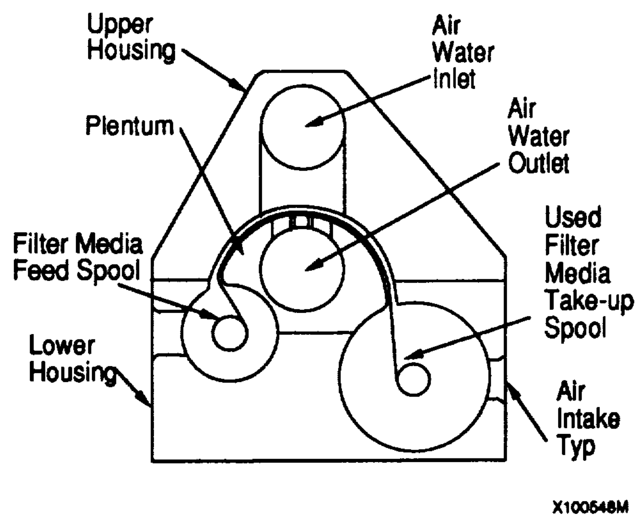
Space Station Prototype Laundry Filter

PI: Phyllis Grounds/SP44
Reference SST 20

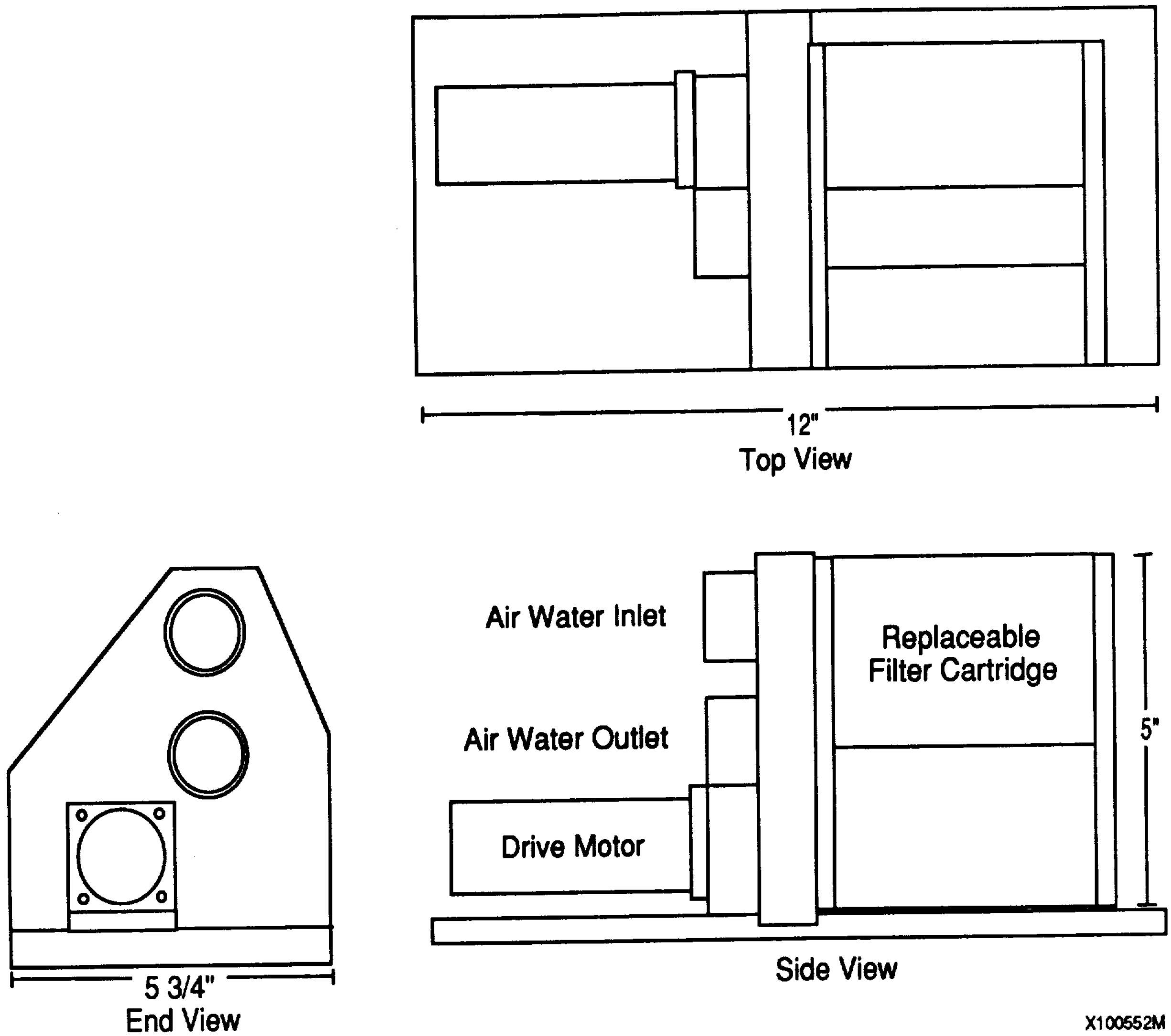
The Space Station Freedom will include a laundry facility for cleansing clothing worn by crewmembers. The water from this facility will be recycled; some of the major contaminants which must be removed are large particles comprised of hair, lint, and epithelia. The purpose of this investigation was to develop a system which will remove coarse material from the waste water as soon as possible in order to prevent fouling valves, pumps, and phase separators downstream of the laundry system.

In commercial washing machines, separation is accomplished with a lint filter that is periodically backwashed to the drain. This method cannot be employed in the Space Station since the suspended material must be removed from the waste stream and immobilized. An in-line design concept was proposed that provides a large surface area to minimize the frequency of changing filters.

A schematic (see figure) depicts a tightly wound roll of filter material contained in a housing. The filter material is passed over a perforated support plate and collected on an empty take-up spool. A pressure drop sensor activates a winding mechanism to provide fresh filter fabric as it becomes loaded with debris. The filter material is wound up on the take-up spool, which would be removed and replaced with a new cartridge of mesh material for continued filtering. The design is capable of processing a 90-day volume of laundry waste water generated by an 8-person crew. The filter media is 146 mesh, 104 μ pore size polyester fabric. The advancement mechanism is activated based on a low-pressure signal from a pressure transducer in the downstream piping. Set points for the advancement mechanism are variable and can be adjusted based on the available suction source.



Laundry scroll filter.



Scroll filter assembly.

Photonics for Autonomous Rendezvous, Docking, Navigation, Hazard Detection, and Avoidance

PI: Richard D. Juday/EE6
Reference SST 21

A broad front of photonic image-processing technologies is being developed at the Johnson Space Center (JSC). They originally were intended for optical image processing, but, in fact, can be used (although more slowly) in digital image processing. In a leveraging action, this task is tied into Defense Advanced Research Project Agency [DARPA] developments of battlefield correlators. We anticipate that ultimately a confluence of NASA needs and funding will prosecute the development of those small, lightweight correlators to a configuration amenable to space operation. Speed, light efficiency, low power, and high space-bandwidth product per volume are the properties being optimized. The optical filtering theory is advancing under NASA funds (with the use of civil service time and through contracts and grants to universities) and by use of leveraging funds from the Army Missile Command (MICOM). Our filtering theory will be applied to reducing the potential effect of noise on pattern recognition for autonomous rendezvous and docking, and also the reduction of 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 advancing at Texas Instruments, primarily under MICOM funds. The main motivating factors for the SC participation in spatial light modulator development are the future applications to autonomous planetary landings and rendezvous and docking.

Following is a summary of the JSC technical elements that were advanced to one degree or another during the reporting period. The JSC technology consists of several intertwined parts being developed in parallel. They are mutually supportive and it is difficult to enumerate them in a clean partition of the problem.

- Algorithms: "Backscratching," in which correlation done in one coordinate geometry (alternately Cartesian and log polar) drives image adjustments in the other (pan/tilt or magnification/rotation). A total of 4 of the 6-degrees-of-freedom (DOFs) relating two bodies in free space are tracked thereby. Hardware and software to effect the changes has been brought nearer to completion.
- Synthetic estimation filter [SEF]: Images are weighted and summed. They thus form a synthetic image of the tracked object, which is used as the reference image for an optical correlation filter. The weights are adjusted so that the correlation intensity has a fine variation, forming a simple and robust estimator of the out-of-plane pose. With the "backscratching" algorithm and the SEF, all six DOFs are tracked. We made the mathematical generalization to an arbitrary number of dimensions.
- Digital image processing hardware: Doing optical correlation in alternating Cartesian and log polar frames presumes that the image is available in each of those geometries. Currently, we have a unique image-processing machine (patent applied for; claims will be granted) that does image coordinate transformations at video rate. Parametric studies are done on this machine that will guide the development of patterned sensors to support the backscratching algorithm with a minimum of real-time, computation-intensive image processing. During the reporting period, one patent application was favorably reported back from the U.S. Patent Office (a number of claims will be allowed) and another patent application was filed on an advanced architecture.
- Fourier optics pattern recognition: In addition to the SEF, a pose estimator, general filter theory is being developed for optimal performance in the signal-to-noise sense for any known spectral characteristics of noise. We also are developing optimal filter theory to accommodate a complex operating curve of the spatial light modulators on which the filter is realized, and - significantly - the one on which the input image is encoded. Several papers reported our progress during the year, some given at conferences and some reported in the archival literature.
- Spatial light modulators (SLM): Several types are being developed as a result of the JSC program. They are all of the "deformable mirror" type. In comparison with other available SLMs, this type is direct in its modulation action (e.g., no crossed polarizers). It is very efficient (as much as 45 percent of impinging light is expected to be diffracted into a chosen order, in the filter version; contrast ratios of at least several hundred, and quick high efficiency will be possible with the image input version). Also, quite significantly, two geometries have been articulated that will permit full complex modulation in either the input or filter location in an optical correlator.

LADAR Tracking of Orbital Debris

PI: K. F. Dekome/EE6
Reference SST 22

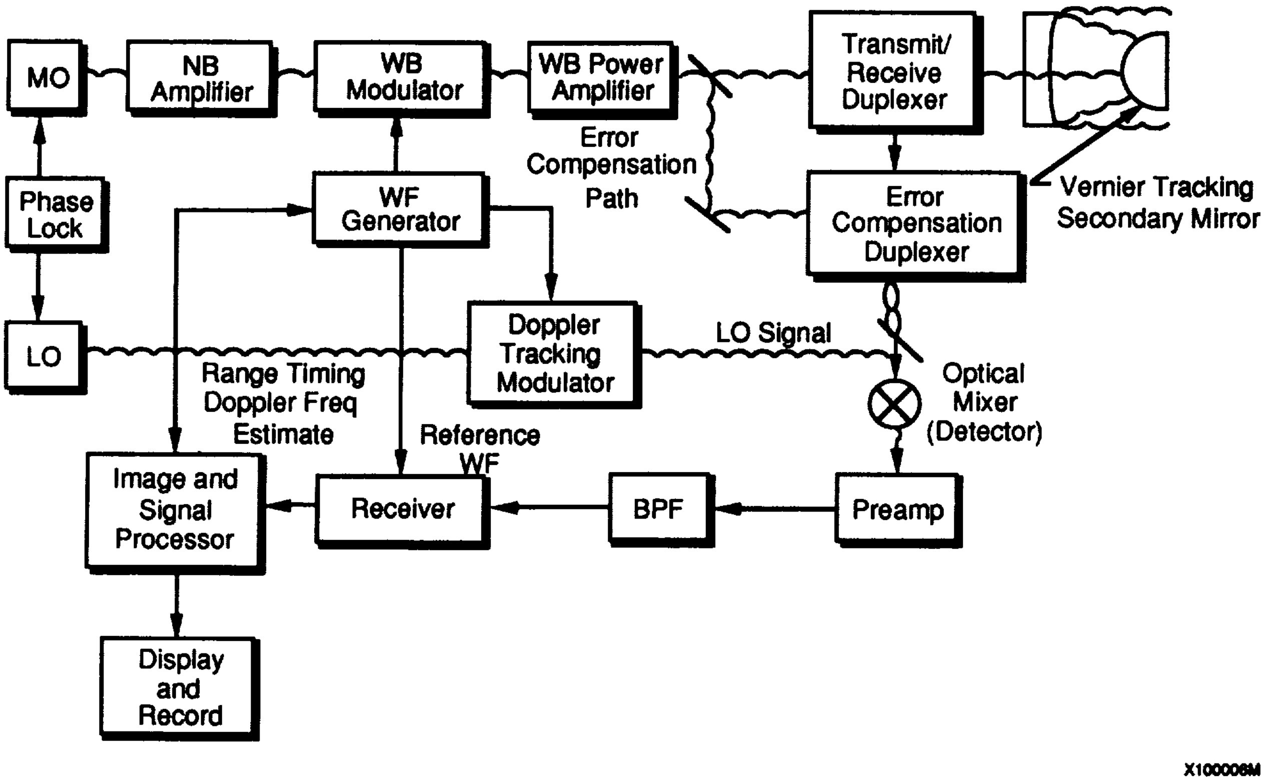
Man-made orbiting debris has been recognized as a threat to the safety of Space Station Freedom (SSF) over the duration of its mission. The tracking facilities of the United States Space Command regularly update a satellite catalog that contains orbit estimates of over 7500 objects. These objects extend from low-Earth to geosynchronous orbit and consist of dead satellites, expended rocket stages, debris from on-orbit breakups, and the like. This tracking capability is limited to objects 10 cm or greater in mean diameter. An estimate suggests that these objects represent only 1 percent of the actual population, however. The more numerous debris in the 1 to 10 cm diameter range cannot be tracked. It is because of this population that a spaceborne laser radar (LADAR) is advantageous.

This task is addressing the feasibility of using a spaceborne LADAR to track hypervelocity orbital debris that poses a threat to the safety of the SSF. The feasibility of various LADAR techniques is being investigated, and a strawman system is being designed. The concept is to provide data that allow a suitably accurate orbit estimate of flyby debris, so an estimate of the threat at subsequent orbit conjunctions can be made and timely avoidance maneuvers can be performed if deemed appropriate.

The LADAR by itself is not deemed sufficient to perform the whole task, as it is unsuited to constant active scanning over the large angular cone required to provide constant coverage of the SSF environment. Its characteristics are best exploited if it is required to track an object whose initial bearing is known roughly (i.e., if it is "handed off" to/by an acquisition sensor). At this point, very accurate relative angle, range, and range rate data can be obtained. The surveillance of the coverage cone for orbital debris acquisition is expected to be performed using sensitive infrared focal-plane arrays, which see the debris based upon its temperature difference relative to the cold space background, using image-processing techniques. The acquisition sensor can then "hand off" to the LADAR so that active tracking can commence.

During fiscal year 1990, several analyses took place to determine the feasibility of the LADAR concept. The primary one involved performing a "flyby" simulation of debris past an orbiting sensor platform (nominally located on SSF). Subroutines describing LADAR performance for particular system configurations (e.g., pulsed, continuous wave, coherent pulsed) were used to dictate acquisition range, field-of-regard, slew rates, and raw measurement accuracies based upon a common link model. The raw measurements were filtered using a Kalman filter to improve the relative state covariance estimate (the "state" in this simulation consisted of position and velocity relative to the sensor platform). After tracking was broken due to loss of signal, the state covariance matrix was propagated to future orbit conjunctions using the Clohessy-Wiltshire linearized equations of motion. Best performance was achieved by the coherent pulsed-doppler model, with standard deviations in position on the order of 1 km after 1 rev.

Due to the relative crudeness of the propagation simulation (not accounting for orbital perturbations through 99 percent of the orbit prop), a new prop model was developed using William Lear's program TRAJ2 as the nucleus. The program was configured so as to be able to perform Monte Carlo analysis of relative state, incorporating perturbations in atmospheric density, debris cross section, gravity, and SSF state. This simulation will be used to provide more reality to the initial performance indicated above, and will be used in conjunction with the flyby simulation. A more accurate assessment of relative sensor capabilities and the role of LADAR will result.



Ladar concept for orbital debris tracking.

Autonomous Lander Sensor Program

PI: W. X. Culpepper/EE6
Reference SST 23

The Autonomous Lander Sensor Program is developing technology to accomplish a safe landing on the Moon or a planet (Mars) for an unmanned spacecraft. The program is concerned with precision landing (PL), landing at a location identified earlier and known to be safe and hazard detection and avoidance (HD&A), and landing at a site having a probability of safe area(s). Sensor studies support the program with Johnson Space Center (JSC) civil service and a continuation of the Charles Stark Draper Laboratory/Environmental Research Institute of Michigan studies initiated in fiscal year (FY) 1989.

An HD&A concept was developed for an onboard hazard detection sensor using a scanned, cw-modulated, GaAlAs laser radar. A simulation of this sensor and the associated image processing was developed. Example cases generated using this simulation indicate that this approach to the detection of local slopes and rocks which are large enough to be hazardous to landing is feasible and should be practical in the next few years.

It was discovered that the Pershing II missile system, deployed by the U.S. Army, has a terminal navigation sensor which exhibits the level of accuracy felt necessary for a PL on a planet. This system was developed with extremely accurate terminal navigation; i.e., pinpoint targeting that many feel led to the INF treaty. As a result, the hardware system is being dismantled and is available under the Pershing Reuse Program. Some $10 M worth of hardware has been requested from the U.S. Army for transfer to JSC for only the cost of transportation. This approach – i.e., using Department of Defense technology – represents tremendous leverage for NASA application.

Precision landing preselects a landing site; and data, such as terrain elevation information, are gathered and processed as reference scenes to compare with radar imagery during terminal navigation and landing. Correlation with these reference scenes allows real-time correction to the landing vehicle trajectory. The Pershing radar guidance approach has advantages that make it attractive in a planetary landing scenario. It is insensitive to lighting conditions, dust storms, and scene changes. It also works well with limited scene information.

A multiyear study/development program has been outlined that eventually will include the development of simulations of radar video, an ability to exercise difference correlators, and the generation of reference scenes from real or simulated planetary terrains. Initial studies will concentrate on performance sensitivity to a lack of knowledge of radar reflectivity, reference scene resolution, and accuracy of reference scene input data. Certain limitations also will be studied (e.g., size of reference area required, speed of correlation, correlation algorithms, and degree of terrain "blandness" allowed). The Pershing hardware being requested also can support a flight test program against Earth analogs of the Mars or the Moon. Alternate funding sources are being investigated to continue the Pershing efforts since Pathfinder funding is unavailable in FY 1991.

Tunable Laser Diode and Optical Phase-Locked Loop

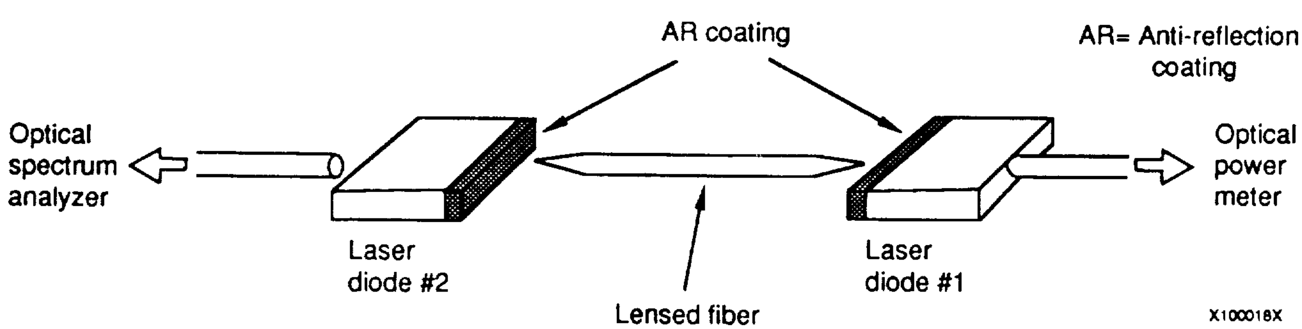
PI: K. F. Dekome/EE6
Reference SST 24

Theoretical performance advantages exist in using optical carrier wavelengths in point-to-point communications systems. These advantages include wide bandwidths, low prime power, and small size and weight relative to representative radio frequency (RF) systems. The bandwidth advantage is best realized in the form of coherent communications links, in which the information is contained in the instantaneous frequency/phase of the carrier itself, referenced to a local oscillator (LO) at the receiving terminal. The quality of these links, whether free space or fiber optic, is improved proportionate to how well various noise sources are minimized in the system, including how well the LO can "track" the instantaneous frequency of the transmitting source, which can vary due to temperature, relative motion (doppler), and other reasons as a function of time. The size and weight advantages are most realized at the near-infrared wavelengths around 800 nm, where semiconducting laser diodes can be utilized, as opposed to larger but more established carbon dioxide gas lasers emitting at 10.6 μ. Semiconductor sources are now available in 2-dimensional array form with total optical output powers exceeding 20 W. The ability to tune the output wavelength of a semiconductor laser sources both dynamically and accurately over several angstroms allows its incorporation into an optical phase-locked loop (OPLL), which is the functional equivalent of the conventional RF phase-locked loop used in microwave/ millimeter wave communications links and the common FM radio receiver.

This effort is a Small Business Innovative Research project to develop and demonstrate a tunable laser diode (TLD) in a precision, ruggedized package. Three techniques were explored to maximize the tunable bandwidth, including a laser-tuning laser approach, an electro-optic modulator-tuning laser approach, and a cleave-coupled cavity approach. All three types were investigated, designed, fabricated, and evaluated. The test results demonstrated a wide tuning range, as was theoretically predicted, and a very narrow line width (100 kHz without thermal isolation).

Two solid-state lasers were then integrated into an OPLL assembly. The TLD OPLL activity planned using the fabricated TLDs had to be aborted due to the inability of locating a test laser diode with an output center wavelength within the capture range of the TLDs. Using a mixture of commercially available and fabricated optical and microwave mixers and amplifiers, a phase-locked loop arrangement was constructed and the loop performance was quantified and documented. Phase lock of two YAG lasers was demonstrated, with lock being attained over a 0.5 hour period.

This research and development work will impact areas of NASA interest such as range/range-rate lidars, optical frequency modulation communications, fiber-optic gyroscopes, optical wavelength synthesizers and radiometers, optical frequency hopping for long-range secure communications, and incoherent optical links envisioned for intersatellite communications.



Optical phase-locked loop concept.

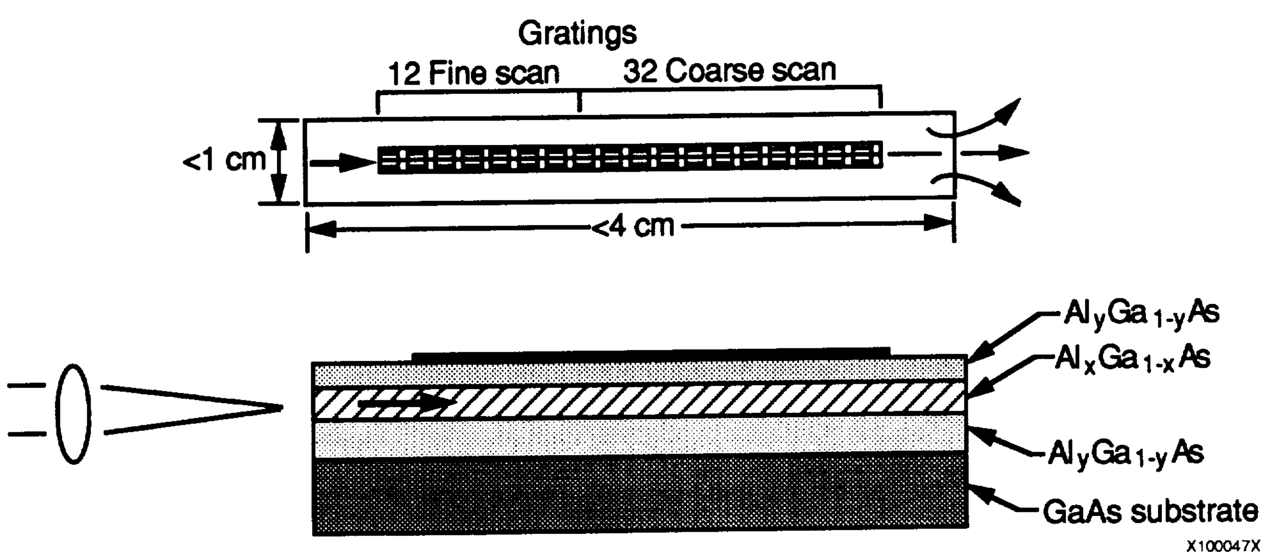
Integrated Optic Device for Laser Beam Scanning

PI: K. F. Dekome/EE6
Reference SST 25

The technology of integrated optics is attaining widespread acceptance as better ways of constructing basic optical processing components such as lenses, gratings, and waveguides are discovered with the use of photolithographic techniques. An investigation into using the electro-optic characteristics of these waveguide materials as a means of performing efficient, fast, nonmechanical steering of laser beams has been completed. The waveguide material of choice was gallium aluminum arsenide, with an index of refraction that can be modulated over a large interval to provide sizable (22° full-angle, in air) deflections of the incident laser energy. A combination of interdigitated and prism electrode structures was deposited over 22 deg of the output laser energy. Another variety provided ~400 positions over a narrower field of view of 14 deg. These prototype devices are on the order of 3 cm in length and have theoretical scan bandwidths on the order of 1 MHz.

This technology should be contrasted with existing optical scanning technology such as galvanometers, rotating polygons, and acousto-optic deflectors. While the first two offer wide fields-of-regard, on the order of 40 deg, they are mechanical scanning techniques that are less suited to application in the rugged space environment. Their associated scan rates are typically less than 10 kHz. Random access pointing ability is limited to the variable frequency galvanometer, which suffers in available scan bandwidth as a result, being on the order of 300 Hz. Acousto-optic scanners, being nonmechanical, are better suited to space application and can scan at hundreds of kilohertz, but are relatively inefficient in laser energy throughput and are limited to fields-of-regard on the order of 3 deg. The small size and low power dissipation of the integrated optic scanner, coupled with its ambitious field-of-regard, as described above, makes it an attractive alternative to the conventional laser-scanning technologies.

Possible applications of these types of devices are in free-space optical communications links, where they would operate as transmitting sources of short-haul, secure, point/point systems (Space Station Freedom (SSF) multiaccess communications), optical tracking (a laser docking/berthing sensor), optical multiplexers/demultiplexers in fiber optic communications links (SSF video distribution), and in optical printers. This work was performed under a Phase II Small Business Innovative Research contract by APA Optics.



Integrated optic laser beam scanner.

Hierarchical 3-Dimensional and Doppler-Imaging Laser Radar

PI: J. L. Prather/EE6
Reference SST 26

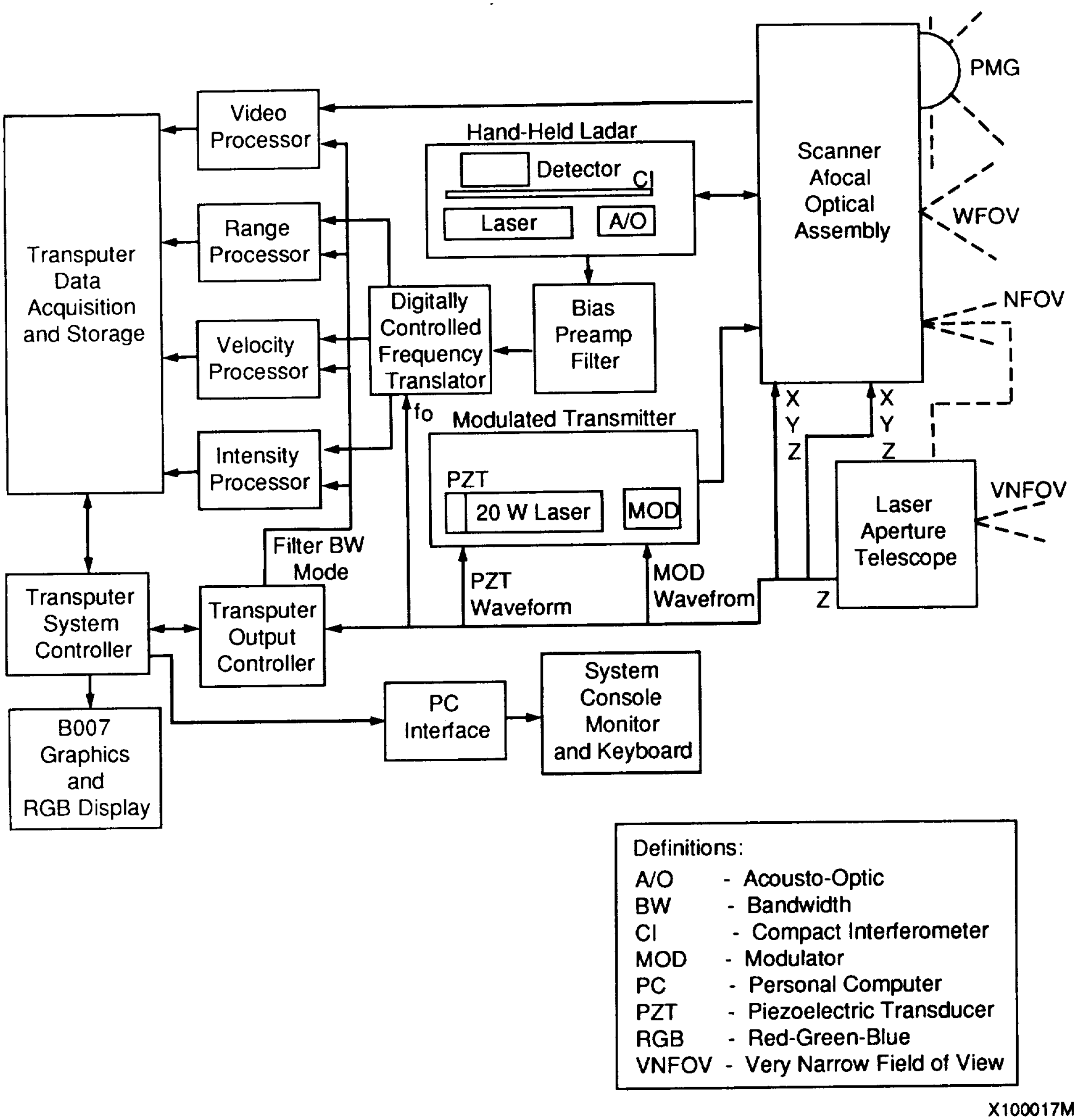
This is a Small Business Innovative Research project to develop an improved 3-dimensional imaging laser radar (LADAR). The LADAR will be applied to robotic vision and spaceborne target tracking for rendezvous and docking, remote manipulator and autonomous robot operations, satellite servicing, proximity operations, and lunar/planetary landing.

This 3-dimensional mapper provides Doppler as well as range and intensity images and programmable/adaptable scans consisting of a fine-resolution fovea and lower resolution peripheral vision (patterned after the human eye). The high resolution can be placed anywhere within the field of view of the sensor according to the region of most interest, while the lower resolution peripheral vision provides for simultaneous monitoring of other objects or target features and obstacle avoidance. Doppler imagery provides range rate information for rendezvous and docking, provides an additional discriminator for object recognition, and could be useful in identifying the rotation axis of a spinning satellite to aid in approach and grappling. In addition to these high-resolution and low-resolution capabilities within a ±10° field of regard, a peripheral mini-gimbal (PMG) will provide hemispherical coverage.

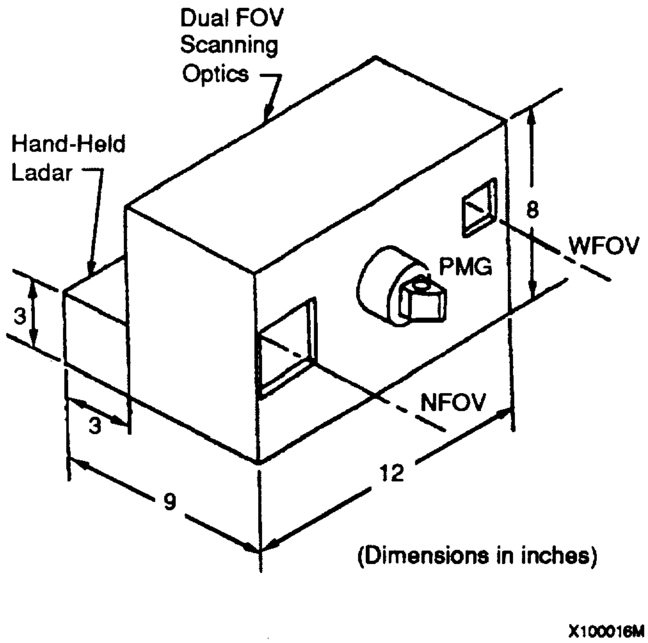
Phase I produced a working laboratory model (not deliverable) which was demonstrated successfully in 1988. A prototype, which is planned to be integrated with the extravehicular retriever or other robotic ground demonstration device, is being developed in Phase II. Delivery of the latter prototype is scheduled for early 1991.

SYSTEM PARAMETERS

Feature	Characteristic
CO_2 LADAR	2 W, 10.6 μ, heterodyne
Registered imagery	Range, velocity, intensity, visible video
Peripheral scan	Hemispherical coverage – PMG
Foveal scan	±20° wide field of view/narrow field of view (NFOV)
Angular resolution	0.5 to 12.5 mrad
Transmitter waveform	Continuous wave, amplitude modulation (AM), frequency modulation (FM), AM/FM
Maximum range	3000 ft: skin targets, NFOV
Pixel format	1 Hz to 100 kHz, $(1024)^2$ programmable
System controller	Transputer network (12)
Sensor head size	1 ft^4
Electronics size	19-in. rack, 10-in. high



Doppler - imaging laser radar.



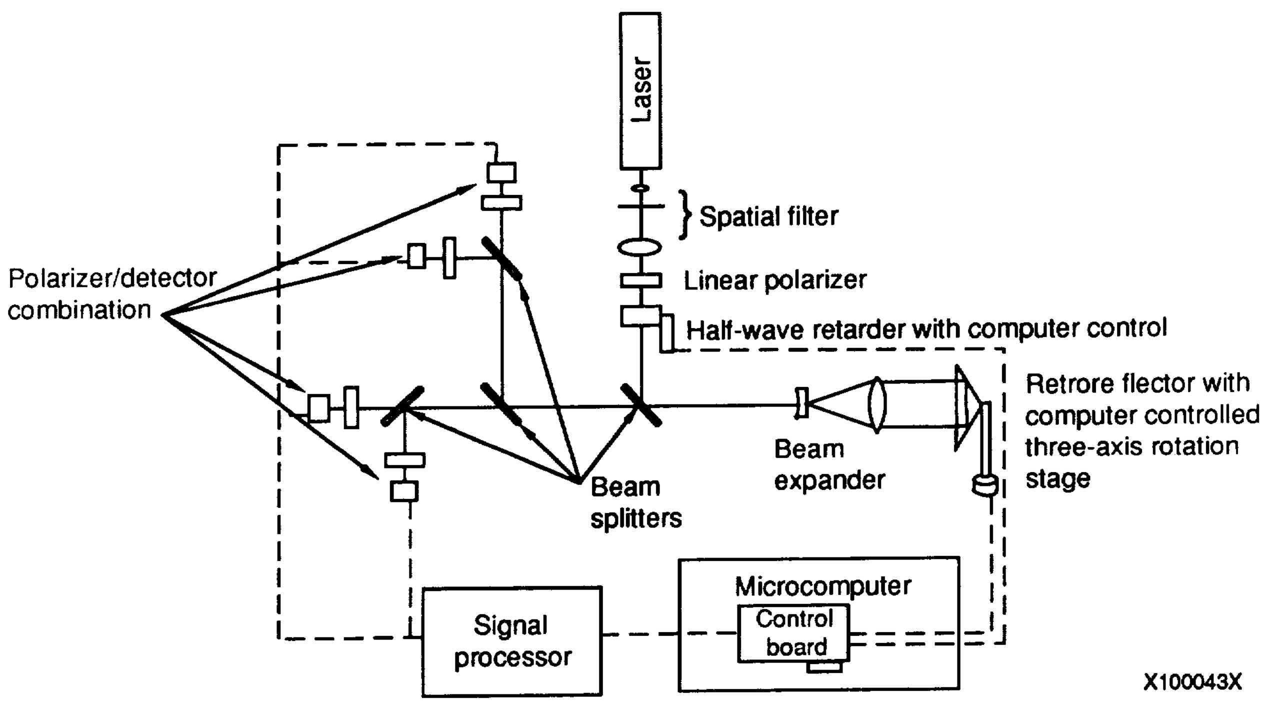
Scanner afocal optical assembly.

