John F. Kennedy Space Center

Research and Technology

2002 Annual Report

NASA Technical Memorandum 211179

Research and Technology
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Foreword

As the NASA Center of Excellence for Launch and Payload Processing Systems and launching space missions, the John F. Kennedy Space Center (KSC) is placing increasing emphasis on advanced technology development. KSC's dual mission includes spaceport and range technologies as well as space launch operations. To focus our technology development efforts, we have created a Spaceport Technology Center initiative with a portfolio of technology developments that will assist us in improving Space Transportation System safety, reducing the cost of access to space, and enabling greater commercial success of our space launch industry. Our technology development activities encompass the efforts of the entire KSC team, consisting of Government and contractor personnel working in partnership with academic institutions and commercial industry. This KSC Research and Technology 2002 Annual Report demonstrates these contributions to the KSC mission.

Dr. Dave Bartine, KSC Chief Technologist, (321) 867-7069, is responsible for publication of this report and should be contacted for any desired information regarding the Spaceport Technology Center initiative.

Roy D. Bridges, Jr.
Director

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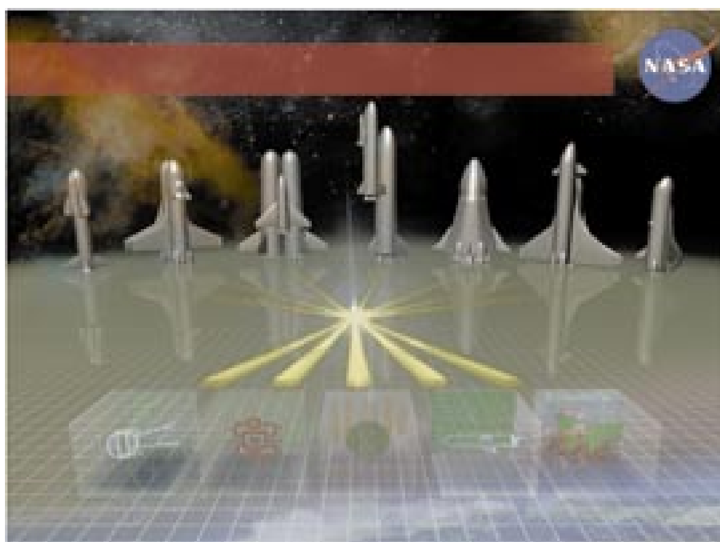


Future Reusable Launch Vehicle Systems

Technology Programs and Commercialization

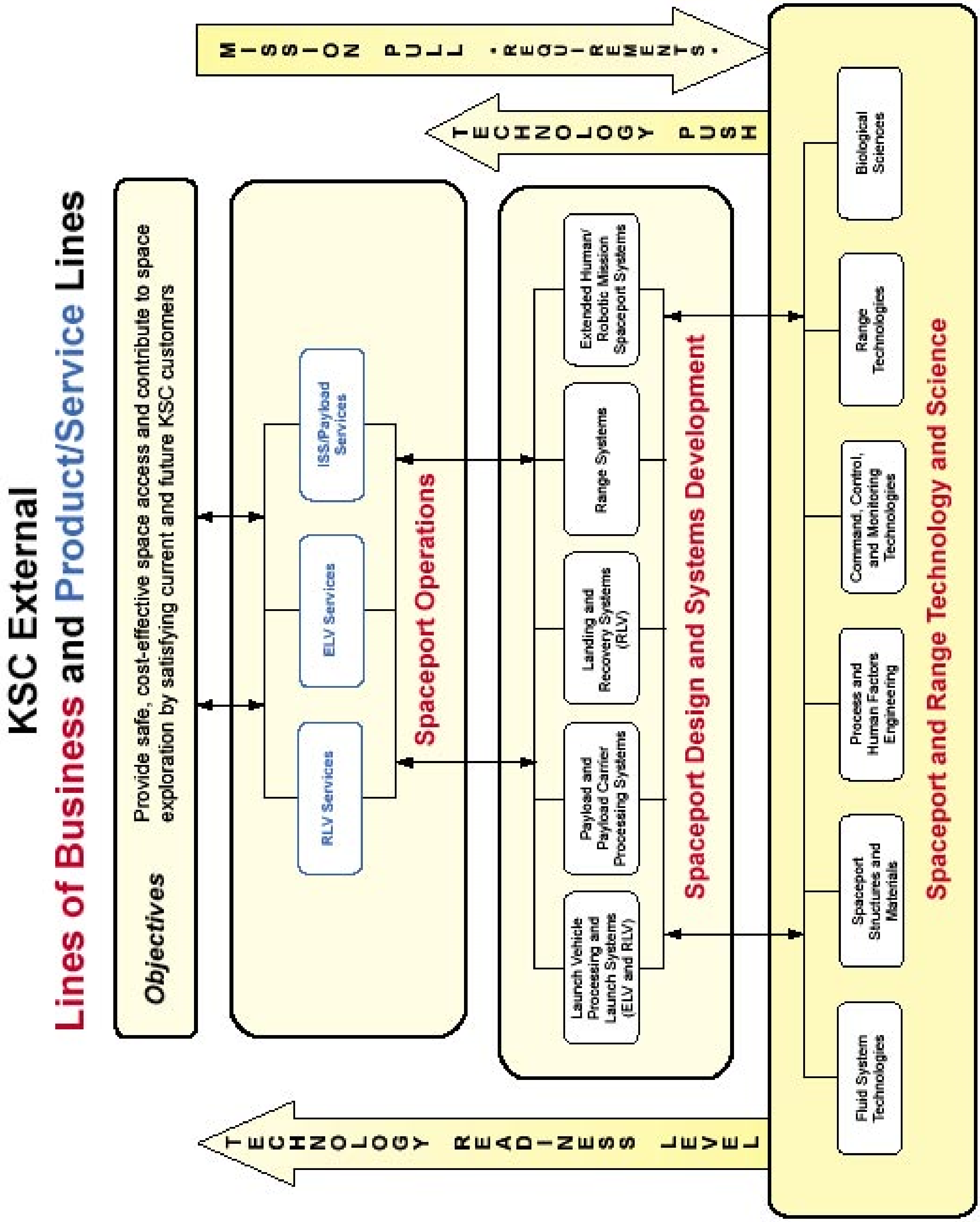
Introduction

The John F. Kennedy Space Center's (KSC) outstanding record of achievements has earned it an honored place in history and an essential role in Space Transportation Systems of today and tomorrow. As NASA's Center of Excellence for Launch and Payload Processing Systems, KSC is increasing the momentum in technology development for current and future spaceports. The Spaceport Technology Center (STC) initiative carries out KSC's role within NASA to meet the goals of increased safety, reduced cost of space access, and rapid expansion of commercial markets by infusing spaceport technologies into all facets of current and future Space Transportation Systems.

KSC's background as the nation's premier launch site creates an ideal environment for the STC. The STC's knowledge, expertise, facilities, and equipment provide technologies and processes to customers who propose to build and operate spaceports on Earth, in orbit, and beyond. The STC is composed of three strategic lines of business: Spaceport Operations, Spaceport Design and Systems Development, and Spaceport and Range Technology and Science. KSC has unparalleled expertise in designing, building, and operating a spaceport with all its complex systems.

STC technology development activities are concentrated in six Spaceport Technology and Science Product Lines — Biological Sciences; Range Technologies; Spaceport Structures and Materials; Command, Control, and Monitoring Technologies; Fluid System Technologies; and Process and Human Factors Engineering. KSC's leadership in incorporating safer, faster, cheaper, and more robust systems and technologies will pave the way for future space industry. This report is organized by these six Spaceport Technology and Science Product Lines.

The primary stakeholders and customers for spaceport and range technologies are the programs and initiatives supporting current and future Space Transportation Systems. KSC aggressively seeks industry participation and collaboration in its research and technology development initiatives. KSC also seeks to transfer its expertise and technology to the commercial sector and academic community. Programs and commercialization opportunities available to American industries and other institutional organizations are described in the Technology Programs and Commercialization Office Internet Web site at *http://technology.ksc.nasa.gov*. Additional information on KSC's Spaceport Technology Center can be found on KSC's home page at *www.ksc.nasa.gov*.


KSC External
Lines of Business and Product/Service Lines
Objectives
Provide safe, cost-effective space access and contribute to space exploration by satisfying current and future KSC customers
RLV Services
ELV Services
ISS/Payload Services
Spaceport Operations
Launch Vehicle Processing and Launch Systems (ELV and RLV)
Payload and Payload Carrier Processing Systems
Landing and Recovery Systems (RLV)
Range Systems
Extended Human/Robotic Mission Spaceport Systems
Spaceport Design and Systems Development
Fluid System Technologies
Spaceport Structures and Materials
Process and Human Factors Engineering
Command, Control, and Monitoring Technologies
Range Technologies
Biological Sciences
Spaceport and Range Technology and Science
MISSION PULL •REQUIREMENTS•
TECHNOLOGY PUSH
TECHNOLOGY READINESS LEVEL

Biological Sciences

Biological Sciences is the KSC science core competency working toward achieving a better understanding of managing closed biological and natural ecological systems for application in space and on Earth. To accomplish this vision, research and technology development will be performed to establish baseline data sets for biological system stability and function for missions beyond low Earth orbit, as well as to expand the understanding of the fundamental issues with biological organisms in microgravity. In addition, the Biological Sciences area includes ecological research to assess environmental impacts to new and old launch sites on Earth and eventually other planetary bodies and to ensure our ecosystems here on Earth and specifically at KSC are understood, managed, and protected.

Science focus areas include the following:

- Bioregenerative Life Support
- Spaceport Biological Research
- Spaceport Ecosystem Sciences

