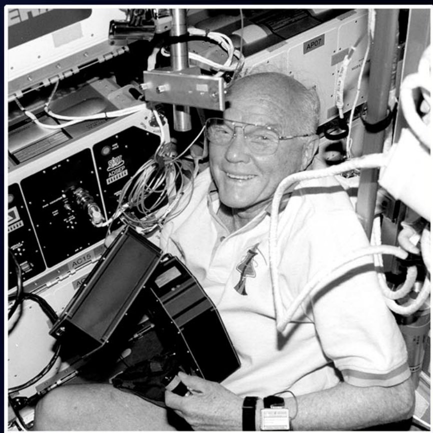
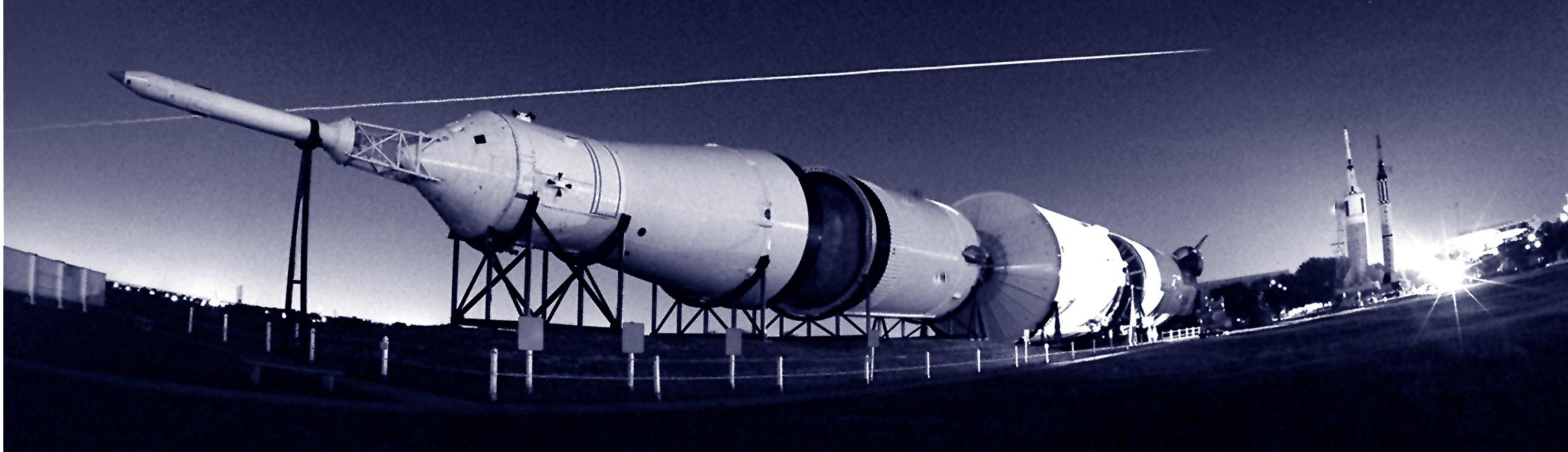


Johnson Space Center Research & Technology Annual Report 1998-1999



NASA Technical Memorandum TM–2000-209904

Foreword

NASA is an investment in America's future. As explorers, pioneers, and innovators, we boldly expand frontiers in air and space to inspire and serve America and to benefit the quality of life on Earth.

- NASA Policy Directive 1000.1

As the principle center for NASA's Human Exploration and Development of Space (HEDS) Enterprise, the Johnson Space Center (JSC) leads NASA development of human spacecraft, human support systems, and human spacecraft operations. An important element in implementing this mission, JSC has focused on developing the infrastructure and partnerships that enable the technology development for future NASA programs.

In our efforts to develop key technologies, we have found that collaborative relationships with private industry and academia strengthen our capabilities, infuse innovative ideas, and provide alternative applications for our development projects. The American public has entrusted NASA with the responsibility for space technology development, and JSC is committed to the transfer of the technologies that we develop to the private sector for further development and application. It is our belief that commercialization of NASA technologies benefits both American industry and NASA through technology innovation and continued partnering.

To this end, we present the 1998-1999 JSC Research and Technology Report. As your guide to the current JSC technologies, this report showcases the projects in work at JSC that may be of interest to U.S. industry, academia, and other government agencies (federal, state, and local). For each project, potential alternative uses and commercial applications are described.

To aid in your search, projects are arranged according to the Major Product Groups used by CorpTech to classify and index types of industry. Some projects fall into multiple categories and are placed under the predominant category, for example, an artificial intelligence project is listed under the Computer Software category, while its function is to automate a process (Automation category). So, take a look through each section to make sure you haven't missed something of interest.

When you find a technology of interest, the JSC Technology Transfer and Commercialization Office is available to assist you in obtaining additional information and for forming a relationship with JSC for utilizing or expanding a technology. Depending on the particular technology, there are possibilities for licensing or sublicensing the technology for your own continued development, entering into Reimbursable Space Act Agreements for the use of unique JSC facilities or capabilities, entering into Non-reimbursable Space Act Agreements for joint development of a technology, and obtaining public domain information including software for use by your business. I urge you to contact the technical point of contact listed for each project regarding specific technical information on the technology and the Technology Transfer and Commercialization Office for information on the technology transfer process and opportunities. They can be reached at:

Technology Transfer and Commercialization Office
Mail Code HA
NASA Johnson Space Center
Houston, Texas 77058
Phone: (281)483-3809
Fax: (281)244-8452
Email: commercialization1@jsc.nasa.gov
Internet: http://technology.jsc.nasa.gov

Thank you for taking the time to review the JSC technologies. I hope you find an area of mutual interest that we can work together to develop for the future.

George W.S. Abbey

George W.S. Abbey
Director, Johnson Space Center

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Transportation

AUTOMATION

Robonaut – Robotic Astronaut Assistant

Robonaut – Robotic Astronaut Assistant

Background

Existing International Space Station (ISS) robots (special purpose dexterous manipulators and Space Station remote manipulator systems (SSRMSs)) may not be sufficient for long-term ISS support because they: (1) require additional special alignment targets and grapple fixtures; (2) are too large to fit through tight extravehicular activity (EVA) access corridors; and (3) are incapable of the fine motion and dexterous manipulation required to handle small and complex items, soft and flexible materials, and most common EVA interfaces. Moreover, the teleoperation controls for these robots, which consist of flat panel monitors and joystick-like hand controllers, are not ideal for coordinating the high level of dexterity required to meet these complex tasks for future missions.

The Robonaut Team is designing, developing, and testing a highly dexterous teleoperated system that can fill this new niche, augmenting the capabilities of larger robots and serving in the role of astronaut assistant. Key engineering challenges to the development of a robotic astronaut assistant (the Robonaut) have been to design for the space environment, develop a dense packaging of mechanisms and avionics that can equal human scale, design an arm and hand system that can work with EVA tools, and develop a control system that includes telepresence immersion for human control of the system.

Project Overview

To meet these requirements, the Robonaut system is being developed as an astronaut surrogate capable of performing high-payoff EVA tasks and providing a "Minuteman"-like response for EVA contingencies. The Robonaut concept is centered on an anthropomorphic robot, similar in size to a suited EVA astronaut, and includes two 7-degrees-of-freedom (DOF) arms; two 12-DOF multi-finger robotic hands; a 7-DOF "stinger tail"; a 4-DOF stereo camera platform; and an 18-DOF telepresence immersion system for operator tracking.

The robotic arms are capable of dexterous, humanlike motion, and are designed to be rugged, safe, and reliable. They are also designed to handle common EVA tools such as a handling tool (the "ice cream scoop"), grasp irregularly shaped objects, and handle a wide spectrum of tasks requiring humanlike dexterity. For stabilization, the Robonaut will plug its stinger tail into worksite interface sockets located around the ISS. This device can potentially be carried by the crew equipment translation aid to various EVA worksites, or it can be picked up by the SSRMS for end-of-arm tasks. The Robonaut will be teleoperated by a crewmember inside the ISS using telepresence equipment, such as a head-mounted display, tracker sensors, virtual reality gloves, or force-reflective arm and hand masters.

Benefits and Uses

The Robonaut will be very different from its predecessors in both capabilities and operations. Through combining advanced dexterous robotics, telepresence, and flight designs, the Robonaut is expected to significantly improve the effectiveness and safety of ISS external operations as well as future Human Exploration and Development of Space [HEDS] missions. This technology can be applied to hazardous material handling and to disarming mines and explosives, and it can be used in assistive roles such as an arm or a hand prosthesis.

This technology has been disclosed as a new invention and patents are in progress.

For further technical information, contact Dr. Robert Ambrose at (281) 244-5561 or robert.o.ambrose1@jsc.nasa.gov.
For technology transfer assistance, contact Kelle Pido at (281) 483-1348 or kelle.i.pido1@jsc.nasa.gov.

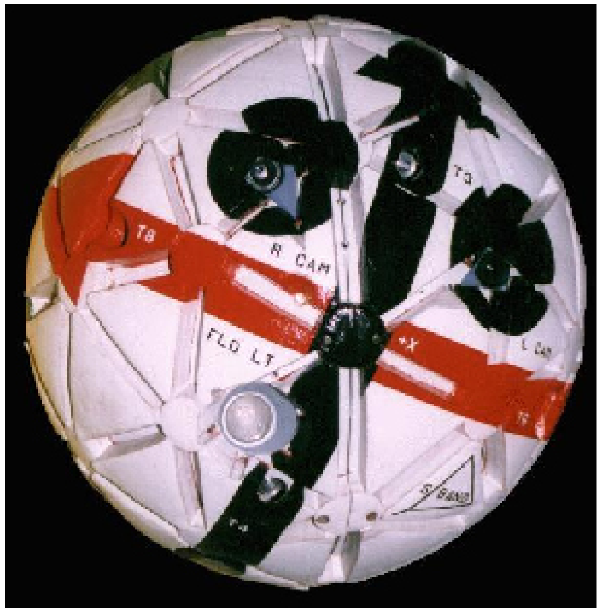

Figure 1. AERCam Sprint free-flyer

Figure 2. AERCam Sprint on STS-87

Autonomous Extravehicular Robotic Camera

Autonomous Extravehicular Robotic Camera (AERCam)

Background

External views of the Space Shuttle, International Space Station (ISS), and future Lunar/Mars transfer vehicles are required to assist onboard crews and ground flight controllers in performing the visual inspections associated with assembly, maintenance, and servicing tasks. Related nonvisual inspection requirements include chemical leak detection, thermal mapping, and structural vibration measurements.

To supplement the existing camera infrastructure and develop a versatile positioning system for nonvisual sensors, the Johnson Space Center (JSC) Automation Robotics and Simulation Division has led the effort to develop an autonomous extravehicular robotic camera (AERCam) (fig. 1) – a low-volume, low-mass, free-flying camera system that can be remotely controlled by a crewmember in order to provide a bird's-eye view.

Project Overview

The AERCam program began with the AERCam Sprint, a 35-lb, 14-in. diameter spherical robot flown in December 1997 as a flight experiment on STS-87 (fig. 2). This 75-minute Sprint test successfully demonstrated the feasibility of teleoperating a free-flying robotic camera in close proximity to the Space Shuttle and to crewmembers performing extravehicular activities (EVAs). This flight was followed by an integrated ground demonstration of enhanced AERCam features for autonomous inspections in March 1998. In the second half of 1998, a conceptual design for an AERCam that would support the ISS was developed. This design capitalized on technology from the Sprint flight experiment and subsequent ground demonstration. A crew evaluation, performed in the Virtual Reality Laboratory (VRL) at JSC and culminating in early 1999, generated a set of crew recommendations for performing inspection missions with the AERCam free-flyer.

The conceptual design of the ISS AERCam and results of the VRL crew evaluation will form the basis for the future in-house or commercial development of an ISS AERCam system.

Benefits and Uses

Because AERCam is a free-flyer, it can provide views unobtainable from fixed cameras, cameras on robotic manipulators, or cameras carried by EVA crewmembers. For example, on ISS the AERCam can supplement camera coverage for robotic berthing and maintenance operations. It can also can enhance EVA productivity by performing visual/nonvisual inspections prior to (or in lieu of) EVA and relieving EVA crewmembers of closeout documentation duties at the end of an EVA.

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BIOTECHNOLOGY

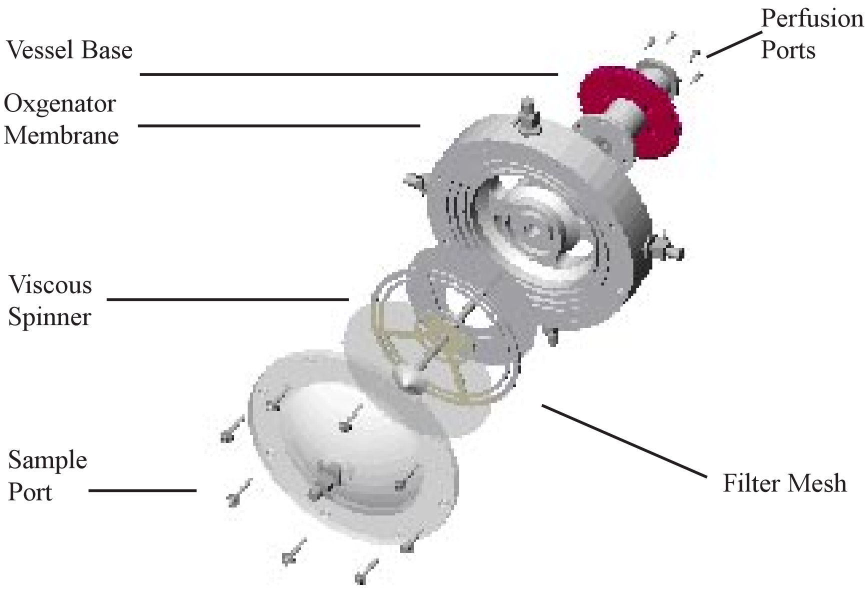

Figure 1. HFB produces a controllable hydrodynamic focusing force.

Figure 2. *En face* view of HFB vessel with suspended baby hamster kidney cells.

Hydrofocusing Biorector

Hydrofocusing Bioreactor (HFB)

Background

Johnson Space Center's (JSC's) successful championship of the design, development, and operation of space bioreactors capable of overcoming gravity-induced limitations has spawned a unique biotechnology for 3-dimensional cell cultures and tissue engineering – the hydrofocusing bioreactor (HFB). This action was necessary because, to date, the on-orbit formation of air bubbles in a culture fluid and attempts to remove those bubbles from the fluid medium of NASA's rotating wall space bioreactors have degraded both the low-shear culture environment and delicate 3-dimensional tissues. Engineering attempts to resolve this issue with the current space bioreactor have proven unsuccessful.

The HFB (figs. 1 and 2), which uses the principle of hydrodynamic focusing, overcomes these limitations while meeting operational and science requirements on orbit. It does this by simultaneously producing a low-shear fluid culture environment and a variable hydrofocusing force that can control the movement, location, and removal of suspended cells, tissues, and air bubbles from the bioreactor.

Project Overview

The HFB project was undertaken to provide a low-shear bioreactor system for long-duration operations in the low-gravity environment onboard orbiting spacecraft. To this end, the HFB will support 3-dimensional cell culture and tissue engineering in a low-shear fluid environment. It achieves this by creating hydrodynamic forces that "herd" biological samples and air bubbles to the sampling port for easy removal without degrading either the low-shear fluid environment or delicate samples.

This new bioreactor is a rotating, dome-shaped cell culture vessel with a centrally located sampling port and an internal viscous spinner. In it, a vessel and a spinner can rotate at different speeds and in either the same or opposite directions. Rotation of the vessel and viscous interaction at the spinner generate a hydrofocusing force where the magnitude of the force is controlled by adjusting the differential rotation rate between vessel and spinner.

HFB has successfully cultured anchorage-dependent and suspension cells, genetically engineered cells, transformed cells, and primary cells. Air bubbles have been focused to the central sampling port for removal without degrading the low-shear fluid environment.

A flight prototype has been built and tested on the KC-135; this prototype will be evaluated on the Space Shuttle. Specific cell culture and tissue engineering experiments will also be conducted in the HFB to further characterize the system and establish a scientific baseline.

Benefits and Uses

The HFB, an enabling technology for 3-dimensional cell culture and tissue engineering investigations, can be used in laboratories on Earth and on orbiting spacecraft. Through use of this technology, new vistas will open in the human understanding of basic cell function and 3-dimensional tissue engineering as related to the basis of disease, tissue modeling, and drug development. In its support of 3-dimensional cell culture and tissue engineering, the HFB has widespread applications in tissue modeling and replacement and future investigations onboard the International Space Station (ISS) in the ISS Biotechnology Facility.

HFB is currently licensed through Wyle Life Sciences to CelDyne (Houston, Texas).

For further technical information, contact Dr. Steve Gonda at (281) 483-8745 or steven.gonda1@jsc.nasa.gov.
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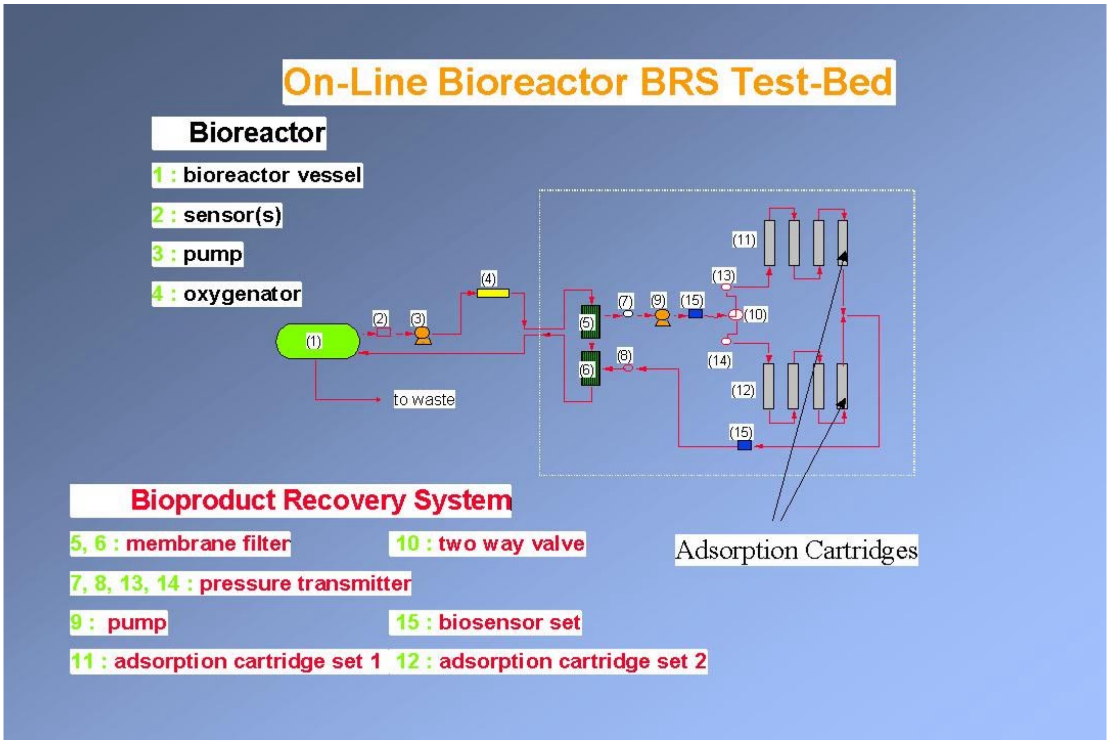


Figure 1. Online bioreactor BRS testbed

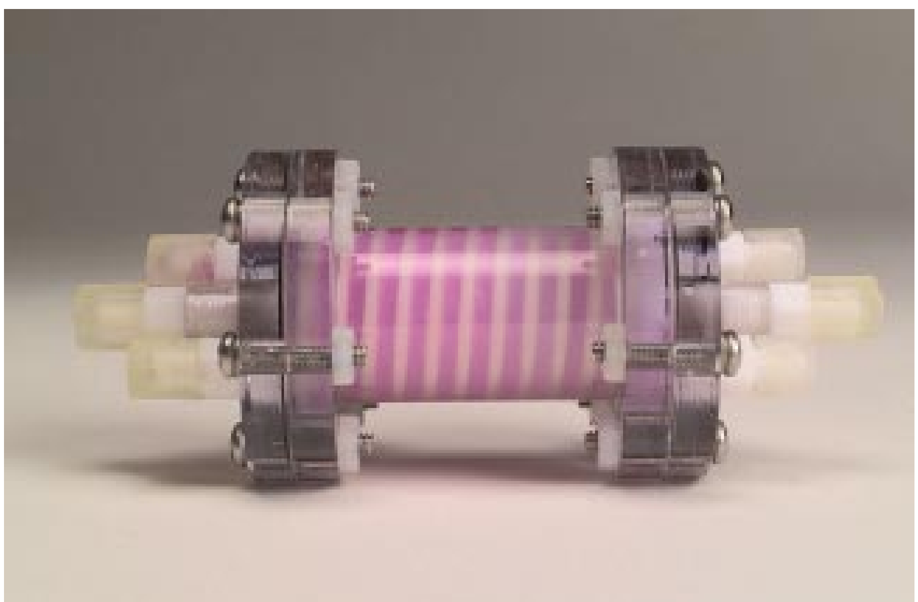


Figure 2. BRS centrifugal adsorption cartridge. Bioproducts are captured as bioreactor fluid flows through specific absorbents

Bioproduct Recovery System

Bioproduct Recovery System (BRS)

Background

A major focus of Johnson Space Center's Biotechnology Cell Science Program is the development of space bioreactors that can be used onboard spacecraft to overcome gravity-induced limitations in cell culture and tissue engineering. Although the current generation of space bioreactors can support some aspects of long-duration cell cultures, they cannot be used to separate and preserve or remove bioproducts. Some of the bioactive molecules present in trace quantities in bioreactors are valuable, while other biomolecules can act as cell inhibitors and will either lead to termination of the cellular production of desired molecules or to cell death.

Project Overview

The purpose of this project is to develop a bioproduct recovery system (BRS) that allows the selective removal of molecules of interest from space bioreactors. The BRS (fig. 1) is designed to target specific biomolecules or waste products, continuously adsorb and separate biomolecules from dilute bioreactor effluents, and stabilize and preserve targeted bioproducts.

A cartridge system, BRS integrates into the space bioreactor perfusion loop. Culture media from the space bioreactor flow from the perfusion loop into the BRS cartridges (fig. 2), each of which is packed with an adsorbent that selectively binds, separates, and retains bioproduct(s) of interest. Each BRS, in turn, contains several adsorption cartridges which hold specific-affinity adsorbents for targeted biomolecules or waste products. During bioreactor operations as the BRS cartridges become fully saturated with target bioproducts, they can be removed for storage or processed further. Further processing may involve flushing saturated cartridges with solutions to stabilize the structural integrity and functional activity of the bound bioproducts. The BRS is miniaturized to meet volume and power constraints and operate in the low-gravity environment of space.

The BRS concept revolves around two distinct systems: (1) an online system, in which bioreactor media continuously flow through BRS cartridges; and (2) a downstream system, in which bioreactor-spent media flow in a single pass through the cartridges. Each BRS cartridge is then packed with a solid phase affinity absorbent which specifically binds the target bioproduct.

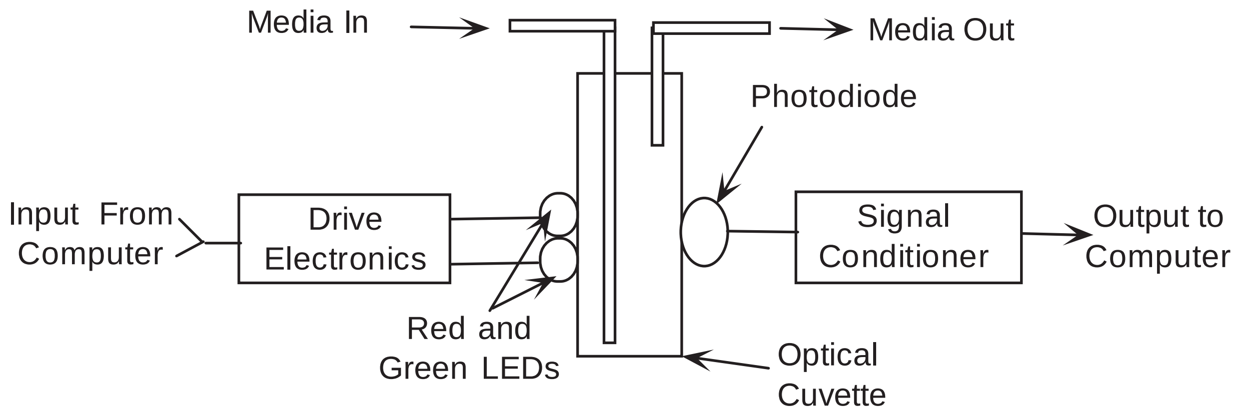
BRS has successfully operated in the range of space bioreactor flow rates, where it has efficiently captured the recombinant protein beta-galactosidase produced in a bioreactor by SF-9 insect cells.

Benefits and Uses

The National Research Council has identified a need to separate and preserve technologies that allow the recovery of high-value biomolecules from dilute aqueous sources, such as bioreactors. Use of a BRS on orbit will enhance the science returns and commercial potential of long-duration experiments in space bioreactors in the International Space Station's BioTechnology Facility. The BRS will also serve as the basis of an enabling technology for NASA's Human Exploration and Development of Space enterprise for on-orbit recovery of valuable products from aqueous resources.

This technology has been submitted as a new invention disclosure.

For further technical information, Dr. Steve R. Gonda at (281) 483-8745 or steven.gonda1@jsc.nasa.gov.
For technology transfer assistance, contact Kelle Pido at (281) 483-1348 or kelle.i.pido1@jsc.nasa.gov.



Optical pH Sensor

Optical pH Sensor

Background

The successful operation of space bioreactors depends, in part, on monitoring and controlling the pH in culture fluids. Measurements of pH in culture fluids should be conducted without compromising the sterility of a bioreactor and, preferably, by using a noninvasive approach. In short-term Space Shuttle missions as well as long-duration cell culture and tissue engineering investigations in space bioreactors, automated sensor technology will be critical to minimizing crew time. A reliable pH sensor that satisfies the above requirements is needed to support NASA's goals for long-duration, continuous bioreactor operations in the BioTechnology Facility onboard the International Space Station.

Although pH sensors based on electrochemical and field effect transistor technologies are often used in commercial biotechnology, they need frequent calibration and are difficult to sterilize. The optical pH sensor – developed at the Johnson Space Center – continuously measures cell culture media pH in a perfused bioreactor system to an accuracy of within $\pm$0.1 pH unit in a pH range between 6.5 and 7.5 and with a single calibration. The principal method used here measures the light absorption characteristics of an organic dye present in media.

Project Overview

An optical pH sensor was developed that could continuously measure the pH of media in the perfusion loop of a rotating-wall bioreactor. The constructed sensor consisted of a light source, an optical flow cell, and an internally amplified photodiode. The illumination source is a pair of light-emitting diodes (LEDs). Each LED can emit either a green light (wavelength maximum of 558 nm) or a red light (wavelength maximum of 625 nm). The flow cell is an optical quality quartz cuvette with a self-masking window. After the pH sensor measures the light absorption characteristics of organic dye present in the media, the ratio of intensity of the transmitted green and red lights is correlated to the pH of the solution. The sensor can then be sterilized using an autoclave or ethylene oxide in a stand-alone or a complete bioreactor configuration mode.

The noninvasive optical pH sensor was tested with a rotating-wall perfused vessel bioreactor system using a baby hamster kidney [BHK-21] cell line for 124 days. A single set of calibration data was used for the pH sensor during the 124-day period. The pH measured by the pH sensor was compared with the solution pH measured by a fiber optically coupled Shimadzu spectrophotometer and blood gas analyzer (BGA). The error in measuring pH using the pH sensor, as compared to a BGA, was $\pm$0.1 pH unit.

New-generation LEDs with stable light output in the 560 nm region will be used for probe light illumination to improve this technology.

Benefits and Uses

The optical pH sensor can measure the pH of media in a perfusion loop of bioreactors. These bioreactors, manufactured by Synthecon Inc., Houston, Texas, are being used extensively in national and international laboratories.

This sensor technology has been submitted as a new invention disclosure.

For further technical information, contact Antony S. Jeevarajan at (281) 483-4298, antony.s.jeevarajan1@jsc.nasa.gov and Melody M. Anderson at (281) 483-3318, melody.anderson1@jsc.nasa.gov.
For technology transfer assistance, contact Kelle Pido at (281) 483-1348 or kelle.i.pido1@jsc.nasa.gov.

Electrically Potentiated Growth of Mammalian Neuronal Tissues Facilitated by Rotating-Wall Vessel Culture

Electrically Potentiated Growth of Mammalian Neuronal Tissues Facilitated by Rotating-Wall Vessel (RWV) Culture

Background

Development and differentiation of 3-dimensional tissues in rotating-wall vessels (RWVs), also known as the bioreactor, has been achieved for some mammalian and non-mammalian tissues. These tissues have developed functional capabilities but, as with all normal tissues, they grow extremely slowly. So, development of an enhanced methodology technology that will increase the rate of normal cell growth to one approaching growth in the *in vivo* environment is of paramount importance.

Current research and testing with regard to development of methodologies to culture 3-dimensional functional tissues, especially neuronal tissues, has been constrained by: (1) the lack of a suitable environment in which to culture large-scale 3-dimensional tissues – i.e., the RWV; and (2) an inability to stimulate and enhance the growth rate of tissues, specifically neuronal tissues, with regard to electrical rather than chemical stimulus.

Project Overview

This project seeks to couple the proven technology of the RWV and 3-dimensional functional tissues with the addition of electrical potentiation across a solid substrate to provide enhanced growth rates and directionally oriented tissues in order to construct finite structures adaptable to neuronal transplantation. Preliminary work on electrical potentiation of tissue has been experimented with since the early 1980s; however, the development of a successful model that will demonstrate growth differentiation and the ability to transplant neuronal tissue has been unsuccessful owing to an inability to construct a model with appropriate stimulus in a 3-dimensional aspect.

The completion of such a model in a 3-dimensional RWV environment will allow the development of directionally oriented neuronal tissues, increased growth rates, and functional capabilities for transplantation, all of which will augment the replacement, repair, and stimulation of damaged neural tissues.

Moreover, this technology will lead to an advance in the already existing state-of-the-art technology in RWV cellular construction and move that technology beyond its present boundaries for development of fragile tissues.

Benefits and Uses

This technology will produce a complex 3-dimensional *ex vivo* model where none exists today to study neural response to external stimuli and illuminate areas of neural development. Through these studies, an ability to culture and produce functional and potentially transplantable neural tissues should emerge. As a result, neural trauma that results from accident (i.e., spinal cord damage) and disease – in many cases is now irreparable – may be ameliorated with corrective techniques at the cellular level that will replace or speed recovery of these damaged tissues.

Long-range application of this technology may lead to an understanding of the methods by which neural tissues retain and convert electrical potential to chemical memory and how that memory is stored in 3-dimensional neural tissue.

For further technical information, contact Thomas J. Goodwin at (281) 483-7129 or thomas.j.goodwin1@jsc.nasa.gov.
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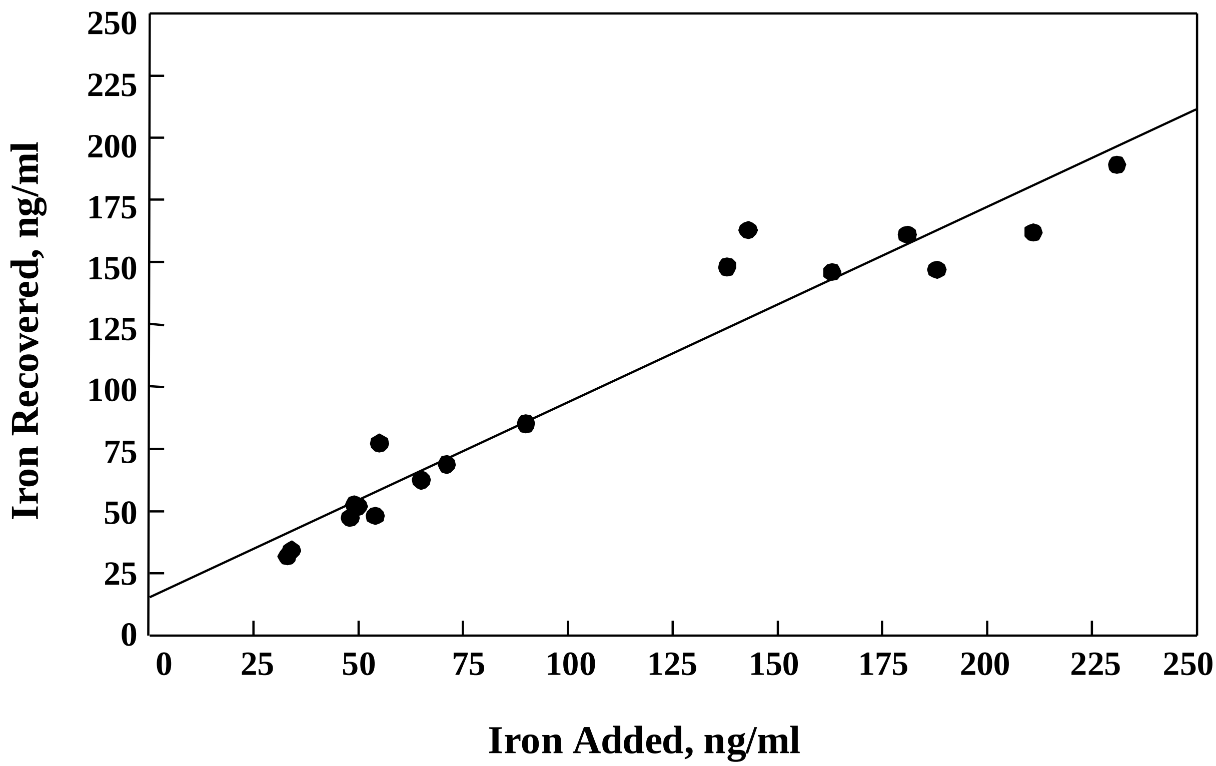


Results of validation studies: satisfactory performance for spiked recovery and linearity.