Laser Orientation Transceiver System

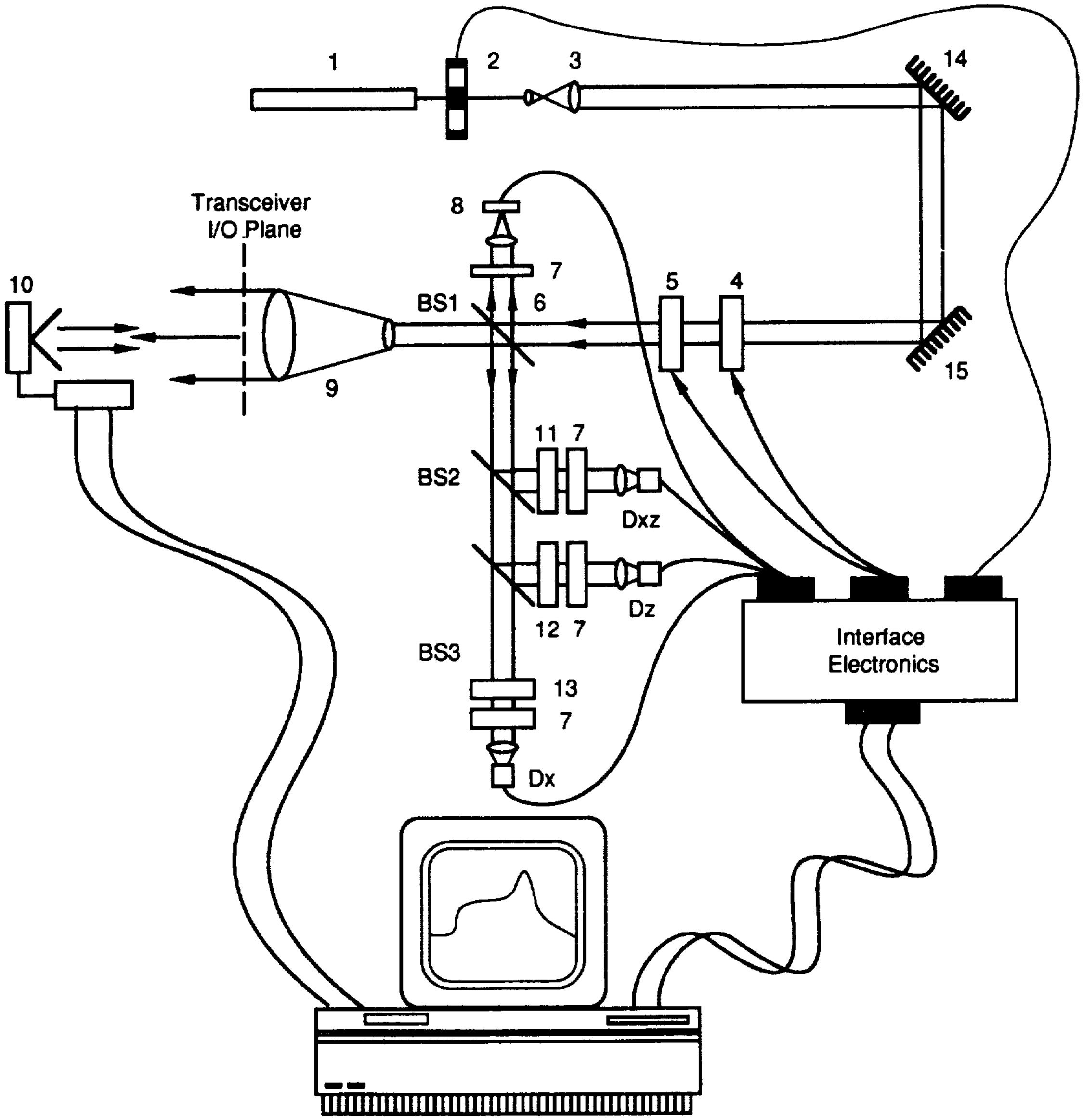
PI: J. L. Prather/EE6
Reference SST 27

This is a Small Business Innovative Research project to develop and demonstrate a capability to determine the relative orientation (pitch, yaw, and roll) of a target on which a single unique retroreflector is mounted. This innovation has potential application to spacecraft rendezvous, stationkeeping, docking, berthing, remote manipulator grappling, satellite servicing, space proximity operations, air-to-air refueling, aircraft landing systems, and industrial and commercial alignment needs.

The technique makes use of the phenomenon in which the polarization of a laser beam is modified uniquely upon retroreflection by an amount dependent on the orientation and material properties of the retroreflector. Three-axis orientation is determined by using a different material on each facet of the retroreflector (e.g., gold, germanium, and molybdenum) and measuring the resulting polarization shift. This technique is relatively simple, with no inherent maximum or minimum range limitations and very small size and weight scarring of the target vehicle. Accuracies within 0.3 deg are predicted based on Phase I analyses and tests. Techniques were devised to resolve ambiguities and regions of high error by using two different transmit polarizations. A system design was completed in fiscal year 1990. Most of the components were obtained or developed and were being integrated prior to testing and calibration. Various optical characteristics of the prototype components and subsystems were measured and used in a software simulator to judge system performance and accuracy. The simulations indicate that the system should meet performance goals; however, no actual system hardware tests have been performed to verify that analysis.



Laser orientation determination system.



1. HeNe Laser
2. Optical Chopper
3. Expander/Collimator with Spatial Filter (SFC)
4. Halfwave plate
5. Linear Polarizer
6. BS1-Primary Beamsplitter
7. HeNe Interference Filter
8. Power Monitor Detector
9. Beam Expander (BEX)
10. Retroreflector Mounted to 3-axis Gimbal
11. Linear Polarizer - Fixed @ 45°
12. Linear Polarizer - Fixed @ 90°
13. Linear Polarizer - Fixed @ 0°
14. Fold Mirror 1 (M1)
15. Fold Mirror 2 (M2)

X100569M

Lots Phase II system diagram.

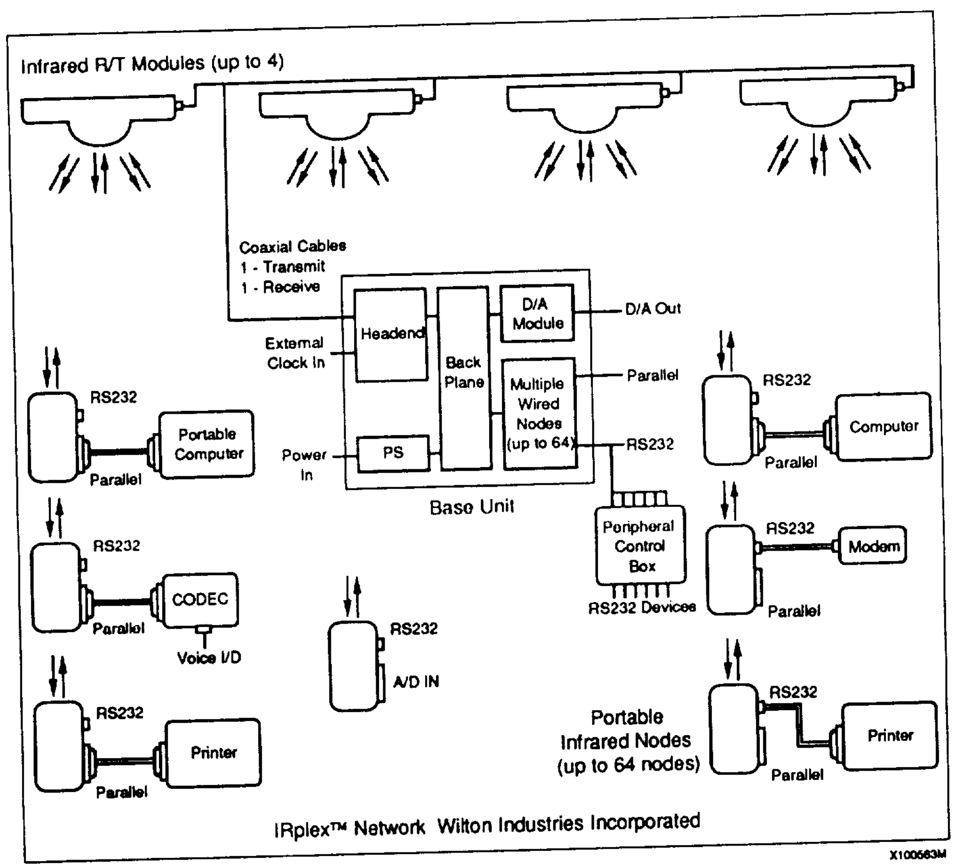
Multiuser Multiaccess Infrared Communications

PI: J. L. Prather/EE6
Reference SST 28

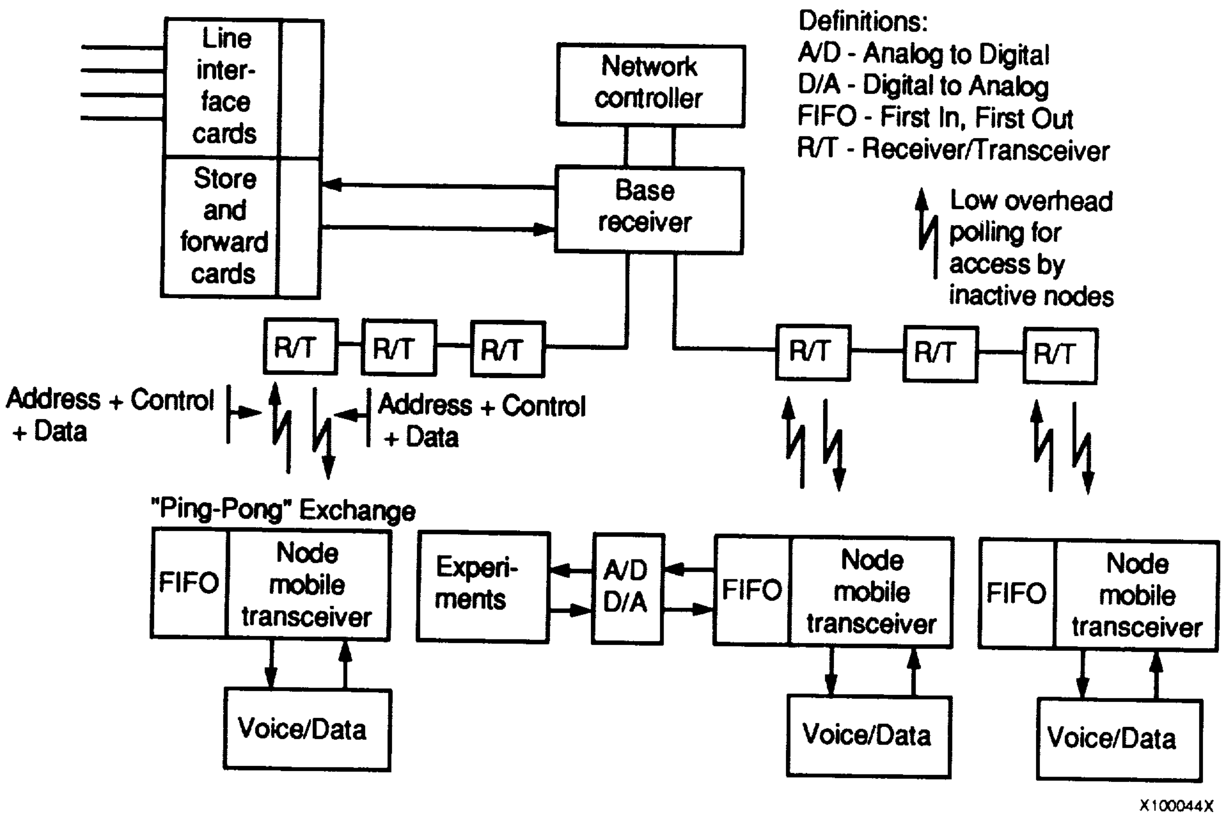
The use of diffuse, free-space infrared (IR) light waves as the transmitting medium offers advantages over existing techniques such as radio frequency (RF) or hardwired systems. Like RF wireless systems, wireless IR provides the user mobility from the obtrusiveness of wires. In addition, wireless IR does not emanate electromagnetic interference that could create noise or operational degradation in surrounding systems, as is the case with some RF communication systems. The greatest advantage lies in the availability of frequency bands. Due to the abundance of RF communication systems, the RF channels still available for use are limited. Wireless IR systems do not have this limitation. Since IR will not transmit through walls and is attenuated by windows, duplicate systems can be used in adjoining rooms without interfering with one another.

The purpose of this task was to develop, construct, characterize, and test a representation of the key elements of a system which would provide full duplex voice communications (i.e., up to 24 channels and 256 addressable users), full duplex data communication (i.e., up to 192 channels and 256 users), and combinations of the two. Data rates would be selectable from 76.8 kbps (asynchronous) or 64 kbps (synchronous) down to 4800 bps (asynchronous). The system could be scaled for a various number of channels, each having a maximum of 256 users, with the potential advantage of auto configuration to service constantly changing communication requirements. Potential applications include the Mission Operations Control Room at the Johnson Space Center (JSC), the Firing Room at the Kennedy Space Center, the KC-135, the Space Station, and the Space Station mockup and crew trainers.

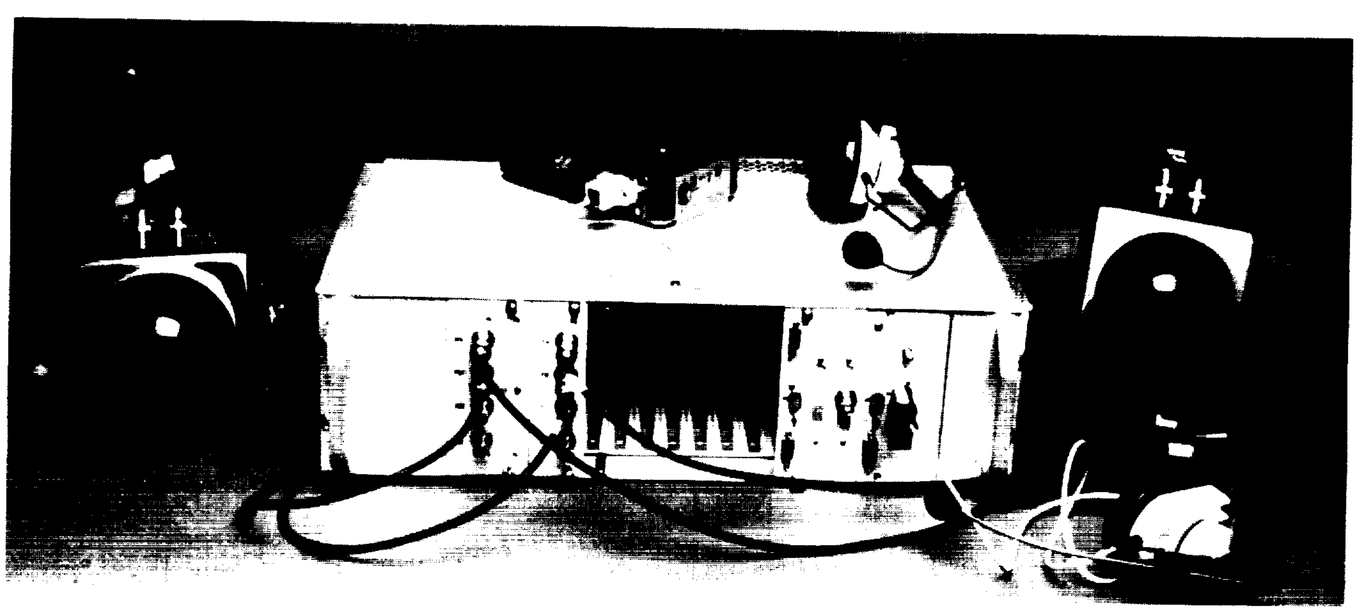
In fiscal year 1990, the hardware was completed and delivered to JSC. It meets the design goals as stated above.



Multiuser multiaccess infrared communications system.



Infrared multiplex network.



Infrared communications system breadboard.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Monolithic GaAs UHF IF Switch for Space Station Applications

PI: Phong Ngo /EE3
Reference SST 29

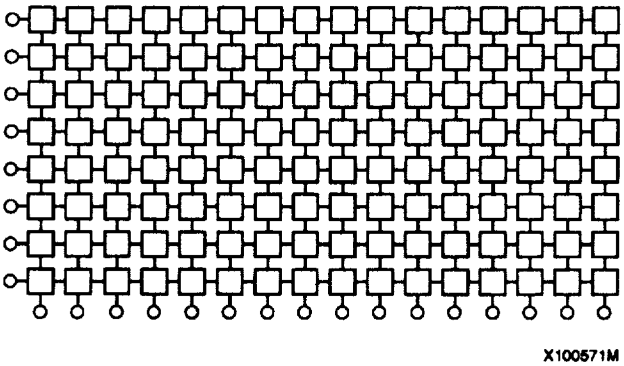
At the heart of a Frequency Division Multiple Access (FDMA) system is the intermediate frequency switch matrix, which dynamically routes multiple signals to the proper antennas and receivers. An 8×16 gallium arsenide (GaAs) monolithic microwave integrated circuit (MMIC) switch matrix has been designed and analyzed for Space Station FDMA communication applications. All 128 crosspoints are contained on a single GaAs monolithic chip measuring $\sim0.5\times0.5\,in^2$. Analysis results clearly indicate that the switch will provide all necessary functionality in a small, lightweight, and highly reliable unit. This advanced MMIC switch matrix occupies only one-fifth the size and weight of all currently envisioned alternatives.

For Space Station applications, where multiple signals must be frequency multiplexed to each antenna port via up/down converters, a non-blocking, bilateral matrix must be used for both transmit and receive. This can be accomplished by using only reciprocal components; i.e., a PIN diode and passive field effect transistor (FET) switching elements. The FET switches were chosen in the design of the matrix due to their low power consumption and reliability. Both the PIN diodes and FETs consume virtually no current in the "OFF" state; however, FETs also consume virtually no current in the "ON" state (microamp range), while their PIN diode counterparts require 10's of milliamps each to achieve the "ON" state. To achieve high isolation levels (>70 dB), the PIN diode implementation would require orders of magnitude more total power consumption than an FET switch approach. Also, the reliability factor is reduced significantly for PIN diode switches due to the dissipation of power at the diode junction.

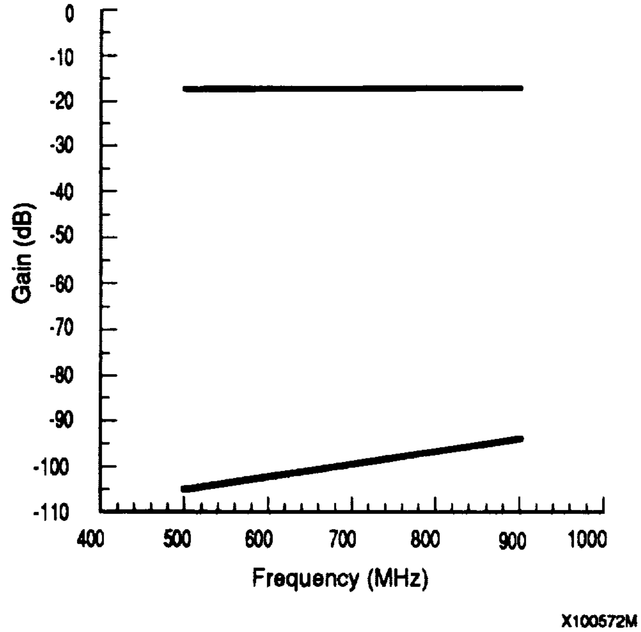
The GaAs FETs are ideally suited for use as ultra-high frequency (UHF) switches from the standpoint of prime power requirements since they do not draw current in either the "ON" or "OFF" state. However, a potential problem is obtaining adequate isolation between all lines that are not intentionally interconnected. A difficult trade-off between insertion loss and isolation exists which can result in severe bandwidth reductions and, at UHF frequencies, cause the physical circuit layout to become extremely large.

A unique crosspoint structure has been identified which provides a solution to these problems in a compact physical layout realizable in monolithic form. The first figure is a schematic representation of the 8×16 switch matrix which consists of a regular array of single crosspoints surrounded by peripheral circuitry and bonding pads. The second figure presents the predicted "ON" and "OFF" insertion loss for one of many possible matrix states. The insertion loss of the "ON" state is predicted to be 20 dB while the "OFF" state is better than 90 dB across the 500–900 MHz band.

In summary, the MMIC switch matrix developed in this Small Business Innovative Research (SBIR) project uses a maximum of 0.5 W, weighs 1.5 lbs (additional weight for telemetry processors, connectors, etc., must be included) as compared to the switch matrix proposed by the contractor in the June 1990 Preliminary Design Review which used 164 W and weighed 144 lbs. Although this communications system was deleted in the Space Station Freedom scrub exercise, eventually such a communications system will be installed. This SBIR will provide the needed technology.



Schematic representation of the 8 x 16 UHF IF switch matrix.



Predicted "ON" & "OFF" characteristics for the UHF IF switch matrix.

Power- and Bandwidth-Efficient Digital Communications

TM: William A. Geisel/EE36
Reference SST 30

An increased demand for digital transmission channels in the radio frequency (RF) band creates a serious problem of spectrum congestion. One way to solve this problem is the use of modulation techniques having high spectral efficiency. To solve this problem, one can employ M-ary PSK or continuous-phase frequency modulation techniques.

The Tracking and Communications Division/ Johnson Space Center was the technical monitor of the Phase I Small Business Innovative Research contract that was awarded to SCS Telecom, Inc., Port Washington, N.Y. SCS Telecom completed their contract in fiscal year 1991 to study, design, and build an efficient narrowband FM system (NFMS).

The purpose of this research was to demonstrate the performance of an NFMS with respect to spectral efficiency and bit error rate (BER). This FM system can transmit and receive data having a nominal bit rate of 1.5 kbps using a bandwidth of 1 kHz.

The FM system consists of a narrowband continuous-phase M-ary FSK modulator using rate-3/4, 64-state trellis coding. The FM demodulator is a phase-locked loop which performs noncoherent detection, nonlinear-adaptive equalization, and trellis decoding using the Viterbi algorithm.

The research that was carried out consisted of the design of a typical NFMS. The design was then simulated, built, and tested.

The system was built using CMOS circuits for low power consumption. The DSP chips also were employed.

The technical objectives of this Phase I effort were to

- Determine the 99-percent energy bandwidth and the upper bound on the probability of error for rate $n/(n + 1)$ trellis-coded continuous phase M-ary FSK ($M = 2n + 1$) with a symmetric and an asymmetric signal constellation.
- Investigate the system performance, with and without use of nonlinear equalization.
- Compare the performance of the proposed system, the probability of error and spectrum efficiency to noncoherent detection of standard modulation techniques such as MSK, Duobinary, and TFM.
- Construct a laboratory model of the trellis-coded FM modem and determine performance.

The final report has verified that trellis-coded FM results in extremely efficient use of spectrum.

Simulation results were presented which showed the effects of fading and predetection filtering on trellis-coded systems. The effect on the performance of nonlinear equalization also was presented. It was demonstrated that the nonlinear equalizer completely opened the demodulated "eye," thereby allowing low BER demodulation.

The experiment system demonstrated system operation. The bit rate used was 1.5 kbps and the resulting bandwidth was 1 kHz. Since the trellis-coded system bandwidth was less than the bit rate, the trellis-coded system yields more efficient spectral utilization than do ordinary BFSK, MSK, Tamed FM, etc., techniques which require that the bandwidth exceeds the bit rate.

Ku-band Active Antenna Module for Space Station User Application

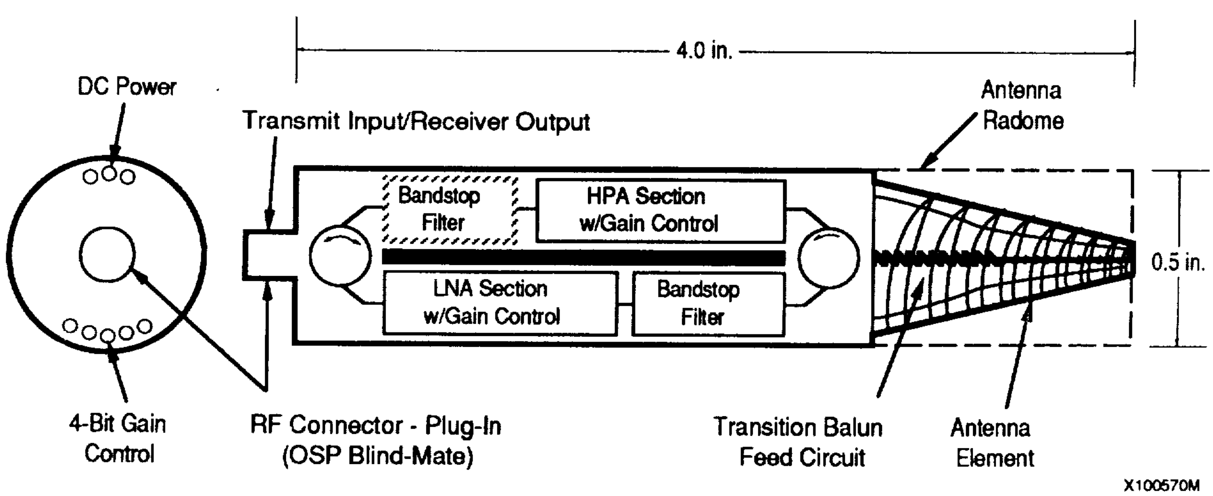
PI: John Ngo/EE3
Reference SST 31

The Space Station Mutiple-Access Communication System would allow simultaneous communications at Ku-band frequencies (13.4 to 14.89 GHz) from the Space Station to a multitude of users. These users (e.g., extravehicular activities, flight telerobotic servicer, and man-tended free-flyers) require that their multiple-access antenna systems be constrained to minimum size, weight, and power consumption. Typically, these antenna systems can be mounted on a backpack of the astronaut space unit or on a small pod of a user that requires multiple antennas for full spherical coverage. The optimum performance of the antenna system can be achieved by having the front-end active circuits such as power amplifiers and low-noise amplifiers mounted as close to the antenna element as is mechanically and electrically feasible.

The integration of the antenna radiating element to planar active circuit using monolithic microwave integrated circuits (MMICs) and the associated implementation of antenna feed network is a multifaceted problem. The innovative solution to this problem was found in the ability to merge the three key functions – i.e., circuitry, feed network, and antenna – into a common design capable of being mounted as a modular plug-in components. The MMICs are active circuits on a single chip. The feed network used is a broadside coupled suspended strip-line circuit that can achieve a wide band (8 to 20 GHz) transitioning microwave energy from the plan transmission lines of the active circuit to the balanced antenna element input (balun). This feed network also acts as an impedance transformer to match the antenna input to the associated active circuit.

The specific tasks are to

- Design the transition balun which will feed the antenna element. Impedance matching optimization to the conical-log antenna design will be carried out. In addition, interference radiation from the feed network located inside the conical spiral will be investigated.
- Fabricate the antenna elements and test its electrical performances. The NASA/Johnson Space Center will test the antenna radiation pattern in the anechoic chamber facility.
- Design of individual circuit components will be carried out. These active designs will make use of commercially available MMICs to the extent that they are feasible; however, the power consumption of the transmit/receive (T/R) module must be given primary consideration. The MMICs (variable power amplifier) developed by NASA for Space Station application will be inserted for use in this T/R module when available and appropriate.
- Review up-to-date published reliability data and implement a reliability evaluation plan especially for this program. As a minimum, some evaluation as to the thermal rise of power transistors and a mean-time between failure analysis will be addressed.



Ku-band active antenna module.

Lifting Body Approach/Land Trajectory Analysis

PI: J. P. Ruppert/EG22
Reference SST 32

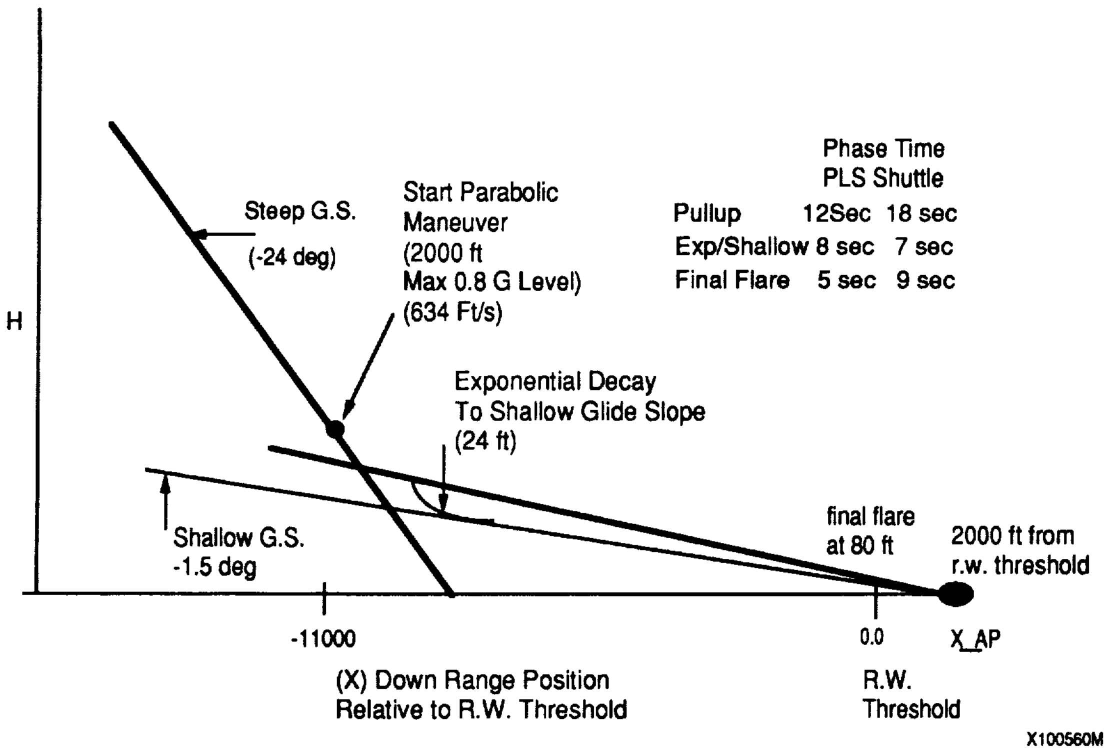
A study was undertaken to examine the flying characteristics of a Langley Research Center (LaRC) proposed lifting body concept vehicle from approach/land (10 000 ft) through touchdown (T.D.). In particular, the study demonstrates the feasibility of flying a lifting body vehicle - automatic and manual modes - through the approach/landing trajectory to T.D., maintaining acceptable aerodynamic limits (i.e., dynamic pressure, g-loads, etc.) and T.D. parameters (i.e., vertical and horizontal velocities). The study will be broadened to analyze the rollout, terminal area energy management, and entry handling characteristics at a future date. For a perspective of the lifting body concept vehicle dimensions and volume, a comparison can be made with the Space Shuttle. Space Shuttle length and weight are approximately one-third and one-eighth of the vehicle, respectively, and it can carry a crew of two with room for up to eight passengers. There is no payload bay, and the passengers are limited to ~200 lbs of "luggage" each. The vehicle is designed to reenter the atmosphere and glide to a predetermined landing site analogous to the Space Shuttle reentry operations.

Three basic developmental phases were associated with creating an approach/landing trajectory simulation. They consisted of: adapting the Space Shuttle's approach/landing guidance algorithm and flight control system (FCS) to the lifting body vehicle; incorporating the LaRC wind-tunnel-derived aerodynamic data, revised Shuttle FCS, and guidance into the Shuttle Engineering Simulator (SES); and interfacing the SES cockpit with the lifting body software program for manual control.

The initial work undertaken was to determine which Shuttle guidance and FCS parameters needed to be modified. The basic Shuttle approach/landing guidance scheme uses a circularization process to transition from a steep (outer) glide slope (−19/−17 deg) to a shallow (inner) glide slope (−1.5 deg) and then performs a final flare for T.D. During these maneuvers, the descent rate is reduced from −190 fps to −12 fps and then finally −3 fps at T.D. The guidance algorithm was developed for the Space Shuttle, however, which has a significantly greater lift-to-drag ratio (L/D = 4.5) than the lifting body (L/D = 2.5). The early simulations demonstrated that the lower L/D lifting body vehicle could not perform the circular pullup within accepted performance margins. Required changes to the lifting body guidance scheme included the increase of the outer glide slope to −24 deg, significantly higher velocities during the outer glide slope to inner glide slope transition which increased the dynamic pressure, and replacing the circularization with a parabolic transition. The next area to be worked was the Shuttle FCS which is a rate command control system with sensed body rate feedback for stability augmentation in all three axes. The major difference between the Shuttle and the lifting body vehicle, besides the airframe differences, is the number of aerosurfaces that can be controlled. The payload systems vehicle has a total of nine aerosurfaces (two elevons/ailerons, four body flaps, one rudder, and two speed brake panels) in contrast to the Shuttle which has seven aerosurfaces. Changes made to the Shuttle FCS consisted of the addition of an aerosurface mixer, the recalculation of the filter coefficients, and the deletion of filters associated with flexible body-bending modes. A software analysis program (MATRIX-x) was used to develop the new coefficients for the FCS filters as well as to perform open/closed loop stability analysis.

Results from the approach/landing simulations indicate the lifting body is a viable candidate for use as a land lander. However, the low L/D of 2.5 provides marginal performance capabilities; an increase in L/D to 4 would significantly improve the handling and landing characteristics. The low L/D vehicle lands with an angle of attack of 13.5°, estimated air speed of 240 knots, and a vertical descent rate of −4.8 fps. A vehicle with an L/D of 4 will be tested in the future and should improve the landing parameters significantly. The relative velocity of the lifting body at the start of the parabolic maneuver is 634 fps which is ~150 fps greater than the Shuttle when it starts its circular pullup. The reason for the higher velocity is that the lifting body requires the higher speed to generate lift. If the speed is too low, the alpha will build up and the vehicle stalls. The other negative aspect of the higher velocity is that the dynamic pressure peaks at 450 psf. Again, a higher L/D vehicle could reduce the value significantly.

Conclusions from the approach/landing trajectory test can best be summarized by saying a lifting body vehicle with an L/D of 2.5 is capable of performing the required maneuvers to land; however, the handling characteristics are marginal. A higher L/D vehicle would be desirable. Due to its high angle of attack and landing speed, this vehicle should be flown in automatic with manual operations as a last resort.



Approach and landing flare profile.

Pathfinder Autonomous Rendezvous and Docking

PI: Stephen Lamkin/EG4
Reference SST 33

Autonomous rendezvous and docking (AR&D) technology is being development under OAET's Pathfinder Program. The 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 terrain, lunar, and planetary orbits.

The Pathfinder AR&D project has three technology areas:

- Systems Integration
- Guidance and Control
- Sensors and Mechanisms

It was necessary to modify the fiscal year (FY) 1990 original work plan due to significant funding reductions. This resulted in a reevaluation of the direction of the AR&D Project and its goals.

The Project was refocused by identifying specific NASA programs that would be users of the AR&D technology. A new schedule was developed that identifies specific program users and their technology need dates so that new AR&D milestones would match those need dates. The project plan was revised to reflect this new focus and includes the new milestones and schedule.

