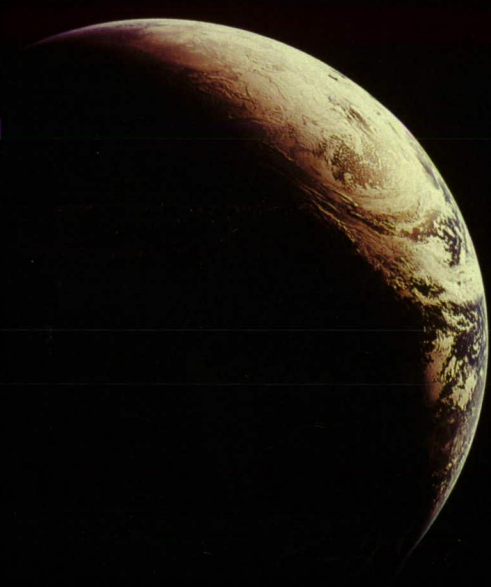


# CIVIL SPACE TECHNOLOGY INITIATIVE

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# Foreword

The Civil Space Technology Initiative (CSTI) is a major, focused, space technology program of the Office of Aeronautics, Exploration and Technology (OAET) of the National Aeronautics and Space Administration (NASA). The program was initiated in 1988 to advance technology beyond basic research in order to expand and enhance system and vehicle capabilities for near-term missions.

CSTI takes critical technologies to the point at which a user can confidently incorporate the new or expanded capabilities into relatively near-term, high-priority NASA missions. In particular, the CSTI program emphasizes technologies necessary for reliable and efficient access to and operation in Earth orbit as well as for support of scientific missions from Earth orbit.

The CSTI program has already produced significant accomplishments in key focused technologies. It is beginning to fill the gaps and voids in these areas and will provide a strengthened technology base in the 1990s that will allow NASA to plan new leadership missions as recommended by its advisory bodies in academia, private industry, and scientific and professional societies.

## OAET

Office of Aeronautics,  
Exploration and Technology

August 1990

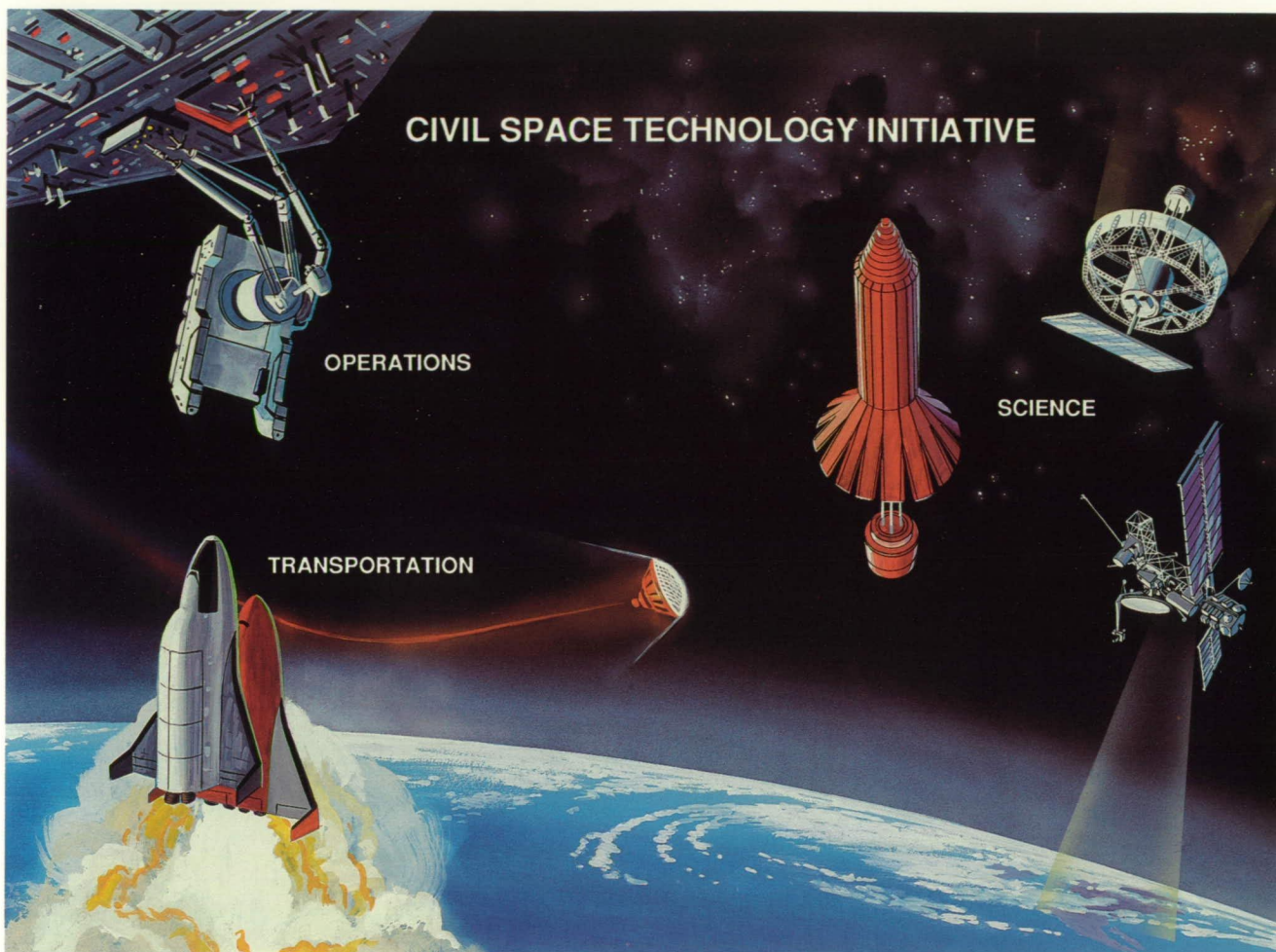
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# Overview



The Civil Space Technology Initiative (CSTI) is a vital component of NASA's Space Research and Development program. It was initiated as the necessary first step in a focused effort to revitalize the technology base for future space missions, with primary emphasis on technology for efficient, reliable, access to and operations in low Earth orbit, and on support of science missions conducted from Earth orbit.

Advanced technology has been a cornerstone of U.S. space activities. Each of our major space programs has been made possible by research and technology efforts conducted many years before the program was started, and in most instances, long before it was defined as an actual program. NASA's space technology base has served the country well; CSTI is a continuation of this tradition of innovative technology development.

CSTI's objectives are to develop specific technologies critical to the accomplishment of near-term, high-priority, national space goals. CSTI will produce substantive capabilities for future mission applications; the products of CSTI will include ground-laboratory and/or flight-demonstrated hardware, software, data, processes, and techniques that can be adapted to the mission systems of the 1990s. Specifically, CSTI is intended to fill technology gaps, demonstrate large-scale hardware, and conduct system-level tests.

The program was developed with extensive user involvement from industry, universities, NASA flight program offices, and NASA flight and research centers. Enhancing progress already achieved in the Space Research and Technology program, CSTI is directed at important advances in transportation, operations, and science. CSTI is organized into these three thrusts and comprises a total of nine elements.

## ***Program Elements***

The transportation program elements address technologies that will enhance the safety and reliability of routine access to space. For advanced launch-system main engines, technologies will be developed for fully reusable, high-performance, oxygen–hydrocarbon and oxygen–hydrogen engines. As an alternative to solid rocket motors for future launch systems, as well as to provide higher performance and a safe abort option, technology for liquid and hybrid engines is being pursued. A flight research program to verify the technology for orbit-transfer aerobraking using atmospheric friction will allow payload mass increases by up to a factor of two relative to propulsion-braked vehicles.

The operations program elements will lead to substantial economies and improved safety and reliability for both ground and space activities in many areas, such as the following:

- Improved capability of telerobotic systems to service satellites and assemble space structures under supervision from the Space Station, the Space Shuttle, or the ground will be demonstrated in the laboratory.
- Enhanced autonomy of launch and flight operations for the next generation of transportation systems will be introduced.
- Increasingly complex autonomous systems technology to support coordinated control of multiple functions and systems will be validated.
- Work will commence on the experimental verification of energy-conversion technology to enable a five-fold increase in electric power from spaceborne reactors such as SP-100.