Determination of Ferritin Iron by Inductively Coupled Plasma Mass Spectrometry

Determination of Ferritin Iron by Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

Background

Serum ferritin determinations are today used to assess iron stores in humans. Low levels of ferritin indicate the first stages of iron depletion. High serum ferritin levels may indicate a potentially fatal disease – hereditary hemochromatosis – which is characterized by progressive organ damage. Serum ferritin is also an acute phase reactant; and, as such, it may be elevated in response to an inflammatory process. In these cases, the elevated ferritin is actually apoferritin, which is the ferritin protein with very little iron in it, and is thus not a good measure of body iron stores.

Project Overview

Assessment of iron status and determination of dietary iron requirements are critical for maintaining crew health on extended-duration spaceflights. As suggested by elevated serum ferritin, elevated iron stores have been observed during spaceflight. This elevation continues well beyond the initial adaptation of blood volume to weightlessness and in iron stores may lead to oxidative damage – a great concern for exploration missions where radiation exposure will increase. In addition to increased serum ferritin, there is an increase in other serum proteins such as C3 complement and cortisol, indicating an inflammatory or stress response. Since inflammation is a confounding variable when are determining iron status based on serum ferritin levels, being able to measure the iron content in ferritin itself may overcome this problem. This would make it possible to distinguish between increased ferritin levels due to iron overload and increased ferritin due to an inflammatory stress response.

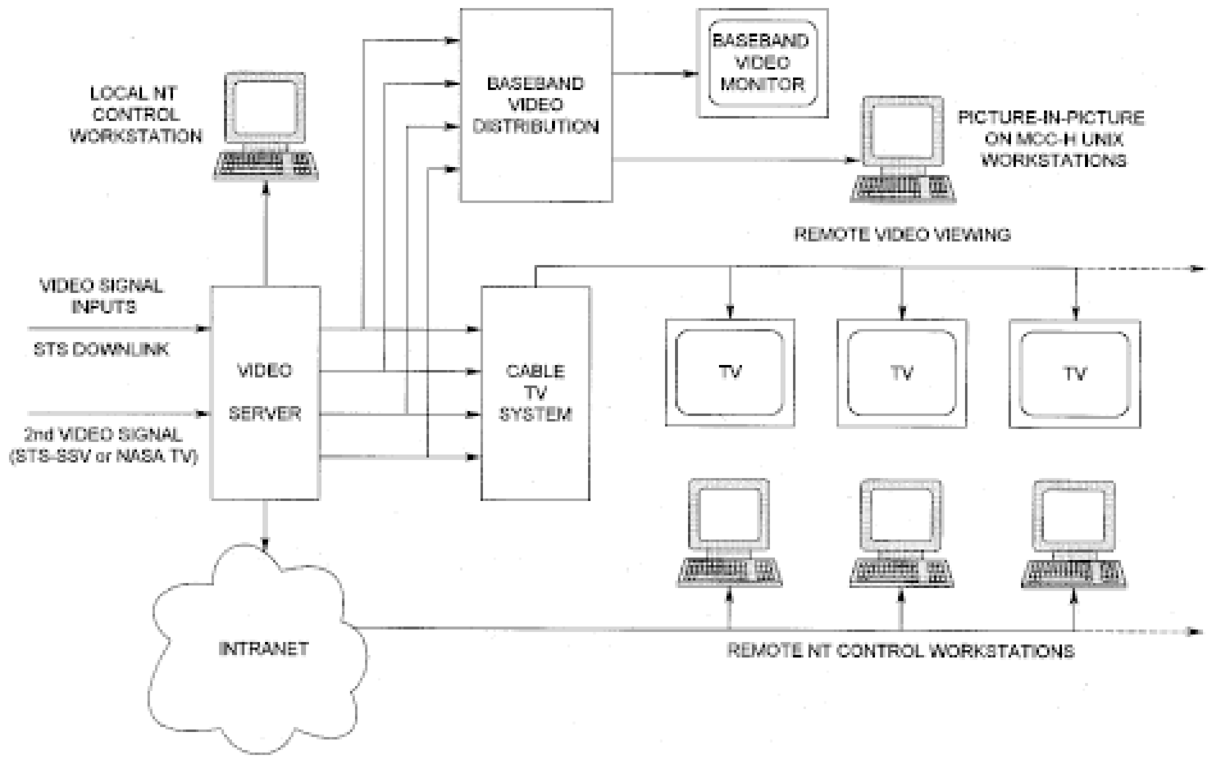
Previous methods for measuring ferritin iron have used large sample sizes, which are often unavailable with flight protocols. Therefore, a new method had to be developed to isolate iron using a very small sample size and a high level of sensitivity. This was done by modifying sample preparation and using an inductively coupled plasma mass spectrometer (ICP-MS) with a sample injection micronebulizer for measuring iron. ICP-MS is a relatively new analytical technique that determines elements present using the mass spectrometry of ions generated by inductively coupled plasma. The development of this method of measuring ferritin iron is complete. Validation studies – spiked recovery, linearity, and reproducibility – have been accomplished with satisfactory results. Studies are now being performed to determine the ability of the method to distinguish clinical changes in iron status. Future plans for measuring ferritin iron before, during, and after spaceflight are under way.

Benefits and Uses

A practical noninvasive laboratory method to assess iron status in populations has been a major clinical problem. Development of this technology could beneficial clinical testing. A vendor is currently working towards developing a clinical test or kit to accurately measure ferritin iron. Results arising from use of this technology will benefit NASA in determining iron requirements during spaceflight and significantly affect NASA's development of a food system.

For further technical information, contact Dr. Scott M. Smith at (281) 483-7204 or scott.m.smith1@jsc.nasa.gov.
For technology transfer assistance, contact Kelle Pido at (281) 483-1348 or kelle.i.pido1@jsc.nasa.gov.

COMPUTER HARDWARE



Operational Video Server

Operational Video Server

Background

During Space Shuttle missions, a playback of segments of vehicle downlink or other video to Mission Control Center (MCC) flight controllers, engineering and payload teams, or mission managers is often needed. These requests are currently answered by relaying a call through several operational consoles to a video system operator who locates the correct video recording, loads the video tape, cues the desired video segment, and plays or replays the needed video over the existing Johnson Space Center (JSC) video distribution systems.

Project Overview

The Operational Video Server Project will provide a more responsive, more capable, less labor-intensive solution to this video playback requirement using video server technology. With such a system, downlink video would be digitized in real time – as it is received – and stored on disk media. Initially the system would be sized to store from 24 to 48 hours of the most recently received downlink video. Older video would still be available for viewing from traditional tape recordings or could be loaded onto a server for more immediate access. Other selected video segments, such as videos of in-flight maintenance procedures, could also be stored on the video server system for ready access and display.

The video server will initially be configured to record up to two simultaneous video signal inputs and play up to four different, simultaneous video signal outputs. Although video will be digitized and compressed to approximately 8 to 24 Mbps, it can still be recorded at full resolution and full frame rate. At first, the playback video will be distributed on a JSC Cable TV channel on site or through a baseband closed-circuit video feed for viewing on a TV monitor or, as a picture-in-picture, on an MCC operational UNIX workstation. One Windows NT-based control workstation will be co-located with the server, and a number of Windows NT-based control workstations will be located within the MCC complex. These workstations will be running a unique video server control application that will communicate with the video server via the JSC Intranet. A system user will identify the beginning time reference of the desired video segment, which will then be played out of the system on demand. Equipment needed to provide this initial system capability has been specified and is currently being acquired.

A proposed future system enhancement will be the development of a browser-based control application that will allow broader system access and use. Under this concept, a user could access the system from anywhere at JSC by accessing a special password-protected web server using any web browser. Another proposed enhancement would be streaming distribution of the video over the JSC Intranet.

Benefits and Uses

All inherent operational changes and benefits resulting from implementing this video search, retrieval, and playback system will be placed directly in the hands of those individuals needing to see and use the imagery. A resource benefit of the system will be improved support capabilities; e.g., significantly faster access to video imagery and an ability to service multiple simultaneous video playback requests. This operational capability could also be expanded and used to support payload, science, management, and public affairs users both on and off site. A further benefit will be the increased efficiency and future support labor cost avoidance associated with implementing the system.

For further technical information, contact Daniel S. Willett at (281) 483-7010 or daniel.s.willett1@jsc.nasa.gov.
For technology transfer assistance, contact Kelle Pido at (281) 483-1348 or kelle.i.pido1@jsc.nasa.gov.

In-Flight Storage System for Onboard Training

In-Flight Storage System for Onboard Training (OBT)

Background

Current spaceflight programs rely heavily on conducting all mission training preflight. For short-duration missions such as those of the Space Shuttle, this makes practical sense. However, for long- and very-long-duration missions, it is neither practical nor possible to train for all nominal and contingency tasks which may be encountered.

As part of the NASA/*Mir* Phase I Program, extensive onboard training (OBT) was conducted. This training revealed the need for large-capacity computer storage to support OBT delivery. The in-flight storage system for the OBT project was designed to leverage off computer off-the-shelf technologies and apply them in a fashion specific to NASA's needs. From the onset, the ability to upgrade was incorporated into the design so that, as technology and user needs evolved, the system could easily accommodate these changes.

Project Overview

While the International Space Station (ISS) Program had envisioned a need for onboard storage of electronic resources, because of the long lead time required for design and operations concept development storage needs grew at a much faster rate than the baseline design could accommodate. Indeed, the design had been baselined prior to the operational experience obtained as part of the NASA/*Mir* missions.

With experience gained on *Mir* and because of a desire to not unduly affect the baseline design, a rapid hardware prototyping effort was put in place. Basic design requirements only included large hard drives; but with an eye to the future, many other features were added to the system along with an assessment of existing ISS server capabilities.

The current prototype consists of an SCSI PCMCIA interface card, power cables, two SCSI towers (each with four half-height bays), two permanently mounted devices (digital video disk drive and CD-R/W [read/write] drive), a removable 2 GB Jaz drive, a removable 20 GB Travan Tape drive, and four removable 18.2 GB hard drives. All of these removable devices are hot-swappable – a significant benefit given the operational nature of the device.

Benefits and Uses

With the capabilities inherent in this device, the ISS Program now has a storage capacity in excess of nine times the baseline design, with an ability to augment the in-flight configuration. further. The ability to generate CD-ROMs in orbit is also a new significant capability, since magnetic media is less stable than a CD due to the effects of radiation.

The device will be a proving ground for a non-low Earth orbit (LEO) mission. Since in order to leave LEO significant computer resources must be available for the onboard crew, this device is an enabling technology for both lunar and Mars missions.

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ENERGY

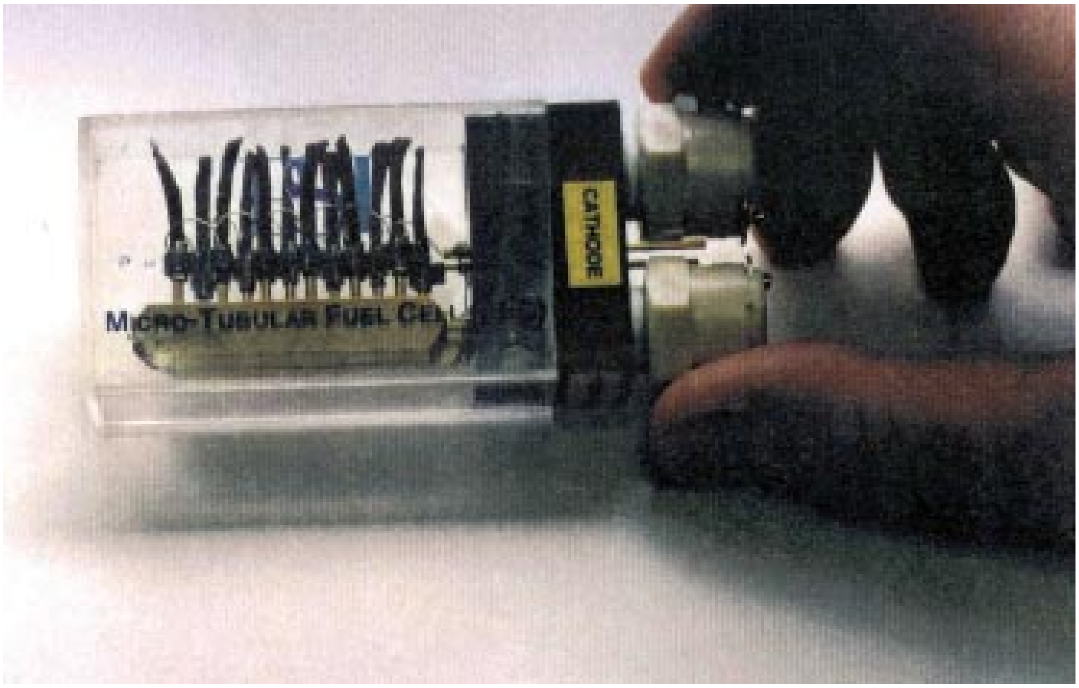

Figure 1. The micro-tubular PEM fuel cell

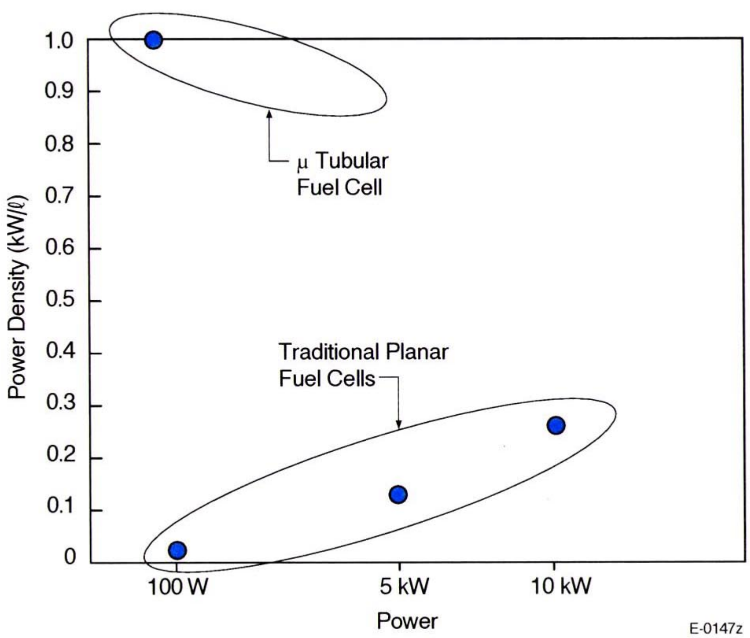

Figure 2. High-power density projects for the micro-tubular PEM fuel cell

Micro-Tubular Proton Exchange Membrane (PEM) Fuel Cells

Background

The traditional development of proton exchange membrane (PEM) fuel cells has focused on producing large power stacks, typically in a range of 1 to 250K for automotive to stationary power generation applications. For low-power applications including laptop computers and portable power tools, fuel cell vendors are being challenged to develop a low-cost, high-power-density fuel cell that can be packaged in an extremely small volume. Most developers of these portable PEM fuel cell stacks simply use the traditional plate and frame design of the large stacks and shrink the size of these stacks into a small volume. This approach has resulted in a very low-power density stack of less than 0.1 kW/kg and 0.1 kW/L. In a Small Business Innovative Research Phase I Program with NASA, Physical Sciences, Inc., has demonstrated the feasibility of using a micro-tubular fuel cell design with a power density greater than 1 kW/L when operating with oxygen and hydrogen gases at ambient pressure conditions.

Project Overview

This project demonstrates the ability of a different design approach to the traditional plate-and-frame design found in large power-producing fuel cell stacks. The micro-tubular PEM fuel cell concept (fig. 1) is based on two driving principles: (1) low currents generated in each tubular cell allow edge-tab current collection and transfer, and (2) low polarization of the anode (hydrogen side) allows the anode area to be much smaller than the cahtode area. The combined effect of these principles enables a significant reduction in the overhead mass and volume associated with the filter-press plate design, reduction in ohmic heating owing to large current conduction between cells, and increased packaging density of cells. A design study of this concept (fig. 2) suggested that a power density of 6 to 8 kW/L is feasible. Single- and 2-cell stacks have been built, tested, and compared with similar sizes of filter-press micro-tubular cells. Based on this, a 12 V, 100 W fuel cell stack is projected to be capable of achieving the 1 kW/L goal. Additional improvement can also be realized with optimum selection of materials, packaging concept, and operating conditions.

Benefits and Uses

Spaceflight applications for the micro-tubular fuel cell include power generation for space suits, surface power systems on the martian and lunar surfaces, and transportation systems including rovers and miniature spacecrafts. Military applications range from providing a portable power source for foot soldiers to undersea vehicle power supplies. Commercial applications for compact, low-power sources are numerous and include portable electronics devices as laptop computers, cell phones, tools, and games.

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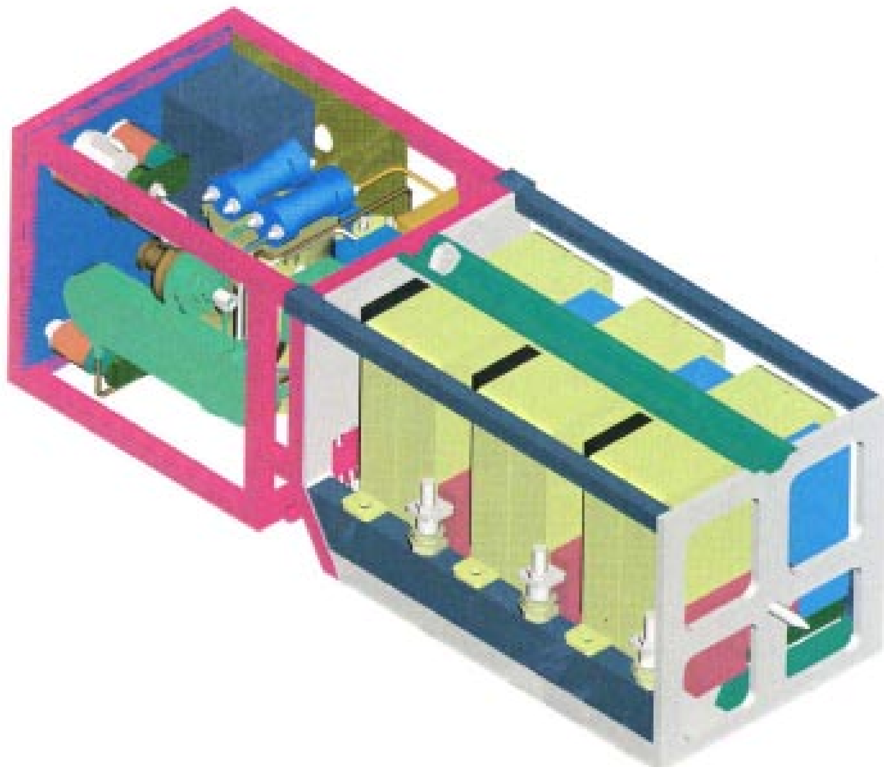

PEM fuel cell

Advanced Development of Proton Exchange Membrane Fuel Cells

Advanced Development of Proton Exchange Membrane (PEM) Fuel Cells

Background

The objective of this task is to develop proton exchange membrane (PEM) fuel cells that can replace the Space Shuttle's alkaline fuel cells. Successful completion of this multi-year technology program would significantly reduce the cost and technical risk of a Space Shuttle PEM fuel cell development program. PEM technology is being pursued because of the robustness of the cell stacks and the potential logistical cost savings to the Space Shuttle Program and future missions.

Project Overview

This technology project evaluates potential PEM fuel cell system designs and components through testing and analysis tasks to ensure that Space Shuttle requirements can be met by the PEM fuel cell. Vendor-supplied fuel cells and combinations of vendor and Johnson Space Center-designed accessory section components were tested and analyzed to determine their acceptability in the proposed application. Reactant gas recirculation devices and water-gas separators are also being evaluated in order to characterize performance and identify areas of design improvement. Moreover, the durability of PEM stacks is being evaluated through long-term testing of vendor hardware.

Preliminary system designs have been completed, and cell stack performance data through 10,000 hours operation on hydrogen and oxygen have been accumulated. A fuel cell product water management design concept demonstration is planned in 1999 with system feasibility determined early in 2000. An evolution into a higher-fidelity system for evaluation purposes is also planned in 2000 and 2001.

Benefits and Uses

PEM fuel cells should have a longer life, higher power capability, and lower operating cost than current alkaline fuels. They are being developed for commercial applications, including electric cars and portable power sources. Some of the work these commercial applications are performing to advance the technology can be applied to PEM fuel cells for space.

This technology has been submitted as a new invention disclosure.

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Solar-powered refrigerator unit developed at JSC

Solar Heat Pump Development

Solar Heat Pump Development

Background

Thermal control systems require significant mass, volume, and energy resources. Air conditioners and refrigerators on Earth use a heat pump cycle. These types of systems are required in space as well. For both aerospace and many Earth applications, solar energy is a good power source because it is most available at midday when the heat pump is required the most. The Johnson Space Center (JSC) and several industry partners have been cooperating for several years to develop highly efficient solar heat pumps to solve various problems.

Project Overview

A NASA site was one of five in the United States chosen as a test site for the Electric Power Research Institute Solar Photovoltaic Heat Pump Project. In this project, a photovoltaic (PV) vapor compression cycle heat pump operated at JSC's Advanced Life Support Laboratory from 1994 to 1997 was used to demonstrate the integration of solar PV panels and cooling systems. The Crew and Thermal Systems Division completed a conceptual design of a lunar base solar PV heat pump using a similar arrangement to reduce power system mass by 43% through direct coupling to the heat pump.

Three smaller-scale solar heat pumps were also tested from 1996 to 1999 in a solar PV refrigerator application. Thermoelectric, Stirling, and vapor compression heat pumps were tested – one at a time – in the same vacuum-insulated refrigerator cabinet. These heat pumps relied on thermal energy storage to stay cold during the night and cloudy days rather than batteries to store electrical energy. Beyond a space application for advanced refrigerators, there is a vast commercial potential for solar refrigeration on Earth.

Benefits and Uses

Solar energy technology, long recognized as environmentally benign, has practical applications in both aerospace and Earth-based energy systems. Solar heat pumps can significantly reduce the mass of thermal control systems on spacecraft for future crewed missions such as a lunar or Mars base habitat. On Earth, solar heat pumps are a promising technology for a variety of cooling applications such as refrigerators and freezers. Recent developments at JSC point to a possibility that this technology may soon be available for licensing.

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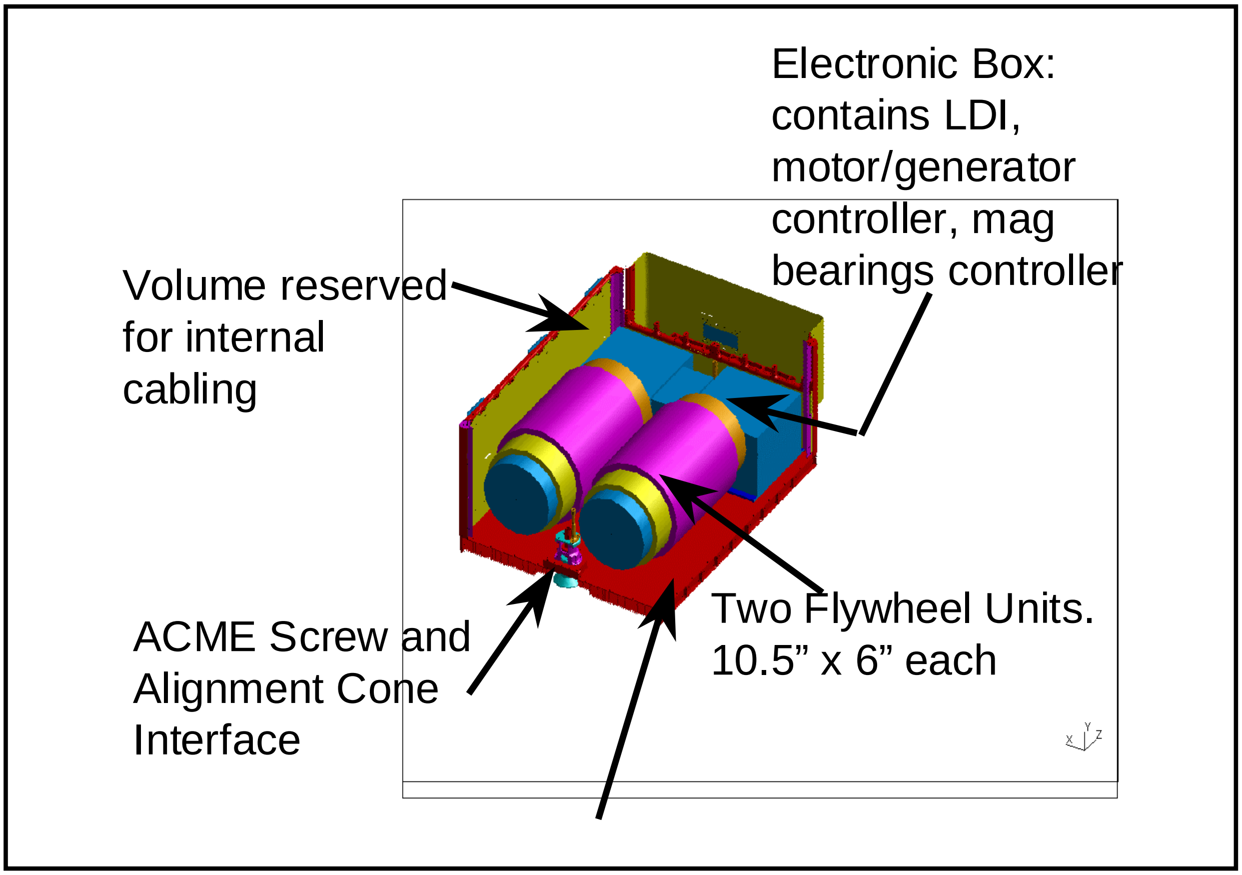

Attitude control and energy storage experiment

Flywheel Energy Storage

Flywheel Energy Storage

Background

Batteries in the International Space Station (ISS) must be periodically replaced – about every 4 years. These batteries, which are heavy, require a significant commitment of upmass/upvolume resources from the Space Shuttle because they are needed to store energy during sunlit orbit periods for ISS use during the dark side of the orbit. But high (50k to 100k) revolutions per minute (RPM) flywheels, which use advanced materials and system components, could correct this problem since they may never need to be replaced and are more efficient at storing and discharging energy.

Project Overview

When an excess of electrical power is available during the sunlit portion of orbit, flywheels in the ISS can store electrical energy by spinning up two contra-rotating flywheels suspended on magnetic bearings. These flywheels are contra-rotating to balance out disturbance torques to ISS. Their stored energy is then discharged and used to supply power for general ISS use during the dark side of orbit. These flywheels will operate at approximately 60,000 RPM and store 2.4 kW-hr of energy.

The flywheel unit, which was initially elected as an Engineering Research and Technology payload, will be demonstrated on an upcoming Space Shuttle flight. It will then likely be installed in a location that would otherwise have been used for a set of batteries. If the demonstration is successful, the flywheel will remain in place and continue to be used for energy storage. Depending on the results of this demonstration, the ISS Program will decide whether to purchase additional flywheel units to replace the current ISS batteries (when maintenance would normally require replacement) and for use instead of additional batteries, which are scheduled to be installed later in the ISS assembly sequence.

Benefits and Uses

Use of the flywheel will decrease Shuttle upmass/upvolume requirements for ISS maintenance, increase ISS energy storage/discharge efficiency (versus the storage/discharge of batteries), and provide rotational momentum that can be used for ISS attitude control by creating a difference in spin rates between the two contra-rotating wheels. Sponsors and developers of the flywheel have also been supporting other industry interests in developing smaller versions for a wide range of applications in industry. The NASA Glenn Research Center, the United S tates Air Force, and their contractors are extensively involved in this activity.

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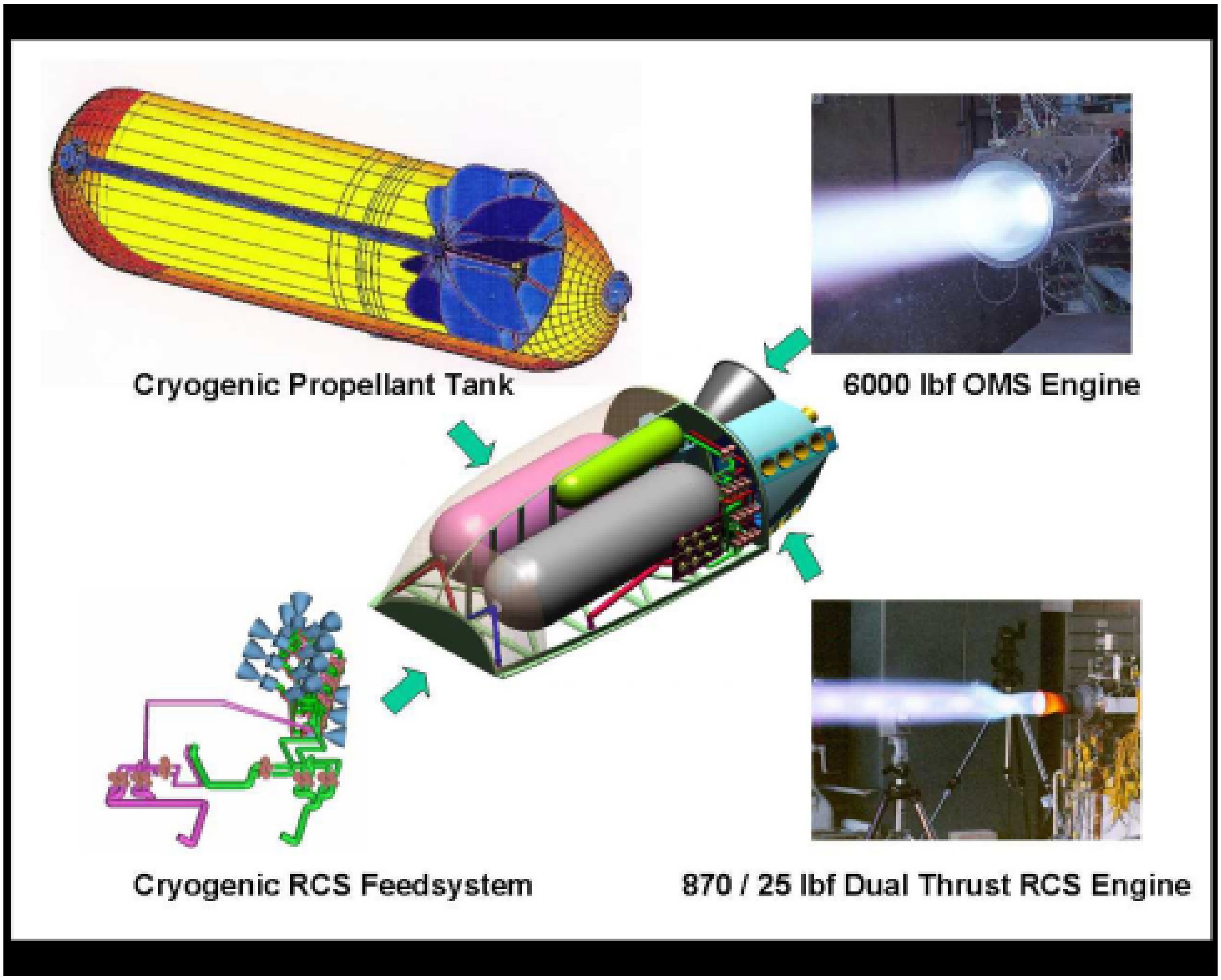

Nontoxic Orbital Maneuvering and Reaction Control System

Nontoxic Orbital Maneuvering and Reaction Control System (NT OMS/RCS)

Background

Current use of toxic propellant on the Space Shuttle creates flight and ground safety hazards and long turnaround times. Previous attempts to develop nontoxic propellants for the Space Shuttle reaction control system have largely focused on pump-fed systems which use hydrogen propellants. This has not been entirely successful or practical for large reusable launch vehicles (RLVs), such as Shuttle. The technology for a nontoxic orbital maneuvering and reaction control system (NT OMS/RCS) simplifies the system by using a pressure-fed liquid oxygen and ethanol system. The result is a safer, more reliable, and simpler system to operate.

Project Overview

The purpose of this project is to demonstrate that an NT OMS/RCS can be flown and operated for an RLV such as Space Shuttle. The NT OMS/RCS can provide critical on-orbit maneuvers, deorbit burns, docking maneuvers, and International Space Station re-boost functions. The design uses pressure-fed liquid oxygen and ethanol stored at 250 and 350 psia. This high pressure increases the sub-cooling of liquid oxygen and results in the improved storability of cryogenic oxygen. A variety of cryogenic insulation technologies are being evaluated to reduce heat leak into the tanks. The project has already completed tank designs and a component demonstration of both the RCS and OMS engines. Tests on a dual-thrust RCS engine and a cryogenic RCS feed system will be completed in 1999. In the next phase (starting in 2000 and completed by 2002), a full system will be assembled and tested in a space environment.

Benefits and Uses

The primary benefit of NT OMS/RCS is improved safety. Nontoxic propellants are not carcinogenic and are less likely to create a fire hazard. The processing time savings resulting from using nontoxic propellants is 65%. For the Space Shuttle, this saves over $24M per year and reduces processing time from 43 to 8 days.

The NT OMS/RCS will also improve performance by better than 5% over current toxic propellants. For Space Shuttle, this means a significant payload increase of up to 3400 lbm. The dual-thrust RCS engine technology, which is part of the NT OMS/RCS, improves vehicle control and re-boost capability.

There are a wide variety of uses for NT OMS/RCS technology on commercial RLVs. Cryogenic liquid oxygen technologies can also be applied in other fields such as life support and power generation.

This technology has been disclosed as a new invention.