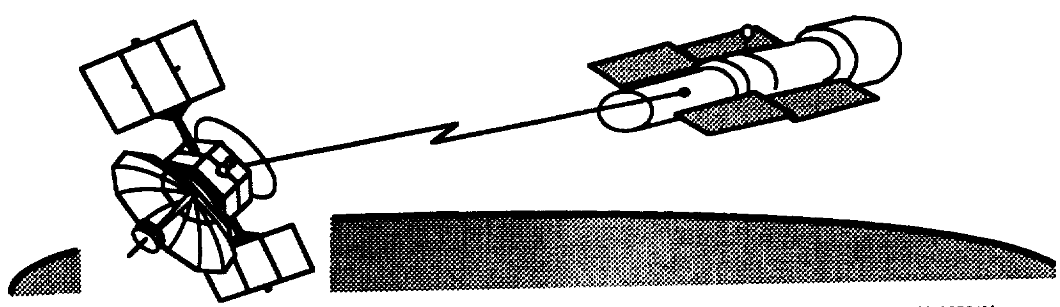
As part of the new schedule and focus, existing NASA capabilities and facilities to conduct meaningful initial demonstrations of AR&D techniques were identified, and demonstrations were planned to be conducted in FY 1991. Two demonstrations are now planned:

- An integrated docking sensor and docking mechanism demonstration using existing hardware, and
- A high-fidelity graphical simulation of rendezvous and proximity operations.

Two activities begun in FY 1989 – the prototype of the AR&D database and the Sensor Trade Study – were completed in the first half of the year while the project was being refocused to reflect the new direction. Sensor Trade Study results were incomplete, so an in-house follow-on effort and evaluation were begun with completion due in early FY 1991.

As a first step in support of the two demonstrations, a graphical playback capability was developed off-line, which can then be used with the high-fidelity graphics simulations. This initial capability permits playback of a predetermined rendezvous and proximity operations trajectory; an interactive capability will be developed later as part of the graphics simulation. The graphical simulation will be used to generate a set of initial conditions for use by the docking demonstration. Use of existing models will speed development of the simulation.

Plans were made for conducting the two demonstrations in FY 1991 if funding is received from Headquarters (Code R). Otherwise, some scaling back will occur, and only the minimal effort necessary to conduct the demonstrations will be accomplished.



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Typical AR&D mission support scenario in low Earth orbit.

Laser-Induced Fluorescence and Spectroscopic Arc Jet Diagnostics

PI: Carl D. Scott, Ph.D./EG3
Eric Yuen/ES3
Sivaram Arcpalli, Ph. D./CG5
Harvel Blackwell, Ph.D./CG5
BSA Services
Stan Bouslog/C95
Reference SST 34

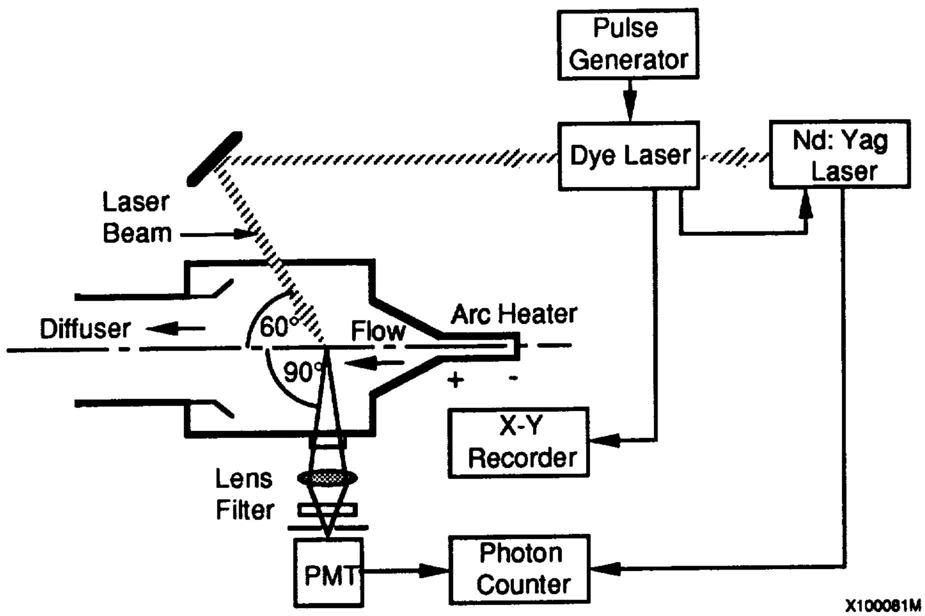
One of the important phenomenon associated with reentry and aerobraking of spacecraft in the atmosphere is the recombination of atoms on thermal protection surfaces. Determining the rate of recombination on materials at high temperatures is necessary for accurate prediction of heat transfer during spacecraft high-altitude flight.

This project has involved Johnson Space Center (JSC) civil service and support contractor personnel with hands-on experience applied to improving the simulation of reentry flows in test facilities and provide the database necessary for calculating design aeroheating environments for the Orbiter as well as for future vehicles, such as the Aeroassist Flight Experiment.

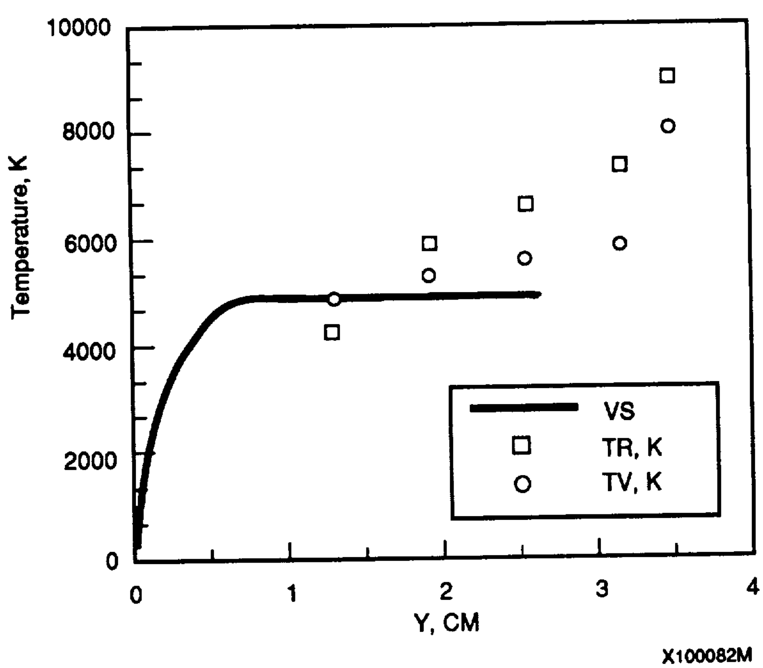
Catalytic surface recombination rates may be measured indirectly in atmospheric entry simulation facilities where air is heated to reentry energies. At these energies, the oxygen and nitrogen in the air dissociate, absorbing a large fraction of the energy. This bond energy can be released as atoms diffuse to the surface and recombine thereon. However, if the surface is not catalytic with respect to atom recombination, the chemical energy will not be transferred to the surface. Thus, a noncatalytic surface experiences much lower heating than a fully catalytic surface. Since the heating due to catalytic recombination depends strongly on both the gas phase chemistry and gas/surface chemistry, the aerothermodynamicist needs both accurate gas phase reaction rates and surface recombination rates to predict the heating to spacecraft entering or aerobraking into the Earth's atmosphere.

To measure surface reaction rates, the composition of the flow must be known. Therefore, measurements of flow properties that allow determination of the composition must be made. Several techniques were developed or implemented recently for the JSC Atmospheric Reentry Materials and Structures Evaluation Facility. Spectroscopic techniques such as measurements of the emission of nitrogen molecular radiation have provided profiles of the temperature in the high-temperature shock layer of test articles inserted into the arc jet flow. The first figure shows a comparison of the vibrational and rotational temperature in the shock layer of a blunt object in the arc jet flow. These temperatures were inferred from the emission spectrum of nitrogen molecules by fitting the measured spectrum to calculated spectra. These measurements can be useful for comparison with flow calculations to verify the physical modeling. Correct chemical and physical models of the external gas flow are necessary for determining the composition of the flow necessary for inferring catalytic recombination rates.

Another measurement technique developed here is the determination of the velocity and temperature of the flow using a laser-induced fluorescence technique. The amount of radiation absorbed and reradiated depends on the Doppler shift and is broadened by the random thermal velocities and bulk velocity in the nozzle flow. One convenient species that exists in the flow in the JSC arc jets is the contaminant copper. Copper resonantly absorbs laser radiation and fluorescently reradiates the energy. By scanning the laser over wavelength and measuring the fluorescent radiation with a photomultiplier tube, one is able to determine the Doppler shift, that will yield the bulk velocity, and the Doppler profile, that will yield the temperature. (The experimental arrangement is shown in the second figure.) The velocity and temperature are needed to verify flow conditions and reduce uncertainties about the flow chemical composition. Differences between the measured and calculated velocities point out the usefulness of measuring the velocity instead of just relying on the computations. This comparison indicates that the flow is more dissociated than the predictions indicate, probably due to nonuniformities in the initial flow and nonequilibrium effects in the arc jet plenum that are unaccounted for in the calculations. From the flow diagnostic information, we are then able to determine the catalytic recombination rates



Experimental setup for Doppler copper laser induced fluorescence.



Comparison of measured vibrational and rotational temperatures with translational temperature from calculation.

Advanced Control Techniques of Large Flexible Spacecraft

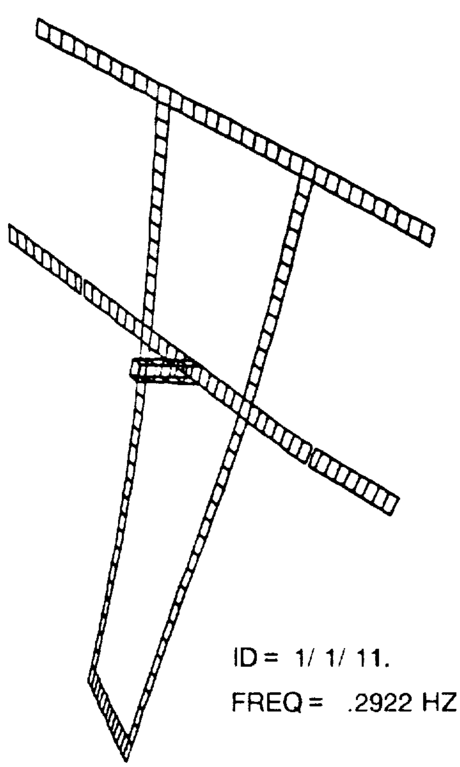
PI: John W. Sunkel/EG3
Reference SST 35

Considerable progress was made in fiscal year (FY) 1990 in the development and evaluation of advanced control system laws for spacecraft. Robust spacecraft control law designs derived from ℓ^1 and H^∞ as theory were applied to the attitude control and momentum management of the Space Station Freedom. This work proved to be very timely in that Honeywell, who is responsible for the design of the Space Station attitude control system, is proposing a design based on H^∞ theory. Our research in this area has given us a good understanding of this design approach and may have been instrumental in Honeywell's decision to adopt it.

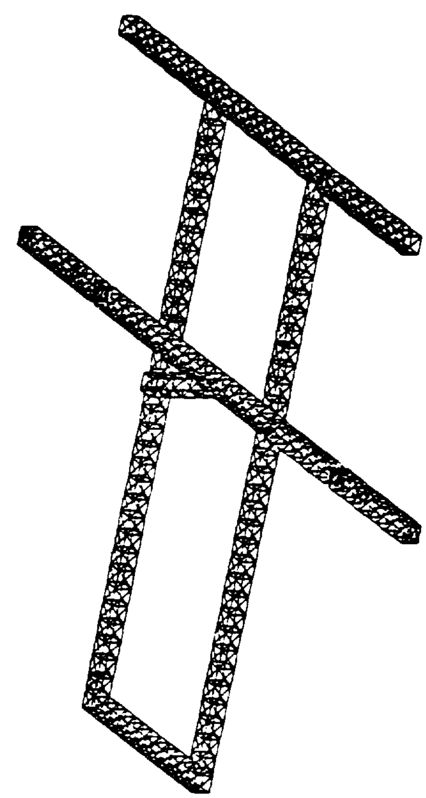
In addition, considerable progress was made on adaptive control techniques. A state space self-tuning adaptive control algorithm was tested on the Johnson Space Center Space Station Control Simulator. This control law successfully controlled the Space Station attitude control and momentum management during large mass property changes which simulate Space Station remote manipulator system operations.

Other work performed during FY 1990 included the feasibility of using a frequency-based localization technique for finding structural flaws. This was studied using Space Station configurations MB1, MB2, and MB15. The results look promising, and work will continue on refining this approach.

Work is progressing on a computational control workstation designed for the efficient solution of multiflexible body dynamics problems. Key hardware components were purchased and assembled. The dynamics solution algorithm for a multiprocessor architecture was developed and optimized. Plans are on schedule for the installation of the prototype by the end of March 1991.



Representative mode shape.



Full truss structure without deflection.

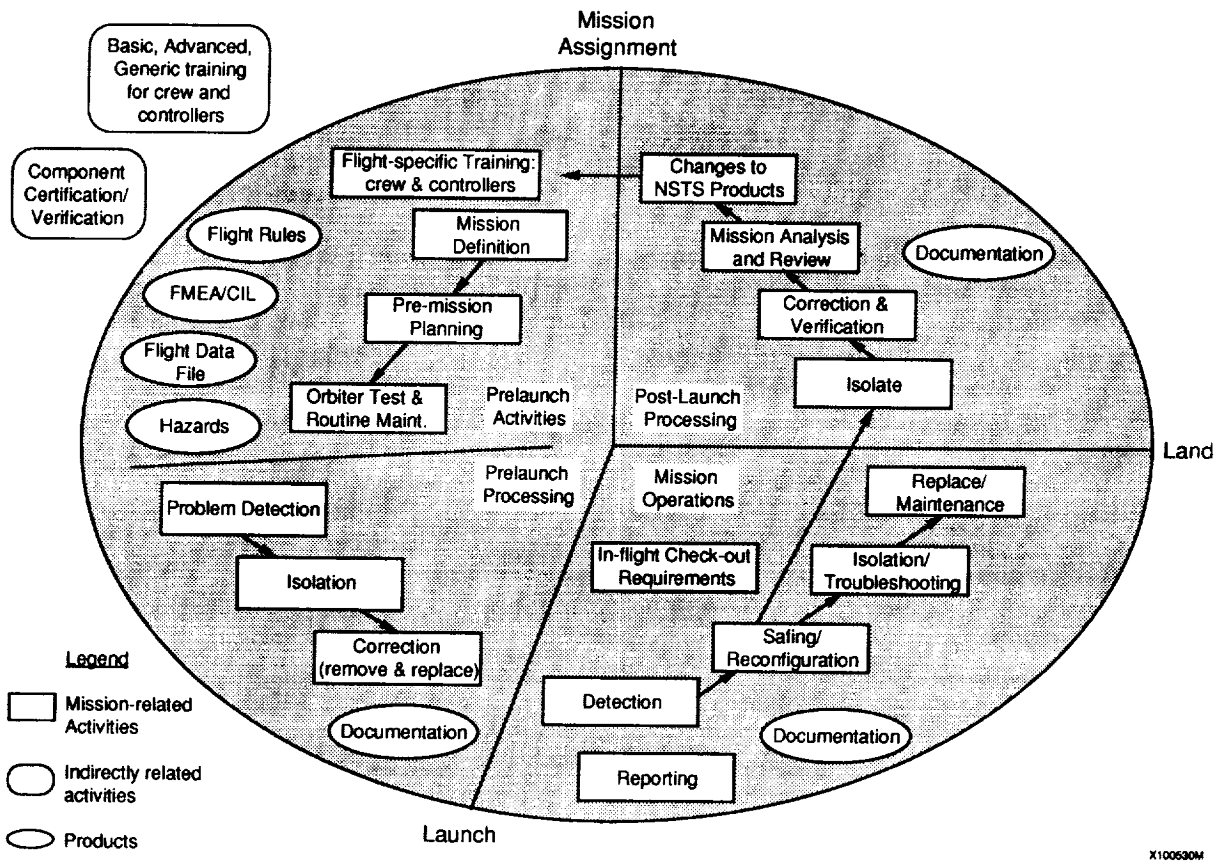
Benefits of Using Expert Systems to Perform Fault Detection, Isolation, and Recovery on Space Station Freedom

PI: Dennis Lawler/ER22
Reference SST 36

Performing fault diagnosis and system recovery are critical functions for managing large, complex systems. Chemical plants, nuclear reactors, and the Space Shuttle typify systems that are monitored and tracked constantly as a part of total fault management. On the Space Shuttle, this function is done primarily with manpower-intensive monitoring of the spacecraft's subsystem and information analysis from the ground. Space Station Freedom (SSF) operational costs will be driven strongly by the manpower requirements for fault monitoring and diagnosis. Automated systems should lower operations costs, increase flexibility, improve reliability, increase productivity and the feasibility of autonomous space vehicles, and reduce hazards to humans. To plan adequately for and accomplish the optimal use of automation for SSF fault management, the costs and benefits of performing fault management with various automation techniques must be known. Valid models are required to develop cost/benefit profiles for the Space Station Freedom Program (SSFP).

An investigation and analysis of the methods used to perform fault management for the Space Transportation System has been performed to provide a basis upon which to formulate these cost/benefit profiles. Fault management for the Space Shuttle is a set of complex, interrelated processes spanning multiple NASA centers, organizations, and contractors (see figure). The real-time portion of fault management – i.e., detection, isolation, and safing of the Shuttle subsystems by flight controllers and the crew – relies on adequate preparation and processing of extremely large volumes of information before a mission. Considerable success has been achieved in automating some real-time fault processes and information handling aspects of fault management that occur before and after a mission. Numerous databases, tools, and pockets of information have been used to support personnel involved in these processes. A bottom-up approach to consolidation and automation has evolved that deals with fault management in this program. Much of what exists now has been developed gradually over the years to assist individuals and organizations in the performance of their tasks. Automation has been used in isolated areas to improve program management visibility into the program. Center-wide and NASA-wide efforts to develop more global information resource management policies and total quality management are providing even greater incentive to streamline processes and consolidate common sources of information. However, the Space Shuttle Program still has a long way to go to achieve effective, optimal use of even current automation technologies (e.g., automated statistical analyses, distributed databases with intelligent interfaces, automated real-time data processing and analyses, process modeling, etc.).

The automation, integration, and coordination of information sources and tools for Space Shuttle fault management has been, and is likely to continue to be, a slow process, but one which promises considerable success in the foreseeable future. For SSF, the opportunity exists to learn from the Space Shuttle Program and to develop wise, cost-effective automation for fault management across the SSFP. Real-time fault management for SSF will rely heavily on the availability, correctness, consistency, and completeness of a wide range of information, including fault histories, maintenance logs, statistical analyses of component lifetime expectancies, operating conditions, component interaction models, fault models or trees, hazard analyses, etc. The proper and effective use must be made of automation to organize, track, maintain, and consolidate this underlying information in addition to the continuous pursuit of real-time fault management technology to achieve the most optimum benefit from automation.



NSTS fault management.

Developing Intelligent Systems for Monitoring and Fault Management: CONFIG Intelligent Modeling and Analysis Tool Kit

PI: J. T. Malin/ER22
Reference SST 37

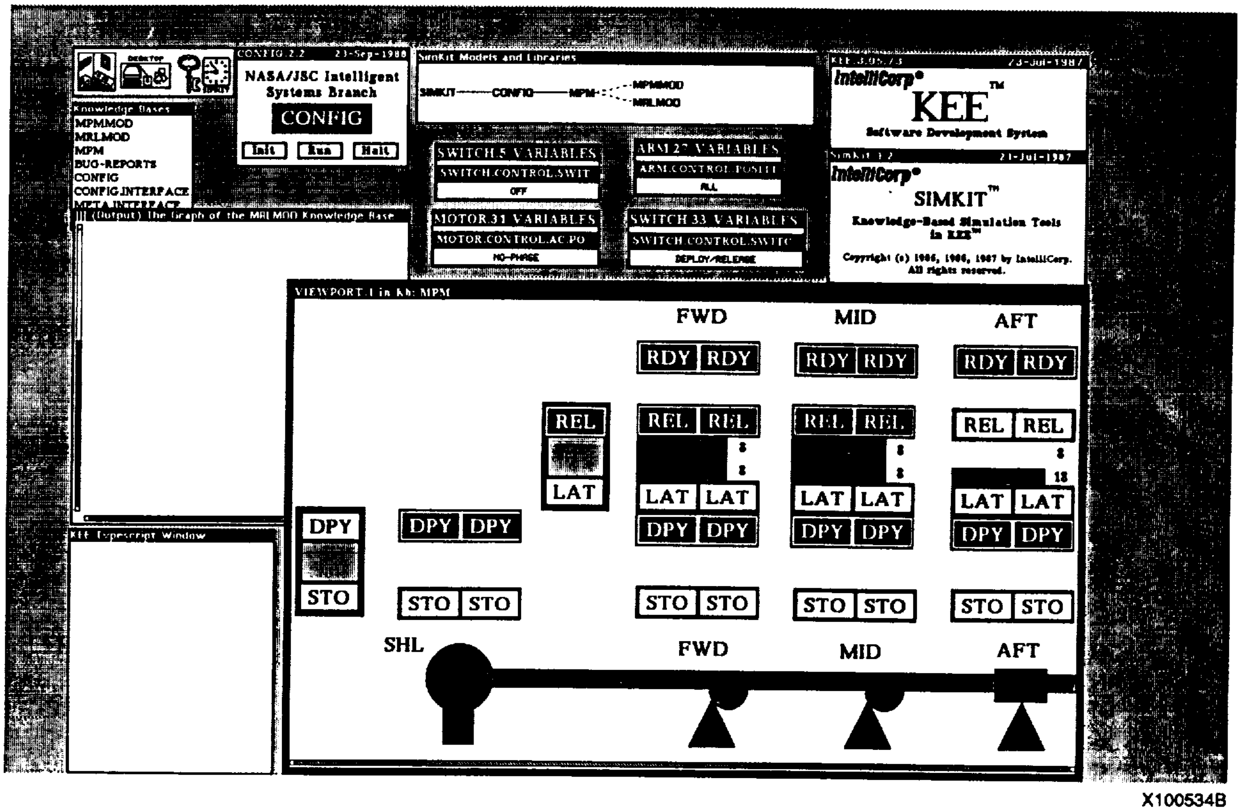
Technology for intelligent automation of monitoring, control, and fault management for space systems will aid personnel responsible for those tasks. This will result in significant reductions in the operational costs of manned and unmanned systems, as well as an increased capability to carry out new types of unmanned missions. In addition, more robust fault-management performance will reduce costs for space system maintenance and repair and reduce risks due to undetected problems.

An important goal of intelligent automation technology is to produce advanced software that is informative and maintainable. To achieve understandability, representations have been developed to correspond to those of intelligent humans. They also have been embedded in user-friendly software development environments. These understandable rule- and object-based systems have been developed successfully and used by flight controllers in the Space Shuttle Program.

Additional key representation types are needed to capture key concepts and strategies used for monitoring and fault management by mission controllers, system designers, and safety personnel. These individuals use mental models of the function and structure of systems and their interrelated components. Representations of these models require further development so they can be added to the set of representations that are used successfully. They can be embedded in user-friendly software tools for modeling, specification, design, and analysis of systems and their requirements and interactions. They also can be designed to maximize reusability and integration with other powerful tools that use less understandable system models and analysis approaches. This integration can result in powerful and informative hybrid tools. Such representations and tools should permit the coordinated modeling and analysis of goals and functions of missions, and nominal and faulty behaviors of components and systems of related components. Further, these representations and tools should support the development of the currently successful intelligent automation systems. They also should be designed to be usable in many phases of the engineering and operations life cycle.

To achieve these goals, concepts are under development that will extend intelligent qualitative system modeling technology and embed it in software tools for modeling, simulation, and analysis of space systems. The CONFIG prototype tool kit has been successfully developed and demonstrated. It integrates qualitative modeling, discrete event simulation, and digraph analysis technologies and embeds them in an easy-to-use tool kit with interactive graphics for analyzing dynamic processing systems. The CONFIG toolkit supports evaluations of system diagnosability and fault tolerance, and supports analyses of the development over time of system effects of problems including faults, failures, and procedural or environmental difficulties. A software patent for CONFIG's innovative representations has been awarded, and their description has been published in *Artificial Intelligence in Process Engineering*.

The CONFIG toolkit has been used to model Space Shuttle remote manipulator system subsystems in order to support the development of a rule-based monitoring and fault management system for the Johnson Space Center's Mission Control Center. Involvement in this application project has resulted in the identification of new requirements for hierarchical, functional, and procedural models. The tool kit is currently being reimplemented in the Common Lisp Object System for rehosting onto engineering workstations and is being enhanced to meet new requirements.



The CONFIG tool kit screen: Space Shuttle remote manipulator system modeling.

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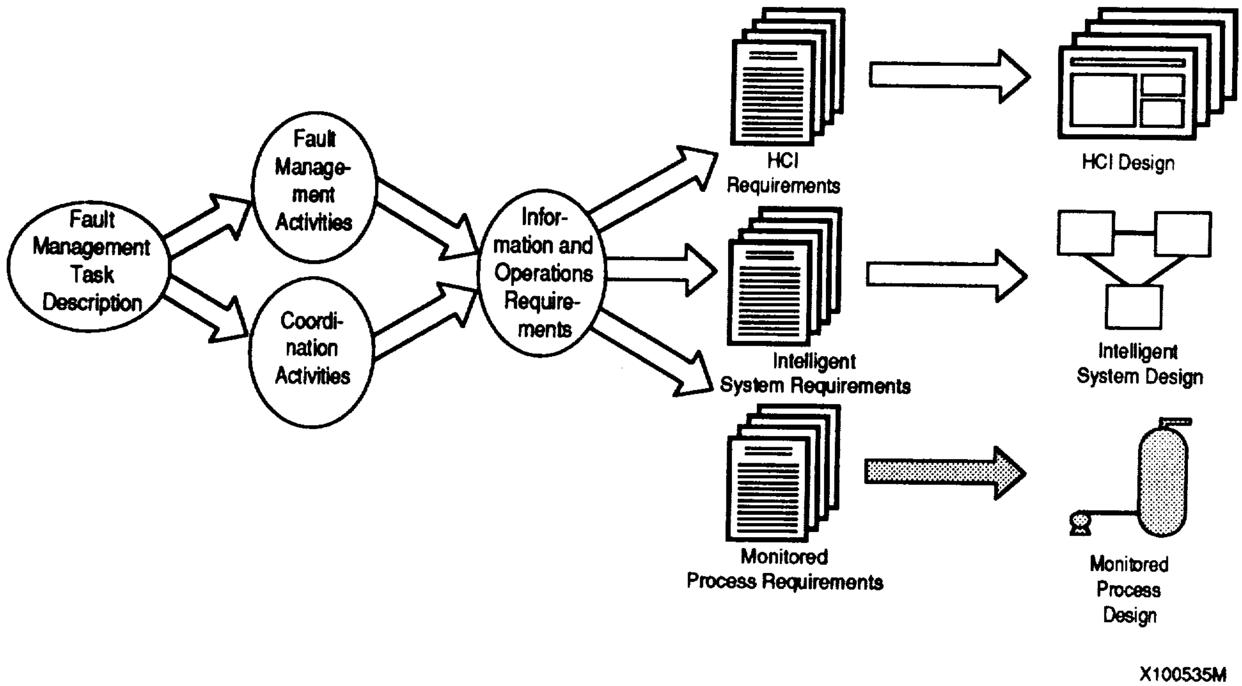
Making Intelligent System Team Players – Design Guidance

PI: J. T. Malin/ER22
Reference SST 38

Human operators use intelligent systems to automate and assist in monitoring and fault-management tasks. Effective user interfaces and supporting intelligent system capabilities are critical to the success of these intelligent systems, especially when the monitored systems are complex space systems. The purpose of this project is to develop and deliver human-computer interaction design recommendations for intelligent systems used for aerospace monitoring and fault management. Recommendations concern two complementary design areas; i.e., design of the intelligent system and of displays. The problem is interdisciplinary; therefore, personnel with expertise in intelligent systems and human engineering are collaborating to develop and deliver the design guidance.

The major effort in fiscal year (FY) 1990 has been an extensive survey of cases and literature on human interaction with intelligent systems. Many NASA and some related non-NASA intelligent systems and prototypes for monitoring and fault management were studied. In selected cases, personnel are participating in intelligent system development projects in both the Space Shuttle and Space Station Programs. This activity has proven to be a productive way to observe the design process, to test and refine preliminary recommendations, and to create and test new design concepts and examples. Initial reports describe case study survey results, including observations on fault management tasks, human and computer roles, and coordination. These reports also include observations on the process of intelligent system design, and on how to deliver design guidance in that context.

A key assumption about human-computer interactions in these situations is that the humans and the intelligent systems are both capable specialists, but the fault management context can be counted on to produce difficult and nonroutine problems which require coordinated problem solving and flexible task sharing as well as productive and safe intervention and override. The design of intelligent systems and displays for this dynamic, distributed, multitasking situation presents several challenges throughout the design life cycle. Additional requirements for information to support productive teamwork have been identified, both from humans and from the monitored and intelligent systems. This extra information leads to new information representation requirements and presents challenges for display design. Intelligent system technology should be able to rise to these challenges, especially since some issues already are being addressed as computer-computer interaction problems in distributed artificial intelligence. Display design also must rise to these challenges, especially with the design of new types of dynamic high-information graphic displays. In FY 1991, a report consolidating the results of all the case studies will be published. Study of design issues, participation in design cases, and generation of display design examples and recommendations will continue. Also, an investigation of the electronic delivery of design assistance and guidance will begin.



Developing intelligent systems for human-computer interaction and teamwork.

Tool Kit for User-Intelligent System Interaction Design

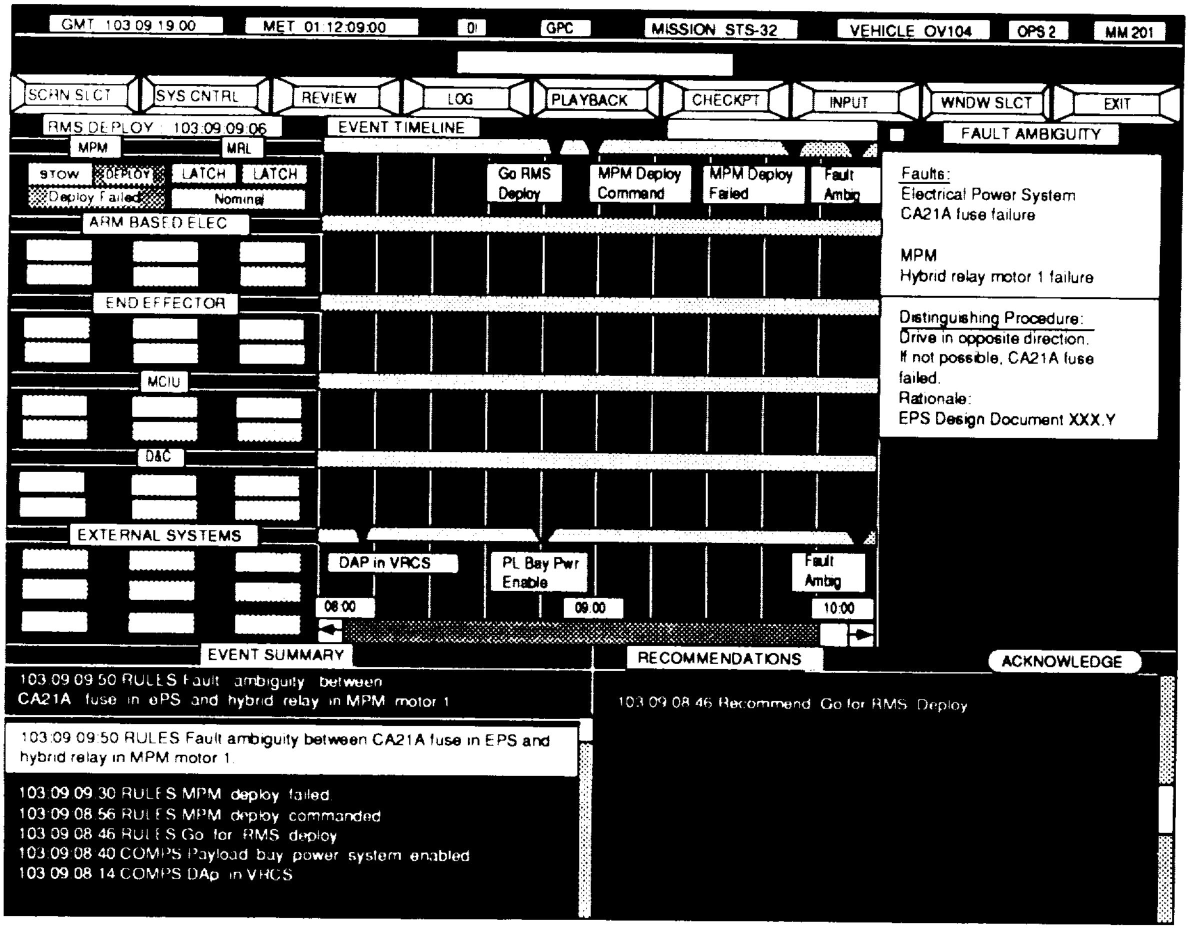
PI: J. T. Malin/ER22
Reference SST 39

Human operators use intelligent systems to automate and assist in monitoring and fault-management tasks. Effective user interfaces and supporting intelligent system capabilities are critical to the success of these intelligent systems, especially when the monitored systems are complex space systems. The purpose of this project is to prototype methodology and tools to support designers of intelligent systems for aerospace monitoring and fault management. These tools would support human-computer interaction design so requirements can be developed simultaneously for three design areas: those of the intelligent system, displays, and sensor and actuator capabilities of the monitored system.

A major product in 1990 is a prototype software tool kit and methodology to support the specification, design, and test of intelligent systems and their user interfaces. A key feature of the software architecture is an object-oriented data model of the information from the intelligent system that is used by the human interface software. This data model also can be used to specify information requirements to support user understanding and intervention. The interfaces are constructed with a graphics tool for building displays and a rule-based connection tool for tying the information layer to the displays and managing the interface. In addition to the software, guidelines and a methodology have been defined to generate the information layer and build the interfaces. This software has been demonstrated using a fault-management scenario for a space thermal control system in which a model-based intelligent system assists the human operator in a difficult fault-management situation.

To study the applicability of the prototype to develop and represent requirements, design concepts have been developed for a human interface for an intelligent system that will manage failures in the Space Shuttle payload deployment and retrieval (PDRS) system. The PDRS project results will be used to exercise and evaluate the prototype in fiscal year (FY) 1991.

Another major product in FY 1990 is the report, "Graphic Interfaces to Intelligent Fault Management Systems: Issues and Guidelines." This report documents lessons learned during the prototype tool kit development activity concerning how to design graphic interfaces to intelligent fault-management systems. The report identifies new information requirements, issues, and guidelines for systems to support dialogue and cooperative human-computer problem solving. It also presents new concepts and designs for schematics and diagrams, and for explanations and explanatory displays.



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Space Shuttle PDRS integrated status display design concept.