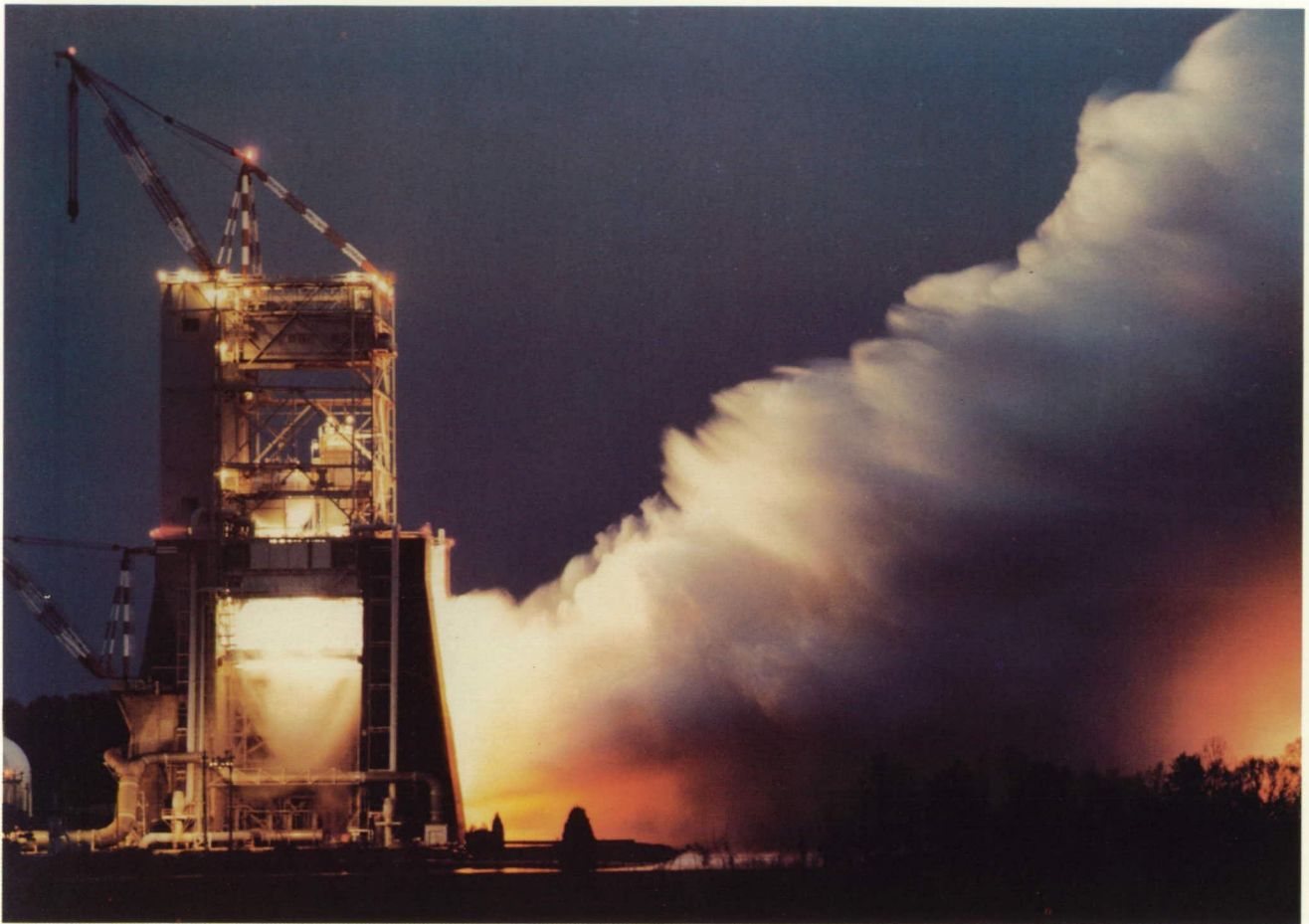
To support scientific missions from Earth orbit, efforts are being directed at improving the spectral range of sensing systems and at creating more efficient means of processing the burgeoning data streams from imaging systems. The ability to fabricate detectors operating in the submillimeter region will enhance astrophysical and Earth science observations, while solid state, tunable lasers will sense otherwise undetectable constituents in the atmosphere.

Onboard image processors and optical storage systems will be produced to enable very high rate, high-capacity, information flow. Cryogenic refrigeration technology will be developed to dramatically improve infrared detector performance and operating life. Lightweight, dimensionally stable reflectors using multiple, control-coupled elements will create surfaces of micrometer-level precision for submillimeter observations. Analytical tools and predictive methods will be provided for the design of future, large, lightweight space systems.

## ***Program Achievements***

In all the areas mentioned, significant progress has been made since the inception of the CSTI program. The increased turbopump bearing durability and resistance to stress-corrosion cracking already developed will contribute directly to the safety and serviceability of the Space Shuttle Main Engine (SSME). A prototype optical plume anomaly detector system installed in the technology testbed stand at the Marshall Space Flight Center (MSFC) will allow the detection of incipient failures in propulsion systems prior to catastrophic failures, thereby enhancing information return and reducing hardware loss. An expert system, developed as part of the artificial intelligence research efforts, was used during the Voyager–Neptune Encounter to successfully detect anomalies in telemetry, diagnose possible causes, and provide valuable information in identifying possible solutions.

The Civil Space Technology Initiative is managed from the Office of Aeronautics, Exploration and Technology (OAET) at NASA Headquarters. Continuing interaction with other NASA organizations and contractor representatives, usually through working groups and specialized workshops, ensures that developed technology is transferred to users for incorporation into missions and projects. Needs for new technology activities are also identified and added to the program. The technical effort is performed at NASA centers, usually in a combination of in-house and contracted efforts and involving industry and universities.



*The CSTI-ETO Propulsion Program utilizes the Space Shuttle Main Engine Technology Testbed (SSME-TTB), shown here in a hot-firing test at NASA's Marshall Space Flight Center.*

The goal of the CSTI Earth-to-Orbit (ETO) Propulsion element is to provide a significantly strengthened technology base (validated with an extensive experimental database) for the design, development, manufacture, and operation of high-performance, long-life, ground-launched and -serviced propulsion systems. An added benefit is the potential for significantly improving and reducing the cost of currently existing propulsion systems of this class.

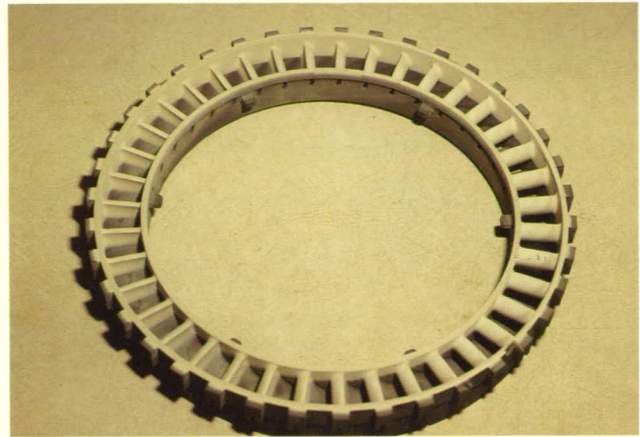
The primary focus of the ETO effort is on propulsion systems that use liquid oxygen as the oxidizer, with either liquid hydrogen or hydrocarbons as the fuels of choice. Advanced engines with these characteristics will contribute immensely to reliable and affordable space transportation in the future. The program thus supports the development and operation of truly low-cost ETO-class launch vehicles — whether expendable or reusable, manned or unmanned, single- or multiple-staged.

The ETO element focuses on extending the knowledge and understanding of basic rocket engine chemical and physical processes so that realistic analytical simulations of internal thermal and mechanical environments can be made, along with accurate predictions of steady and unsteady loads, material behavior, structural response, and failure mechanisms leading to statistically predictable and safe design margins. Efforts are also being focused on technologies for reducing ground-servicing and operations costs and ensuring safer, more reliable flight operations through the technology development of onboard, integrated, safety- and condition-monitoring systems and controls.

The ETO program consists of a technology development and acquisition phase followed by a technology validation and demonstration phase. It is focused on the major engine subsystems: combustion devices, turbomachinery, and systems monitoring and controls.



*Vacuum Plasma Spray (VPS) application of a zirconia/nicaloy thermal-barrier coating on an SSME turbine component*



*Finished VPS-applied thermal-barrier coating on an SSME High Pressure Fuel Turbopump (HPFTP) turbine nozzle ring*

## ***Deliverables***

The ETO element will provide a number of analytical methods and validated component subsystem design codes for Earth-to-orbit propulsion, including the following:

- Integrated combustion, ignition, and nozzle flow codes
- Multistage-turbine, pump-impeller, and complex-flow-passage computational fluid dynamics codes
- Bearing, fluid-dynamic, and rotor-dynamic models; low/high cycle fatigue interaction and life prediction models (including probabilistic methods)
- Experimental databases generated in subscale combustor hardware and appropriately sized air- and water-flow test rigs

Also, ETO will produce ground-tested, appropriately scaled, advanced subsystem experimental devices such as the following:

- 2000–5000-psia combustion-pressure thrust-chamber assemblies and gas generators with very high combustion efficiencies and high stability margins
- Over 100 mission-life reusable turbopumps with high turbine and pump efficiencies (2000–6000 psia, 3:1 flow range)

System monitoring and control components, devices, and models previously demonstrated in systems simulation laboratories and the SSME Technology Testbed will be developed. These include the following:

- Advanced flowmeters, pressure transducers, speed sensors, bearing-wear detectors, turbine-

blade temperature and heat-flux detectors, and plume-anomaly detectors

- Sensors, electronics, expert systems, real-time engine dynamic simulation models
- System safety- and condition-monitoring and control architecture, operation, and response

## ***Accomplishments***

Technology acquisition has been under way for several years and progress has been made in the development of improved analytical techniques in the areas of Three-Dimensional Computational Fluid Dynamics (3D CFD) codes for combustion processes, multistage turbine and impeller stages, and complex flow ducts. Bearing and damping-seal models have also been developed and initially validated with bearing and seal dynamic test rigs.

Advanced-design concepts, including diagnostic sensors, advanced turbine blades and blade protective coatings, improved wear-resistant bearing materials and coatings, and longer life, lower cost combustor liners, have been evaluated in either laboratory testing or small-scale test rigs. A number of these items are ready for verification testing in the SSME Technology Testbed.