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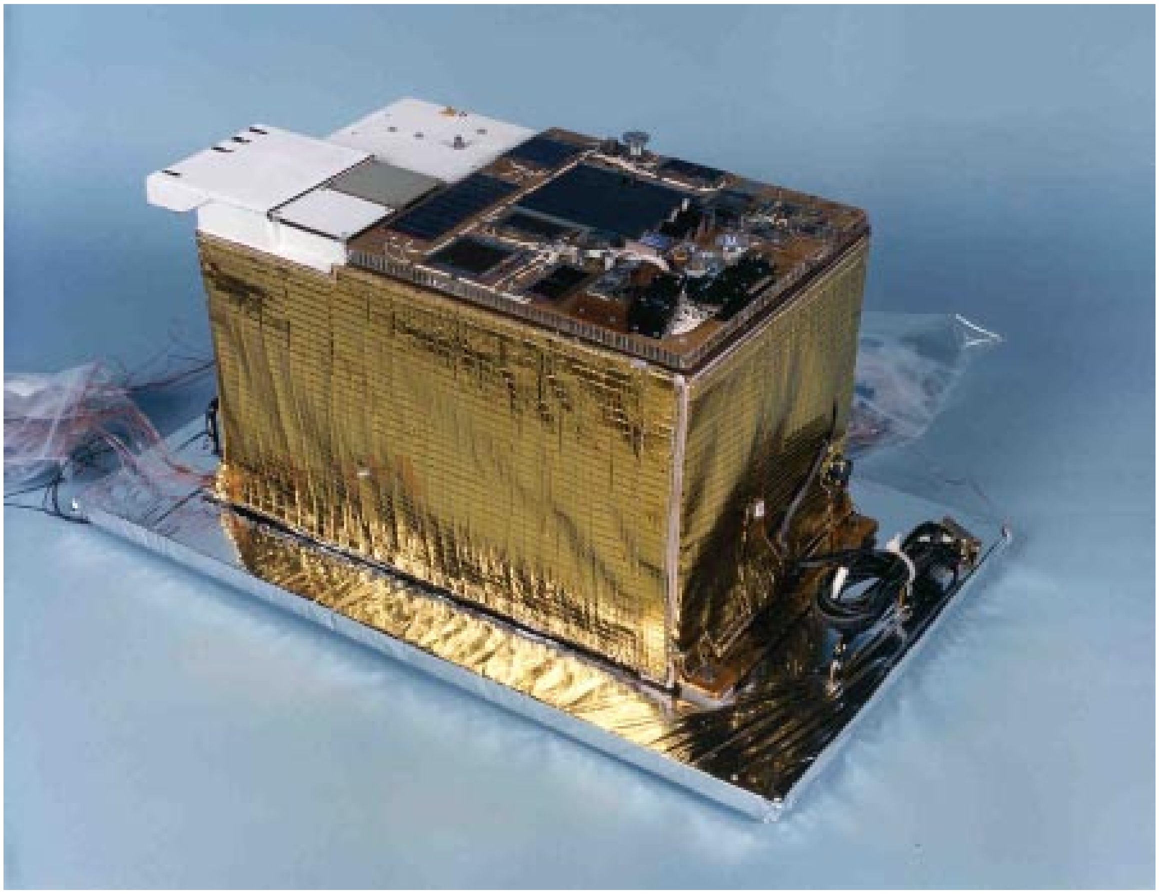

Mars In-situ Propellant Production Precursor Flight Demonstration Project

Mars In-situ Propellant Production (ISPP) Precursor (MIP) Flight Demonstration Project

Background

Strategic planning for human exploration missions to Mars has identified in-situ propellant production (ISPP) as a highly desirable technology. A team of engineers from the Johnson Space Center, Jet Propulsion Laboratory, and Glenn Research Center is preparing the Mars ISPP precursor (MIP) flight demonstration. The objective of MIP is to characterize the performance of the processes and hardware that are important to ISPP concepts and that interact directly with the Mars environment. Because of uncertainties associated with the Mars environment and conditions that cannot be adequately simulated on Earth, operating this hardware in the actual Mars environment is extremely important.

Project Overview

Manifested for launch to Mars on the Surveyor Lander in April 2001, the MIP flight demonstration will be the first hardware to use the indigenous resources of a planet or moon. Its successful operation will pave the way for future robotic and human missions to manufacture and rely on propellants produced using martian resources as feedstock.

MIP is comprised of five distinctive experiments. Their purpose is to:

- selectively absorb and compress CO_2 from the martian atmosphere;
- produce propellant-grade, pure oxygen;
- test advanced photovoltaic solar cells for energy production;
- test techniques to mitigate the settling of airborne dust onto solar arrays; and
- test thermal radiators.

The MIP package will be small and lightweight. Design requirements specify an overall maximum external envelope of approximately 40 x 24 x 25 cm (15.7 x 9.4 x 9.8 in.) and a package mass of 8.5 kg (18.7 lbm).

Benefits and Uses

Successful performance of the five individual demonstrations of MIP will provide both knowledge of and confidence in the reliability of this technology. At completion of this flight demonstration, the MIP team will be able to:

- recommend preferred hardware configurations for the intake and adsorption of CO_2 from the martian atmosphere;
- recommend preferred hardware designs for innovative thermal management including the radiation of heat to the outside environment;
- understand the long-term performance degradation characteristics of advanced solar array and radiator concepts operating in the actual Mars environment;
- evaluate the functionality of electrostatically repelling airborne dust from landing on the solar array; and
- understand the performance characteristics of zirconia cells to generate propellant-grade oxygen.

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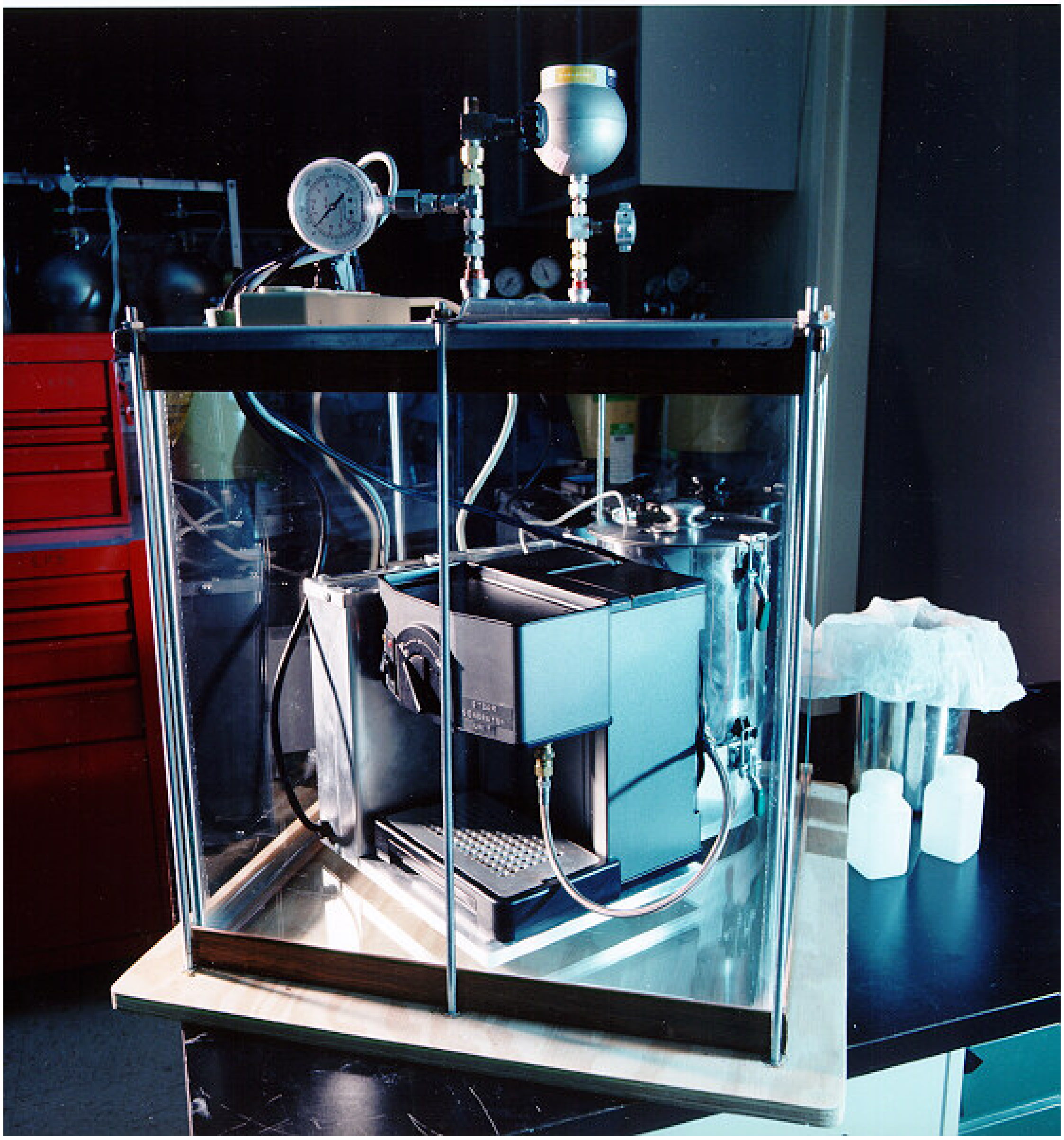
ENVIRONMENTAL



Volatile analysis setup for soy milk machine

Bioregenerative Planetary Life Support Systems Test Complex

Bioregenerative Planetary Life Support Systems Test Complex (BIO-Plex)

Background

Johnson Space Center is constructing a ground-based testbed – the Bioregenerative Planetary Life Support Systems Test Complex (BIO-Plex) – to simulate the confined environments required for long-duration space missions such as a lunar outpost mission or an extended mission to Mars. This testbed will use crops to perform life support functions while optimizing volume, mass, energy, and labor. The goal is near-complete closure of processes for regeneration of air, water, and food. The food system will be based on raw food products obtained from higher plants grown in controlled environmental chambers and processed in an interconnecting tunnel. Food processing in this closed system will significantly impact water requirements, waste production, and air revitalization, which may affect crew health and safety. Specifically, the project goal is to assess the impact of food processing on air quality by identifying and quantifying the volatiles evolved from different food processing equipment.

Project Overview

Since wheat and soybeans are baselined to be grown in the BIO-Plex, various food processing equipment will be required to convert these crops into edible products such as bread, soy milk, and pasta. Volatiles evolved from a bread machine, a soy milk machine, and an extruder were analyzed. The bread machine and soy milk machine were individually placed inside an air-tight chamber (volume » 0.12 m^3) and an air sample was drawn using an evacuated sample bomb (500 mL). For the extruder, the air sample was drawn from specially designed bags attached to the extruder barrel. All samples were analyzed using a gas chromatograph-mass spectrometer. Results show that alcohols, aldehydes, ketones, and various other compounds were produced from food processing. Ethanol and acetaldehyde especially were shown to exceed the 180-day spacecraft maximum allowable concentrations for the BIO-Plex if no means of scrubbing for the volatiles is used. Additionally, some equipment may need to be placed under a fume hood when used to avoid excessive production of these volatiles.

Benefits and Uses

Similar data may be required when people are exposed to the volatiles that develop during operations of various types of equipment in enclosed areas for extended periods of time. Examples of enclosed environments include submarines and remote bases in the Antarctic. It is important to realize that food processing equipment may contribute to an accumulation of volatile compounds; these compounds may accumulate to a concentration that is hazardous to human health.

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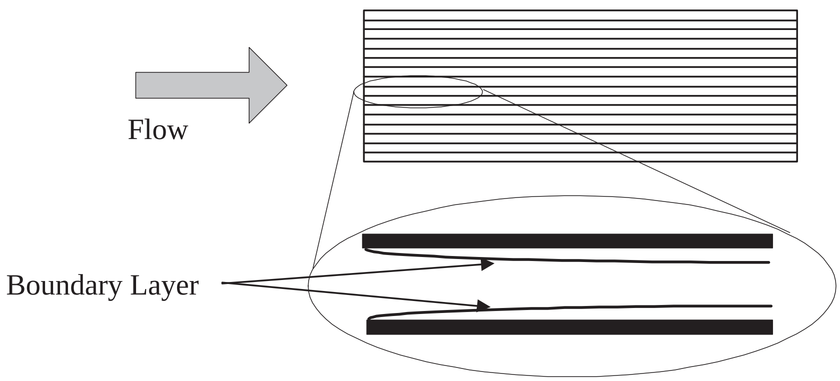

Figure 1. Boundary layer buildup in a conventional monolithic converter

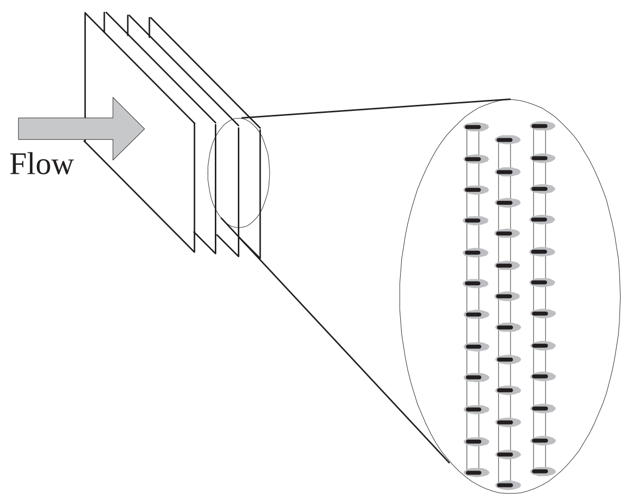

Figure 2. Boundary layer minimization by metal monolith technology

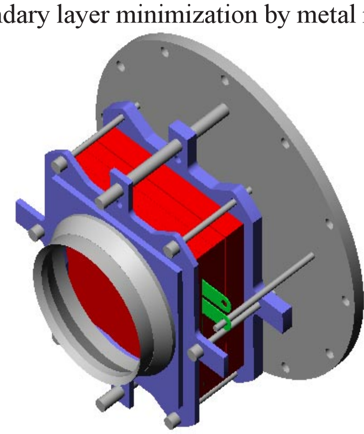

Figure 3. Metal monolith catalytic converter

Metal Monolith Catalytic Converter

Metal Monolith Catalytic Converter (MMCC)

Background

The internal atmosphere on the International Space Station (ISS) must be continuously filtered to remove both CO_2 and CO. Since the units currently used to accomplish this require fairly frequent maintenance and replacement, this represents significant crew time and transport to orbit requirements.

Project Overview

The metal monolith catalytic converter (MMCC) (figs. 1 through 3) is based on innovative reactor design techniques that use high cell density, short channel length metal monoliths, and specialized catalytic coating processes to extend catalytic oxidizer service life by at least 5 years and charcoal bed service life by 2 to 3 years.

Development and ground testing were originally selected as an Engineering Research and Technology experiment. The testing work has been completed; the technology will be demonstrated by installing it on the ISS at an appropriate maintenance opportunity.

Benefits and Uses

As well as providing longer life and greater time between maintenance requirements, the MMCC will provide a 41% reduction in power and a 98% reduction in the amount of time required for the system to recover from a system poisoning event as compared to the current system. The MMCC was originally developed through a Small Business Innovative Research (SBIR) activity. The Phase A design effort for the SBIR flight unit and associated integrated tests of a flight-type unit with a ground version of the ISS environmental control and life support system have been completed.

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Advanced water recovery system schematic

Biological Water Processing Systems Development

Biological Water Processing Systems Development

Background

The Biological Water Processing Systems Development Project was started to create an advanced water recovery system (WRS) based on the microbial bioreactors that convert the contaminants in water into basic chemical forms. Such a WRS would handle a combined feed stream, thus preventing the need to separate urine from the remainder of the waste water generated and simplifying the system. By reacting instead of adsorbing or exchanging contaminants, consumables are greatly reduced and the mass for long-duration missions becomes more realistic. Additionally, the WRS under development will recover essentially 100% of waste water, so no brine waste solution will be generated. This prevents the need for resupply water, thus saving on mass for long-duration missions. Research is currently focused on addressing the adaptation of this proven ground technology to a microgravity environment.

Project Overview

The purpose of the project was to develop a WRS that could purify 100% of incoming waste water in a microgravity environment while using fewer expendables than current state-of-the-art systems. The designed system consists of five subsystems: (1) an anaerobic-packed bed bioreactor for degrading organic carbon; (2) an aerobic tubular bioreactor for converting ammonia to nitrate; (3) a reverse osmosis system for separating salts from the waste stream; (4) an air evaporation system for recovering water in the reverse osmosis brine; and (5) a post-processing system for residual organic carbon degradation and salt removal.

This technology has been successfully demonstrated with humans in a closed test chamber for 91 days at Johnson Space Center. It is currently being developed as individual subsystems that will be integrated early in 2000 to test a completed system from waste water generation to potable water production.

Benefits and Uses

The WRS will minimize expendables using only adsorbents and ion exchange resins when no other method is available for polishing instead of as the main processing step. The system will use minimal power, is small and compact, and generates very clean water. Alternative uses under investigation include remote locations where water is difficult to obtain. Work is being conducted with the Pike's Peak manager to develop a modified system for recycling gray water in the summit house. This technology is also being actively pursued for application in specific areas.

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Lightweight configuration baseline advanced space suit assemblies

Extravehicular Activity Soft Space Suit Design

Extravehicular Activity Soft Space Suit Design

Background

Previous space suit assemblies incorporated a wide variety of fabric elements and hardware structures as well as a combination of each to provide operational mobility capabilities in a pressurized condition. Although these efforts achieved good mobility results, they also produced suit systems that were too heavy and bulky. Recent development efforts undertaken by this research activity investigated maximizing the use of fabric soft goods elements for both structural and mobility systems to minimize the weight and bulk of space suit assemblies while maintaining a high degree of pressurized mobility.

Project Overview

Two different lightweight configuration baseline advanced space suit assemblies were designed and developed to serve as mobility joint technology testbeds in which to conduct and assess various test subject pressurized comparative performance task activities. The D-1 (S1035X) space suit assembly, one of two independent configurations, was based on the current lightweight S1035 advanced crew escape suit worn by Space Shuttle crewmembers during the launch and re-entry phases of flight, but it was upgraded to incorporate specific mobility enhancements. The design objective of the D-1 suit was for a predominantly "all-soft" (i.e., fabric) suit system that would incorporate only upper arm bearings and could operate at a 3.75 psi (25.8 kPa) pressure level. The D-1 suit weight was only 26 lbs (11.8 kg). The second suit configuration, the I-1 space suit assembly, also designed for a 3.75 psi (25.8 kPa) operational pressure level, has a configuration that incorporates a limited number of bearing elements in the overall mobility system. Bearings are used only in the shoulders, upper arm, and hip areas of the suit. The basic torso areas of both the D-1 and I-1 suits are composed of fabric structures, as are the mobility joint elements located in the shoulder, elbow, waist, hip, knee, and ankle joint areas.

Benefits and Uses

A lightweight, all-fabric space suit system that exhibits a high degree of pressurized mobility would provide enhanced performance capabilities for future planetary surface explorers. The mobility features and materials selected for use in the advanced technology suit demonstrator models may be applicable within other diverse hazardous abatement equipment development areas.

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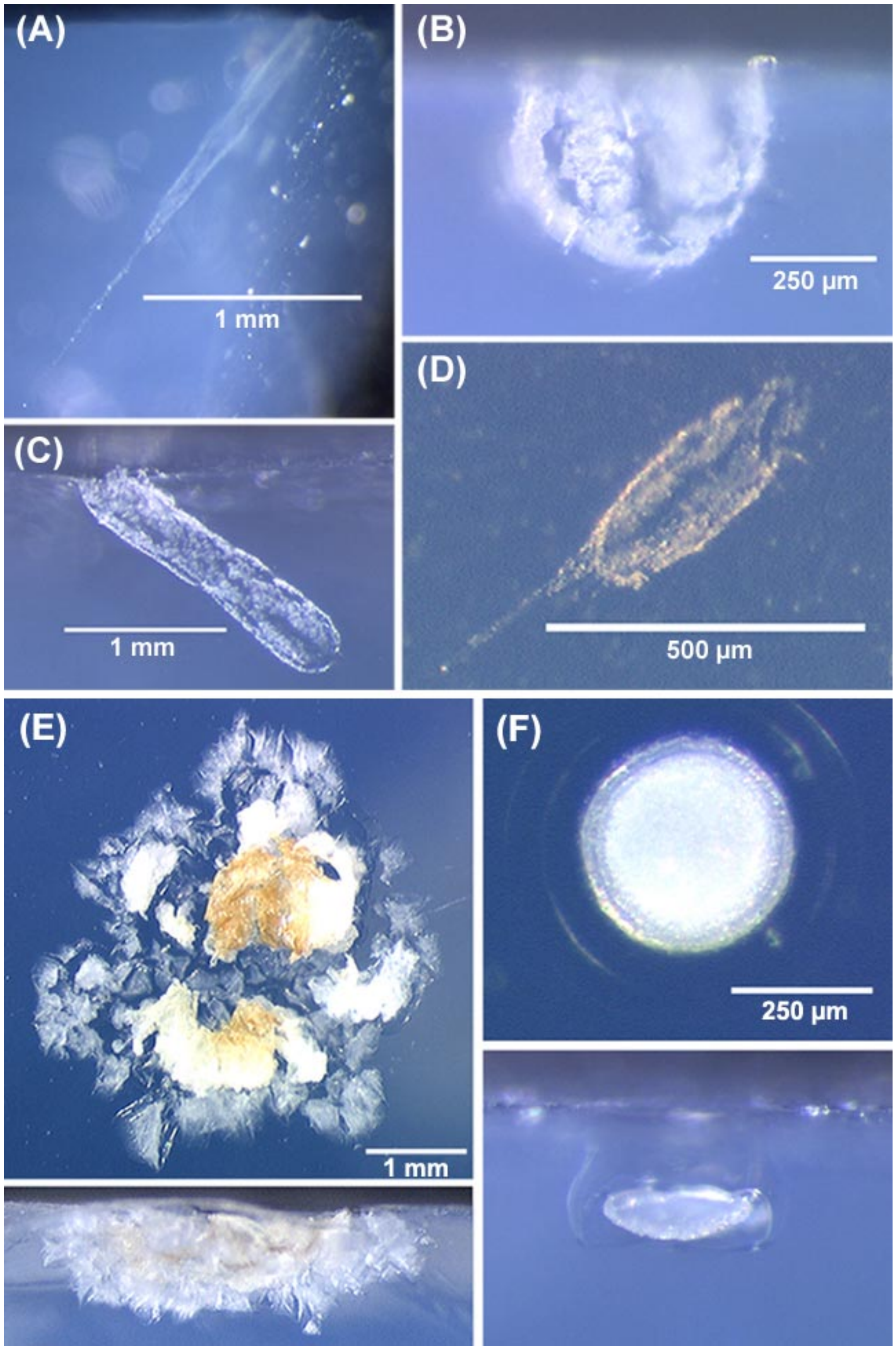

Figure 1. Representative impact features in aerogel exposed on *Mir*. (A) Typical, deep, carrot-shaped penetration track; (B) shallow, nearly hemispherical pit; (C) cylindrical cavity, intermediate between tracks and pits; (D) cylindrical cavity displaying a parasitic track, the result of a small chance fragment; (E) plan view (top panel) and cross section view (bottom panel) of large, irregular depression caused by solid human waste; and (F) plan and side views of circular solution features caused by the encounter of waste water droplets. Note the thin deposit of evaporites lining the bottoms of these features.

Impact Features and Projectile Residues in Aerogel Exposed on *Mir*

Impact Features and Projectile Residues in Aerogel Exposed on Mir

Background

The low bulk densities (< 0.01g/cm^3) and associated micro-structural properties of SiO_2-based aerogels – informally referred to as "frozen smoke" – seem highly suited to gently decelerate hypervelocity particles. Laboratory tests at impact speeds as high as 7 km/s reveal that unmelted projectiles reside at the tip of deep, carrot-shaped penetration tracks and these particles can be recovered for compositional and textural analyses using scanning or transmission electron microscopes. This recovery ability renders aerogel the material of choice to capture relatively unmodified projectiles in low Earth orbit (LEO) and retrieve them to Earth for detailed mineralogical, compositional, and textural characterizations.

Project Overview

The *Mir* Environmental Effects Package was deployed on *Mir* by STS-86 in March 1996 and was retrieved after 18 months by STS-96. The orbital debris collection (ODC) experiment, which was part of this package, exposed 0.6 m^2 of aerogel. Visual inspection of the space-exposed aerogel reveals two classes of hypervelocity impact features: (1) long, carrot-shaped tracks (fig. 1A) identical to those produced in the laboratory; and (2) shallow pits of nearly hemispherical shape (fig. 1B) that have no laboratory analog. Blunt-nosed, cylindrically shaped cavities attest to transitional morphologies between tracks and pits (figs. 1C and 1D). All the deep tracks contain unmelted projectile residues. In contrast, the shallow pits rarely contain even traces of projectile material. These and other observations suggest that deep tracks form at systematically lower velocities than shallow pits and that projectiles of modest encounter speeds remain unmolten and penetrate deeply while high velocity impactors melt and vaporize close to the surface, making them poor penetrators. The threshold velocity for successfully capturing unmelted residues in a 0.02 g/cm^3 aerogel is estimated to be 15 to 18 km/s. Harvesting and analysis of individual projectiles, typically < 20 um in size, is in progress; and we have already identified a variety of manmade materials (metallic aluminum, aluminum oxide, stainless steel, paints, and diverse electronic components) and natural cosmic dust, largely composed of the minerals olivine, pyroxene, spinel, and troilite.

ODC aerogel also contains numerous shallow depressions of irregular outlines that are occupied by tan to brown flakes (fig. 1E), some barely embedded into the aerogel and – judging by the small volume of crushed aerogel (fig. 1E) – all representing very low impact speeds. Compositional analysis of these flakes reveals predominantly Na, K, S, P, and Cl, and identifies them as human waste. We also observed numerous, exceptionally circular and bulbous structures, all < 1 mm in diameter and containing a thin film of tan to brown material in Petri-dish-shaped bottoms (fig. 1F). Since this material is compositionally identical to the tan to brown flakes, this illustrates that tiny droplets of waste water encountered the aerogel.

Benefits and Uses

Our observations verify aerogel as the capture medium of choice for hypervelocity particles in LEO because aerogel is vastly superior to dense, nonporous targets. Some 70% of all high-velocity features are deep-penetration tracks containing unmelted, well-preserved impactor residues. We also observed that the Space Shuttle practice of dumping 75 L of waste water every 3 days produces a readily detected cloud of co-orbiting solids and even droplets. Our efforts will contribute to the Stardust Discovery Mission, currently on its way to comet Wild 2. During comet encounter in 2003, freshly released particles will be captured with aerogel collectors for a return to Earth in 2007, where the collectors will be processed and curated in Facilities for the Curation of Extraterrestrial Materials at Johnson Space Center.

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Flow visualization chamber used to simulate, measure, and control martian dust and wind environments for evaluation.

Mars Dust and Wind Environment Simulation, Measurement, and Control

Mars Dust and Wind Environment Simulation, Measurement, and Control

Background

Human Exploration and Development of Space [HEDS] missions to Mars require hardware certification to design environments. Environments with relatively well-known specifications (e.g., atmospheric composition, pressure, and temperature) have existing test facilities for verification. However, environments with relatively unknown specifications (e.g., dust loading, dust precipitation, and wind velocity) do not have test facilities to support verification activities.

Project Overview

This project enables verification-by-test for hardware design environments by developing the facility capability and personnel experience to reliably measure martian dust and wind environments while evaluating alternative methods to control the respective environments.

The Johnson Space Center (JSC) Energy Systems Test Branch has researched anticipated martian environments and proposed test facility simulation requirements for the respective environments. Relationships were established with experts in government, industry, and academia to keep abreast of the latest developments with respect to anticipated martian environments. Also, preliminary martian dust and wind environments have been created at the bell jar level, thus enabling studies of environmental instrumentation and alternative generators.

This project will produce improved planning for simulating full-scale environments in test chambers. One example of improvement comes from recent development testing of the Mars in-situ propellant production precursor flight demonstrator, which used wind-generation methods established from this activity to provide a uniform atmosphere temperature within the facility chamber. To date, JSC's Energy Systems Test Branch has established methods of generating and measuring dust and low wind environments using commercial-off-the-shelf equipment. Future activities will be oriented towards controlling environmental parameters and improving test-to-test repeatability.

Benefits and Uses

The primary benefit of this activity is advancing NASA's readiness to provide reliable cost estimates and implement cost-effective verification plans for specified design environments.

To fulfill their verification plans, researchers from government, industry, and academia who are preparing martian experiment proposals routinely contact the Energy Systems Test Branch to make use of unique facility capabilities without incurring duplicative costs.

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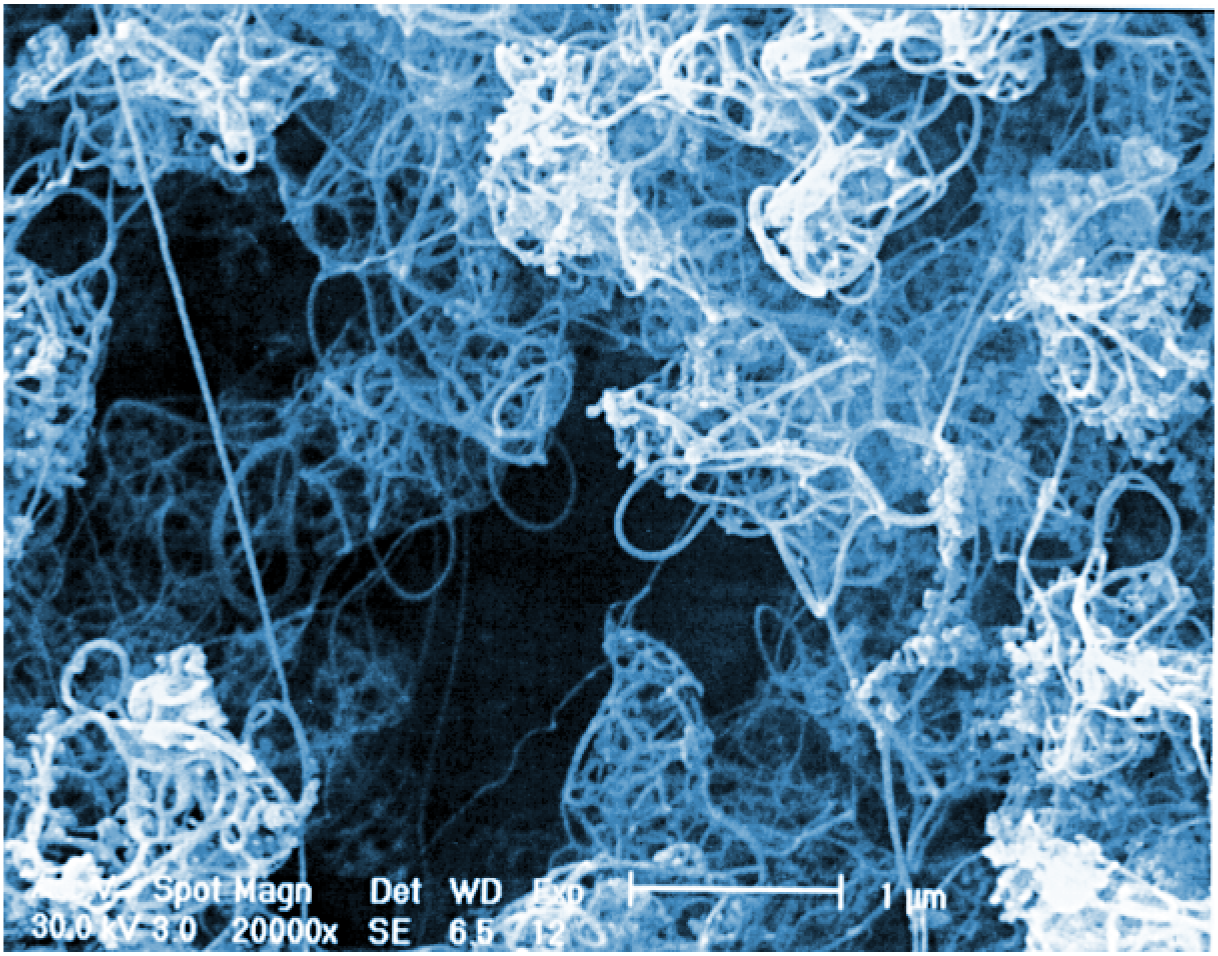
ADVANCED MATERIALS



This scanning electron micrograph of SWNTs shows only bundles of nanotubes, since individual tubes are too small to be viewed at this magnification.

Carbon Nanotubes – Production and Applications

Carbon Nanotubes – Production and Applications

Background

Since the discovery of Buckyballs in 1985 at Rice University, the study of fullerenes has grown tremendously. Although the Buckyball has not resulted in the applications expected when it was discovered, a potential application has appeared in the 1990s with the discovery of carbon nanotubes. Single-wall carbon nanotubes (SWNTs) are not only the strongest material known today but also may be the strongest material ever possible. And that's just the beginning. SWNTs of the type made at Johnson Space Center (JSC) are also as electrically conductive as copper and as thermally conductive as diamond. This combination of properties make nanotubes of enormous interest in many fields including materials science, physics, chemistry, and all types of engineering. Specific NASA uses for nanotubes include advanced materials and composites, nanoelectronics and nanodevices, flat panel displays, energy storage, and biomedical uses.

Project Overview

In January 1997, JSC and Rice University began collaborating on the production and application of carbon nanotubes. Nobel Prize winner Richard Smalley's research group was instrumental in bringing the ability to produce nanotubes using the double laser ablation technique to JSC. Now the Center has expanded this project from its early production to using diagnostic methods to study nanotube growth by studying the plasma plume in a laser system. Also, the project has set up an electric arc chamber for nanotube production that is much simpler, cheaper, and faster than the laser process. However, since this arc process produces nanotubes much less pure than those produced with the laser process, these nanotubes means must be purified. Purification is also done at JSC so that the nanotubes can be used to make composite materials. Tests of mixing and processing of composite materials are under way. The purpose of these tests is to generate materials with the highest strength-to-weight ratio ever produced.

Benefits and Uses

Within 10 years, nanotube technology will be infused into many aspects of the scientific community including materials science, chemistry, physics, biomedicine, and electronics. In a much shorter time (i.e., 3 years), nanotubes will begin to be used for applications such as conductive polymers and field emission arrays for flat panel displays. It is hoped that high-strength materials will be developed within 3 to 5 years. Carbon nanotubes have demonstrated such wide-ranging promise for applications such as those listed above that both government and industry will invest large sums in this technology in coming decades.

