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**OAST SPACE RESEARCH & TECHNOLOGY
APPLICATIONS**

-Technology Transfer Successes

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Office of Aeronautics and Space Technology

OAST

February 1992

INTRODUCTION

OAST

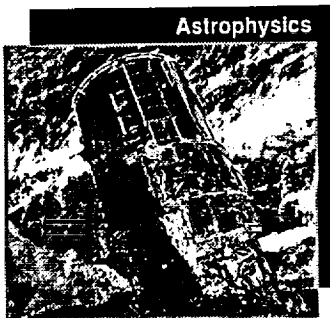
The ultimate measure of success in the Space R&T program is the incorporation of a technology into an operational mission. These charts describe technology products which OAST has helped support that (1) have been used in a space mission, (2) have been incorporated into the baseline design of a flight system in the development phase, or (3) have been picked up by a commercial or other non-NASA user. We hope that these examples will demonstrate the value of investment in technology. Pictured on each of the following charts are illustrations of the technology product, the mission or user which has incorporated the technology, and where appropriate, results from the mission itself.

Future U.S. competitiveness in the world economy will increasingly depend upon the speed and effectiveness with which new technologies and new, high quality products can be brought to maturity and the marketplace. A strong investment in advanced space research and technology, including focused programs directed at rapidly developed breadboards and demonstrations can make a significant contribution to national competitiveness across a wide range of critical technologies. Many of these technologies will also be applicable to private U.S. civil space users, will indirectly support future DOD space mission needs, and will have numerous spinoff uses in the private sector. In this way, all our future national space endeavors will be enhanced by an investment in NASA Space R&T.

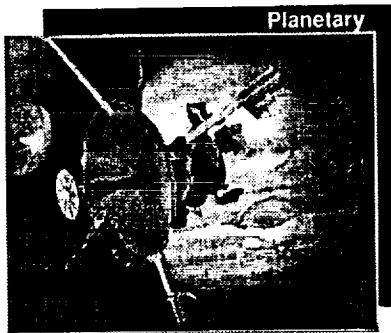
The evolution of a technology from proof-of-concept, through validation in successively more realistic environments, and eventually to development can be a complex and time-consuming process. In many of the examples selected, the technology efforts were completed a number of years ago and the time required to complete the development phase is evident. An objective of the NASA technology program is to facilitate this process and minimize the time required.

We believe that involving the technology "users" as early as possible in this process is critical to achieving this goal. OAST has developed a strategic planning process which is focused on involving the user community at the critical phases of technology development. Concurrent participation by technologists and mission developers in the selection and maturation of technologies should lead to a level of understanding and a sense of ownership that will improve all aspects of technology development and transition.

TECHNOLOGY CONTRIBUTIONS TO SCIENCE SPACECRAFT

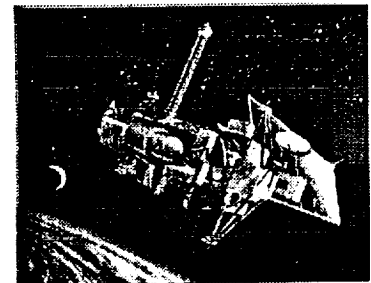


- Hubble - VLSI Data Processing
- Astro - Startracker
- Hubble - Battery Technology
- Hubble - Image Restoration



- Galileo (& Hubble) - CCD Array
- Voyager - Spacecraft Health Monitoring
- Magellan - Radar Ground Processor

- UARS - 205 GHz Limb Sounder Technology
- Shuttle Imaging Radar - SAR Technologies
- TOPEX - Millimeter Accuracy Laser Ranging



Earth Science

Office of Aeronautics and Space Technology

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SYNTHETIC APERTURE RADAR PROCESSOR

OAST

The Magellan spacecraft launched onboard the Space Shuttle in April of 1989 uses a radar-based high resolution imaging technique to carry out its mapping of the Venus surface. Many real aperture radar echos are computer processed to create a large synthetic aperture image through a Synthetic Aperture Radar (SAR) technique. Multiple swaths are combined to produce image mosaics. The creation of synthetic aperture images must account for the relative geometry and movement between the target and spacecraft radar and for multiple surface images of different amplitudes and phases. For Magellan an advanced SAR technique is responsible for the highly detailed, nearly seamless photographs of the surface of Venus - but it is computationally intensive.

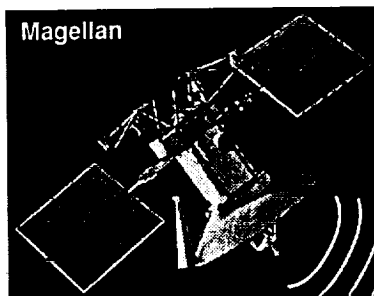
The Advanced Digital SAR Processor (ADSP) technology developed by OAST has been adapted and used for the ground processing of the radar data returned by Magellan. This processor integrates algorithm elements into a programmable pipeline architecture with great speed.

This ADSP provides a peak compute rate of 6 gigaflops, more than that of a Cray 2 computer. The significance is that this compute rate permits processing four times faster than real-time acquisition rates. It is the Input/Output computer system that limits the actual processing rate to approximately real time.

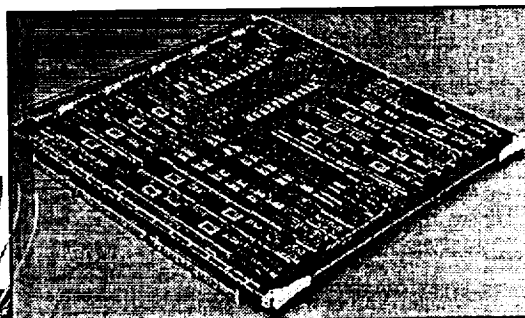
Work was initiated in 1980 to provide an engineering technology demonstration of (ADSP) to support late 1980's missions. In 1983 it was decided that the ADSP technology development would be focused on Magellan requirements. In 1985 the Magellan Project decided to modify and use the engineering model of ADSP as the prime mission operations processor for SAR data.

OAST completed work on this technology with the delivery of the ADSP engineering model to the Magellan Project in 1986. Magellan demonstrated the success of the ADSP technology which now provides a flexible architecture that can serve many missions. For more information please contact: Paul Smith, NASA Headquarters, Code RC, Washington, D.C. 20546. Phone: (202) 453-2753.

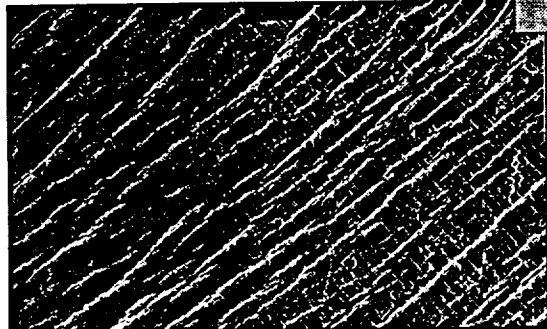
— SYNTHETIC APERTURE RADAR PROCESSOR —



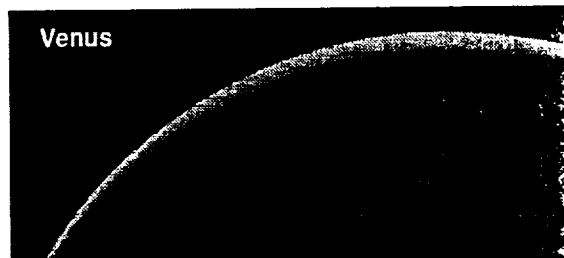
Magellan



SAR Processor



Venus Surface Characteristics



Venus

BATTERY TECHNOLOGY (HUBBLE SPACE TELESCOPE)

OAST

The nickel-hydrogen battery design has resulted in the most advanced, long-life, rechargeable battery technology developed over the last 50 years. The dramatic advances in capabilities of this technology are opening a whole range of possibilities for both NASA and the commercial space sector. During periods of darkness, rechargeable batteries supply the power needs of the spacecraft. Recently, breakthroughs have been achieved in the low-Earth-orbit (LEO) cycle life of individual pressure vessel nickel-hydrogen battery cells. The cycle life was improved by more than a factor of 10 over state-of-the-art cells. Ground-test cells containing 26 percent potassium hydroxide (KOH) electrolyte were cycled for 40,000 stressful accelerated LEO cycles at a deep depth of discharge (80%). Cells containing 31% KOH had achieved only 3500 cycles.

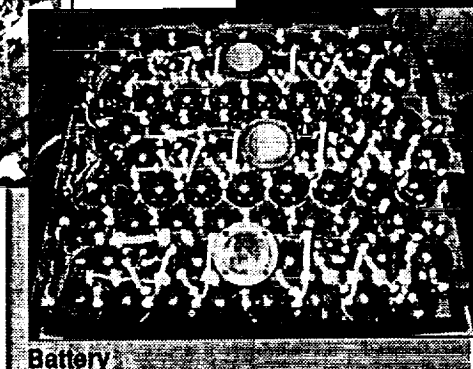
The significance of this breakthrough is that long term LEO missions can now rely on a greater than 5 year life span for advanced nickel hydrogen batteries. This advance will result in a significant reduction in life cycle cost. In addition, nickel-hydrogen batteries provide the capability of operating at a deep depth of discharge which could enable reductions in the mass devoted to batteries and increases in payload capability.

The dramatic benefits of this technology led directly to the Office of Space Science Application's (OSSA) decision to utilize nickel hydrogen batteries for the Hubble Space Telescope. Technologists at the Lewis Research Center participated in the review task team to assess battery options for Hubble and provided technology support to OSSA on the use of nickel hydrogen batteries for the actual mission. The batteries are performing very well in their first nonexperimental use in LEO. In addition, the Earth Observing System has chosen to use OAST's nickel-hydrogen battery technology. Technologists at Lewis are working closely with OSSA to meet this mission's power needs. This program is based on a close working relationship with not only NASA mission offices, but also the military, and industry. The Air Force is using Lewis's advanced nickel hydrogen cell technology for military flights. The aerospace industry, meanwhile, has adopted a scaled-up version of the Lewis design which is currently undergoing cell testing at Loral Corporation.

As we look to the future, nickel-hydrogen is fast replacing nickel-cadmium as the standard satellite storage system. It is projected that nickel-hydrogen will be the major rechargeable battery system for future aerospace applications. The ongoing technology development efforts at Lewis are aimed at increasing the life, power density, and reliability and at reducing the mass and lowering the cost of the nickel-hydrogen battery system.

Sponsored under the auspices of OAST, work was initiated on nickel-hydrogen battery technology at Lewis in the early 1980's. For additional information, contact: Gary Bennett, NASA Headquarters, Code RP, Washington, D.C., 20546. Phone: (202) 453-2856.

BATTERY TECHNOLOGY



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ASTROS STAR TRACKER (CCD SENSOR TECHNOLOGY)

OAST

Star sensors are used to determine a spacecraft's attitude relative to a star, or a group of stars, and to point science instruments at selected targets. Star trackers are a special class of star sensors that image an area of the sky to provide precision star position data relative to a fixed line of sight. Technology provided by OAST was critical to the development of the Star Tracker used on the recent Astro-1 mission on STS-35 in December 1990 and was also a crucial element in Astro-1's successful outcome.

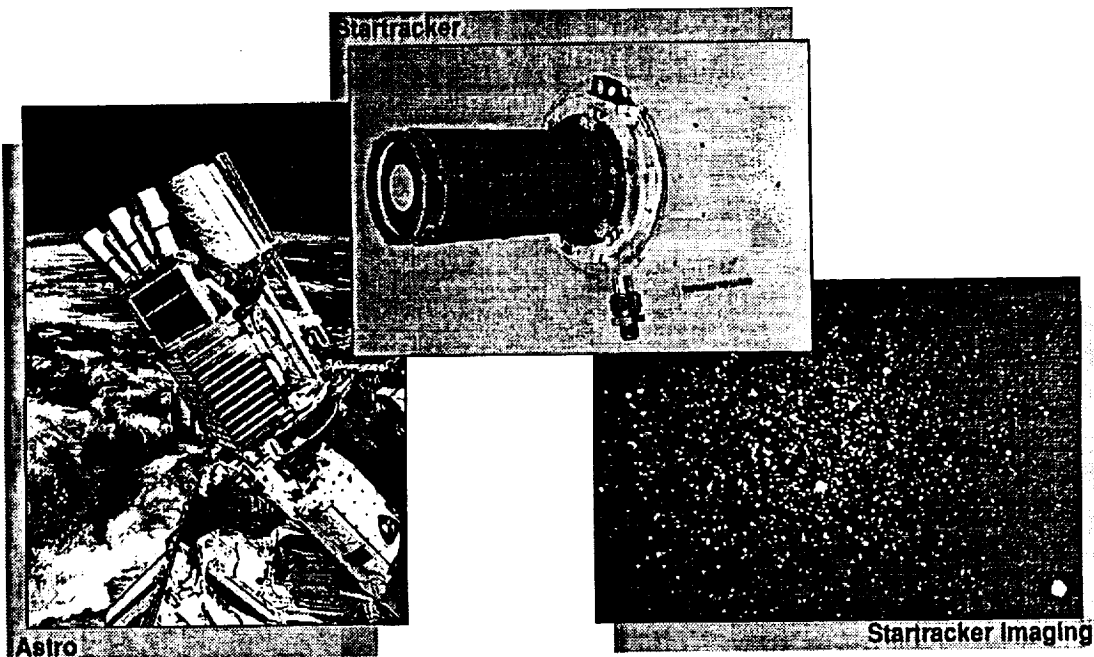
As initially conceived, the Astro Star Tracker (AST) was designed to assist Astro's Image Motion Compensation System in stabilizing the pointing of the Ultraviolet Imaging Telescope and the Wisconsin Ultra Photo-Polarimeter Experiment. The AST acquired the three brightest stars in its field of view and then provided star position information to the IMCS for in-flight correction of gyro drift parameters. Based on Charge Coupled Device (CCD) sensor technology, the AST tracks objects over a 10,000:1 brightness range and allows very accurate and stable position determination at any point within their field of view.