In the near future, work will begin on the design and fabrication of testbed assemblies for subsystem-level technology validation. In the long term, the program will provide a comprehensive technology base to support the development of highly reliable, high-performance, lower cost, ground-launched and -serviced, either expendable or reusable ETO-class propulsion systems.

# Aeroassist Flight Experiment



*Artist's conception of AFE performing aerobraking maneuver*

The goal of the CSTI Aeroassist Flight Experiment (AFE) program is to investigate the critical vehicle design technologies and upper atmospheric characteristics applicable to an Aeroassisted Orbital Transfer Vehicle (AOTV). The key advantage of an aeroassist maneuver versus the all-propellant equivalent is the large saving on the weight of propellant otherwise required to perform the braking and/or orbital-capture engine firings. In some instances, this weight reduction could account for a doubling of useful payload.

The experiment is concerned with the regime of geo- and lunar-return velocities that support both near-Earth and exploration activities. Because the flight regime of an AOTV is distinct from that of previous missions, and because no ground-test facilities are adequate to fully simulate an

AOTV reentry, a flight experiment is required to complete the technology development. The three subelements of AFE are Carrier Vehicle, Aero-brake, and Experiments.

The AFE objectives include providing a flight database for definition of the environment in which an AOTV must fly, including the radiative and convective heating to the forebody and afterbody regions of the blunt aeroshell. The program will provide the means to verify computational flow-field codes through specific measurement of gas and wall parameters and through performance data obtained during a representative AOTV aeroassist trajectory.

Finally, the program will demonstrate state-of-the-art guidance, navigation, and control techniques for flying vehicles with low lift-to-drag ratios in a variable density atmosphere and the performance of candidate thermal protection



system materials and surface coatings in the AOTV flight regime. Eleven fundamental experiments have been selected for inclusion in AFE: Radiative Heating, Wall Catalysis, Forebody Aerothermal Characterization, Pressure-Distribution/Air Data Systems, Base Flow Heating, Microwave Reflector Ionization Sensor, Alternate Thermal Protection System, Heat Shield Performance, Aerodynamic Performance, Afterbody Radiative, and Rarefied-Flow Aerodynamic Measurement.

The AFE hardware will be assembled into a free-flying, autonomous, Space Shuttle-launched and -recovered spacecraft. It will simulate reentry at geo- and near-lunar-return velocity regimes by using a solid rocket motor (the main propulsion system) to increase the orbital energy of the spacecraft. The experiments will be placed at various locations on the spacecraft and will gather entry data during the atmospheric pass.

### ***Deliverables***

The deliverables for AFE include a flight experiment database for critical aerothermodynamic parameters such as the following:

- Radiative heating levels
- Wake-flow base heating levels
- Aerodynamics and control characteristics
- Wall catalysis effects

Also covered in the database will be the following:

- Aerothermodynamic/thermodynamic, flight-validated, computational fluid dynamics, design-guideline codes for minimum-weight, aeroassisted, space transportation vehicles
- Alternate thermal protection system materials to permit development of lightweight flexible drag-device concepts



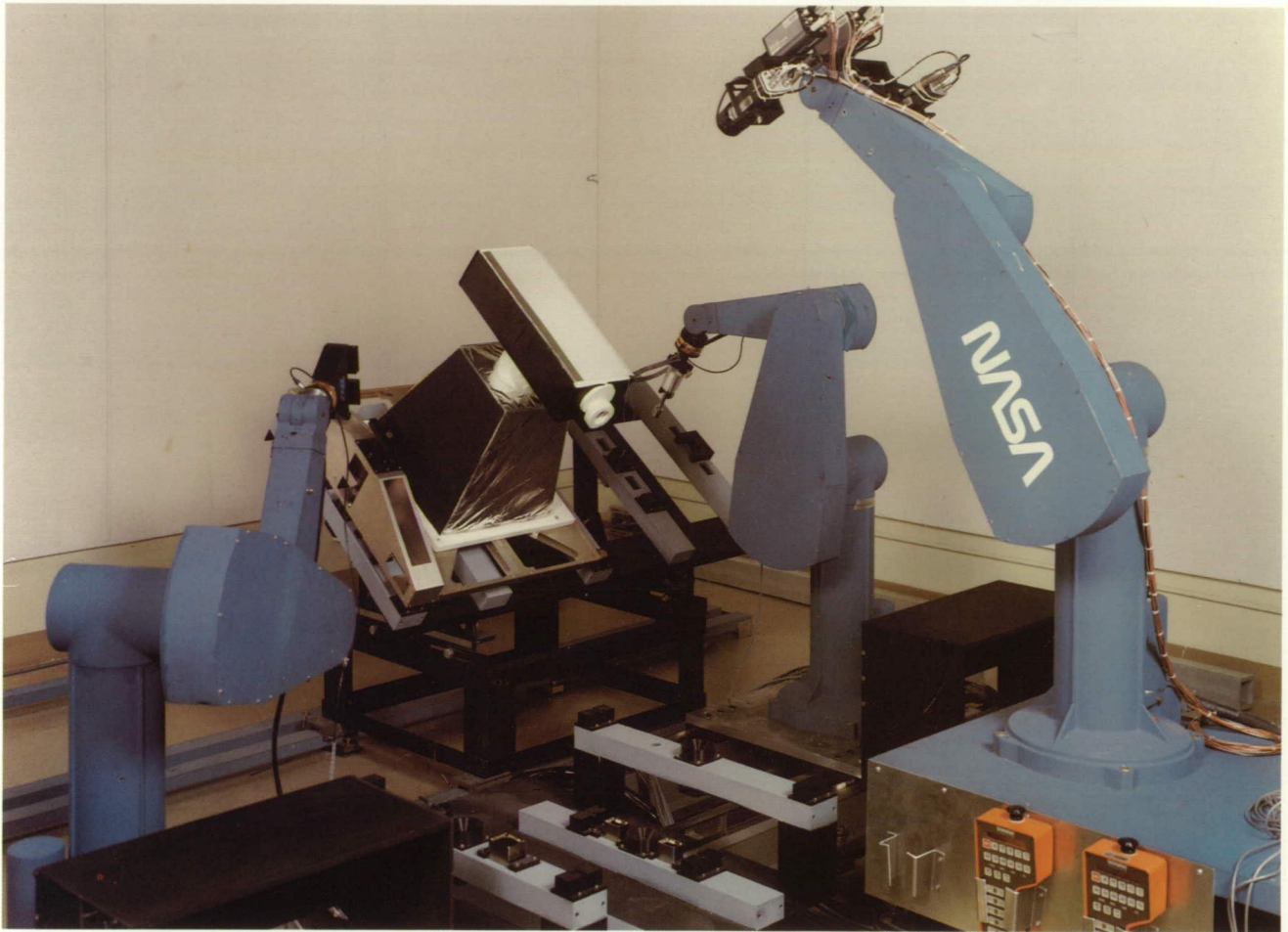
*Heat shield (Shuttle Tile) installed on aerobrace mockup*

### ***Accomplishments***

Work to date includes the preliminary design of the carrier vehicle, aerobrace, and nine of the eleven experiments. Preliminary design reviews (PDRs) have been held for these nine; the remaining experiment PDRs will be completed in 1990. Detailed designs of the carrier vehicle, aerobrace, and nine experiments have begun, with all designs planned for completion by March 1991. Long-lead-time items such as the inertial measurement units and mission and experiment computers have been ordered. Spacecraft assembly is scheduled for completion in 1993, with launch scheduled for late 1994.

# Telerobotics

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*JPL Telerobotic Testbed preparing to perform ORU (Orbital Replacement Unit) changeout*

The overall goal of the CSTI Telerobotics element is to develop, integrate, and demonstrate the science and technology of remote manipulation. This will lead to increased operational capability, safety, cost effectiveness, and success probability for NASA missions. To perform both complex and mundane tasks more efficiently and safely, telerobotic systems will be used for space assembly and construction, satellite servicing, and platform maintenance and repair.

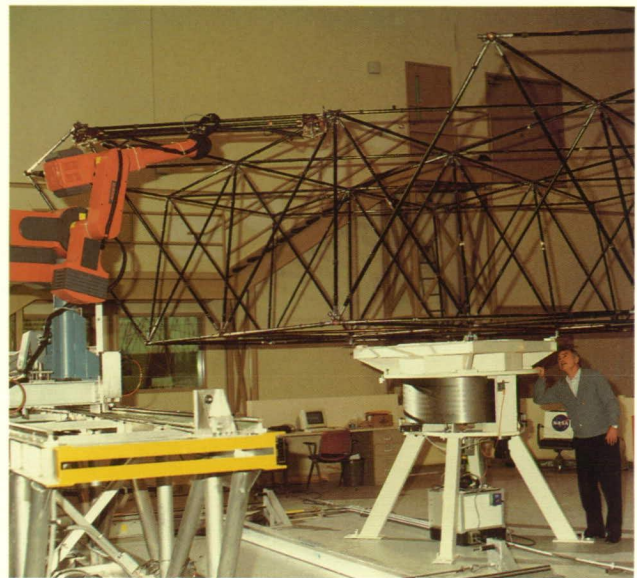
The Telerobotics element is made up of a sequence of demonstrations in four component technology areas:

- Robotics
- Supervisory Control
- Advanced Teleoperations
- Launch Processing

Long-term goals include developing mobile telerobotic vehicles, autonomous and teleoperated control of seven-degrees-of-freedom arms, laser sensing techniques, computer-aided design/artificial intelligence planning techniques, and error-detection and recovery algorithms.