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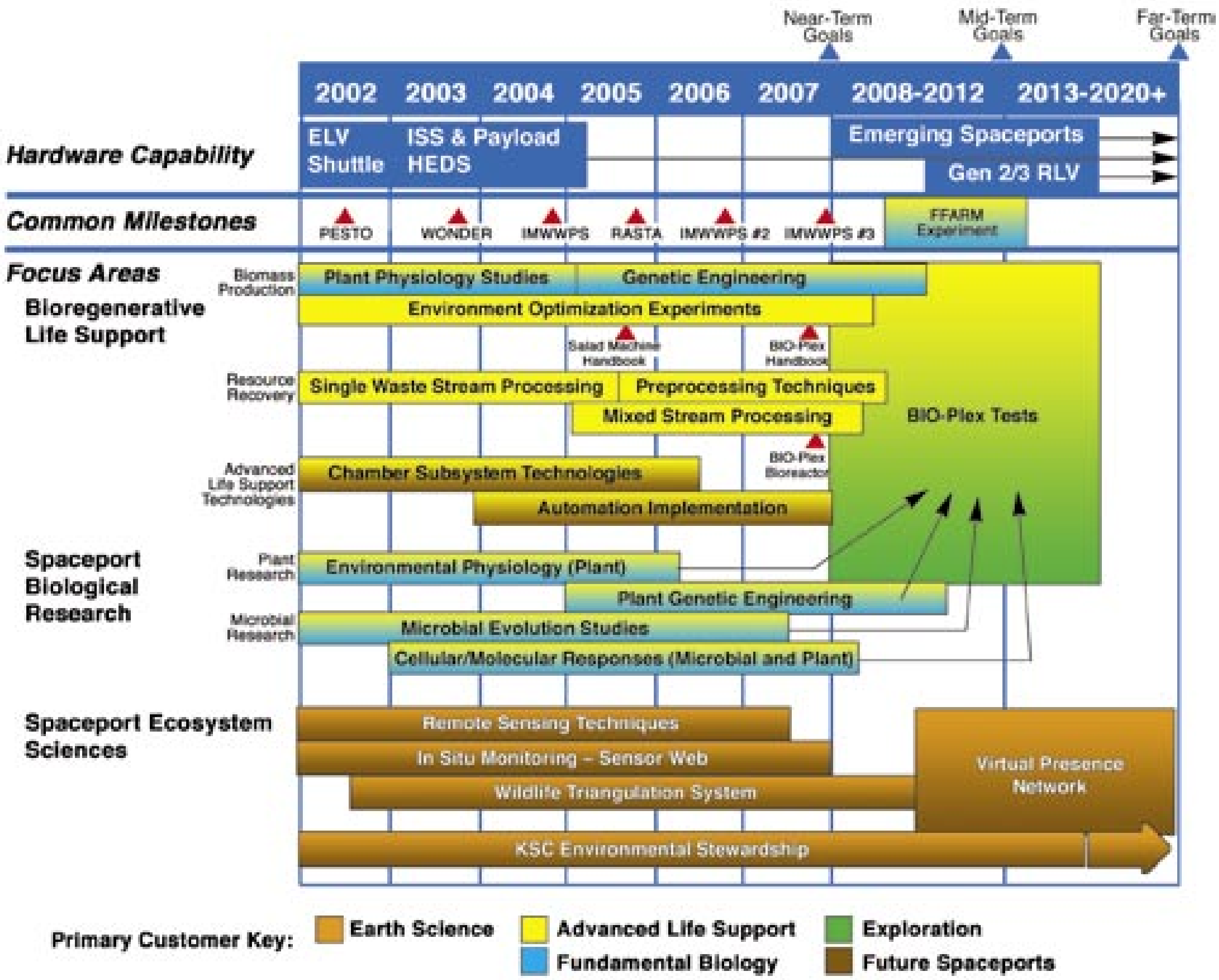
KSC Biological Sciences Roadmap



Goals Specific to Focus Areas

- Develop fully regenerative integrated systems technologies that provide air, water, and food and recover resources from wastes
- Obtain fundamental knowledge of the evolution and development of terrestrial organisms and ecological systems in altered environments
- Gain scientific understanding and develop technologies to support the sound management and conservation of our Spaceport Technology Center's ecological resources

Development of Optical Components for Space-Based Plant Lighting

The objective of this project is to develop the technology base for a solar plant lighting system for space-based plant growing. The technology implements an innovative concept of dividing the ambient solar radiation into two spectral components: photosynthetically active radiation (PAR) used for plant growth and non-PAR spectra for electrical power. Applications of this solar plant lighting system include orbit/transit flight, lunar colony, and Mars colony. The specific tasks currently being performed are developing the design concept of solar concentrators for the various applications, conducting photovoltaic (PV) electric power generation tests using GaSb cells with the non-PAR solar spectra, and developing fabrication and test prototypes of key components (hull penetration port, cable connector, optical switching device, and light distribution panel).

The solar plant lighting system has the potential for generating electric power while providing plant growing light without any penalty to the plant growth activity. The electricity can be stored in power storage devices such as batteries or fuel cells and can be used to provide electric lighting when solar light is not available. Conversion of the non-PAR solar spectra can be accomplished by using low-bandgap PV cells. Candidate PV cells include Si (λ_{bg} = 1.11 micrometers [μm]), InGaAs (λ_{bg}= 1.55 μm), and GaSb (λ_{bg} = 1.8 μm). Recently, PV power generation experiments using the GaSb cells were conducted. In this experiment the concentrated solar radiation was divided by the selective spectral reflector into the PAR component (400 nanometers [nm] $< \lambda <$ 700 nm) and the non-PAR component ($\lambda >$ 700 nm). The PAR spectra are transmitted to the plant lighting laboratory and the non-PAR spectra are transmitted to the low-bandgap solar cell for conversion to electricity. Figure 1 shows the GaSb cell (12.5 mm × 10 mm, made by JX Crystals) mounted on the PV cell module.

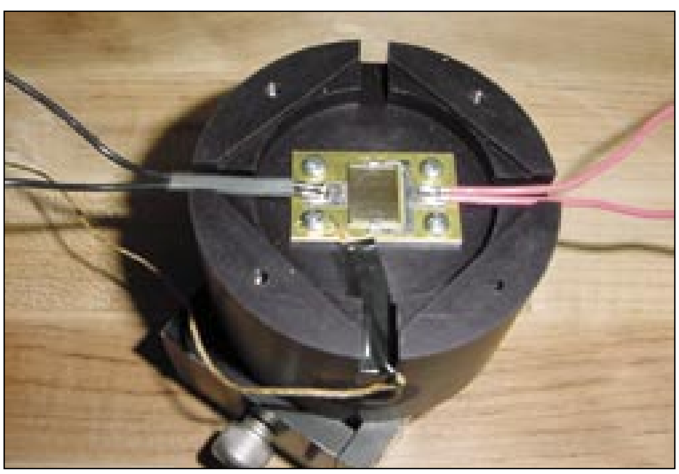


Figure 1. GaSb Cell (12.5 mm × 10 mm: Made by JX Crystals) Mounted on the PV Cell Module

The PV power experiment was conducted using 20-inch concentrators and the following tasks were accomplished: (1) characterized performance of the PV cells when operated with the non-PAR solar spectra; (2) evaluated the effect of solar concentration on the PV conversion efficiency; and (3) measured the relationship between the PAR delivered by the lighting cable and the electric power generated. A solar test for transmission of the PAR spectra and PV power generation for the non-PAR spectra is shown in figure 2. The PV cell module at the focal point of the

Figure 2. Transmission of the PAR Spectra and PV Power Generation for the Non-PAR Spectra

Figure 3. The Lightguide Inlet Receiving the PAR Spectra From the Cold Mirror

concentrator reflects the PAR spectra onto the inlet of the 10-meter (m) lightguide cable (see figure 3), which then transmits the PAR inside of the laboratory. The PAR light emitted at the outlet end of the lightguide is clearly visible in figure 2. The GaSb cell mounted on the PV cell module was generating electric power. To the best of our knowledge, this test is the first successful demonstration of the feasibility for transmission of the solar PAR spectra and the PV power generation using the solar non-PAR spectra. Based on the voltage-current (V-I) characteristics taken during the solar experiments, the maximum cell efficiency was calculated to be about 15 percent. This means that 15 percent of the non-PAR radiation directed to the GaSb cell was converted to electric power. Our preliminary analysis indicates a transmission efficiency for the PAR spectra over the 10-m lightguide to be approximately 65 to 70 percent.

Key accomplishments:

- Conducted a series of experiments to separate solar spectra into the PAR and the non-PAR components.
- Demonstrated, for the first time, the feasibility of generating electric power using the non-PAR solar spectra while transmitting the PAR spectra to the location for the plant growth.
- Quantified the non-PAR-based PV generating efficiency.
- Quantified the PAR transmission efficiency.

Key milestones:

- Develop design concepts of solar concentrators for the orbit/transit flight, lunar colony, and Mars colony.
- Fabricate test prototypes of key optical components.
- Develop a design of the engineering model of the optical components to be built and tested in Phase II.

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Participating Organization: Physical Sciences Inc. (T. Nakamura)

Moisture and Oxygen Content Sensor Suite (MOCSS) for Nutrient Delivery Systems

Management of water and oxygen supply to plant root zones is critical to the development of healthy plants and will be necessary as more sophisticated plant growth systems are developed for use in reduced gravity. Because the microgravity substrate environment operates in a force balance between surface tension and capillary forces, it cannot readily be simulated on Earth (1g). Maintaining proper oxygen levels in microgravity requires flight systems to be able to monitor and manage for both optimum substrate water and oxygen concentrations inside the substrate itself. The MOCSS was developed to provide the necessary feedback to manage both moisture and oxygen in the root zone of space-based plant growth systems. The MOCSS sensors provide the information needed to minimize moisture and oxygen stress to plants and provide a tool for studying and understanding the mechanisms of water transfer and oxygen diffusion in microgravity root zone environments.

The integrated MOCSS system is composed of three elements that can stand alone or be used as an integrated system. These elements include the soil moisture sensor, the soil oxygen sensor, and a substrate gas and liquid distribution model.

The soil moisture system developed during the MOCSS project is shown in figures 1a and 1b. The system can be used in three modes – soil moisture and soil temperature monitoring mode, soil moisture measurement mode (more rapid cycling between readings), and a "front detection" mode that allows tracking of water movement into a dry matrix (figure 2).

The oxygen sensor was modified for use in space-based nutrient delivery systems, including integration of Teflon barriers for use in wet environments, miniaturization of the sensor (figure 3), use of flight-approved materials, development of tempera-

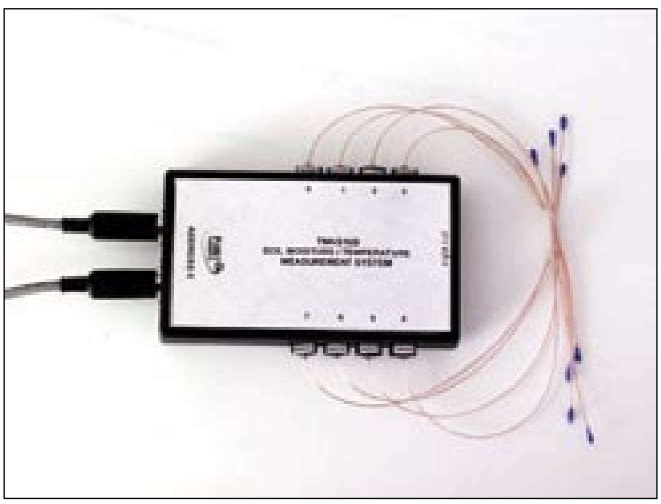

Figure 1a. Single TMAS Sensor Box With 8 Soil Moisture Probes

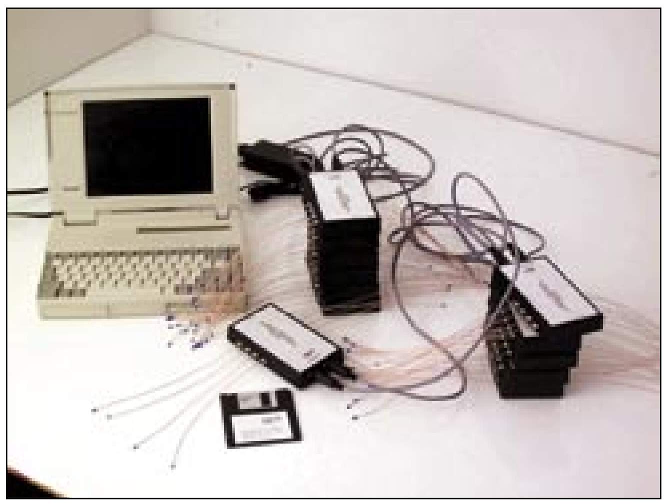

Figure 1b. Full Array of 16 Sensor Boxes With 8 Soil Moisture Sensors Per Sensor Box (The sensor boxes are linked together serially.)