The AST took on a vital role early in the mission when problems with the prime star trackers prevented Astro's automated Instrument Pointing System from locking onto the operational guide stars. AST then became the primary means of target acquisition. The Shuttle crew was able to compare star positions acquired with the AST with on-board small field of view star maps and manually point the instruments to the science target with a joystick. Problems for the mission were compounded when the Shuttle's second onboard Digital Display Unit failed. AST star positions could then no longer be displayed to the crew. Ground support crews were able to resolve this glitch by identifying each star field acquired by the AST in real-time and issuing instructions to the astronauts who then manually repointed the telescopes. The MSFC mission manager stated that this capability "saved the mission."

Astro Star Tracker technology and expertise will provide the base for future space science missions such as the CRAF/CASSINI target and star tracker function, and the the Space Infrared Telescope Facility (SIRTF) fine guidance sensor.

OAST sponsored the initial critical phases of CCD based star tracker research at JPL beginning in 1973. Several years of research effort achieved technology transfer to flight hardware development in the 1980's. For more information, please contact: Fred Hadaegh, Guidance and Control Section 343, Mail Stop 198-326, Jet Propulsion Laboratory, Pasadena, CA 91109. Phone (818) 354-8777.

STARTRACKER



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IMAGE RESTORATION FOR THE HUBBLE SPACE TELESCOPE

OAST

Imagine seeing the universe as if it were just outside your window. Clouds and lightning form as a storm brews on Jupiter. An icy moon revolves nearby. In the distance, you see billions of stars. The Hubble Space Telescope (HST) offers us a valuable window to the universe. Researchers at NASA are working hard to restore images being transmitted back to Earth by the HST. Technologists in OAST have actually demonstrated a ground computer processing technique that restores the Hubble image to the original design resolution. This technology compensates for the well-known flaw in the HST mirror.

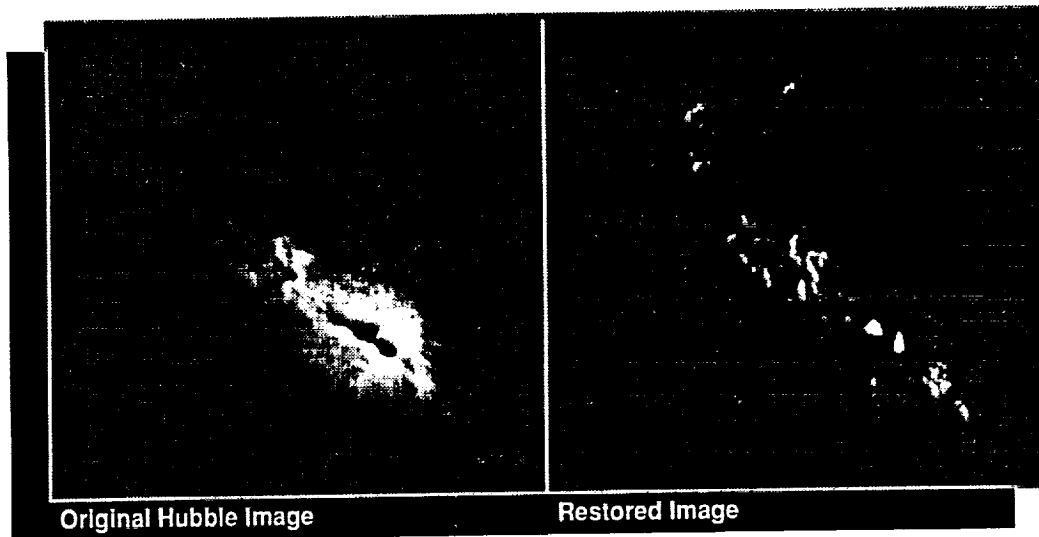
Because it is considered to be somewhat of a Rosetta Stone for many astrophysical processes, the R Aquarii star system (pictured above on the left) was one of the first objects observed by the HST. Due to Hubble's spherical aberration, most of the light from the star and its surroundings has spread out into a blurred, oval nebula. The brightest areas are saturated, producing a dark, central valley of useless data. However, by means of an algorithm known as Maximum Entropy, OAST researchers have been able to enhance the structure of the image to its original design resolution. In the restored version in the upper right panel, R Aquarii - comprising a cool red giant, a hot companion and its accretion disk - lies within the rightmost peak.

The benefits of this technology are considerable. Image restorations are now possible in minutes as opposed to hours or days of computer time. Ultimately as the technology undergoes further development, NASA will be able to enhance images to the point that they exceed the HST's design resolution. In addition, researchers will be able to apply the technology to any mission that transmits imaging data back to Earth. The technical challenge is to build up a library of the necessary tools. An important legacy of the HST may well be its advancement of restoration techniques in addition to its legacy of advancements in astronomical sciences.

OAST sponsored this technology during 1991 under the OAST Research and Technology Base at the Goddard Space Flight Center. For more information contact: Dr. Jan M. Hollis, Goddard Space Flight Center, Code 930, Bldg. 28, Greenbelt, MD. 20771. Phone - (301) 286-7591.

HUBBLE SPACE TELESCOPE IMAGE RESTORATION TECHNOLOGY

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UNIVERSITY SPACE ENGINEERING RESEARCH CENTER VLSI CHIP DESIGN

OAST

Students at the University of Idaho Space Engineering Research Center for VLSI design are designing electronic systems which have thousands of transistors miniaturized onto a computer chip smaller than a postal stamp. This technique, known as Very Large Scale Integration (VLSI), is making it possible for NASA to enhance communications and improve information storage capabilities for a number of its current and future missions.

Idaho researchers designed a computer chip set for the Hubble Space Telescope that is currently being installed in the Earth-based ground data system. These chips will decode the information sent back to Earth by the telescope and will automatically check and correct errors in the data transmission. Natural events such as interference from ionized particles in space can cause errors in transmissions from the telescope to the ground. The computer chip is designed to detect and correct these errors.

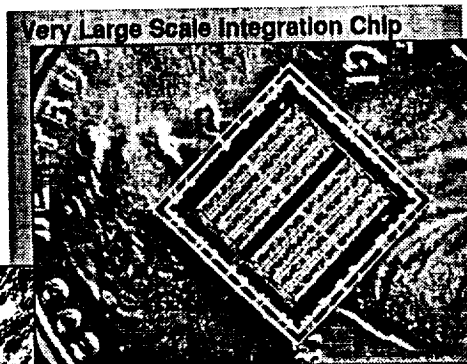
The University of Idaho chips are faster, computationally more powerful, and consolidated onto fewer chips than the chips currently used by Hubble, thus reducing the complexity and parts count for the system. Having the capability to process over 80 million bits of information per second, this chip makes sure that scientists on Earth can receive valuable information they need to conduct their research. In addition, this computer chip represents the first use in a NASA mission of a product from the University Space Engineering Research Center program. This program is creating the next generation of space engineers by directly involving students in engineering research tied to NASA mission needs. The University's ongoing program is investigating future use of this chip in space, as a part of a Hubble flight data system refurbishment.

Students are working on other projects as well, including techniques to compress large amounts of data being transmitted from space. As an example, it is estimated that the Earth Observing System will transmit back to Earth on the order of one large library's worth of information every day. Such large volumes could saturate the communication channels of future space satellites. Students are meeting this challenge by developing codes which compress or condense the data and images collected by spacecraft sensors. Upon completion, this project will help meet NASA's need for high speed information processing and transmission.

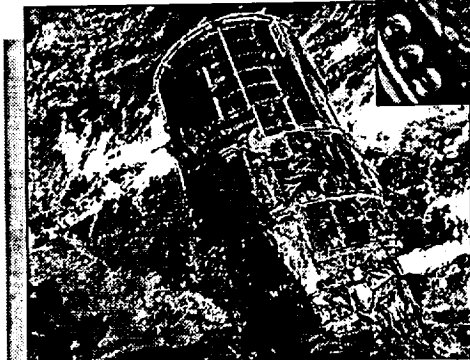
The Center for VLSI design was established in 1988 as one of nine universities in the Space Engineering Research Center program. For more information, please contact: Gordon Johnston, NASA Headquarters, Code RS, Washington, D.C. 20546. (202) 453-2755.

HUBBLE SPACE TELESCOPE GROUND DATA PROCESSING

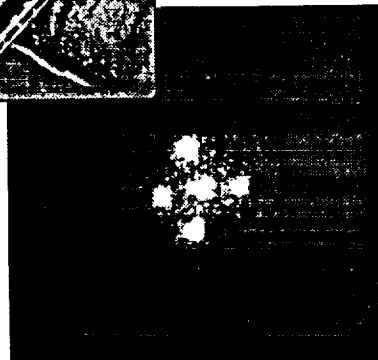
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Very Large Scale Integration Chip



Hubble Space Telescope



Einstein's Cross

THE SPACECRAFT HEALTH AUTOMATED REASONING PROTOTYPE (SHARP)

OAST

Voyager's near encounter of Neptune in August 1989 gave NASA the opportunity to introduce automation and artificial intelligence technologies to the process of monitoring spacecraft operations. The new expert system, called the Spacecraft Health Automated Reasoning Prototype (SHARP) provides telecommunications personnel with an environment that allows them to have a more complete understanding of how the telecommunications link is functioning between a spacecraft and the Deep Space Network Tracking Stations.

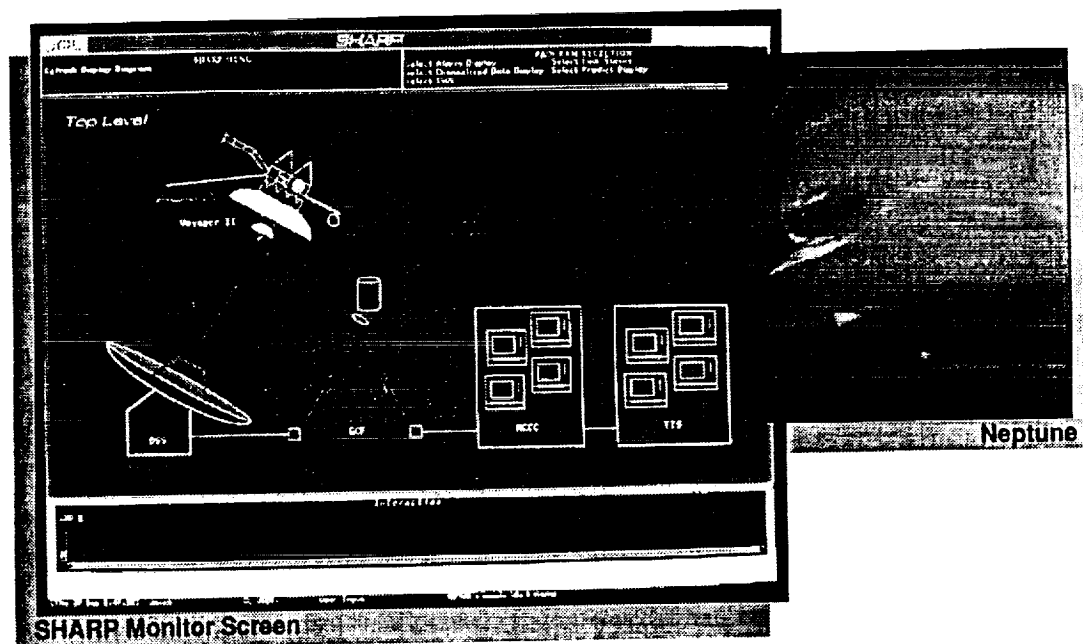
The SHARP system combines conventional computer science methodologies with artificial intelligence techniques to produce an effective method for detecting and analyzing potential spacecraft and ground system problems. The system performs real-time analysis of spacecraft and ground system engineering data, and is also capable of examining data in historical context. The data is centralized into one workstation which serves as a single access point for all data. If the real-time data fails to correlate to the expected behavior, SHARP informs the operator responsible for the condition being monitored that an alarm condition exists. It also lists the potential causes for this anomaly and suggests what actions to take in response.