*Operator at controls of JPL Telerobotic Testbed*



*ASAL (Automated Structures Assembly Laboratory) at LaRC*

## ***Deliverables***

The Telerobotics element will produce a series of ground-based demonstrations that show the ability to perform tasks with telerobotic devices to improve system performance. These include the following:

- An automated nonplanar structure assembly
- Advanced teleoperation for satellite servicing tasks equivalent to the Solar Max Repair Mission
- Telerobotic control of remote tasks
- Automated STS tile inspection

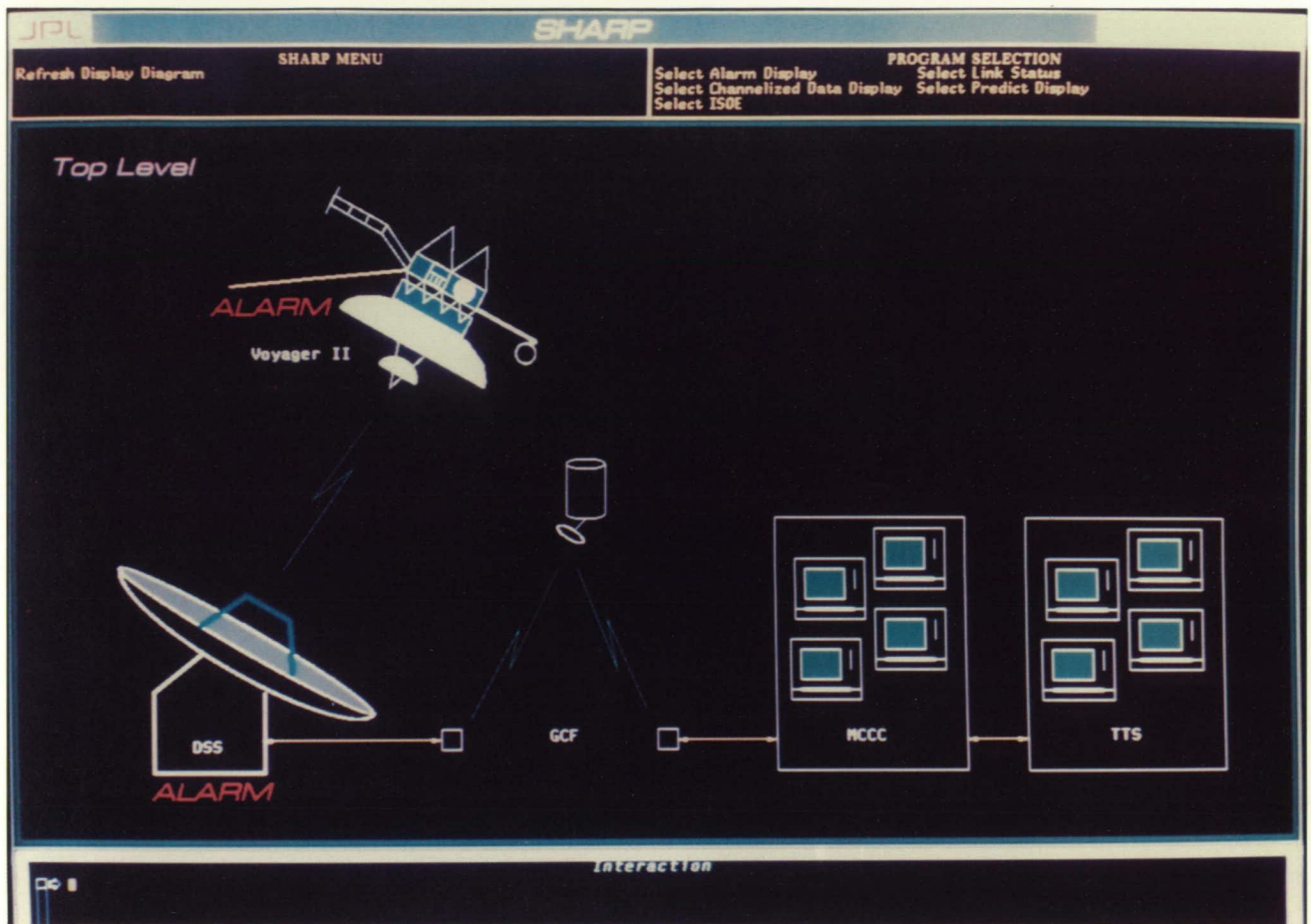
Telerobotics will also provide a number of advanced technologies for the Space Station Flight Telerobotic Servicer, such as the following:

- System architecture
- Testbed software and task boards
- Force-reflecting hand controllers
- Flight-like manipulator arms and software
- A machine-vision subsystem

## ***Accomplishments***

Accomplishments to date include delivery of the laboratory telerobotic manipulator at Langley Research Center (LaRC), evaluation of technologies for free-flying telerobotic systems in neutral buoyancy simulation, demonstration of telerobotic servicing of flight-instrument task boards, integration of the operator control station into the integrated telerobotic testbed at the Jet Propulsion Laboratory (JPL), and automated assembly of a planar truss structure.

# Artificial Intelligence



Top-level display for JPL SHARP (Spacecraft Health Automated Reasoning Prototype) expert system for satellite mission control

The goal of the CSTI Artificial Intelligence element is to develop, integrate, and demonstrate artificial intelligence (AI) technology for NASA missions. As future space missions become more complex, it will become necessary for operations to become more efficient. The element objectives will be accomplished by the following core technology research subelements:

- Planning and Reasoning
- Control Execution
- Operator Interface
- Systems Architecture and Integration
- Demonstration Projects
  - Space Station Testbeds
  - Specific Domain Demonstrations

Near-term goals include developing coordinated, real-time, decision-making schemes using multiple knowledge sources, machine learning, uncertainty planning, and software verification and validation methodologies. Future objectives include developing reconfigurable fault-tolerant systems and hierarchical and distributed control systems for multiple subsystems, systems integration of numeric and symbolic functions, and demonstrations of multiple subsystem control systems.

## ***Deliverables***

The AI element will deliver ground-demonstrated, knowledge-based expert systems capable of procedural planning, corrective action, and fault detection and diagnosis for

- Aiding the Integrated Communications Officer (INCO) in the Mission Control Center (MCC)
- Control of the Space Station's thermal control and power testbeds

Artificial Intelligence will also provide advanced technology capability in the areas of planning and reasoning, control execution, operator interface, and systems architecture and integration. This capability will lead to

- Real-time AI-based systems
- Machine learning
- Uncertainty management
- Control of multiple knowledge-based systems
- AI-system verification and validation

## ***Accomplishments***

An expert system for the INCO console in the MCC at Johnson Space Center (JSC) was developed to aid in the monitoring and diagnosis of all Shuttle communications systems. It was first used on STS-26 and was so successful that it served as a prototype for similar expert systems being developed for all other major MCC consoles. The capability for this technology will be incorporated into the new MCC to be built for Space Station Freedom.

An expert system is also being used at MSFC to monitor and control the nickel cadmium batteries for the Hubble Space Telescope's electrical power system testbed. Another expert system,