Figure 2. MOCSS Soil Moisture Sensors in Root Module Planted With Dwarf Wheat Plants

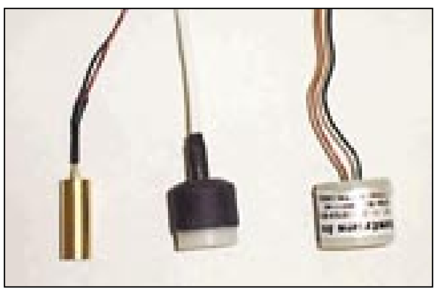

Figure 3. Oxygen Sensor Size Reductions Under the MOCSS Program

ture compensation circuits, and testing to select electrolytes not toxic to plants.

The BlueBurst software program was developed to simulate transport of liquids (e.g., water), gas species (e.g., oxygen and carbon dioxide), and solutes in a 2-dimensional vegetated porous medium. Unlike any other program, BlueBurst was designed to handle multiple domains (atmospheric, vegetative, porous medium) and coupled processes under variable gravity force settings. The user-friendly graphical user interface (GUI) facilitates input and provides a variety of graphical and textual output options. In the near term, this model will allow optimization of space-based nutrient delivery systems and provide a tool for visualization of the root environment based on sensor inputs.

Key accomplishments:

- Developed soil moisture probes with integrated control software and tested hardware and operating protocols in high-fidelity space-based nutrient delivery systems.
- Optimized soil moisture oxygen sensor technology and tested hardware and operating protocols in high-fidelity space-based nutrient delivery systems.
- Developed model for simulating liquid and gas flows in a porous medium.

Key milestones:

- Developed TMAS16 Moisture Sensing System and provided units for testing to KSC and Johnson Space Center plant scientists.
- Developed TMAS485 Moisture Sensing System and circuit boards for testing with WONDER nutrient delivery system test payload.
- Incorporated MOCSS into FHAME fluid systems research payload.
- Integrated MOCSS technology into design requirements for Plant Research Unit for the International Space Station.

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Participating Organizations: Orbital Technologies Corporation (Dr. R.C. Morrow) and Space Dynamics Laboratory (Dr. G.E. Bingham)

Small Payload Automatic Fluid Separation System (SPAFSS)

The technical objective of this effort is to develop a flight-ready miniaturized degasser system that includes all support hardware needed to operate on-orbit with minimal crew interaction. The degasser assembly utilizes hydrophilic and hydrophobic membranes under low pressure to separate gas bubbles from a fluid line. The key properties of the membranes are bubble point and water intrusion pressure, respectively. The degasser was fully characterized for pressure-versus-flow-rate dependence, bubble point, water intrusion pressure, and typical contamination rate. Three different sizes of degassers were developed and manufactured (see figure 1). The increase in degasser size offers an increasing life (time to contamination). The table shows a summary of the specifications for the three different degasser sizes.

A prototype system was built that combines the degasser with the support electronics and mechanical components necessary to circulate the fluid through the degasser assembly while monitoring system pressure and possible system failures. Priming and recirculation protocols are part of the standard operations and can be accessed from the top panel of the system (see figure 2). Recirculation is also automated by the system if bubbles are detected in the outlet fluid line of the degasser.

The SPAFSS Integrated System has the potential for drastically reducing crew time on orbit for plant growth experiment functions such as root module and reservoir priming. A manual priming procedure could be replaced with the use of the SPAFSS Integrated System. The system may also be used for a variety of other experimental systems requiring a bubble-free fluid line because the flow rate of the system is adjustable to 50, 100, 150, and 200 millimeters per minute (ml/min) and operable pressure ranges are up to 8 psi.

A flight-ready SPAFSS Integrated System is currently under development. Capabilities are being added to the system to detect system flow and add redundancy to the bubble detection system. The SPAFSS Integrated System will be designed to fly and operate in the Space Shuttle Middeck and in the International Space Station (ISS). The SPAFSS Integrated System will be one-fourth the size of a Standard Middeck Locker and will be transported in a half-size cargo transfer bag. Power consumption is approximately 12 watts and the system weight is approximately 11 pounds.

Figure 1. The Three Degasser Assembly Sizes, Three Each Shown

Degasser Assembly Capabilities and Specifications

Specifications	SPAFSS Degasser Assembly	Half-Size SPAFSS Degasser Assembly	Super-Mini Degasser
Mass[a]	292 g	224 g	Approximately 85 g
Volume	720 cm^3 (44 in^3)	303 cm^3 (18.5 in^3)	120 cm^3 (7.3in^3)
Dead Volume	166 cm^3 (10.1 in^3)	81 cm^3 (4.9 in^3)	15 cm^3 (0.92in^3)
Major Dimensions (Without Fittings)	8.10-cm diameter × 14.00-cm long	8.10-cm diameter × 8.08-cm long	5.51-cm diameter × 4.93-cm long
Major Dimensions (With Fittings)	8.12-cm diameter × 15.09-cm long	8.12-cm diameter × 9.14-cm long	6.68-cm diameter × 7.37-cm long
Maximum Operating Pressure Drop	8.0 psid	8.0 psid	8.0 psid
ΔP Across Degasser at Water Flow Rate	0.35 kPa (0.05 psid) at 50 ml/min	0.41 kPa (0.06 psid) at 50 ml/min	5.2 kPa (0.75 psid) at 70 ml/min
Maximum Allowable Air Flow[b]	>150 ml/min	>150 ml/min	>120 ml/min

[a] *Mass of degasser assembly dry.*
[b] *Estimate assuming 100-percent air input.*

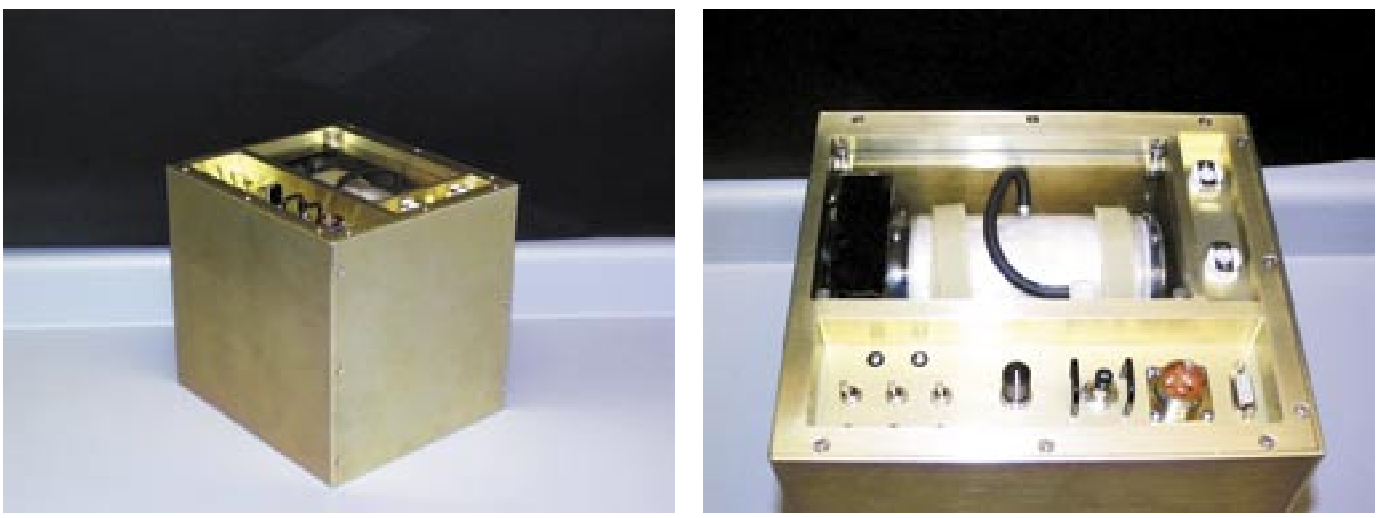

Figure 2. Prototype SPAFSS Integrated System

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Participating Organization: Orbital Technologies Corporation (J. Maas)

Carbon Cycle Research at Kennedy Space Center

It is well established that atmospheric carbon dioxide (CO_2) (a greenhouse gas) is increasing in large part due to human activities such as the burning of fossil fuels. The atmospheric concentration of CO_2 is reported to have increased from about 280 to 370 parts per million (ppm) during the past 200 years. Some experts predict the global climate change will alter landscapes appreciably as CO_2 doubles over the next 50 to 100 years. The effects of increasing CO_2 on plants are well known: increased photosynthesis, reduced water loss, and more efficient use of nutrients and other resources. These effects lead to more growth, particularly in roots, and this adds carbon to the soil and stimulates microbial activity.

Forest ecosystems are responsible for large amounts of carbon flux in the atmosphere, and forest productivity is expected to increase with the projected rise in concentration of atmospheric CO_2. Land management practices at Kennedy Space Center and Merritt Island National Wildlife Refuge include the use of controlled burning for fuels management to reduce wildfires and also the reintroduction of natural fire return cycles into ecosystems that historically have fire as an integral part of their dynamic processes. With expected increases in forest productivity and with the relative uncertainty regarding the effects of elevated CO_2 on forest ecosystem processes, Kennedy Space Center is currently embarked on a partnership with the Smithsonian Environmental Research Center (SERC) and the Department of Energy to understand the long-term effects of elevated atmospheric carbon dioxide on Florida scrub oak ecosystem processes. Understanding carbon storage or release by fire-driven ecosystems is central to predicting long-term trends in ecosystem carbon change and the resultant impact on processes critical to the maintenance of habitat of threatened and endangered species. This is important to the long-term operation and land stewardship programs of the KSC Spaceport.

Currently, there are two research efforts underway at KSC to understand the carbon cycle and other ecosystem processes that may be influenced by increasing atmospheric CO_2. Both open-top chambers and eddy flux towers are used in the studies. The project unites researchers from SERC, KSC, and several national and international universities performing experiments in a natural Florida scrub oak ecosystem. The study is designed to gain insight into the effects of increased carbon dioxide on natural vegetation growth and structure, soils, nutrient cycling, and water relations among several attributes that are important to ecosystem processes. The experiment features a 4-acre site just north of the Launch Complex 39 area with 16 open-top chambers (19 cubic meters in volume measure 3.6 meters across and 2.3 meters high encompassing a surface area of 10 square meters) placed over areas dominated by naturally occurring Florida scrub oaks and other associated species. The Florida scrub oak was chosen for study in part because it is small in stature and woody and has the attributes of much larger forest ecosystems. Elevated amounts of carbon dioxide (ambient plus 350-ppm CO_2) are piped into 8 of the 16 open-top chambers to simulate the expected doubling of atmospheric CO_2. Eight chambers are maintained at ambient atmospheric CO_2 concentration (about 360 ppm) and 8 sites without chambers are maintained as part of the experimental treatment. The results of the research are being published in the open literature, and the site has become recognized as one of the most important native ecosystem sites in the world.