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Space Station Freedom Exercise Countermeasures Intelligent System (ExerCISys)

PI: Laurie Webster/ER2
Reference SST 40

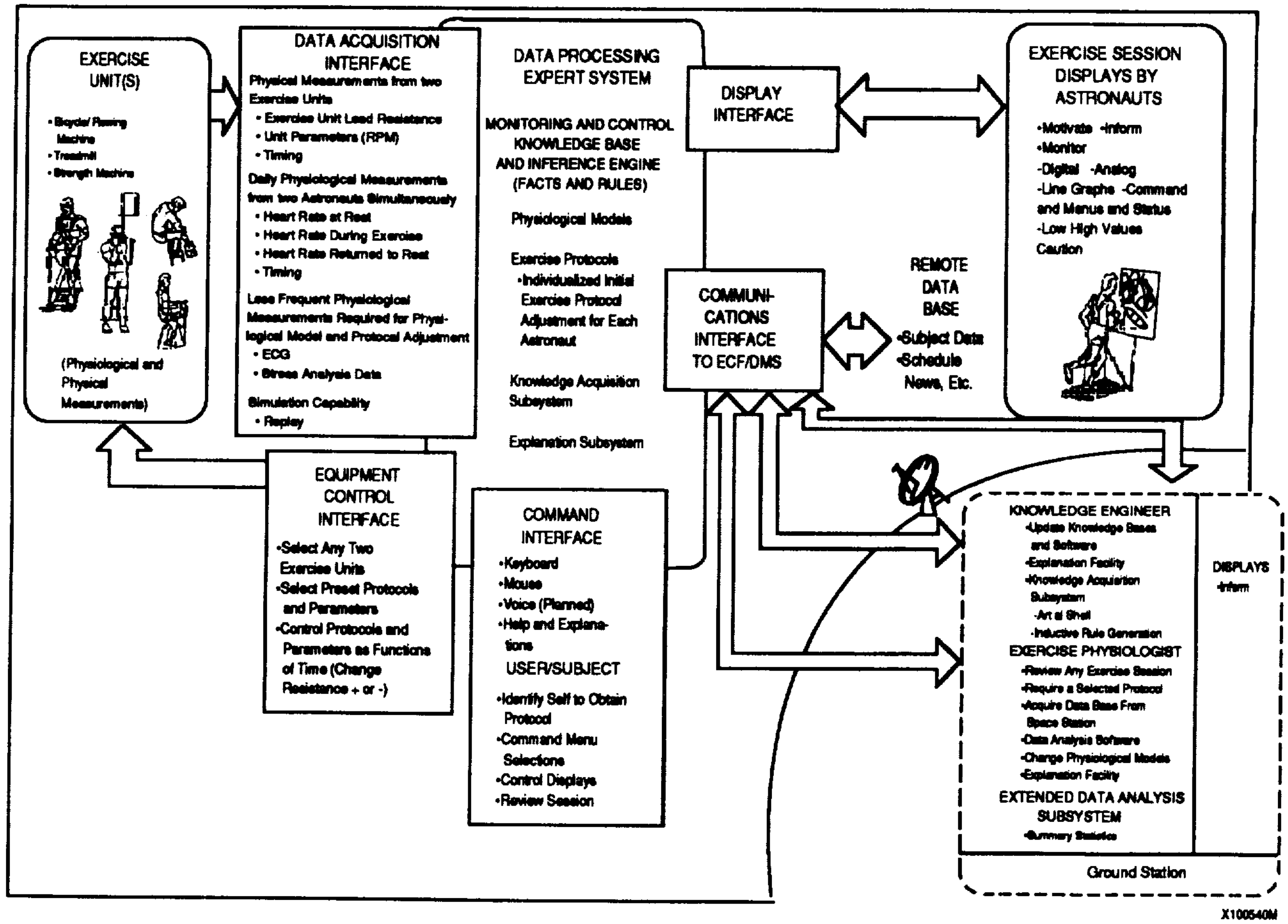
The Exercise Countermeasures Intelligent System (ExerCISys) is a prototype system that is designed to demonstrate the use of artificial intelligence technology as an integral part of NASA's Exercise Countermeasures Facility (ECF) project to develop exercise countermeasures against some of the physiological problems encountered in space flight.

This system is being developed by the Artificial Intelligence Laboratory of the ECF under the Exercise Countermeasures Project of the Space Biomedical Research Institute.

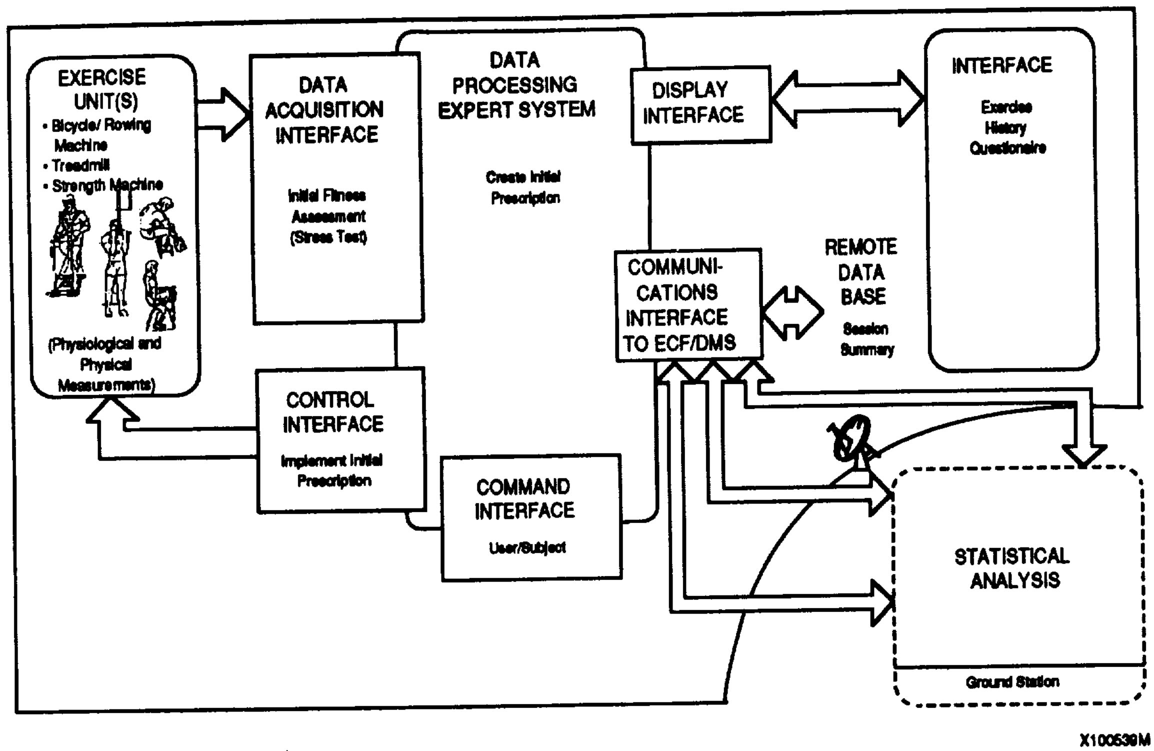
The major components of the overall system design are shown in the figure 1. Figure 2 depicts the part of the expert system that was developed and tested in fiscal year (FY) 1990. The present system consists of a data processing expert system to create and evaluate exercise prescriptions, and an exercise unit to assess a subject's fitness by providing physiological and physical data with the ability to provide a statistical analysis of the data, and a control and monitoring unit of control application of the stress test and an exercise prescription.

In FY 1990, we performed an experiment to test the performance of ExerCISys. That test consisted of giving the expert system the same data (data from eight subjects) that was given to nine exercise physiologists to diagnose, thus determining if the expert system decided on the same baseline prescription as did the exercise physiologists. Included in the test was a comparison of whether the expert system performs baseline exercise prescription writing (i.e., decides on the same prescription) employing the same reasoning steps (reasoning processes) and the same reasoning factors as did the exercise physiologists. An expert system developed from authentic methods has a goal to achieve a correct solution in the way the practitioners do it.

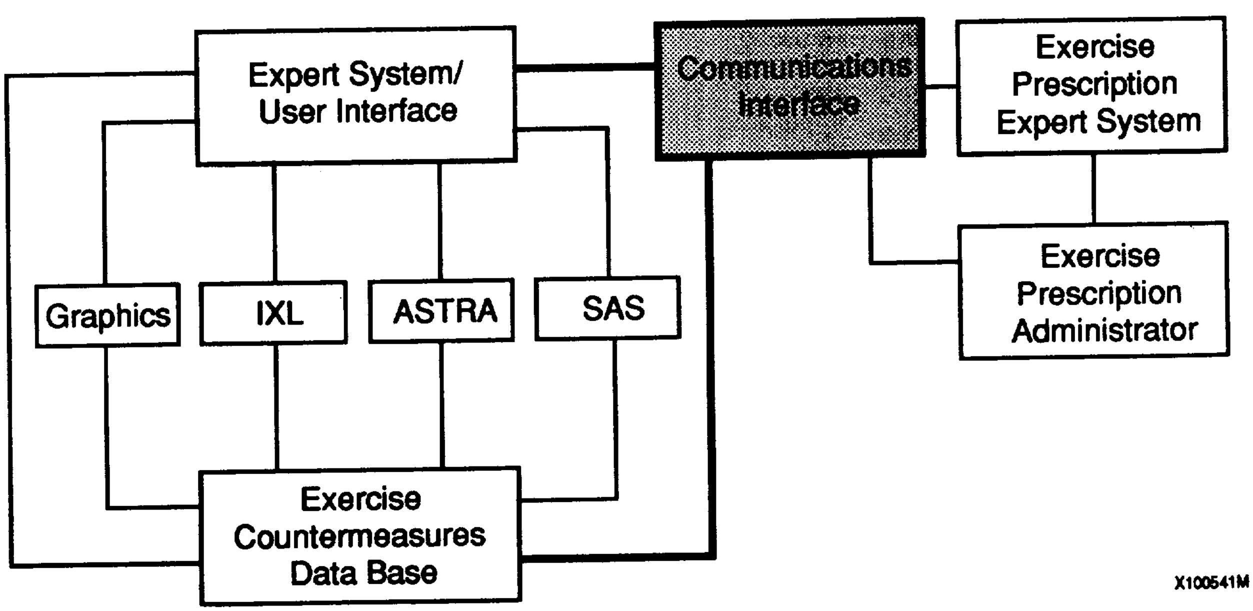
Also, the ground base portion of the system was enhanced with an intelligent database management and analysis interface that included Graphics, induction on extremely large databases, automated structural rule acquisition, and a statistical analysis system (see fig. 3).



Exercise countermeasure facility (ECF) monitoring and control expert system.



Exercise countermeasures facility (ECF) monitoring and control expert system for writing baseline exercise prescriptions.



ExerCISys architecture for extended data analysis and inductive learning.

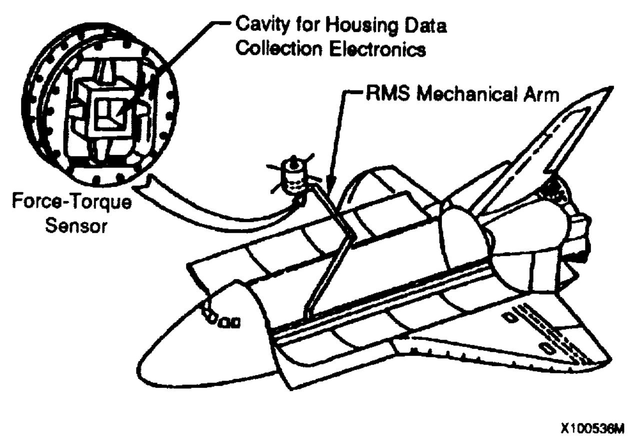
Shuttle Remote Manipulator System (SRMS) Advanced Force Torque Control

PI: Donald A. Barron/ER3
Reference 41

The objective of the Shuttle remote manipulator system (SRMS) advanced force/torque control task is to provide a demonstrable capability to use force/torque sensing at the SRMS end-effector to improve control and to influence the definition of future SRMS upgrades. Closed-loop force control provides automatic accommodation of contact forces between the arm and other external structures. It can be applied to increasingly complex future Shuttle missions to reduce risk and enhance performance. Force feedback control techniques developed for the SRMS may be applied to other remote manipulator systems (RMSs) and servicers (i.e., flight test system, Materials Service Center) for Space Station as well.

The advanced force torque control task is divided into three phases. The first phase (fiscal year (FY) 1989) investigated and applied candidate control laws to an industrial robot arm and demonstrated force feedback control using this industrial arm. The second phase (FY 1990) identified the SRMS dynamic characteristics that influence the feasibility of transferring the technology learned from the industrial arm to the SRMS. A demonstration of these force feedback control techniques on the RMS-like robot arm in the Manipulator Development Facility (MDF) also was planned. The third phase of the study applies candidate control laws using the Shuttle engineering simulation high-fidelity model of the SRMS. A 6-degree-of-freedom table will provide contact forces for the berthing scenario to be used in the demonstration.

The first phase of this study has been accomplished, and a report has been published. The second phase was worked on in fiscal year (FY) 1990 when the impact of the SRMS nonlinear characteristics on force feedback controllability was identified using simulated models of the SRMS. An additional task board was built for the robot laboratory to develop force control laws further. The Jet Propulsion Laboratory force/torque sensor and electronics were not delivered in time to perform testing in the MDF during FY 1990. However, a plan was established with the SRMS Dexterous Manipulation task group to test and demonstrate the closed-loop force control in the MDF in conjunction with their open-loop force display task. It is anticipated that this testing will be completed by the end of the first quarter of FY 1991. The contractor also visited Sandia Lab, Goddard Space Flight Center, and Rensselaer Polytechnic Institute to increase his knowledge of other laboratory research projects.



Proposed force-torque sensor on SRMS.

Failure-Tolerant Manipulator Joint and Controller Development

TM: John Chladek/ER4
Reference SST 42

The design of the Shuttle remote manipulator system (SRMS) on the Orbiter is based on a chain of six serial mechanical joints controlled by a single string of electronics and electromechanical actuators. It is an excellent system but, due to the possibility of failures causing uncommanded motion, the SRMS is restricted in those operations which it is allowed to perform. In addition, if a joint electromechanical failure occurs, the coordinated control of the SRMS end-effector is lost, making the usefulness of the manipulator system practically zero.

A multiple actuator joint design was thus investigated which could transparently absorb a drastic control or electromechanical failure. This would eliminate current space manipulator operational problems, prohibit uncommanded motion due to failures, and provide continuance of the task after a failure. Headquarters Research and Technology Objectives and Plans funds were granted in fiscal year (FY) 1989 to pursue this development, and a continuance was granted for FY 1990.

The concept investigated uses a differential drive mechanism with two motor modules driving an output joint. This would allow one failure while continuing the normal joint operation without degradation. Engineering modeling and simulation have proceeded, and a laboratory implementation is to be performed to verify modeling and simulation results. The efforts in the first year were to analyze a differential drive concept and to attempt to develop a failure-tolerant joint design. Transient effects during a failure are the main area of focus, with an attempt to minimize these effects.

Differential gear train dynamics were modeled with torsional flex for the elastic mechanical components to include torsional resonance phenomenon. Several mechanical configurations were assessed, and the effects of fault transient response were studied. The analysis initially was accomplished using ADAMS, a dynamic and kinematic analysis package capable of handling redundant constraints. The nonlinear equations of motion of the differential were converted to linearized versions and verified using AUTOLEV, a symbolic manipulation package. This in turn allowed the use of MATRIXx for a detailed linearized analysis. Nonlinear backdriving was implemented in the models for differing percentages of commanded torque from the two motors. Linear time-varying state equations were developed to allow the utilization of MATRIXx for three configurations. A paper was submitted to the IEEE International Conference on Robotics and Automation entitled "A Fault Tolerant Joint Drive System for the Space Shuttle Remote Manipulator System."

A concept for a mechanism hardware testbed was developed to provide testing of the various proposed mechanical configurations. The major components were ordered, including gearboxes which approximate the joint characteristics of the SRMS and harmonic drives as used in both the flight test system and the robotics research manipulators. Design and fabrication of a testbed to contain the mechanical components is to be accomplished in FY 1990. Development also continues on the controller systems and instrumentation to allow comparison of operational transient responses to the analysis from models and simulations.

Implementation of a Compact 6-Degree-of-Freedom Force Reflecting Hand Controller with Cueing Modes

PI: Duane Johnson/ER3
Reference SST 43

Teleoperated control of remote robotic devices requires a master human interface device that can provide haptic input and output which reflect the responses of a slave robotic system. This Phase II Small Business Innovative Research effort is implementing a 6-degree-of-freedom (DOF) Cartesian coordinate hand controller for this purpose. The device design recommended is an XYZ stage attached to a three-roll wrist which positions a flight-type handgrip. The 6-DOFs are transduced and control direct current motor servo-electronics that are similar in design to those used in computer-controlled robotic manipulators. This general approach supports scaled force, velocity, and position feedback to aid an operator in achieving telepresence.

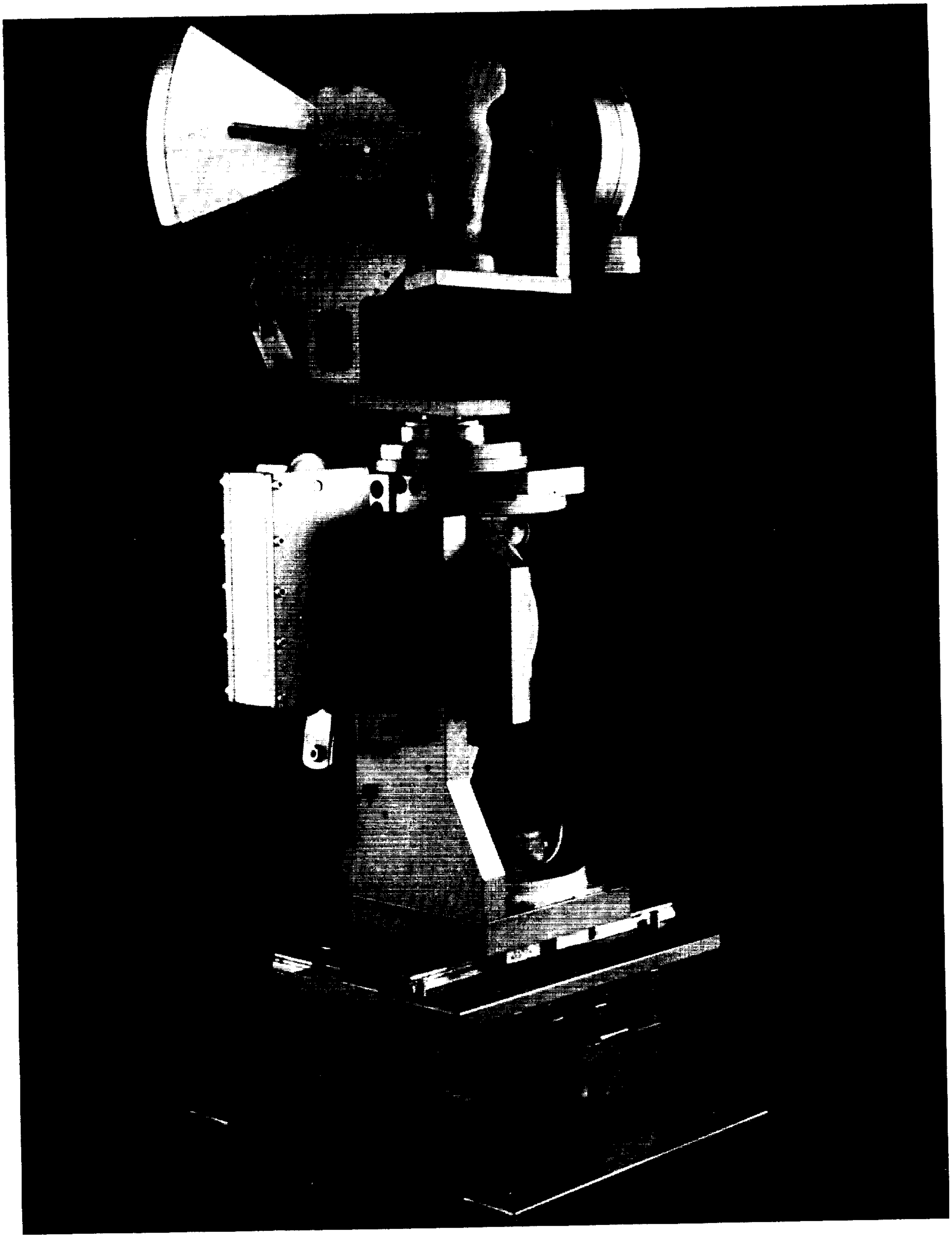
The electronic control system is implemented on a single VME computer card augmented by six power amplifiers and a switching power supply. The mechanical unit measures $\sim 15 \times 10 \times 10$ ft and provides a $5 \times 5 \times 5$ ft range of motion in X, Y, and Z. The unit can exert better than 5 lbs in X, Y, and Z, and better than 20 lb-in. pitch, roll, and yaw. The positioning accuracy is better than 1 part in 4096, and the force resolution is better than 0.1 oz. In addition, for support for simple teleoperation force feedback control modes, the hand controller software package provides a library of "feels" which allows construction of virtual force models.

The Phase I work was completed in August 1989. Following that design effort, a project funded by the Michigan State Research Fund continued the product into fabrication of the first three stages of the six-stage hand controller device. These two efforts helped us to determine basic design feasibility.

The NASA-funded Phase II effort began in June 1990 and has allowed completion of the prototype device begun earlier, implementation of an electronic controller, and coding/testing of the preliminary software systems. Refinement of the electronics and software coupled with three major mechanical design revisions culminated in a very usable prototype unit which Cybernet demonstrated at the end of November 1990 (at the NASA Technology 2000 Exposition in Washington D.C.).

Lessons learned from that prototype are being used in a mechanical systems redesign to reduce unit size and weight by 30 to 40 percent. Electronic systems will be repackaged as well. A final unit to be shipped to NASA's Johnson Space Center should be available by circa June 1991. This will support further NASA testing of force-torque sensor feedback versus force-feedback derived from reverse robot kinematics.

Force-reflecting hand controllers have advantages in space-based applications where an operator must control several robot arms in a simultaneous and coordinated fashion. They also have applications in intravehicular activities (within the Space Station) such as microgravity experiments in metallurgy and biological experiments that require isolation from the astronaut's environment. For ground applications, universal or computer-controlled hand controllers are useful in underwater activities where the generality of the hand controller becomes an asset for the operation of many different manipulator types. Also. applications will emerge in the military, construction, and maintenance/manufacturing areas including ordnance handling, mine removal, nuclear, chemical, biological [NBC] operations, control of vehicles, and operating strength and agility-enhanced machines. Future avionics applications including advanced helicopter and aircraft control also may become important.



Compact 6-degree of freedom force reflecting hand controller.

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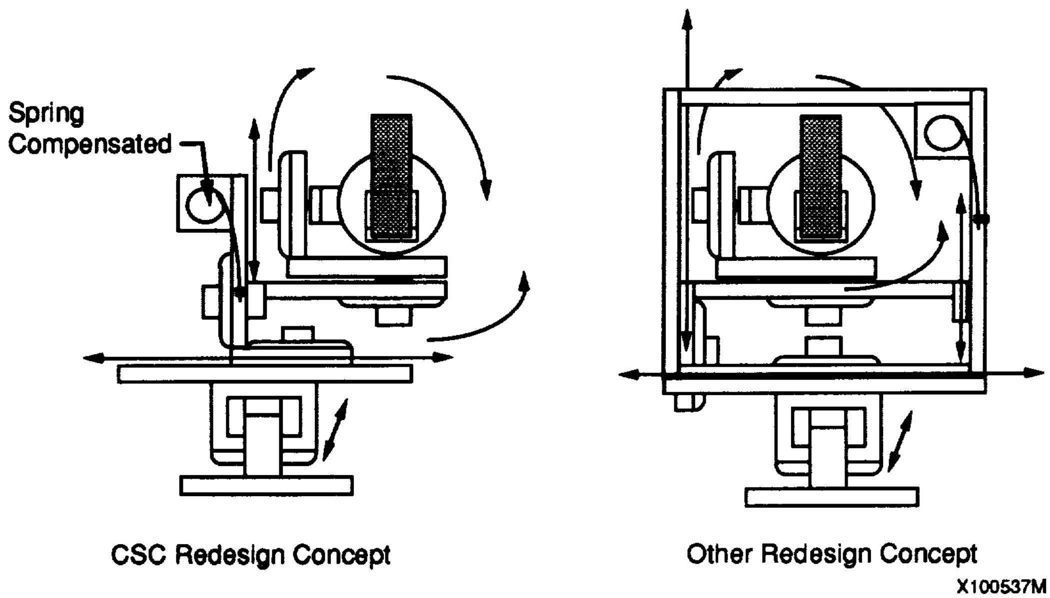


Redesign concepts for hand controller

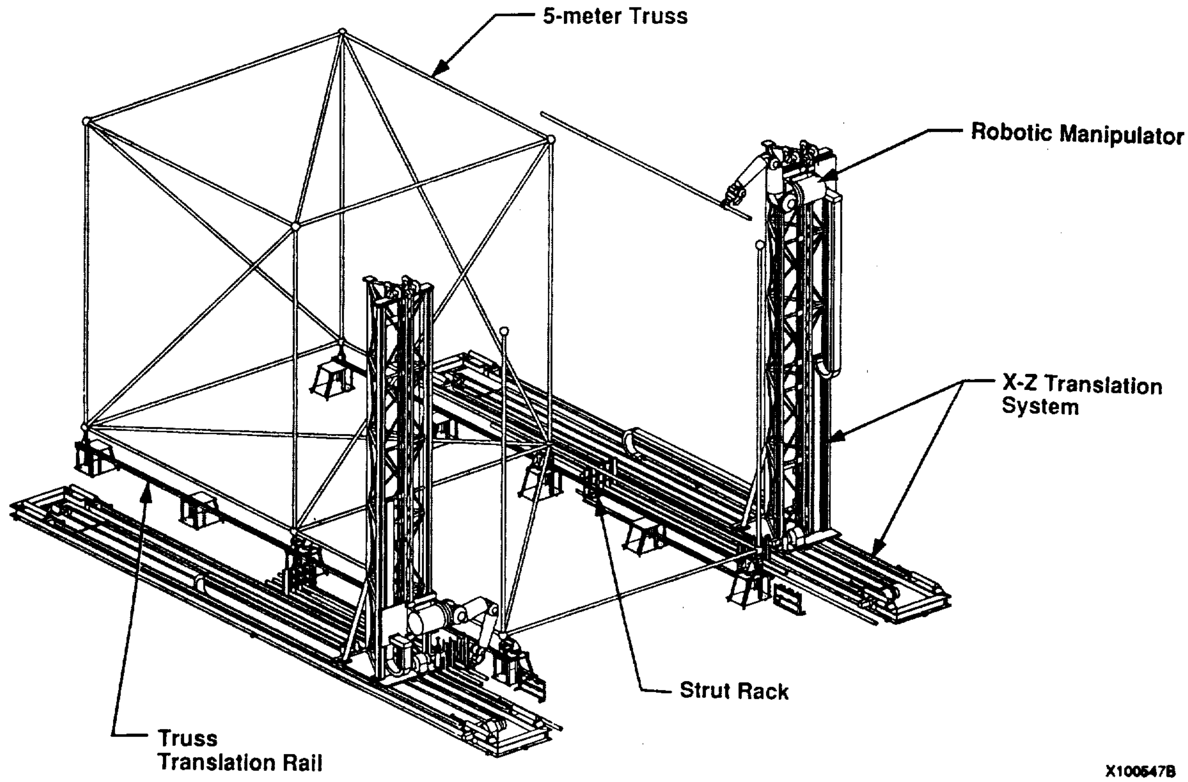
Automated Robotic Assembly of the Space Station

PI: George Parma/ES6
LeBarian Stokes/ER4
Reference SST 44

NASA has been given a Congressional mandate to incorporate automation and robotics into the Space Station Freedom Program. The Structures and Mechanics Division of the Johnson Space Center (JSC) is striving to help NASA achieve that mandated goal by designing and developing a representative Orbiter payload bay work cell to perform a ground demonstration of robotic assembly of Space Station WP02 systems. This project is called the Automated Robotic Assembly of Space Station (ARASS) demonstration. Initially, the Space Station truss structure would be assembled. Other Space Station hardware assembly will be demonstrated in later phases; e.g., assembly of utility trays, resource pallets, etc.

In 1988, conceptual designs for automated assembly of the Space Station truss structure using the Orbiter as a base platform were developed by the Robotics and Mechanical Systems Laboratory. Technology required to perform this completely automated task also was identified. The selected configuration was primarily driven by the one-g environment and available resources. This project was approved in 1989 by the JSC Structures and Mechanics Division's management, and design teams were organized for each of the various elements to implement this task.

The four major elements of ARASS consist of the Automated Space Structure Assembly Platform (ASSAP), the integration of the overall control system, the robotic manipulator with appropriate end-effector/end-of-arm tooling, and the development of a "robot-friendly" structural fastener. Almost all of the detail design and analysis of the ASSAP has been completed. Control system development and integration has progressed to the point where most major modules have been implemented, and the fundamental system has been impressively demonstrated. Design of the end-effector to complete the fastening operation has been initiated. Four prototype robot-friendly structural fastener hardware concepts were manufactured and tested, and the best fastener for the demonstration was selected.



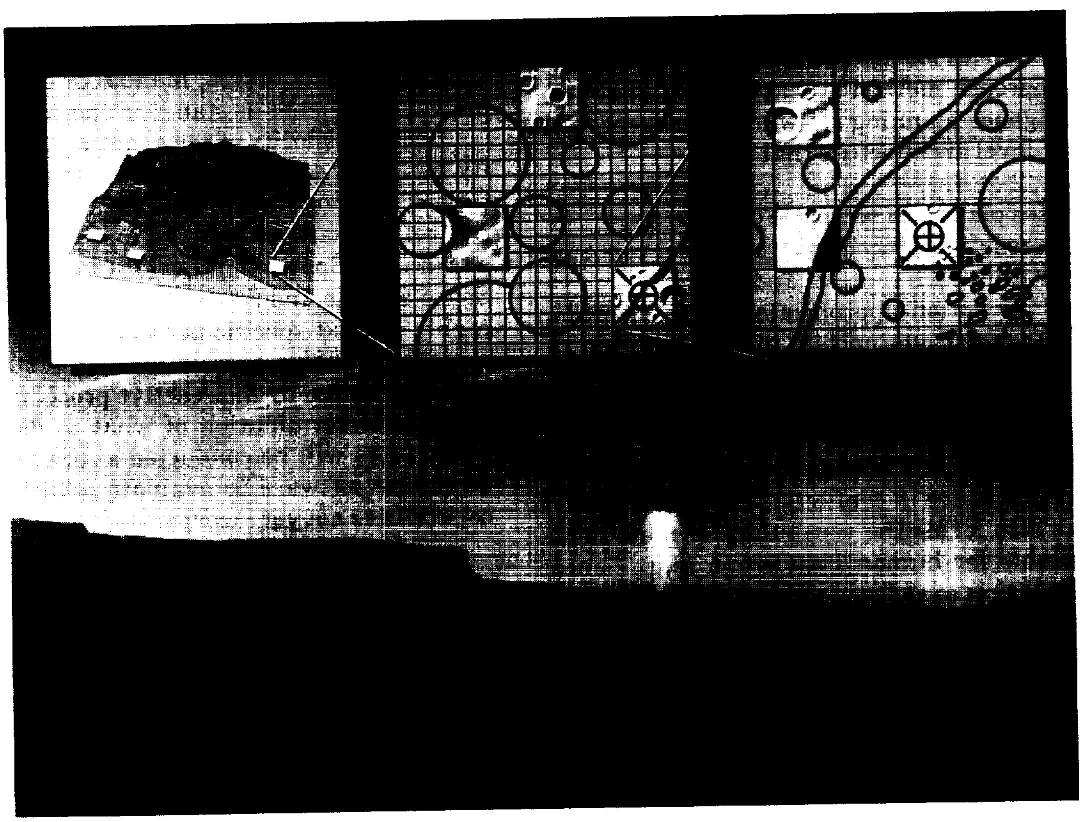
ARASS workcell configuration.

Autonomous Lander Project

TM: K. Baker/ER2
Reference SST 45

The manned exploration of Mars and/or the establishment of a manned Lunar Base and associated unmanned precursor missions will require the capability to land a spacecraft safely, accurately and autonomously. The Autonomous Lander Project of the Pathfinder Program is aimed at technical problems that are key to these capabilities: accurate navigation with respect to the target planet's surface and detection from the lander of a safe place to land during the terminal descent stage. This is a multicenter project led by the Johnson Space Center (JSC) with the JSC/Navigation, Control, and Aeronautics and Automation and Robotics Divisions doing the landing safety and navigation analysis, the Jet Propulsion Laboratory (JPL) developing a Mars surface model, the JSC/Tracking and Communications Division and JPL working on landmark navigation, and the JSC/Automation and Robotics and Tracking and Communications Divisions and the Ames Research Center working on active and passive methods of onboard hazard detection.

In fiscal year 1990, the Automation and Robotics Division – with the assistance of the Tracking and Communications and the Navigation, Control, and Aeronautics Divisions – conceived an onboard hazard detection sensor using a scanned, continuous wave-modulated GaAlAs laser radar. A simulation of this sensor and associated image processing were developed. Example cases generated using this simulation indicate that, for hardware performance that should be practical in the next few years, such an approach to onboard detection of local slopes and rocks large enough to be hazardous to landing is feasible. However, its practicality remains to be determined from additional simulation of performance in the detection of safe landing sites that are within the maneuver range of a practical Mars lander and from a preliminary design that establishes the required weight, power, and volume. Also, a simulation of the frequency of safe landing sites established that, for areas similar in rock population to the Viking Lander II site, a 250 m area should contain several safe landing sites ranging from 10 to 15 m in size.



Mars landing in a safe location as detected from a sequence of onboard images.

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Architectures for Semiautonomous Planning

PI: Jon D. Erickson/ER
Reference SST 46

Enabling intelligent systems to act in dynamic, unrestricted, real space environments is both a current and a future need in manned space missions. Such situations place difficult requirements on robot systems; since the environment may change (spontaneously or by the action of independent agents), robots must sense the situation and react to events on a short time scale. Since the environment is uncontrolled, the robot must deal with a variety of situations where its actions may not produce the desired effects. In problems of this kind, "by rote" mechanisms cannot succeed; robots require plans that encode alternatives and react to circumstances.

To meet this need, reactive planning software is being developed with emphasis on human instruction and override. The research is directly applicable to the needs of lunar and Mars exploration surface operations and to the extravehicular activity (EVA) Retriever robot requirement for dealing with an environment of moving objects. It also may be applied to Space Station Freedom systems by employing different vocabularies for instruction.

The approach method is that conventional artificial intelligence planning software is replaced with a new, high-level architecture that

- Expresses plans as a sequence of contexts,
- Defines reactive procedures to control robot behavior within each context, and
- Selects the action appropriate to the situation and the context appropriate to the plan each robot decision cycle.

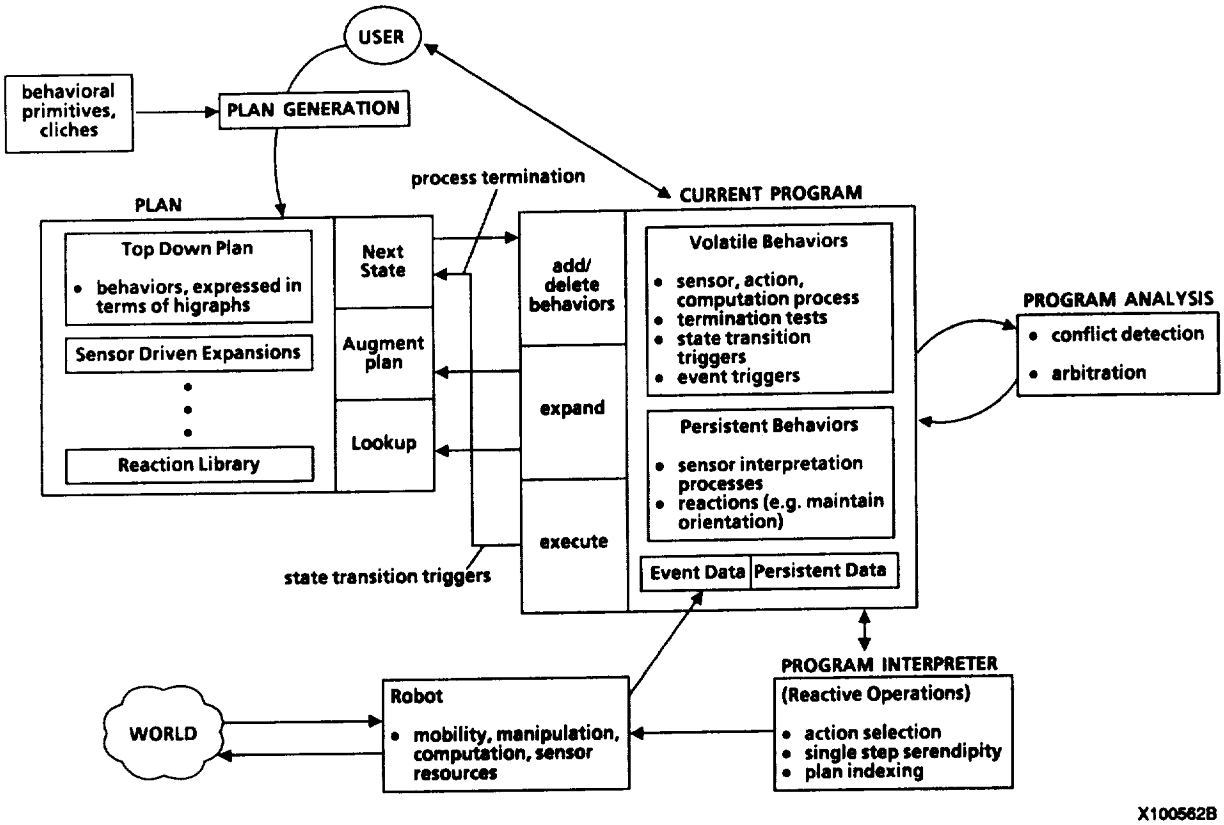
This allows the robot to follow the plan and react to the environment simultaneously (arbitrating when the requirements are in conflict). The set of reactive procedures also forms the vocabulary of robot behaviors available for human instruction (e.g., "enter target acquisition mode" or "commence approach-to-tumbling-object"). Task-oriented behavior usage is expected to be a powerful programming metaphor. In addition, such an approach allows the use of highly specific sensing routines (e.g., "measure distance to a tumbling object"). This addresses a critical robot perception computational problem.