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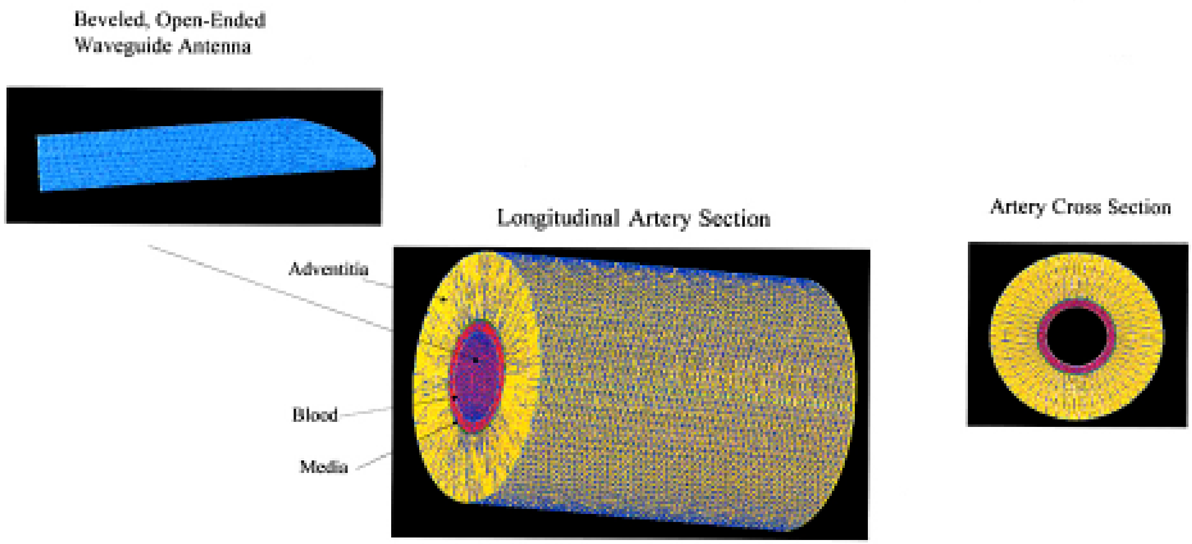
MEDICAL



Millimeter wave angioplasty applied to biomedical applications

Millimeterwave Catheters for Treatment of Atherosclerotic Lesions

Millimeterwave Catheters for Treatment of Atherosclerotic Lesions

Background

The purpose of this project is to develop and test a millimeterwave (94 GHz) catheter for treating atherosclerosis that can be commercialized by a catheter company. This treatment would replace the angioplasty that now has to be repeated in up to 50% of patients.

Project Overview

Atherosclerotic lesions on coronary artery walls are the major culprit in heart disease that can lead to, if not control heart attacks and the untimely death of cardiac patients. All treatment methods in use today result in either full or partial destruction of the superficial cell layer (endothelial cells), thus inducing an inflammatory response that acts to reduce the arterial lumin – a phenomenon called restenosis.

Millimeterwave angioplasty (MA) holds promise of a permanent cure coupled with a reduced restenosis. Unlike other methods that rely on mechanical trauma, excision, or perforation to achieve the desired widening of the artery, MA uses electromagnetic wave heating of arterial walls. By judicious selection of excitation frequency, radiated power level, exposure interval, and antenna beam design, it is theoretically possible to preserve the first 100 mm of the intima while eliminating the deeper fat in the media. At present, a prototype has been built and will be tested in the laboratory in the autumn of 1999.

Benefits and Uses

Permanent Cures Atherosclerotic lesions can be removed with a single application. This is in contrast to balloon angioplasty treatment, which may have to be repeated.

Better The use of MA will also result in reduced restenosis when compared to any other method in use today.

Non-traumatic The patient requires only a small incision where the catheter is inserted into the groin. This means the patient stays alert and reasonably comfortable during the procedure.

Cost effective Since lesions are eliminated with one application, the patient's projected cardiac care costs are markedly reduced and quality of life is considerably improved after the procedure.

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The TIP provides video imaging for eye ear, nose, throat, and skin; biomedical monitoring capabilities for ECG, $SpO_{2,}$ blood pressure, and heart rate; and an electronic stethoscope for heart, lung, and bowel sounds.

Terrestrial Application on the Telemedicine Instrumentation Pack

Terrestrial Application of the Telemedicine Instrumentation Pack (TIP)

Background

The telemedicine instrumentation pack (TIP) was designed to extend medical support capabilities on the Space Shuttle and the International Space Station. TIP, which is packaged into a single case that weighs 36 lbs with dimensions of 19 in. x 16 in. x 9 in., represents a portable multimedia doctor's bag that contains several medical instruments interfaced to an embedded Pentium-based computer. This computer can gather data from these various instruments and transmit data via a variety of communication modes. Depending on the available communication bandwidth, TIP can acquire and transmit data in real time, just in time, or in a store-and-forward mode.

Project Overview

Two TIP units were built by the Johnson Space Center's (JSC's) Technology Transfer Office for use. The first of these units was delivered to the Partners in Health Telemedicine Network (PHTN), a collaborative project based in Billings, Montana. PHTN has developed and is currently implementing a plan to use the TIP in extending health care services to inactive diabetic patients on the Northern Cheyenne reservation in Montana. The first phase of operation will witness TIP being used to perform home examination of patients and store-and-forward data transmission to the consulting physician. JSC's Medical Operations Branch has worked with PHTN to train clinicians and identify aspects of the project that have co-lateral benefit for NASA medical operations. Among these benefits is the opportunity to have TIP deployed in a truly clinical context, thus permitting an evaluation of the clinical efficacy of the TIP instrumentation and communication capabilities. Valuable information will also be forthcoming on the ergonomics and human factors of the entire system, and the robustness and reliability of TIP under conditions of repeated daily use. The first patient data will be collected beginning in August 1999. Completion of the technology transfer agreement with PHTN is scheduled for August 2000.

The second of the two TIPs will be used by Christus Health Spohn Memorial Hospital in Corpus Christi, Texas. This TIP will be installed in a Family Health Center (FHC) located in Robstown, 20 minutes west of Corpus Christi. The FHC is linked to the main hospital campus via a wide area network. Consequently, with TIP connected to this network there will be a capability for both real-time and just-in-time modes of telemedicine as well as store-and-forward activities.

Benefits and Uses

TIP is capable of performing portable and relatively inexpensive telemedicine. As such, it represents a new state of the art in telemedicine instrumentation – one which is able to operate without high bandwidth communication lines, expensive encoders/decoders, and installation in dedicated facilities. In turn, these benefits offer health care providers a new mode of delivering health care in remote and/or underserved regions. The current test and evaluation of TIP under two technology transfer agreements will allow NASA to gather valuable information to enable future enhancements. In conjunction with these, the program will demonstrate to the health care community the advantages afforded by this technological innovation.

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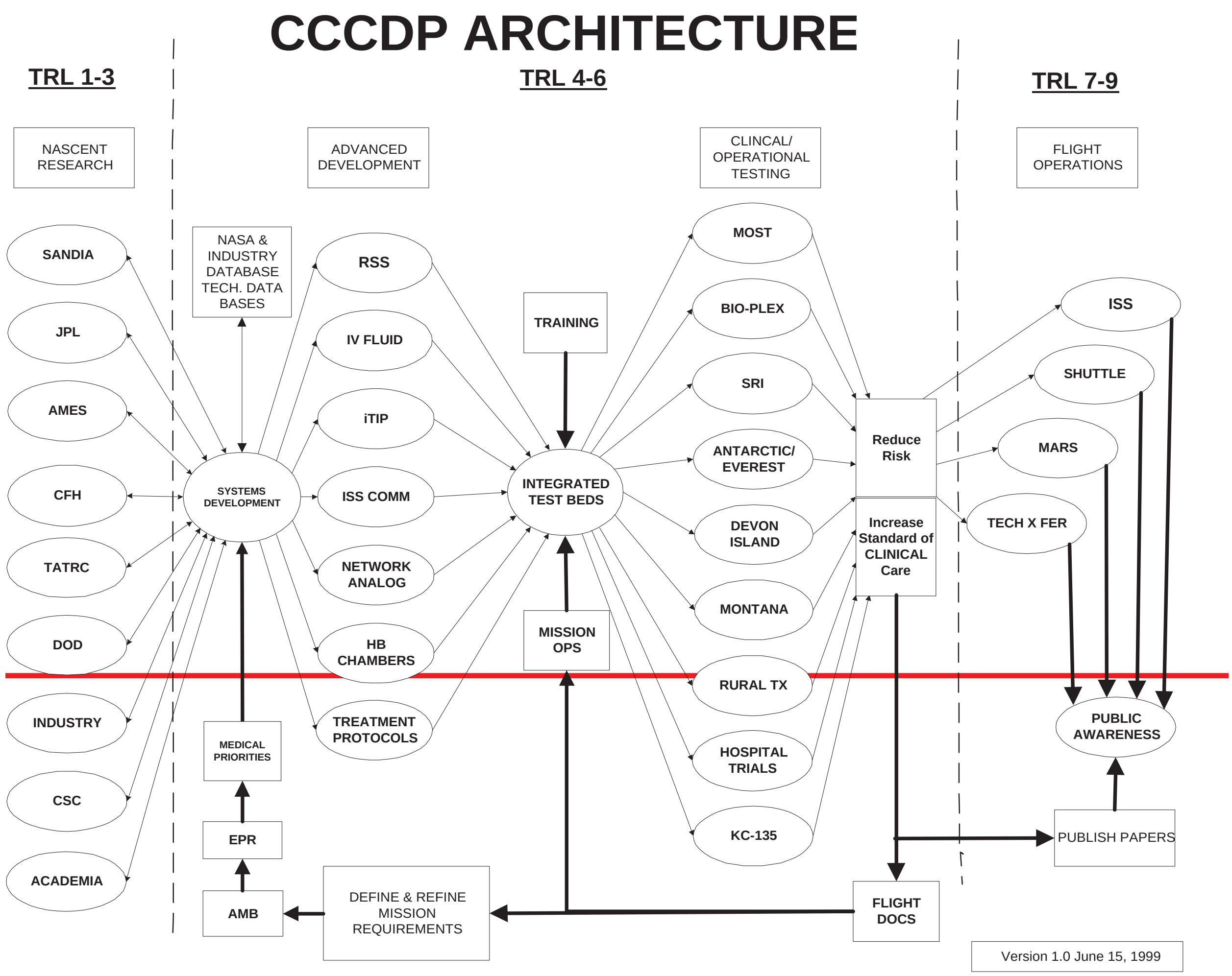

Clinical Care Capability Development Program

Clinical Care Capability Development Program (CCCDP)

Background

Johnson Space Center's Clinical Care Capability Development Program (CCCDP) addresses the limitations of current operational space medical systems, procedures, and protocols. Recent mishaps on *Mir* illustrate the potential magnitude of clinical space medicine emergencies and highlight deficiencies in this arena. CCCDP defines the scope and practice of medical care needed for each phase of human spaceflight based upon probabilities derived from the *Longitudinal Study of Astronaut Health*, analog populations, and expert opinion. The CCCDP implements an end-to-end process that transitions raw technology concepts into operational space systems in order to increase the standard of medical care in flight and reduce risk to both the mission and the crew.

Project Overview

The purpose of CCCDP is to design, implement, and manage a comprehensive health care program for spaceflight that will include health monitoring, prevention, and intervention for all mission phases. Specifically, CCCDP will be responsible for defining medical care requirements for all mission types and recommending the level of training necessary for the crew medical officer at each mission risk level. The program will also provide leadership and expertise in the positive evolution of space medicine. CCCDP evaluates and continually updates the clinical care standards available for each mission and the clinical training of each level of medical care provider. In addition, emerging clinical technologies under development will be evaluated for potential to enhance the standard of care during missions.

CCCDP manages the development of several technologies including integrated telemedicine systems, advanced respiratory support systems, compact hyperbaric chambers, compact ultrasound, intravenous fluid formulation and administration systems, global medical communications, and noninvasive real-time blood analysis and imaging technologies. The maturity of each project depends on scheduled implementation and overall mission phase. The extreme reliability needs of spaceflight dictate that new technologies or medical protocols are validated via terrestrial testbeds or environments analogous to spaceflight before becoming operational in flight. A key characteristic of the CCCDP is its collaboration with academia, industry, and Federal agencies other than NASA, something which must occur to eliminate redundant technology development and foster relationships for future endeavors. A network of technologists and researchers allows CCCDP to identify efforts driven by commercialization, efforts conducive to partnerships, and efforts NASA must fund independently to satisfy mission goals at an acceptable risk level.

Benefits and Uses

The technologies cultured through the CCCDP process will create highly integrated, reliable, and intuitive medical solutions that will optimize crew training requirements and vehicle power, data, and logistical resources. These same medical systems could be used here on Earth when patient and healthcare provider are geographically separated yet connected via a telecommunications modality (e.g., in prisons, mining and oil operations, the maritime industry, military operations, remote expeditions, and mass casualty emergencies). Licensure of these medical systems would be appropriate if a viable business model and regulatory compliance can be demonstrated.

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PHOTONICS

Hybrid Vision Laboratory

2 Civil servants   8 patents
3 Contractors   Approx. 100 publications

Major Disciplines:
Digital and optical image processing

Prime applications:
Small, fast vision systems for space robotics

Ancillary applications:
Short-term consulting to other JSC functions

Examples of consulting w/in JSC
- Pyrotechnic optics for X-38 [*EP*]
- ‘Spoiled’ retro for TRAC [*ER*]
- Digital image processing for Station
  - Space Vision System [*MV*]
  - ORU target surveying [*ER*]

Vigorous SBIR program
- Active: analog “correlator on a PC card”
- Recently completed: aperture coding for extended focus range of a camera

Optical information processing
- Coherent light carries an image
- Correlation-based image information extraction
- Advanced methods and devices
- Military associates:
  - Navy (Naval Surface Warfare Center)
  - Army (ARL, AMCOM)
  - Air Force (Rome Lab)
- University associates: Carnegie Mellon, U.Mo/KC, CU/Boulder, others

Facilities
- Full optics lab
- Some specialized digital equipment
- Optical correlator test bed
- Model positioners for ‘truth’ imagery

Hybrid Vision

Hybrid Vision

Background

Optical information processing (OIP) uses light to carry information and various photonic devices to affect how information appears as light propagates. The most common example may be the watch on your wrist. Information is impressed on the arriving light field by the liquid crystal diode, which is electrically modified by circuitry within the watch. In more exotic examples, extremely high data rates are processed in communication or vision applications. In some instances, photonic implementation operates to an advantage over digital or electronic processing (e.g., all-photonic switching of fiber-optic signals or 2-dimensional convolution processing of an image).

Project Overview

Since the mid-1980s, the Hybrid Vision Laboratory at Johnson Space Center (JSC) has been developing spatial light modulators (SLMs), optical correlators/convolvers, electrically driven holograms, and optimal pattern recognition theory. Several patents are held in the area, including implementation of fully complex modulation (phase and amplitude, independently), holographic control of light focus for addressing multilayer optical information storage, etc. An operating computer code implements our state-of-the-art optimal optical filter theory, including optimizing the Rayleigh quotient and the Fisher ratio ordinarily found only in digital computation pattern recognition.

Laboratory methods include area characterization of the SLMs at the heart of light control. Indeed this is the only group carrying out full-face fully complex quadrature interferometric modulator characterization. The group has also developed and patented a method of using those measured characteristics to control the focal depth and pattern of light so that nonmechanical, faster adjustments may be made in addressing optical information storage media such as multilayer computer disks. Work is continuing to transition these technologies into commercial practice with companies under contract to the government while fostering further growth in both government and contractor abilities.

Benefits and Uses

One JSC patent (available for license) describes a method of tracking eyeball motions during laser procedures such as retinal photocoagulation. This method would permit a surgeon to work closer to the fovea – the point of highest resolution; i.e., the point of direct vision – by maintaining closer control of exactly which part of the eye is being hit. This would minimize collateral damage and shut down the surgical laser far faster than a human operator could when tracking is lost. Another JSC patent (also available for license) describes how separate layers of compact disks can be addressed without moving mechanical parts, thereby potentially speeding up the rates at which information can be extracted from them. The devices and architectures being developed under contract can increase the speed of machine vision to the point of doing literally hundreds of full-frame image correlations per second, thus inferring part identification and orientation on a production line at a full video frame rate. Another JSC-patented technique permits reconnection of light-borne information switching within the vertical retrace time of a video frame without changing the information from light-borne to electronic and back to light-borne form. All these applications are available for commercial use.

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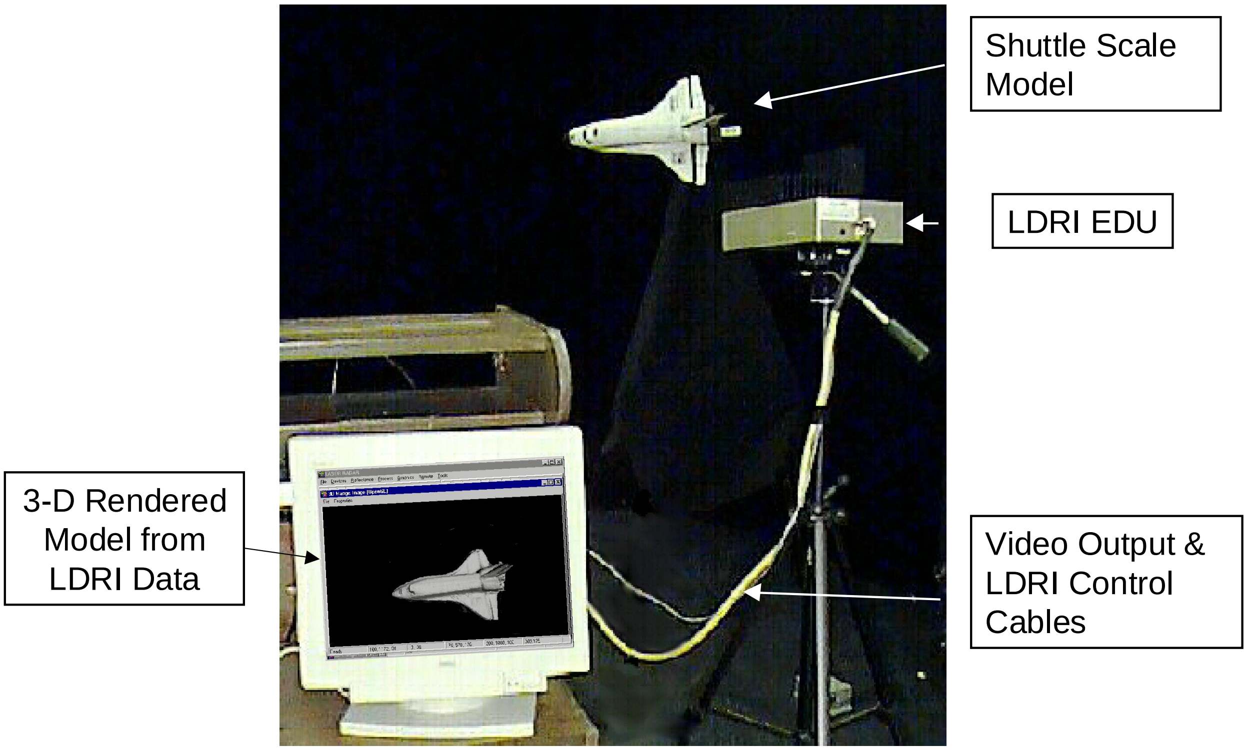

LASER Dynamic Range Imager

LASER Dynamic Range Imager (LDRI)

Background

Static and dynamic measurements, which are key to validating on-orbit assembled and deployed space structures, are very challenging to obtain with conventional instrumentation. The complexity of these space structures demands that large numbers of locations be measured simultaneously. Photogrammetry measurements have limited utility due to the field of view available when zoomed in to obtain high resolution. Laser vibrometers can scan to address one point at a time, but this is not sufficient to address the great number of measurement locations during structural-dynamic motion decay.

The LASER dynamic range imager (LDRI) fills the hole in this on-orbit structural-dynamic measurement capability. Sandia National Lab's scannerless (LASER) range imager technology was selected to create range images at video rates because each pixel, representing an individual range measurement, can be used to characterize the structural-dynamic response or the static structural conditions. Data is thus provided with unlimited options for combining a multitude of measurements taken of the entire field of view for each digital frame.

Project Overview

The primary purpose of the project is to demonstrate LDRI's new measurement capabilities on the Space Shuttle and obtain measurements of International Space Station structure. Secondary purposes include ground and on-orbit demonstrations of LDRI applications to other Human Exploration of Space projects (e.g., robotics and extravehicular activity crewmember assistance, space vehicle proximity operations and inspection, planetary rovers and landers, and potentially particulate density/flow measurements).

The LDRI infrared LASER beam is amplitude-modulated and then diffused over a field of view. Its receiver filters all but reflected energy from the scene at the LASER wavelength (850 nm) and amplifies it with an image intensifier coupled to a charge-coupled device. The resulting black-and-white intensified video images and the time-of-flight related phase information are used to create real-time range digital video images. These images provide instant depth perception to an operator in almost any lighting condition. Real-time calculations can be performed to produce range, range rate, and orientation to an object. Post-test calculations can provide high-resolution 3-dimensional static geometric models and surface maps, 3-dimensional dynamic models that provide modal parameters, and mode shapes for low-frequency vibration.

Johnson Space Center currently has a working engineering unit for application testing in its labs. A spaceflight unit is under development that will operate on the Space Shuttle to image the dynamic response of the giant Space Station solar arrays after a series of thrusters is fired. The next step is to reduce the LDRI, which is now the size of a shoe box, to about one-quarter that size – but with higher resolution and frame rates as well as more internal processing capability for use with navigation/robotics applications.

Benefits and Uses

LDRI is a revolutionary imaging and measurement technology that can help the space program reduce the number of sensors needed on space vehicles and provide the structural-dynamic measurements that have been impossible up to now. It represents a leap forward for military autonomous space and robotic sensors and new opportunities for the soldier to identify and characterize threats. LDRI could become the first scannerless LASER vibrometer, the first truly 3-dimensional video camera, and the next-generation robotic sensor for manufacturing and inspection. University and research institutions can use LDRI's digital imagery for documenting human, animal, fluid, and structural testing by range-imaging the resulting motion.

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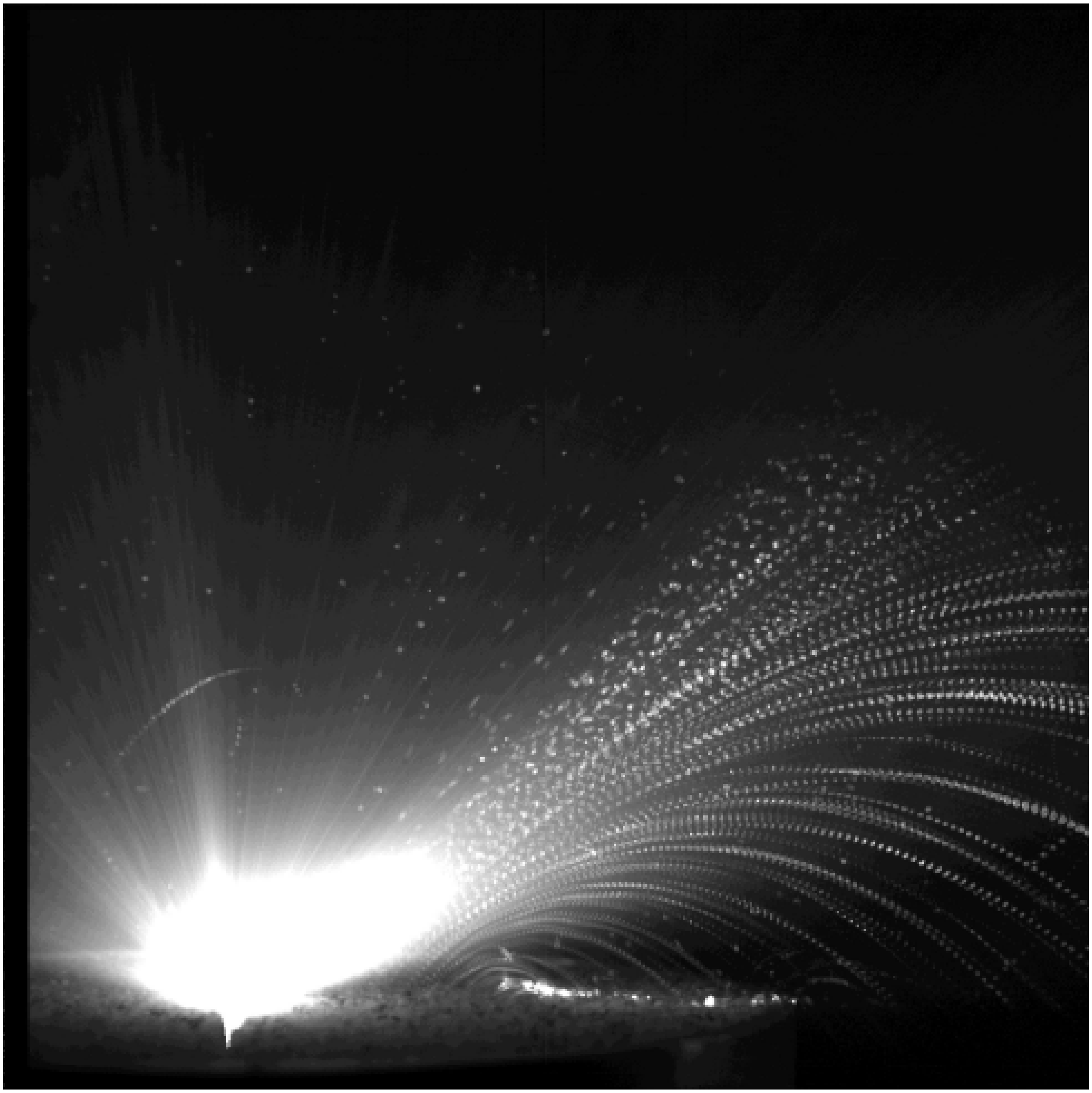

This photograph, which was taken with the ejection-velocity measurement system, shows ejecta from the impact of a 4.2-mm aluminum sphere into coarse sand at 900 ms^{-1}. The large, bright flash is produced by light generated by the impact itself. Note the well-defined, parabolic trajectories of ejecta to the right of the photograph. Each laser burst lasted 200 µs; the period between flashes was 1800 ms.

Ejection-Velocity Meaurement System

Ejection-Velocity Measurement System

Background

Impacts affect the surfaces of planets, including the Earth, in a variety of ways. Some of the more obvious and important ways are related to ejecta, the material thrown out of a crater through action of the shock wave created by a collision. Deposits of ejecta along with the hole created, the crater, constitute most of the topography created by an impact. Meteorites arrive at Earth as fragments of ejecta from asteroids, Mars, and the Moon. To understand impact craters, it is important to understand the process of ejection.

Project Overview

Impact craters are created in laboratory settings on a regular basis, and ejecta from those impacts can be easily photographed. Unfortunately, historically measuring the velocities and trajectories of ejected fragments has been made difficult because of the photographic confusion caused by huge numbers of fragments being ejected in all directions. A method devised by a group at the University of Dayton in the 1970s has been modified and updated with 1990s technology to study the ballistics of ejection at Johnson Space Center.

Laser light is passed through a cylindrical lens, generating a sheet of high-intensity illumination. This sheet of light is then directed through the impact point in a plane perpendicular to the surface of the target and parallel to the focal plane of the camera. A waveform generator can then be used to modulate laser output into a timed series of flashes. A cooled-charge coupled device (CCD) camera takes a time exposure of the cratering event as it is illuminated by the flashing laser. The resulting stroboscopic photographs provide timing (the time between laser flashes is known since the time was programmed) and geometric information on the trajectories of ejected fragments (the shapes of which can be measured easily). Data obtained with this technique have shown, for example, how and where state-of-the-art, quantitative approaches to cratering phenomena are not yet complete.

Benefits and Uses

This approach to measuring particle motion can be used in a variety of situations in which motion occurs in a plane. Convection cells is an example of a process that is well suited to this sort of study. Spray from nozzles or rocket motors, particle motion in wind tunnels, and sedimentation are other examples of processes that could be examined in detail using this technique. The principal cost of such a system is in the cooled-CCD camera, which is necessary because of the time exposures used in collecting the data. (Thermal noise in uncooled cameras would lead to image degradation.) The color and output intensity of the laser is dictated by the characteristics of the subject material.

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SOFTWARE

Figure 1. Camera system with moving optics

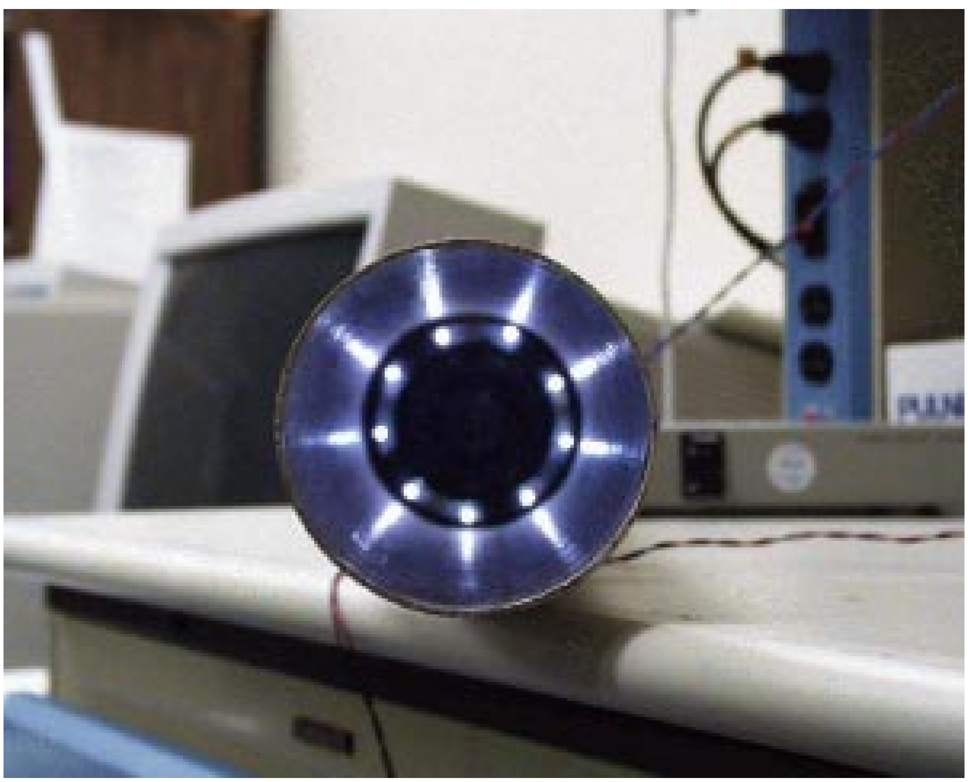

Figure 2. Full circumference radial view down pipe

Video Mosaicing for Pipeline Inspection

Background

Visual inspection of gas pipelines is performed using small camera systems that have moving optics which permit the operator to pan the camera from side to side for either a down pipe view or to view a portion of the side of the pipe wall. Moving optics (fig. 1) expand the camera's narrow field of view by allowing the operator to pan and tilt the camera line of sight for down pipe views or rotate and look at the pipe wall. There is a desire to increase reliability by eliminating the need for moving parts and to provide simultaneous down pipe and full circumference radial views.

Project Overview

This technology applies computer vision techniques – known as video mosaicing – to enhance graphic views for visual inspection of gas pipelines. The video mosaicing vision system can provide simultaneous forward and integrated full circumference radial views in real time of a pipeline being inspected. Video mosaicing software has been designed specifically to image a cylindrical surface. A wide-field-of-view camera lens is used to capture down pipe images and radial views of the pipe wall (fig. 2). Unfortunately, a wide-field-of-view lens also captures a distorted image; this must be remapped and reintegrated via software into a contiguous picture of the pipe wall. A prototype camera system has been assembled and initial software developed that can remap distorted pictures and mosaic them into a contiguous image of the interior of a pipe wall.

Potential enhancements include promoting visual pipeline inspection to supervised inspection (a precursor to fully automated inspection). One scenario for this technology is for a visual pipeline inspection system to provide enhanced graphical displays, possibly with highlights on potential defects found within the pipe or with an audible alarm to alert operators to a suspect area within the pipe.

Benefits and Uses

A large number of companies are offering visual inspection equipment that can be used in pipeline inspections. But to our knowledge, almost all of them offer only unprocessed video images for human inspection. One major drawback of this approach is that it relies on the human operator to perform pipe inspection by viewing video images either in real time or from prerecorded tapes over a long period of time. Fatigue induced by long viewing of mostly featureless images makes human inspection less reliable and more labor intensive. We believe the potential of visual pipeline inspection cannot be realized without exploiting well-developed computer vision techniques. With the enhancements from computer vision techniques, visual pipeline inspection can be promoted to supervised and/or automated inspection.

This technology is still under development. Remapping the distorted images and mosaicing into a contiguous sequence of radial views as a camera system is being moved down a pipe have been performed successfully. This technology can be applied to the internal inspection of 4-in. diameter or larger pipes.

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Camera system on telescope mount for recording Leonids meteor storm

Video Analysis

Background

In addition to being subjected to the risk of collision with pieces of debris in orbit, spacecraft are at risk of being bombarded by micrometeoroids. The meteor showers that recently exhibited the most danger to spacecraft are the Persieds – these occur each August and were most prevalent in 1994 – and the Leonids, which occur each November and are predicted to storm in 1999. The November 1998 Leonids shower was videotaped at Johnson Space Center (JSC) and at the JSC observatory in Cloudcroft, New Mexico. The output of this effort was a meteor hourly rate and the generation of a meteor mass distribution. The mass distribution generated by Leonids video data exhibited a difference from the theoretical model used as input for risk assessment calculations associated with Space Shuttle missions. In the past, the model assumed a meteor mass distribution. The 1998 analysis, along with an analysis planned for the 1999 storm, will either verify the assumptions of the model or demonstrate that a modification is warranted.

Project Overview

An analysis of the 1999 Leonids meteor storm is expected to verify the model currently being used or indicate where a modification is warranted. Equipment both at JSC and in Cloudcroft is a low-light-level video camera and a hi -8 video recorder. The JSC camera is mounted on a telescope mount; a camera tripod was used at Cloudcroft.

The 1998 analysis was performed using the JSC Video Digital Analysis System (VDAS) Laboratory, but the 1999 analysis will be performed by a newly developed meteor analysis system because the capability used in the VDAS Laboratory was retired due to obsolescence.