Studies with the open-top chambers have some "chamber effects" limitations, such as elevated temperatures in the chambers, shielding from ambient rainfall, some light blockage from the Mylar used to

construct the chamber walls, restrictions of normal movement of insects (grazers) and other wildlife essential to ecosystem processes, and restrictions of normal atmospheric movement in the plant canopy. The study sites also have to be small due to intense maintenance required for each chamber. Over the past year, another technique for measuring ecosystem carbon flux has been employed in concert with the chambers. That technique uses an eddy flux tower, which allows for continuous measurement of carbon flux between the ecosystem and atmosphere. The results show good agreement between values of carbon flux measured with the tower and those values obtained from the chambers. Thus, the tower system provides for an unchambered technique estimating the flux (uptake and/or storage) of carbon between the vegetation and the atmosphere. This tower approach takes advantage of a high-precision multidimensional anemometer system to establish precision estimates of vegetation canopy air flow, which, when coupled with measurements of atmospheric CO_2 can be used to predict carbon flux between an ecosystem and the atmosphere. The resultant modeling allows for the estimation of unit area carbon flux within the area of the tower and can be used to estimate carbon uptake and/or storage. Two eddy flux towers are in operation at KSC and expand the spatial footprint of the chamber studies. One tower is in place near the current CO_2 site (for comparative purposes), and another tower is located in the Pine Flatwoods area (TEL-4) to collect data that will allow landscape-scale projections of carbon flux.

Key accomplishments:

The results of the project to date have demonstrated some significant responses to elevated CO_2 in the Florida scrub oak since the project started in 1996. The overall results indicate that interactions between the effects of elevated atmospheric CO_2 on carbon metabolism, ecosystem nutrient cycling, and water relations have resulted in stimulation of carbon accumulation that has been sustained for over 5 years. The large increases in photosynthesis coupled with smaller effects on respiration have resulted in increased aboveground biomass, total leaf area, and greater fine root production in areas exposed to higher CO_2. There are large yearly variations in these carbon pools, which make it difficult to conclusively determine patterns in partitioning of carbon within the system, particularly for the belowground portion. Total nitrogen has increased in the shoot and root portion of the biomass pool under elevated CO_2 because of the greater biomass produced under elevated CO_2 in the pools. The additional demand for nutrients with increased growth under elevated CO_2 has reduced soil nitrogen and phosphorous levels. Soil water content in surface soils has increased under elevated conditions due in part to reduced loss of water from leaves, which have lower stomatal conductance and greater shading in denser canopies.

Key milestones:

Current funding from the Department of Energy will support the site for 2 more years, at which time renewal proposals will be submitted. The study as planned will continue until the site has at least 8 to 10 years of growth since the last controlled burn. The site will be burned again and the study will continue for a number of years to look at system responses under elevated CO_2 immediately after fire and during early recovery. An additional eddy flux tower is planned to allow for carbon flux studies in other sites of the same ecosystem type and also in different ecosystems. This new eddy flux tower will be designed as a portable unit to allow for short-term monitoring of carbon flux dynamics related to events such as controlled burns or wildfire.

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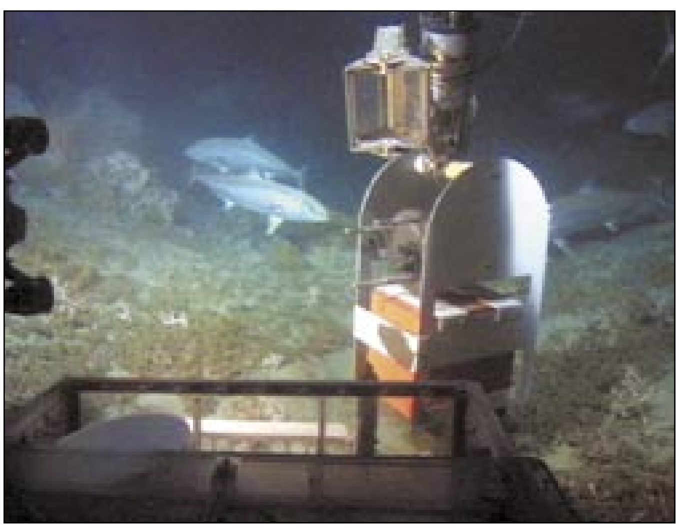
Participating Organizations: SERC (Dr. B.G. Drake, Dr. G. Hymus, and D. Johnson), National Research Council (Dr. S. Dore), and Dynamac Corporation (Dr. C.R. Hinkle)

Development of Passive Acoustic Systems To Assess Aquatic Biological Resources and Human Activities

Fish-spawning activities and marine mammal social activities are often difficult if not impossible to study continuously without passive acoustic systems, at least for those species that are documented in producing sound during spawning events. Similarly, human activity in remote aquatic environments is best assayed using passive acoustic techniques. The development of cost-effective passive acoustic receiver and data transfer/analysis systems would greatly enhance both biological and human activity assessment in aquatic environments, which are basically opaque to light. Kennedy Space Center is currently developing a programmable portable computer-hydrophone system that stores large volumes of acoustic data across a wide frequency spectrum with source recognition and filtering capabilities and records ambient temperatures when deployed to depths of up to 1,000 meters. This system is sufficiently robust that a number of environmental sensor systems may be integrated into a single portable unit. Deployment duration is dependent on preprogrammed sensor and computer activity rates. The ultimate goal is to deploy an array of hydrophone units in the protected waters of Kennedy Space Center to better understand the spawning habits of soniferous fish and effects of NASA KSC launch activities on the local aquatic resources.



PAMS Unit on the Sea Floor

A key component of the Passive Acoustic Monitoring System (PAMS) is the hydrophone. The hydrophone frequency range must be broad enough (10 to 80,000 hertz) to detect most low-frequency fish sounds, marine mammal sounds, boat sounds, and high-frequency sonic tags used on marine mammals and fish for migratory studies. Experimental tests using a variety of hydrophones are currently underway to determine the hydrophone specifications for optimum operation. A prototype PAMS unit was completed in mid August 2001 and tested in the upper Banana River Lagoon. Initial sea trials were conducted during the National Oceanic and Atmospheric Administration (NOAA) Ocean Exploration-sponsored Islands in the Stream Program during August and September 2001. The PAMS was deployed at a grouper spawning site used for research over the past 25 years. Groupers are soniferous, particularly when conducting prenuptial displays associated with social interactions, sex reversal, and spawning. The PAMS was found to be rugged and watertight.

Passive Acoustic Monitoring System (PAMS)

KSC PAMS Team

The future principal deployment site will be a spotted sea trout spawning site in the upper Banana River Lagoon adjacent to Launch Pad 39A. This is also the site at which the Jet Propulsion Laboratory (JPL) Sensor Webs, led by Dr. Kevin Delin, was deployed in mid 2002. The JPL Sensor Webs and the KSC PAMS array deployment complemented one another in providing a powerful continuous underwater monitoring system for both environmental and biological activity.

Key accomplishments:

- Designed and fabricated prototype portable hydrophone/computer system (PAMS) unit.
- Deployed PAMS unit during NOAA Ocean Exploration Program expedition to the continental shelf off Kennedy Space Center.

Key milestones:

- Perform aquatic tests using a sound generator capable of accurately reproducing target biological sounds and evaluate operation of submerged PAMS unit.
- Develop additional programmable portable computer-hydrophone units.
- Investigate possible array configurations (depth, spacing between units, etc.).
- Develop laboratory protocols and software for data processing, management, and analyses.
- NOAA Ocean Exploration Program in the spring of 2003 will deploy the NASA PAMS unit again with manned submarines on the continental shelf adjacent to KSC in the Oculina Habitat, a Southeast Fisheries Council fishing reserve.
- For a full description of JPL's Sensor Webs, see *http://sensorwebs.jpl.nasa.gov/*

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Participating Organizations: YA-F2 (M.A. Lane and S.D. VanMeter) and Dynamac Corporation (Dr. R.G. Gilmore)

Plant Lighting Systems

When given a sufficient quantity and certain quality of light, plants can produce food, regenerate oxygen, and purify water for space inhabitants. Conventional lighting technologies would be prohibitive to growing plants on a large scale in space due to low electric power conversion efficiencies. Current lighting research for space-based plant culture is focused on innovative lighting technologies that demonstrate high electrical efficiency and reduced mass and volume. Accordingly, light-emitting diodes (LED's) and microwave lamps are promising technologies being developed to efficiently generate photosynthetic radiation. LED's can illuminate near the peak light absorption regions of chlorophyll while producing virtually no near-infrared radiation. The sulfur-microwave electrode-less high-intensity discharge (HID) lamp uses microwave energy to excite sulfur and argon, which produces a bright continuous broad-spectrum white light. Compared to conventional broad-spectrum sources, the microwave lamp is highly efficient and produces limited amounts of ultraviolet (UV) and infrared radiation. The work in the KSC Life Sciences Support Program in association with the Johnson Space Center (JSC) Advanced Life Support (ALS) Program gives insight into the feasibility of using LED's and/or microwave lamps as innovative alternative light sources for plant biomass production.

Within the ALS Program, salad-type plants represent crops that could provide a portion of fresh food as well as psychological benefits to the crew aboard future space transportation vehicles. Laboratory data generated with salad-type crops in the presence of various lighting sources will provide important data for the modeling and development for future missions. Work was completed with Swiss chard, spinach, radish, and lettuce plants grown in the presence of different lighting sources for 28 days. Three lamp banks represented broad-spectrum white light sources (microwave, high-pressure sodium, and cool-white fluorescent). Past tests have also included separate LED arrays filled with a given peak wavelength of red (664, 666, 676, 688 nanometers) LED's. Each LED array contained single rows of blue LED's (474 nanometers) evenly distributed within the multiple rows of red LED's. Current research has begun to measure the relative stoichiometry of photosystem I and II reaction centers in response to light quality. Laboratory instrumentation was incorporated, which monitors plant chlorophyll fluorescence, accessory pigment concentrations, and responses of photosynthetic rate to light and carbon dioxide levels.

Key accomplishments:

- 1999: Began experiments with salad-type plant growth with LED's and microwave lamps.
- 2000: Completed initial salad-type plant growth studies with LED's and microwave lamps. NASA NRA Solicitation 98-HEDS-01 grant to Dynamac Corporation extended through 2001.
- 2001: Began experiments with mixtures of salad species to compare the growth of multiple crops in a common environment/

Swiss Chard Plants Growing Under Arrays of Red and Blue LED's With Green

hydroponics system. Testing included evaluation of green LED's as an aid to improve visual perception of leaf color.

Key milestone:

- 2002: Initiate experiments to characterize photosynthetic reaction center stoichiometry (photosystem I versus II) in response to light quality.

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Participating Organization: Dynamac Corporation (Dr. G.D. Goins)

Swiss Chard Plants Growing Under Arrays of Red and Blue LED's Without Green

Development of the Porous Tube Insert Module (PTIM): A Modular Tray Supporting Both Porous Tube and Substrate Nutrient Delivery Systems for Plant Studies in Space

There is a need for microgravity-based plant culture nutrient delivery systems (NDS's) for both bioregenerative Advanced Life Support and plant research functions. The provision of adequate levels of water (without causing waterlogging) and oxygen to the root zone is the most crucial component deterring major advancements in this area. The dominance of the surface tension of water under microgravity conditions has often been found to lead to either severe waterlogging or excessive drying in the root zone. Consequently, differences in plant growth responses between spaceflight experiments and their ground controls are expected based merely upon differences in moisture distribution patterns between the two conditions. The Water Offset Nutrient Delivery ExpeRiment (WONDER) will address the question of "comparability of environmental conditions" between spaceflight and ground control experiments for both a porous tube plant NDS and a substrate-based NDS by employing three different wetness level treatments for each of these approaches. It is anticipated that different preset wetness levels than those used on Earth will be required to support optimal plant growth in space. Dry wheat seeds (N = 60-72) will be loaded 3 days prior to Orbiter liftoff, and the system will be initiated by the crew on orbit. Time-lapsed video recording of the plants will monitor growth over time. At recovery, the plants will be measured, and extensive tissue analyses relating to gene expression and stress-associated metabolites will be undertaken.