In more detail, reactive procedures consist of intentions concerning sequential actions (that may not apply), actions that might become relevant, and (potentially) problems to be solved once the situation is better known. For sufficiently narrow problem contexts, it is possible to encode goal-achieving actions for all possible environmental factors. Reactive plans do not consist of fixed-action sequences.

These developments are mandatory to enable the construction of supervised intelligent systems that perform real work safely and reliably in space. Software thus produced is essential to the Phase III EVA Retriever. This approach contrasts with conventional artificial intelligence methods that assume a static situation and replan on change (which is not practical because of the computational overload this can cause).

High-level control software addresses intentions and commitments, data flow and message passing, and operators for add/delete, transition, monitor, execute, create, augment, next state, and lookup. It also addresses the analysis and arbitration of conflicts, contexts of states and transitions, behaviors specified by procedures, manual or continuous interaction, and cliches as standard operations.

The feasibility of the eventual software capability has been demonstrated by testing of initial prototype software integrated into the EVA Retriever control software and run against various scenarios of a Johnson Space Center (JSC) simulation of the Space Shuttle and Space Station environments. The highly context-specific perception that JSC software provides is a rich description of the state of the environment used by the reactive procedures to achieve a proper determination of what to do next. Additional tests will be conducted at JSC with enhanced prototype software to evaluate additional required capabilities not yet incorporated.



A reactive plan execution architecture.

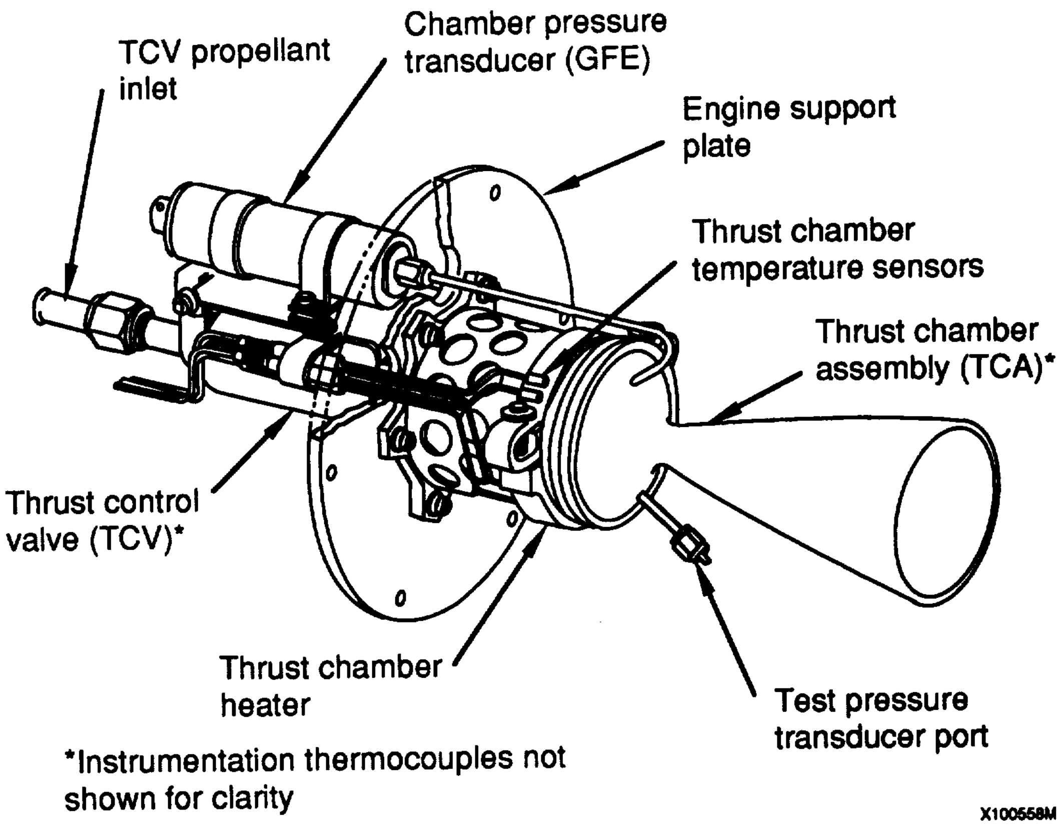
Long-Life Monopropellant Hydrazine Thruster Evaluation for Space Station Freedom Application

PI: Christopher G. Popp/EP4
Reference SST 47

The Space Station Freedom (SSF) will use a blowdown monopropellant hydrazine propulsion system with 6400 lb propellant storage (1.5 million lb-sec impulse) capability. The resultant throughput capability required for the SSF orbital adjustment (reboost) thrusters is at least a factor of 3 greater than has been demonstrated previously for similarly sized hydrazine thrusters. Some difficulty is anticipated in maintaining specific impulse (Isp) performance while designing the reboost thruster to minimize the hydrazine catalyst attrition to achieve this throughput requirement.

In support of the hydrazine thruster manufacturer selection by the Work Package 2 prime contractor – McDonnell Douglas Space Systems Company – NASA Johnson Space Center (JSC) initiated an inhouse effort to procure and test long-life hydrazine thrusters (LLTs) that are potentially applicable to reboost operations (see figure). One LLT was procured from United Technologies Hamilton Standard, Rocket Research Company, and The Marquardt Company. Design requirements include a design goal of 2 million lb-sec impulse minimum, 50 lbs thrust at 300 psia supply pressure, standard performance including an Isp of 233 lb-sec/lb at 300 psia supply pressure and an area ratio of 50:1, and utilization of off-the-shelf hardware and technology as applicable. The Hamilton Standard LLT concept is derived from the Mark II certified design, with material improvements to solve life issues associated with exposure to hydrazine and its decomposition products. The Rocket Research LLT concept employs the catalyst bed active spring-retention system currently employed in the Shuttle improved auxiliary power unit gas generator. The Marquardt LLT concept utilizes the certified R-30 thruster design modified with a passive differential expansion "thermal spring" which had been demonstrated previously on a long-life 5 lb thruster U.S. Air Force Test program. All concepts utilize a low-catalyst bed loading in the range of 0.037 to 0.046 lb/sec-in^2 maximum. All contracts were awarded in June 1990. The scheduled delivery date for the Marquardt LLT is December 1990. The Rocket Research and Hamilton Standard LLTs are scheduled for delivery in January 1991.

Upon delivery to NASA JSC, each LLT will be subjected to simulated launch and on-orbit duty cycle testing to assess the suitability and impulse life capability of each concept. First, each unit will be tested to a vibration environment simulating three Shuttle launches. Then each LLT will be fired at a simulated 100 000 ft minimum altitude with representative SSF propulsion module blowdown pressures and projected thruster cycling (resulting from thrust imbalances between propulsion modules) for a throughput of 6400 lb of hydrazine. Monopropellant-grade hydrazine will be used in all hot-fire testing. Finally, each concept will be tested to a life margin of 30 percent minimum through testing at worst-case soakback and restart conditions for long-duration firings. Due to facility storage limitations, test sequences will consist of a 100 gal (838 lb) maximum throughput, resulting in continuous burn times of up to 3400 and 8400 sec at 350 and 100 psia supply pressures, respectively. Primary test objectives include determination of impulse life (throughput) capability for each concept and evaluation of each design for washout and hot restart sensitivity when tested with monopropellant-grade hydrazine.



Typical hydrazine thruster.

Gaseous Oxygen/Hydrogen Engine

PI: D. Krohn/EP4
T. Lucht/EP4
B. Studak/EP4
Reference SST 48

Planned use of a water-electrolysis-based propulsion system on Space Station Freedom has led to an in-house design and development program for a 50 lbf, 8:1 mixture ratio gaseous oxygen/hydrogen (O_2/H_2) thruster. The primary function of this thruster would be to provide thrust for required periodic orbital reboosts of the Space Station.

The engine will obtain its thrust by the combustion of oxygen and hydrogen generated by water electrolysis. In this process, electricity is used to break apart the molecular bonds of water and form H_2 and O_2. These gases are then stored at high pressure for use in the propulsion system. Due to the molecular structure of water, eight times as much oxygen as hydrogen (by mass) is produced by the electrolysis process. This requires a thruster capable of performing at mixture ratios as high as 8:1, although maximum performance is obtained at a 4:1 mixture ratio.

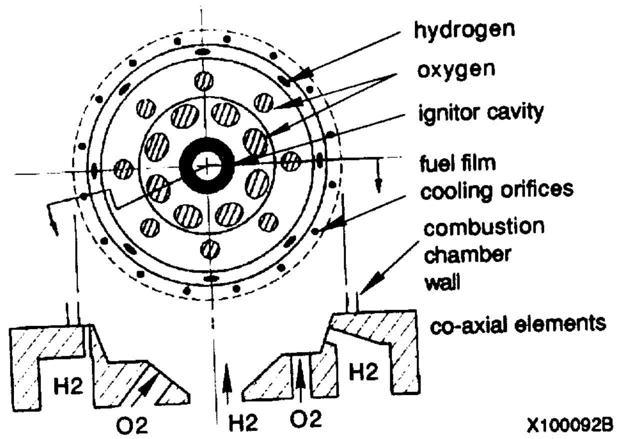
Several major areas of thruster design will be examined individually and then integrated to produce the final thruster. Propellant manifold and injector design, thrust chamber design, thrust chamber cooling methods, propellant ignition, propellant flow control, and instrumentation are the major areas of interest.

Development efforts began with a literature review of current thruster designs, a theoretical analysis of thruster chamber performance, and a heat transfer analysis of the thruster chamber wall. This investigation led to the conceptual design of two injectors. A test program will investigate the performance and operational capabilities of both injector concepts. The injectors will be attached to a variable-length heat sink chamber since chamber length affects both performance and heat transfer to the thruster walls. The chamber will be instrumented to measure chamber pressure as well as temperature along the chamber wall from the injector face to the nozzle. This data will be used to compare the injector designs on the basis of chamber wall heating rate and overall thruster performance.

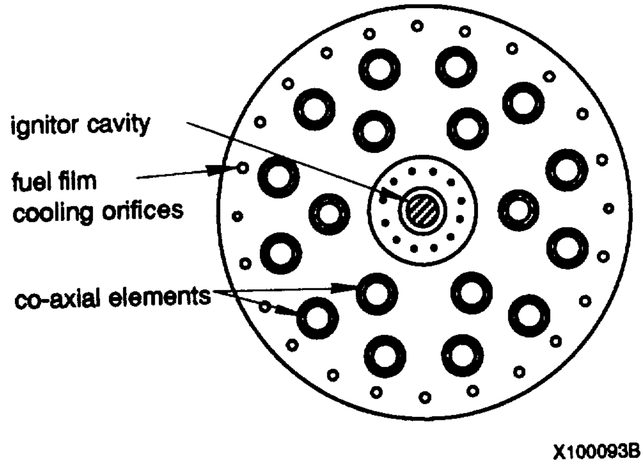
The first injector design is illustrated in the first figure. The injector configuration provides a higher mixture ratio (oxidation (ox) flow rate/fuel flow rate ~11) and high-temperature core flow in the combustion chamber. The core is then surrounded by 8 ox/fuel doublets which provide for an annulus of lower mixture ratio (~5) and lower temperature flow. To prevent further chamber wall overheating, hydrogen will be channeled down the wall through 16 fuel film cooling orifices. Propellant ignition in the heat sink chamber will be accomplished by core hydrogen flow excitation using a spark-type igniter. Among features of this design are its simplicity and ease of manufacture.

The second injector design (second figure) utilizes 18 coaxial elements to provide its thrust. The outer ring is comprised of 12 elements while the inner ring has 6 elements. Fuel film cooling is provided by 24 orifices which flow hydrogen along the chamber wall. Each coaxial element flows oxygen through the center post and hydrogen through the annulus. In contrast to the previous design, ignition will be performed by core oxygen flow excitation utilizing a spark igniter. Heat sink chamber testing will investigate the performance and thermal soakback effects of various coaxial element designs and will lead to an optimized injector design.

After the two injector designs have been successfully tested with the heat sink chamber, a prototype engine will be developed utilizing one of the injector designs. The design will incorporate regenerative hydrogen cooling by flowing hydrogen through channels in the combustion chamber wall.



Doublet injector design.



Coaxial injector design.

On-Orbit Compressor Technology

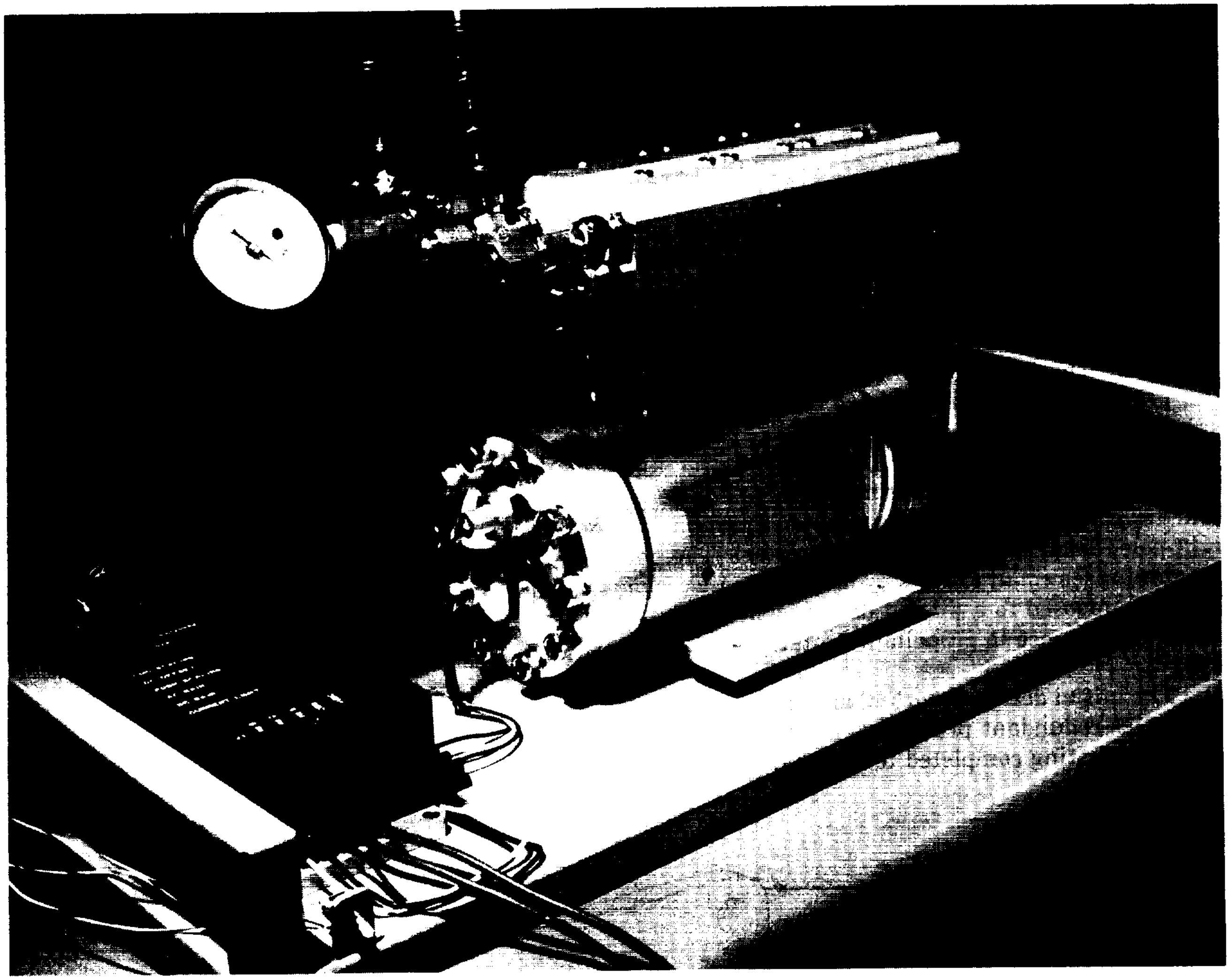
PI: John P. Masetta/EP4
Reference SST 49

Requirements for a wide range of gases, gas mixtures, and operating conditions have been identified for various Space Station and related on-orbit fluid systems operations. These operations range from the collection, storage, and disposal of Space Station waste gases to the recompression of pressurant gases used on satellite propellant systems. Practical use of these systems for fluid storage and transfer will require compressors capable of long-term on-orbit operations over the entire range of requirements. However, many of these design requirements are not met by current off-the-shelf hardware, and compressors designed for space-based operations are not readily available. Typically, compressors designed for ground-based operations are not constrained by power availability, weight limitations, envelope, or efficient thermal control, which are all key design drivers for these on-orbit applications. A technology development program is necessary to extend the current state of the art to the unique requirements of high-pressure, low volumetric flow rate, compact, light, and low power devices designed to operate in space without maintenance over their operational lifetimes.

The objective of the On-Orbit Compressor Technology Program is the exploration of compressor technology (designs, materials, and manufacturing techniques) applicable for use by the Space Station fluid management system (FMS), Space Station propulsion system, and orbital spacecraft consumables resupply system. The approach is to develop a detailed design for the FMS mixed-gas application and fabricate a development prototype for performance evaluation. Requirements for this application include compression of a constantly varying gas mixture with flow rates that range from 0.2 to 1.1 lbm/hr at inlet pressures that range from 5 to 15 psia. The gas mixture consists primarily of nitrogen, argon, and air with small amounts of carbon dioxide, krypton, xenon, and trace contaminants. A contract with the Southwest Research Institute (SwRI) led to the development of a prototype compressor which meets these requirements and provides a test article for further hardware evaluation. Key technical challenges identified by the SwRI include achieving enhanced and controlled heat transfer throughout the compression cycle for very small volumetric flow rates; developing miniature long-life, dynamically stable valves; controlling inlet and outlet pressure pulsations; minimizing or eliminating maintenance; selecting materials compatible with the bulk gases and trace contaminants, and meeting life requirements of up to 10 years.

The prototype is a 3-cylinder, 2-stage reciprocating piston compressor with pressure-actuated check valves utilizing an eccentric crankshaft and antifriction bearing driven pistons. Combining a 3-piston configuration with a balanced crankshaft assembly minimizes the induced vibrations inherent with reciprocating machinery. Lubrication is minimized by using self-lubricated piston seal and guide rings and sealed, grease-packed bearings. Compressor operation can be controlled for variable or constant speed by a brushless direct current motor that is used to drive the crankshaft. The development prototype weighs 30 lbs, fits in an envelope of 0.5 ft^3, and has a total displacement of 0.625 in^3. This hardware (see figure) represents a "first of its kind" compressor designed to operate continuously for 10 000 hours without maintenance. Significant testing is required to validate sufficiently the operating life characteristics of this design and to identify weaknesses that must be corrected before a flight hardware development program can be initiated.

The development prototype compressor has been installed in an endurance test stand at the Johnson Space Center that is fabricated to subject the hardware to simulated operating conditions. Tests will include long-duration continuous operations and short-duration cyclic operations at one-g in both ambient and vacuum environments. The condition of the compressor will be established prior to test initiation and compared to its condition at the end of the program or after a critical failure that interrupts the test program. Primary objectives of these tests are to generate performance data relative to nominal operations and examine component wear and failure modes. Endurance testing is scheduled to begin in January 1991 and continue through June 1991. Information obtained from this program will be used to support the Space Station prime contractor in the selection of compressor hardware that will be installed in the FMS and in the development of specifications for flight hardware.



Prototype piston compressor.

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Electronically Variable Pressure Regulator

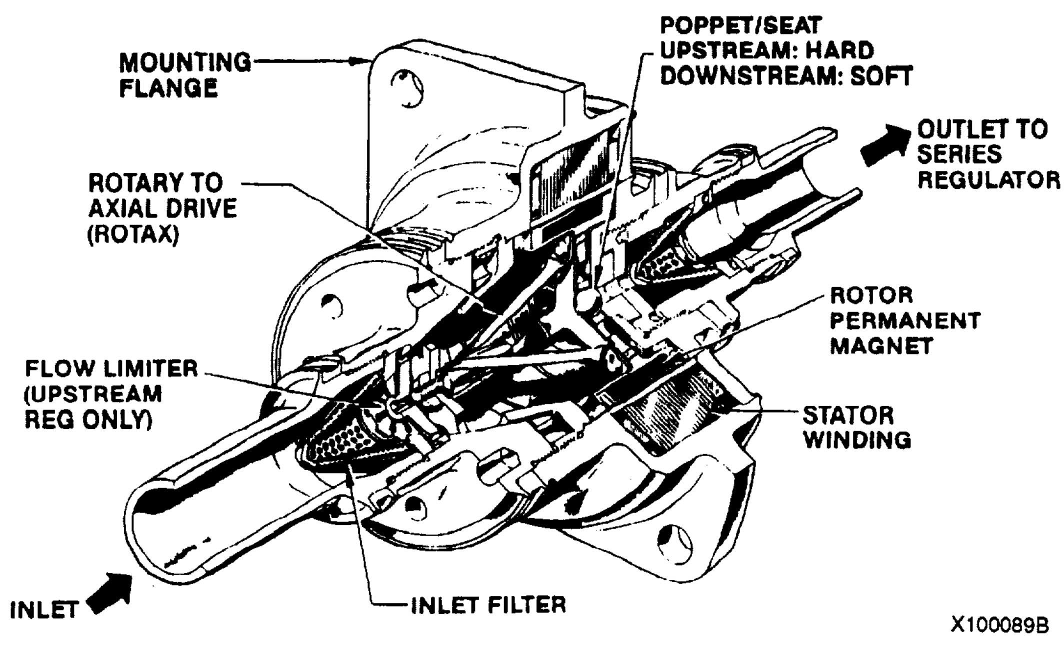
PI: Eric Hurlbert/EP4
Reference SST 50

A key element in the design of orbital resupply tankers and advanced propulsion systems is the requirement for precise and, in some cases, variable gas pressure control. Such control can best be accomplished by using an electronically variable pressure regulator. These regulation requirements, along with propellant compatibility, are the main drivers in the design.

The design developed in this program (see figure) utilizes a ball poppet positioned by a rotary-to-axial drive element which is driven by a three-phase, eight-pole, electrically commutated motor. The design minimizes small orifices by using a single-stage design as opposed to a piloted design, which should improve resistance to propellant contamination failures.

The initial design program has been completed. Two series-redundant prototypes have been manufactured. Testing completed to date has shown that the concept is capable of regulating pressure. Variable set-point regulation pressures have been demonstrated successfully, including ramping the pressure from 50 to 500 psia. Deficiencies found with the design are in the controller and the bearings that support the rotary-to-axial drive. These bearings had more friction than expected. This showed up as a sticking problem during rapid flow transients. The controller can be improved by using an adaptive control loop logic which would provide variable gains to adjust the regulator response depending on system conditions. Both the bearings and the controller can be improved with further development. Prototypes were delivered to the NASA Johnson Space Center (JSC) from Eaton Valve and Actuator Division at the completion of the contract.

For fiscal year 1991, the regulators have been shipped to Fairchild Controls. Fairchild Controls will improve the design of the controller and the rotary-to-axial drive bearings using IR&D funds. After completing this 1-year activity, the regulators will be tested at the JSC Thermochemical Test Area to evaluate their performance.



Electronically variable pressure regulator.

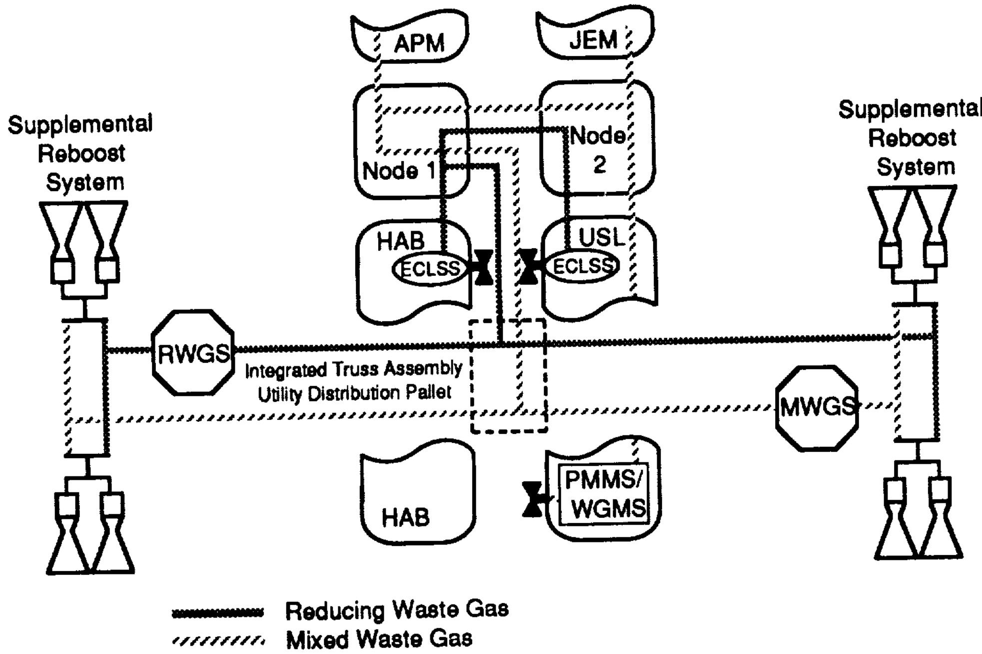
Space Station Waste Gas System Material Compatibility Study

PI: Gerald B. Sanders/EP4
Reference SST 51

The Space Station integrated waste gas system (IWGS) is designed to collect, store, and later propulsively expel waste gases produced on Space Station Freedom. The system is divided into two subsystems. One subsystem, the mixed waste gas system (MWGS) is designed to store gases used in experiments and other Space Station fluid systems. The other subsystem, the reducing waste gas system (RWGS), stores gases which are by-products of the environmental control and life support system (ECLSS). Each subsystem is configured similarly (except for materials) and is located on opposite sides of the truss (see figure). To meet the proposed 30-year life requirement, materials selected for each waste gas subsystem must have excellent corrosion resistance to trace contaminants potentially collected from the experiments (see Allowable Contaminant List).

A comprehensive study of the IWGS was completed in 1990. The main focus of the study was to determine which materials were the best candidates for construction of the waste gas system from a material compatibility point of view. The study also assessed the potential for allowing hazardous chemical reactions to occur during storage through the examination of a compiled list of laboratory chemicals proposed for Space Station use. A report summarizing study results was generated ("Space Station Waste Gas Composition Impact Study, JSC-24407"). Besides noting the corrosion resistance of pure metals such as platinum and tantalum, the study strongly recommended the use of nickel-based alloys such as Inconel 625, Incoloy 825, and C-276/C-22 for use in the MWGS. Stainless steels (304L and 316L), A286, and Nitronic 40 were recommended for use in the RWGS. This was due to the large amount of hydrogen expected to be produced by the ECLSS when Bosch was the baseline CO_2 reduction system. If the Sabatier CO_2 reduction system is used, the driving compatibility concerns for the RWGS would be CO_2 and methane, not hydrogen as was previously the case with the Bosch system.

Besides recommending the use of candidate materials for construction, the study report also proposed and outlined the use of compatibility tests to verify the materials chosen for use in the MWGS before construction of the waste gas system begins. Final plans for initiating vapor corrosion tests for both metal and nonmetal candidate materials are in progress. Since a wide number of chemicals are listed for possible use in Space Station experiments and the exact mixtures to be handled by the MWGS are unknown, it is important to choose chemical reagents or reagent mixtures that represent worst-case situations for the corrosion tests to be run. The major concern of this test program is whether testing materials with a limited number of reagent combinations actually will prove whether a material should or should not be used in the construction of the MWGS. NASA and McDonnell Douglas personnel are examining this concern, as well as what reagent mixtures should be used if testing is initiated.



Mixed Waste Gas Mixture	
Nitrogen	60.0%
Argon	19.3%
Air	11.3%
Oxygen	3.0%
Carbon Dioxide	1.9%
Krypton	1.8%
Xenon	0.6%
Helium	0.2%
Trace reductants	<0.5%
Trace contaminants	<1.8%
Dew Point	-30°F

Allowable Contaminant List (5 ppm ea.)
Acids
Organic
Inorganic
Bases
Organic
Ammonia (NH_3)
Inorganic (see particulates)
Halogens (Cl_2, F_2, Br_2, I_2)
Particulates (>10 microns)
Organic Classes
Gases
Solvents

X100090M

Layout of the integrated waste gas system.

Generic Fluid Transfer Model Computer Program

PI: Richard J. Schoenberg/EP4
Reference SST 52

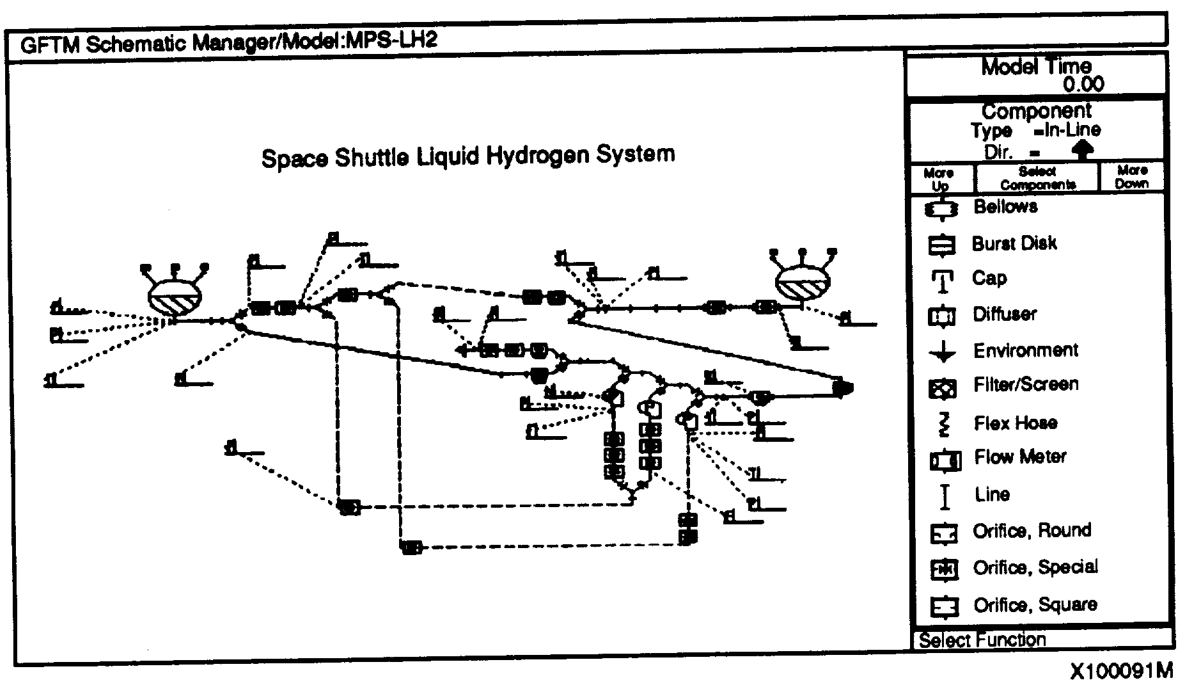
The ability to predict fluid system performance and capability accurately along with fluid conditions is an important part of the design of on-orbit fluid management systems. This aspect of system design will take on an even greater role in the design and evaluation of the numerous fluid systems required to manage the variety of Earth-storable and cryogenic fluids involved in the operation of Space Station Freedom and its interfacing elements.

The development of the generic fluid transfer model (GFTM) marks the start of a new era in engineering analysis, leading from the batch-job specialty programs of the 1960's and 1970's into the realm of advanced, dynamically reconfigurable generic models. The result of this effort is a computer model capable of higher analytical capability at an earlier stage in the design of fluid systems. The model is particularly well-suited for use in the preliminary or conceptual design phases.

The GFTM allows the creation of fluid systems utilizing a wide range of available components (e. g., valves, lines, orifices, regulators, check valves, storage tanks, etc.) for any fluid storage type (i.e., gaseous, subcritical, or supercritical). The user may define the specific feed system and tankage configurations which are schematically represented using standard component "icons" on the user's high-resolution color graphics display. The GFTM automatically discerns the connectivity relationship between components and generates a set of simultaneous equations that is required to analyze the constructed schematic.

In terms of analytical capability, GFTM can analyze the fluid transfer mechanisms, fluid and ullage gas thermodynamics, and heat transfer effects involved in various fluid system processes. The model utilizes "real" fluid properties which are included in the fluid database. Operationally, the model is highly tutorial in its instructions to the user on the definition of fluid system configuration, fluid type and conditions, and environmental conditions using the latest state-of-the-art techniques for menus, windows, and zooming. The accompanying figure is an example of the schematic construction panel.

Accomplishments in fiscal year 1990 include a continuing software evaluation and enhancement effort. The program currently is being used and evaluated at a number of government and contractor facilities.



Generic fluid transfer model schematic construction menu.