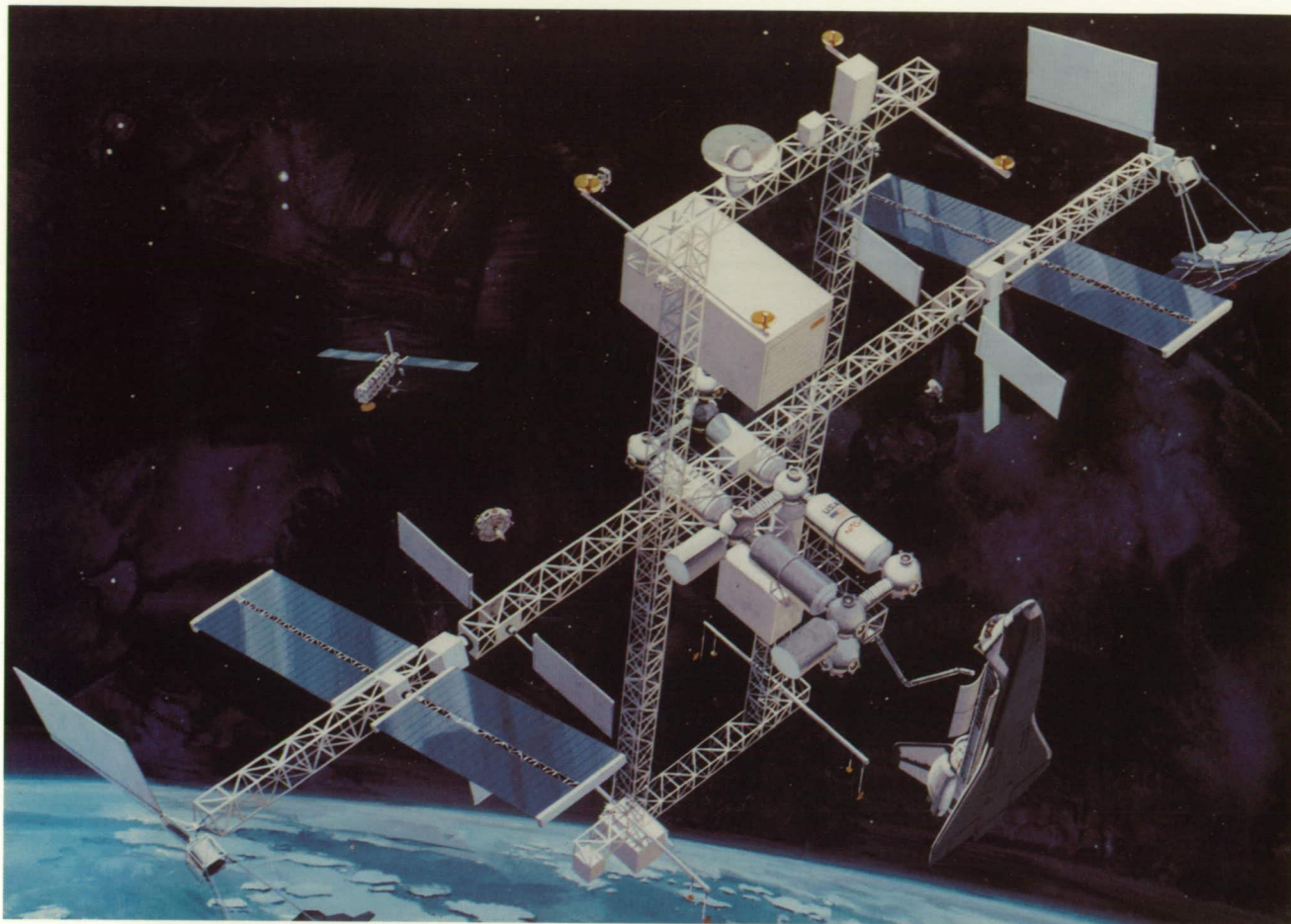


*INCO (Integrated Communications Officer) workstation in Shuttle Mission Control Center at JSC*

the Pioneer-Venus scheduler, is in operational use at Ames Research Center (ARC). And a last example of AI research in practical application at NASA, the AutoClass system, takes a large, potentially noisy set of data and determines the optimal classification of the database into physically meaningful subsets. Astronomers have applied AutoClass to the Infrared Astronomical Satellite's database, leading to the development of an improved catalog of infrared objects.

The Artificial Intelligence program has funded the development of the INCO and AutoClass knowledge-based systems and has thus had a first-order effect in bringing the new generation of automation to NASA operations.

# Control/Structures Interactions



*Very large, flexible space structures with low-frequency dynamics and multiple-interacting control systems will require CSI technology to meet mission requirements.*

The goal of the Control/Structures Interactions (CSI) element is to develop methods to design, analyze, and test lightweight, high-performance, controlled structures. These structures are needed to meet the requirements of NASA missions using large, flexible structures. The CSI program is composed of four subelements:

- Control/Structures System Design Concept
- Integrated Analysis and Design Methods
- Ground Test Methods
- In-Space Flight Experiment

CSI's long-term goals are

- To develop a controlled-structure technology
- To validate the technology with ground and flight demonstrations of large, flexible, controlled space structures

## ***Deliverables***

The CSI element will produce a methodology for the design, analysis, and test of lightweight, flexible, controlled spacecraft structures that includes a unified system for controlled-structure analysis and design in order to achieve the following:

- Factors of 2–10 weight reduction
- Factors of 2–10 faster slew/reacquisition times
- Factors of 5–100 increase in damping
- Factors of 50–10,000 reduction in pointing jitter

The methodology will also include ground verification on large, controlled-structure testbeds and flight verification that incorporates comparative ground and flight test results.

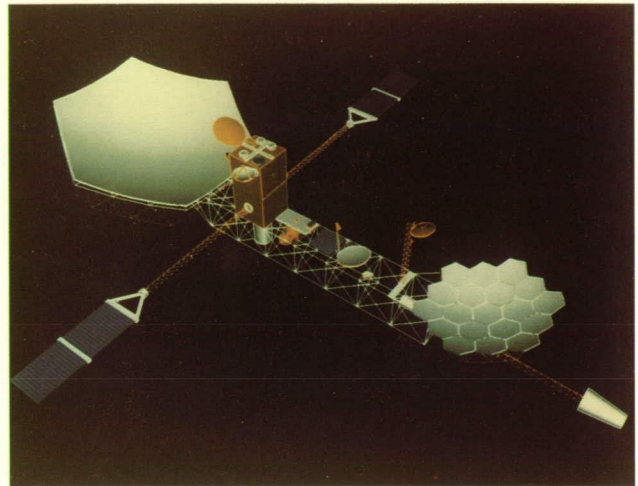
## Accomplishments

A set of testbeds has been constructed that emulates the range of advanced NASA mission structural control problems. Preliminary structural control experiments on several of these testbeds have been successfully performed; progressively more advanced tests are continuing. Testbeds involved in the program include the following:

- LaRC's Minimast and Evolutionary Testbed for studying the control of large, flexible, space platforms and the pointing/control of large flexible antennas
- MSFC's Active Control Evaluation of Spacecraft (ACES) and Control, Astrophysics, and Structures Experiment (CASES) booms for emulating the pointing and stabilization of instruments on long booms
- JPL's Precision Trusses and Phase I Precision Testbed for emulating the disturbance isolation, vibration suppression, and precision control/pointing required by large (mirror-array) space telescopes and 10–100-m baseline optical interferometers

System studies have been conducted to show the benefits of incorporating CSI technology in future space systems. Significant potential benefits have been shown for a large "Mission to Planet Earth" type geostationary platform, a large optical interferometer, and flexible remote manipulator systems. Also, new, integrated control structures design and analysis methods for flexible space structures are being developed; existing methods are being extended for use on large complex systems. This effort is developing the foundational methodology for the simultaneous optimal design of a structure and its control system.

The first year of a two-year, Phase-I, Guest Investigator program whose objective was to validate CSI theory and technology using ground-test facilities was completed. Six investigators from universities and industry conducted CSI experiments at LaRC and MSFC. A NASA Research Announcement for a Phase II program was issued. In addition to LaRC and MSFC facilities, JPL and Air Force Astronautics Laboratory (AFAL) facilities will be used during Phase II.



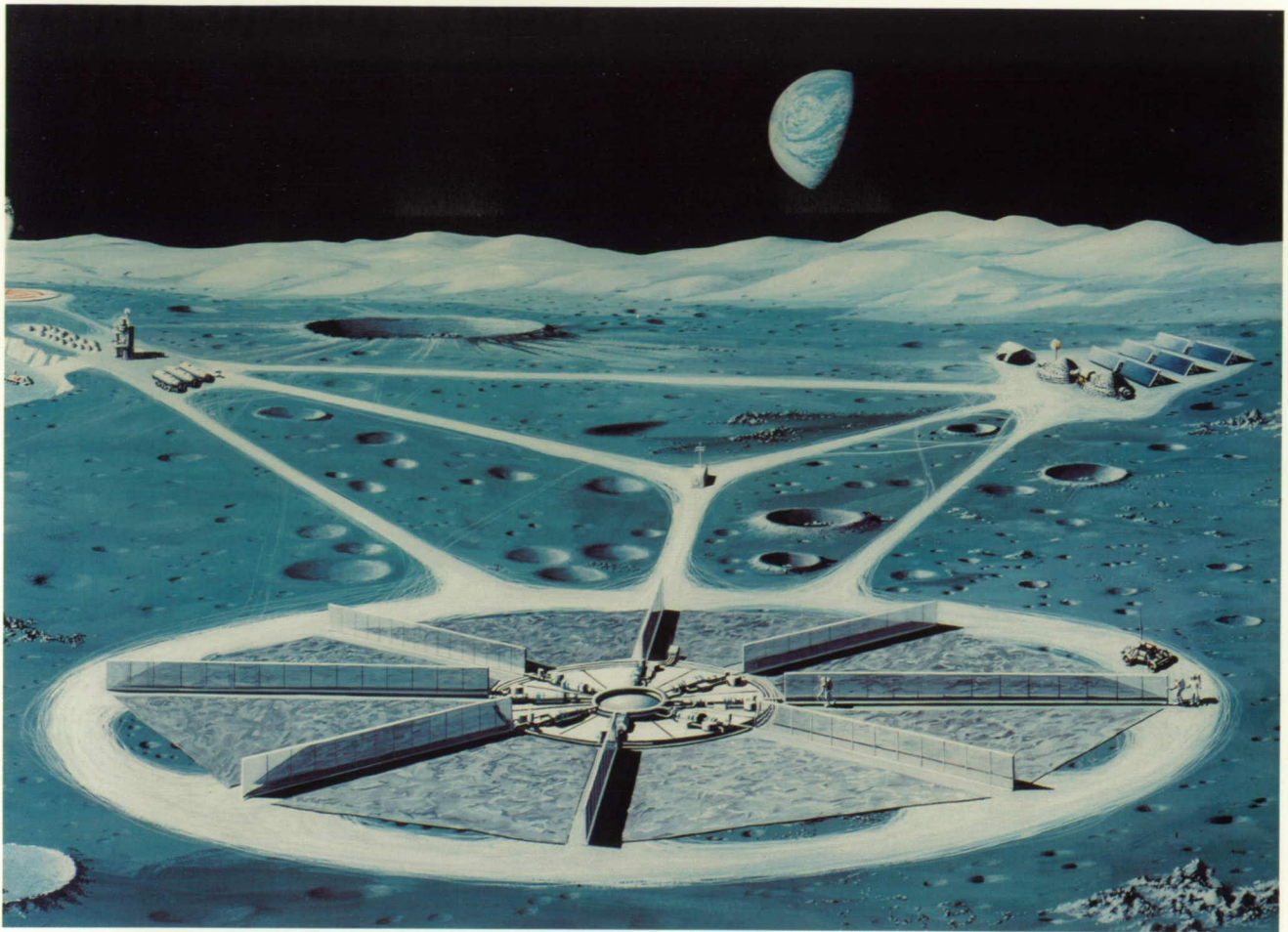
*Significant potential benefits from CSI technology will give future "Mission to Planet Earth" geostationary platforms increased pointing precision and flight path control.*

A ground testbed of Space Station Freedom has been developed that will help validate the use of dynamic-scale-model technology for large space systems. New active structural elements have been developed, installed in a structure, and successfully demonstrated to suppress vibration response by a factor of 100. Incorporation of passive damping elements is now under way in order to permit even more aggressive active control of structures without destabilizing high frequency modes.