The Porous Tube Insert Module (figure 1) was designed to fulfill the requirements of this project specifically and to provide a testbed for a multitude of space-based plant studies. PTIM delivers water to both a series of "naked" porous tubes (figure 2) and porous tube/substrate compartments (figure 3). PTIM software will allow the crew to interact with the system's watering initiation protocols. The PTIM incorporates moisture sensors to both monitor and control the wetness levels on both the three "naked" porous tubes and within the three substrate compartments contained within the PTIM. A fixed-feed water provision mechanism functions as a backup mode in the event of a system failure.

Key accomplishments (2001):

- Completed high-fidelity Science Verification Test using a prototype PTIM unit.
- Completed a 90-percent Critical Design Review.
- Continued ground studies to define experimental methods and requirements.

Key milestones:

- Conduct KC-135 testing of critical hardware designs (2002).
- Complete flight hardware fabrication (2002/2003).
- Conduct high-fidelity Payload Verification Test using flight hardware (2003).
- Conduct spaceflight experiment on Space Shuttle (2004).

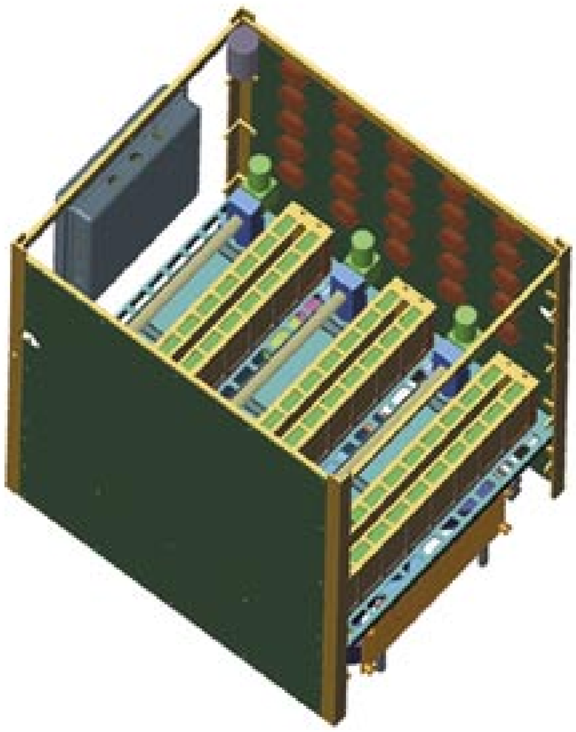

Figure 1. The Porous Tube Insert Module (PTIM) Design (Alternating porous tube and substrate-based NDS's are visible. An array of 25 cameras to monitor and document plant growth over time is also evident along one side wall. A similar array is present on the opposite wall.)

Figure 3. A Single Substrate-Based Nutrient Delivery System Compartment (Without Plants) (This approach mimics the traditional growing of plants in soil with a bottom-situated porous tube for water provision.)

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Participating Organizations: Dynamac Corporation (Dr. H.G. Levine and Dr. T.W. Dreschel) and Bionetics Corporation (K.A. Burtness and H.W. Wells)

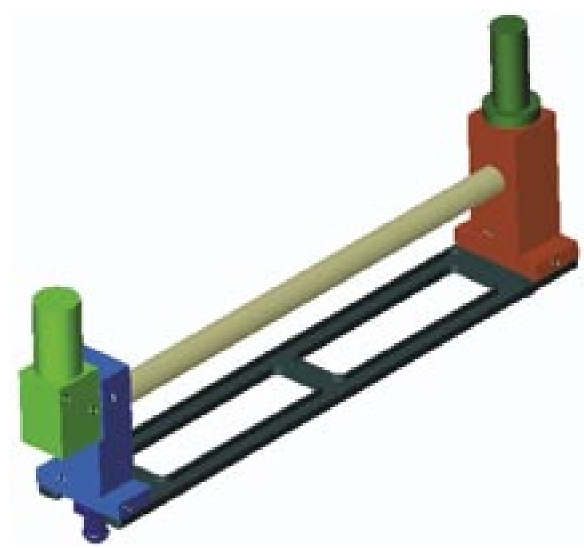

Figure 2. A Single Porous Tube Nutrient Delivery System Module (Without Plants) (Upon germination, the plant roots encircle the water-providing porous tubes. This approach eliminates the use of particulate substrates, resulting in considerable savings in mass and volume.)

Photosynthesis and Metabolism of Superdwarf Wheat in Microgravity

The photosynthetic rate of higher plants is a critical component of plant-based atmospheric regeneration systems being proposed for long-duration space missions. The Photosynthesis Experiment and System Testing and Operations (PESTO) experiment is designed to directly measure photosynthesis in microgravity so that an informed decision on the feasibility and design of these systems can be made. The overall objective of this research is to determine the effect of microgravity on photosynthetic response of plant tissues developed in either gravity or microgravity. The specific objectives of this research are to:

- Determine the effect of microgravity on carbon dioxide (CO_2) and light response curves of wheat.
- Determine the effect of microgravity on metabolism and electron transport processes associated with photosynthetic and respiratory gas exchange.
- Determine the effect of microgravity on carbohydrate partitioning in wheat.
- Determine the effect of microgravity on gas exchange, including water, over a range of atmospheric vapor pressure deficits.
- Utilize the knowledge gained to understand the response of plants grown under elevated CO_2 conditions of commercial, controlled-environment crop production systems.

The PESTO experiment, which will be performed on the International Space Station (ISS), is one of the most complex plant experiments to be conducted by NASA. The experiment will be done in a special plant growth chamber, the Biomass Production Chamber (BPS) that is being built by Orbitec Inc. Photosynthesis and water movement of wheat will be measured for the duration of the experiment. A total of six harvests are anticipated on orbit. Postflight analysis of the tissue for primary photosynthesis parameters, including photosystem I, photosystem II, electron transport, and carbohydrate partitioning, will be made and correlated to in-flight data. These measurements of whole canopy gas exchange in microgravity will be used to understand the effects of microgravity on photosynthesis, to quantify the effects on metabolism, and to model the impact of microgravity on biological approaches to atmospheric regeneration for long-duration space missions.

A number of long-duration preflight experiments were conducted in the BPS during FY 2001, including a 24-day test to evaluate two dwarf wheat cultivars, a 10-day muffler test to evaluate elevated air temperatures, a 50-day Mission Verification Test (MVT) that incorporated all elements of the flight experiment, and intensive training of the ISS Increment IV astronauts. In addition to the experiments in the BPS flight hard-

Biomass Production System (BPS) on the ISS During the PESTO Experiment

Biomass Production System (BPS) PESTO Experiment

ware, experiments were performed to quantify the movement of water in the rooting media and the effects of elevated root zone temperatures on wheat growth and development.

Key accomplishments:

- Completed 24-day test of PESTO experiment protocols in the BPS hardware (December 2000).
- Completed 10-day Acoustic Muffler test in the BPS hardware (March 2001).
- Completed 50-day MVT in the BPS hardware (May 2001).
- Completed training of the ISS Increment IV astronauts.
- Completed seven 24-day experiments using Ground Control Root Modules.
- Published three manuscripts in peer-reviewed journals.
- Published one invited presentation in the Proceedings of International Conference.
- Presented five talks at international scientific meetings.

Key milestones:

- Launch of experiment to the ISS aboard STS-110 (April 2002).
- Complete ground control experiments.
- Present results at international meetings.
- Submit results for publication.

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Participating Organization: Dynamac Corporation (G.W. Stutte and Dr. O.A. Monje)

Effect of Microgravity on Raphanus Sativus L. in Microgravity

The objective of this proposal is to determine the effects of microgravity on the growth and development of radish (Raphanus sativus L.). Salad-type crops that have a short planting-to-harvest cycle may be used to supplement the primary diet of crews on short-to-medium duration space missions. In addition to the life support applications, radish serves as a model system for evaluating the effect of microgravity on carbohydrate partitioning to the root.

A number of experiments were conducted during FY 2001 in order to determine the effects of expected spaceflight conditions on growth and development of radish. These included evaluating effects of carbon dioxide (CO_2) concentrations for 400-to-10,000-part-per-million (ppm) CO_2. These experiments showed that optimum concentration was near 1,500 ppm and that superoptimal concentrations greater than 5,000 ppm resulted in a degree in plant growth. In addition, 7 experiments were completed to determine the effects of temperature on growth and development of 19 radish cultivars.

Leaf Epinasty at High Ethylene Concentrations (0, 300, and 500 ppb)

Radishes were grown at temperatures ranging from 18 to 30 degrees Celsius (°C). The cultivars were classified as intolerant (no radish formation between 18 and 30 °C); low-temperature-tolerant (less than 22 °C), mid-temperature-tolerant (22 to 26 °C), or high-temperature-tolerant (greater than 26 °C). One cultivar from each classification was then selected for experimental testing to obtain more detailed morphological, developmental, and physiological analysis.

Experiments were performed in small, specialized growth chambers to determine the effects of the volatile plant hormone ethylene on plant growth. Cherry Belle radishes were exposed to ethylene concentrations of less than 12, 25, 40, 100, 200, 300, 500, and 1,000 parts per billion (ppb). These results revealed a threshold response at less than 50 ppb, and significant physiological and morphological changes are occurring with chronic exposure to 100-ppm ethylene. A series of experiments was initiated to develop techniques for quantifying the production of volatile organic compounds from these plants.

The Radish Assimilation in Spacecraft Testbed Atmospheres (RASTA) experiment is an International Space Station (ISS) spaceflight experiment scheduled to be conducted no earlier than 2003 in a specialized plant growth chamber, the Plant Growth Facility-Split Plenum (PGF-SP) that is being built by Bionetics Corporation (Kennedy Space Center).

Radishes Growing in Oasis Foam

Key accomplishments:

- Completed experiments to determine effects of superoptimal CO_2 on radish development.
- Completed evaluation of 19 cultivars for high temperature tolerance.
- Completed experiments to determine dose response curve of radish to ethylene.
- Initiated experiments to quantify production of volatile organic compounds from radish.
- Made presentations at five international conferences.
- Published two peer-reviewed manuscripts.

Key milestones:

- Initiate testing of ersatz ISS atmosphere on radish growth.
- Determine developmental effects of starch partitioning in radish.
- Characterize morphological and physiological adaptations to temperature and light stress.
- Begin evaluating experimental protocols in prototype flight hardware.
- Submit three peer-reviewed manuscripts for presentation.
- Present results at international scientific conferences.