The benefits of this technology were underscored prior to Voyager's Neptune encounter. SHARP helped find the cause of a science data error which appeared in the telemetry from the spacecraft. After SHARP detected the problem, its graphic displays were used by telecommunications personnel to identify the problem and characterize its magnitude. In a matter of hours, SHARP was able to assist operators in solving an anomalous condition which could have easily escalated to a more serious problem during the encounter itself, and could have taken human operators days or weeks to isolate without SHARP.

SHARP has validated the use of AI-based systems for autonomous monitoring and diagnosis of unmanned spacecraft systems. NASA plans in the future to expand SHARP functionality to application in the Deep Space Network, Network Operations Control Center at JPL, with an operational system planned for later in 1991. In addition, SHARP capabilities have been expanded to the Magellan mission currently mapping the planet Venus.

The SHARP technology was developed over a year and a half period between 1987 and 1989 under the auspices of the OAST Civil Space Technology Initiative. For additional information, contact: Melvin Montemerlo, NASA Headquarters, Code RC, Washington, D.C. 20546. Phone - 202-453-2744.

SPACECRAFT HEALTH MONITORING



CHARGE-COUPLED DEVICE (CCD) IMAGING ARRAYS FOR GALILEO AND HUBBLE

OAST

In recent years, a revolution in both home and studio video recording has been made possible by the development of the silicon charge-coupled device (CCD), a solid-state chip that turns light into the electric signals that are recorded onto video tape. CCD video cameras are light-weight, require little power (so the batteries are light as well), are inexpensive, and are more sensitive to light than the large, bulky, and power-hungry vacuum tubes previously used for television cameras. Earlier space missions, such as the Viking Orbiter mission to Mars and the Voyager spacecraft which flew by Jupiter, Saturn, Uranus, and Neptune, used versions of the old television vacuum tubes called vidicons. Since 1974, the Office of Aeronautics and Space Technology (OAST) has been investing in the new CCD technology, making it available for flight on missions such as the Galileo mission to Jupiter, the Hubble Space Telescope, the Yohkoh Soft X-ray Telescope, and the Shuttle Electronic Still Camera.

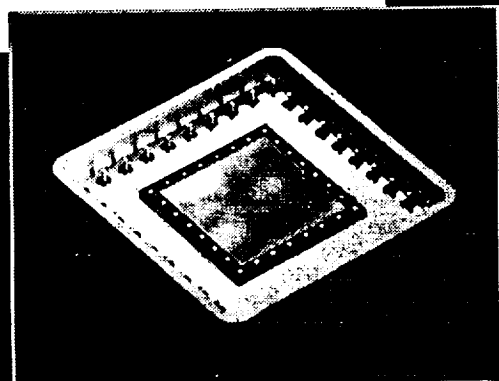
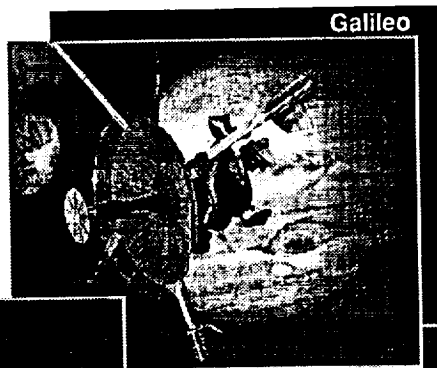
Charge coupled device technology was first demonstrated in 1969 at the Bell Laboratory. In 1974, under the sponsorship of OAST, the Jet Propulsion Laboratory began a program to increase the size of CCD arrays (then less than 100-by-100 picture elements, or pixels) and to lower their readout noise levels. Shortly thereafter, the Office of Space Science and Applications (OSSA) added funding, and by 1978 CCD arrays of 500-by-500 pixels had been produced, achieving noise levels of 10 electrons rms (root mean square). After this, OSSA continued the development of the 800-by-800 arrays that are currently being used by Galileo (1989 launch) and the Hubble Space Telescope (1990 launch).

In 1982, OAST substantially increased its funding and, combined with OSSA advanced development funds, initiated the development of the second generation of CCD detectors. This work proceeded successfully and led directly to three current CCD instruments, one of which is already operating in space. These are the Yohkoh Soft X-ray Telescope (successfully operating in orbit), the Cassini Imaging Science Subsystem, and the Advanced X-ray Astrophysics Facility (AXAF) CCD Imaging Spectrometer. These second generation CCD's surpass their predecessors in almost every characteristic. They have larger formats (1024-by-1024 verses 800-by-800), smaller pixels (12 μm verses 15 μm), lower noise (2 electrons vs 10 electrons rms), lower cost, and higher reliability, than the first generation CCD's. Such an improved CCD recently flew on the Space Shuttle as part of the Johnson Space Center's Electronic Still Camera.

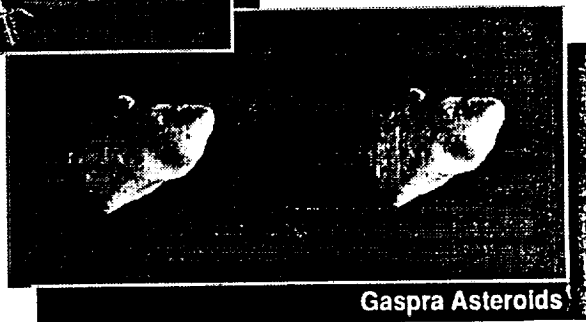
OAST is not currently funding further developments of CCD technology. As the accomplishments of the current CCD missions continue to accrue, interest in the scientific community is growing for the development of a possible third generation of very large format CCD arrays. This is an area of possible future investment by NASA and OAST.

For more information contact: Gordon Johnston, NASA Headquarters, Code RS, Washington, DC 20546. Phone - (202) 453-2733.

CHARGE-COUPLED DEVICE (CCD) IMAGING ARRAYS



CCD Imaging Arrays



Office of Aeronautics and Space Technology

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ANTENNA, MIXER, AND ELECTRONICS TECHNOLOGIES FOR THE UPPER ATMOSPHERE RESEARCH SATELLITE (UARS)

OAST

All light, whether X-rays, visible light, or radio waves, is part of the electromagnetic spectrum. The difference is in the wavelength (or the frequency) of the light. Our society knows how to observe visible light and radio waves, but in between is the millimeter and sub-millimeter region, where the wavelengths are too short for radio and too long for visible light techniques. Many molecules, including ozone and many of the ozone destroying chemicals, emit light at unique frequencies in this region. Using these emissions, we can measure the amount of these chemicals in the earth's protective ozone layer.

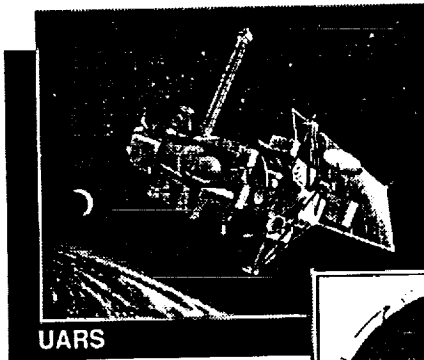
Since 1974, The NASA Office of Aeronautics and Space Technology (OAST) and Office of Space Science and Applications (OSSA) have been involved in the joint development of the Microwave Limb Sounder (MLS) instrument. OAST developed critical technology elements including antenna, mixer and electronic components while OSSA was responsible for the instrument development. A balloon version of the instrument was successfully flown on several occasions, demonstrating the technology.

In 1991, the MLS instrument was launched on the Upper Atmosphere Research Satellite (UARS), and it is currently observing atmospheric thermal emissions from chlorine monoxide (ClO), ozone (O₃), water vapor (H₂O), sulfur dioxide (SO₂), and molecular oxygen (O₂), at frequencies of 63, 183 and 205 GHz. Measurements are performed continuously day and night giving global maps of the vertical distribution of these molecules. The vertical resolution is approximately 3 km. One percent accuracy in the measurement of ozone has been demonstrated.

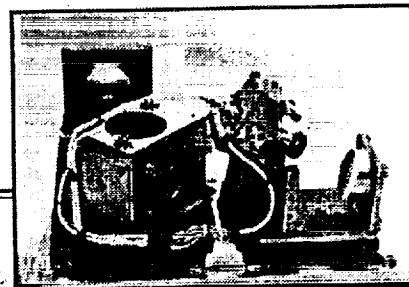
The UARS MLS uses high spectral resolution heterodyne radiometers, in which the emissions from the atmosphere of the earth are mixed with known, reference frequencies (generated by local oscillators), and the differences (which are at much lower frequencies, in the range that can be handled by conventional electronics) are measured and analyzed. The specific, OAST supported technologies involved in the UARS MLS include the local oscillator injector, the dual mode feed-horn, quasi-optical filter technology, and gallium arsenide (GaAs) Schottky diode development.

OAST continues to play a role in technology development for the follow-on MLS for the Earth Observing System (EOS), pushing the upper limit of the frequency that can be measured from space beyond the 205 GHz of the UARS MLS to the 600 GHz of the EOS MLS. For more information contact: Gordon Johnston, NASA Headquarters, Code RS, Washington, DC 20546. Phone - (202) 453-2733.

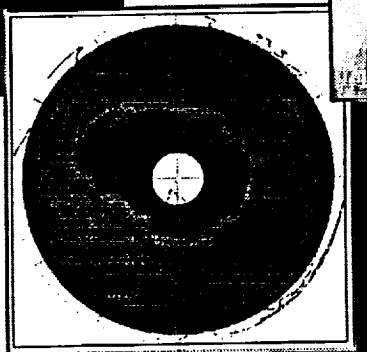
SUBMILLIMETER SENSING TECHNOLOGIES



UARS



MLS 205 GHz
Heterodyne Receiver



Antarctic Ozone Hole

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Office of Aeronautics and Space Technology

LASER RANGING TECHNOLOGIES

OAST

Satellite laser ranging (SLR) has been used for almost two decades in the study of a variety of geophysical phenomena including global tectonic plate motion, regional crustal deformation near plate boundaries, the Earth's gravity field, and the orientation of its polar axis and its rate of spin. The subcentimeter precision of this technique is now attracting the attention of a new community of scientists, notably those interested in high resolution ocean, ice and land topography. Over the next several years, the international SLR network will provide an essential link to two new oceanographic satellites, ERS-1 and TOPEX/Poseidon, which range to sea and ice surfaces using microwave altimeters.

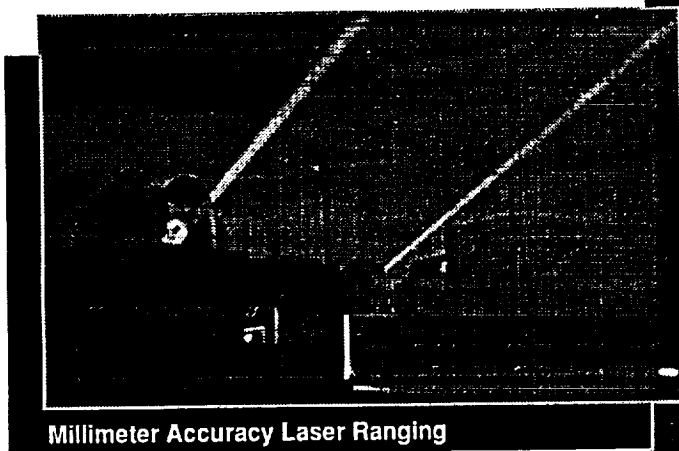
In 1964, NASA was the first organization to successfully demonstrate laser ranging to satellites and has continued to support their development to the present. OAST has developed lasers, rapid detectors, and timing circuits which have become a key part of the worldwide network managed by the Goddard Space Flight Center. In satellite laser ranging, ground based stations transmit short intense laser pulses to a retroreflector equipped satellite, such as LAGEOS. The round trip time of flight of the laser pulse is precisely measured and corrected for atmospheric delay to obtain a geometric range. Ranging to these retroreflectors with a global network of laser stations allows NASA to determine both the precise orbit of a satellite and the station positions. By monitoring these stations over time, researchers can deduce the motion of the Earth-based observing sites due to plate tectonics, or other processes such as subsidence. This system is being used in precise orbit determination support of the ERS-1 and TOPEX/Poseidon missions to measure the topography of the Earth's oceans and ice sheets.

As we look to the future, OAST is developing advanced electro-optics and laser technologies for spaceborne laser ranging and altimetry earth science applications. This will invert the traditional SLR system with the ranging hardware being placed onboard a satellite and passive targets placed on the ground. This technology is a candidate to fly on the Earth Observing System B series platforms and will help measure geodynamic, ice sheet, cloud, and geological processes and features.