A microdynamic component testing machine has been built to measure stiffness and damping at nanometer displacements and millipound force levels. Component characterizations from this testing machine will be used to develop integrated control structures models that are applicable to both the micromotion and macromotion regimes.

Feasibility of laser metrology and microgravity accelerometer systems for accurate sensing/control of small amplitude motions is being demonstrated for ground and flight tests. Candidate designs for in-space, controlled-structure flight experiments have been developed. The CASES Flight Experiment completed a Phase-A study and initiated two parallel Phase-B studies.

# High-Capacity Power



*Lunar Base: Nuclear Reactor Power System installation*

The goal of the CSTI High-Capacity Power element is to develop the technology base needed to meet the long-duration, high-capacity power requirements for future NASA space initiatives, particularly elements of the Space Exploration Initiative (SEI) such as long-duration lunar missions and missions to Mars. Efforts will be focused on increasing system thermal and electric energy conversion efficiency at least five-fold and on achieving systems that are compatible with space nuclear reactors.

The technology program comprises six subelements:

- Free-Piston Stirling Power Converters
- Thermoelectric Power Converters
- A Thermal Management System
- Power Management
- System Diagnostics
- Space Environmental Interactions



## Deliverables

The High-Capacity Power element will deliver an advanced, 25-kW, electric, free-piston Stirling power converter that operates in the 1050–1300-K temperature range and demonstrates (at least)

- 25-percent power-conversion efficiency
- 10-year life
- 6-kg/kWe specific mass

Advanced, high-temperature (875–1273 K) thermoelectric materials based upon silicon germanium will be developed and doped with gallium phosphorus (to demonstrate figure of merit,  $Z = 0.85 \times 10^{-3} \text{ K}^{-1}$ ) as well as other advanced dopants (to demonstrate figure of merit,  $Z > 1.4 \times 10^{10-3} \text{ K}^{-1}$ ).

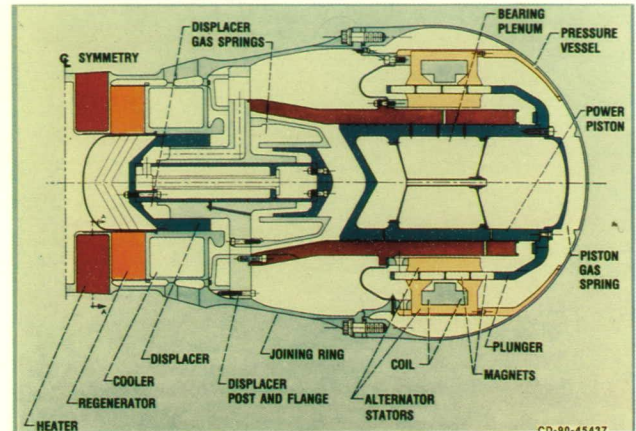
The High-Capacity Power element will also provide advanced thermal management technology to support the development of

- Radiator systems with specific mass  $< 5 \text{ kg/m}^2$
- Radiator surfaces with 0.85 emissivity (without coating)

## Accomplishments

The Stirling Space Power Demonstrator Engine has produced 11.2 kWe; additional loss reductions predicted by advanced computer codes will allow demonstration of the 12.5-kWe design goal. An electrical and thermodynamic model of n-type silicon germanium is guiding the development of melt-grown silicon germanium doping capable of at least a 30-percent improvement in the n-leg. P-leg modeling coupled with promising double-doping could provide at least a 65-percent overall improvement in thermoelectric performance by mid-1993.

Advanced radiator-development effort at 875 K (for a thermoelectric system) and 600 K (for a Stirling system) is completing the component



1050-K Stirling Space Power Converter

feasibility phase. Results indicate radiator mass reductions by a factor of two are achievable. Irradiation of a variety of solid state power switches with gammas and neutrons to the SP-100 user plane specification have revealed that static induction transistors were the most resistant to radiation but offered poor switch performance.

A robust fiberoptic current sensor developed at NIST has been delivered to Lewis Research Center (LeRC) for testing. A plasma-arcing tendency at the SP-100 User Interface Module has been identified by the LeRC-developed computer program; the joint design will be modified to prevent possible failure. A graphite copper composite radiator fin has been produced and will demonstrate the capability to replace beryllium as the leading radiator material candidate. PWC-11 has demonstrated a five- to six-fold improvement over Nb – 1Zr at 1500 K. Tungsten niobium composites offer another two- to three-fold strength gain over PWC-11, if joining and fabrication issues can be resolved.

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# Science Sensor Technology



*Laser Atmospheric Wind Sounder (LAWS)*

The goal of the Science Sensor Technology program is the development of critical technologies in support of space remote-sensing disciplines. The missions supported by these technologies include both terrestrial and astrophysical observations planned for the late 1990s and beyond.

The technology areas in this element focus on the development of advanced solid state imaging arrays, detectors and sensor systems, together with the cryogenic systems needed for long-life, low-temperature operation. Specifically, there are four mission-driven elements designed to reflect all aspects of remote sensing:

- Passive Noncoherent Systems (infrared detection)
- Passive Coherent Systems (submillimeter-wave detection)

- Active Systems (lidar)
- Cryogenic Systems

The technology resulting from these research elements supports a broad array of sensing requirements for advanced missions such as the following:

- The Large Deployable Reflector (LDR)
- The Space Infrared Telescope Facility (SIRTF)
- Mars Rover Sample Return (MRSR)
- Comet Rendezvous Asteroid Flyby (CRAF)
- The Lidar-In-Space Technology Experiment (LITE)

Also supported will be the Earth Observing System (EOS), whose requirements involve several instruments:

- The Lidar Atmospheric Sounder and Altimeter (LASA)

- The Laser Atmospheric Wind Sounder (LAWS)
- The Geodynamics Laser Ranging System (GLRS)
- Spectroscopy of the Atmosphere Using Far Infrared Emissions (SAFIRE)

## Deliverables

The Science Sensor Technology element will demonstrate advanced detector systems for the space environment that provide maximum detector quantum efficiency with the following:

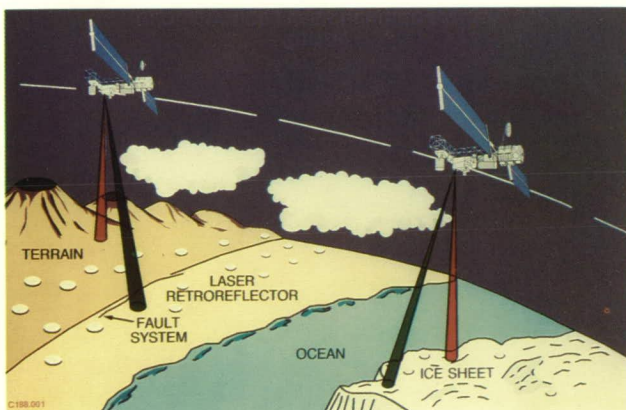
- Low-noise (<100 electrons/pixel), 30- $\mu\text{m}$  detector arrays
- Far-infrared to 300- $\mu\text{m}$  cutoff wavelength. A submillimeter sensing capability for observing clouds of interstellar dust will be provided, with superconductor-insulator-superconductor (SIS) mixer arrays to 1 THz

The element will demonstrate tunable, solid state, gaseous (eye-safe) laser technology for the continuous coverage of the electromagnetic spectrum in order to achieve

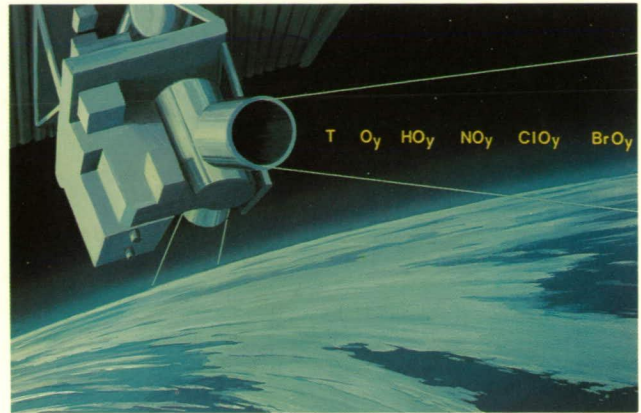
- 25–10,000-nm range
- 10 J/pulse
- 10-Hz repetition rate
- $10^9$ -pulse lifetime