Since data-gathering observations depend on the weather, two primary sites are being used – JSC and Cloudcroft. A JSC Astronomical Society member has volunteered to videotape Leonids in the Canary Islands to provide a backup, and another volunteer plans to videotape Leonids at an observatory southwest of Houston.

Benefits and Uses

The proposed analysis will either verify the present model or point to a modification. A study of variations in the direction of the Leonids radiant is also planned that will aid the accuracy of modelers in predicting the severity and densest location of the Leonids meteors. These techniques might be extended to other meteor showers; and from this the risks of commercial and government spacecraft being damaged by meteors could be more accurately predicted.

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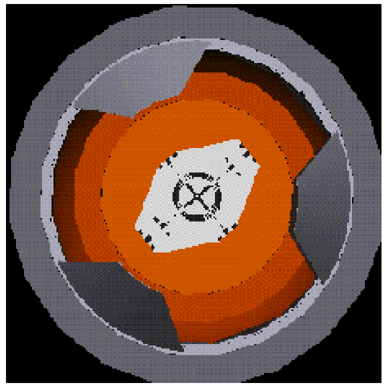

Figure 1. Docking target model with no shadow or glare

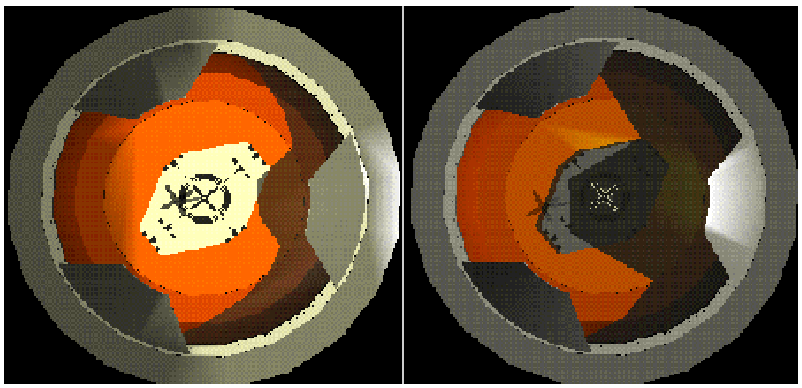

Figure 2. Docking target model with shadows and glare

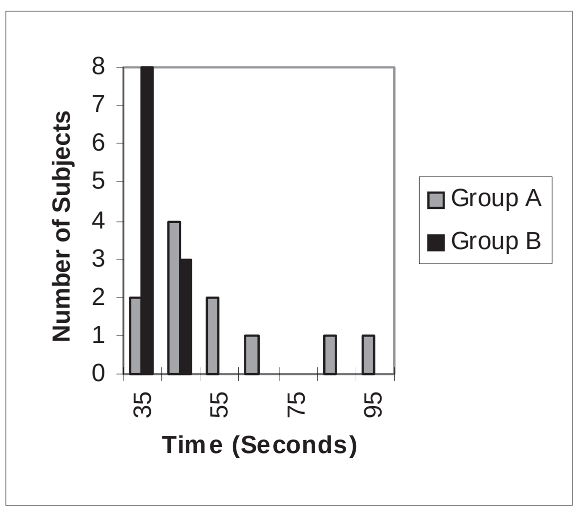

Figure 3. A comparison of times to complete the actual task. Group A trained without lighting. Group B trained with lighting.

Measuring the Effects of Lighting on Human Performance in Training

Background

Many tasks performed by astronauts in orbit, such as deploying payloads, depend on obtaining visual cues either from a camera image or direct viewing. Direct exposure to intense sunlight and rapidly changing sunlight direction makes the crew response to high-contrast shadows and variations of incident light angles an essential part of carrying out mission operations. Crews have positively responded to undergoing training with mockups and lighting hardware prior to missions involving docking. However, since much of this training is done with computer simulators using conventional shaded geometric models, these models do not simulate actual lighting environments – including effects such as shadows and glare. The purpose of this project is to compare the effect different types of training images has on actual task performance. Specifically, the effect of computer task training with accurate lighting images, shadows, and glare was compared to computer task training with basic shaded models with no shadows and glare effects.

Project Overview

To compare task performance with respect to different types of training, a simple alignment task, one similar to the alignment of the Orbiter with the *Mir* docking target, was used (figs. 1 and 2). Two different experiments were conducted with two groups of subjects: (1) those trained without lighting and (2) those trained with lighting. In the first experiment, alignment accuracy only was emphasized. For this experiment subjects were allowed any amount of time needed to obtain the required alignment. Objective results were inconclusive, but subjects who trained with lighting images felt more confident that (1) their test results were accurate, (2) training would generalize to other tasks, and (3) training was reasonably realistic. The second experiment emphasized alignment accuracy and alignment response time. In this case, subjects who trained with lighting (Group B) as part of the scenario had a significant advantage (an average execution time of 34.9 sec) over those who did not (Group A with an average execution time of 40.7 sec) (fig. 3).

Benefits and Uses

When time constraints are imposed on a task, training with lighting effects improves task performance without sacrificing accuracy. Also, subjective evidence suggests that subjects who trained with lighting effects had lower stress levels when executing the actual task. While computer technology is not yet able to generate real-time ray-tracing images for training, lighting conditions can be modeled for specific cases using existing computer hardware lighting parameters and special-case shadowing effects. The results of these tests also support the use of lighting and illumination techniques for noncomputerized image creation using mockups and artificial lights.

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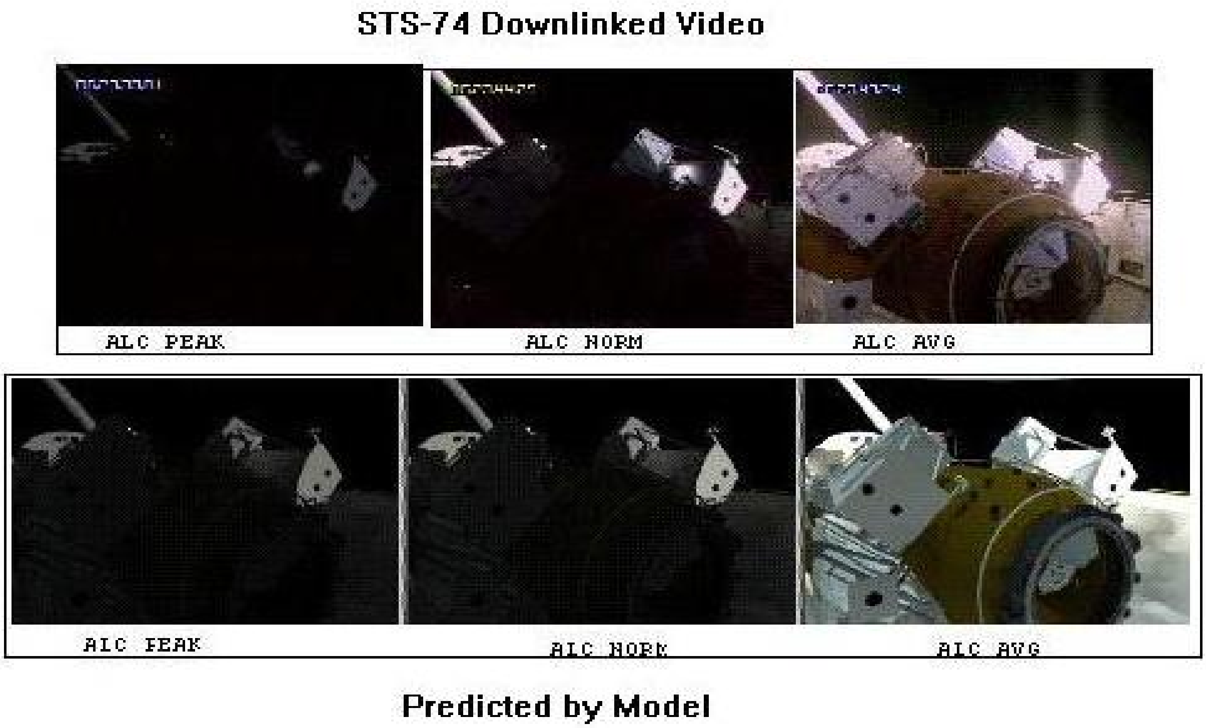

Results of post-processing video downlinked from the Space Shuttle Orbiter

Camera Images from Luminance Maps

Camera Images from Luminance Maps

Background

This project developed and validated computer models of the Space Shuttle TV cameras based on scene illumination and camera parameters such as noise, gamma, and gain. Input to the camera model is an accurate computer calculation of the scene luminance; i.e. the amount of light reflected from objects in the scene into the camera lens. Such calculations can be very accurate but are also slow to generate (~20 minutes). The computer model of a Space Shuttle TV camera will allow preflight prediction of lighting conditions for camera-based operations.

Project Overview

Post-processing techniques of luminance maps created by a physically based lighting program modeled the camera parameters of automatic light control (ALC) and gamma control (image transfer function) for the CTVC (Shuttle color camera). In order to model ALC, the luminance map is scanned for a specified region that does not vary in luminance more than a designated amount determined by the ALC settings of average (AVG), normal (NORM), or peak (PEAK). A scale factor is then calculated that will display the average luminance in this area as average brightness in the image (128 on a color scale between 0 and 255). This scale factor is applied to the entire image. Light entering the camera is displayed by controlling the CTVC with two gamma mode settings, GAMMA BLACK STRETCH and GAMMA LINEAR. To effect gamma control, only the camera's influence on the transfer function was modeled. Influences on the display from monitors and printers were not considered in this project. To validate results, computer-generated images were compared to ground-based images created with CTVC camera and lights. Video images broadcast from the Space Shuttle were also used for comparison.

Benefits and Uses

An accurate computer-based camera model will allow preflight lighting analysis to predict the best times in orbit for camera viewing of a specific activity. Such analysis is critical to mission success for operations which depend on camera viewing. A quick assessment of lighting impacts that occur due to flight schedule changes can also be provided with this predictive camera model. For example, performance of the camera-based space vision system during International Space Station (ISS) assembly will depend on good camera images during Space Shuttle berthing operations for ISS assembly; and pre-launch camera selection and location can be optimized to examine critical components while on orbit.

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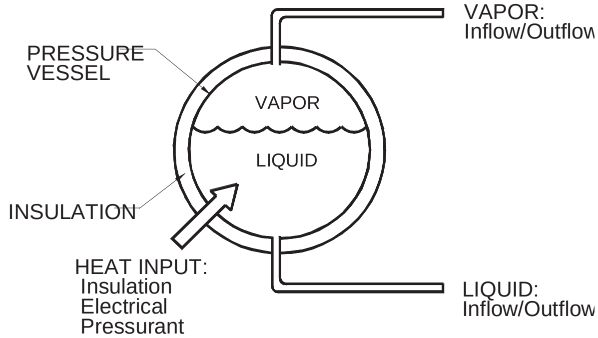

Figure 1. Basic schematic of cryogenic storage system

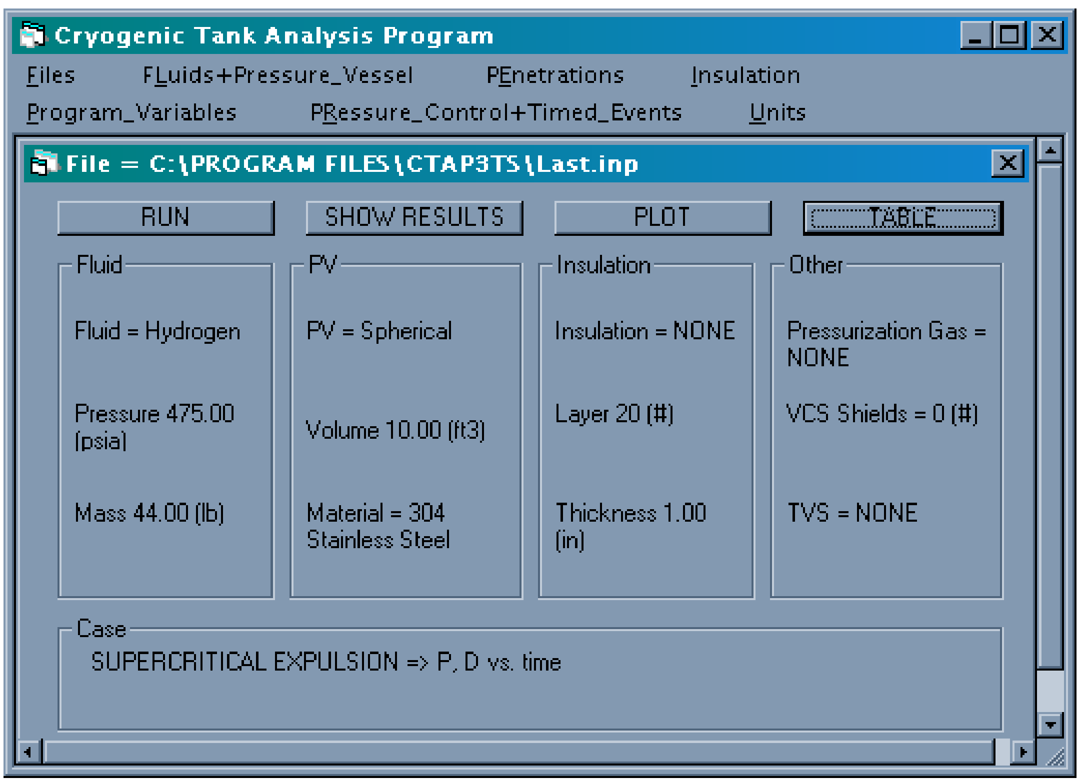

Figure 2. CTAP input display

Cryogenic Tank Analysis Program (CTAP)

Background

Designing a cryogenic storage system requires a series of detailed analyses to compute the thickness of the pressure vessel, required amount of insulation to achieve the desired heat leak input, and sizing of the heater or gaseous pressurization systems that will expel the cryogenic fluid at desired rates. This is often an iterative process. The Cryogenic Tank Analysis Program (CTAP) was developed to provide an easy-to-use software tool that would allow a design engineer to quickly determine the effects of varying design parameters while investigating the conceptual design of a cryogenic storage system. The user can input design parameters in a spreadsheet-like environment and select from a number of operating scenarios to perform both steady-state and transient analyses on the proposed system.

Project Overview

Technology Applications, Inc., (TAI), which was awarded a Small Business Innovative Research (SBIR) grant to design a demonstration version of CTAP software, developed a Windows-based program that allows users to input a wide range of design parameters such as type of cryogenic fluid, size and shape of storage tank (spherical or cylindrical), type of insulation system, type of pressurization system (gaseous helium or electrical heaters), and desired mission profile (flow rate versus time) (fig. 1). CTAP software can be used to develop a preliminary design of a storage tank and analyze its performance during an entire mission. It is currently being used by Johnson Space Center engineers to design cryogenic storage tanks for propulsion systems (fig. 2). The design of the cryogenic tank and the gaseous helium pressurant tanks was developed using CTAP software while the design was still in the conceptual stage. TAI is pursuing follow-on funding through the SBIR Program to take the CTAP from a demonstration level to a final product that can be marketed commercially.

Benefits and Uses

CTAP software can be used to quickly develop a conceptual design of a cryogenic storage system and to train new design engineers on the parameters that must be considered in the design and operation of a cryogenic fluid storage system. Since CTAP software was developed under an SBIR grant, the software's developer, TAI, retains sole marketing rights.

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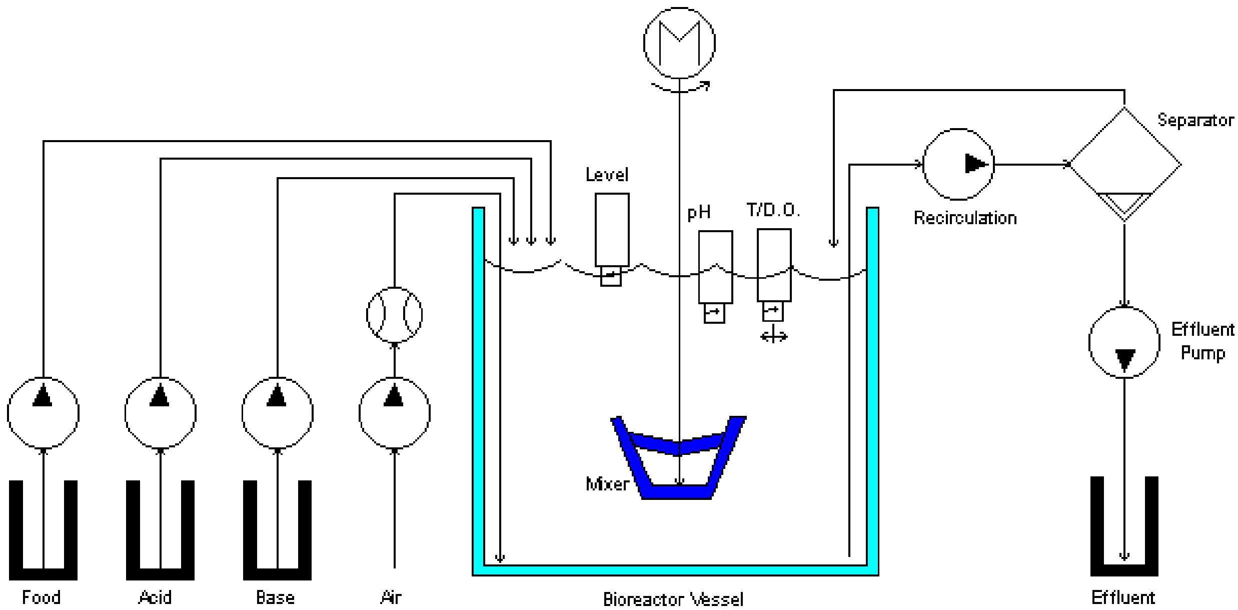

Screen shot of schematic editor showing structure of magnetically activated sludge reactor

Autonomous Fault Diagnosis and Recovery for Advanced Life Support (ALS) Systems

Background

The advanced life support (ALS) systems being developed for long-term crewed missions are complex and are characterized by a lack of sensors and redundancy. While diagnosis of and recovery from faults within them will require deliberative analysis and human intervention, remoteness and economy will also require that astronaut crews have a high degree of self-reliance and autonomy from ground support. These issues demand technologies for the reliable automation of health maintenance activities, technologies that can efficiently call upon a crew to conduct inspections and repair operations. Techniques that reason from structural and behavioral models of the ALS system are needed to ensure maximum coverage of faults, including unanticipated faults. The efficient use of experiential knowledge is needed to ensure timely response. Handling of unanticipated contingencies also requires the capability to dynamically generate recovery and repair plans.

Project Overview

This Phase II Small Business Innovative Research project is being conducted by Stottler Henke Associates, Inc. Its objective is to develop a suite of tools that can be used to create onboard health maintenance systems configured to handle problems in a variety of ALS systems. These tools will provide knowledge editors that enable acquisition and representation of structural and behavioral models, descriptions of previously encountered anomaly cases, and descriptions of the operations and procedures which can be employed to obtain diagnostic information and to effect repairs. The tool suite will include reasoning engines that synergistically combine model-based reasoning and case-based reasoning to perform fault diagnosis, and it will employ knowledge-based planning to generate recovery/repair plans. Finally, the suite will include a crew interface that can guide crewmembers step-by-step through execution of generated procedures, employing multimedia presentations as communication aids.

The current work focuses on the deliberative health maintenance tasks of diagnosis and recovery/repair planning. Future enhancements will add capabilities to perform the reactive subtasks of our health maintenance architecture; i.e., monitoring, fault detection, fault isolation, and initial response generation.

Benefits and Uses

Because the health maintenance system contains all the necessary information and expertise, an onboard system will permit diagnostic information gathering and repair operations to be carried out by an intelligent crewmember with no special knowledge of life support systems. This ALS system will improve crew self-reliance and autonomy from ground support, thus significantly reducing mission operations costs. With further development, ALS technology can be applied in any industry where the physical plant is complex and under-instrumented and where faults can involve hazards to personnel.

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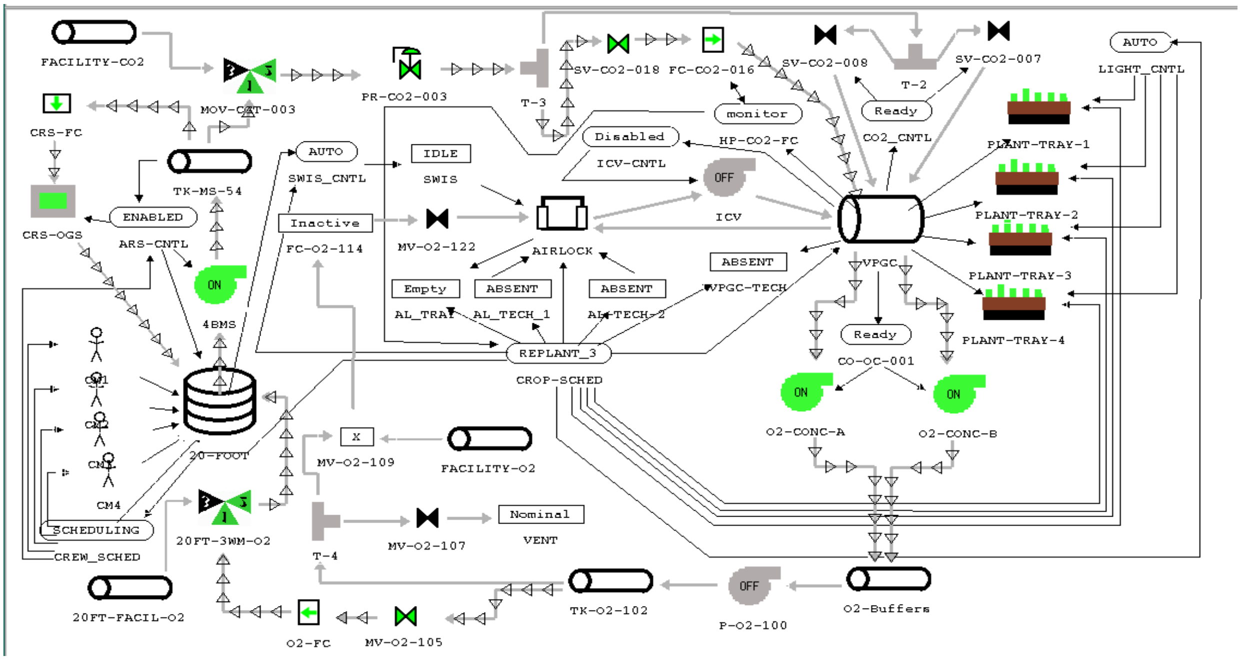

A CONFIG model of an advanced life support system in the Phase III lunar-Mars life support test

CONFIG Modeling and Simulation Tool

CONFIG Modeling and Simulation Tool

Background

Automation of continuous and batch manufacturing of industrial products requires concurrent engineering supported by new hybrid approaches to simulation. Many manufacturing, power-generation, and communications systems have become highly automated. As process automation systems become more complex, a hybrid simulator is needed that can analyze and evaluate automated plant operations. A hybrid simulator is capable of modeling the heterogeneous discrete and continuous activities in a plant.

Project Overview

CONFIG, a hybrid modeling and simulation tool, supports design, analysis, and validation testing of process automation systems. It can help its user to interactively test software and procedures extensively before deployment in a real system and retest user hardware, procedures, or software as they are changed during operations. CONFIG uses discrete event simulation technology enhanced with capabilities for continuous system modeling. Among these capabilities are continuous integration algorithms and qualitative simulation, based on fuzzy sets. The user can develop or specialize object-oriented models of equipment and, with nominal and failure modes, plant topology and operations procedures and control. CONFIG supports modeling, simulation, and analysis of those system behaviors that are affected by events which dynamically change the topology of a system by providing efficient graph analysis methods to determine local effects of global changes in flows and pressures. And although discrete event simulation technology has typically been used for stochastic analysis, the CONFIG simulations are typically deterministic for analysis of operational scenarios.

CONFIG has been used to test intelligent control and monitoring software for oxygen and CO_2 transfer between chambers in the Phase III Lunar-Mars advanced life support test. The simulation models the crew, plants in the growth chamber, gas processing systems, flow configurations, operating modes, schedules, procedures, and controllers. We plan to further enhance the development environment and integrate with continuous hybrid simulation, and to enhance procedure modeling to support studies of operator error and coordination of automated and manual operations.

Benefits and Uses

CONFIG can be used to validate advanced process automation software including continuous and discrete control, with asynchronous interactive dynamic simulation. The technology can be used to analyze and predict effects of control actions and other events on the plant in various modes – whether local or global, immediate or delayed. It can also be used to analyze failure modes and effects and the capability of instrumentation to support fault diagnosis.

Potential applications include analysis and design evaluation for industrial process automation of batch and continuous manufacturing, power-generation systems and transmission networks, heating and ventilation systems, and telecommunications systems.

This technology is patented and available for licensing. The current implementation runs on Unix operating systems, but cooperative agreements could support porting to Windows and Java as well.

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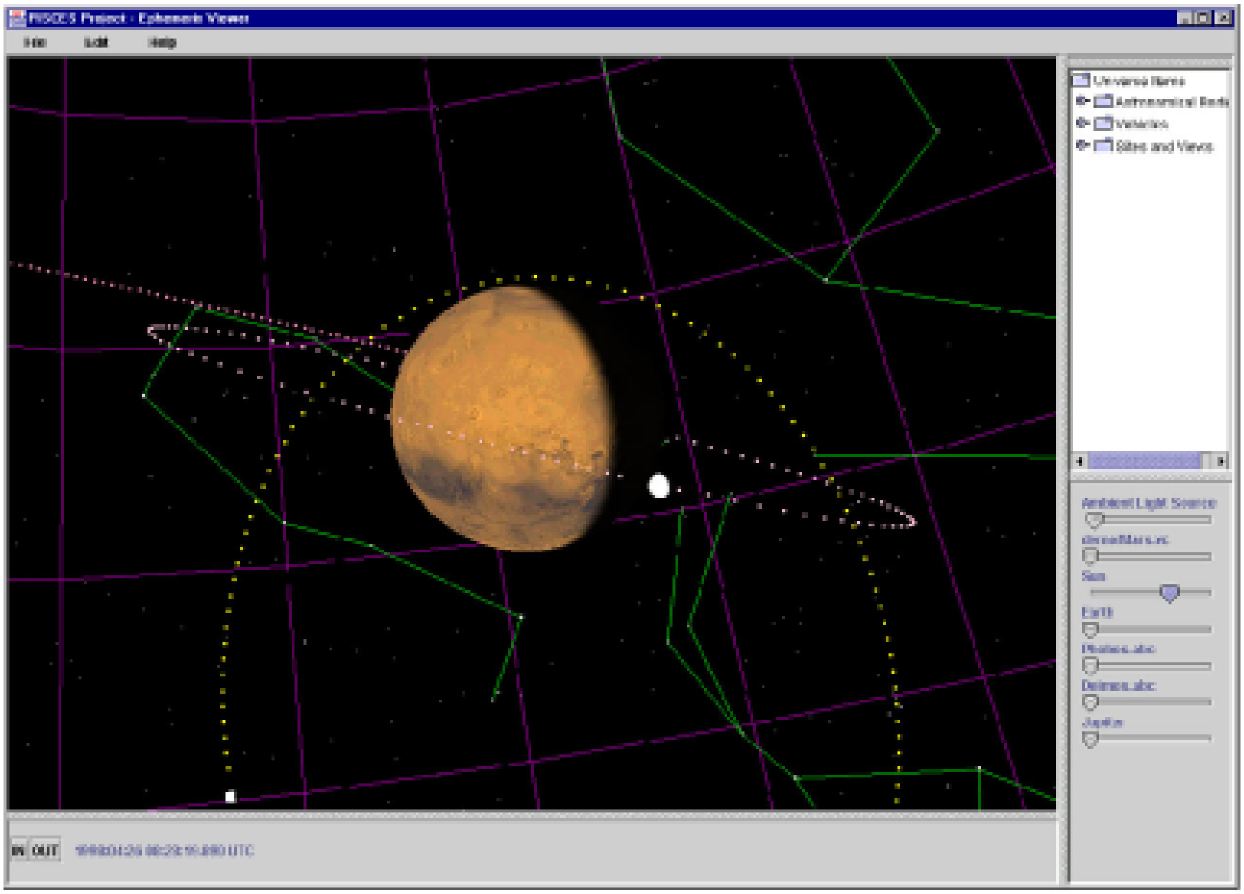

PISCES output display illustrating lunar trajectory against celestial background

Platform-Independent Software Components for the Exploration of Space

Platform-Independent Software Components for the Exploration of Space (PISCES)

Background

PISCES [platform-independent software components for the exploration of space] is a software development effort to design a basic web-based architecture for orbital mission design and analysis. In 2000, PISCES will provide NASA with a multiprogram rendezvous design and analysis capability capable of supporting missions around the Earth, Moon, Mars, and other planetary bodies. It will also provide an enabling software library for future automated rendezvous techniques design and development and a software environment for evaluating ground versus onboard software partitioning.

Project Overview

We are retooling current trajectory design algorithms into a single object-oriented software library using a collaborative effort between NASA and universities across the country, both to demonstrate alternatives to traditional contracts for this type of software development and as a Human Exploration and Development of Space [HEDS] strategic initiative to "form partnerships with educators to bring space exploration experience into the classroom . . . through implementation of new initiatives to inspire students to study science, mathematics, engineering, and technology."

In 1999, PISCES demonstrated its ability to perform precision trajectory propagation around the Earth, Moon, and Mars using complex gravitational models and atmospheric models and the perturbative effects of solar radiation and N-body gravitation due to other planetary gravitations. Three-dimensional interactive graphics were also developed to allow the user to visualize these precise orbits using a virtual-reality type interaction. A generic framework for extendable software development was produced.

Benefits and Uses

NASA's "trusted legacy code" for mission design is becoming difficult to maintain. Current applications, which consist mainly of FORTRAN and C codes, were written 25 years ago and are generally limited to low Earth orbit (LEO) operations. These applications are difficult to understand, maintain, and enhance, and are not easily portable to new computer systems. The legacy code is unattractive to newly emerging college graduates, who are schooled in the object-oriented world and in a Windows environment, and limiting to NASA, which needs maintainable and expandable capabilities. The future of NASA will depend on its ability to perform detailed mission design and rendezvous operations in orbits beyond LEO. PISCES is positioned to become the tool of choice for rendezvous design and analysis for future NASA programs.

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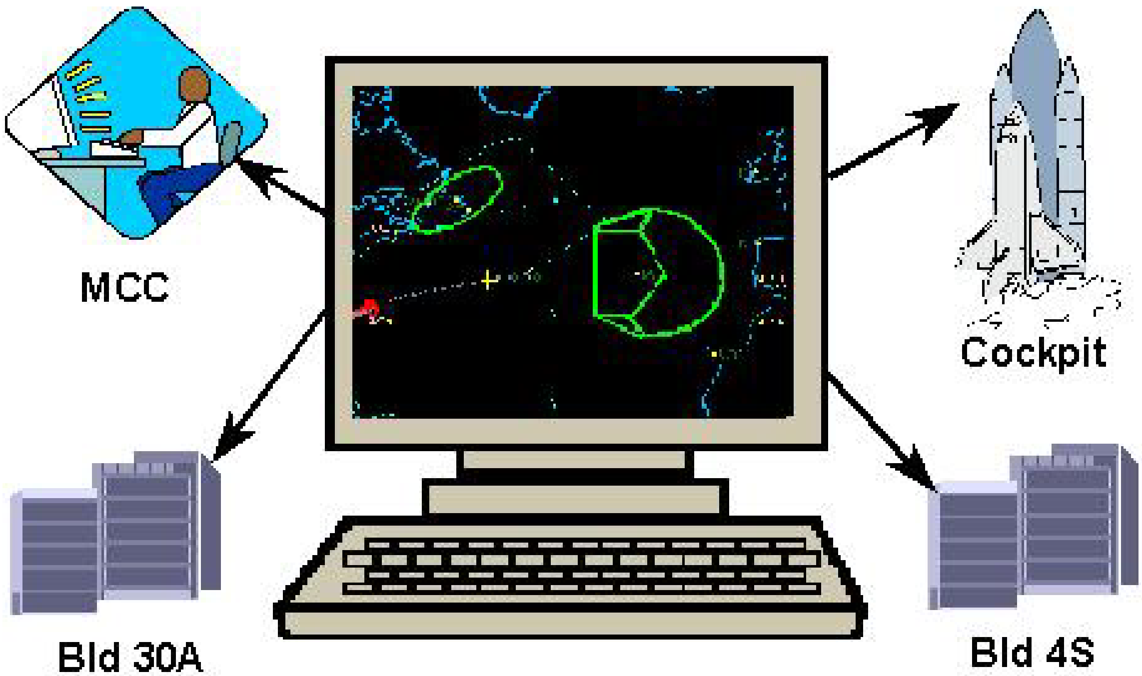

Platform-independent ascent situational awareness tool for use in multiple facilities and computational environments

Platform-Independent Downrange Abort Evaluator

Platform-Independent Downrange Abort Evaluator (PIDAE)

Background

The downrange abort evaluator (DAE) currently is being used in the Johnson Space Center (JSC) Mission Control Center (MCC) mainframe mission operations computer (MOC) to provide flight controllers with real-time graphical situational awareness of landing capability for transoceanic abort landing (TAL) aborts. Various assumptions are made regarding the number of Space Shuttle main engines running at the time of engine failures. External tank (ET) impact locations are also displayed for range safety limit line avoidance evaluation.

This developmental version will be platform-independent so it can be deployable to a laptop computer onboard the Space Shuttle Orbiter, as well as to the MCC workstations and various organizational trainers. This tool will greatly enhance a crew's situational awareness for emergency landing capability and proximity to range safety limit lines. Currently crew insight into these items is minimal or nonexistent.

Project Overview

This project has enabled the development of a universal trajectory application that would support the needs of multiple users throughout the JSC community. This planned application would replace the prime MOC DAE application and output ET footprint capability for operational sequence (OPS) 3 TAL, as well as OPS 6 East Coast abort landing/Bermuda aborts with enhancements to improve the fidelity of the footprint. The application, which will use a graphical user interface that requires minimal user interactions, will be coded in JAVA programming language for ease of portability.

By the end of 1999, initial rehosting of the existing capability into JAVA and a preliminary driver for the OPS 6 display will be completed. In 2000, work will continue with additional graphics and a better program driving the OPS 6 DAE.