Experimental Investigations of Spacecraft Glow

PI: James T. Visentine/ES5
Reference SST 53

In early 1990, contract negotiations were completed between the Johnson Space Center and the Lockheed Palo Alto Research Laboratory for Phase "C/D" development of the Experimental Investigations of Spacecraft Glow (EISG) flight experiment. The EISG – scheduled for flight as an element of the OAET-1 payload on the Space Transportation System (STS) flight STS-61 during June 1993 – will be developed to study and characterize glow emissions in the ultraviolet (UV), visible, and infrared (IR) wavelength ranges, and to determine how these emissions vary with orbital altitude and spacecraft surface temperature. To accomplish these mission objectives, glows investigated by this experiment will be produced by

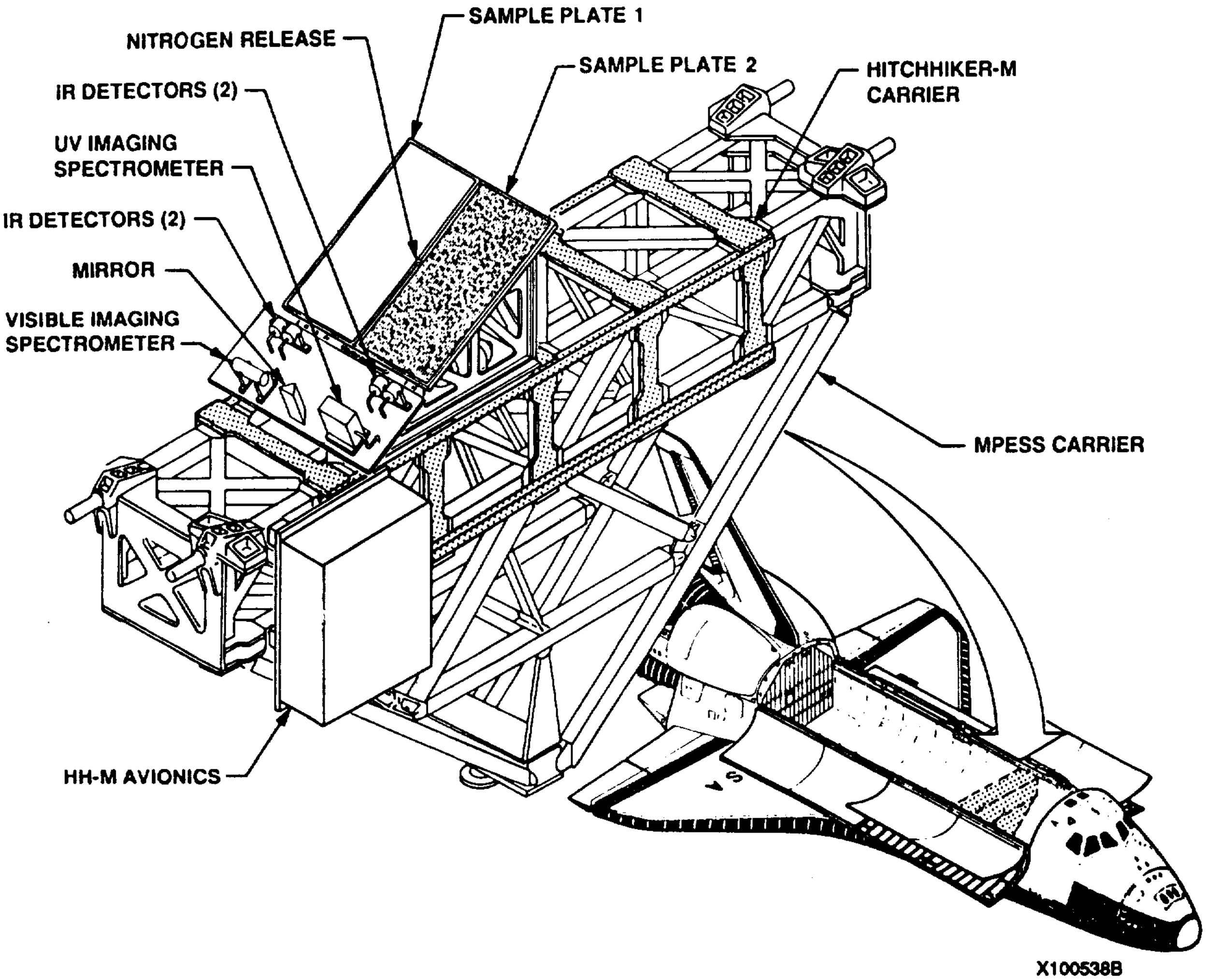
- The natural atmosphere,
- Orbiter thruster effluents passing above the ram (or normal incidence) side of two passive sample plates, and
- Molecular nitrogen released above these plates by an onboard pressurized gas cylinder and flow control system.

This experiment (see figure) will include a pallet-based set of sensors, passive sample plates coated with two materials which glow, and a nitrogen gas-release system for study and operation within the Orbiter cargo bay. Sensors developed for this experiment include

- A visible imaging spectrometer,
- A far UV imaging spectrometer, and
- Two cryogenically-cooled, indium antimide IR detectors.

During the mission, the IR detectors will be cooled to at least 84 K by a Joule-Thompson cryostat system which operates using a noncontaminating (argon) pressurized fluid as the refrigerant gas. A dedicated experiment processor and avionics system also will be developed to control sensor operation for at least four orbits (two circular and two elliptical) of data-taking sequences.

During fiscal year 1990, design of the optical sensors was initiated and fabrication of candidate sample plates was completed using technology derived from the Aeroassist Flight Experiment. Thermal vacuum test results indicate the plate design will produce the desired temperature (180° K) by radiative energy transfer to the deep-space environment. If current OAET funding plans are maintained, the EISG will be available for OAET-1 integration by the Goddard Space Flight Center early in 1993. The database generated by these measurements should enable NASA, the Department of Defense, and other users to establish operational procedures and design guidelines which reduce the undesired effects of glow on sensitive scientific experiments conducted during future missions of the Space Shuttle and Space Station.



Experimental investigation of spacecraft glow.

Space Environment Effects – Materials Technology

PI: Steven L. Koontz, Ph. D./ES53
Reference SST 54

The Johnson Space Center (JSC) is engaged in several research and technology (R&T) projects, all of which are designed to provide a better understanding of space environment effects on materials. The ultimate objective of these R&T projects is to improve the performance, longevity, safety, and reliability of NASA and Department of Defense space hardware.

The JSC directs an OAET Research and Technology Objectives and Plans project on space-durable materials. Approximately two-thirds of the effort goes to atomic oxygen work and the remainder to meteoroid/debris impact studies. The meteoroid/debris work is performed at the JSC/Solar System Exploration Division using light gas guns and computer simulations of the hypervelocity impact process.

Atomic oxygen work is done primarily at Los Alamos National Laboratories (LANL), though significant supplement work is accomplished at JSC. The high-velocity atom beam system at LANL was developed with OAET funding and is the best characterized and most accurate laboratory simulation of the low Earth orbit (LEO) environment now available. The flowing afterglow and plasma asher systems at JSC make reactivity and reaction efficiency measurements possible in thermal (low-velocity) oxygen atom environments for comparison with in-space and high-velocity beam data.

The OAET program objective is to provide realistic laboratory simulations of LEO orbit processes for

- Calibration of flight instruments,
- Studies of materials degradation mechanisms,
- The development and validation of accelerated test methods for full-life certification testing of spacecraft materials and systems, and
- The development of a better understanding of hypervelocity impact phenomena and meteoroid/debris armor.

During fiscal year (FY) 1990, several program milestones were achieved, all of which were firsts in this area of technology.

- The first direct measurement of the major gas phase reaction products produced by interaction of hypervelocity oxygen atom beams with Kapton, polyethylene, D4-polyethylene and FEP-Teflon was made. Identification of the gas phase reaction products is an essential step towards understanding the reaction mechanism and validating accelerating testing methods. For the hydrocarbon-based polymers, the main reaction products were CO, CO_2, and H_2O. In contrast, FEP-Teflon produced a range of high molecular weight oxidation products which may be a source of condensable contamination.
- A modulated atom beam kinetics package was made operational in the high-velocity oxygen atom beam system at LANL. Modulated beam kinetics studies provide more accurate measurement of the relative amounts of various gas phase products and is a powerful technique for determining reaction mechanisms and detecting changes in reaction mechanisms as the various accelerated testing parameters are changed.
- The reaction of silicone nitride and boron nitride thin films with high-velocity oxygen atoms was determined for the first time using the atom beam system at LANL as well as the Intelsat Solar Array Coupon flight experiment on the Space Transportation System flight STS-41 and flight samples on the Delta Star vehicle. Excellent correlation was achieved between the ground-based and flight results. Silicon nitride forms a surface oxide which acts as a barrier to further reaction, while the boron nitride reacts to a porous oxide/nitride mixture.
- Preliminary calibration of the EOIM-III flight mass spectrometer was completed in FY 1990. The calibration procedure will be refined further and developed in FYs 1991 and 1992 with both pre- and post-flight calibration checks planned as a part of the EOIM-III data verification. Calibration studies with the LANL atom beam provided important insight into the mechanism of mass spectrometer measurements of the ram oxygen atom flux as well as demonstrating the feasibility of the EOIM-III mass spectrometer experiment.

An extensive list of publications, which represents the product of this task, is available from the principal investigator.

Large Space Robot – A Multisegment Approach

PI: Reginald B. Berka./ES221
Reference SST 55

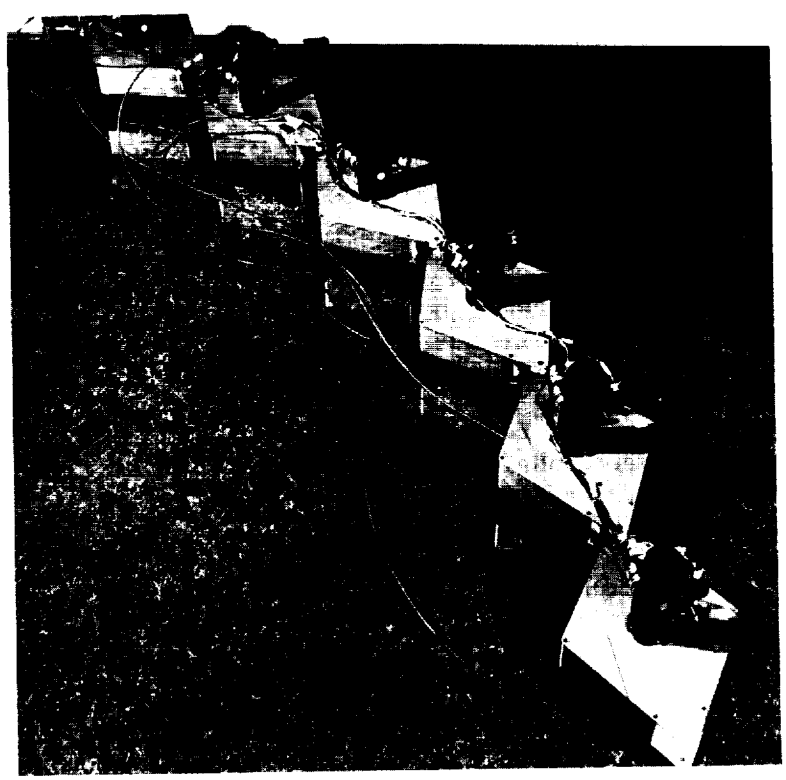
A multisegment robot is developed as a candidate for use in space-based construction operations. The multisegment robot is envisioned as a member of a class of large space robots, or space cranes, used in the assembly of advanced spacecraft. The unique problems which arise when robots grow to large sizes were identified. The unique, inherent capabilities of the multisegment robot to solve these problems makes it a viable candidate in this class of robotics.

The multisegment robot is a collection of common bodies, or segments, that are pinned together to form a snake-like, or train, configuration. A rotation degree of freedom is retained at each pinned connection. Reaction flywheels are suspended within each segment and provide the control necessary to position each body segment.

Algorithms were developed to position this serpentine robot to a prescribed location and orientation. The first algorithm computes a general shape, based on a constrained polynomial function, that locates the robot tip at the proper position. Next, an algorithm was developed that positions the discrete bodies along the shape function and determines their relative positions. This information is used as the target values in a control system that employs the reaction flywheels to position each body into the desired relative position.

An n-body simulation program was developed based on Newton-Euler equations of motion for the robot. The simulation was used to develop the control strategy, verify performance, and size prototype hardware.

A prototype system, shown in the attached figure, was designed, fabricated, and tested. Motion tests were conducted to compare test results with the analytical predictions. The analysis and successful tests of this system have proven the viability of this robotic concept. Its capacity to solve the unique problems associated with large space robots makes this type of robot an attractive candidate for those systems.



Multisegment robot.

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Robotic Assembly of the Aerobrake Thermal Protection System (TPS)

PI: Reginald B. Berka/ES221
Gerard D. Valle/ES22
Irene E. Verinder/ES22
Reference SST 56

The large size of the Pathfinder proposed aerobrake requires on-orbit final assembly. The focus of this particular task is to investigate the problems and methods for installing the thermal protection system (TPS) onto the aerobrake primary structure. For this study, the primary aerobrake structure is assumed to be a tetratruss. (The tetratruss has a hexagonal surface pattern comprised of six equilateral triangles. The truss consists of four-sided tetrahedrons from which the name is derived.) The TPS is assumed to be composed of a fragile surface material; however, the actual TPS material is not assumed.

After TPS installation, the surface must not have any holes or gaps that would allow the hot atmospheric gases to impinge directly onto the primary structure. Consideration also must be given to the radiant heating nature of the reentry trajectory. Radiation blocks must be provided in the gaps of the TPS to protect the structure from this type of heat transfer. Also, once assembled, the TPS surface must be aerodynamically smooth to maintain an evenly distributed and deterministic flux to the TPS surface.

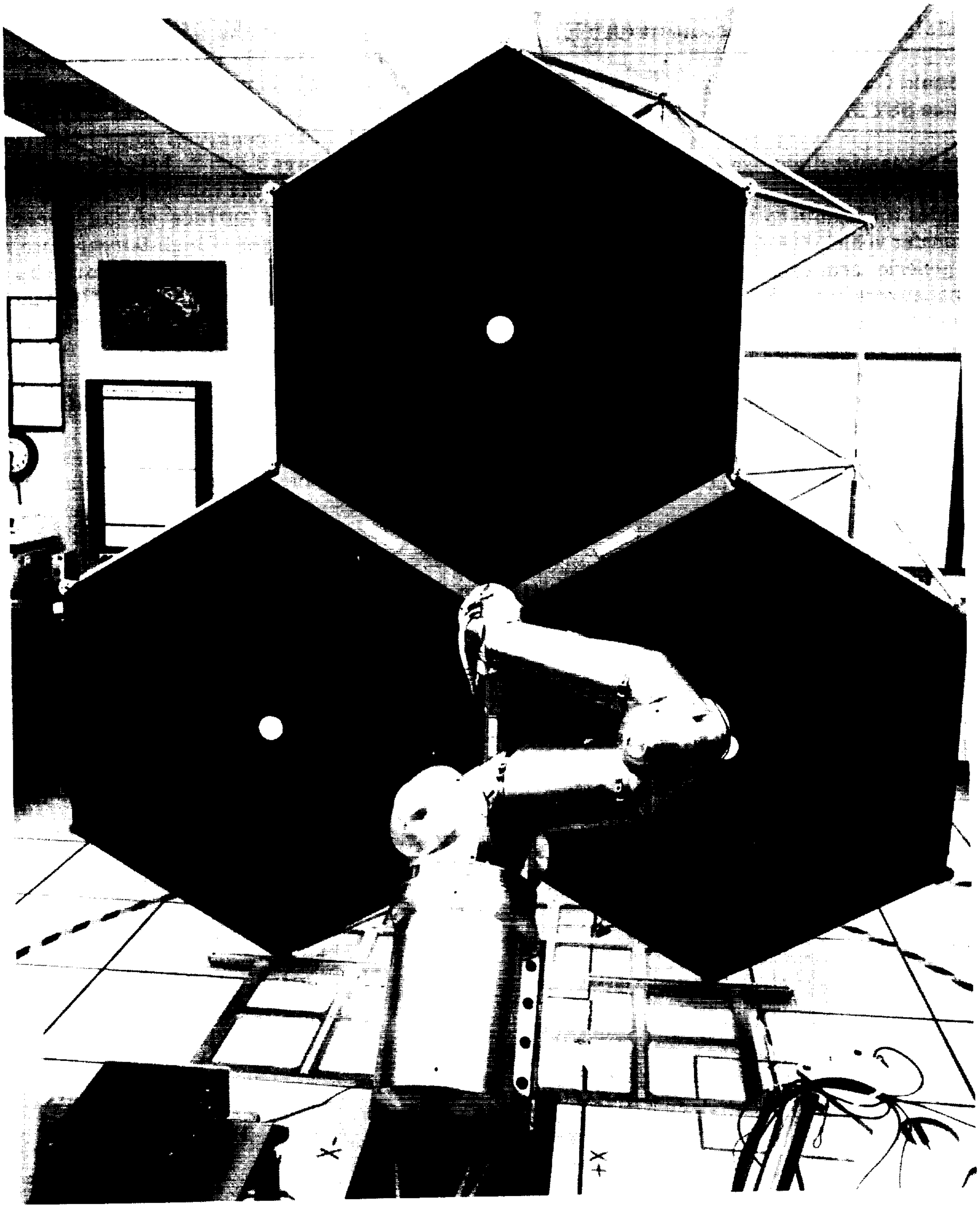
The design strategy is based on a layering concept whereby the TPS is assembled in a sequence of subassemblies comprised of successively smaller parts. Each assembly layer is retained only by a soft capture until the final assembly process. This allows the parts to be self-aligning throughout the assembly process. The final step in the assembly scenario installs small fastening plugs which fill the remaining holes in the TPS and rigidize the entire assembly. A more detailed description of the assembly process follows.

The first assembly process loosely applies broad acreage of a TPS that is held to the primary structure only by a soft capture. The large TPS panels are hexagonal shaped and supported at the center and at each of the six vertices. The soft capture allows the large TPS panels to rotate slightly but not to translate. Translation requirements are accounted for by generous end tolerances that ensure the placement of the next subassembly. The robot picks up these large panels by the geometric (and mass) center to minimize rotational inertia. The robot then positions the panel over a truss node in the proper translational and rotational alignment. Soft capture is achieved when the robot places the panel onto the node and the end effector is released. All of the large hexagonal TPS panels are installed prior to the installation of the next subassembly.

The objective of the second assembly step is to fill the gaps between adjacent hex panels. The filler strips, as they are called, are sized to fit along the length of one side of the hexagonal TPS panels. The filler strips are simply supported on each end by the truss nodes located at the vertices of the hex panels. Again, a soft capture is used to hold the filler strips in place. The soft capture feature of this part is similar to a spring-loaded door latch which snaps in place during assembly. This design allows for generous end tolerances contributing to the overall ease of assembly. After completing this phase of assembly, the large hex panels have been aligned and the gaps between them have been filled. However, the overall assembly is still in a loose state due to the soft capture designs. All of the filler strips are installed before moving on to the final assembly process.

The final assembly process performs the function of filler strip alignment and preloaded fastening of the entire assembly. At this phase of assembly, 3-in. sized holes exist at every truss node. A plug with a "T" cross-section is inserted into these holes. This cross-section is utilized to push the filler strips into translational alignment along the edge of the hex panels. Once the insertion of the plugs has aligned the filler strips, the robot presses the plugs into place. A spring-loaded backplate is compressed during this process, providing preload at each node. This preloading task is the final step in the assembly of the aerobrake TPS. The following figure depicts the final stages of TPS assembly for a partial section of a large aerobrake.

The successful completion of robotic assembly tests verifies the construction aspects of this design.



Partial section TPS assembly using a dextrous manipulator.

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Aeroassist Flight Experiment (AFE)

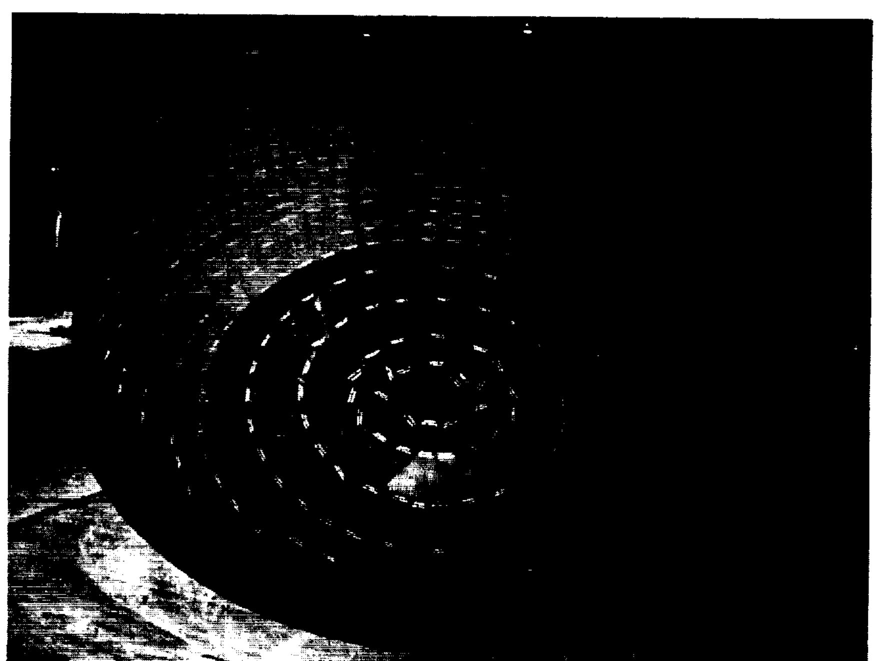
PI: Donald Curry, Ph.D./ES3
Reference SST 57

The aeroassist flight experiment (AFE) will investigate environmental and critical vehicle design technologies applicable to the design of aeroassist space transfer vehicles (ASTVs). Aeroassist is defined as a generic term encompassing various aerodynamic maneuvers in which a vehicle enters and exits the atmosphere to achieve braking without making a complete entry. An ASTV aerodynamic braking maneuver will penetrate the upper regions of the Earth's atmosphere at geosynchronous or planetary return velocities; therefore, the AFE is needed to provide design environments that cannot be simulated in ground facilities or determined through validated analysis.

The AFE is composed of three basic components: the aerobrake, the carrier vehicle, and the main propulsion unit. The AFE overall project is managed by the Marshall Space Flight Center. The Johnson Space Center (JSC) is responsible for the design and fabrication of the aerobrake.

Using design drawings and analyses supplied by the JSC design team, the JSC Technical Services Division has fabricated four development test articles, including full-scale mockups of the aerobrake. Foam tiles using the JSC generated thermal protection system tile patterns were fabricated by Lockheed Missiles and Space Company, Sunnyvale, California. The tiles' structural components and experiment instrumentation were installed in the mockups. Figures 1 and 2 show the aerobrake TPS tile installation on the full-scale mockup. The TPS for the windward surface of the aerobrake is composed of two types of high-temperature reusable insulation tiles developed for the Space Transportation System Orbiter. Figures 1 and 2 show the tile pattern and location of the two kinds of tile material: 22 pound per cubic foot (pcf) Lockheed insulation (LI-2200) on the elliptical surface and 12 pcf fibrous refractory composite insulation (FRCI-12) on the conical and skirt surfaces

A development test article (full-scale 30° segments of the cone area) was designed and fabricated for static, acoustic, and thermal testing. Flight tiles and structures were used in the fabrication. Figure 3 shows this test article mounted in the JSC acoustic chamber. It has successfully completed modal, acoustic, and static load testing. A second acoustic/modal test was conducted using this test article with instrumented tiles, thermocouple reference junction brackets, and representative mass for one radiometer and associated bracket. These tests have provided valuable engineering data and experience in installing both tiles and instrumentation.



Aerobrake - frontal view (elliptical and conical surfaces).

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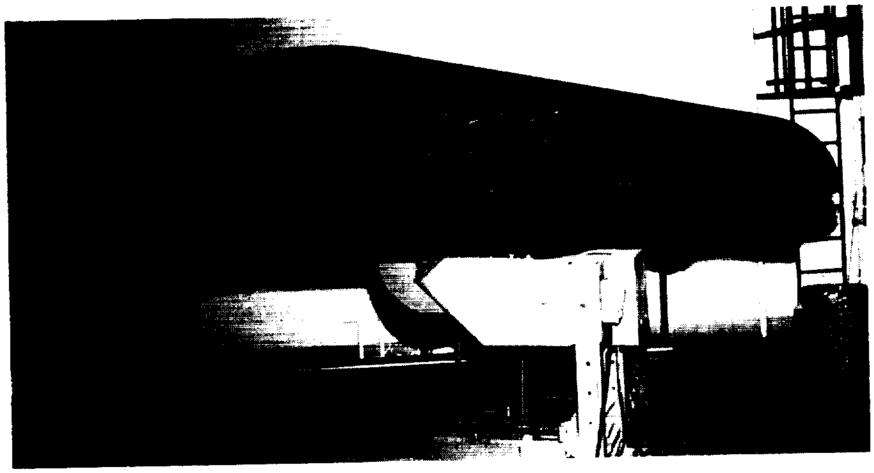
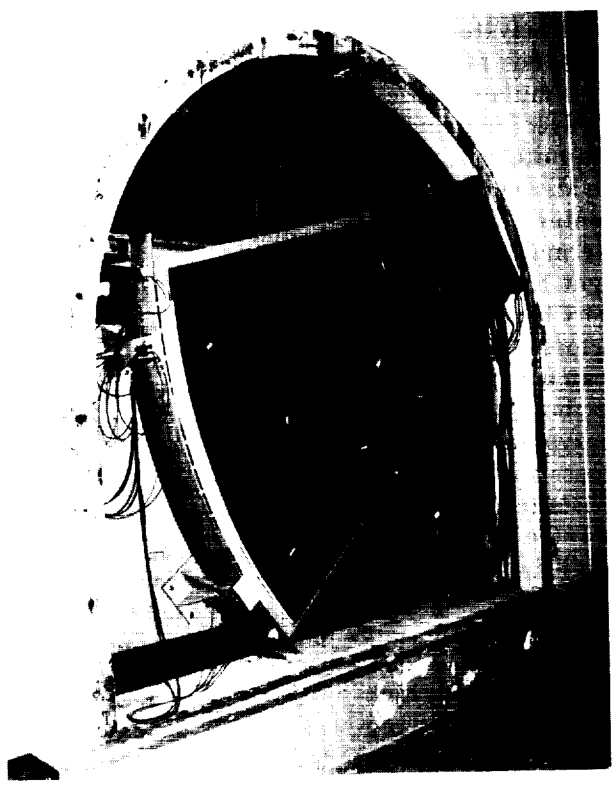


Aerobrake - side view (conical and skirt surfaces).



Aerobrake - full scale 30° conical segment test article.

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Intelligent Tutoring Systems Integrated with Simulators

PI: Thomas T. Chen
Diann E. Barbee
TM: Robert T. Savely/PT4
Reference SST 58

Global Information Systems is developing an Intelligent Tutoring System (ITS) to be used with NASA simulators of the Shuttle robotic arm. A kinematic model of the arm is used on all but one of the Space Shuttle simulators as well as on a stand-alone version called the "P2T2," which is hosted on a Silicon Graphics workstation. Prior to the Global work, no built-in capabilities for tutoring, performance monitoring, or evaluation feedback existed for any of these simulators; all tutoring and evaluation had to be performed by human instructors.

The need for integrated expert-system-based training functions such as performance monitoring and evaluation in training using simulators is evident. These simulators usually deliver very complex mission training scenarios and are quite expensive to operate. For example, the Shuttle Mission Simulator at the NASA Johnson Space Center can simulate 56 subsystems with 6800 possible malfunctions. In addition, four teams of up to eight highly-qualified instructors are required to support training on this one simulator. The number of factors effective in the simulation at any one moment can accrue exponentially as the number of crewmembers, instructors, other support personnel, active systems, relevant switches, and malfunctions increases and interacts.

Clearly, a pressing need exists for monitoring and evaluation capabilities integrated with current and future simulators. Such capabilities would allow training on simulators to become more efficient, uniform, objective, and less expensive. Also, the missions supported by these simulators would greatly benefit from having built-in tutors to maintain highly-perishable operator skills (most specifically, cognitive-based skills) in the field; e.g., on Space Station Freedom.

In implementing the ITS funded by this Small Business Innovative Research contract, two goals have been deemed of paramount importance: enhancing the adaptability of the ITS to other domains, and easing maintenance of P2T2 and the ITS. In line with these goals, the following general approach has been taken:

- Minimize the modification of P2T2. As the P2T2 simulator is modified and enhanced, it is P2T2/desirable to see those changes propagated to the ITS. The number of changes to P2T2 required by the ITS has been minimized to make it easier to maintain the P2T2 portion of the tutor.
- Segregate P2T2 and the ITS as much as possible. To make the ITS portion of P2T2/ITS adaptable to other domains and new tasks, the ITS portion and the P2T2 portion of P2T2/ITS must communicate through well-defined interfaces.
- Minimize assumptions about the remote maneuvering system (RMS) domain. The ITS should make as few assumptions about the RMS domain as possible. This will make the ITS more portable to other task-oriented domains.

A system diagram is shown in the figure. The ITS will have two modes besides the existing (unmonitored) simulation mode:

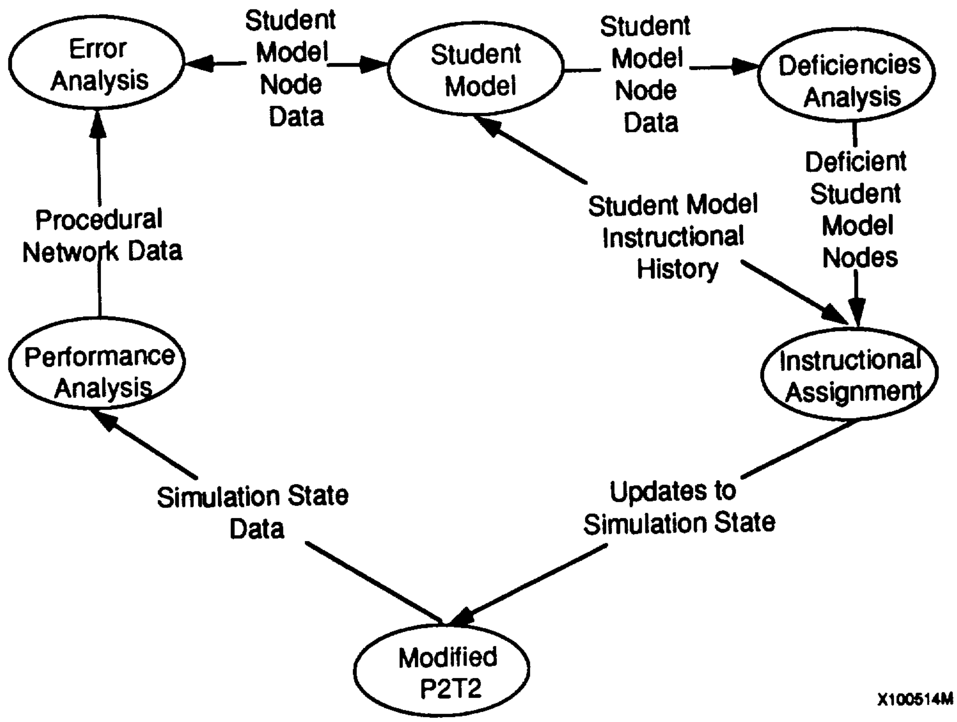
The Tutorial Mode consists of an ordered series of part tasks (using the simulator) which allows guided practice with the various knowledges and skills associated with flying the arm. Students must master each part task at increasing levels of difficulty before proceeding to the next task.

The Skill Maintenance Mode is used once the student has mastered all the part tasks in Tutorial Mode. The ITS first unobtrusively monitors the student as he/she performs one of the two whole tasks associated with flying the arm (i.e., deploy or retrieve a payload). Regardless of student performance, no tutoring or evaluative feedback is given to the student during this testing.

Future work will focus on the integration of the P2T2/ITS for the robotic arm with a different simulator; e.g., the Manipulator Development Facility (a one-g arm). Such technology also could be used to automate scenario generation based on performance data. Moreover, this technology could be transitioned into an onboard training/advisory system.

To sum the important conclusions:

- Future simulators should have a built-in student diagnostic and evaluation component as well as a remedial training capability.
- The Intelligent Tutoring System methodology is feasible for producing these types of training capabilities.



System diagram of intelligent tutoring systems with simulators.

Adaptive Control of a Robot Arm Using an Artificial Neural Network with Stereo Vision Input

PI: Dr. Timothy F. Cleghorn/PT41
Reference SST 59

Teleoperation is the mode of operation currently proposed for space and planetary surface robotics. While this may prove satisfactory for tasks in the immediate vicinity of a manned spacecraft, it is clear that there will be numerous occasions for which more autonomous robotic behavior will be required. Examples of such tasks include satellite servicing, for which transmission time delays are unacceptable; routine inspections, requiring intense human concentration for long periods of time, thus raising the probability of error due to fatigue or boredom; and planetary surface rover operations for which the round-trip transmission times exceed the real-time requirements.

Tasks of these sorts have been addressed, usually by what can be called "automatic" robotics; i.e., the arm or vehicle is preprogrammed to carry out a specific operation. It has little or no sense of its environment; and, if an unanticipated event occurs, at best it shuts itself off and waits for a human to restart it. What will be needed to carry out more demanding tasks is the development of "autonomous" robotics in which the computer attached to the arm or vehicle possesses a wealth of sensory input about the environment and the ability to respond to that input without human intervention. The system thus adapts to the environment and can continue to function in the face of unforeseen events or obstacles.

Until recently, two major factors have limited the development of autonomous robotics. The first of these was a lack of sufficient computing power. This is no longer seen as a limiting problem, especially with the advent of parallel architectures. Even serial computers are now becoming fast enough, and have sufficient memory and storage capabilities, to handle some of these problems. The other limiting factor was the lack of success of the "classical" artificial intelligence techniques. Combinatorial explosions usually derailed any attempt to teach computers about their environments. However, with the rediscovery and development of artificial neural network (NN) technology in the 1980's, this problem is being addressed. One class of NN, adaptive resonance theory (ART), is particularly suitable for the environment-sensing and response problem.

A simulation has been developed on a Silicon Graphics computer, which demonstrates a Robotics Research Corporation K-1607 robot arm learning to reach out and touch a spherical target object. The learning process occurs with an ART-like NN similar to one developed by Neurogen, Inc., for a Microbot arm. Inputs to these networks are stereo images of the target and arm. There are two phases: a learning phase and a production phase. During the learning phase, the arm manipulates the target sphere within the field of view (FOV) of the cameras in much the same way that a baby observes his hands moving in front of his face. This allows the weights of the NN to make an association between the view and the position and motion of the arm. During the production phase, the target is placed at random within the FOV of the cameras; and, depending upon the degree of learning, the arm reaches out and touches the target. It was found that, initially, learning occurred quite rapidly. After about 20 000 learning manipulations, the arm could touch the target in more than half of its attempts. The system continued to learn less rapidly for up to 200 000 manipulations, at which point it was able to touch a randomly placed target more than 90 percent of the time. The time needed for 200 000 learning trials was ~10 hours.

This demonstrates the potential of NN technology for solving problems involving unstructured or dynamic environments, which will likely be encountered both in space and planetary surface robotics operations.

A Machine Vision Algorithm for Autonomous Proximity Operations

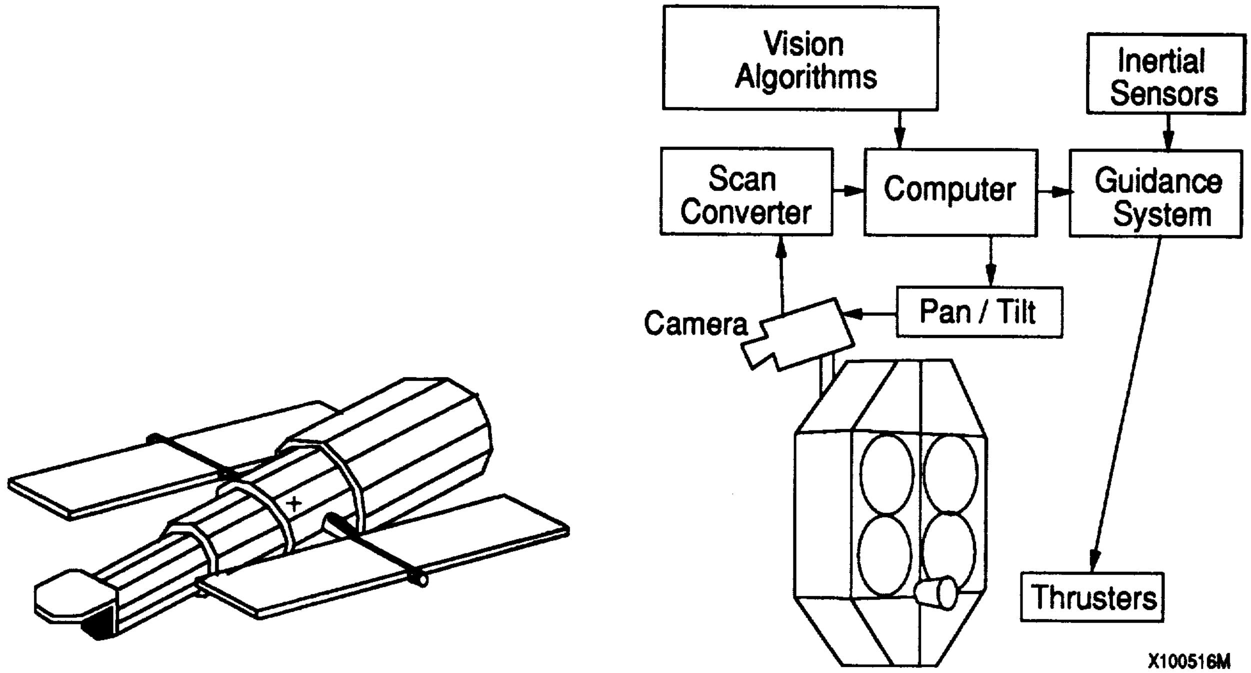
PI: Dr. Timothy F. Cleghorn/PT41
Reference SST 60

To perform a rendezvous and docking operation in space, it is necessary to determine the attitude and attitude rates of the target vehicle, as well as the relative position and trajectory of the maneuvering craft with respect to that target vehicle. These parameters are obtained currently by using Shuttle astronauts' eyes to guide the maneuvering craft to the desired position so that a grapple with the Shuttle remote manipulator system can be performed by a crewmember. In the future, it will be desirable to perform these operations with increasing degrees of autonomy, particularly satellite servicing and lunar and martian orbiter rendezvous. To do this, a full array of sensors will be required; however, it is likely that vision will remain as the major source of input data. One of the chief drawbacks of any sensing system based upon vision data is the sheer number of those data, with the correspondingly long computation times required to process the input. Therefore, it is very important to develop methods of data compression that permit analyses in keeping with the time scale defined by the characteristic motions of the target/sensor system in question.