In addition, an advanced cryogenic cooling system will be developed to survive the space environment and to provide

- Passive cooling for  $T < 70$  K
- Vibration-free coolers for  $T < 1$  K



Geodynamics Laser Ranging System (GLRS) collecting geophysical data

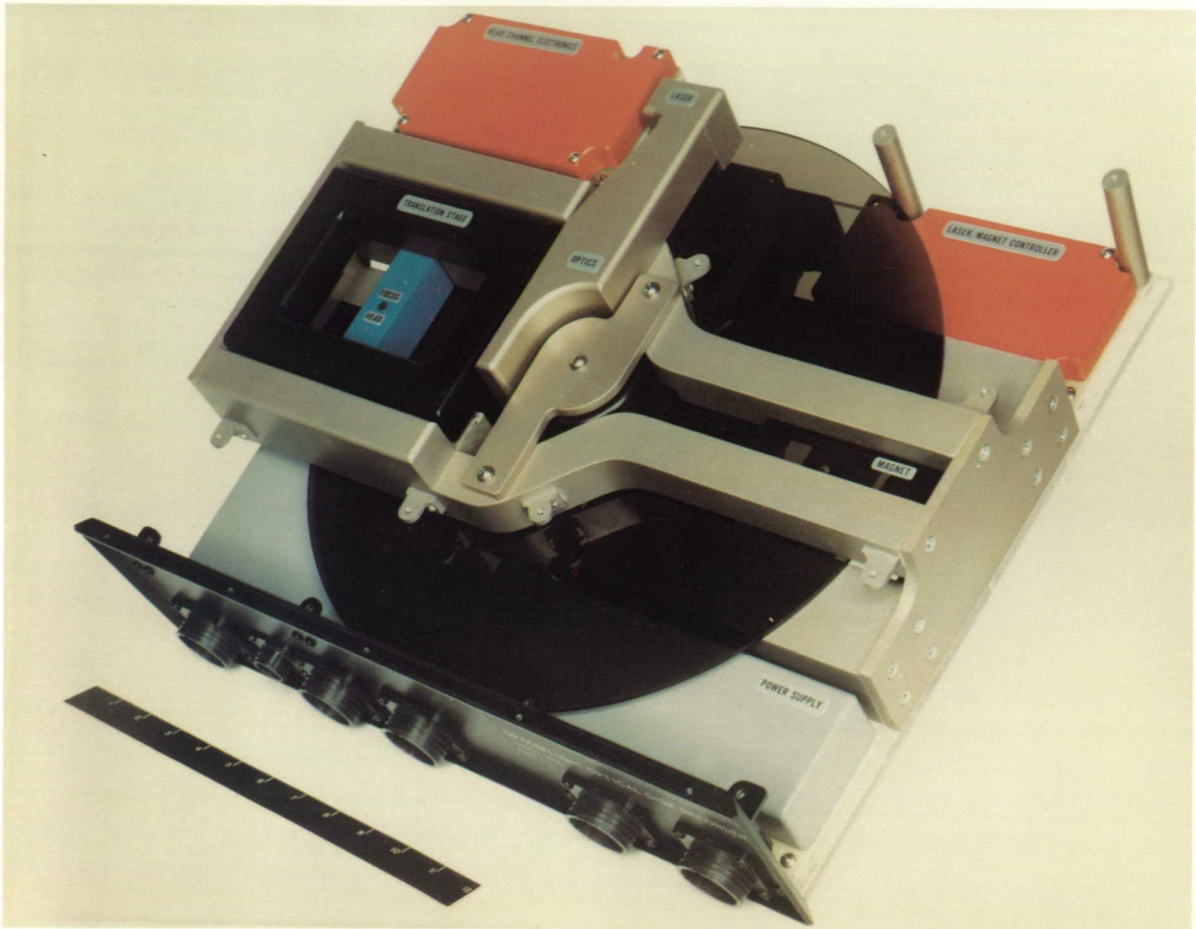


Spectroscopy of the Atmosphere Using Far Infrared Emissions (SAFIRE)

## Accomplishments

Recent accomplishments and breakthroughs in the Science Sensor Technology Program include technology development in several areas:

- Germanium blocked impurity band (BIB) detectors with far-infrared coverage, quantum efficiency, and dark-current performance, and optimized, backside-illuminated, BIB, arsenic-doped, radiation-hardened, silicon arrays for infrared astronomy, both for the SIRTIF mission
- A titanium-doped sapphire for LITE
- The first laser-diode pumped, room-temperature, single-frequency, holmium:yttrium aluminum garnet (YAG) laser system for mid-infrared sensing
- A silver gallium selenide optical parametric oscillator tunable from 2.6–5.1  $\mu\text{m}$
- Far-infrared Fabry-Perot filters operating over a broad spectral region (25–150  $\mu\text{m}$ )
- Room-temperature mercury iodide detectors/spectrometers for X-ray, gamma ray, and charged-particle sensing
- Carbon dioxide laser local oscillators with a ten-fold improvement in size and weight over comparable systems
- Diode-pumped neodymium:YAG laser altimeter transmitters for laser ranging and altimetry
- The first superconductor mixers at 200-GHz use
- Gallium arsenide/aluminum arsenide quantum-well devices for 600-GHz use
- Room-temperature, 2.1- $\mu\text{m}$  laser diodes with gallium antimonide and aluminum gallium arsenic antimonide active layers
- Operational  $^3\text{He}$  liquid refrigerant coolers in a zero-gravity environment using a sounding rocket



*Spaceflight Optical Disk Recorder (SODR) — High-rate, high-capacity data storage has been identified as an enabling capability for Earth observation and geostationary missions in the 1990s and beyond.*

The goal of the CSTI Data Systems element is to develop the high-speed, high-volume, data-handling technologies and systems that will be needed to meet the scientific and operational requirements of future missions. Missions such as the Earth Observing System (EOS), for instance, will generate large amounts of data.

To ensure high scientific returns while keeping operational costs low, it will be necessary to perform recognition, extraction, and transmission of significant observations on board the space-

craft. The Data Systems element consists of six subelements designed to meet this requirement:

- High-Rate System Architecture Definition
- Special Purpose Processor
- General Purpose Computer
- Data Storage Devices
- Storage Technology Development Testbed
- Onboard Processing Testbed
- High-Speed Fiberoptic Transceiver

## Deliverables

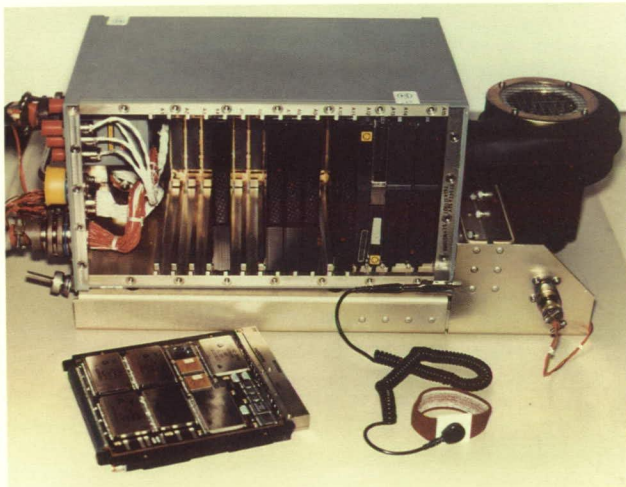
The Data Systems element will produce advanced image processors that interface with the high-rate sensors and onboard intelligent systems in order to provide

- Gflop/sec processing capability
- Lossless, 2:1 data-compression capability
- High-rate (up to 30:1), limited data-loss compression

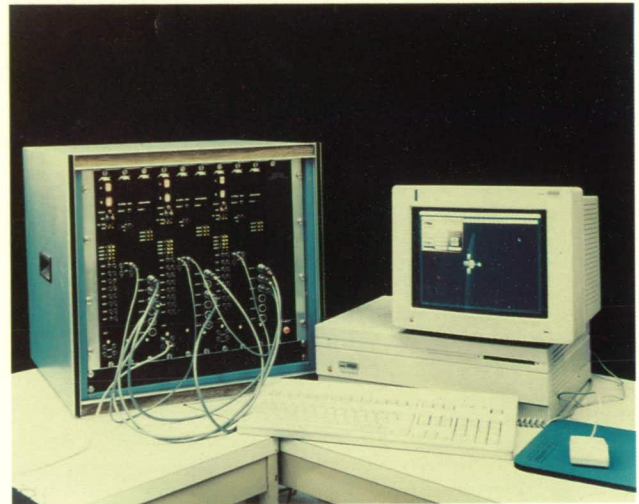
In addition, a high-rate optical disk recorder element for an onboard data storage system will be developed that is based on a 300-Mbps, 10-Gbyte drive and that supports expandable system architecture with a transfer rate up to  $2 \times 10^9$  byte/sec and a storage capability of  $1.2 \times 10^{12}$  bits.