Benefits and Uses

The resulting application will be platform-independent and readily portable to various users and computer systems. The final product will reduce software-sustaining costs since it will replace multiple versions of the DAE currently being used across JSC (the MOC, Crew Trainer, Flight Design & Dynamics Division Ascent/Entry Trainer, Flight Design, and crew kneeboard personal computer version).

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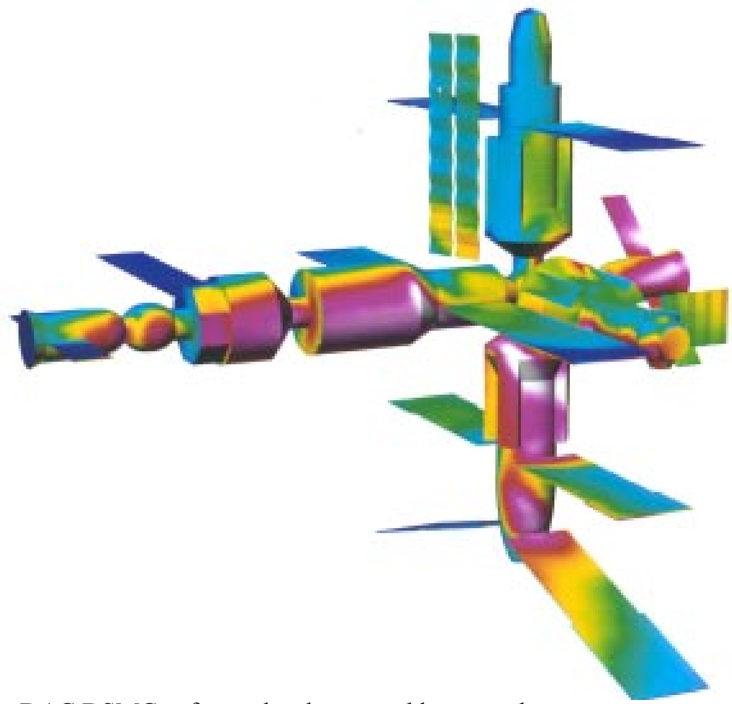
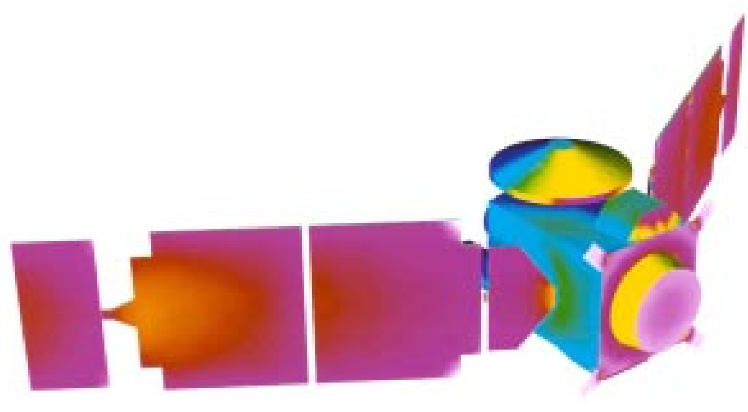
Low-Earth orbiting satellites and space stations encounter small, albeit long-duration, aerodynamic forces. The picture changes significantly when another spacecraft in the vicinity and is using its maneuvering thrusters. This was the case during the Space Shuttle-*Mir* mission, where the Space Shuttle Orbiter's thrusters could potentially damage delicate structural members. DSMC analysis was employed to validate engineering models used to design docking flight rules. The image shows the resultant pressure distribution on *Mir* if the Space Shuttle performed a Norm-Z burn (three jets pointing directly at the station) at a docking distance of 5 m.



DAC DSMC software has been used by a number of corporate and educational organizations. This image was provided by a Department of Defense contractor that needed to investigate the surface heating environments of an optical sensor for a candidate exo-atmospheric missile defense system. Displayed are surface heating rates on the optical tracking system and the flow field temperature profile as the vehicle flies at a slight angle-of-attack.

In 1997, the Mars Global Surveyor began aerobraking into the martian atmosphere, thus becoming the first mission to use aerobraking as a primary means of changing orbit. Anomalies that occurred in early orbits forced mission controllers to suspend aerobraking temporarily to protect the vehicle. These events presented a unique challenge to provide the spacecraft accurate aerothermodynamic predictions in the rarefied transitional flow regime. DSMC analysis played a critical role in understanding these anomalies and in formulating operational constraints for the safe resumption of aerobraking, thus permitting the vehicle to successfully complete the first phase of its mission.



Direct Simulation Monte Carlo Analysis

Direct Simulation Monte Carlo (DSMC) Analysis

Background

A computer code is being developed that will analyze rarefied gas dynamic environments that cannot be properly modeled with more traditional computation fluid dynamics approaches. This project, a joint development effort between Johnson Space Center and Langley Research Center, has as its goal providing government and industrial organizations an effective means of simulating low-density flows in lieu of costly testing. The software – named DAC – employs G. A. Bird's direct simulation Monte Carlo (DSMC) method, which is widely accepted as the preferred method for simulating rarefied flows. Although a number of DSMC packages have been developed over the years, they typically have maintained more of a research focus. As such, they lack the requisite capabilities needed to handle the more challenging problems of today in high-altitude aerodynamics, aerothermodynamics, satellite contamination, and reaction control system plumes analysis.

Project Overview

The development strategy for DAC software combines the successful techniques of previous implementations with new and innovative features so that as much of the process is automated as possible. DAC code employs a surface discretization technique with the versatility necessary to model the most complex geometric features that can be created using widely available unstructured grid generation tools. Once the surface geometry is created by a user, DAC software can automatically produce an appropriate flow field discretization based on the requirements of DSMC methodology. This approach spares the user from an inconvenient and time-consuming process while ensuring the simulation is properly formulated. The inclusion of state-of-the-art internal energy and relaxation process modeling and a variety of gas-surface interaction models and boundary condition options further contributes to the overall flexibility of DAC software. The underlying power of DAC software is its ability to use a single-processor computer, a network of computers, or even the fastest parallel supercomputers not only effectively but in an automated manner.

Benefits and Uses

The overall intent of this project was to create a general-purpose implementation of the DSMC method that could be applied to a wide range of problems, while limiting user workload and requisite expertise. The enabling feature of DAC is its ability to apply literally hundreds of processors to a single problem; this allows analysis of some of the largest, most complex, rarefied gas dynamic problems ever performed. Recent applications include Space Shuttle plume impingement on the Space Station and *Mir*; aerothermodynamic assessment of the Mars Global Surveyor performing an aerobraking maneuver at Mars; and aerothermodynamic heating to the optical sensor of a candidate exo-atmospheric missile defense system. In addition to traditional aerospace applications, the DSMC method has more recently been applied to the semiconductor industry to address problems that occur in rarefied environments (e.g., plasma etching and chemical vapor deposition). The small scales involved in the emerging micro electromechanical system field may also warrant a rarefied characterization, and thus require a DSMC analysis. Although development work continues to enhance the capabilities of DAC software, the software is available for distribution to interested parties under certain restrictions.

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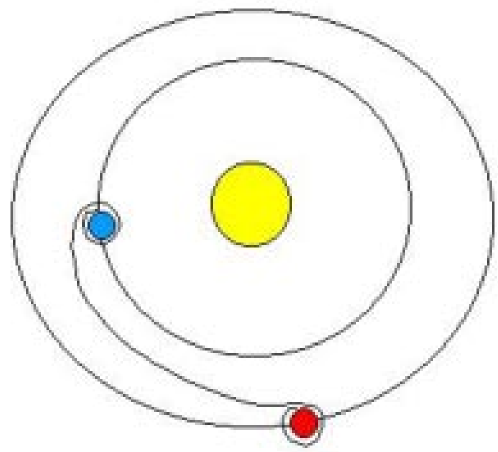

Example of low-thrust trajectory for Earth to Mars

Fuel Optimal Control Algorithm for Low-Thrust Propulsion

Fuel Optimal Control Algorithm for Low-Thrust Propulsion

Background

While the idea of low-thrust propulsion has been around since the early 1960s, spacecraft that use this technology for interplanetary missions may become a reality in the next decade. Low-thrust vehicles use highly efficient electric thrusters to generate thrust that may be controlled by varying specific impulse (Isp). The same low-thrust vehicle is capable of either rapid manned missions with light payloads or longer duration unmanned missions with large payloads. Since the thrusting arcs are on the order of months, impulsive solutions cannot be used. Indeed, Isp limits must be imposed and gravitational influences of multiple planets must be included in the low-thrust trajectory optimization.

Project Overview

This project developed a new control law and trajectory simulation which imposes the appropriate Isp limits and includes the gravitational effects of relevant planets. The first problem addressed was to minimize fuel for a fixed-time Earth-Mars trajectory. This trajectory is divided into two phases: (1) an Earth-centric phase, which includes the Earth escape spiral and a portion of the heliocentric trajectory; and (2) a Mars-centric phase, which includes the rest of the heliocentric trajectory and a Mars capture spiral. Problem formulation treats the mass of the spacecraft as an explicit state variable, thus coupling s spacecraft and trajectory designs. Using a fixed initial mass in low Earth orbit (LEO) and transfer time, approximately 30 mt of additional payload will be delivered to Mars as compared with previous methods. The next problem being addressed is minimizing the initial mass in LEO for a fixed transfer time and desired payload mass at Mars.

Benefits and Uses

This is a unique mission design tool that is being developed by Johnson Space Center in partnership with Texas A&M University. This tool uses both variable and constant Isp to enable the development of complete and accurate low-thrust missions for near Earth operations and for exploration to other solar system bodies. The tool is currently in the development stage.

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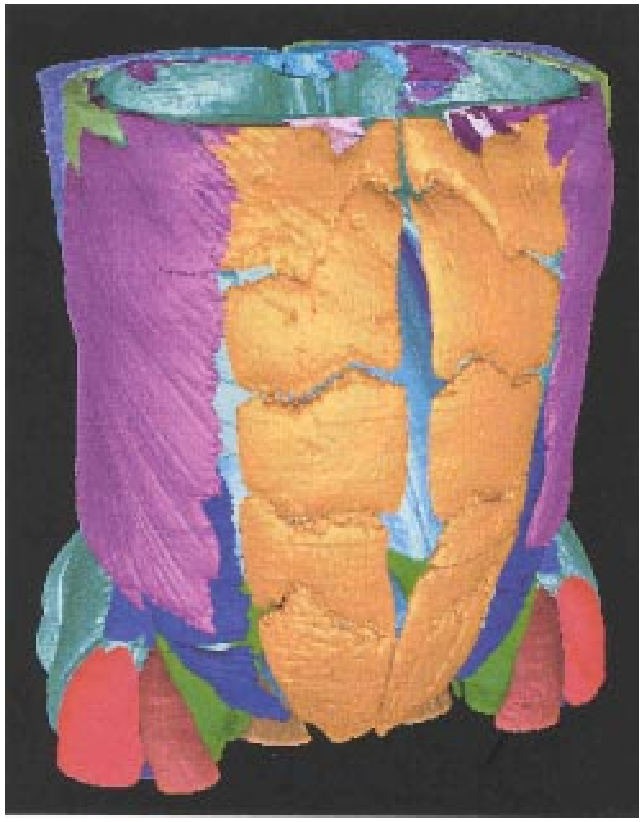

Visible human models used in the S3 project offer detailed anatomy with customized content, such as this muscle wall seen from inner and outer surfaces.

Somatic Sciences Simulation Project

Somatic Sciences Simulation (S3) Project

Background

The Somatic Sciences Simulation (S3) Project enhances and expands NASA's use of virtual reality (VR) modeling, prototyping, and simulation to expedite a human-centered approach to future mission planning and operations. Johnson Space Center has used VR technology to create remarkable training environments that replicate Space Shuttle mission experiments, Hubble space telescope servicing, and International Space Station (ISS) modules. However, highly realistic and interactive VR models of astronauts functioning within a virtual spacesuit during extravehicular activity (EVA) or undergoing progressive bodily changes produced by an absence of gravity have not been developed to date. The S3 Project focuses attention on the human spacecraft, creating an alternative means of mission planning, on-orbit data analysis, and time- and cost-saving design and engineering for improved astronaut safety, mobility, comfort, and productivity.

Project Overview

ISS construction will require more EVAs in the next several years than all the EVAs performed since the space program began. These numbers will only increases since NASA is also formulating mission plans for exploration of Mars and the Moon. There is, therefore, a critical need for a virtual prototyping mechanism to develop an advanced space suit and related support systems; upgrade and customize the EVA mobility unit currently in use; assess and implement effective countermeasures to microgravity; and enhance human factors analysis of mission training/ performance.

The S3 Project is creating a high-resolution, interactive VR model of human anatomy and physiology, including anthropometric scaling, realistic motion and muscle action, a haptic (force feedback) interface, and an array of reference databases to support dynamic simulations of human tissues. Computer software and data capture/ visualization technologies offer modeling of virtual equipment and environments as well as integration with the customized parameters of a virtual human. Together they produce a simulation tool that can be used to evaluate and train for an array of mission-specific goals, conditions, and variables.

Future developments include the addition of viscera (i.e., internal organs) to the VR human model.

Benefits and Uses

The S3 Project is a virtual replica of the human body – a replica that can conform to any shape or size, strength or limitation, attribute of health or disease. There are already a number of examples of the dramatic time and cost savings realized through use of virtual prototyping of products in major US industries. For wherever there are man-in-the loop issues of human factors engineering; ergonomics; simulations of hazardous conditions, product design, fit or function; training scenarios; alternatives to animal research; market research; or custom manufacturing, there is now available a highly realistic and customizable VR human model. The virtual human(s) can be fully integrated into virtual environments and can actively interface with virtual products. The S3 Project technology, which has a patent pending, is available to be licensed for specific project applications.

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Multi-Application ControlH Flies X-38

Multi-Application ControlH (MACH) Flies X-38

Background

NASA's X-38 Program consists of a series of test vehicles leading up to a crew return vehicle (CRV) that will first serve as an International Space Station crew lifeboat. X-38 test vehicles include subsonic vehicles dropped from the wing of a B-52 bomber and an orbital/entry test vehicle that will be deployed by the Space Shuttle. Aggressive X-38 schedules call for all systems to be efficiently designed, including the automatic flight control system (FCS). The classical FCS design approach is to tune point designs to meet performance and robustness requirements at selected flight conditions before linking them via gain scheduling, and reiterating the process each time vehicle aerodynamics and mass properties change. Since a single Multi-Application ControlH (MACH) design can fly the entire flight regime for multiple similar X-38 test vehicles with minimal modification, the X-38 Program is using Honeywell's MACH design to reduce FCS design resource requirements for multiple test vehicles.

Project Overview

MACH is an implementation of a modern dynamic inversion control design technique. MACH dynamically inverts an onboard aircraft (OBAC) model of a flight test vehicle to cancel measured vehicle dynamics in real time and replace those dynamics with desired response characteristics in the roll, pitch, and yaw axes. The dynamic inversion process may be thought of as real-time, model-based gain scheduling. Ideally, a single MACH design can fly throughout an X-38 test vehicle flight regime modeled by the OBAC as well as flying other X-38 test vehicles with similar OBAC models inserted.

Whereas classical control design techniques often focus on one vehicle axis or single-input, single-output feedback loop at a time, MACH can handle multiple input, multiple output (MIMO) systems and optimize coupled aerodynamic flap control of multiple axes. This is especially useful for X-38 lifting-body test vehicles with their highly coupled lateral-directional dynamics and strong rudder control authority in both the roll and yaw axes.

The X-38 Project has used autocoding technology to generate C code from the MACH FCS design as well as Shuttle-derived guidance and navigation designs. MACH source code was originally written in Honeywell's ControlH language, from which an autocoder generates C code for integration with guidance and navigation software and compilation in X-38 vehicle simulations and flight computers.

MACH flew the X-38 V-132 and V-131R subsonic test vehicles. Incorporation of reaction control system jet models into OBAC will enable MACH to fly the V-201 orbital/entry test vehicle. Ultimately, MACH may be applied to the operational CRV as well.

Benefits and Uses

MACH reduces FCS design resource requirements by applying a single-core design to an entire flight regime and even multiple similar vehicles. MIMO capability and optimal control allocation enables MACH to control a given number of vehicle axes with an equal or larger number of control effectors. Autocoding reduces the time required to convert a MACH design into flight code. MACH offers control designs for flight vehicles with highly nonlinear or coupled dynamics. Before X-38, MACH was applied in a High Angle-of-attack Research Vehicle Program where aircraft aerodynamics became very nonlinear near stall points. Commercially, MACH can also be applied to the automated flight control of a wide range of aircraft and spacecraft.

Questions regarding licensing and commercial application of MACH should be directed to Dale Enns and Dan Bugajski of the Honeywell Technology Center, enns_dale@htc.honeywell.com and danbug@htc.honeywell.com.
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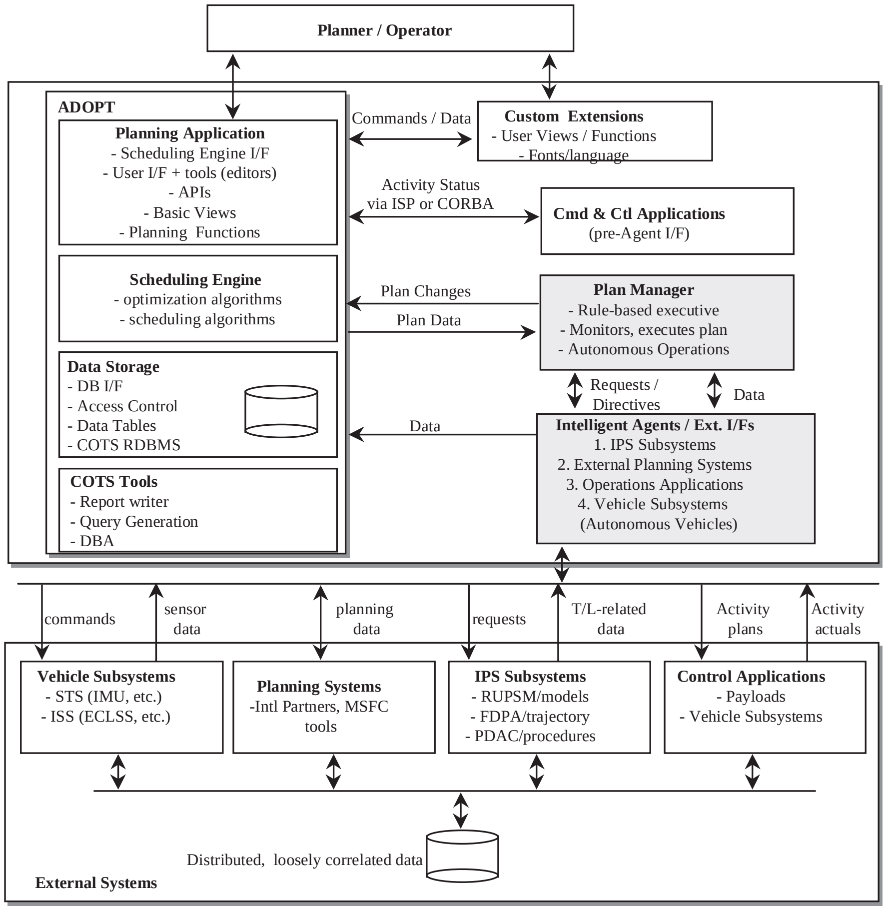
Advanced Distributed Operations & Planning Technology



Advanced Distributed Operations Planning Technology

Advanced Distributed Operations Planning Technology (ADOPT)

Background

Numerous fundamental questions arise from the changes in mission planning and scheduling that occur because of an increased flight manifest and a transition to distributed operations: Can planning and operations be better integrated through automation? How can data interchange between global planning systems be improved? How can planning work be spread across the office and mission environments more effectively? Can the architecture of the system be improved to reduce the cost of ownership? And can a planning system be generalized that will be usable by other domains? The Advanced Distributed Operations Planning Technology (ADOPT) Project was conceived to address the implementation feasibility of these questions. This project is a 3-year effort with prototypes delivered at the end of each year.

Project Overview

The ADOPT Project was conceived to develop and evaluate, in partnership with other planning center developers, a prototype portable, scalable mission planning system that would support the automated planning, execution, and monitoring of ground, payload, and vehicle activities. Evaluation areas include: an extensible architecture with a standard internal data interchange mechanism, a server-based scheduling engine/database and support for multiple client applications supporting the office, ground (i.e., Mission Control Center), and onboard (i.e., portable computer system laptops and future autonomous vehicles) environments. The ADOPT system also will replace obsolete commercial scheduling software with standard C++ library routines. The project has completed a prototype-distributed architecture and has demonstrated a platform-independent user interface.

Benefits and Uses

The principal usable product from this and other efforts is an activity planning and scheduling system for a domain with resources that must be shared to accomplish a set of well-defined objectives. The system can be applied to any domain where resource limitations and constraints make it difficult to achieve optimum performance. Activities, constraints, and resources are user-definable; and the system has a feature-rich capability to produce a customized timeline of events. This technology can be licensed but will need further development for commercial application. The developer, Lockheed-Martin, could support customization of the tools to other domains.

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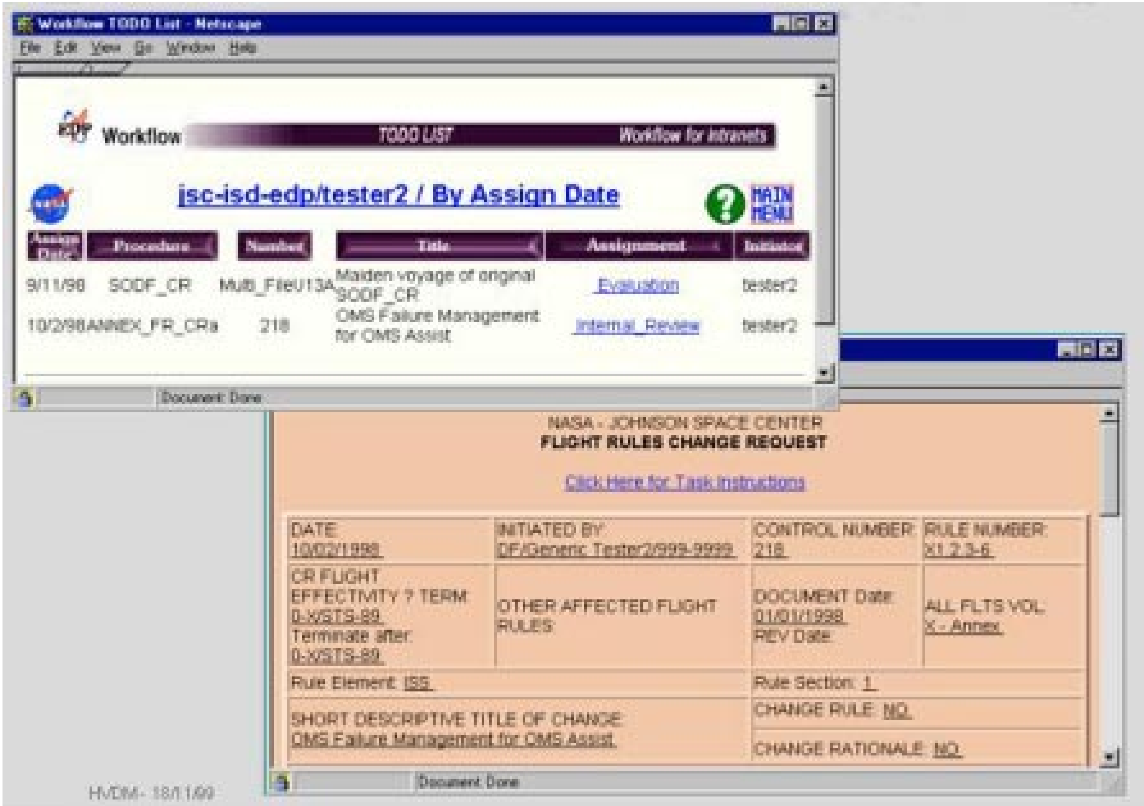

High-Volume Data Management Workflow System

High-Volume Data Management (HVDM) Workflow System

Background

The High-Volume Data Management (HVDM) Project was conceived to develop a web-based workflow system that could increase the efficiency and reduce the costs associated with process control and change management. As space operations become more distributed and the volume and frequency of updates to data increase, a paper-based change control process becomes ineffective.

To reduce costs and increase efficiency, electronic, automated processes are required to support authoring, revising, reviewing, controlling, and releasing changes to operations documents. Automated routing of a change request (CR) for approval and providing real-time electronic tracking of the status of each CR has eliminated the need for paper copies of CRs.

Project Overview

HVDM will provide a web-based workflow system capable of automating any manual, paper-based process regardless of complexity. It does this by providing a system of web-based, electronic forms which are submitted by users and automatically routed to appropriate people for electronic review, revision, and approval. The HVDM system also provides real-time tracking, monitoring, and viewing of all CRs in a system so the current status of a CR may be determined at any time. Process metrics may be viewed to identify bottlenecks and allow process improvement.

The HVDM Project implements workflow systems for two operationally significant processes: the Flight Rules CR for the Space Shuttle and the System Operations Data File CR for the International Space Station. The Flight Rules and Operations Data File groups currently use the HVDM workflow system to submit, review, approve, and control all CRs to their operational data books.

In addition to these operational systems, some prototype workflow development tools have been developed – including prototype versions of a graphical process editor, a web-based electronic form designer, and a set of generic scripts used to perform the processing required at each step in the workflow process. Further development of these tools is required to expand their capabilities, simplify their interfaces, and integrate them into a cohesive workflow development tool set.

Benefits and Uses

Workflow automation directly saves reproduction and distribution costs in paper copies because every part of the included process is now in an electronic format. It also significantly reduces CR processing time, thus enhancing overall organization productivity. Specific improvements are based on the complexity of the process being modeled, but in general there is an approximately 40% improvement in efficiency. Since the system is web-based, it supports distributed operations, allowing worldwide users to participate in the change process; and it lowers training costs because people are already familiar with the use of web tools and applications. Also, it provides the information required for process management and improvement. The workflow system contains all relevant information about any process, including time spent for any process or even any process step based on operational data. Such information enables process owners to identify process bottlenecks and make decisions about how to streamline the process or use available resources better. This technology is currently licensed to Oak Grove Systems.

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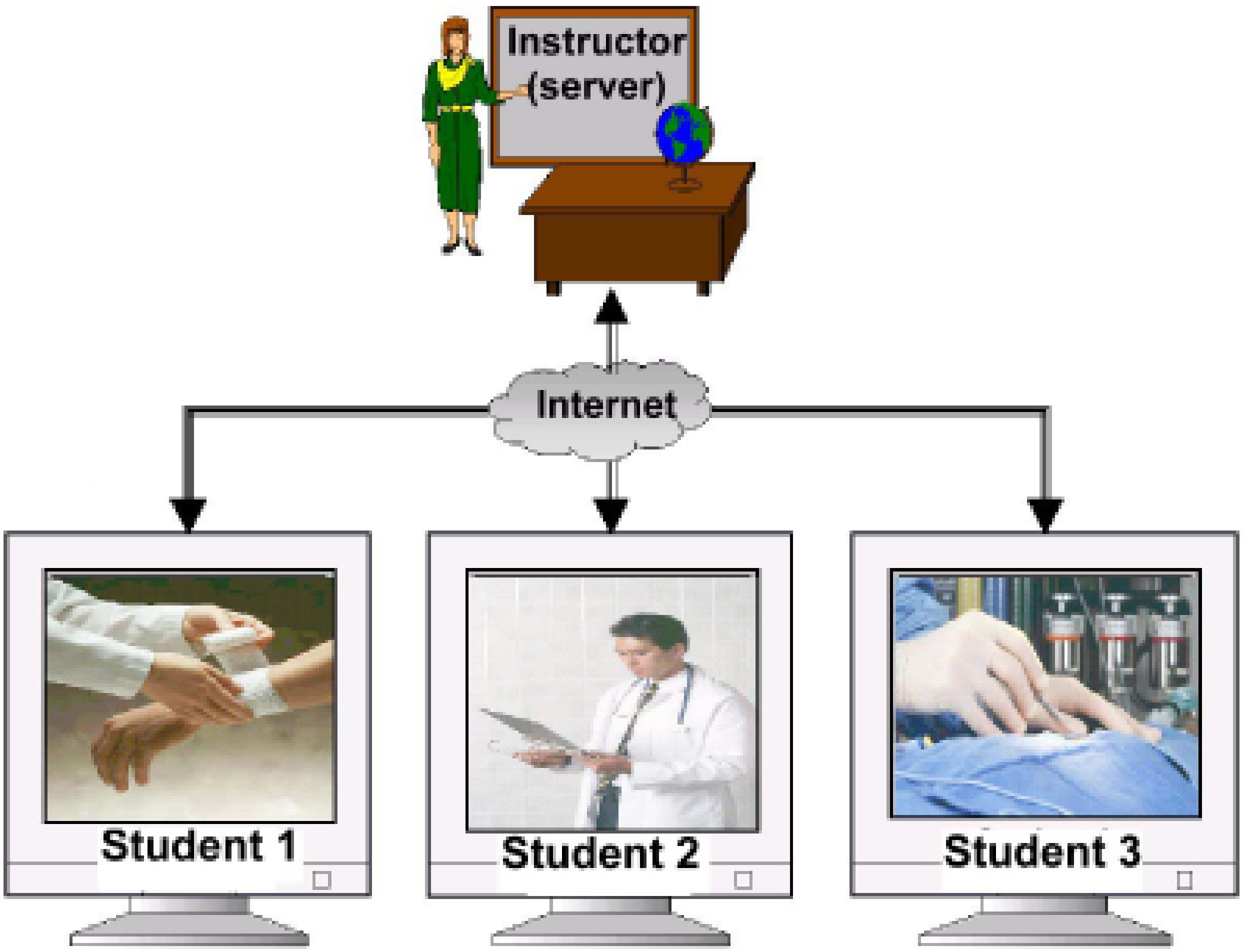

ICTT links team members at different sites into a single, simultaneous training experience.

Intelligent Collaborative Team Training

Intelligent Collaborative Team Training (ICTT)

Background

Intelligent collaborative team training (ICTT) technology was developed to address the lack of training architecture to support the collaboration of a team of students training in a simulation-based environment from remote locations. This technology addresses methods of synchronizing student training simulations by coordinating which student should perform which actions and storing team and student model information. Prior research with intelligent computer-aided training primarily focused on training one student at a time. There was no proven technology that could support remote training of a team of students. A move was thus made to support distance learning for Space Shuttle/International Space Station crewmembers in a flexible environment using either the Internet or a local area network as the networking medium.

Project Overview

The objective of the ICTT Program was to develop a software architecture that could support a real-time, team-training paradigm in areas too interactive and complex to be taught by workbooks or by classroom instruction. This technology serves to capture the knowledge of subject matter experts and the best trainers to provide sophisticated, individualized training. Artificial intelligence technology is integrated with training and tutoring methodologies as a means of capturing scarce expertise and automating its use for training novices. The ICTT technology consists of a software library, which is written in JAVA and is cross-platform compatible, and a set of knowledge capture tools that aid in the creation of domain expert portions of the training system. The library is integrated with a simulation-based interface to provide training similar to what a human would provide – but within a computer-based, instructor-less environment. The project has been completed and continues to be enhanced, as required, by various NASA tasks. Work is under way to improve the capabilities of the tools to support the capture of team training knowledge more fully.

Benefits and Uses

ICTT technology has many benefits including a generic training library that can be applied to various domains, reusability, cross-platform compatibility, and robust training in an instructor-less environment. It also can be applied in many ways – web-based training, desktop applications, embedded training, virtual environments, etc. And unlike many other intelligent tutoring systems, since no coding is involved, the lessons developed using ICTT tools make maintenance very simple and cost effective. Many industries – including medical, airlines, manufacturing, process control, utilities, and military – have training needs that could be addressed by team-oriented ICTT simulations. A very large potential target market for ICTT is in training soft people skills; e.g., in areas such as emergency response coordination, how to work in teams, group decision making, etc. ICTT technology is currently available for license, although further maintenance is needed to bring the software up to speed with rapidly changing state-of-the-art Internet and Java technologies.

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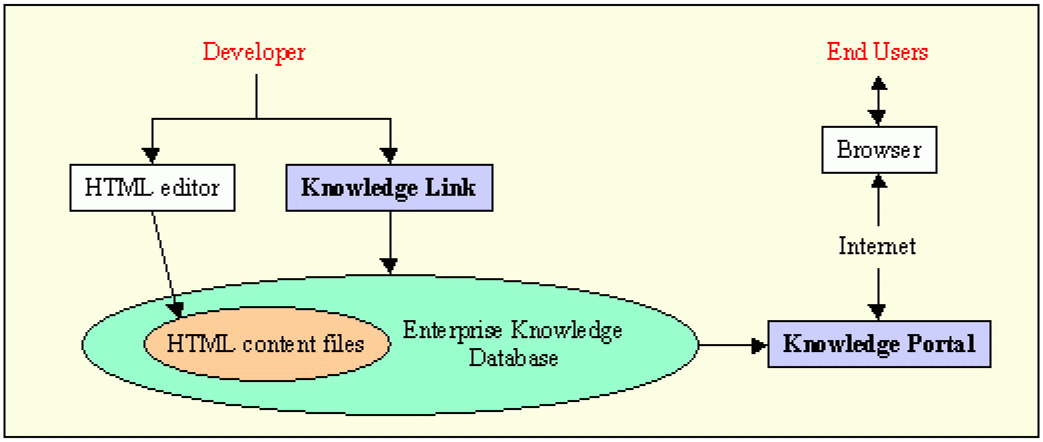

The AFIT uses Knowledge Link and Knowledge Portal subsystems to create custom training sessions for individual trainees.

Automatic Feedback Intelligent Trainer (AFIT)

Background

This project addresses the general problem of producing high-quality online (computer-based) training materials at a reasonable cost. The goal is to create a general-purpose software system that can produce these materials – an automatic feedback intelligent trainer (AFIT). Previous research has shown that although AFIT systems can be constructed, their inputs must be presented in a specific, highly specialized format unfamiliar to the wide audience of professional trainers and educators. The feasibility of this entire line of research therefore rests on the development of an interface that can bridge the gap between input required by the underlying system and the natural expression of educational objectives familiar to professional trainers and educators.