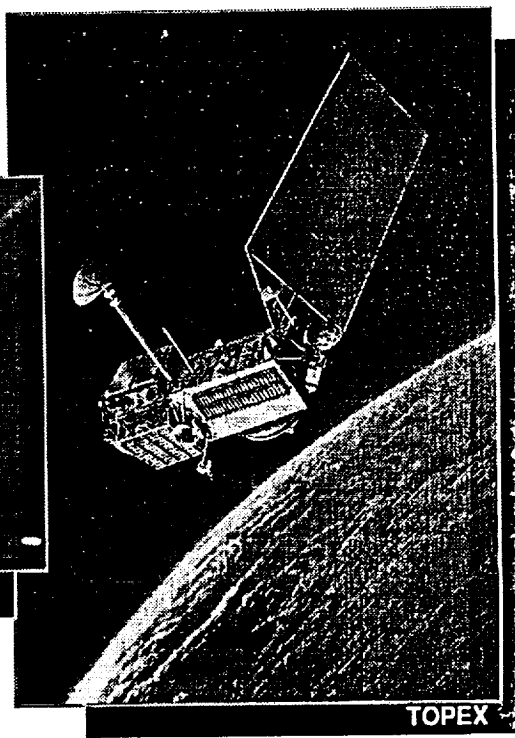
For more information, contact Marty Sokoloski, NASA Headquarters, Code RS, Washington, D.C. 20546. Phone- (202) 453-2273.

LASER RANGING TECHNOLOGY

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Millimeter Accuracy Laser Ranging



TOPEX

Office of Aeronautics and Space Technology

92-8028

TRAVELLING WAVE TUBE AMPLIFIERS FOR DEEP SPACE COMMUNICATIONS

OAST

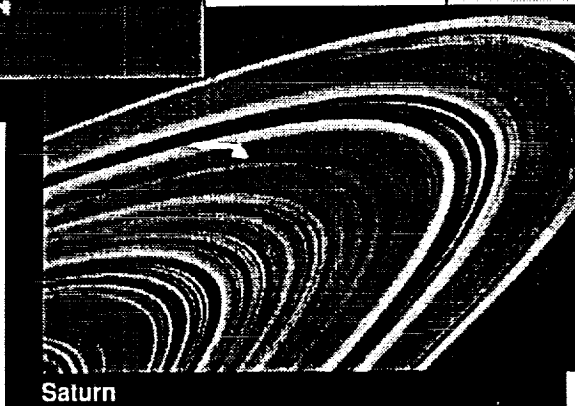
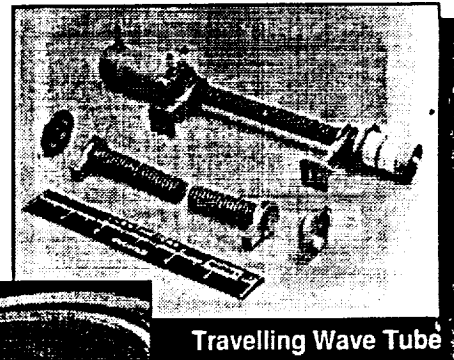
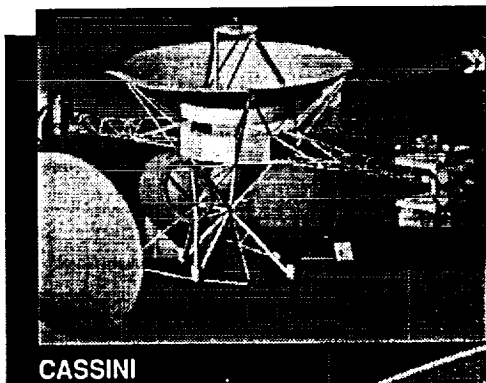
In the near future, NASA will launch a spacecraft to venture to the outer solar system and study the rich diversity of the Saturnian system. Known as Cassini, this journey will survey Saturn's rings and satellites and the surface of and atmosphere of its principal moon, Titan. These volatile-rich objects preserve unique records of different key phases in the formation and evolution of the solar system. Indeed, we think that every large object in the universe was originally formed by gas and dust coming together eventually giving rise to planets and stars and whole galaxies. By studying Saturn's rings, we will be able to see this process in operation.

OAST is developing technologies for a high-efficiency low-power travelling-wave tube amplifier (TWTA) to transmit all of Cassini's data back to earth. This technology has been baselined to fly on the Cassini flight. The required radio frequency power output of the TWTA is 9.6 watts, while the input dc power from the spacecraft is limited to about 30 watts. To achieve this capability, more than doubling the efficiency of Ka-Band TWTA's now available at this power level, several novel technologies are incorporated into the tube. One contribution, a slow wave circuit, has made it possible to sharply increase the output power and efficiency of the communications system. Other technologies have made it possible to recover energy being used for data transmissions so that it can be reused for future communication of mission data. These advances will enable Cassini to send greater volumes of information back to earth with low distortion and less energy than is currently possible. Mission planners will thus be able to acquire greater science return from Cassini.

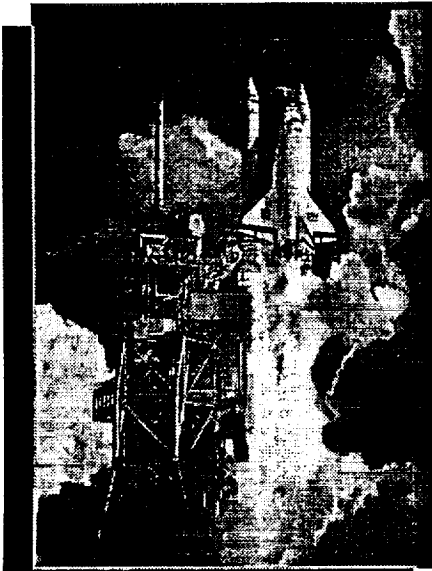
The potential commercial applications of this technology include intersatellite communication links and other low power uses. Most of the technology advances to be incorporated into the TWTA can also be scaled for higher-power uses including uplinks to satellites. Significant increases in efficiency with attendant reduced energy usage can be expected with these applications. As currently planned, the OAST program will conclude with the delivery of four fully-functional Engineering Model TWT's along with one breadboard model electronic power conditioner that will be integrated and tested with one of the TWT's.

Initiated in early 1990, this technology is being developed under the auspices of the OAST Research and Technology Base program at the Lewis Research Center. Over the past twenty years, Lewis has pioneered advances in TWT technologies that have become the industry standard for civil and military spacecraft communications. For additional information, contact: Arthur Curren, Lewis Research Center, Cleveland, Ohio. Phone - (216) 433-3519.

DEEP SPACE COMMUNICATIONS TECHNOLOGY



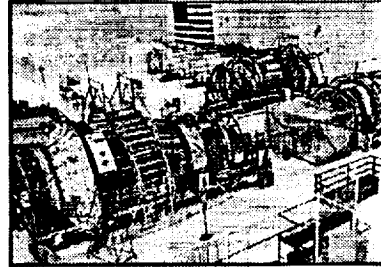
TECHNOLOGY CONTRIBUTIONS TO TRANSPORTATION



Space Shuttle

- Structural Analysis for Solid Rocket Motor (SRM) Redesign
- Vacuum Plasma Spray Coatings & Chambers
- Health Monitoring (Test Facilities)
- Thermal Protection System
- Bearing Cooling Analysis
- Real Time Data System
- Orbiter Experiments
- Damping Seals
- Modified Tires

Expendable Launch Vehicles



- Advanced Primary Battery

Office of Aeronautics and Space Technology

92-8023

ORIGINAL PAGE
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ADVANCED PRIMARY BATTERY FOR TRANSPORTATION SYSTEMS

OAST

Lithium-thionyl chloride primary batteries are of interest to both NASA and the military because of their enhanced energy storage capability and long active shelf life. NASA is planning a number of unmanned low-power planetary space missions for the late 1990's and early 2000's to send probes into comets, asteroids, and outer planets. Based on these interests, OAST has sponsored a research and technology program at the Jet Propulsion Laboratory (JPL) to meet the needs of these missions.

In 1987, the JPL Battery Systems Group demonstrated the capability of a high specific energy (> 300 Watt hours per kilogram), high discharge rate lithium-thionyl chloride battery. The technology development effort had been geared towards developing a high specific energy, safe, primary cell for NASA mission which could be discharged within two hours. Following this demonstration, the Air Force Space Division became interested in the efforts at JPL based on an Air Force requirement for a battery system with a reduced mass that could provide extended periods of power. The Air Force then contracted with JPL to develop 250 ampere-hours, 300 watt hours per kilogram, prototype lithium - thionyl chloride cells and batteries for the Centaur Launch Vehicle.

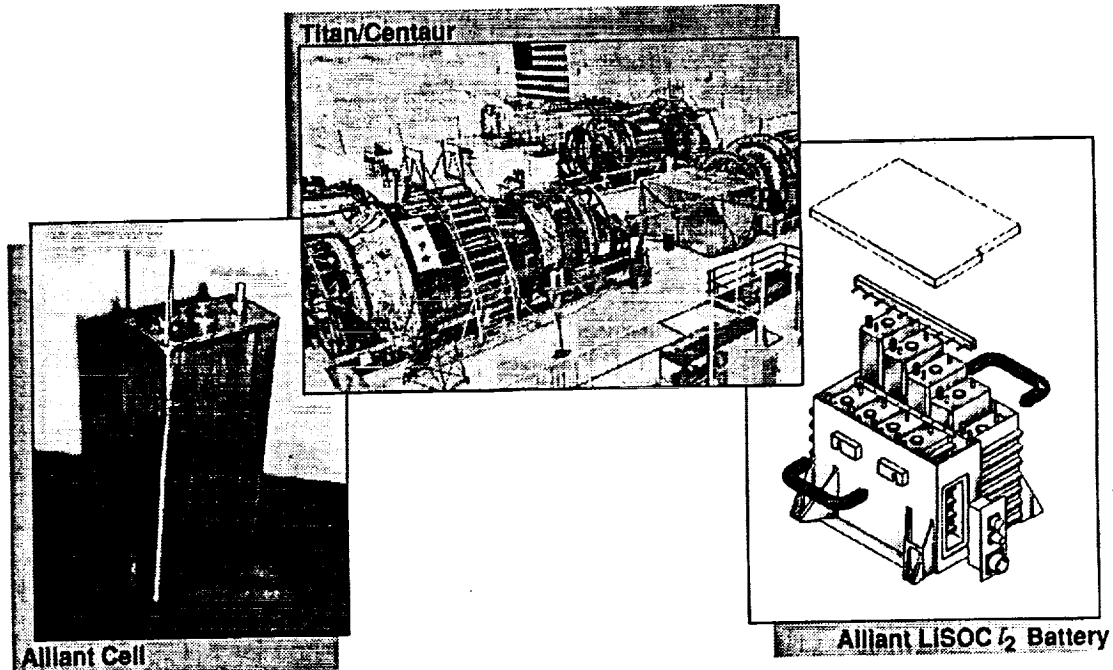
This effort involves the transfer of the OAST funded technology developments at JPL to two contractors (Alliant Techsystems and Yardney Technical Products) to meet the Air Force's requirements. The Centaur Phase 1 effort was to develop a 250 ampere-hour cell that is capable of meeting launch vehicle performance, environmental, and safety requirements. This has now been completed. The phase 2 effort to develop batteries has involved assembling and environmental testing of mock-up batteries and is currently under way. JPL plans to deliver a Manufacturing Control Document to the Air Force in the Fall of 1991 to procure lithium-thionyl chloride batteries.

JPL's demonstration of this technology verifies the capability of this electrochemical energy storage device to exceed that of all other existing primary cells by a factor of 3 to 5. In addition, the lithium-thionyl chloride battery will result in a 50% weight savings over the current Centaur power silver-zinc system. Success can be ascribed to three factors: having a fundamental understanding of the process and design considerations, cooperation with manufacturers with experience in this technology, and a critical need on the part of the Air Force. In terms of future considerations, the three fold increase in energy density of this device offers a unique opportunity to significantly reduce mass and cost for any application where a primary battery is needed. Such examples include tethered spacecraft and an Assured Crew Return Vehicle for Space Station.

For additional information, please contact, Gary Bennett, NASA Headquarters, Code RP, Washington, D.C., 20546. Phone: (202) 453-2856.

BATTERY TECHNOLOGY

ORIGINAL PAGE
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DAMPING SEALS FOR THE SPACE SHUTTLE MAIN ENGINE (SSME)

OAST

Turbopumps for rocket engines are very high power rotating machines that move large quantities of liquid propellants in short periods of time. They are subjected to loads and forces that can quickly trigger severe and sometimes catastrophic rotor dynamic instabilities. The Space Shuttle Main Engine (SSME) liquid oxygen and liquid hydrogen turbopumps represent the highest pressure and highest power rocket engine turbomachines ever built in this country. It became apparent during the development of the SSME that the liquid oxygen pump had potential rotor dynamic instabilities (termed subsynchronous whirl) under certain operating conditions.