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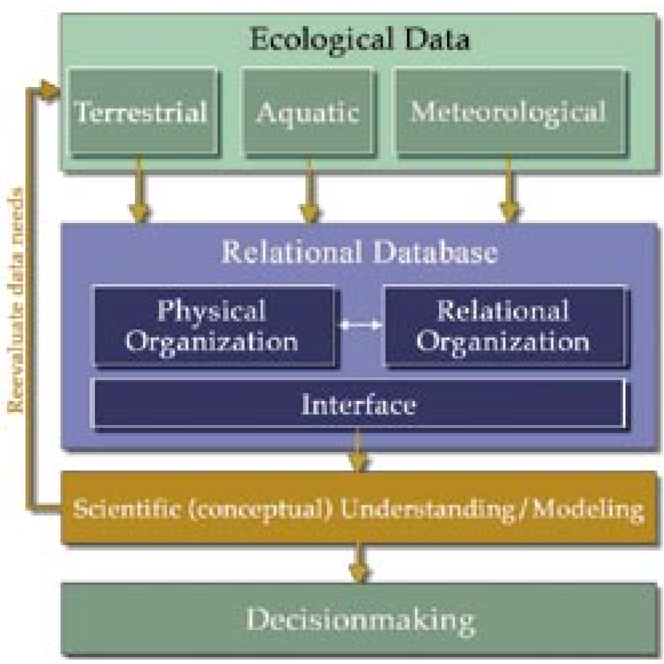
Participating Organization: Dynamac Corporation (G.W. Stutte and Dr. O.A. Monje)

Earth Systems Modeling and Data Management

The Earth Systems Modeling and Data Management Laboratory supports the Life Science Services Contract. A major component of that contract is to utilize emerging technologies permitting data generation and the logical warehousing, analysis, synthesis, and visualization of data that (1) assists in the interpretation of ecological processes and (2) permits a proactive approach to ecological research and environmental management. This endeavor involves development of a diverse set of information tools including rule-based expert systems, numerical models, time series analysis, and fusion of a variety of data collection systems and databases.



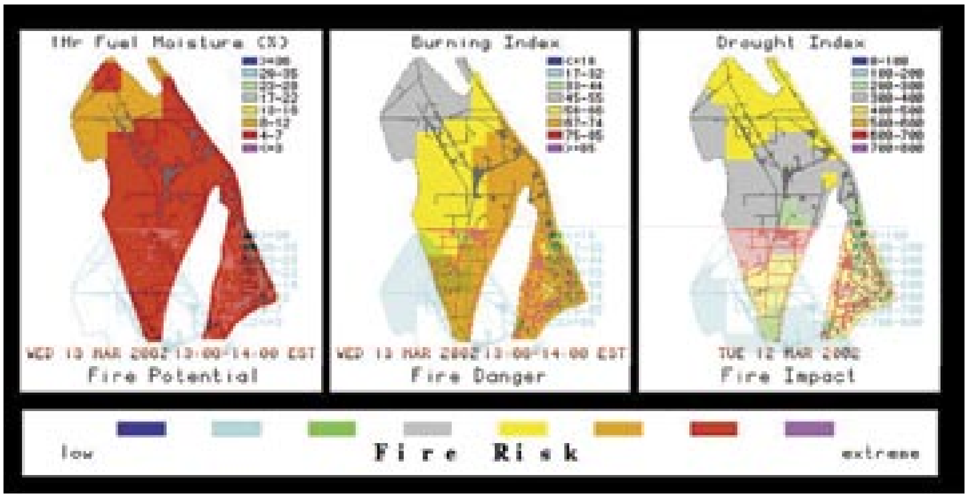
Visualization of Earth Systems Modeling and Data Management Schema

Key priorities as they pertain to environmental initiatives include:

- Provide data and synthesized information to optimize the management of natural resources.
- Develop a conceptual/ mathematical understanding of our complex ecosystem and provide framework needed to continuously reevaluate our data needs.
- Incorporate remote sensing and advanced Geographic Information System (GIS) technology into the decisionmaking process.
- Enhance capabilities to comply with Federal and state environmental regulations.

Major initiatives and activities include:

- Development of geography network to disseminate spatial data and information through the World Wide Web.
- Assessment of wildland fire risk using local meteorological grid as source data. Analysis is fully automated providing hourly updates (24/7) of current situation (*http://dugong.ksc.nasa.gov/fireman/*).
- Acquisition (automated loading in an Oracle relational database) and dissemination (via the Web) of real-time meteorological conditions at KSC (*http://geomod.ksc.nasa.gov/*).
- Development of a hyperspectral database and a Web interface archive and analysis of spectral scans. Hyperspectral data are used to develop methodologies in extracting information on various



Wildland Fire Hazard Analysis

Collection of Downwelling Radiation
(400 to 2,000 Nanometers)
To Correct Imagery for Atmospheric Effects

environmental parameters (e.g., water quality, vegetation classification) from airborne or spaceborne remotely sensed imagery.

- Establishment of the Remote Sensing and Environmental Optics (ReSEO) Laboratory to assist in developing methodologies for estimating various environmental parameters, such as water quality and vegetation characteristics from airborne and satellite-based radiometric imagers.
- Initiating development of a rule-based expert classifier to interpret data fusion of soil/plant associations, radiometric estimates of biomass, and laser-imaged (LIDAR) structural geometry to characterize the natural landscape in relation to wildland fuels and habitats.
- Support of Indian River Lagoon Wetlands Initiative to evaluate management alternatives to local wetlands.
- Development of visualization and dissemination techniques for the Rocket Effluent Exhaust and Dispersion Model (REEDM).

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Participating Organization: Dynamac Corporation (R. Schaub, M. Gimond, and M.J. Provancha)

Thermal Groundwater Remediation Using Dynamic Underground Stripping

At NASA's Launch Complex 34 groundwater cleanup site on Cape Canaveral Air Force Station, a steam flood with coair injection was deployed to remove dense nonaqueous-phase liquid (DNAPL) trichloroethylene (TCE) from the subsurface. A steam flood, which is also referred to as Dynamic Underground Stripping (DUS), is an engineered combination of steam injection and vapor groundwater extraction. Hydrous Pyrolysis/Oxidation (HPO) is a secondary destruction mechanism that accompanies DUS. HPO initiates the destruction of underground contaminants through oxidation in the presence of injected steam. The purpose of the Launch Complex 34 demonstration was to test the effectiveness and evaluate the cost to deploy DUS/HPO with coair injection at a DNAPL-phase TCE-contaminated site.

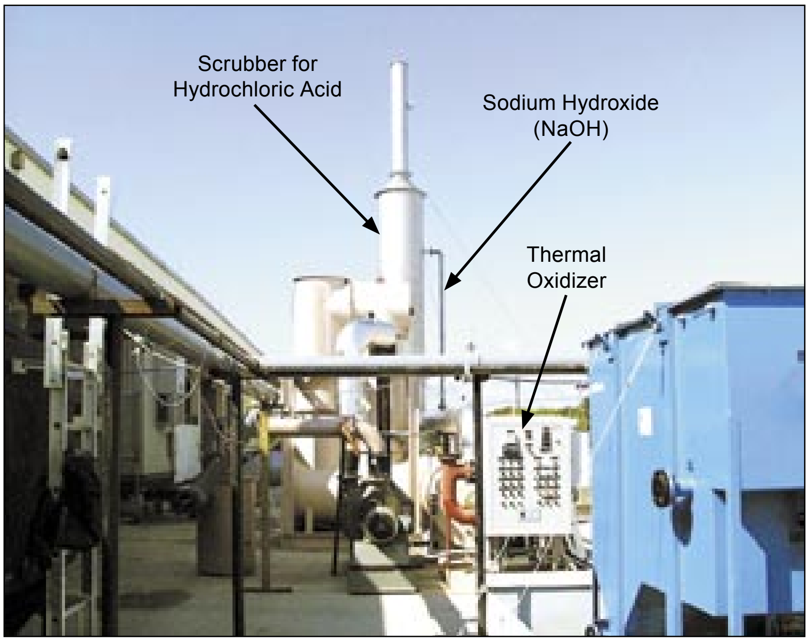
Launch Complex 34's geology consists of several stratigraphic units containing layered, heterogeneous lithology with permeability contrasts of up to two orders of magnitude. The aquifer has three distinct lithologic units for treatment: an Upper Sand Unit (USU), a Middle Fine-Grained Unit (MFGU), and a Lower Sand Unit (LSU). For a 120-day operating period, steam with coinjection of air was deployed at two depth intervals that targeted the USU and LSU within the aquifer. The MFGU was alternatively heated as buoyant steam rose to the surface.

During the deployment, steam was injected in the center of the 50- × 75-foot plot at a maximum rate of 2,000 pounds per hour. Air was coinjected at a rate of 45 standard cubic feet per minute. Groundwater and vapor extraction wells were operated on the edges of the plot throughout the demonstration. Extracted groundwater and vapors laden with heated TCE were treated on the surface using a combination of stripping towers and onsite thermal oxidation units.

This demonstration was the first deployment of DUS with the coinjection of air in the United States. Previously, the use of air with steam injection had only been applied in the Czech Republic and Denmark. Conceptually, the mixture of steam and air produces a more controlled thermal front, with a large volume of air saturated with TCE rising to the surface under buoyancy influences. The controlled thermal front minimizes condensation of the contaminant and creation of nonaqueous-phase liquid on the edges of the heated zone, thereby minimizing the potential for its downward migration.

Key accomplishments:

- 2000: DUS/HPO design completed.
- 2001: DUS/HPO Remediation System constructed onsite. DUS/HPO Remediation System startup.
- Postdemonstration DUS/HPO Remediation System evaluation.



Vapor Treatment System

Key milestone:

- 2002: DUS/HPO Remediation System performance and cost evaluation.

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Participating Organization: Integrated Water Resources (Dr. D. Parkinson)

Dynamic Underground Stripping With Coair Injection

Groundwater Remediation Using In Situ Chemical Oxidation

In situ chemical oxidation using potassium permanganate was chosen as a demonstration technology to treat dense nonaqueous-phase liquid (DNAPL) trichloroethylene (TCE) at NASA's Launch Complex 34 groundwater cleanup site. The site geology consists of several stratigraphic units containing layered, heterogeneous lithology with permeability contrasts of two orders of magnitude. TCE was present before treatment at up to 30,000 milligrams per kilogram in soil and 1,500 milligrams per liter in groundwater. Approximately 6,100 kilograms of TCE were estimated to lie within the 50- × 75-foot demonstration plot. The permanganate injection strategy consisted of direct-push pressure injection (lance permeation). Over 150,000 pounds of permanganate were injected at 2-foot discrete intervals at numerous locations across the demonstration plot in a 3-phase injection program. The total reduction in TCE mass was calculated through collection and analysis of over 192 discrete soil samples. The results indicate an overall reduction of 75 percent using statistical Kreiging analyses.

The injection system was designed to deliver permanganate at precise dosages over 2-foot vertical intervals from the top of the contaminated zone to the base of the demonstration at 45 feet below grade. This design was chosen because the formation permeabilities and contaminant mass distribution varied both laterally and vertically. The permanganate dose and application rate and duration were adjusted at each point to provide the desired loading corresponding to the level of contaminant mass at that location and vertical interval. The demonstration plot was divided into three different lithologic units for treatment: an Upper Sand Unit (USU), a Middle Fine-Grained Unit (MFGU), and a Lower Sand Unit (LSU). The MFGU and LSU contained a high proportion of silt, clay, and shell lenses. Nineteen separate injection rods and injection tips were driven to the desired depths by a direct push rig. The injection tip consisted of a customized Geoprobe open 9-interval, 360-degree circumference, hole-perforated drive stem located between 2 wider sections that functioned as packers. The perforated drive probe had 0.25-inch perforations and a 0.010-inch-slot continuous wire-wound stainless-steel screen.