Project Overview

The purpose of this project is to develop a practical and commercially viable AFIT training tool that can automatically create customized presentations and feedback for a trainee. The tool is divided into two subsystems, Knowledge Link and Knowledge Portal.

Professional trainers (i.e., developers) use the Knowledge Link subsystem in conjunction with any third-party HTML [hypertext mark-up language] editing tools to produce a knowledge database. The database is a general-purpose, format-free representation of knowledge to be conveyed to trainees. Knowledge Link uses a point-and-click style interface that can be utilized by developers without any specialized background or training. The Knowledge Portal subsystem is a completely automated, server-based program that can read a knowledge database, format it, and present it to trainees (end-users) over the Internet or an Intranet. Knowledge Portal keeps an internal model of each individual trainee, presents knowledge in a variety of different formats, and customizes knowledge presentation to meet specialized needs. Knowledge Portal is a completely online application that can be run through any standard Internet browser.

Knowledge Portal and Knowledge Link are currently being tested with commercial partners. Planned enhancements include adding XML compatibility, enriching the knowledge representation capabilities of Knowledge Link, and adding more presentation formats to Knowledge Portal.

Benefits and Uses

With the advent of the Internet, distribution costs associated with knowledge dissemination can be cut dramatically. The last bottleneck is the cost of developing knowledge content. This places the burden squarely on the shoulders of developers, who must be able to develop high-quality content in a form flexible enough to meet the demands of different end-users in different settings. Knowledge Portal and Knowledge Link currently are the only system available that permits developers to produce a single source of knowledge that can be automatically presented in multiple formats (e.g., help systems, tutorials, customer support systems) and that are customized to individual end-user needs.

Because of a continuous need for high-quality training that affects both government and industry, a wide variety of potential applications exist for this technology. Specific potential applications include developing a general-purpose tool for constructing automatic certification programs, interactive software training applications, prerequisite training courses, self-paced education courses, and continuing education applications for professionals.

A patent filed for this technology is pending. Future plans call for the technology to be licensable as soon as initial commercial testing has been completed.

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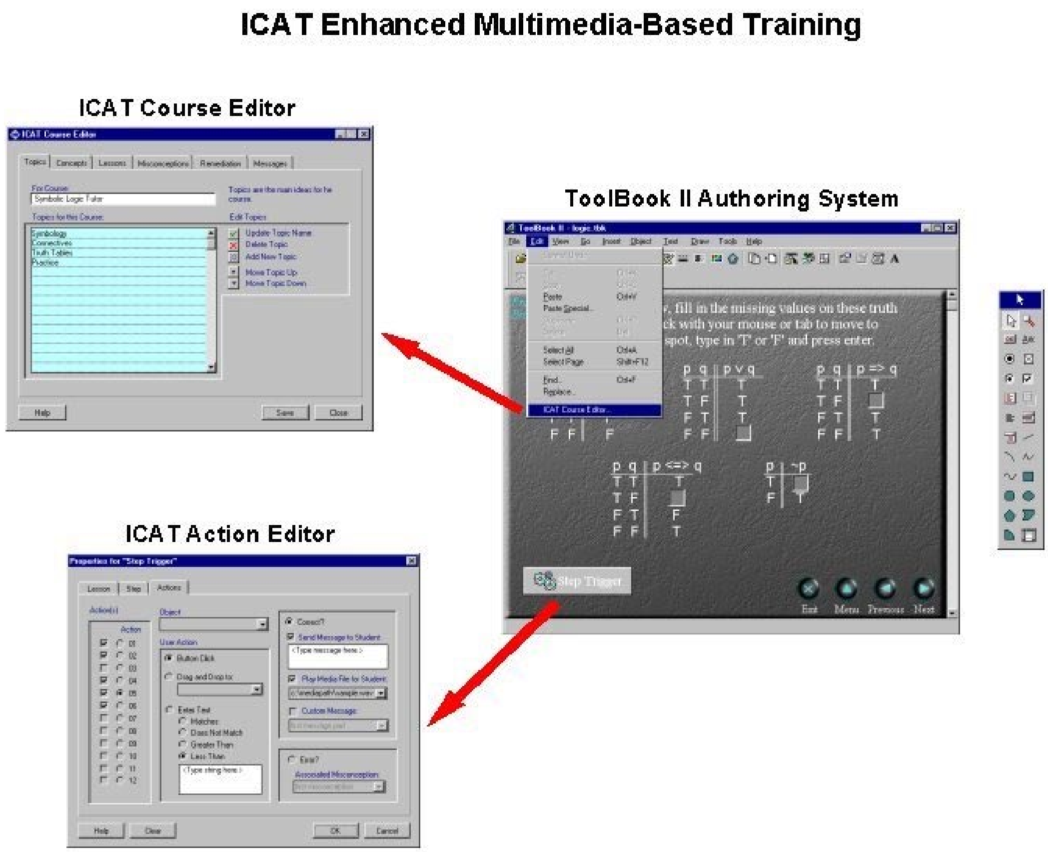

The ICAT plug-in adds intelligent navigation and adaptive feedback to CBT.

Intelligent Computer-Aided Training Enhanced Multimedia-Based Training

Intelligent Computer-Aided Training (ICAT) Enhanced Multimedia-Based Training

Background

Traditional computer-based training (CBT) developed with current commercial authoring systems, such as Authorware and ToolBook, can provide very powerful interactive multimedia presentations for teaching and training students. To date, however, traditional course designers and developers are not taking full advantage of interactive capabilities to produce new training approaches. And although there had been some interest in "intelligent navigation branching" in the past, the resulting approach was a rather clumsy analysis of a user's pre-test performance that built a navigation path based on a series of questions. Intelligent computer-aided training (ICAT) technology, developed previously for high-fidelity flight simulations in the Space Shuttle Program, is an improvement on this. Its strength lies in intelligent behaviors, such as student modeling and adaptive navigation and feedback. By combining ICAT's intelligent aspects with the powerful interactive multimedia capabilities of CBT, CBT courseware can become more challenging and effective in training critical skill areas in the Space Shuttle and International Space Station Programs.

Project Overview

The objective of the ICAT Enhanced Multimedia-Based Training Project is to develop a plug-in software that incorporates ICAT technology in Asymetrix's ToolBook II authoring systems. This plug-in has two modes; namely, author mode and reader (runtime) mode. In author mode, it provides editing tools for course developers to lay out the course structure and capture expert knowledge – all within the ToolBook environment that developers use to create training contents. In runtime mode, the plug-in uses ActiveX technology to allow the ICAT runtime library to track and evaluate student interactions, provide adaptive feedback, and dynamically navigate through course material. ToolBook's OpenScript scripting language is being used extensively to implement ICAT functionality in ToolBook. This project is in its first year of a 2-year Phase II Small Business Innovative Research contract. An ActiveX component has been implemented for the ICAT runtime library. Editing tools and ToolBook templates are being developed for the author mode. Student reporting capability and a prototype application will be developed in the second year.

Benefits and Uses

The ICAT plug-in for multimedia-based authoring systems adds intelligent navigation and adaptive feedback to traditional CBT courseware without requiring course developers to learn software programming. By distributing, installing, and setting up a few extra files, ICAT technology becomes rapidly embedded in CBT applications. Potential users include courseware developers from industry, government, education, or CBT consulting. Plug-in software will be developed for integration into ToolBook II authoring products and deployed via CD-ROM, DVD, and local area network and will be distributed as a shrink-wrapped commercial product at the end of the project. A follow-on product for Macromedia authoring systems and Internet- and web-based delivery methods will be created afterwards to ensure the broadest possible commercial application.

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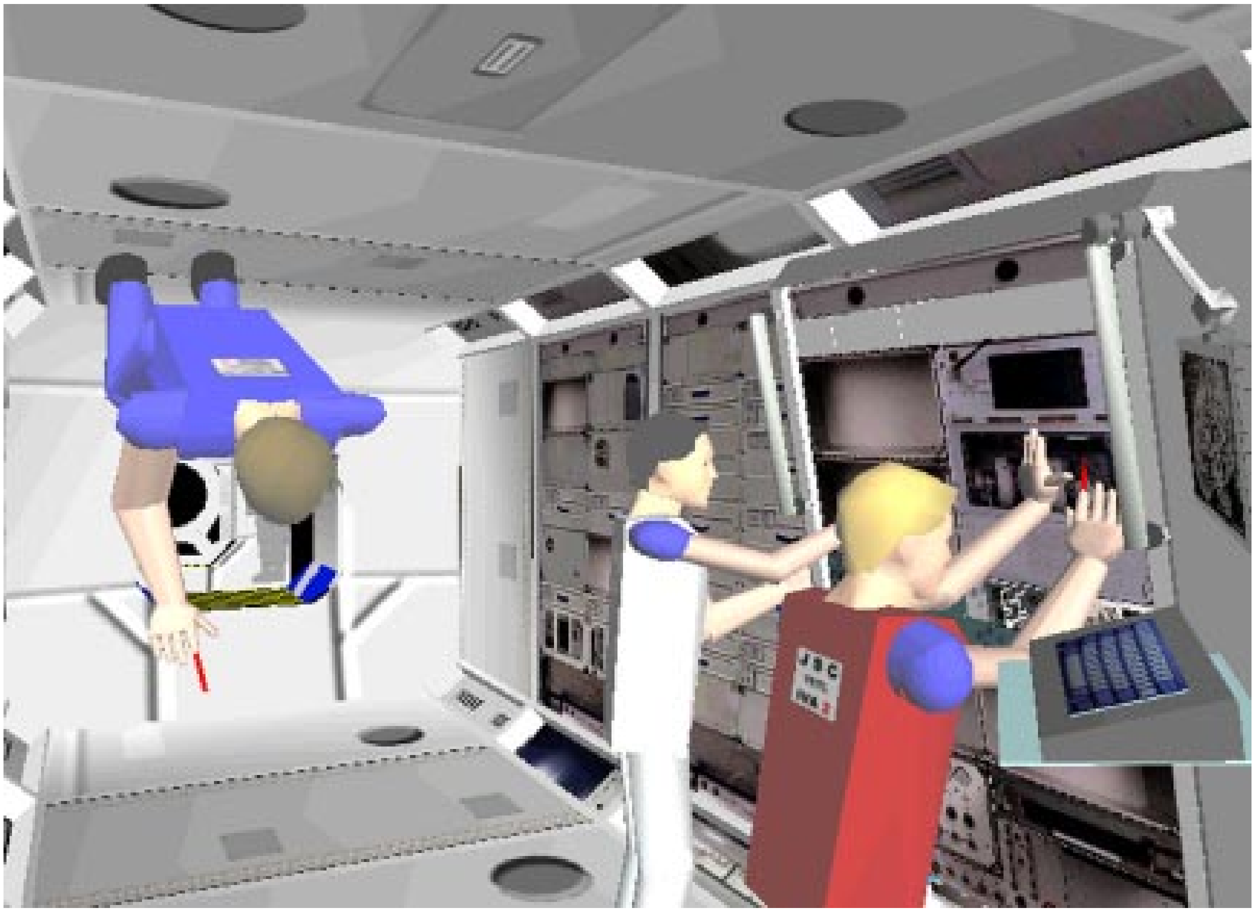
For technology transfer assistance, contact Kelle Pido at (281) 483-1348 or kelle.i.pido1@jsc.nasa.gov.



The interior of an ISS module provides an example of a shared virtual environment where multiple crewmembers can train simultaneously from different locations.

Shared Virtual Environment for Team Training

Shared Virtual Environment for Team Training (SVETT)

Background

Many Space Shuttle flights include a crewmember from a foreign country. These crewmembers usually carry out most of their training at the Johnson Space Center (JSC) or in special facilities at other NASA Centers. The support of international crews for Space Shuttle has therefore been at great cost to the nation from which the crewmember comes and has had a high personal cost both for crewmembers and their families.

This problem will become more pronounced as training for International Space Station (ISS) operations is added to that for the Space Shuttle. To reduce the costs of such training and remove the issue of where training should occur, the NASA training community has sought a means of training teams of astronauts, at least to some extent, while each astronaut remains in his or her home country. The Shared Virtual Environment for Team Training (SVETT) Project is JSC's principal effort to address the preparation of international teams of astronauts and ground-support personnel.

Project Overview

Based on the success of experiments conducted between Houston and Germany using the Hubble space telescope maintenance mission as context, a more refined testbed has been developed around the ISS. The training focus of this testbed is the conduct of scientific experiments and execution of repair and maintenance operations within the ISS. Models of the interiors of some ISS modules have been created and populated with highly detailed interactive models of the elements for which the training has been developed and detailed but non-interactive models of the remaining interior elements. Trainees, equipped with a small number of tracking devices (usually four), control human representations (known as avatars). Trainees in the SVETT can thus see each other as they carry out their tasks and communicate nonverbally as well as verbally.

Any number of sites can be connected through a variety of communication network technologies, enabling team training to be delivered when and where needed. Integrated training for certain tasks of the international ISS crews can now take place while individual crewmembers remain in their home countries, thus removing the complication of coordinating training schedules with travel plans.

Benefits and Uses

Shared virtual environments offer a number of uses for NASA, other government agencies, education, medicine, and the private sector. Benefits of these shared virtual environments include reduced costs and time for collaborative design, decision making, mission planning, team training, telemedicine, and distance learning. The shared virtual environments may also reduce travel requirements for bringing participants to a single location for training and will increase the efficient utilization of facilities and resources.

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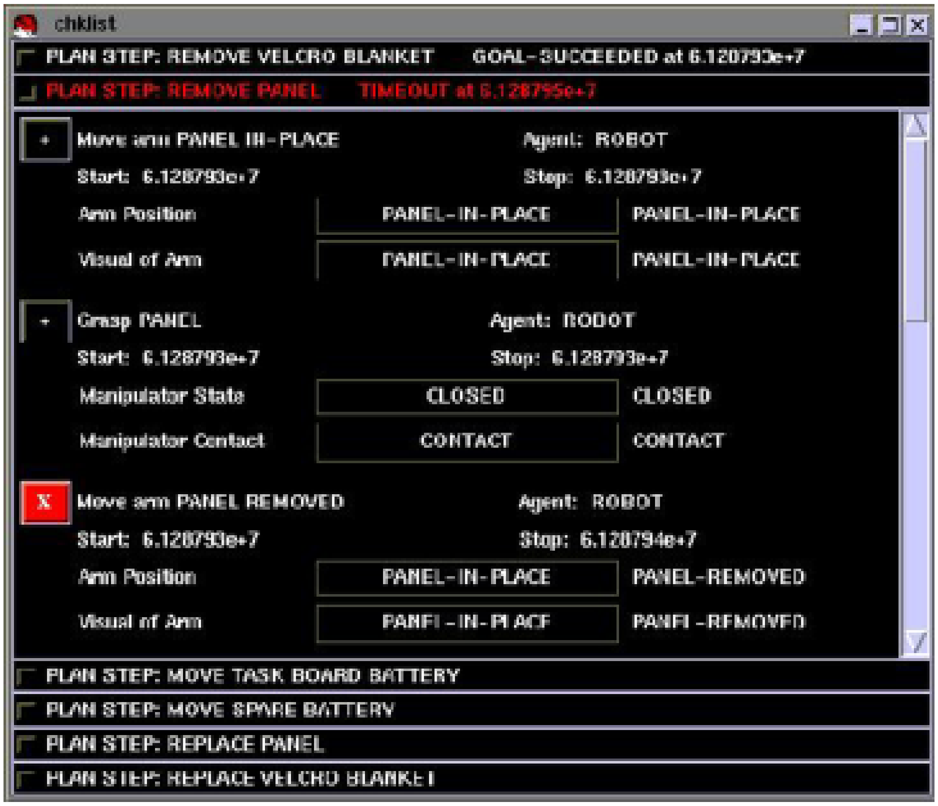

Figure. 1 Graphical user interface

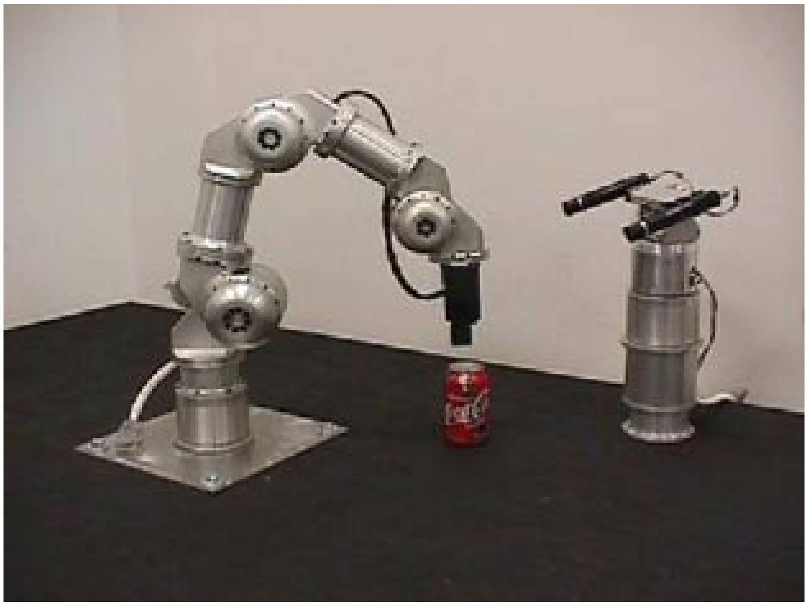

Figure. 2 Robotic manipulator and vision system

Intelligent Robotic Systems

Background

This research addresses approaches for integrating human and robotic tasks to complete activities required in human space exploration that neither human nor robot alone could perform – or perform efficiently. Previous approaches have been constrained to tasks that could be performed manually by humans or to tasks performed by robotic systems that were teleoperated, again requiring the undivided attention of the human operator. Intelligent robotic systems, at varying levels of functionality, are able to determine the current situation and to carry out the required task or goal-directed response to that situation. The approach of this research enables the use of intelligent robotic systems to augment human capabilities while allowing humans to support robotic systems with the human's unique cognitive and other skills when required.

Project Overview

The purpose of this project was to adapt a state-of-the-art architecture for autonomous control of an intelligent robotic system that could provide integrated human interaction with the system and demonstrate the feasibility of the approach. The architecture chosen for adaptation – the 3-T architecture – has been successfully used in research applications at Johnson Space Center (JSC) involving mobile robots, robotic manipulators, and environmental systems for life support. The architecture supports classical artificial intelligence technology planning at the top level, sequencing of incremental tasks resulting from planning at the middle level, and reactive interaction between robot and the environment at the lowest level. Adapting to the architecture, which uses the planner at the top level to plan both human and robot tasks based on respective capabilities, provides an enhancement of the sequencing and monitoring capabilities to enable the system to record task progress when performed by the human. It also provides a user interface (fig. 1) that allows humans to understand what the control system is doing and intervene if necessary.

A state-of-the-art stereo vision system and 6-degree-of-freedom robotic manipulator (fig. 2) performing a space-related system maintenance task has been used to develop and demonstrate the technology.

The system was delivered to the JSC Engineering Directorate, Automation, Robotics and Simulation Division's Intelligent System Branch where it is being used for research in the development of human-machine systems. The manipulator will be mounted on a mobile base to provide further research and development opportunities.

Benefits and Uses

Ongoing research now allows a robot to work in an unstructured environment with human personnel. Such environments include space applications as well hazardous/nuclear waste clean-up, the pharmaceutical industry, and food processing. The significance of this research is that it enables the use of intelligent robotic systems to augment human capabilities while enabling the human to support a robotic system with the human's unique cognitive and other skills when required. This technology is available for further development in commercial applications.

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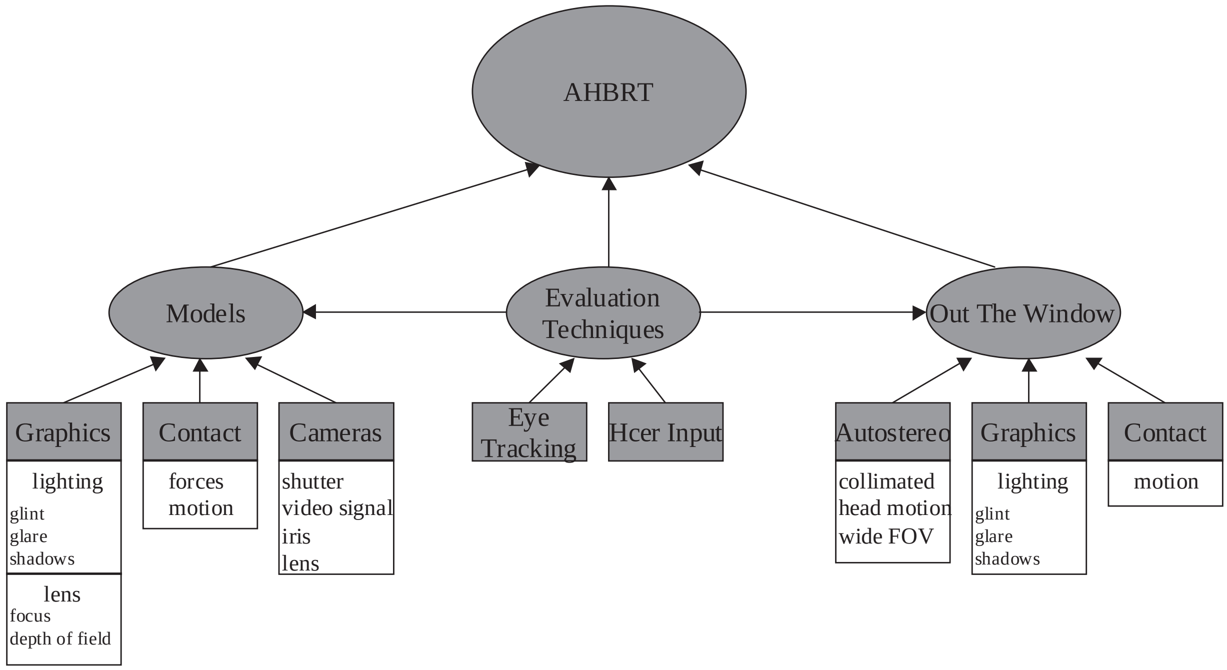
AHBRT
Models
Evaluation Techniques
Out The Window
Graphics
lighting
glint
glare
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depth of field
Contact
forces
motion
Cameras
shutter
video signal
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Eye Tracking
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Autostereo
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Alternatives to Hardware-Based Robotics Training (AHBRT)

Background

Since the beginning of the Space Shuttle Program, training for robotics operations has included the use of both hardware- and software-based facilities. Hardware facilities are used because of the realistic visual cues they provide with window views looking at real hardware and real camera systems. Operating the hardware systems also allows contact of hardware against hardware, thus producing cues to the operator when determining the position of a payload relative to surrounding structure. The operator learns to use subtle cues from real-world visual effects to develop situational awareness. But it is the operator's deficiency in modeling visual effects and physical contact that necessitate using hardware facilities for robotics operations training.

Project Overview

The Alternatives to Hardware-Based Robotics Training (AHBRT) Project goals are to develop and demonstrate software techniques and define technologies needed to simulate hardware effects so that software robotic simulators can be improved. AHBRT will develop and demonstrate software models and techniques that will simulate cameras and the visual effects displayed from real cameras. These camera models will control visual effects and simulate camera design and its effect on the scene rendered. The visual effects of physical contact with surfaces will also be simulated.

AHBRT will develop techniques for evaluating robotics simulators and investigate systems for simulating out-the-window views as needed for robotics training. To maximize efficiency, AHBRT will further examine techniques to make these models transportable and reconfigurable so they may be utilized in all robotic simulators used in training.

This project is currently starting its second year of a proposed 3 years effort. Accomplishments to date include the development of visual effect models to simulate various camera effects including glare, shadowing, and blooming. Work has also been completed that will enable these models to be ported to simulators other than the development laboratory. An initial strategy for evaluating the simulators has been developed that will be used to evaluate robotic simulators. A prototype collimated stereo display has been obtained and is being integrated into an existing robotics simulator for evaluation.

Benefits and Uses

Successful completion of the AHBRT Project will lead to greatly improved simulation capabilities in the areas of camera and contact modeling; these can be used in a variety of simulation environments. The project should identify technologies applicable to out-the-window scene generation that can be applied to the many applications involving simulators which model window views and applications requiring visualization of data. AHBRT evaluation techniques can be applied to other simulation environments to help to determine which features are most effective in simulators.

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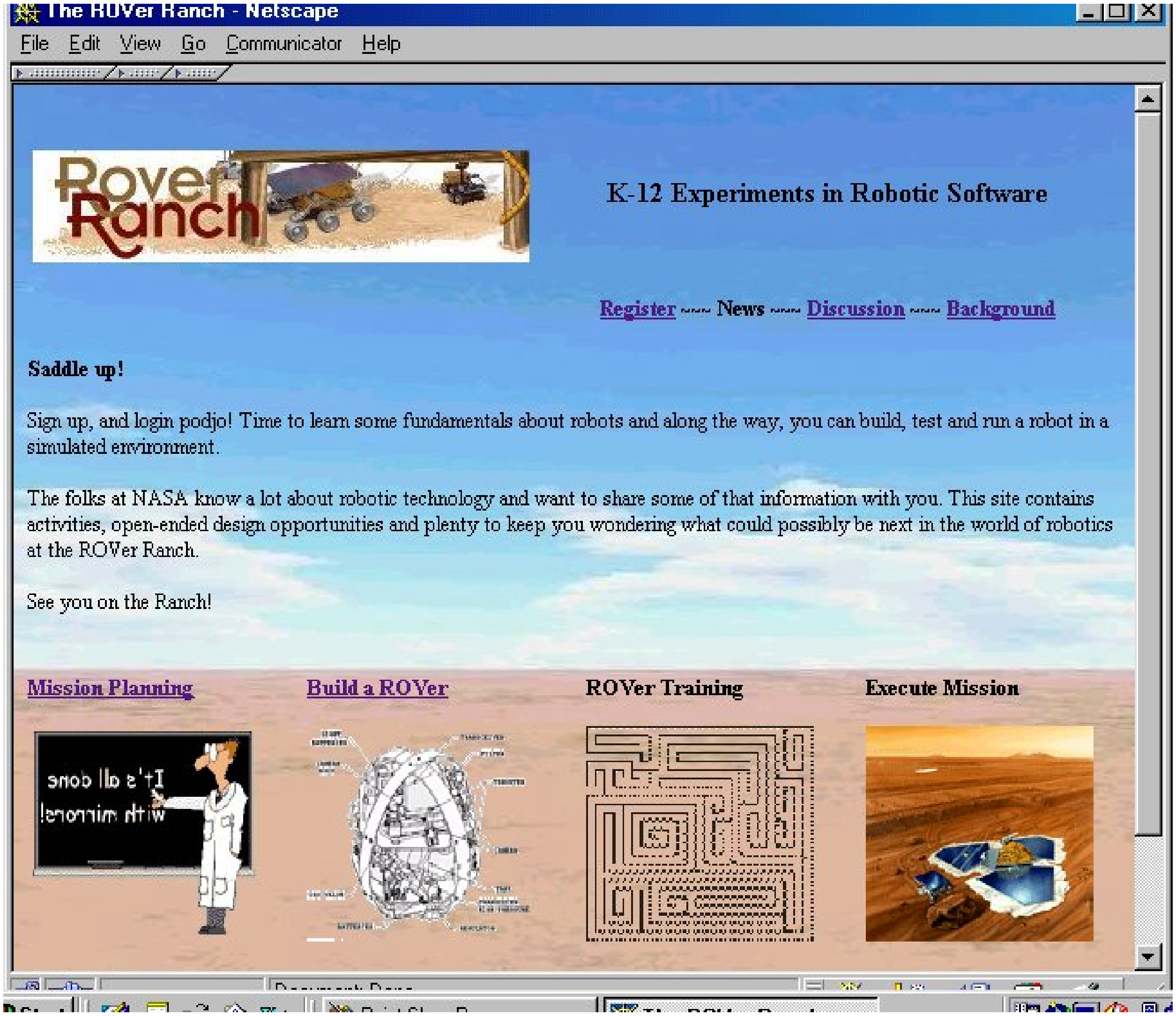

The ROVer Ranch provides an opportunity to explore robotics through games and activities.

ROVer Ranch

ROVer Ranch

Background

The ROVer Ranch is a component of the Learning Technologies Project (LTP), NASA's leader for educational technology. LTP supports the NASA Plan for Educational Excellence to research and develop products and services that facilitate the application of technology to enhance the educational process.

ROVer Ranch is a technology-based robotics teaching tool based on NASA's mission which utilizes emerging software and network technologies. It complements other approaches to robotics education such as the FIRST Robotics Competition, Botball, and the Texas BEST Program.

Project Overview

ROVer Ranch fosters complex learning and thinking skills within the framework of NASA's robotics mission. It is a website where students can build, test, and run a software robot. Each student may select a mission and, based upon mission criteria, develop an appropriate robot to complete that mission. The first ROVer Ranch mission utilizes an abstraction of the Sprint AirCam, a teleoperated robot used for remote inspection of the International Space Station (ISS). The display is a 3-dimensional VRML model of the ISS driven by a Java simulation engine.

Students build their ROVer with components selected from a parts hierarchy organized according to function. Selections are motivated by mission requirements, environmental factors, and general principles of robotic design. ROVers are tested by issuing commands or sequences of commands in a training environment. Once the robot passes basic training, it is moved to the proving grounds for its mission run. These proving grounds contain uncertainties of the real world that may not necessarily appear in the training section.

ROVer Ranch is currently under development with a beta release scheduled for the end of 1999. During 2000, two additional mission environments – exploration of a planetary surface and an underwater sample retrieval – will be added. These scenarios will require different aspects of mechanics, planning, and critical thinking.

Benefits and Uses

ROVer Ranch benefits the educational community by providing an inquiry-based, technology-rich tool based on NASA missions. Users must engage in problem-solving, data analysis, planning, and critical-thinking exercises to accomplish a successful robotic mission. The underlying architecture of this software could also be used as a basis for modeling other industry sectors which require similar aspects of planning and critical thinking skills.

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Qwhiz – a fun way to learn about NASA

NASA Qwhiz

NASA Qwhiz

Background

NASA has long contributed to education in the United States, delivering instructional materials and services that spark interest and enhance learning experiences in science, engineering, and mathematics. With the advent of the Internet and in keeping with national goals for science and technology education, NASA's Learning Technologies Project (LTP) has emphasized the development of new and exciting technology-based educational products which are made available to the widest audience possible through the Internet.

Given the increasing demand for "NASA knowledge" and NASA's expanded efforts to make that knowledge widely available, both NASA and the education community will benefit from the availability of reusable tools that facilitate or otherwise enhance the process of developing and disseminating NASA-based educational products.

LTP's Internet Tools for Teachers and Students component at Johnson Space Center has developed a suite of tools that make and deliver multimedia science, mathematics, or general subject quiz games and is providing them via the Internet to educators, students, and the general public. This suite consists of Qwhiz, Qwhiz Maker, and Qwhiz Miner.

Project Overview

Qwhiz, Qwhiz Maker, and Qwhiz Miner were developed to provide a fun way to share NASA knowledge with educators, students, or anyone with access to the Internet. This means the Qwhiz suite of tools can serve both formal and informal educational needs.

NASA Qwhiz educational software products provide a way to take quiz games over the Internet in single or multi-player modes, allow users to make their own web-based quiz games, and provide support for content development of quizzes. In addition to normal editing support (storage and retrieval of quizzes, editing abilities, etc), the tools also provide a customized search engine for finding content on the web and facilitate processing that data into a question-and-answer format.

Web-based, client-server technologies used to implement the NASA Qwhiz tools maximize ease of use. For example, making and taking quizzes involves simple interaction with the website; there is nothing to download or install. Functional areas of the Qwhiz tools include interactive game design, editing support, personal work storage areas, content development support (search engine and data processing), process automation (product submission, review, and approval), and user interface design. These functional areas manifest as single and multi-user client-server applications that are optimized to run in Netscape and implemented using HTML, perl cgi, Java, and JavaScript.

Benefits and Uses

NASA Qwhiz tools serve formal education by expanding standards-aligned technology and science content in the classroom, easing teachers into the operation of computer applications, and providing for and encouraging resource sharing of instructional materials through Qwhiz Libraries.

Children and the informal education community benefit by having an entertaining way to expand their knowledge of the workings and benefits of science and engineering while gaining experience with technology applications.

This product could be easily applied to web-based testing/training in industry, especially for distance learning/remote site learning. The product is available to the public for use via website: http://prime.jsc.nasa.gov/Qwhiz/index.html.

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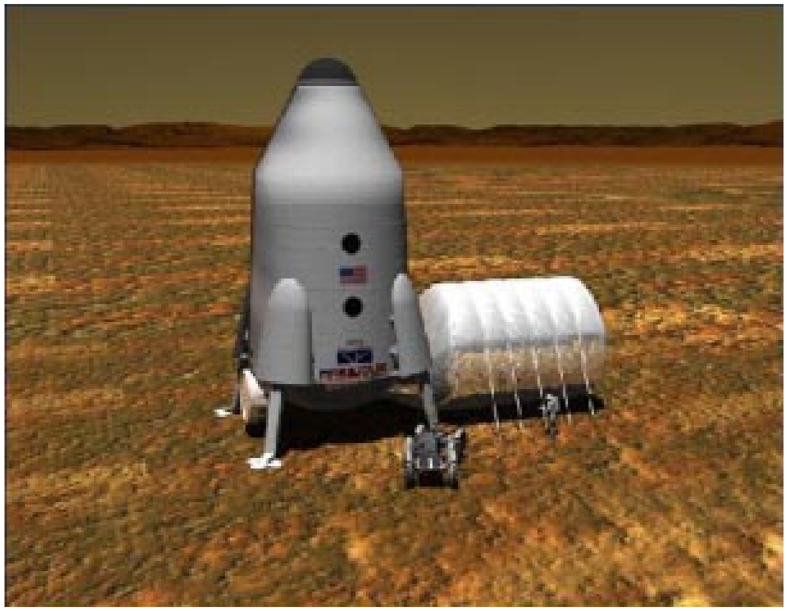

Example of crew station on Mars

Reconfigurable Crew Station

Reconfigurable Crew Station (ReCS)

Background

In preparing for exploration missions beyond low Earth orbit, NASA has been addressing the unique challenges of long-duration and long-distance operations. These challenges influence the design of a vehicle's crew station, its command and control (C&C) architecture, and the human-computer interface (HCI). Operations concepts, including the relationship between onboard and ground-based capabilities and crew and flight controllers interaction, are also influenced by these challenging factors. In addition, there are many emerging technologies, such as advanced automation, that must be considered for future space vehicle operation.