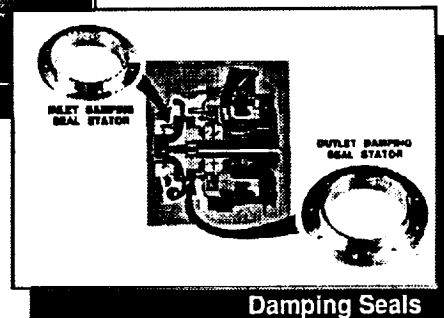
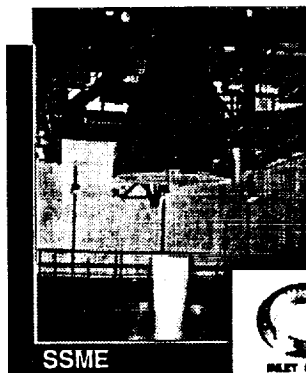
Generic research on approaches to improving the damping characteristics and rotordynamic response of turbopump rotor support structures has been part of the OAST ETO Propulsion Technology Program for many years. Damping seals for high speed turbomachinery were identified as one of the most promising approaches towards alleviating rotor instability problems. Their technology development and demonstration thus became a major focus of the propulsion technology program. The major advantage of damping seals is that they can be designed to not only significantly reduce seal leakage compared to standard seal designs, but also to act like fluid film bearings in that fluid trapped between the damping seal and the rotating shaft provides rotor support similar to that provided by rolling element mechanical bearings. The demonstrated effectiveness of this concept in rig testing offered evidence that it could provide increased damping in the SSME liquid oxygen pump and thus help alleviate the instability problem by increasing the subsynchronous whirl margin.

The SSME liquid oxygen pump is different from most rocket engine pumps in that there are actually two pumps mounted on one shaft. The main liquid oxygen flow enters and exits the primary pump radially at the center of the shaft, while a small, but very high pressure centrifugal pump that delivers a fraction of the total oxygen flow to the turbine drive gas generators (preburners) is mounted on one end of the shaft. The turbine that rotates the shaft and drives the pumps is mounted on the other end of the shaft. Two pairs of ball bearings support the shaft and complete the overall pump assembly. With so many rotating parts mounted on the shaft, the difficulty of balancing the overall assembly becomes more pronounced.

It was determined by analysis and subsequent testing that if the standard labyrinth seals used in the small high pressure pump were replaced with damping seals, a significant increase in the subsynchronous whirl margin would be realized. Damping seal designs based on the technology development results were incorporated in the small preburner pump and indeed, significant improvements in the subsynchronous whirl margin were achieved, thus significantly enhancing engine reliability and safety.

Damping seal technology is being continued with the objective of achieving even better damping characteristics and lower leakage than were demonstrated in earlier designs. Improved designs will be available for the next generation and all future engines. The earlier damping seal technology was developed over a four year period, from 1983 through 1986, as part of the OAST Earth-to-Orbit Propulsion Technology Program. The work is continuing under the same program which is now a key element of the OAST Civil Space Initiative (CSTI). For additional information, contact William J. D. Escher, NASA Headquarters, Code RP, Washington, D.C. 20546. Phone: 202-453-2858.

DAMPING SEALS TECHNOLOGY



Office of Aeronautics and Space Technology

VACUUM PLASMA SPRAY COATING - SPACE SHUTTLE MAIN ENGINE FUEL VALVE HOUSING

OAST

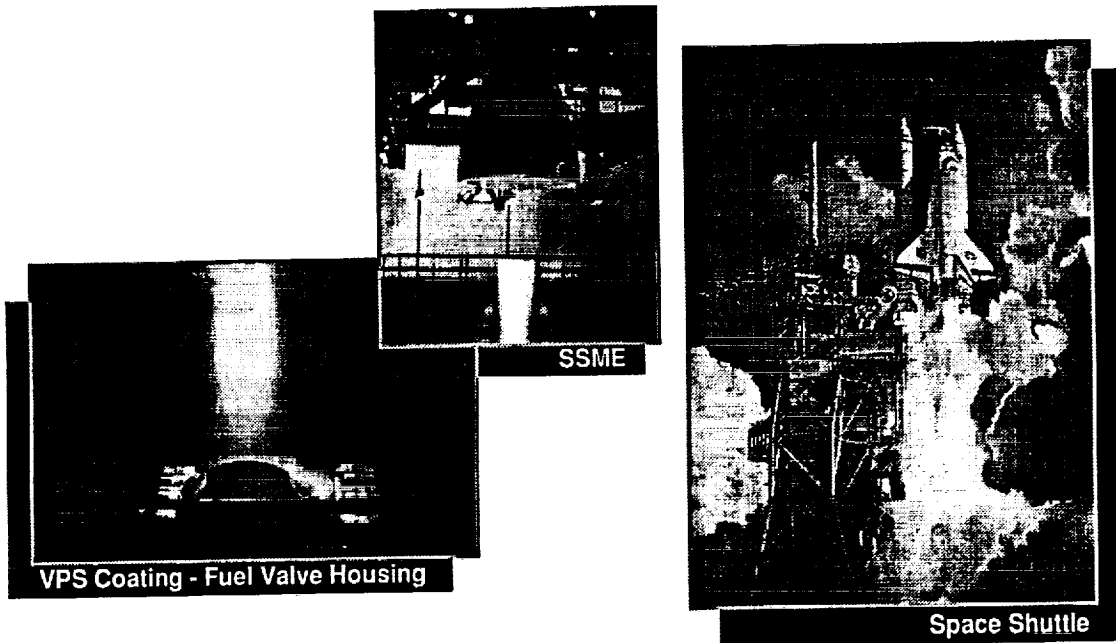
Developing processes for successfully applying metallic or non-metallic coatings to liquid rocket engine components has long been a focus of the OAST rocket engine materials research program. One of the primary drivers for perfecting such processes has been the need for and benefits of protecting and extending the life of metal engine parts subjected to very high combustion temperatures and heat transfer rates. Earlier attempts at developing thermal barrier coatings utilizing air plasma spray (APS) techniques have been generally unsuccessful due to poor bonding properties attributed to high oxide content. Thermal barrier coatings applied to Space Shuttle Main Engine (SSME) turbine blades in this manner consistently flaked off due to inadequate bonding.

The development of vacuum plasma spray (VPS) coating techniques has essentially solved this problem by producing a tough coating in a single application. A key aspect of this advance was eliminating most oxides in the coating. Excellent bond properties have now been achieved. For example turbine blades coated in this manner with ceramic materials have undergone severe thermal shock testing with essentially no coating removal. The success of this process has greatly expanded our horizons in searching for potential applications. Valve bodies are currently being fabricated for the SSME with the VPS process and offer the promise of significantly reducing fabrication time and cost, as well as greatly improving producibility.

The future of this coating process is limitless. For example, if used to fabricate combustor liners for future rocket engines, NASA could realize considerable savings due to lower production costs and ease of reproducibility. In addition, higher reliability and ultimately increased flight safety is envisioned because of higher quality products and very few welds. The ability to apply effective thermal barrier coatings to turbine blades operating in very high temperature, turbulent environments offers the possibility of greatly extending blade life and/or improving engine performance by allowing higher turbine inlet temperatures without compromising engine reliability or life. A number of commercial applications could also take advantage of this technique, such as in the fabrication of oxide-free, structurally sound crucibles and test tube-like containers for chemical process applications.

This technology was developed over a ten year period starting in the early 1980's as part of the OAST Earth-to-Orbit Propulsion Technology Program, which is now a key element of the OAST Civil Space Initiative (CSI). For additional information, contact William J. D. Escher, NASA Headquarters, Code RP, Washington, D.C. 20546. Phone: 202-453-2858.

VACUUM PLASMA SPRAY COATINGS & CHAMBERS TECHNOLOGY



Office of Aeronautics and Space Technology

92-807

MODIFIED SPACE SHUTTLE MAIN LANDING GEAR TIRE

OAST

The high landing speeds of the Space Shuttle coupled with the highly textured runway surface at the Kennedy Space Center (KSC) result in excessive Shuttle main-gear tire wear. Because the runway surface is textured to avoid tire hydroplaning during wet landing operations, grinding the runway smooth is an impractical way to reduce tire wear. Researchers at NASA's Langley Research Center Aircraft Landing Dynamics Facility (ALDF) took the alternative approach of modifying the tire to improve tread life and increase safety during Shuttle landing operations.

The Space Shuttle's landing speed is 200 knots, much more than commercial aircraft. The tire instantly experiences wear at touchdown. However, steering adjustments during roll-out to counter the effects of a crosswind and maintain alignment with the runway centerline cause the most wear. Testing showed that the maximum allowable wear limit for Space Shuttle tires is the tread plus six cords. This wear limit sets the landing crosswind limit. Maintaining the Shuttle on the runway in a 15 knot crosswind requires the pilot to continually apply steering pressure, exposing the main-gear to approximately 2.5 million foot-pounds of side energy due to the steering friction force between the tire and the textured runway. Spin-up during landing on the textured runway destroys about two-thirds of the tread depth.

The current and modified tires differ only in the tread design. The current tire tread is 0.2 inches of 100 percent natural rubber (0.1 inches of groove and 0.1 inches of undertread). The modified tire's undertread was doubled and the tread was changed to a composition of 65 percent natural rubber and 35 percent synthetic rubber. Under identical landing conditions, changing the composition reduces the amount of tread destroyed due to spin-up to less than 40% of the current tire loss. This allows the tread to absorb more energy during the critical roll-out.

The current Shuttle tire crosswind limit at KSC is 15 knots, less than the design goal of 20 knots, because the associated side energy is sufficient to destroy six cords. With the new tread, six cords of the modified tire are destroyed only after it has dissipated more than 8.5 million foot-pounds of side energy--an improvement in tire life of more than 300 percent. The modified tire easily handles a 20-knot crosswind, since the main-gear is exposed to a maximum of 4 million foot-pounds of side energy.

As a result of the marked improvement in treadlife, the Shuttle Project Office is accelerating the certification tests for the modified tire for installation on the orbiter for STS-45 which is currently scheduled for mid-1992. Tire development began in 1986. This collaborative effort, led by the Aircraft Landing Dynamics Facility, included the Michelin Aircraft Tire Company, NASA Johnson Space Center, and the USAF Wright Laboratory, and was performed under the auspices of the OAST Material and Structures Division with additional funding from the Office of Space Flight. For additional information, contact: Terrence J. Hertz, NASA Headquarters, Code RS, Washington, D. C. 20546. Phone: 202-453-2865.

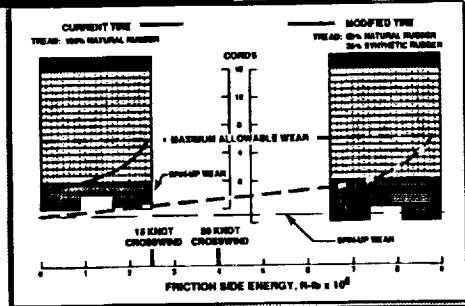
SPACE SHUTTLE LANDING GEAR TECHNOLOGY



Modified Main Landing Gear Tire



Space Shuttle Discovery



Main Gear Tire Wear

ORBITER EXPERIMENTS AEROTHERMODYNAMIC DESIGN TOOL VALIDATION

OAST

The Orbiter Experiments (OEX) Program has enabled use of the Shuttle Orbiter as an entry flight research vehicle. OEX experiment hardware/instrumentation are unique in that they are installed integrally with the Orbiter structure, rather than simply "riding" in the Orbiter payload bay as a mission cargo. Integrated in this fashion, the experiments do not interfere with the normal operational missions of the Shuttle. A primary focus of the OEX Program has been the collection of benchmark entry aerothermodynamic flight data to be used for validation of design tools which will be used for the design of the next generation of space transportation vehicles.

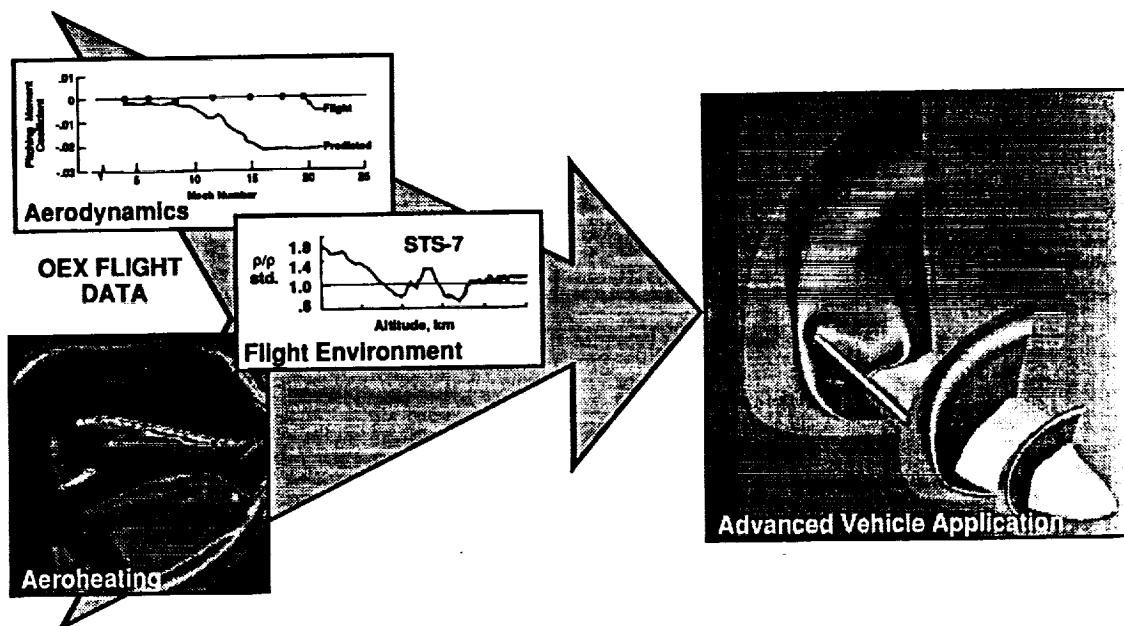
The OEX Program experiment complement comprises multiple instruments, each of which obtains data for ongoing research. This experiment complement includes instruments which: provide in situ measurements of the freestream flight environment and vehicle attitude throughout atmospheric entry; measure vehicle dynamic motions (from orbital altitude to landing) to determine aerodynamic characteristics; and measure aerodynamic surface temperatures to determine aerodynamic heating rates experienced by the vehicle during entry.