The permanganate delivery system consisted of an onsite continuous-mix, automated-feed system developed by the permanganate supplier, Carus Chemical Company. Combining the dry, free-flowing potassium permanganate solid with hydrant water mixed the permanganate solution to an injection concentration range of 0.2 to 3.0 percent. The permanganate treatment was conducted in phases so that the interim results obtained could be used to focus subsequent injections.

In Situ Chemical Oxidation: Original Configuration

Key accomplishments:

- April 2000: Field-scale deployment complete.
- June 2000: Postdemonstration data collection.
- 2001: 9-month postdemonstration data collection.

Key milestone:

- 2002: Data evaluation and comparison to other DNAPL cleanup technologies.

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Participating Organization: IT Corporation (W. Leonard and E. Mott-Smith)

Thermal Groundwater Remediation Using Six-Phase Heating

A demonstration of Six-Phase Heating (SPH) was conducted at NASA's Launch Complex 34 groundwater cleanup site on Cape Canaveral Air Force Station. The site geology consists of several stratigraphic units containing layered, heterogeneous lithology with permeability contrasts of two orders of magnitude. The purpose of the demonstration was to test the effectiveness of SPH at remediating trichloroethylene (TCE) as a dense nonaqueous-phase liquid (DNAPL).

SPH passes an electrical current through the soil and groundwater that require treatment. The electrical current warms the soil and then boils a portion of the soil moisture (typically 10 to 20 percent by volume) into steam. This in situ steam generation occurs in all soil types, regardless of permeability. Electricity evaporates the target contaminant and provides steam as a carrier gas to sweep the volatile organic compounds (VOC's) to recovery wells. After the steam is condensed and the extracted air is cooled to ambient conditions, the vapors are treated using conventional vapor treatment methods. Because in situ steam generation is governed by the passage of electrical current (not the fluid flow within the soil matrix), SPH remediation is not significantly affected by low-permeability or heterogeneous soils.

The SPH design employed at Launch Complex 34 included preferentially heating the deep sections of the site's aquifer and then sweeping TCE upward into the vadose zone for extraction and treatment on the surface using granular activated carbon (GAC). This process worked effectively at the site until two intense storms virtually eliminated the vadose zone (more than 4 feet of vadose zone lost to rainwater infiltration) where TCE extraction was occurring.

After several system shutdowns, the system did run continuously for several months, removing 90 percent of the TCE from the demonstration plot.

Key accomplishments:

- 2000: Field-deployed SPH.
- 2001: Collected postdemonstration performance data.

Key milestone:

- 2002: Cost and performance data evaluation.

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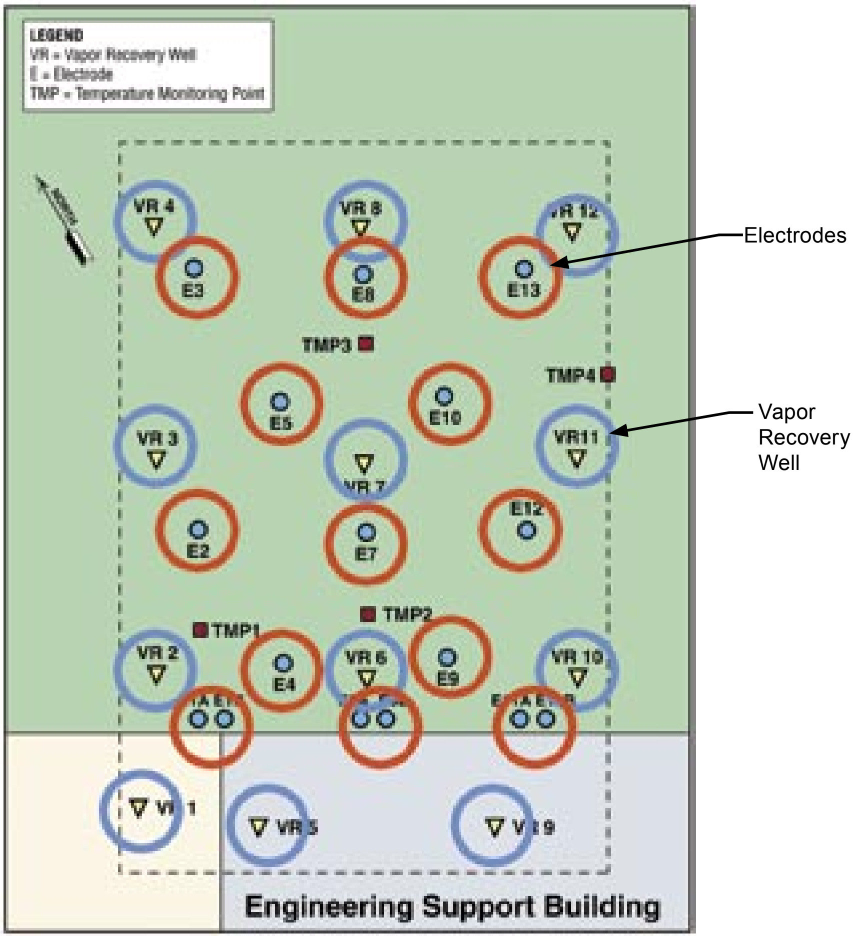
Participating Organizations: Thermal Remediation Services (G. Beyke) and Current Environmental Solutions (B. Heath)

Launch Complex 34 SPH Demonstration Site



Six-Phase Heating Cell

Bioaugmentation for Groundwater Remediation

GeoSyntec, working with the University of Toronto (U of T), has isolated a stable, natural microbial consortia (referred to as KB-1) capable of stimulating rapid dechlorination of trichloroethylene (TCE) to ethene at groundwater contamination sites where this activity is otherwise deficient. Figure 1 shows the performance of KB-1 added to microcosms in which TCE dechlorination had stalled at cis-1,2-dichloroethylene (DCE), despite continued electron donor addition. Bioaugmentation of these microcosms with KB-1 (also referred to as dehalococcoides ethenogenes) immediately stimulated dechlorination of cis-1,2-DCE via vinyl chloride (VC) to ethene; cis-1,2-DCE was completely transformed to ethene in a matter of days. Development of these and similar microbial cultures now provides the ability to accelerate bioremediation of TCE and related chlorinated solvents at sites where complete dechlorination reactions do not otherwise occur. Furthermore, studies using KB-1 indicate that this culture can dechlorinate very high concentrations of TCE (in excess of 100 milligrams per liter [mg/L]) and its daughter products, suggesting that containment and/or treatment of source areas may be possible via bioaugmentation.

The initial phase of this project involved evaluating biodegradation of TCE at progressively higher concentrations, with the objective to demonstrate dechlorination at and above saturation concentrations (i.e.,

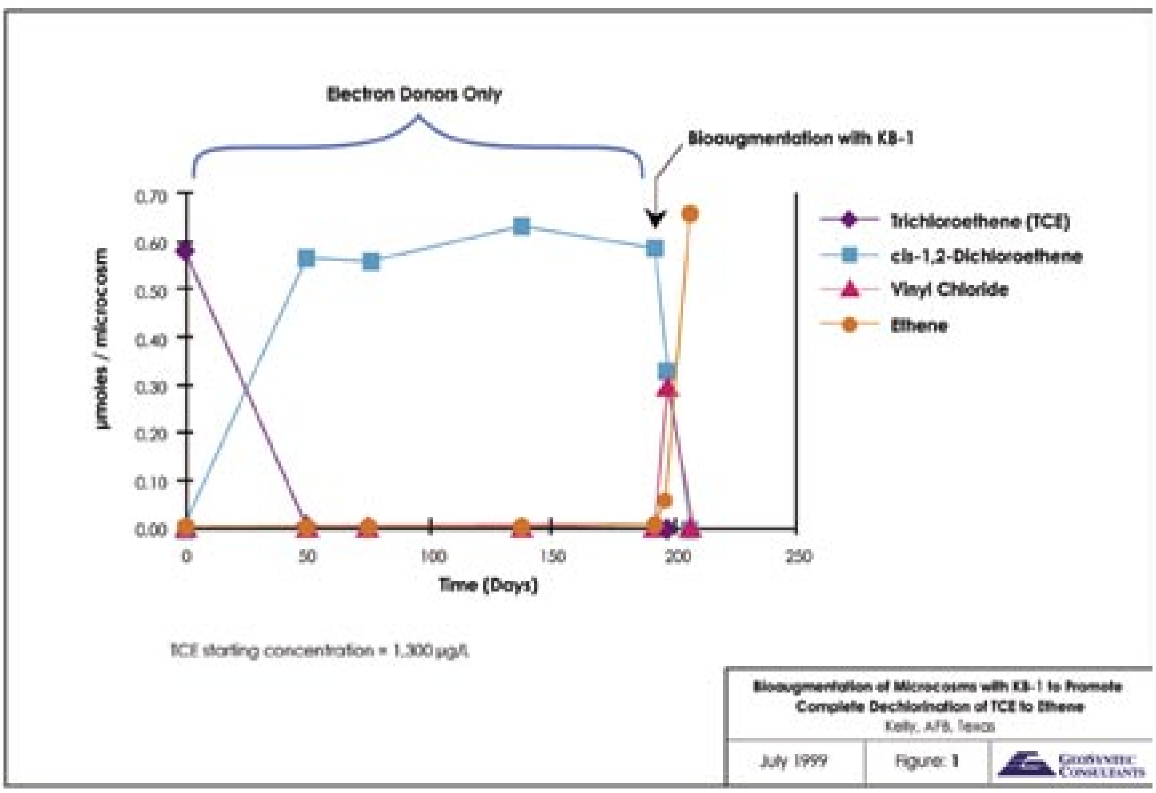


Figure 1. KB-1 Performance

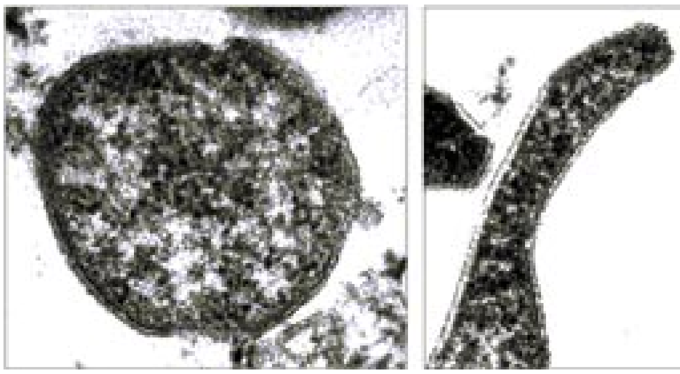


Figure 2. Dehalococcoides Ethenogenes
(Thin-section electron micrographs showing coccoid and elongated cells, courtesy of Steve Zinder, Cornell University)

in the presence of a dense nonaqueous-phase liquid [DNAPL]). Various dechlorinating consortia were used for these experiments. Batch incubations were carried out to determine dechlorination rates at various chloroethene concentrations. Perchloroethylene (PCE) was dechlorinated up to its aqueous saturation limit. The results of the experiments indicate that the cultures can dechlorinate chlorinated ethenes at dissolved concentrations typically associated with their presence as DNAPL's (i.e., hundreds of milligrams per liter). The cultures can convert 50 mg/L of PCE rapidly through TCE to DCE within 16 days, and all cultures could dechlorinate TCE up to 200 mg/L. The results of the laboratory studies indicated that the cultures would function in the DNAPL source zones and thus improve the dissolution rate and provide biological containment of DNAPL sources.