An algorithm has been developed which permits small errors or drifts in trajectory to be identified and corrected, based upon the view of the target vehicle as seen by a single camera on a maneuvering craft. This algorithm runs on a personal computer (PC) with EGA or VGA graphics. It is assumed that the target object, as modeled by a PC-based computer-aided drawing (CAD) system, (ModelMATE, by Generic Software, Inc.), is located within the field of view of the camera, and that the target is recognized by the system; i.e., target identification is not the issue, although the techniques described herein could well be used for that purpose also. This algorithm utilizes the radial signatures of a sequence of images to determine a calculated position and trajectory for the maneuvering craft.

The complete program consists of two parts: an off-line training phase, and a series of run-time calculations, as the maneuvering craft approaches the target vehicle. The training phase presupposes the existence of an accurate 3-dimensional CAD model of the target vehicle, and typically runs for 2 days on an 80386-type computer for the level of accuracy used in this work. The training phase consists of the building of decision trees which permit the association of a radial signature of the target's image with an angular orientation of the target vehicle with respect to the maneuvering craft. Following the off-line training, a "desired" rendezvous trajectory is selected. It is assumed that the angular orientation of the target craft is known to within an accuracy of about 20 deg at some initial time t0. An angular normalization is made around the camera-target axis to align the image axes with those used during the training phase. Radial signatures of successive images are extracted as the maneuvering vehicle attempts to fly its desired course during the training phase.

Points on these radial signatures are fed into a decision tree to determine whether the camera "recognizes" the view. Normally, several adjacent views are recognized for each image. Based upon the linear extent of an image compared to a reference image, the apparent distance between the camera and the target also can be calculated. Thus, a sequence of images generates a "point cloud" through which a curve or apparent trajectory can be fit. This permits the trajectory of the next segment to be predicted, and corrections can be made to drive it closer to that which was planned originally. In addition, or as an alternative, it is possible to calculate the attitude and attitude rates of the target vehicle. These parameters are necessary for an autonomous docking to be performed.



System block diagram.

The COSTMODL Program and Ada COCOMO Calibration Database for Space Station Freedom

PI: Bernie Roush/PT4
Bill Reini/PT4
Reference SST 61

The development of computer software is projected to be one of the largest single cost items associated with the development of Space Station Freedom (SSF). It is therefore essential that NASA has available a means of estimating the effort and schedule required to develop a software product.

Several mathematical models have been constructed over the last decade which perform this function. The most widely used of these models is the Constructive Cost Model (COCOMO) devised by Dr. Barry Boehm in 1979. Another is the "Keep It Simple, Stupid" [KISS] model, a simplified linear model developed at the NASA Johnson Space Center (JSC) using cost data derived from past NASA projects. An automated implementation of these two models has been developed at JSC for use on SSF software.

Since the COCOMO model is over 10 years old, significant advances have occurred in software engineering and the technology of developing and managing computer software since COCOMO was developed. NASA is in the process of moving toward a software development environment where much of the new software will be developed employing the Ada programming language using modern software engineering practices. Therefore, it is necessary to update the COCOMO model to reflect the changes in software development productivity that can be anticipated in this environment.

The JSC automated software cost estimation tool (COSTMODL) was developed initially in fiscal year 1987 and has been expanded to include the latest enhancements to the COCOMO model. These enhancements are designed specifically to accommodate changes in programmer productivity resulting from the development of software in Ada using the latest in software engineering techniques. However, any model must be calibrated for the specific type of software developed by a particular organization, as well as the development environment which exists within that organization. To accomplish the required calibration, a database was constructed that contains productivity data derived from completed aerospace projects developed using the Ada programming language.

Due to the small number of Ada projects that actually have been completed and the small number of projects for which good productivity data were captured, usable calibration data are very sparse. The total database contains data for 191 non-Ada projects and 50 Ada projects. This is the largest currently available database compiled specifically for purposes of calibrating the COCOMO model for aerospace projects in an Ada environment.

Using the calibrated Ada model, COSTMODL can predict the effort required to complete the projects which make up the calibration database within 20 percent of the actual effort for more than 60 percent of the cases.

This work has been of considerable interest to the software cost-estimating community and has resulted in several invitations to present the results to conferences both here and abroad. The calibrated COSTMODL program and its accompanying calibration database are being made available to government agencies and their contractors.

Due to the fact that a model can be calibrated only with data from completed projects, it is important that the calibration database continue to be developed as more projects are completed. The COSTMODL program and its associated calibration database will continue to be refined and expanded as advances are made in software engineering methodologies and as additional projects are completed using the Ada programming language.

Space Transportation Analysis and Intelligent Space Systems

PI: Dan Greenwood
J. Villarreal/PT4
Reference SST 62

Work carried out in this area was principally directed at health monitoring for space propulsion systems. The primary method employed was the application of feedforward neural networks (NNs) trained with back propagation; and, in the case of each problem area, the constructed NNs were able to make the decisions required of them successfully.

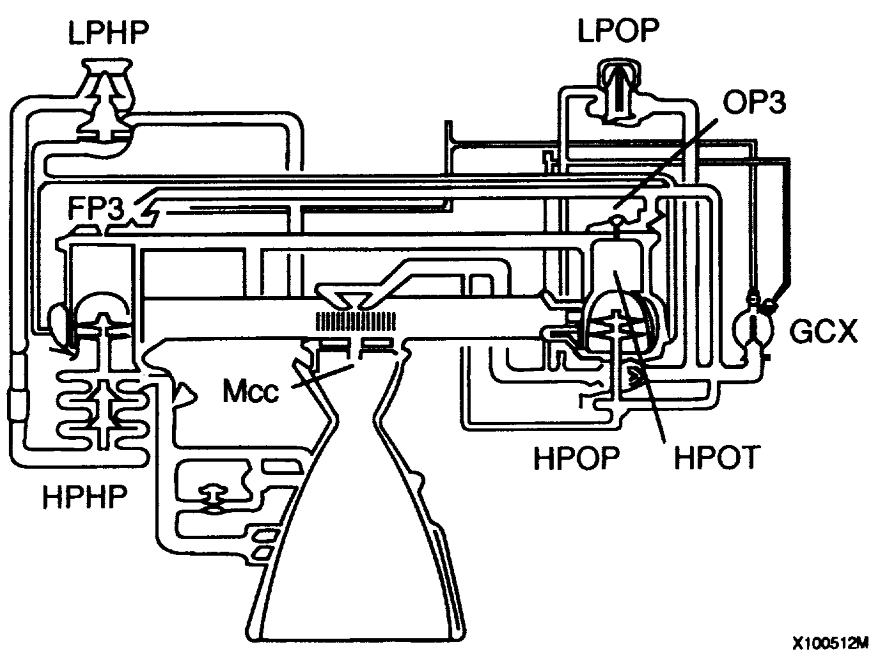
The first work, which is ongoing, addresses the problem of on-line anomaly detection and fault typing for the Space Shuttle main engine (SSME). The basic method under investigation involves sensor data compression through NNs and is based on features representing the time-variance of and relationships between SSME sensor values. It has been possible to make use of actual test-stand, test-case data.

The second piece of work addresses the issue of distinguishing valve signatures in the Atlas rocket (which contains some 150 valves of various types), again using feedforward NNs. In this case, data were collected in the form of current signatures from Atlas rocket valves installed on a pneumatic test bench. The data were then used as training and test data for two NNs. One NN was trained to distinguish between signatures for individual valves falling into three separate types of valves during a valve-open state change (rising current), and the other NN was trained to distinguish between signatures for the same three types of valves during a valve-close state change (failing current).

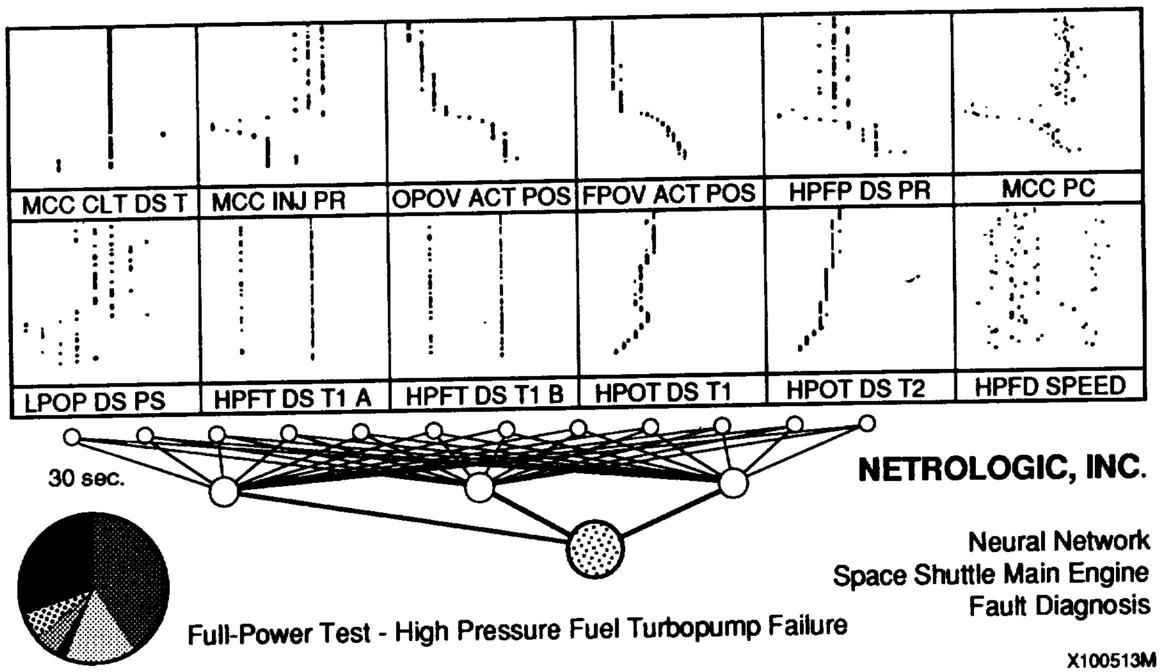
The third investigation involved the use of feedforward NNs to gauge cryogenic fuel tanks by estimating the amount of mass in the tank from spectral resonance measurements. Two types of networks were investigated: the first employing a compact representation of the input space, the second retaining all of the information in the resonance measurements.

The last piece of work is involved in determining the quality of an industrial inertia weld by examining data accumulated during the welding operation. This work could conceivably be applied in areas where stringent weld requirements are necessary, such as in the development of the SSMEs.

The techniques used to solve each of these problems from a different area of health monitoring for space propulsion systems can be generalized to many similar problems in space transportation analysis.



Schematic of the rocket engine components.



Full-power test – high-pressure fuel turbopump failure.

The NETS - A Tool for the Development and Delivery of Neural Networks

TM: Robert O. Shelton/PT4
Reference SST 63

The NETS is a neural network simulator developed by the Information Systems Directorate at the NASA Johnson Space Center (JSC). When using NETS, it is possible to create and execute arbitrary configurations of neural networks that use the "back propagation" learning technique. The NETS is portable and will run on a variety of machines from mainframes to personal computers.

With the latest release of NETS (version 2.01), the most significant addition is the delivery capability. A new "g" option allows the user to generate C source code which implements the network loaded into the system. This permits the placement of networks as components, or subroutines, in other systems; hence the name "delivery" option. In short, once the network performs to the user's liking, the "g" option provides the means for creating a program separate from NETS for running the network.

Several users noted the fact that the weights files produced by NETS were difficult to move among computer systems due to the fact that the files were written in binary format. The NETS 2.01 allows the user an option when creating a weights file to use either the old format (now termed FAST FORMAT) or a new PORTABLE FORMAT which saves the weights as ASCII text.

Earlier versions of NETS used a scaled integer internal representation for floating-point numbers in an effort to speed the learning process for machines that did not have a floating-point coprocessor. However, many NETS users have access to higher power machines or simply desire the extra precision available when using true floating-point representation. The NETS 2.01 includes a feature for allowing the user to select, at compile time, which of the two formats is desired. **Note**: The NETS comes compiled to be used in scaled integer format.

The propagate feature ("p" command) has been updated in version 2.01. Previously, only a single input could be propagated through the network using the "p" command. In NETS 2.01, the user is prompted for the number of inputs (starting with the first in the file) to be propagated through the network. The default case propagates the entire file contents and prints the results.

Previous versions of NETS did not include a feature of the back propagation algorithm called "bias values." Biases are used to offset the value produced by the neurons of a network, thus adding another dimension to a network's learning space. This, together with the option to control how often NETS prints out its error values, has served to greatly decrease learning time.

Another new feature in version 2.01 is the addition of a scaling factor which modifies the learning rate. This scaling factor is dynamically calculated based on a network error generated during the learning process. The result is a decrease in learning time due to the fact that the learning rate is more sensitive to the network error. This is especially true for networks with very large layers.

Many times a network will learn more rapidly if its input/output (I/O) pairs are presented in a random order. The NETS 2.01 includes an "o" option which will reorder an I/O file and create a new ASCII version of the I/O pairs.

The NETS is free to NASA and its contractors, and may be obtained by calling the Help Desk at (713) 280-2233. The NETS also may be purchased by the general public through COSMIC at (404) 542-3265.

Parametric Avalanche

PI: Robert Dawes
Robert O. Shelton/PT4
Reference SST 64

The Parametric Avalanche Neural Network (PA) was introduced by the principal investigator in 1988. This network paradigm is composed of two clusters of nodes, or neurons, which are interconnected by adjustable synaptic weights that encode learned knowledge acquired automatically during operation of the network. The PA differs from most network architectures in that it is designed to learn the behavior of continuous dynamical systems by exposure to example trajectories of such systems. Once the dynamics are encoded in the synaptic weights, this knowledge can be exploited to accomplish short-term prediction which, among other things, can be used to exercise effective adaptive control.

Use of the PA as a control module for a highly nonlinear dynamical system was first demonstrated in the research sponsored as a Phase I Small Business Innovative Research (SBIR) grant awarded to Martingale Research Corporation of Allen, Tex. A prototype PA controller was constructed to maintain control of an inverted pendulum. The inverted pendulum or so-called "cart-pole" problem is known to be extremely difficult to solve with an adaptive or learning controller. This difficulty arises from the fact that most network-based control systems do not provide explicitly for encoding the dynamics of the system but, rather, learn patterns of associations between discrete system states. The PA proved to be an extremely effective controller for this problem. The PA was able to learn to control the system without allowing the pendulum to fall. After the system achieved equilibrium, the controller proved capable of recovery from random perturbations which were of sufficient magnitude and frequency to carry the pendulum well away from the linear range of control; e.g., maximum displacements of more than 70 deg from vertical.

These impressive results motivated the award of a Phase II (NAS 9-18355) continuation of the SBIR grant. The goal of the second phase is to develop a general adaptive controller for complex dynamical systems based on the PA architecture. The particular system chosen as the first demonstration arena for this technology is the control of tethered satellites. A prototype version of the system has been built which will simulate and control a satellite modeled as a massless rigid tether. While extremely preliminary, the results of this work are as encouraging as the initial "cart-pole" studies. The current thrust of the work is to

- Host realistic (bead model) simulation software on high-performance platforms;
- Make such modifications as necessary to the control architecture based on deficiencies discovered from the introduction of more realistic and, therefore, less easily controlled simulations; and
- Include perturbations such as plume effects, electromagnetic forces, and atmospheric drag.

A Space-Time Neural Network (STNN)

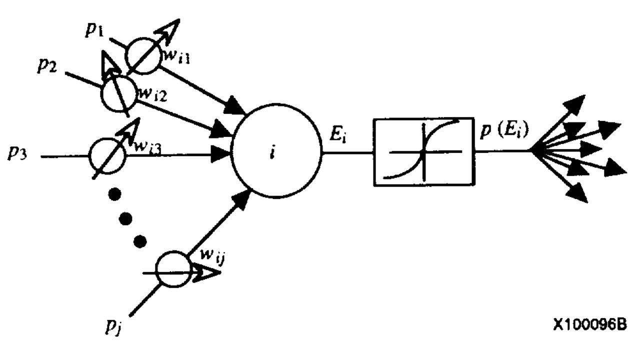
PI: James A. Villarreal/PT4
Robert O. Shelton/PT4
Reference SST 65

Neural network (NN) technology has impressively demonstrated the capability of modeling and discovering patterns in spatial domains. However, the application of NNs to processing temporal data has been restricted severely. This work introduces a novel technique which adds the dimension of time to the well-known back propagation NN algorithm.

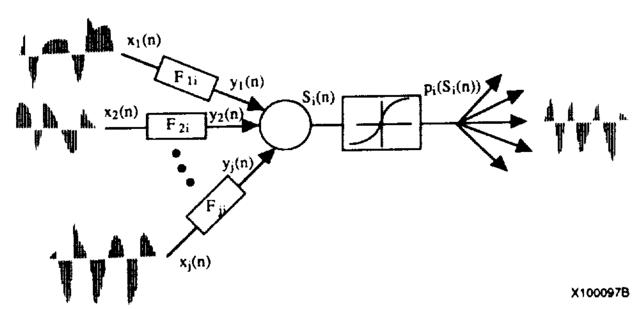
The need for space-time knowledge capture representation clearly is evident. Human cognitive thought processes involve the use of both space and time. At the microscopic level, investigations reveal a need to incorporate time or sequence discovery and adaptation into the modeling framework. The more advanced engineering systems have characteristics that vary over time. For instance, complex machines such as the Space Shuttle main engine abound with sensors, each varying over the machine's operational lifetime. These few examples demonstrate that a model which is capable of automatically associating spatial information with its appropriate position in time becomes increasingly significant.

Another dimension can be added to the processing element shown in the first figure by replacing the synaptic weights between two processing elements with an adaptable-adjustable filter. Instead of a single synaptic weight which, together with the standard back propagation NN, represented the association between two individual processing elements, several weights now represent not only associations but also temporal dependencies. In this case, the synaptic weights are the coefficients to adaptable digital filters. The biological implication of this representation can be seen when one considers that synapses undergo a refractory period – responding less readily to stimulation after a response. The second figure illustrates a space-time neural network (STNN) where the regular synaptic weights have been replaced with digital filters, thereby allowing a whole sequence of patterns to be processed at each synapse.

The STNN is a software package created by the Information Systems Directorate at the NASA Johnson Space Center. The STNN has found uses in automatically interpreting the complex interrelationships between the time-varying, multisensored signals found in complicated machinery, learning the temporal dependencies in visual patterns found in vision-recognition problems, predicting future patterns from past information such as those found in chaotic sunspot patterns, and many more. Other potential uses of the STNN include seismograph interpretation, biomedical signal interpretation, DNA encoding, and as an aid in financial decision making, trend analyses, etc.



Processing element in a back propagation network.



A pictorial representation of the STNN processing element.

Fuzzy-CLIPS – The C Language Integrated Production System with Fuzzy Language Capability

TM: Robert N. Lea /PT4
Reference SST 66

During Phase I of this Small Business Innovative Research (SBIR) contract, a unique expert system development environment has been explored through combining the conventional symbolic processing capability of the NASA/Johnson Space Center's (JSC's) C Language Integrated Production System (CLIPS) with a fuzzy logic based approximate reasoning capability. No commercial software tool of this type currently exists which will allow the development of fuzzy logic systems within the framework of a conventional expert system shell.

Phase I SBIR results demonstrated that the integration of a fuzzy logic capability into CLIPS will provide a useful tool for developing purely conventional, purely fuzzy, and hybrid conventional/fuzzy expert systems. During Phase I – as proof of both the feasibility and applicability of a Fuzzy-CLIPS, – Togai Infralogic coded two software systems for evaluation. The first is a limited prototype of Fuzzy-CLIPS based on CLIPS version 4.3. This partial implementation augments CLIPS with three constructs which allow the user to define a fuzzy logic system; i.e., the *deffuzzy* construct defines a series of fuzzy logic production rules, the *defmember* construct defines membership functions, and the *dofuzzy* construct provides the mechanism for calling a fuzzy rule base from a standard CLIPS rule. The second software system demonstrates the implementation of a hybrid expert system by exercising the prototype Fuzzy-CLIPS system. In this software, the knowledge base to perform single-axis spacecraft attitude control was developed to demonstrate that Fuzzy-CLIPS can provide a flexible interface for knowledge base definition and execution.

During this Phase II SBIR, the prototype will be enhanced by allowing different options for inferencing and defuzzification, supporting multiple outputs from the fuzzy rule base, and determining which of the rules has fired. In Phase II, Togai Infralogic proposes to add a generalized differential competitive learning (DCL) capability that can assist greatly in developing rule bases and membership functions. Preliminary studies of applications of DCL to the inverted pendulum and to a class of target-tracking problems during Phase I gave promising results. Mechanisms for verification and validation of the fuzzy rule bases and real-world system examples will be developed to exercise fully the advanced capabilities of the system including the DCL and fuzzy information processing.

Overall, the results of the Phase I efforts have demonstrated that the combination of fuzzy logic and CLIPS will empower CLIPS users with a cohesive, leading-edge artificial intelligence tool. The architecture appears quite feasible to implement and will give CLIPS users a new dimension in expert system development with minimal learning time impact for development of fuzzy logic systems. Such a tool will be useful in many key technological areas (e.g., autonomous vehicle control and guidance systems, structure vibration control, health monitoring and diagnostic systems, intelligence sensor fusion and data interpretation, and heuristic pattern recognition and adaptation). These issues will be investigated in the course of the Phase II implementation of Fuzzy-CLIPS.

A fuzzy/symbolic computation capability can be applied to flight planning and control, risk analysis, intelligent data fusion and interpretation, heuristic pattern recognition, and diagnostic systems. The Fuzzy-CLIPS product should be particularly useful in the area of system diagnostics where, currently, the problem of integrating uncertainty into such systems has received little attention. Using this product, it would be very convenient to mix crisp logic and fuzzy logic in expert systems, as appropriate. The DCL and verification and validation features that will be added to Fuzzy-CLIPS during the Phase II SBIR should make expert systems development very flexible and less time consuming to implement and verify.

A Phoneme-Based Speech Recognition System for High-Stress, Moderate-Noise Environments

PI: J. Villarreal/PT4
D. Trawick/Speech Systems Inc.
Reference SST 67

The main goal of this project was to develop a high-performance, phoneme-based speech recognition development testbed for NASA. This has included development in a number of areas to improve system performance in general, and development in a number of areas to make the system more appropriate for NASA's specific requirements. Applications with requirements similar to those of NASA (i.e., those requiring accuracy under conditions of moderate stress and noise) also have benefited from these improvements.

The Phase II research was divided into three primary tasks. The first task was the development of a system tailored for NASA. Since NASA's requirements are not unique among Speech Systems Inc.'s (SSI's) potential customer-application areas, this development also has improved the performance, versatility, and applicability of SSI's speech recognition system in general. This task included research and development in the areas of dialect sensitivity, using a headset input device, and speech model development for NASA personnel. This effort has produced a headset system that is now SSI's standard input device. It also had produced a method, called profiling, which allows the system to adapt generic speaker models to new speech environments, including new applications, new speakers, new dialects, etc. (within reason).

The second task was work directed at improving system performance in general by making improvements to the basic technology. This task included research and development in the areas of parallel processing for the Phonetic Decoder, and improved accuracy in the presence of noise. This effort has resulted in performance improvements primarily by reducing the decoding time and increasing the recognition accuracy, especially in noise.

The third task was a consolidation of the results and a delivery to NASA of the final improved system.

Passive Knowledge Acquisition System

TM: Robert T. Savely/PT4
Gary Riley/PT4
PI: Vince Kovarik
Reference SST 68

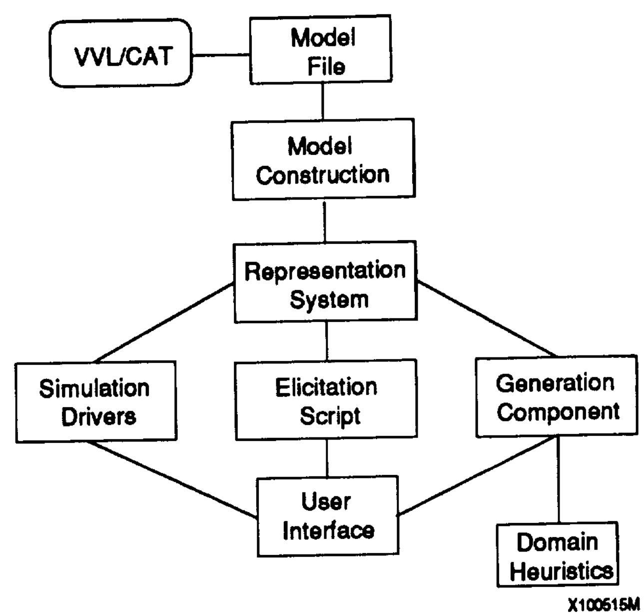
The acquisition and application of expert knowledge to complex reasoning tasks remains a human-intensive activity. Efforts to extract knowledge directly from domain experts have not lived up to expectations. Current tools for knowledge acquisition fall far short of the capabilities required to support direct acquisition from the expert. This is because tools developed previously have focused on providing the knowledge engineer with powerful abstractions for building the representation of the acquired knowledge, not on the actual acquisition process. Consequently, current endeavors must rely heavily on the knowledge engineer to both extract and appropriately represent the knowledge of an expert.

The goal of this project is to develop an approach to the direct acquisition of knowledge from experts by emulating a human knowledge engineer. Consequently, this effort is not a software environment for use by the knowledge engineer. Rather, the Passive Knowledge Acquisition System (PaKAS) is designed as an interactive system that "observes" the expert in the performance of a task. Following this observation, PaKAS elicits the expert's rationale and background knowledge that led to the observed actions and develops a rule-based representation of the acquired knowledge.

The observation of an expert by an automated system does rest on certain assumptions and concessions regarding the actual mode of observation. Of course, PaKAS does not visually observe a human carrying out a task. Instead, the PaKAS provides a simulation of the task to be observed and monitors the interactions of the expert with the simulation – identifying the actions taken by the expert in response to simulation stimuli, noting the objects acted upon by the expert, and recording the changes of state brought about by the expert's actions. The expert need have no knowledge of the observations that are under way as the task is performed.

The PaKAS project builds on previous work at the Johnson Space Center. In particular, the Vacuum Vent Line Intelligent Computer-Aided Training system provides the simulation upon which this implementation of PaKAS is built.

The figure shows the basic architecture of PaKAS. The results of the Phase I effort have demonstrated the feasibility of implementing a more powerful and robust version of PaKAS that could ultimately be integrated with the large-scale simulators that are available at the NASA field centers. Such systems could provide access to the expert knowledge of NASA astronauts and ground support personnel in a manner which avoids the intrusions and lack of domain context that characterizes the usual knowledge acquisition process.



The PaKAS architecture.

The Automated Online Library – AutoLib

PI: Ernest M. Fridge III/PT4
Mark Rorvig/PT4
Reference SST 69

The Automated Online Library (AutoLib) is a software system that catalogs, retrieves, and manipulates information in a distributed, heterogeneous computer environment. AutoLib provides an object-oriented, X-window system interface for managing on-line and off-line objects including program source code, graphic images, documents, design drawings, and data in many other formats. Users can easily browse the library contents by topic, without concern for physical location of the objects, operating system differences, or object format. Descriptive information about each object can be stored and displayed by the system, and objects can be copied to the user's workstation for reuse. Advanced information-retrieval functions are provided, including a natural language interface. The system supports UNIX workstations, personal computers, Macintoshes, and other user nodes. If desired, computer programs can be installed in the library to run on remote machines to provide a friendly, distributed operating framework.

The AutoLib effort was motivated by the desire to decrease system development costs by promoting the reuse of existing products. Before building a new object, the library can be searched for the existence of an object of the same or similar function.

Since its initial release in 1987, the AutoLib system has proven to be extremely useful for integrating the capabilities of dispersed organizations over wide-area networks. The distributed nature of the system supports local autonomy while maintaining a high degree of resource sharing.

During fiscal year 1990, many enhancements were added to the system; the current production release is AutoLib Version 3.2. New capabilities include support for several graphic formats including TIFF, GIF, Raster, and Interleaf. Distributed configuration management functions and many new security features also have been introduced. Work continues with AutoLib Version 4 to incorporate the Open Software Foundation [OSF] Motif interface standard. An alternate VT100 Terminal Emulation feature also will be provided to support text-oriented workstations.

The benefits introduced by AutoLib are many. Large, distributed organizations can better manage their information resources. Productivity is increased by reducing dependency on humans for locating information and products. Users do not have to be trained on multiple computers and operating systems. Products can migrate between hardware platforms, when convenient, without changing the user interface. Redundancy can be managed better since products may be shared across multivendor platforms. Most importantly, AutoLib provides cost savings by promoting the reuse of existing resources.

ART/Ada Prototype

PI: Chris Culbert/PT4
Reference SST 70

Although they have reached a point of commercial viability, expert systems were developed originally in artificial intelligence (AI) research environments. Many of the available tools still work best in such environments. These environments typically utilize special hardware such as LISP machines and relatively unfamiliar languages such as LISP or Prolog. Space Station applications will require deep integration of expert system technology with applications developed in conventional languages, specifically Ada. The ability to apply automation to Space Station functions could be enhanced greatly by the widespread availability of state-of-the-art expert tools based on Ada. Although some efforts have been exerted to examine the use of Ada for AI applications, when this project began in 1986, no existing products provided state-of-the-art AI capabilities in an Ada tool.

The goal of the ART/Ada Design Project is to conduct research into the implementation in Ada of state-of-the-art hybrid expert systems building tools [ESBTs]. This project takes the following approach: in using the existing design of the ART-IM tool as a starting point, the project analyzes the impact of the Ada language and Ada development methodologies on that design, redesigns the system in Ada, and analyzes its performance. The research project will attempt to achieve a comprehensive understanding of the potential for embedding an expert system in Ada systems for eventual application in future Space Station Freedom projects. During Phase I of the project, initial requirements analysis, design, and implementation of the kernel subset of ART-IM functionality were completed. During Phase II, the effort has been focused on the implementation and performance analysis of several versions with increasing functionality. A fully functional prototype was completed early in fiscal year (FY) 1990, and the majority of the FY 1990 tasks focused on an extended evaluation of the ART/Ada prototype at a number of NASA and U.S. Air Force (USAF) sites.

To evaluate properly how well we are able to provide state-of-the-art expert system capabilities in Ada, it is necessary to examine the products of the ART/Ada development in representative technical environments. This was accomplished by putting the ART/Ada prototypes through an extensive user evaluation (beta test) period. This evaluation used eight different evaluation sites; four NASA sites and four USAF sites. Each beta test site was supposed to develop or convert an appropriate expert system application using the ART/Ada tool.

To begin the evaluation, ART-IM 1.5 with ART/Ada 1.0 was delivered to each of the beta test sites for use on either a VAX or a Sun system. These sites evaluated ART/Ada by implementing appropriate expert systems using the hardware and software systems available. The ART/Ada 1.0 contained all ART-IM functionality except for the schema object description capabilities. While the evaluation teams were beginning their development work, Inference completed the schema additions to ART/Ada. Later during the project, ART/Ada 1.0 was replaced with ART/Ada 1.5, the full Ada implementation of ART-IM 1.5. From feedback we received from the evaluation sites, we tried to achieve a comprehensive understanding of the operational issues and the potential for embedding expert systems in Ada systems.

Near the end of FY 1990, evaluation responses were gathered from each of the beta test sites and an evaluation of both ART/Ada and a similar NASA-developed tool (CLIPS/Ada) was documented in a report delivered to NASA Headquarters in November 1990. The responses from the beta testers of ART/Ada were generally positive. In particular, the development environment was considered very useful. Issues were raised about the cost of commercial versions of ART/Ada, the size of the Ada source code elements created by ART/Ada, and bugs in the deployment code generated by ART/Ada. Inference will address some of these issues in future commercial releases of ART/Ada.

The FY 1990 work completed the original goals of the ART/Ada project to evaluate the use of Ada for state-of-the-art expert system tools. No future work is anticipated on the project from NASA, although Inference Corporation intends to sell a commercial version of this tool.

The Intelligent Physics Tutor

PI: Robert T. Savely/PT4
Dr. R. Bowen Loftin/U of H
Reference SST 71

The integration of the computer into the precollege instructional program began in the 1960's and has accelerated with the availability of inexpensive computing hardware and a growing amount of useful instructional software. Unfortunately, the bulk of computer-aided instruction today is limited to rather simple programs that are useful for drill-and-practice, automated "page-turning," and the administration of objective examinations. The Intelligent Physics Tutor exemplifies a new generation of instructional software which relies upon artificial intelligence technology to provide individualized assistance to students in a number of educational settings. Intelligent Tutoring Systems will complement other new technologies to provide an integrated learning environment that has the potential to revolutionize instructional delivery and permit every student to acquire knowledge and skills under optimal conditions.

Since 1986, the NASA Johnson Space Center and the University of Houston-Downtown, with support from the Office of Space Flight, have been actively developing intelligent computer-aided training (ICAT) systems for use within NASA by astronauts, flight controllers, and systems engineers. NASA's Technology Utilization Program is supporting the application of this ICAT technology to the development of an intelligent tutoring system for introductory physics. The tutor is designed to provide an interactive environment for the application of physics concepts to the solution of problems. The principal goal of the tutor is to enable a student to acquire efficiently the problem-solving skills necessary for successful mastery of high school or introductory college physics. The tutor is intended to integrate with the lecture and laboratory portions of a typical instructional program. Its strength lies in its ability to observe the student develop problem solutions continually and to intervene, when appropriate, with assistance specifically directed at the student's difficulty and tailored to the skill level and learning style of the student. Student progress through the tutor is governed by a global strategy that evolves the complexity of problems presented to the student at a rate suitable for the individual. In addition, the curriculum organization and problem repertoire can be altered by the teacher to match that of his/her own textbook and instructional strategy. This same facility enables the teacher to examine the performance models of individual students or entire classes. The tutor has been designed to facilitate its application to other problem-solving domains; e.g., chemistry, mathematics, and engineering.

During fiscal year (FY) 1990, the design of the expert problem-solver portion of the tutor, together with the error detection, error remediation, and interface elements, reached maturity. The problem sets for the areas of one- and two-dimensional kinematics also were completed. The tutor was employed in high school physics classes at Clear Creek High School in League City, Texas, and at West High School in Columbus, Ohio. Evaluations of the tutor in these institutions have been exceptionally positive. Feedback obtained from students and teachers will be used during FY 1991 to refine the tutor further as it is extended to statics and dynamics.

Principal investigator, Dr. R. Bowen Loftin, observes a physics student at Clear Creek High School, League City, Texas, using the Intelligent Physics Tutor.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

A Literacy Tutor

PI: James A. Villarreal /PT4
Reference SST 72

A Ford Foundation national study published in 1979 reported that one out of five American adults is functionally illiterate. Since the appearance of that report, the crisis has apparently worsened. Business, education, and government have achieved a unanimous consensus that swift action is required now to avoid and reverse a continuing growth in the number of illiterate citizens in our nation.