Ground-based experimental facilities cannot provide fully accurate simulations of the aerothermodynamic flight environment of an entry vehicle. Consequently, efficient aerothermodynamic design of advanced space transportation vehicles demands validation of state-of-the-art computational fluid dynamic techniques which will be applied in that design process. The data derived from the OEX complement of experiments represent benchmark hypersonic flight data not available, heretofore, for a lifting entry vehicle. These data are being used in a continual process of validation of state-of-the-art methods for predicting the aerothermodynamic characteristics of advanced space transportation vehicles.

Elements of OEX instrumentation first flew aboard the Orbiter Columbia on STS-1. Major OEX aerothermodynamic experiments were flown over a four flight period during 1989-91. The final flight scheduled to carry OEX experiment hardware will occur in 1992.

For further information, please contact: David Throckmorton, Langley Research Center, Aerothermodynamics Branch, Hampton, Virginia, 23665. Phone:(804) 864-4406

ORBITER EXPERIMENTS AEROTHERMODYNAMIC DESIGN TOOL VALIDATION



REAL TIME DATA SYSTEM (RTDS)



By introducing state-of the art techniques in expert systems, software engineering, human/computer interfaces, and distributed systems, NASA is improving the quality of flight decision making and the cost effectiveness of Space Shuttle Mission Control Operations. As manned spacecraft missions and flight operations increase in frequency and complexity, greater demands are being placed on flight controllers to perform more problem solving tasks. The goal of the RTDS is to relegate the repetitive, monotonous monitoring tasks in mission control to automated systems and free the flight controller to concentrate on the more challenging aspects of space flight such as schedule modifications and trouble shooting.

Under the RTDS program, a number of real-time expert systems have been introduced into Mission Control Center (MCC) consoles at the Johnson Space Center. The principal mission benefits from the RTDS applications are improved data monitoring and more thorough analysis of fault data in a shorter period of time. By supplying this capability, RTDS will provide much needed savings in manpower.

RTDS has resulted in dramatic and new capabilities. For example, by acquiring real-time telemetry, RTDS enables an animated view of the position of the Space Shuttle's Remote Manipulator System (RMS). Flight controllers who monitor the RMS traditionally had to determine the position of the robot arm by observing digital readouts of the angles of each of the arms joints. A combination of off line tools and mental gymnastics allowed operators to determine the arm's position. This new capability not only lowers the flight controller's workload, but also allows the controller to visually monitor for potential collisions of the Shuttle and payloads. During retrieval of the Long Duration Exposure Facility (LDEF) on STS-32 in January 1990, this system was used by the MCC to monitor RMS activity during a video loss of signal.

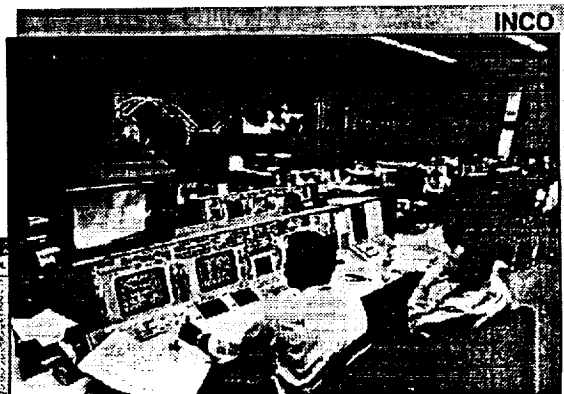
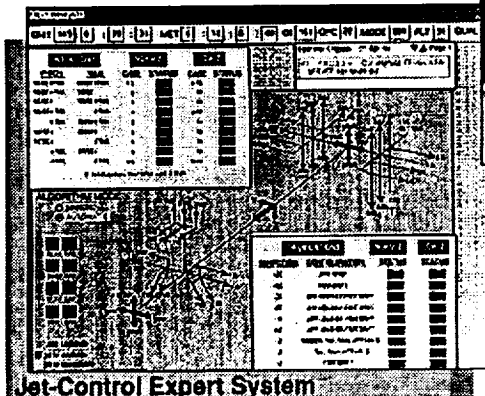
RTDS also provides a Reaction Control Expert System that monitors the performance of the 38 attitude control jets on the shuttle via real time telemetry and determines the valid attitude control modes based on the jet availability. This monitor diagnosed the loss of 3 thrusters on STS-31 in April, 1990 and concluded that there was no loss of control capability. The future plan for RTDS is to upgrade most flight controller consoles at the MCC to give them a RTDS capability and to add a capability for coordinating between expert systems.

RTDS has been developed over the last 4 years beginning in 1987 under the auspices of the OAST Civil Space Technology Initiative. For additional information, contact: Melvin Montemerlo, NASA Headquarters, Code RC, Washington, D.C. 20546. Phone - 202-453-2744.

REAL TIME DATA SYSTEM

APPLICATION

- INCO Systems Monitor
- Main Engines
- Tire Pressure Monitor
- Jet-Control Expert System
- OMS/TVC Monitor



- Wind Monitoring System
- RMS Position Monitor Display
- RMS Temperature Monitor
- DATACOM Expert System
- Fuel Cell Expert System

THERMAL PROTECTION SYSTEM FOR THE SPACE SHUTTLE

OAST

In the 1970's our space flight scientists and engineers undertook the challenge of building a reusable launch system that would give the country routine access to space. The 1981 debut of the National Space Transportation System, better known as the Space Shuttle, symbolized the largest and most complex technological project ever undertaken by our country during peacetime. The Shuttle carries satellites, experiments, and flight crews into space and has engaged in dramatic rescues and repairs of disabled satellites, such as the Solar Maximum Satellite rescue in April, 1984. As we look to the coming century, the Shuttle will play the key role in building and maintaining a permanent Space Station in-orbit.

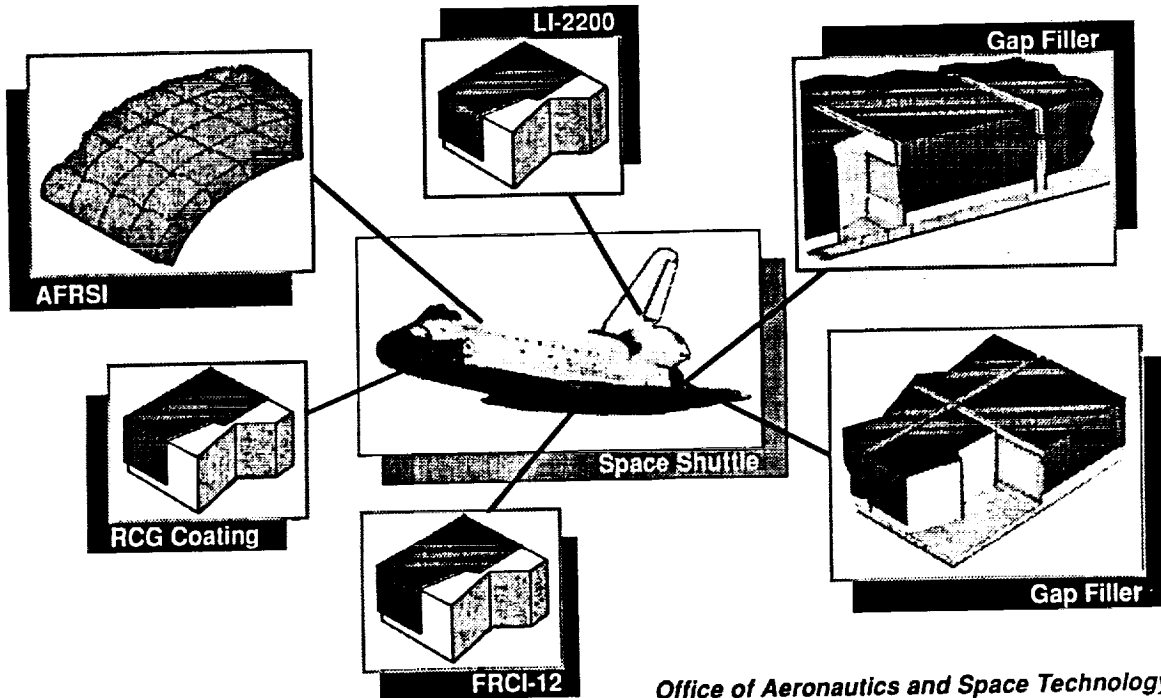
Thermal tile insulation and blankets (also known as the thermal protection system) cover the underbelly, bottom of the wings, and other heat-bearing surfaces of the Shuttle orbiter and protect it during its fiery reentry into the Earth's atmosphere. Some 24,000 individual tiles- no two alike- must be installed on the orbiter's surfaces. OAST invented a black borosilicate coating called Reaction Cured Glass which covers two-thirds of the orbiter surface. This glass coating provides a thermally stable high emittance surface for the silica tiles and has made it possible to manufacture tiles to the demanding tolerances required.

Through the Ames Research Center, OAST has played a major role in advancing the state of the art in tile technology for the Shuttle. In response to a critical tile strength problem encountered by Columbia, OAST developed a stronger insulation material that replaced 10% of the baseline tile system on the orbiter. OAST also developed a new more durable class of tile materials called Fibrous Refractory Composite Insulation (FRCI-12) that has led to weight savings of more than 1,000 pounds. In addition, OAST working with a contractor designed a blanket insulation material for the Shuttle's top surface called Advanced Flexible Reusable Surface Insulation which is cheaper, lighter and more easily maintained than the material it replaced. These advances have yielded tiles that are as light as balsa wood, and dissipate the heat so quickly that a white hot tile can be taken from an oven and held in bare hands without injury.

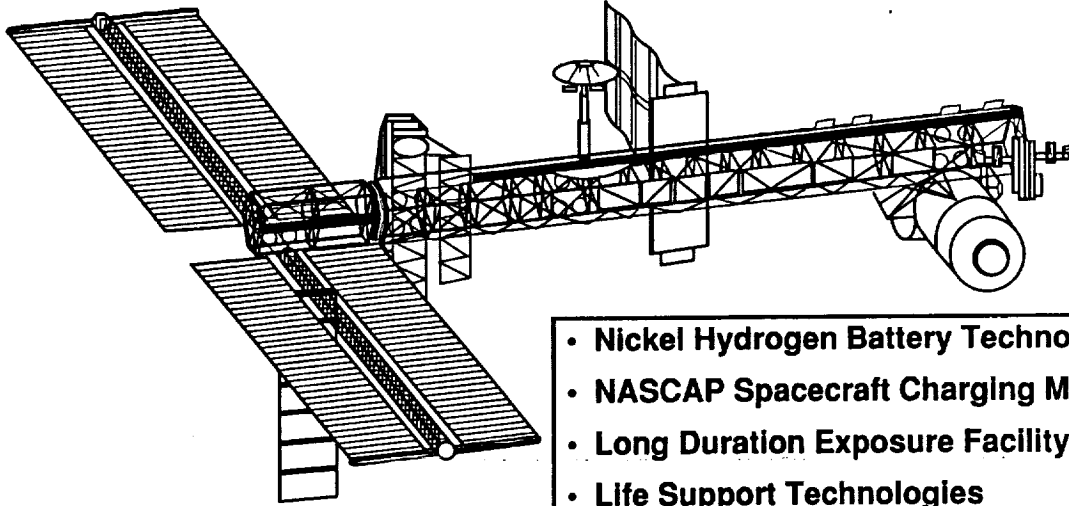
Finally, OAST technology has solved the serious problem of hot gas flow between tiles during atmospheric entry. OAST developed a gap filler, consisting of a ceramic cloth impregnated with a silicone polymer, that has now been standardized on all the orbiters. In excess of 10,000 are used on each Shuttle.