To effectively and efficiently develop and refine crew station architectures and operations concepts, it is useful to have a visual representation of the crew station that can be rapidly reconfigured. The purpose of a reconfigurable crew station (ReCS) facility is to provide this capability.

Project Overview

The ReCS Project addresses the development of crew station architectures and operations concepts for exploration missions and upgrades to current vehicles. The focus in 1998 was on basic research, including building a scenario-based report on concepts and architectures applicable to an exploration vehicle and mission. Virtual reality (VR) models were developed to illustrate basic C&C options. During 1999, emphasis shifted to determining capabilities and requirements for a ReCS Facility. Facility construction will be preceded by a 2-year capability demonstration phase in which existing facilities will be used and hardware and software will be purchased to demonstrate key capabilities of the facility. This will have the added benefit of allowing some work to be done in the ReCS prior to facility completion.

Crew stations in the ReCS Facility will be developed, modified, visualized, and utilized in a virtual environment that provides rapid prototyping capabilities. Software models will drive reconfigurable displays and advanced visual scenes. The crew station will contain sufficient hardware to support HCI and C&C concept development and implementation while maintaining a reconfigurable layout. This project will consider advanced technologies for virtual environments, intelligent automation, advanced crew interfaces, and related areas.

Benefits and Uses

By developing a reconfigurable facility, crew station architectures can be visualized, worked with, and modified to incorporate new findings in a relatively low-cost facility compared to building high-fidelity hardware models and simulators for each potential configuration. Results can be fed back into the vehicle design process. The facility can also be used to develop and mature mission operations concepts by executing basic simulations.

This project uses existing technologies in a way that meets the unique needs of NASA. However, other industries which require rapid prototyping and visualization can use a similar approach. Some industries (e.g., automobile manufacturing) are currently using VR in their design and development process.

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SUBASSEMBLIES & COMPONENTS

Figure 1. Robonaut dexterous hand

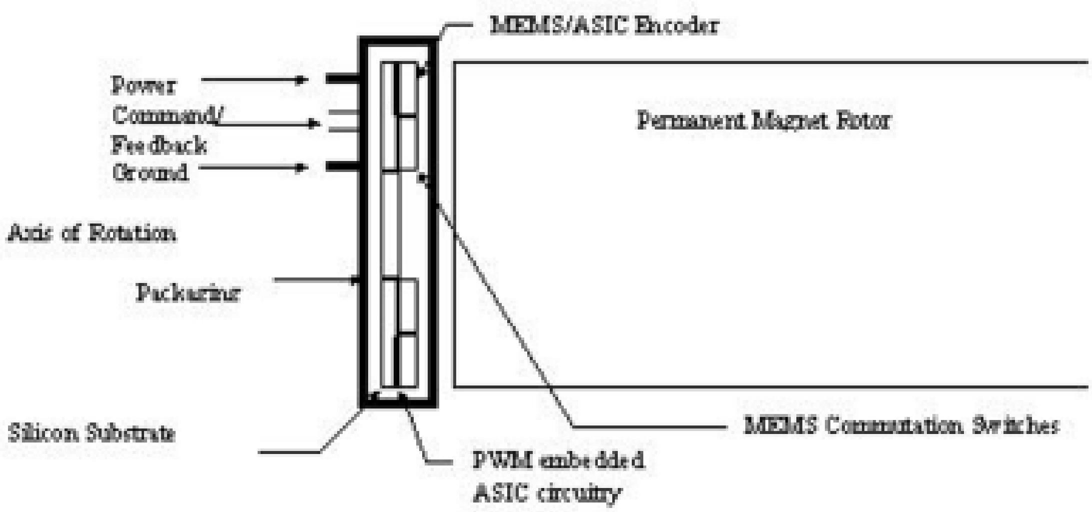

Figure 2. Schematic of the smart motor control chip. The device will be manufactured by producing an ASIC and surface micro-machining the necessary components for the encorder and communication switches on top of the substrate.

Smart Motor Controller

Smart Motor Controller

Background

As a part of its technology demonstration, the Robonaut Project is pushing the envelope in integrating electronics into a highly dexterous and compact robotic system (fig. 1). The state-of-the-art in mechatronic design, which is inadequate for a truly integrated system, requires the application of micro electromechanical system (MEMS) and application-specific integrated circuit (ASIC) technologies to provide a robust integrated solution.

The project expands on the innovative work being performed at the Jet Propulsion Laboratory (JPL) and the Johnson Space Center (JSC) in ASIC and MEMS technologies and on their application to control of brushless direct current motors. These technologies show great promise for increasing the level of integration achieved for future dexterous robotics. Without this development, human scale and smaller dexterous robotics would be unable to achieve fully embedded electronics, a minimum cable harness, and serviceable electronics and motor modules; and dexterous space robotics would be faced with the prospects of using existing bulky commercially available motor technologies, developing costly single-purpose designs, or waiting for innovative new technologies to emerge elsewhere that could achieve further integration in mechatronic design.

Project Overview

The objectives of the smart motor control chip (fig. 2) are to provide motor commutation; pulse width modulation control; velocity and current control; and position, velocity, and current feedback in an integral package with the motor. The primary difference between existing technology and proposed technology development is the fabrication of ASIC and MEMS electronics that will make possible smart motors that are 1.5-in. in diameter or less.

The smart motor control chip will integrate a radiation-tolerant ASIC control chip, a MEMS encoder, and a commutation stage on a silicon wafer die. The power stage will be integrated into the motor along with the smart chip to provide a fully functional motor. Integration of these fundamental components of motor control promises to provide intelligent actuators will perform signal and power processing integral to their electromechanical structure. This greatly reduces external components, reduces the volumetric requirements, and simplifies the interface to the motors.

In the first year of funding, the project has designed and fabricated a motor control ASIC and designed a MEMS encoder. Encoder fabrication and performance testing is planned for the second year, with the third year focusing on integrated fabrication and environmental testing.

Benefits and Uses

This component technology can be applied to a wide range of aerospace and possible commercial uses. Any device requiring motor control in minimum packaging could make use of these products. Applications include manipulator drives, sampling devices for planetary missions, instrument pointing devices, interferometer translators for spectrometers and other systems, and antenna tracking systems. Classification of the technology would "push" the Robonaut Program in particular and in general dexterous robotics, sampling, and rover programs. For example, the Mars 2001 Program, directed by Dr. Jake Matijevic, has expressed interest in its use. Also, Dr. Patricia Beauchamp and Dr. Dave Rogers, who lead JSC for in-situ exploration, and the Sample Return Office at JPL expressed interest in using this device in sampling systems for future robotic instruments and manipulators.

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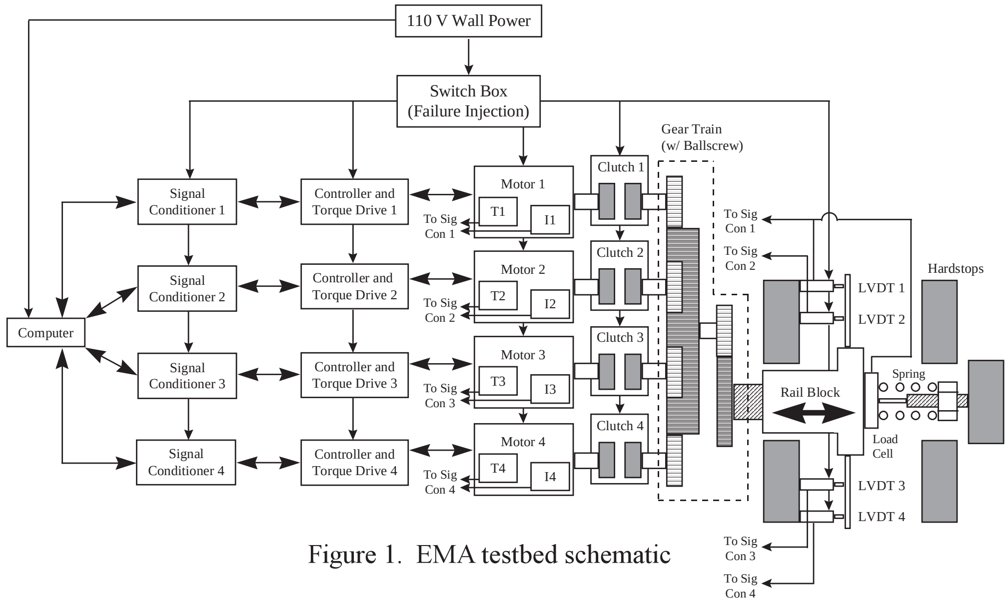

Figure 1. EMA testbed schematic

Figure 2. EMA testbed configuration

Electromechanical Actuator (EMA) Testbed

Background

Electromechanical actuators (EMAs) have been baselined to actuate X-38/crew return vehicle aerosurfaces and thrust vector control (TVC) for lunar/Mars lander engines. They are also being considered as replacements for the hydraulic actuation system on the Space Shuttle Orbiter.

Although EMAs have been used in numerous aircraft and spacecraft mechanical systems, they have not typically appeared in high-response, safety-critical, primary flight control system (FCS) applications that require multi-string redundancy. Thus the development and demonstration of various EMA architectures and redundancy management schemes must be performed to facilitate their use in primary FCS applications.

Project Overview

The EMA testbed (figs. 1 and 2) is being used to develop in-house expertise in designing, testing, and operating EMAs, thus mitigating the risks associated with future primary flight control, TVC, or other safety-critical multi-string applications. The primary objective of the EMA Testbed Project is to investigate hardware configurations and redundancy management schemes for optimal servo-control of a multi-string EMA system.

The EMA testbed consists of a dual-fault-tolerant EMA and an associated power and control system. The EMA itself includes four torque-summed brushless direct current motors equipped with friction-type clutches which are driving a common gear train and ballscrew to produce a linear output. The power and control system includes motor controllers, torque drives, sensors, signal conditioners, power supplies, and a failure injection switch panel as well as a high-end personal computer equipped with LabView software for use in commanding, data acquisition, and critical fault-detection, isolation, and recovery (FDIR) tasks.

A full-scale checkout of the EMA testbed is under way. The initial FDIR algorithms have been written and incorporated into LabView for testing (including failure injection). Additional FDIR algorithms and/or hardware configurations will also be tested.

Benefits and Uses

The hardware configurations and redundancy management schemes evaluated in this project for optimal servo-control of a multi-string EMA have many potential uses within NASA, other government agencies, and private industry. In general, these concepts will be applicable anywhere multiple electric motor drives are used for safety-critical (multi-fault-tolerant) positioning and control of an output.

Possible applications include process plant pumps and valves, aircraft aerosurfaces, elevator and escalator drives, construction and farm equipment actuators, and motion-based vehicle simulator actuators. Critical FDIR algorithms still need further refinement and exhaustive testing before being used in commercial applications, however.

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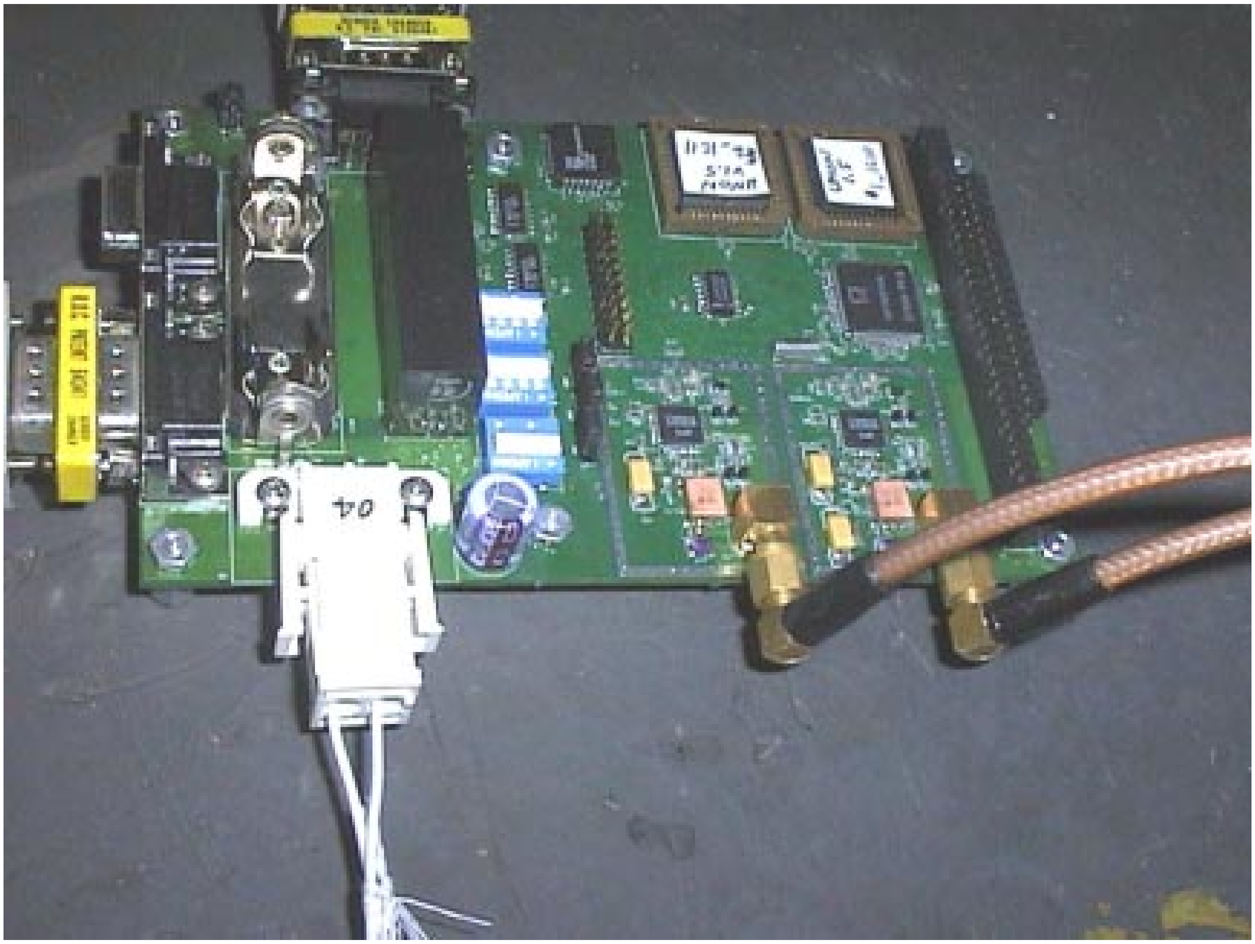
TELECOMMUNICATIONS



The GPS and RF front-end heading boards

Global Positioning System for Heading and Position Determination

Global Positioning System (GPS) for Heading and Position Determination

Background

The Port of Houston Authority and NASA have collaborated to produce a low-cost global positioning system (GPS)-based navigation system that will provide heading and position determination for Houston Ship Channel traffic. Previous systems used a standard GPS receiver and provided only position determination or high-cost heading solutions that required an initial heading estimate.

Project Overview

The Houston Ship Channel Navigation System uses signals from GPS satellites to calculate the position and heading of a ship. Information provided by the system gives ship's pilots an extra tool for safe passage, even in marginal weather, through the Houston Ship Channel. System capabilities will eventually be expanded to provide radio broadcasts of current position and heading data to nearby ships to aid in collision avoidance.

The unit consists of a modified GPS receiver with two radio frequency (RF) ports and custom heading determination software. The system, which was built and tested at Johnson Space Center, has been field tested on two fireboats. The software was written and incorporated into the unit to compute heading with or without an initial heading estimate. Results show an accuracy of about 1 degree in heading, which meets the Port's expectations.

Additional units have been built and software modifications are under way to operate in space at orbital velocities and track pseudo GPS satellites. The unit could be expanded to produce outputs of roll, pitch, and heading.

Benefits and Uses

Unit reproduction costs are much lower than the costs for comparable units on the market. The GPS for heading and position determination could be used by any vehicle or device needing or desiring position and heading information. If expanded, the unit could provide 3-axis pointing information.

The drawings and software executable are currently available. This project has been disclosed as a new technology.

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TRANSPORTATION

X-38 – Prototype for Crew Return Vehicle

X-38 – Prototype for Crew Return Vehicle (CRV)

Background

The X-38 Project is an in-house experimental spacecraft project that will demonstrate and develop requirements for the crew return vehicle (CRV) for the International Space Station (ISS). This project, which utilizes a rapid-prototyping approach for developing and testing the technologies necessary for use in the CRV, consists of three atmospheric demonstrator vehicles and one spaceflight vehicle. The atmospheric demonstrator vehicles are single-string vehicles that test the aerodynamic flight below Mach 1 of a lifting body vehicle and the transition from lifting body flight to parafoil flight of the system. The spaceflight vehicle will be CRV-like with full redundancy and a life support system capable of supporting human life. All X-38 tests will be performed in a crewless configuration.

After 12 previous studies for CRV concepts, this is the first project to develop hardware and produce flight test results. This is possible because of its rapid prototyping approach and advances in technology in the avionics and parachute fields that greatly reduce the cost and time required to develop and test these systems.

Project Overview

The X-38 uses a lifting body shape to provide cross-range advantages over previously proposed ballistic shapes. Utilization of the lifting body ensures that the crew will have a minimum of three landing opportunities in any 9-hour period after departure from the ISS. In most cases, the crew will be on the ground in fewer than 2.5 hours.

Since the CRV has a requirement to be fully automated from ISS departure to landing, the X-38 will demonstrate this capability during the space test flight of the final X-38 vehicle. The spaceflight vehicle will be taken into space using the Space Shuttle and will be deployed by the Shuttle's robot arm. The X-38 spaceflight vehicle will then fly automated from space to its designated landing site on Earth.

The vehicle uses commercial-off-the-shelf (COTS) systems in many of its avionics and systems areas. COTS use greatly decreases the overall cost of the Project and, in many cases, decreases the amount of time required to integrate and test the systems for use on X-38 vehicles. The greatest areas of new technology are in the parafoil systems, electromechanical actuators, and advanced thermal protection systems, and in the use of dynamic inversion for the flight control system. The project uses many new technologies for software development and maintenance and has optimized the design and construction of the vehicle with advanced software and measurement tools.

The X-38 Project is currently in the atmospheric test phase with two active atmospheric vehicles. The spaceflight vehicle is under development, and the structure is almost complete.

Benefits and Uses

The primary benefit of the X-38 Project will be low-cost development of the CRV for ISS. The X-38 has been developed with the cooperation of the European Space Agency (ESA). ESA has an interest in advancing the design as a crew transfer vehicle that can be launched off an Ariane 5 expendable vehicle. The overall design of the X-38 will allow it to be modified for future vehicle considerations.

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Figure 1. Remote cockpit van (exterior view)

Figure 2. Remote cockpit van (interior view)

Remote Cockpit Van Integrated Hand Controller and Display Technology

Remote Cockpit Van Integrated Hand Controller and Display Technology

Background

One of the major challenges discovered as part of the development of a new crew return vehicle (CRV) for the International Space Station (ISS) is how to transition between crewmember decision making and an autonomous operating vehicle. Any transitional interface must be capable of allowing a crewmember to intervene and then seamlessly return control of a mission back to autonomous operations as needed. The development of an optimal crew interface requires close coordination with potential operators and an ability to rapidly respond to crew input with changes to the operating system. Each new change to the interface must be evaluated in a realistic simulation, providing a valid simulation of real-world flight conditions.

Project Overview

The Remote Cockpit Van Integrated Hand Controller and Display Technology Project is designed to provide rapid prototyping of displays in an integrated environment, including a motion-based simulation capability. A prototype cockpit installation (figs. 1 and 2) is located in back of a 15-passenger van nicknamed the "Vomit Van" due to its similarity as a mobile testbed to the KC-135 "Vomit Comet."

The combined system has three primary functions. First, the system provides a rapid prototyping cockpit testbed for display software development and evaluations; digital terrain and video sensor fusion development; hand controller evaluations; and external sensor display and control evaluations. Second, the van functions as a motion base simulator for the parafoil and landing flight phases of the CRV. It does this by simulating the forward motion of the CRV while the crew lies recumbent as they would in an actual CRV landing. Third, the van incorporates a remote cockpit to allow a crewmember to actually control vehicle flight during CRV flight test and development. Since the crew flying the CRV from the ISS will probably be somewhat incapacitated from their extended time on orbit, the controls in the CRV must take into account limited crew capability and restrictions on motion due to their recumbent position.

The remote cockpit van is a multi-directorate project, involving personnel from the Engineering Directorate, the Astronaut Office, the Mission Operations Directorate, and the CRV Program Office at Johnson Space Center.

Benefits and Uses

This study is expected to produce the optimization and incorporation of a display unit and an integrated hand controller into various remote piloting activities; e.g., parafoil/vehicle guidance, navigation, and control; vehicle systems monitoring; display navigation and control; and communications. The work will help define requirements for the CRV crew interface as well as refine strategies for the optimal interface and control of a mostly autonomous vehicle. Additionally, since this platform supports rapid reconfiguration and display changes, future cockpit studies for advanced vehicles could be quickly and inexpensively performed with rapid responses to crew inputs. Both advanced commercial cockpits and the future manned Mars landers could benefit from this study.

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TransHab Inflatable Module

TransHab Inflatable Module

Background

The concept for the TransHab inflatable module originated in 1997 at Johnson Space Center (JSC) as a possible design for living quarters on future Mars-bound spacecraft. JSC engineers were challenged to find a way to develop a lighter, cheaper spacecraft for manned missions to Mars, but the basic design and technology are appropriate for space and planetary surface habitats as well.

Project Overview

Instead of the standard aluminum shell used for most space structures, TransHab incorporates a layered shell over inflatable air bladders as its primary structure. The outer shell is comprised of layers of Nextel spaced between layers of open cell foam. A layer of woven Kevlar holds the module shape, and triple-redundant Combitherm air bladders provide the pressure shell. The innermost layer that forms the inside wall of the module is fireproof Nomex cloth, which protects from scuffs and scratches. With almost two dozen layers, TransHab's foot-thick shell provides better debris protection and thermal insulation than metal.

TransHab is under consideration for use as the habitation module for the International Space Station (ISS). It would provide a home for up to 6 astronauts onboard the ISS, complete with bedrooms, a kitchen, a dining table that seats 12, two windows, a gym, a pantry, and storage space. The TransHab would provide more room (about three times the room) and weigh less per cubic foot than conventional metal modules.

In 1998, NASA successfully demonstrated the structural integrity of the fabric structure with a pressure test to four times the maximum operating pressure of the ISS – higher than any other space module. A full-scale inflatable module was also built that demonstrated the packaging, deployment, inflation, and operating characteristics of the inflatable structure in a space simulation environment. In tests, TransHab demonstrated its superior performance in elements such as radiation and orbital debris protection.

As the first inflatable spacecraft, TransHab could be a steppingstone to future space exploration. Inflatable spacecraft may have great potential for use onboard a Mars-bound spaceship and as inflatable shelters on the Moon or Mars.

Benefits and Uses

This technology offers significantly reduced weight and manufacturing costs for highly loaded pressure vessels. The technology, which can be applied across industry sectors for various space- and Earth-based applications, is available for licensing and can be customized to suit the required application.

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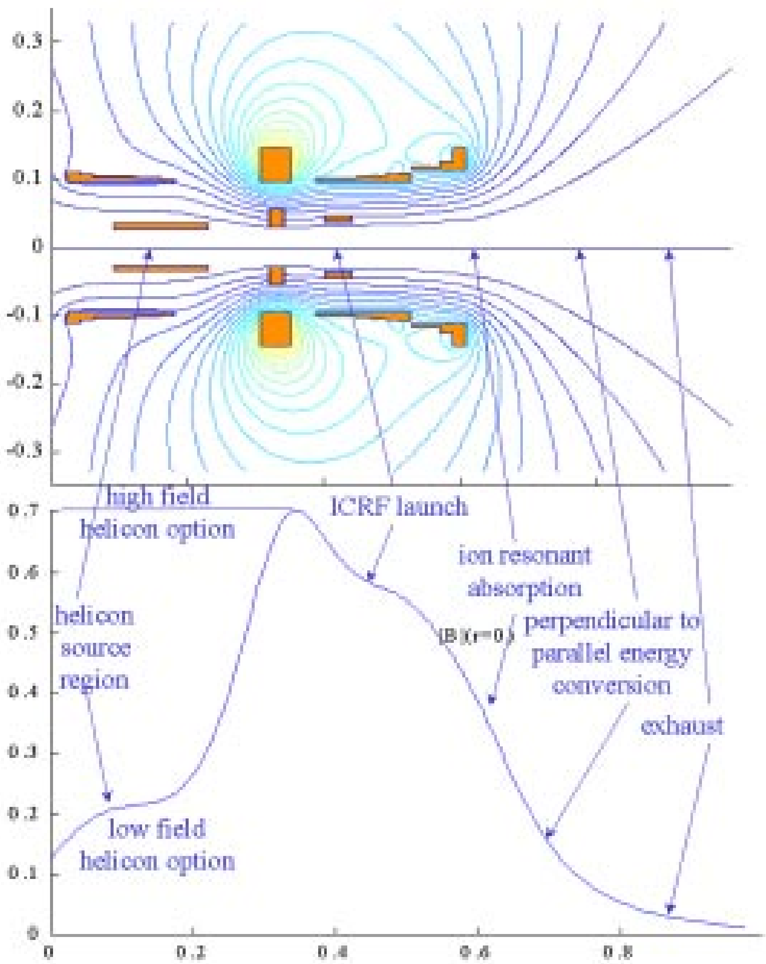

Variable Specific Impulse Magnetoplasma Propulsion

Variable Specific Impulse Magnetoplasma Propulsion

Background

The variable specific impulse magnetoplasma rocket (VASIMR) is an advanced propulsion technology that has been under development at Johnson Space Center since 1980. Its design addresses the need for a faster and more efficient in-space transportation capability than provided by current chemical rockets. The ability to have rapid and efficient access to all points in our solar system is one of the most compelling reasons for its development.

Project Overview

The VASIMR system is a high-power, electrothermal plasma rocket capable of exhaust modulation at constant power. It consists of three major magnetic cells: forward, central, and aft where plasma is, respectively, injected, heated, and expanded. During operations, a neutral gas (typically hydrogen, helium, or a gas mixture) is injected at the forward cell and ionized. The resulting plasma is heated with radio frequency (RF) energy in the central cell to the desired temperature and density by ion cyclotron resonance. After heating, the plasma is accelerated in a two-stage magnetic nozzle at the aft cell to provide modulated thrust.

Present research addresses the physics and engineering of the VASIMR in a multifaceted effort addressing the various experimental, theoretical, and systems engineering issues. In the experimental area, major advances in plasma generation, solid-state RF equipment ,and high-temperature superconducting magnet design have been accomplished. In the theoretical area, mechanisms for plasma heating, acceleration, and detachment at the magnetic nozzle have been demonstrated. And in the systems engineering area, a self-consistent conceptual design of a flight experiment has been completed and proposed for flight in 2003. VASIMR studies will continue to strengthen our understanding in these three areas and will contribute to in an effort that will lead to an early implementation of the technology.

Benefits and Uses

VASIMR enables rapid and flexible human or robotic interplanetary travel, with greatly improved payload mass fraction over conventional chemical rockets. Its constant power throttling capability enables a 90-day Mars transfer and abort capability for human missions. For the commercial sector, VASIMR technology can provide economical access to the Earth-Moon environment for resupply, maintenance, and repair of telecommunications and remote-sensing satellites. The hydrogen propellant and VASIMR's magnetic field also provide effective radiation shielding against solar and cosmic radiation. Magnetoplasma technology contributes to important developments in solid-state power devices, materials, coatings, and magnetic systems using state-of-the-art, high-temperature superconductors. In its present form, VASIMR operates as a driven solar or nuclear electric rocket. However, the technology paves the way for future high-power fusion propulsion.

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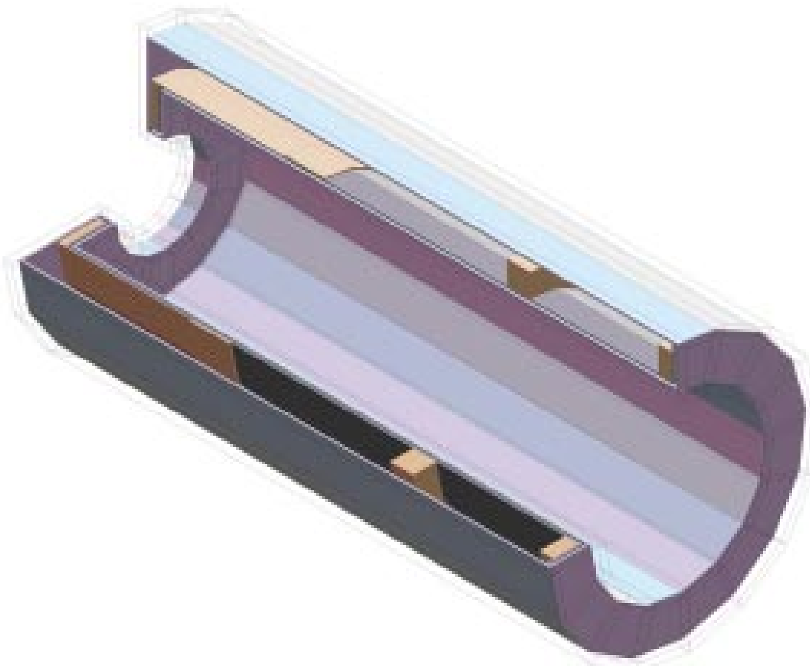

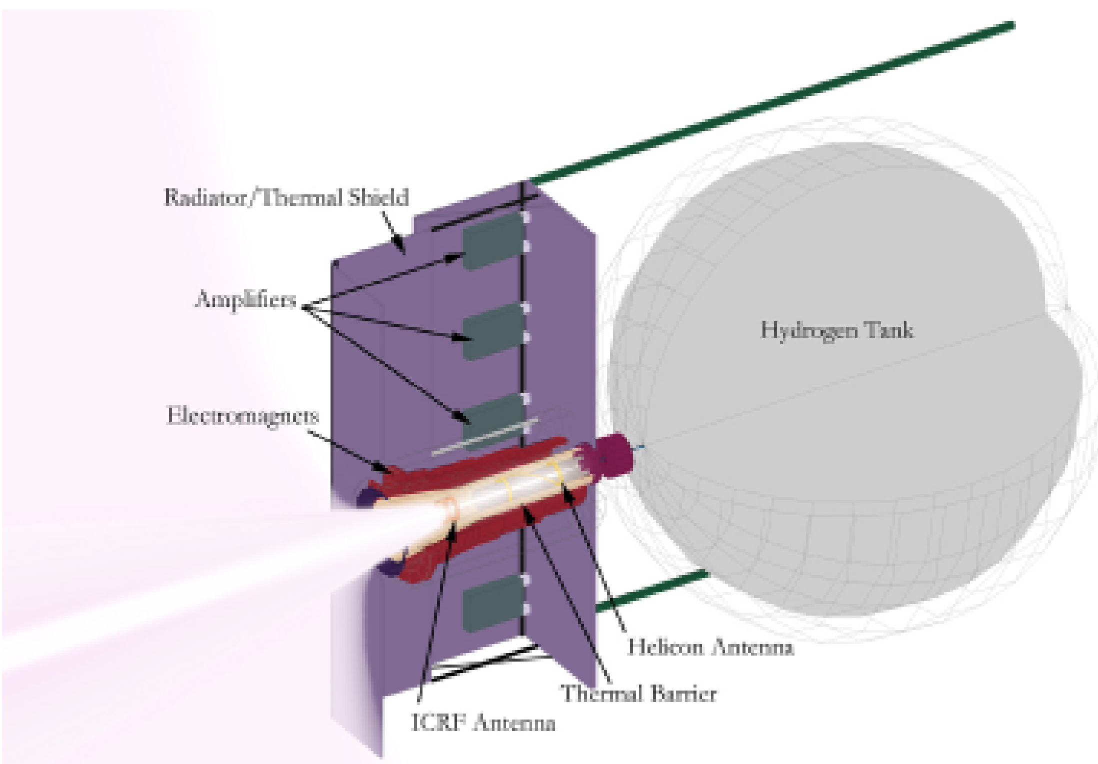

High-Temperature Superconducting Magnets for Space Applications

High-Temperature Superconducting Magnets for Space Applications

Background

The development of superconducting technology for space enables a host of important capabilities for commercialization, exploration, and research that are currently beyond our reach. Superconductivity has reached a level of maturity that brings some of the materials out of the research laboratory and into the realms of technology and manufacturing. Moreover, the natural environment of space may offer favorable thermal control strategies that will make these applications even more attractive.

The Advanced Space Propulsion Laboratory (ASPL) team is engaged in developing these technologies in support of the Human Exploration and Development of Space [HEDS] enterprise. This effort relates to ongoing activities in plasma propulsion as well as concepts for magnetic shielding that were proposed by ASPL investigators in 1996. The technology is also being developed in support of basic space-borne research in particle physics.

Project Overview

The project goal is to design a full-scale, high-temperature superconducting magnet prototype as a potential flight component of a 10 kW variable specific impulse magnetoplasma rocket (VASIMR) propulsion system for the proposed Radiation And Technology Demonstration (RTD) flight. A preliminary design of this magnet has been completed in collaboration with the Oak Ridge National Laboratory.

The magnet, which comprises a continuous solenoid in an insulated cylindrical mandrill, is built of 2223 bismuth strontium calcium copper oxide in a silver-stabilizing matrix. It operates at a temperature of 35 K with a field strength of .7 Tesla at its highest point on axis. Compressive and tensile stresses are well within acceptable limits. Thermal control of the system is achieved by the supercritical hydrogen propellant for the thruster as well as by multilayer insulation. Construction and ground testing of this magnet is expected in late 2000.

Benefits and Uses

Important areas of near-term application include: (1) magnetoplasma space propulsion; (2) high-energy particle physics; (3) magnetic shielding of human and robotic spacecraft against high-energy-charged particles; and (4) energy storage and magnetic actuator devices for space.

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Administration

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