The NASA Johnson Space Center (JSC) in cooperation with the NASA Technology Utilization office, the Houston READ commission, the University of Houston, and the Department of Justice are developing an adult Literacy Tutor. This project aims at using NASA-developed technologies to eradicate the illiteracy problem. The integration of technologies such as artificial intelligence to bring the expertise of the very best reading teachers and speech recognition/synthesis to permit dialogue between student and computer has the potential of providing individualized, one-on-one instruction to large numbers of students in a distributed computing environment.

A committee with members from each of the aforementioned participants was formed on April 1990 to structure requirements for the development of the Literacy Tutor. This committee has isolated two key areas that will form the core for the Literacy Tutor. In general, these two areas consist of

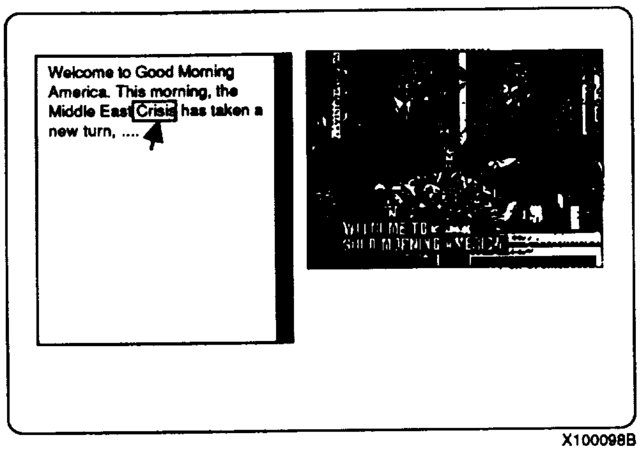
- Interactive speech capabilities, such as pronunciation and reading tools; and
- A closed-captioned television (CCTV) interceptor for curriculum development.

Originally designed for the deaf and hard of hearing, CCTV was used to teach reading to hard-of-hearing elementary students (*Koskinen*, 1983) using "Sesame Street" and "Different Strokes." Harvard University has been using CCTV to teach students of English as a Second Language. The Literacy Tutor committee is embarking on a new initiative which will integrate advanced computer technologies with CCTV. The CCTV offers an ever-growing curriculum filled with life-skill situations. Most, if not all, adult curriculum suffers from being stagnant or intended for an audience of children. That is, adult students usually are not concerned with what happened 50 years ago but with what is happening today – events that directly affect their everyday lives. Nor are adult students concerned with the likes of "See Jane run." The committee has determined that the staff of the Houston READ commission along with its adult student population should be responsible for developing curriculum for adult students through the use of CCTV.

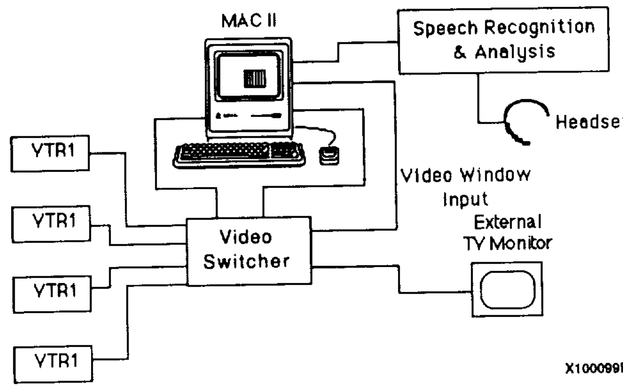
The JSC will be integrating CCTV with other advanced computer technologies in parallel with this effort. The CCTV will provide adult students with material which is both highly interesting and continually changing. As envisioned, a live (or previously recorded) image from a television (TV) source can be placed within a standard computer screen. By providing not only the TV image but also the accompanying text, a student can exercise complete control over the incoming program. For instance, this capability will allow the student to pause the program to study the usage and pronunciation of a particular word. An on-line dictionary can be called to find the meaning of a word, find other synonyms, or interact a word with the pronunciation tools. In addition, a computer-aided curriculum generator [CACG] will be developed which provides the teacher a tool with which to orchestrate the presentation of materials to the student. For instance, while presenting a certain program, the teacher may want to program the Literacy Tutor to pause the video so it will interact with the student to ensure comprehension. A peripheral that displays full-function TV on the Macintosh II series will be used. *Of particular interest is that this device can capture and store, as a text file, any closed-captioned information in the TV signal.*

Visits to the various READ commission learning centers have demonstrated that pronunciation assessment and aids are vital elements to successful literacy training. Imagine a live speech therapist (this is possible because of TV and laser disk technology) on the computer screen who is prompting the student to speak several words. By integrating speech recognition and other speech analysis techniques that take into account the well-understood mechanics of speech production, it is possible for the computer to assess the student's speech and provide the appropriate corrective prescriptions through video – a simple indexing to the proper video segments on the laser disk TV and/or a VHS VCR. Also, in conjunction with the speech therapist on the video screen, simple speech graphs will appear that form a visual representation of the teacher's voice superimposed by the student's response to the same word – in effect becoming a biofeedback mechanism. This "bull's- eye" graphic representation now provides the student with a target goal to aid in pronouncing the word correctly.

The learning process also will be aided by a continuous-speech, speaker-independent speech recognizer. This capability will allow students to read text aloud while the computer listens and interacts with the student. The integration of CCTV, pronunciation tools, and computerized speech recognition and generation promises a revolutionary new method to aid in the fight against illiteracy. A configuration of the various hardware peripherals for the Literacy Tutor are displayed in the following figures.



A typical Macintosh screen illustrating the uses of CCTV for teaching reading skills.



Hardware configuration of the Literary tutor.

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References

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LS 1	**Ventilator Function in Hyperbaric Conditions** Funded by: Code M/472-54-21-02 Technical Monitor: Charles W. Lloyd, Pharm.D./SD2/483-7120 Principal Investigators: Wm. T. Norfleet/M.D./KRUG Life Sciences, Inc. Joey B. Boyce, M.D./SD2 Task Performed by: Johnson Space Center KRUG Life Sciences, Inc., NAS9-17720
LS 2	**Phase I Evaluation of Aerosolized Medications During Parabolic Flight** Funded by: Code S/199-02-31-40 Technical Monitor: Charles W. Lloyd, Pharm.D./SD2/483-7120 Principal Investigators: Charles W. Lloyd, Pharm.D./SD2 William J. Martin, Pharm.D./St. John Hospital, Detroit, MI John Gosbee, M.D./KRUG Life Sciences, Inc. Task Performed by: Johnson Space Center KRUG Life Sciences, Inc., NAS9-17720
LS 3	**On-Orbit Formulation of Intravenous Fluids** Funded by: Code M/ 472-53-21-02 Technical Monitor: Charles W. Lloyd, Pharm.D./SD2/483-7120 Principal Investigators: Gerald J. Creager/KRUG Life Sciences, Inc. Charles W. Lloyd, Pharm.D./SD2 J. Ogle/Baxter Healthcare Task Performed by: Johnson Space Center KRUG Life Sciences, Inc., NAS9-17720 Baxter Healthcare
LS 4	**Development of a Surgical Support System for Space Station Freedom** Funded by: Code M/472-53-21-02 Technical Monitor: Roger D. Billica, M.D./SD2 Principal Investigators: Roger D. Billica/M.D./SD2 Frank T. Eichstadt, M.D./MDSSC Task Performed by: Johnson Space Center KRUG Life Sciences, Inc., NAS9-17720 McDonnell Douglas Space Systems Company
LS 5	**Venipuncture and Indwelling Intravenous Infusion Access During Zero-Gravity Flight** Funded by: Code S/199-02-31-40 Technical Monitor: Joey B. Boyce, M.D./SD2/483-7890 Principal Investigators: Debra L. Krupa, R.N./KRUG Life Sciences, Inc. Gerald J. Creager/KRUG Life Sciences, Inc. Joey B. Boyce M.D./SD2 Task Performed by Johnson Space Center KRUG Life Sciences, Inc., NAS9-17720

LS 6 **Effectiveness of Intranasal Scopolamine in Normal Subjects**
Funded by: Code S/199-18-11-16
Technical Monitor: Nitza M. Cintron, Ph.D./SD4/483-7165
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LS 7 **Development of a Card Filler Module for the Automated Microbiology System II**
Funded by: Code S/199-04-11-20
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LS 8 **Determining Energy (Caloric) Requirements in Space**
Funded by: 307-51-40-01
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LS 9 **A Combustion Products Analyzer for Contingency Use During Thermodegradation Events on Spacecraft**
Funded by: Code S/106-30-63-11
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LS 10 **Ion Mobility Spectrometry: A Key to Real-Time Monitoring of Volatile Organic Compounds**
Funded by: Code S/106-30-63-11
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LS 11 **Sample Collection Device for Rapid Immunological Identification of Group A Strep**
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LS 12 **Endothelin Production by Blood-Brain Barrier Endothelial Cells**
Funded by: Code S/199-18-11-15
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Principal Investigators: Peggy A. Whitson, Ph.D./SD4
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LS 13 **Johnson Space Center Biotechnology: Cell Culture Process**
Funded by: (ode S /694-01-23-03
Technical Monitor: Glenn F. Spaulding, M.D./SD4/483-7160
Principal Investigators: David A. Wolf, M.D./CB
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Task Performed by: Johnson Space Center
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LS 14 **Telemicrobiology: A Ground-Based System to Perform Microbiology Tasks in Extraterrestrial Human Habitats**
Funded by: Code S /99-04-11-20
Technical Monitor: Duane L. Pierson, Ph.D./SD4/483-7166
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LS 15 **Analysis of Eye, Head, and Body Movement During Locomotion**
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LS 16 **The Effect of In-Flight Exercise on Decompression Sickness During Extravehicular Activities**
Funded by: Code S/199-04-11-01, (Code M) 568-12-KK-95
Technical Monitor: James M. Waligora, M.S. /SD5/483-7200
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LS 17 **Dynamic Posturography Laboratory**
Funded by: Code S /106-30-11-42, 106-30-63-11
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Funded by: 307-51-69-09
Technical Monitor: Suzanne Fortney, Ph.D./SD5/483-7214
Principal Investigators: Nitza M. Cintron, Ph.D./SD4
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Funded by: 141-20-41-04
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LS 20 **Pharmacological Countermeasures to Space Motion Sickness**

Funded by: Code S/199-16-11-07
Technical Monitor: Millard F. Reschke, Ph.D./SD5/483-7210
Principal Investigators: Randall Lee Kohl, Ph.D./National Research Council
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National Research Council

LS21 **Computer-Predicted Human Strength**

Funded by: OAET/591-32
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Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Company, NAS9-17900

LS 22 **Overhead and Forward Reach Capability During Exposure to +X Accelerations**

Funded by: Code R/506-71
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Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SOLAR SYSTEM SCIENCES (SSS)

SSS 1 **Sample Acquisition, Analysis, and Preservation**
Funded by: Code RZ/591-12-89-01
Principal Investigators: Doug Ming/SN14
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Judy Alton/LESC
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SSS 2 **Lunar Base Agriculture: Synthetic Soils for Plant Growth**
Funded by: OSSA (Code SB)/99-61-11-01
Principal Investigators: Doug Ming/SN14
Don Henninger/EC3
Task Performed by: Johnson Space Center
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SSS 3 **The Long Duration Exposure Facility (LDEF) Satellite: New Data on Cosmic Dust and Spacecraft Debris**
Funded by: RTOP 152-11-40-23 and 152-20-40-05
Principal Investigator: Michael Zolensky/SN2
Task Performed by: Johnson Space Center

SSS 4 **Manned Observation Technologies: Optical-Quality Windows for Space Station Freedom & Beyond**
Funded by: OSSA (UPN 506-49-31)
Principal Investigator: David L. Amsbury/SN15
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SSS 5 **Optical Observations of Orbital Debris**
Funded by: 906-34
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SSS 6 **Orbital Debris Radar Measurements**

Funded by: 906-34

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SSS 7 **Hypervelocity Impact (HVI) Effects on Materials**

Funded by: 506-43-21

Principal Investigator: Eric L. Christiansen/SN3

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

SSS 8 **Lunar Meteorites**

Funded by: RTOP 142-13-40-21 and 152-20-40-04

Principal Investigator: Marilyn M. Lindstrom/SN2

Task Performed by: Johnson Space Center

SSS 9 **The Angrite Meteorites: New Insights**

Funded by: RTOP 152-12-40-24

Principal Investigator: J. H. Jones/SN2

Task Performed by: Johnson Space Center

SSS10 **Europium in Mare Basalts: Support for a Global Lunar Magma Ocean?**

Funded by: RTOP 152-12-40-21

Principal Investigator: Gordon McKay/SN2

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

SPACE TRANSPORTATION TECHNOLOGY (STT)

STT 1 **Real-Time Data System**
Funded by: Code M/906-21-01-01, Code R/590-12-21-01, Code S/488-60-01-01
Principal Investigator: Troy A. Heindel/DF24/483-2639
Task Performed by: Johnson Space Center
Unisys Corp., NAS9-18000
Mitre Corp., NAS9-18057
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STT 2 **Flight-to-Flight Overlay of Shuttle Mission Data**
Funded by: Code M/906-21-03-04
Principal Investigator: Linda A. Perrine/DF72/483-2885
Task Performed by: Johnson Space Center
Intergraph Corp., NAS9-18000

STT 3 **Voice Command System Flight Experiment**
Funded by: Code MD/928-50-03-01
Principal Investigator: George A. Salazar/EE22/483-0162
Task Performed by: Johnson Space Center

STT 4 **Intelligent Computer-Aided Training (ICAT)**
Funded by: Code MD/906-21-03
Code MT/488-60-03
Principal Investigator: Robert T. Savely/PT4/483-8105
Task Performed by: Johnson Space Center
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Computer Sciences Corp., NAS9-17885

STT 5 **Computer Aided Scheduling System: COMPASS**
Funded by: Code MD/906-21
Principal Investigator: Ervin Grice/PT4/483-8082
Task Performed by: McDonnell Douglas Space Systems Co., NAS9-17885

STT 6 **Expert Systems for Crew Procedures Execution**
Funded by: Code M/906-21-03-10
Principal Investigator: H. K. Hiers/ER2/483-2036
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

STT 7 **Fuzzy Logic for Adaptive Control and Operational Decision Making**
Funded by: Code MD/906-21-03
Principal Investigator: Robert N. Lea/PT4/483-8085
Task Performed by: LinCom Corporation, NAS9-17885

STT 8 **Advanced Software Development Workstation (ASDW)**
Funded by: Code MD/906-21-03-04
Code MT/488-80-01
Principal Investigator: Ernest M. Fridge III/PT4/483-8109
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Task Performed by: Inference Corp. NCC9-16, SE.25
Softech Inc. NCC9-16, SE.33
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STT 9 **C Language Integrated Production System (CLIPS)**
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Principal Investigator: Gary Riley/PT4/483-8073
Chris Culbert/PT4/483-8080
Task Performed by: Johnson Space Center
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STT 10 **Cooperating Expert Systems**
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Principal Investigator: Chris Culbert/PT4/483-8080
Task Performed by: McDonnell Douglas Space Systems Co., NAS9-17885

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Funded by: Code MT/488-80
Principal Investigator: Chris Culbert/PT4/483-8080
Task Performed by: Johnson Space Center
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Task Performed by: Johnson Space Center
LinCom Corporation, NAS9-17885

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Principal Investigator: Mike Goza/ER42/483-4695
Task Performed by: McDonnell Douglas, NAS9-17885

STT 14 **Autonomous Guidance**
Funded by: Code M/906-21-03-85
Principal Investigator: Gene McSwain/EG2/483-8295
Task Performed by: McDonnell Douglas Space Systems Co., NAS9-17885

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Principal Investigator: Karla Fulton/EP4/483-6019
Task Performed by: Johnson Space Center

STT 16 **Electromechanical Orbiter Fuel Cell Program**
Funded by: Code M/906-11-01-04
Principal Investigator: Nanette M. Faget/EP5/483-9045
Michael Le/EP5/483-9044
Task Performed by: Johnson Space Center International Fuel Cells, NAS9-18277

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Funded by: Code ME/551-15-15-06
Principal Investigator: Richard J. Schoenberg/EP4/483-6437
Task Performed by: Aerojet Propulsion Div., NAS9-17215

STT 18 **Shuttle Evolution Phase II Crew Escape Study**
Funded by: Code MD/560-30-GF-01
Principal Investigator: Kevin C. Templin/ET2
Steven R. Nagel/CB
Task Performed by: Rockwell International-Space Systems Division, NAS9-18400

STT 19 **Shuttle Evolution Crew Escape Module (CEM) Study**
Funded by: Code M/906-11-01-02
Principal Investigator: Kevin C. Templin/ET2
Task Performed by: Johnson Space Center Rockwell Space Systems Division, NAS9-14000
Lockheed Engineering & Sciences Co., NAS9-17900

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Principal Investigator: Jerry Craig/IA13/283-5311
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Kennedy Space Center

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Funded by: Code M/906-11-01-01
Principal Investigator: Andrew Petro/ET2/483-6622
Task Performed by: Johnson Space Center
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Funded by: Code M/906-30-04-40
Principal Investigator: J. L. Prather/EE6/483-1483
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

STT 23 **Visual Docking Aids**
Funded by: Code M/906-25-01-02
Principal Investigator: Richard D. Juday/EE6/483-1486
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

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Funded by: Code M/906-30-04-41
Principal Investigator: J.L. Prather/EE6/483-1483
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900
MacDonnell Douglass Systems Co.

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Funded by: Code MD/906-30-03-30
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Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

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Funded by: Code MD/906-30-03
Principal Investigator: Richard J. Schoenberg/EP4/483-6437
Task Performed by: Moog Space Products, NAS9-17872
Ball Aerospace , NAS9-18021

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Funded by: Code MD/906-30-03-04
Principal Investigator: Mark S. Falls/EP4/483-8627
Task Performed by: Johnson Space Center

SPACE SYSTEMS TECHNOLOGY (SST)

SST 1 **Rotating Bubble Membrane Radiator for Spacecraft Waste Heat**
Funded by: RTOP (Code 506-41-51-01)
Principal Investigator: John Thornborrow/EC2/483-9130
Task Performed by: Johnson Space Center
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SST 2 **High Heat Flux Thin Film Condenser for Spacecraft Thermal Management**
Funded by: SBIR (Code 324-02)
Principal Investigators: John Thornborrow/EC2/483-9130
Task Performed by: Johnson Space Center
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Principal Investigators: Patricia A. Petete/EC2/483-9119
Task Performed by: Johnson Space Center
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Principal Investigator: Mariann F. Brown/EC3/483-9238
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Funded by: OAET/Code 591-34
Principal Investigators: Marybeth A. Edeen/EC7/483-9122
Task Performed by: Johnson Space Center
Lockheed Engineering & Science Co., NAS9-17900

SST 6 **Electrochemical Water Recovery System for Treatment of Waste Waters**
Funded by: CR/SBIR Program Office/324-01-89-01-6A-EC2511
Principal Investigator: Charles E. Verostko/EC3/483-9228
Task Performed by: Johnson Space Center
Umpqua Research Co., NAS9-18336

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Funded by: CR/SBIR Program Office/324-01-89-01-6A-EC2511
Principal Investigator: Charles E. Verostko/EC3/483-9228
Task Performed by: Johnson Space Center
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Funded by: (Code RC/591-31-11-01)
Principal Investigator: Joseph J Kosmo/EC6/483-9235
Task Performed by: Johnson Space Center
Albany International Research Corp., NAS9-17635

SST 9 **Human-Computer Interaction Laboratory – Applied Research**
Funded by: OAET/506-47-11-34
Principal Investigator: Marianne Rudisill, Ph.D./SP34/483-3706
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 10 **Human-Computer Interaction Laboratory – Multitasking Research**
Funded by: OAET/506-49-31-02
Principal Investigator: Marianne Rudisill, Ph.D./SP34/483-3706
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 11 **Human-Computer Interaction Laboratory – Pathfinder Research**
Funded by: OAET/591-32-21-01
Principal Investigator: Marianne Rudisill, Ph.D./SP34/483-3706
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 12 **Concept Maintenance Workbench – Work Surface Evaluation**
Funded by: OSF/472-48
Principal Investigators: Frances Mount/SP34/483-3723
Jason Beierle/C95/333-6656
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Lockheed Engineering & Sciences Co., NAS9-17900

SST 13 **Hatch Viewport Size and Its Impact on Viewing on Space Station Freedom**
Funded by: OSF/1472-48
Principal Investigators: Frances Mount/SP34/483-3723
Boyd Morrison/C95/333-7464
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 14 **Derivation of Space Station Window Viewing Locations**
Funded by: OSF/1472-48
Principal Investigators: Frances Mount/SP34/483-3723
Boyd Morrison/C95/333-7464
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 15 **The Role of Perturbed Sensory Feedback in Space Remote Manipulation Tasks – Preliminary Guidelines**
Funded by: OAET/506-47
Principal Investigator: A. Jay Legendre/SP34/483-3697
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 16 **Space Station Hand Controller Commonality Tests**
Funded by: OSF/472-48
Principal Investigators: Dean G. Jensen, Ph.D./SP34/483-4798
Gregory C. Blackburn/EK54/483-1517
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 17 **Space Station Freedom Fluid Coupling Tasks – An Evaluation of Their Space Operational Compatibility**
Funded by: 486-81
Principal Investigator: A. Jay Legendre/SP34/483-3697
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 18 **Extravehicular Activity (EVA) Speech Recognition**
Funded by: OAET (Code R) 506-47
Principal Investigator: Barbara Woolford/SP34/483-3701
Jose Marmo/ECS/483-9233
Charles Sheperd/C95/333-6746
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 19 **Computer-Aided 3-Dimensional (CAT) Stowage**
Funded by: SBIR-Code CU
Principal Investigator: L.W. Lew/SP33/483-3741
Task Performed by: Johnson Space Center
Aptek, Inc., NAS9-18305

SST 20 **Space Station Prototype Laundry Filter**
Funded by: SBIR-Code CU
Principal Investigator: Phyllis Grounds/SP44/483-7479
Task Performed by: Johnson Space Center
Umpqua Research Company, NAS9-17996

SST 21 **Photonics for Autonomous Rendezvous, Docking, Navigation, Hazard Detection, and Avoidance**
Funded by: 591-21-31-01, 591-13-31-01
Principal Investigator: Richard D. Juday/EE6/483-1486
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 22 **LADAR Tracking of Orbital Debris**
Funded by: RC/584-01-31-01
Principal Investigator: K.F. Dekome/EE6/483-1453
Task Performed by: Johnson Space Center

SST 23 **Autonomous Lander Sensor Program**
Funded by: OAET/591-13
Principal Investigator: W. X.Culpepper/EE6/483-1479
Task Performed by: Johnson Space Center
C. S. Draper Laboratory, NAS9-18147

SST 24 **Tunable Laser Diode and Optical Phase-Locked Loop**
Funded by: CR/324-02-EA-11
Principal Investigator: K. F. Dekome/EE6/483-1453
Task Performed by: E-Teck Dynamics Inc., NAS9-17922

SST 25 **Integrated Optic Device for Laser Beam Scanning**
Funded by: CR/324-02-EA-07
Principal Investigator: K. F. Dekome/EE6/483-1453
Task Performed by: APA Optics, Inc., NAS9-17813

SST 26 **Hierarchical 3-Dimensional and Doppler-Imaging Laser Radar**
Funded by: RC/324-02-EA-12
Principal Investigator: J. L. Prather/EE6/483-1483
Task Performed by: Johnson Space Center
Autonomous Technologies Corporation, NAS9-18166

SST 27 **Laser Orientation Transceiver System**
Funded by: Code M/324-01-87-12
Principal Investigator: J. L. Prather/EE6/483-1483
Task Performed by: Applied Research Inc., NAS9-18164

SST 28 **Multiuser Multiaccess Infrared Communications**
Funded by: M/324-01-EA-10
Principal Investigator: J. L. Prather/EE6/483-1483
Task Performed by: Wilton Industries, NAS9-17988

SST 29 **Monolithic GaAS UHF IF Switch for Space Station Applications**
Funded by: SBIR
Principal Investigator: Phong Ngo/EE3/483-7990
Task Performed by: Microwave Monolithics, Inc., NAS9-18319

SST 30 **Power- and Bandwidth-Efficient Digital Communications**
Funded by: SBIR
Principal Investigator: William A. Geisel/EE3/483-0164
Task Performed by: SCS Telecom, Inc.

SST 31 **Ku-band Active Antenna Module for Space Station User Application**
Funded by: 324-02-EE-02
Principal Investigator: John Ngo/EE3/483-7494
Task Performed by: Shason Microwave Corp., NAS9-18358

SST 32 **Lifting Body Approach/Land Trajectory Analysis**
Funded by: Code MD and R
Principal Investigator: J. P. Ruppert/EG22/483-6515
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 33 **Pathfinder Autonomous Rendezvous and Docking**
Funded by: Code RC-591-21
Principal Investigator: Stephen Lamkin/EG4/483-8264
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 34 **Laser-Induced Fluorescence and Spectroscopic Arc Jet Diagnostics**
Funded by: Code M/551-15-01-04, Code R/591-42-21-00
Principal Investigator: Carl D. Scott, Ph.D./EG3/483-6643
Eric Yuen/ES3
Sivaram Arepalli, Ph.D./C95
Harvel Blackwell, Ph.D/C95
BSA Services
Stan Bouslog/C95
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 35 **Advanced Control Techniques of Large Flexible Spacecraft**
Funded by: OAET/Code RC-506-59-61
Principal Investigator: John W. Sunkel/EG3/483-8591
Task Performed by: Johnson Space Center
Texas A&M University, NAG-347
University of Houston, NAG-385
Arizona State University, NCC-9-16
Charles Stark Draper Laboratory, NAS9-18147

SST 36 **Benefits of Using Expert Systems to Perform Fault Detection, Isolation, and Recovery on Space Station Freedom**
Funded by: Code RC/506-49
Principal Investigator: Dennis Lawler/ER2/483-2037
Task Peformed by: Mitre Corp., NAS9-18057

SST 37 **Developing Intelligent Systems for Monitoring and Fault Management: CONFIG Intelligent Modeling and Analysis Tool Kit**
Funded by: 951-15
Principal Investigator: J. T. Malin, Ph.D./ER22/483-2046
Task Performed by: Johnson Space Center
Mitre Corp., NAS9-18057
Lockheed Engineering & Sciences Co., NAS9-17900

SST 38 **Making Intelligent System Team Players – Design Guidance**
Funded by: OAET/CST1/590-11-12
Principal Investigator: J. T. Malin, Ph.D./ER22/483-2037
Task Performed by: Johnson Space Center
Mitre Corp., NAS9-18057

SST 39 **Tool Kit for User-Intelligent System Interaction Design**
Funded by: OAET/506-71-51
Principal Investigator: J. T. Malin/ER22/483-2037
Task Performed by: Johnson Space Center
Mitre Corp., NAS9-18057

SST 40 **Space Station Freedom Exercise Countermeasures Intelligent System (ExerCISys)**
Funded by: RTOP/199-70-31-11
Principal Investigator: Laurie Webster/ER2/483-2034
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences, Co., 054-22-ASX

SST 41 **Shuttle Remote Manipulator System (SRMS) Advanced Force Torque Control**
Funded by: Code RC/ 590-11
Principal Investigator: Donald A. Barron/ER3/483-1529
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 42 **Failure-Tolerant Manipulator Joint and Controller Development**
Funded by: Code RC/590-11
Technical Monitor: John Chladek/ER4/483-1528
Principal Investigators: James Hwang/C95
Eugene Wu/C95
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 43 **Implementation of a Compact 6-Degree-of-Freedom Force Reflecting Hand Controller with Cueing Modes**
Funded by: 324-02
Principal Investigator: Duane Johnson/ER3/483-1519
Task Performed by: Johnson Space Center
Cybernet Systems Corp., NAS9-18351

SST 44 **Automated Robotic Assembly of the Space Station**
Funded by: Code RC/590-11
Principal Investigators: George Parma/ES6/483-8959
LeBarian Stokes/ER4/483-8965
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 45 **Autonomous Lander Project**
Funded by: 591-13-11, 591-13-31
Technical Monitor: K. Baker/ER2/483-3041
Task Performed by: Johnson Space Center
Charles Stark Draper Laboratory, NAS9-18147
Environmental Research Inst. of Michigan

SST 46 **Architectures for Semiautonomous Planning**
Funded by: Code C/324-02
Principal Investigator: Jon D. Erickson, Ph.D./ER/483-1508
Task Performed by: Johnson Space Center
Advanced Decision Systems, NAS9-18162

SST 47 **Long-Life Monopropellant Hydrazine Thruster Evaluation for Space Station Freedom Application**
Funded by: Space Station Program Office/472-28
Principal Investigator: Christopher G. Popp/EP4/483-9014
Task Performed by: Johnson Space Center
Hamilton Standard, NAS9-18376
Rocket Research Company, NAS9-18375
The Marquardt Company, NAS9-18374

SST 48 **Gaseous Oxygen/Hydrogen Engine**
Funded by: N/A
Principal Investigators: D. Krohn/EP4/483-9000
T. Lucht/EP4/483-9054
B. Studak/EP4/483-9029
Task Performed by: Johnson Space Center

SST 49 **On-Orbit Compressor Technology**
Funded by: Space Station: Non-Prime: 472-49
Principal Investigator: John P. Masetta/EP4/483-9007
Task Performed by: Southwest Research Institute, NAS9-18051

SST 50 **Electronically Variable Pressure Regulator**
Funded by: IR&D
Principal Investigator: Eric Hurlbert/EP4/483-9016
Task Performed by: Fairchild Controls

SST 51 **Space Station Waste Gas System Material Compatibility Study**
Funded by: N/A
Principal Investigator: Gerald B. Sanders/EP4/483-9066
Task Performed by: Johnson Space Center

SST 52 **Generic Fluid Transfer Model Computer Program**
Funded by: Space Station, 472-28-06
Principal Investigator: Richard J. Schoenberg/EP4/483-6437
Task Performed by: Rockwell STSD, NAS9-18048

SST 53 **Experimental Investigations of Spacecraft Glow**
Funded by: OAET/589-01-21
Principal Investigator: James T. Visentine/ES5/483-8923
Task Performed by: Johnson Space Center
Lockheed Palo Alto Research Laboratory, NAS9-13287

SST 54 **Space Environment Effects – Materials Technology**
Funded by: OAET/506-43-21
Principal Investigator: Steven L. Koontz, Ph.D./ES53/483-5906
Task Performed by: Johnson Space Center
Los Alamos National Laboratory, T5726P
Lockheed Engineering & Sciences Co., NAS9-17900

SST 55 **Large Space Robot – A Multisegment Approach**
Funded by: OAET/591-22
Principal Investigator: Reginald B.Berka/ES221/483-8808
Task Performed by: Johnson Space Center

SST 56 **Robotic Assembly of the Aerobrake Thermal Protection System (TPS)**
Funded by: OAET/593-22
Principal Investigators: Reginald B. Berka/ES22/483-8808
Gerard D. Valle/ES2/483-8835
Irene E. Verinder/ES22/483-8844
Task Performed by: Johnson Space Center

SST 57 **Aeroassist Flight Experiment (AFE)**
Funded by: OAET/592-01
Principal Investigator: Donald Curry, Ph.D./ES32/483-8865
Task Performed by: Johnson Space Center
Lockheed Engineering & Sciences Co., NAS9-17900

SST 58 **Intelligent Tutoring Systems Integrated with Simulators**
Funded by: SBIR (Code CR)
Technical Monitor: Robert T. Savely/PT4/483-8105
Task Performed by: Johnson Space Center
Global Information Systems, NAS9-18170

SST 59 **Adaptive Control of a Robot Arm Using an Artificial Neural Network with Stereo Vision Input**
Funded by: SBIR
Principal Investigator: Dr. Timothy F. Cleghorn/PT41/483-8090
Task Performed by: Johnson Space Center
Machine Vision International
University of Washington, NAS9-17814

SST 60 **A Machine Vision Algorithm for Autonomous Proximity Operations**
Funded by: SBIR
Principal Investigator: Dr. Timothy F. Cleghorn/PT41/483-8090
Task Performed by: Johnson Space Center
Machine Vision International
University of Washington, NAS9-17814

SST 61 **The COSTMODL Program and Ada COCOMO Calibration Database for Space Station Freedom**
Funded by: In-house
Principal Investigators: Bernie Roush/PT4/483-9092
Bill Reini/PT4/483-8099
Task Performed by: Johnson Space Center

SST 62 **Space Transportation Analysis and Intelligent Space Systems**
Funded by: In-house
Principal Investigators: Dan Greenwood
J. Villarreal/PT4/483-8076
Task Performed by: Johnson Space Center

SST 63 **The NETS – A Tool for the Development and Delivery of Neural Networks**
Funded by: In-house
Technical Monitor: Robert O. Shelton/PT4/483-5901
Task Performed by: Johnson Space Center

SST 64 **Parametric Avalanche**
Funded by: SBIR Phase II, NAS9-18355
Principal Investigators: Robert O. Shelton/PT4/483-5901
R. Dawes/Martingale
Task Performed by: Johnson Space Center
Martingale, NAS9-18355

SST 65 **A Space-Time Neural Network (STNN)**
Funded by: In-house
Principal Investigators: James A. Villarreal/PT4/483-8076
Robert O. Shelton/PT4/483-5901
Task Performed by: Johnson Space Center

SST 66 **Fuzzy-CLIPS – The C Language Integrated Production System with Fuzzy Language Capability**
Funded by: SBIR Phase I, NAS9-18335
Technical Monitor: Robert N. Lea/PT4/483-8085
Principal Investigator: M. Togai
Task Performed by: Johnson Space Center
Togai Infralogic, Inc., FTS 525-8085

SST 67 **A Phoneme-Based Speech Recognition System for High-Stress, Moderate-Noise Environments**
Funded by: NASA SBIR Phase II
Principal Investigators: J. Villarreal/PT4/483-8076
David Trawick
Task Performed by: Johnson Space Center
Speech Systems Inc., NAS9-17994

SST 68 **Passive Knowledge Acquisition System**
Funded by: SBIR (Code CR)
Technical Monitors: Robert T. Savely/PT4/483-8105
Gary Riley/PT4/483-8073
Principal Investigator: Vince Kovarik
Task Performed by: Johnson Space Center
Software Productivity Solutions, Inc., NAS9-18334

SST 69 **The Automated Online Library – AutoLib**
Funded by: In-house
Principal Investigators: Ernest M. Fridge III/PT4/483-8109
Mark Rorvig/PT4/483-4808
Task Performed by: Johnson Space Center
Barrios Inc., NAS9-18002

SST 70 **ART/Ada Prototype**
Funded by: In-house
Principal Investigator: Chris Culbert/PT4/483-8080
Task Performed by: Johnson Space Center

SST 71 **The Intelligent Physics Tutor**
Funded by: Code CU/The State of Texas Higher Education
Principal Investigators: Robert T. Savely/PT4/483-8105
Dr. R. Bowen Loftin
Task Performed by: Johnson Space Center
University of Houston, NAG9-405
Computer Sciences Corp., NAS9-17885

SST 72

A Literacy Tutor
Funded by: NASA TU and Department of Justice
Principal Investigator: James A. Villarreal/PT4/483-8076
Task Performed by: Johnson Space Center

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16. Abstract

The Johnson Space Center (JSC) Research and Technology (R&T) Report presents the accomplishments of the Center during Fiscal Year 1990. The report serves to communicate within and outside the Agency significant R&T JSC activities and identifies principal researchers and technologists as contacts for further information. This report is organized into four sections: Life Sciences, Solar System Sciences, Space Transportation, and Space Systems Technology. Each of these sections is comprised of a summary followed by detailed descriptions of significant tasks. The task descriptions are written, not with technical jargon, but in a style that aids comprehension with the use of data and illustrations. Special attention is paid to define acronyms and special technical terms. The report can therefore be used by both technical management communities. A listing of project descriptions, along with funding code and principal investigators, is provided in the Index of this report.

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