This technology and its derivatives could be used for future aerobraking and manned entry vehicles such as the Personnel Launch System. Each of the technologies discussed were adopted by the Shuttle over a period spanning from the mid-1970's to the early-1980's. For further information, please contact: Murray Hirschbein, NASA Headquarters, Code RS, Washington, D.C. 20546. Phone - 202- 453-2859.

REUSABLE THERMAL PROTECTION MATERIALS



TECHNOLOGY CONTRIBUTIONS TO SPACE PLATFORMS



- Nickel Hydrogen Battery Technology
- NASCAP Spacecraft Charging Model
- Long Duration Exposure Facility
- Life Support Technologies
- Multipropellant Resistojet
- Large Area Solar Cells
- Arcjet Thruster

Office of Aeronautics and Space Technology

92-8024

BATTERY TECHNOLOGY (SPACE STATION FREEDOM)

OAST

The nickel-hydrogen battery design has resulted in the most advanced, long-life, rechargeable battery technology developed over the last 50 years. The dramatic advances in capabilities of this technology are opening a whole range of possibilities for both NASA and the commercial space sector. During periods of darkness, rechargeable batteries supply the power needs of the spacecraft. Recently, breakthroughs have been achieved in the low-Earth-orbit (LEO) cycle life of individual pressure vessel nickel-hydrogen battery cells. The cycle life was improved by more than a factor of 10 over state-of-the-art cells. Ground test cells containing 26 percent potassium hydroxide (KOH) electrolyte were cycled for 40,000 stressful accelerated LEO cycles at a deep depth of discharge (80%). Cells containing 31 percent KOH had previously achieved only 3500 cycles.

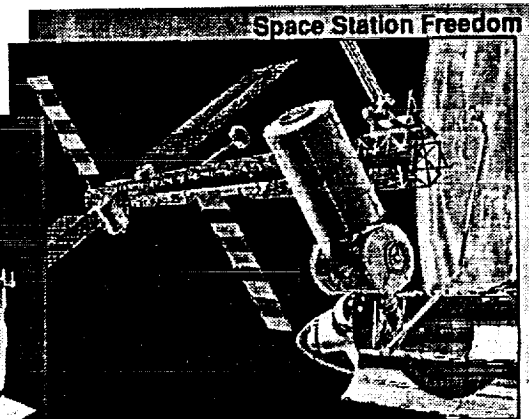
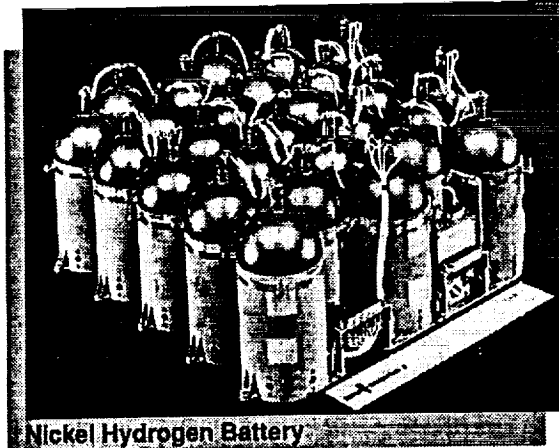
The significance of this breakthrough is that long term LEO missions, such as Space Station Freedom, can now rely on a greater than 5 year life span for advanced nickel hydrogen batteries. This advance will result in a significant reduction in life cycle cost. In addition, nickel-hydrogen batteries provide the capability of operating at a deep depth of discharge which could enable reductions in the mass devoted to batteries and increases in payload capability.

This program is based on a close working relationship with NASA mission offices, the military, and industry. Technologists at the Lewis Research Center are coordinating with the Space Station Freedom power office on advanced nickel hydrogen cell design features which promise to significantly enhance the SSF mission. In addition, the Earth Observing System has chosen to use OAST's nickel-hydrogen battery technology. Technologists at Lewis are working closely with OSSA to meet this mission's power needs. The Air Force, meanwhile, is using Lewis's advanced nickel hydrogen cell technology for military flights. Finally, the aerospace industry has adopted a scaled-up version of the Lewis design which is currently undergoing cell testing at Loral Corporation.

As we look to the future, nickel-hydrogen is fast replacing nickel-cadmium as the standard satellite storage system. It is projected that nickel-hydrogen will be the major rechargeable battery system for future aerospace applications. The ongoing technology development efforts at Lewis are aimed at increasing the life, power density, and reliability and at reducing the mass and lowering the cost of the nickel-hydrogen battery system.

Sponsored under the auspices of OAST, work was initiated on nickel-hydrogen battery technology at Lewis in the early 1980's. For additional information, contact: Gary Bennett, NASA Headquarters, Code RP, Washington, D.C., 20546. Phone: (202) 453-2856.

BATTERY TECHNOLOGY



NASCAP SPACECRAFT CHARGING MODEL

OAST

In the space environment, spacecraft materials undergo a variety of electrodynamic behaviors resulting from space radiation, magnetic fields and electric currents, particularly in the ionosphere around the earth. NASCAP (NASA Charging Analysis Program) is a computer program that models this electrodynamic behavior in terms of the electrical potential and currents of spacecraft surfaces. It permits the prediction of the electrodynamic conditions that result in payload or instrument damage or in materials degradation in space.

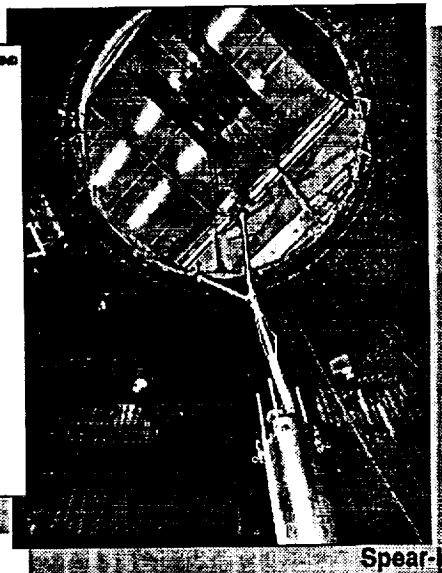
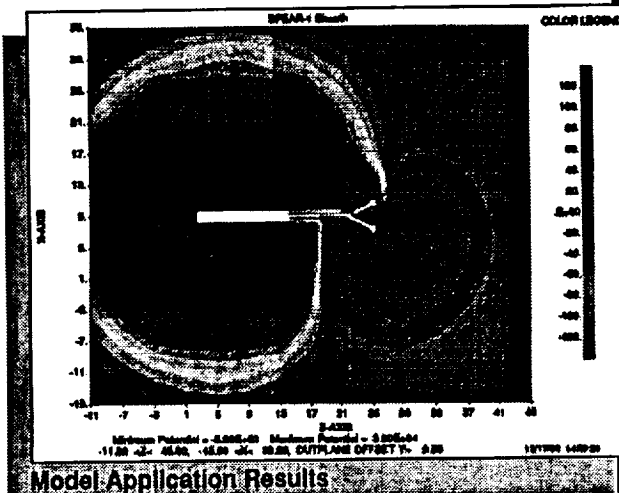
The SPEAR-I flight experiment was conducted to demonstrate the feasibility of using gas release as a grounding mechanism for spacecraft and to determine the parameters that could allow a ground test chamber to more effectively simulate flight conditions. Spear-1 was flown in December 1988 on a Black Brant sounding rocket by the Defense Nuclear Agency and SDIO. NASCAP was used to calculate the expected steady state surface potentials and collected currents for low earth, polar orbits. The flight experiment applied bipolar potentials up to 45 kilovolts to exposed surfaces in the ionosphere without causing electric discharge or breakdowns. The NASCAP predictions were in agreement with the measured values taken by SPEAR-I instruments.

Use of NASCAP in modeling Space Station Freedom (SSF) identified a potential problem from deleterious high voltage interactions. SSF solar cells are larger than standard solar cells and have a peculiar geometry. NASCAP determined that the floating potential of the cells in the space plasma resulted in a negative ground (about -140 volts) relative to the plasma. The magnitude of this voltage is high enough that the incoming positive ions in the plasma will hit with sufficient energy to "knock off" material from SSF (that is, sputtering will occur). Moreover, dielectric breakdown could occur, that is, the voltage is high enough that there would be arcing or breakthroughs of the anodized surface. The calculated arc rate is one arc every two seconds. If this occurred all surfaces would be denuded in two to three years. Awareness of this problem and quantitative predictions by NASCAP about its effect have permitted a solution to be devised - change the floating potential by either increasing the ion collection or decreasing the electron collection.

NASCAP was first initiated in 1975 and funded mainly by OAST, with some support from the Air Force Geophysics Laboratory. OAST continues to support improvements, along with the Office of Space Flight. Detailed improvements will be made in NASCAP for low-Earth orbit (LEO) applications. Furthermore, several models including NASCAP will be integrated into an analytical tool that can be used for design of spacecraft for these environments.

For more information, please contact Gary Bennett, NASA Headquarters, Code RP, Washington, D.C. 20546. Phone: (202) 453-2856.

NASCAP SPACECRAFT CHARGING MODEL



ARCJET THRUSTER TECHNOLOGY

OAST

A significant part of the OAST technology program is directed toward support of NASA's needs for advanced vehicles and propulsion capabilities. Much of the research OAST is conducting has benefits to the commercial space sector as well. As an example, OAST sponsored the development of an arcjet thruster for station keeping on geosynchronous communications satellites. Arcjets have recently been baselined for use on AT&T's Telstar 4 satellite series.

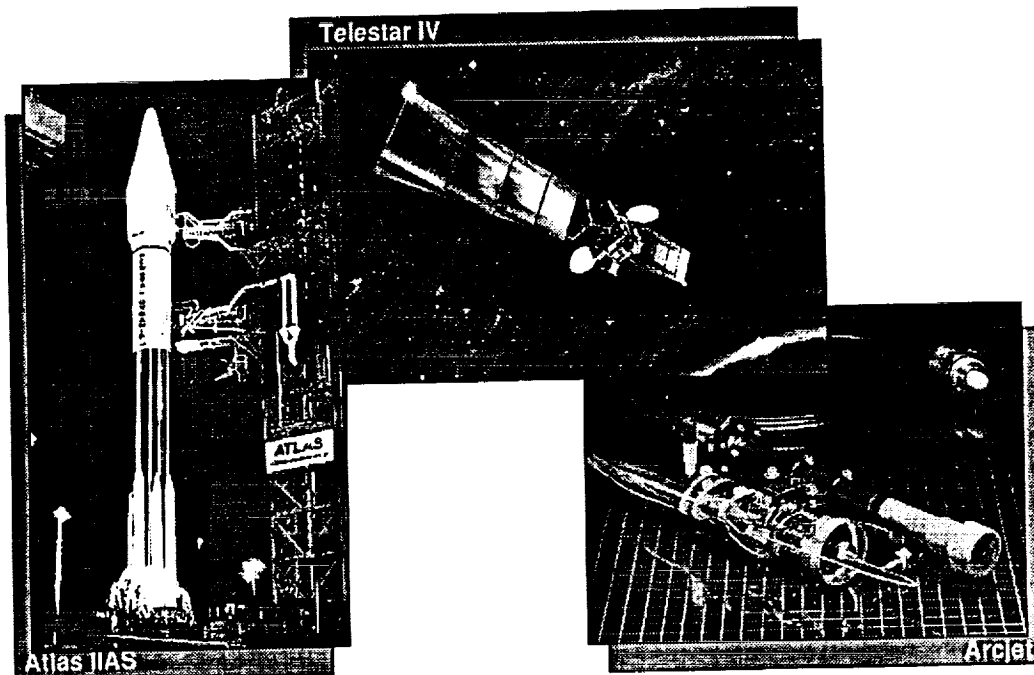
Arcjet technology is of interest to the spacecraft community because it offers 1.5 to 2 times the fuel efficiency currently available from state-of-the-art chemical or resistojet thruster systems. This improved efficiency can be used to extend mission life by more than 50 percent, to reduce launch mass, or to increase payload. Switching to arcjet systems for north-south stationkeeping on a geosynchronous communications satellite can reduce propellant requirements by several hundred pounds. In the case of the Telstar 4 satellite, the arcjet's direct weight savings enable the use of the Atlas launch vehicle as opposed to a larger vehicle which would have been required for a conventional station keeping system.

The arcjet system consists of a thruster, a gas generator, and a power processing unit. The hot, slightly ionized gas exits the rocket nozzle at an average velocity 1.5 to 2 times that attained in conventional thrusters. For example, the 1.8 kilowatt (kW) arcjet systems developed by Rocket Research Company of Redmond Washington for the Telstar 4 program, provide a specific impulse (thrust divided by the propellant consumption rate) of about 500 seconds.

Arcjet research and development efforts began in 1983 at Lewis Research Center. The ongoing goal of this program is to provide and transfer this technology to the user community. The future issues to be addressed are system performance, lifetime/reliability, and other issues important to the integration of arcjet systems on spacecraft. Results to date suggest that electromagnetic interference with satellite systems should be minimal and that there will be no problem sending radio signals through the thruster exhaust plume.