A testbed will be developed that provides connectivity for CSTI technology components to evaluate the performance of the following:

- The 100-Mb/sec control network
- The Gflop/sec point-to-point, high-rate data network
- The control and high-rate image processor



*Very High Speed Integrated Circuit (VHSIC) Multiprocessor for real-time graph management multiprocessor technology for enhanced VHSIC performance in future NASA missions*



*Max — Flight Multicomputer to support large, heterogenous tasks in an unpredictable, event-driven environment*

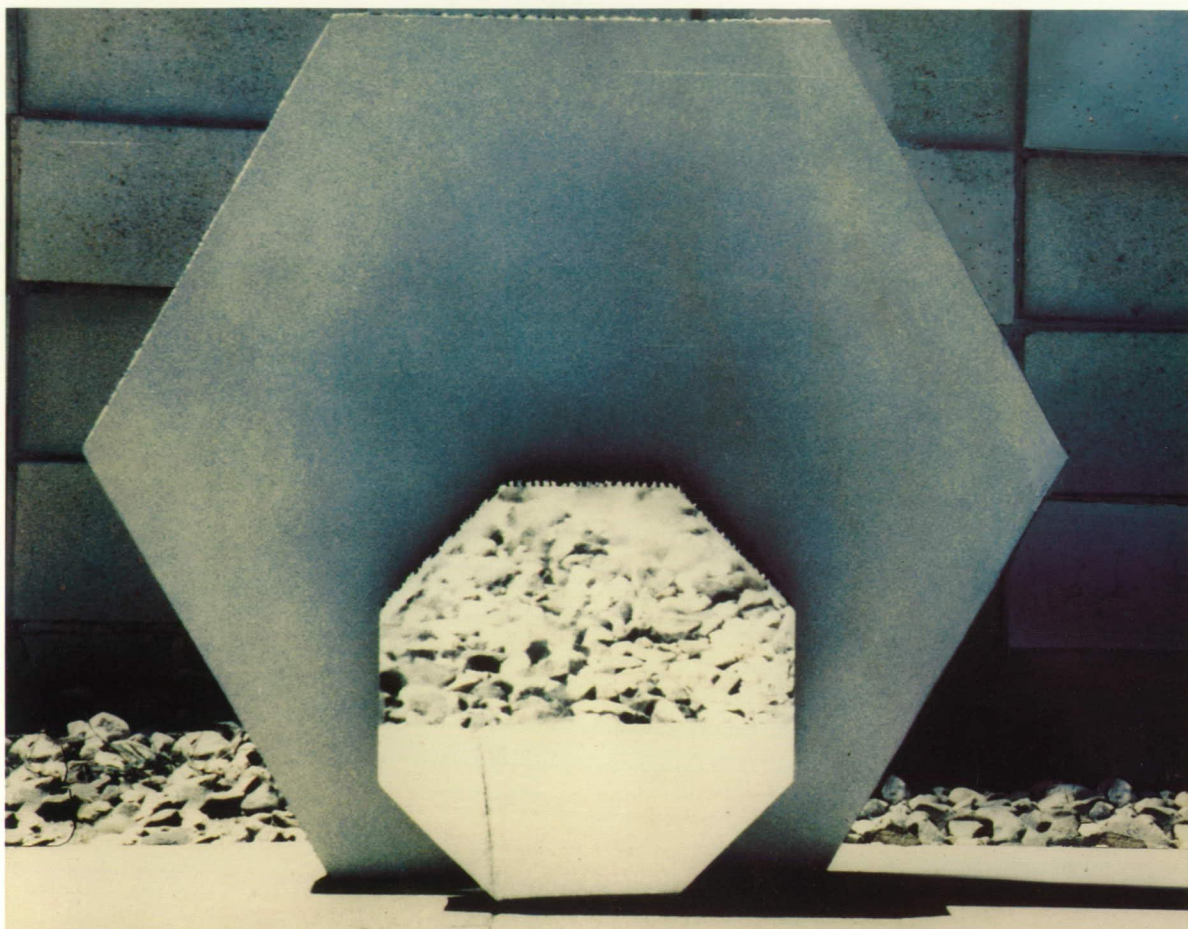
## Accomplishments

To date, work in the Data Systems element has resulted in

- Demonstration of a four-node multicomputer
- Operation of the ECL autocorrelator chip
- Demonstration of the signal conditioner
- Design of the SAR preliminary architecture
- Demonstration of an initial graph-management multiprocessor approach
- Development of a theoretic-based concept for execution of data-driven algorithm graphics
- Completion of initial designs for a high-speed fiberoptic transceiver
- Evaluation of the performance of an AT&T prototype front-end transceiver design
- Design of a high-rate system architecture and initial testbed

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## Precision Segmented Reflectors



*0.9-m and polished, small-scale, lightweight reflector panels (aluminum honeycomb core with composite facesheets — accurate to less than 3  $\mu\text{m}$  as manufactured)*

Future space observatories will be much larger than current systems and will provide new information about the basic development and structure of the universe that cannot be observed through Earth's atmosphere. In particular, observatories operating in the submillimeter spectrum may have primary apertures as large as 20 m across. Space-based instruments such as these cannot be built on Earth or placed in orbit in any practical manner using the available technology. The Precision Segmented Reflector (PSR) element of CSTI will develop materials, structures, and a control technology that enable the design and on-orbit construction of large, lightweight, orbiting observatories.

The concept of a segmented reflector is to build a very large aperture (10–20 m across) from an array of smaller segments. This approach has been developed for terrestrial application using

heavy glass and steel construction; it was proposed in the early 1980s as a way to build large telescopes in space. However, Earth-based telescope technology is not compatible with either launch-vehicle constraints or the cost and operational requirements of space missions.

During its planned four-year duration, the PSR program is focused on requirements for medium-sized and very large submillimeter telescopes. This class of instruments currently has the earliest "need date" for PSR technology, with a clear set of requirements. PSR is developing new technology in the areas of precision reflector panels, multi-panel controls, and precision backup structures; the program will demonstrate this technology in a systematic manner to validate the capability to design, build, and control a large, lightweight, segmented reflector.

Precision composite honeycomb panels about a meter in size are being developed that will weigh only about 5 kg/m<sup>2</sup>, have a surface accuracy to within 3-μm RMS, and be environmentally stable in space. This activity involves the development of advanced materials, specialized structural design methods, and fabrication methods that assure the accuracy and reproducibility of curved panels. Controls concepts including sensors, actuators, and algorithms are being developed that can keep the individual panels aligned to maintain an overall surface accuracy of 5-μm RMS over the entire reflector surface. An erectable precision truss concept is also being developed to support the entire reflector system.

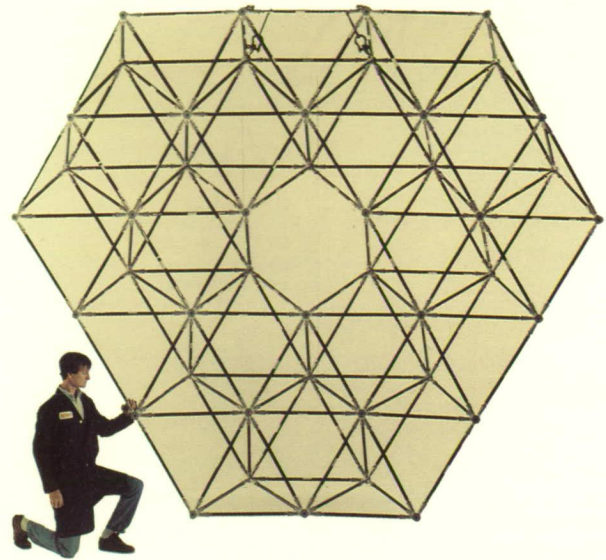
### Deliverables

The PSR element will provide

- Environmentally stable, reproducible, lightweight reflector panels for both low and high Earth orbit. The panels will feature
  - 3-μm RMS surface precision, < 10 kg/m<sup>2</sup> specific weight
  - 3.0–7.5-m radius of curvature
- A validated, multipanel, figure initialization and figure maintenance concept
- A 4-m precision erectable support structure with active damping and an 8-m large-scale support structure

### Accomplishments

One-meter panels with 7.5-m radius of curvature have been fabricated with a measured surface accuracy of 1.7-μm RMS. These are the most precise, lightweight, curved reflector panels produced for intended use in space.



*Small-scale, precision, erectable parabolic truss (approximately 75-μm RMS over 4 m)*

An overall, multipanel, figure-control system has been designed, and a submillimeter-panel position-sensing method based on laser interferometry has been demonstrated. A soft, voice-coil actuation method that can damp spurious vibration along with precisely positioned panels has also been demonstrated. The system and hardware concepts are designed to meet requirements for in-space use and on-orbit installation.

A 4-m parabolic erectable support truss concept has been developed and tested. Surface precision is on the order of 100 μm. A 20-m scaled version of this concept using the same design methods would be accurate to less than a millimeter. The truss would weigh about 2.5 kg/m<sup>2</sup> and could easily be assembled in space. In addition, active strut members with 10-percent critical damping have been developed to suppress modal vibration in the truss as well as low-frequency, system-level disturbances.

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## *Summary*

The Civil Space Technology Initiative is targeted at the development of specific technologies vital to the next generation of NASA and other U.S. space projects. CSTI challenges and encourages not only NASA, but the country's aerospace industry and academic community as well. CSTI, like the longer range, exploration-oriented Exploration Technology Program, is critical to the continuation of a vigorous space program that remains a source of national pride.

For additional information on the CSTI program, please contact the following:

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