Lewis researchers are also investigating a range of power options to enhance the versatility of hydrazine arcjet technology. Examples include low power (1 kW) systems for power limited satellites and high specific impulse systems for advanced communications satellites. For additional information please contact: Frank Curran, Code RP, NASA Headquarters, Washington, D.C., 20546. Phone: (202) 453-2869.

ARC JET



Office of Aeronautics and Space Technology

SPACE STATION LIFE SUPPORT TECHNOLOGIES

OAST

Space Station Freedom (SSF) will be a permanently manned space station in low Earth orbit. Its mission requirements include the recycling of air and water in order to confine the 90 day resupply requirements to food, makeup nitrogen and some oxygen. With the restructuring of SSF, which includes a long man-tended phase, the regenerative air and water systems are being deferred and less recycling will be used initially.

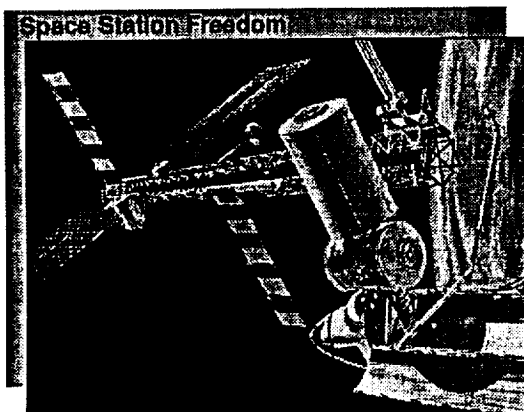
However, because future plans for SSF require increased air and water recycling, four technologies will be integral to closing the life support system. These are technologies which have been developed by OAST and picked up by the mission office for SSF use: (1) Atmospheric CO₂ exhaled by the crew will be collected from the cabin air by a molecular sieve - a technology which was first flown on Skylab. The Sabatier processor for CO₂ reduction will then convert the CO₂ to carbon and oxygen of which the O₂ will then be recycled into the cabin air for breathing. (2) The multi-filtration potable water recovery unit will remove contaminants from humidity condensate water which is collected from the cabin atmosphere and comes primarily from crew expiration. This multi-filtration unit can convert the humidity condensate to potable-quality (drinking) water for crew consumption. (3) The static feed electrolysis oxygen production unit will electrolyze a portion of the recovered waste water to produce additional oxygen for crew consumption. (The reduction of collected CO₂ in the Sabatier processor as described above does not furnish enough O₂.) (4) The vapor compression distillation hygiene water recovery unit (VCD) will recover water from crew showers and commode flush operation for reuse as hygiene-grade, but not potable-grade water.

These air and water regeneration technologies have been developed over a period of 20 years under NASA's research and technology development (R&T Base) program. In fact, the VCD has been in a R&T status since 1958, begun by the Air Force. Some of these technologies were first tested by NASA in a closed chamber environment in the early 1970's as a feasibility project. Currently, the technologies above are being tested with some use of human subjects in closed environment tests in which the product air and water are being carefully analyzed for chemical and microbial constituents. The goal is to produce water and air which have the consistently high-grade quality needed for human consumption.

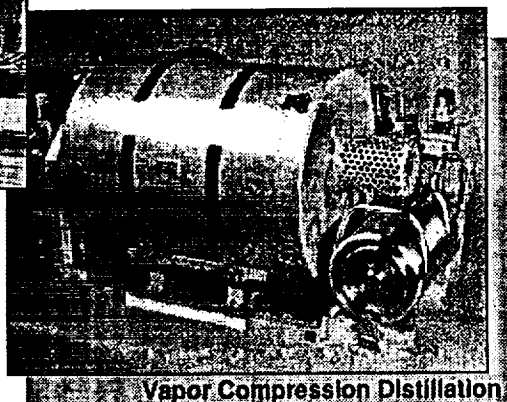
The validation and use of air and water recovery systems on the future SSF will lead to increased confidence and knowledge of the ability of humans to live for extended periods of time in space. Furthermore, this data and experience will guide the development of life support technologies for a future lunar and/or Mars mission.

For further information, please contact, Ms. Peggy Evanich, NASA Headquarters, Code RP, Washington, D.C. 20546. Phone: (202) 453-2857.

SPACE STATION LIFE SUPPORT TECHNOLOGIES



- Sabatier Processor CO₂ Reduction
- Multi-Filtration Potable Water Recovery
- Static Feed Electrolysis Oxygen Recovery
- VCD Hygiene Water Recovery



MULTIPELLENT RESISTOJETS FOR SPACE STATION FREEDOM

OAST

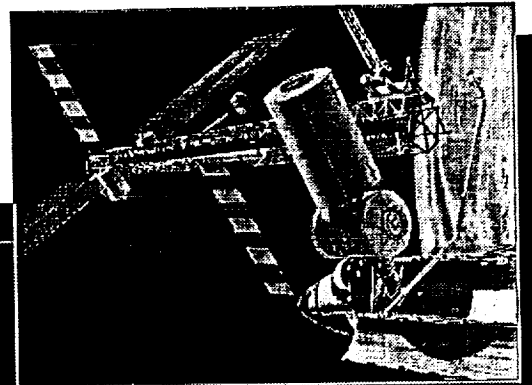
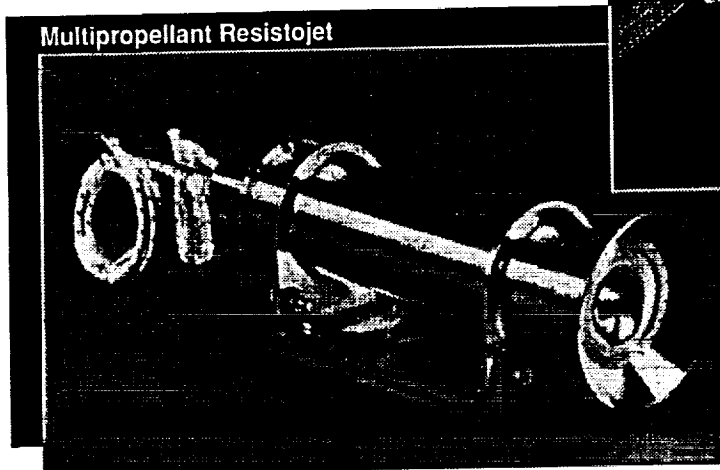
The Space Station Freedom (SSF) propulsion system must provide reboost to compensate for the atmospheric drag that space platforms encounter in low earth orbit. OAST has developed a resistojet which helps provide this capability while also having the added benefit of using wastes as a fuel. This advance will minimize propellant resupply requirements for SSF and eliminate the need to return some wastes to Earth. In the multipropellant resistojet, a resistive element is used to heat waste gases which are then exhausted through a nozzle to produce thrust. The design of these low power, low thrust devices is driven both by performance and by long life and integration considerations.

The waste gas resistojet has been baselined for the permanently manned configuration of SSF. In addition, a program is currently in place to develop the zero-g vaporizer technology necessary for a resistojet to operate with a water/waste gas system.

Use of the waste gas resistojet leads to a savings of at least 3000 pounds/year in launch weight alone. Utilization of a water/waste gas system (currently under development) to provide the entire SSF propellant reboost requirement would lead to savings of over 12,000 lbs/year. In addition, significant ground processing costs would be avoided through the use of water/waste gas system. A Rocketdyne/Technion team has designed and fabricated a low power (~ 0.5 kW) thruster utilizing grain-stabilized platinum in critical areas. This device has been successfully tested on hydrogen, helium, methane, nitrogen, argon, air, carbon dioxide, and steam and has demonstrated 10,000 hours of operation.

As we look to the future, water/waste gas resistojets could provide a key capability for commercial space platforms. Due to the ease and safety of water resupply, aerospace companies have proposed that water resistojets be considered for application on the Industrial Space Facility as these platforms become a reality. Multipropellant resistojet technology has been and is currently supported by OAST's Research and Technology Base Program. For additional information, contact: David C. Byers, NASA Lewis Research Center, Cleveland, Ohio 44135 (M/S SPTD-1). Phone (216) 977-7543.

— SPACE STATION FREEDOM PROPULSION SYSTEM —



Office of Aeronautics and Space Technology

MATERIALS DESIGN DATA FOR SPACE STATION FREEDOM

OAST

Snatched from a decaying orbit weeks before it would have plunged into Earth's atmosphere, the Long Duration Exposure Facility (LDEF) tested the effects of long-term exposure on spacecraft materials, components, and systems. Its 12-sided, 30-foot long aluminum frame provided an open grid on which 86 experiment trays of varying sizes were secured. In all, 57 experiments containing 10,000 test samples flew on LDEF, representing the work of scientists from the U.S. and eight other countries. The LDEF experiments gathered unique information on space radiation, atomic oxygen, meteoroids, contamination, space debris, space systems and life sciences, information crucial to the design of future spacecraft such as the Space Station.

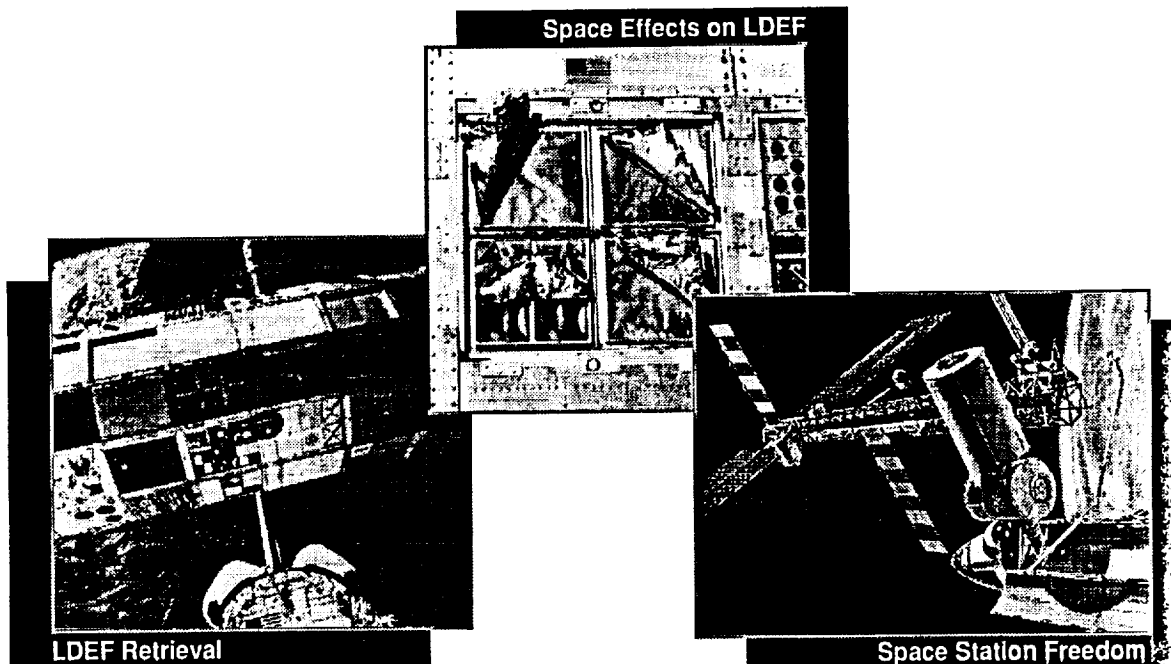
LDEF has already directly influenced Space Station design. For example, LDEF confirmed that NASA needs to shield the most vulnerable areas of the Station with bumpers to protect it from meteoroids and space debris. Light foil bumpers currently being designed by engineers at the Johnson Space Center to benefit from the tendency of small, high velocity projectiles to shatter on contact with thin outer layers of material, protecting the structural surface beneath. LDEF also brought back unique information about the direction of approach of meteoroids and space debris. The impact pattern will be similar for the Space Station. Confining the heavier shielding to susceptible areas can save thousands of pounds of material - perhaps a shuttle load. That would represent a savings of considerable funds in launch costs alone.

LDEF is also dispelling many of the unknowns of the radiation hazards inherent in low earth orbit. Using radiation measurements obtained from the spacecraft, researchers are improving the models used to develop Space Station radiation protection requirements. LDEF gives the first precise long-term measurements of the radiation's intensity and destructive capability. These measurements, like those of debris and meteoroids, will lead to significant savings in construction of the Space Station.

Selecting materials that can last up to 30 years - Freedom's projected lifetime - has been made easier as a result of data collected from LDEF. Important changes have already been made to coatings on Freedom's radiators, solar arrays, and to the material used for its trusses. LDEF leaves an important legacy as NASA will be developing "lessons learned" guidelines that promise to impact the design of future spacecraft for years to come.

Continuing support for this program is being provided by OAST under the Research and Technology base. For more information, contact: Robert J. Hayduk, NASA Headquarters, Code RS, Washington, D.C. 20546. Phone - (202) 453-2962.

SPACE FLIGHT ENVIRONMENTAL EFFECTS



Office of Aeronautics and Space Technology

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