The primary objective of the second phase of this project is to enhance the dissolution of a DNAPL source via enhanced biological activities (i.e., electron donor amendment and bioaugmentation). In demonstrating this, we will show that controlled stimulation of microorganisms can be an effective means of containing the source area by rapidly degrading the highly concentrated dissolved phase emanating from DNAPL source area and/or enhancing the flux of dissolved DNAPL to reduce cleanup time by removing the DNAPL free-phase.

The study approach will consist of a field trial at NASA's Launch Complex 34 on Cape Canaveral Air Force Station to demonstrate that there is a significant increase in the extent of dechlorination and the mass flux from a source zone when biological dehalorespiration activity is enhanced through nutrient addition and bioaugmentation. Predesign laboratory batch and column studies will be conducted to establish key design parameters for the pilot-scale field demonstration.

Key accomplishments:

- Laboratory testing of biological culture on DNAPL source zone.
- Field-scale design submission and approval by state and Federal regulators.
- Field-scale implementation of a bioaugmentation remedial action at a trichloroethylene DNAPL site.

Key milestones:

- 2001: Completed laboratory testing of biological culture on TCE DNAPL source contamination.
- 2002: Design approval by state and Federal regulators and initiate field-scale deployment of bioaugmention.
- 2003: Review data after steady-state conditions reached in the field.

Contact: Dr. J.W. Quinn (Jacqueline.Quinn-1@ksc.nasa.gov), YA-C3-C, (321) 867-8410

Participating Organization: GeoSyntec Consultants (Dr. D. Major and Dr. E. Hood)

Groundwater Remediation Using Emulsified Zero-Valent Iron (EZVI)

Groundwater cleanup research conducted at the University of Central Florida and at NASA's Launch Complex 34 on Cape Canaveral Air Force Station is demonstrating the feasibility of using emulsions containing iron particles to expedite dehalogenation of dense nonaqueous-phase liquids (DNAPL's). The emulsion consists of a surfactant-stabilized, biodegradable oil-in-water emulsion with nanoscale or microscale iron particles contained within the emulsion droplets. It has been demonstrated that trichloroethylene (TCE) diffuses through the oil membrane of the emulsion particle, whereupon it reaches the surface of an iron particle and dehalogenation takes place. The reaction by-products of the dehalogenation reaction, primarily ethene (low level of chlorinated products detected only after using ultrasound to burst the droplets), diffuse out of the emulsion droplet. Laboratory studies have demonstrated this type of emulsion system could be injected into the ground where DNAPL contamination exists. Using this system, liquid TCE is degraded at a rate comparable to the degradation of dissolved-phase TCE by iron particles, while pure iron has a very low degradation rate for free-phase TCE. In laboratory studies, the iron-emulsion systems were injected into a soil matrix, where they became immobilized and were not moved by flowing water. This study showed that surfactant micelles possess the ability to pull pooled TCE into emulsion droplets where degradation of TCE takes place.

Key accomplishments:

- Testing of various emulsion possibilities.
- Optimization of emulsion mixture for TCE treatment.
- Testing of nanoscale and microscale iron emulsions.
- Column studies of nanoscale iron emulsions.

Key milestones:

- 2001: Laboratory development of emulsified zero-valent iron completed.
- 2002: Laboratory column tests completed. EZVI injected into the subsurface at Launch Complex 34, Cape Canaveral Air Force Station in July.

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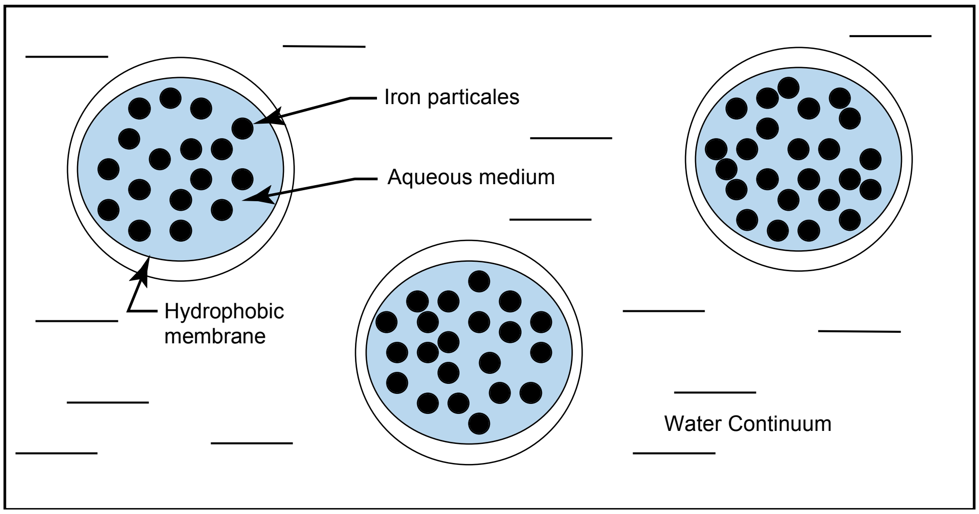
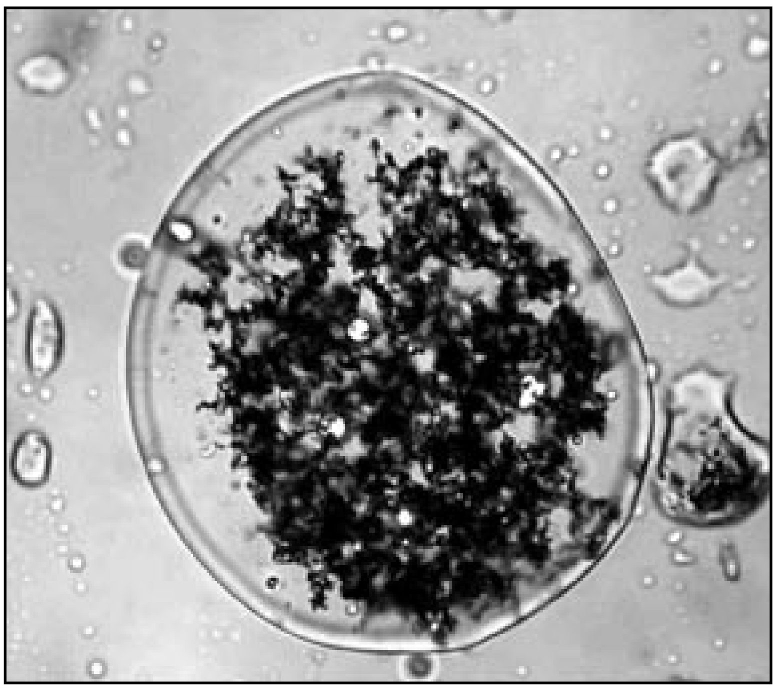
Participating Organization: University of Central Florida (C. Clausen, C. Geiger, and D. Reinhart)



Nanoscale Iron Particles Contained in Emulsion Droplet



Micrograph of Nano-Iron Emulsion

Advanced Life Support (ALS) Project: Food and Crop Systems

This task agreement provides for testing of candidate crops under controlled environments and developing crop production technologies applicable to Advanced Life Support Systems. FY 2002 will include testing alternative lighting sources and systems with candidate salad crops, developing and testing hydroponic trays and crop supports for baseline tests, and monitoring root zone microbial communities throughout growth and development of salad crops for International Space Station and future testbeds. This task also provides for computational and laboratory support and development and testing engineering components of bioregenerative technologies for ALS, plant growth chambers, control systems, and databases.

The primary objectives of this task are to define the environmental conditions and horticultural methodologies to optimize both edible biomass production and life support functionality in candidate crop species and assess how they interact with overall system efficiency. Environmental conditions include carbon dioxide (CO_2) concentration, light quantity and quality, temperature, relative humidity, and nutrient media elemental concentrations. An important consideration of this task involves the screening of different cultivars of candidate crops and the compilation of all crop growth data for inclusion in a crop handbook. This effort will use a standardized testing procedure for all candidate crop species selected from the Crop Selection Meeting held at KSC in May 1997. Development of crop management strategies for reuse of nutrient solutions with a special emphasis on biologically active organic materials that may accumulate in the nutrient solution is being addressed. This task includes coordination of NASA-supported tasks at the New Jersey NASA-Specialized Center of Research and Training (NJNSCORT) for tomato and salad crops, at Tuskegee University for peanut and sweet potato, and at Utah State University for wheat, soybean, and rice. Other significant collaborations include Cornell University for dry and snap bean research and Texas Tech University for onion research.

The development of a bioregenerative life support system requires that the horticultural methodologies and the range of suitable environmental conditions for various candidate crops be well understood. This is an integrated activity requiring coordination with several research organizations and ongoing ALS tasks in order to maximize the benefit to the ALS program.

The candidate crop research and technology conducted at KSC during 2001 included:

Onion Cv. Kinka Grown for 42 Days

Radish Cv. Cherry Bomb II Grown for 21 Days

- Beans: Performed tests in collaboration with Cornell University to determine the growth and yield characteristics of both dry beans (cv. Etna) and snap beans (cv. Hystyle) at varying levels of CO_2.
- Lettuce and Radish: Performed tests to evaluate the growth and yield characteristics of both lettuce (cv. Waldmann's Green) and radish (cv. Giant White Globe) at superelevated CO_2 levels.
- Lettuce: Conducted tests to determine the effects of narrow-band spectral radiation provided by light-emitting diodes (LED's) on the growth and yield of lettuce in collaboration with the ALS lighting task, KSC Center Director's Discretionary Fund (CDDF), Cornell University, and a NASA Research Announcement (NRA) grant.
- Radish: Performed evaluations of growth and yield characteristics of eight varieties of radish under high-pressure sodium (HPS) lamps.
- Potato: Conducted tests to determine nutrient management approaches for reducing vegetative growth of potato crops.
- Lettuce: Conducted tests in collaboration with the resource recovery/water recovery task to determine the effect of reuse of inorganic nutrients recovered from fixed-film bioreactors.

Key accomplishments:

- 2000: Completed experiments investigating the effects of superelevated CO_2 up to 16,000 parts per million on the growth, yield, and stomatal functioning of two cultivars of beans. Completed experiments investigating the effects of narrowband spectral radiation provided by LED's on the growth and yield of spinach and radish.
- 2001: Completed experiments investigating the effects of superelevated CO_2 up to 15,000 parts per million on growth, yield, and stomatal functioning of lettuce and radish. Completed experiments evaluating eight radish cultivars under HPS lamps. Published four peer-reviewed articles and three book chapters. Completed a Ph.D. dissertation as part of a NASA graduate fellowship project.

Key milestones:

- First edition of the crop handbook for ALS candidate crops.
- Complete cultivar trial and baseline testing with radish.
- Begin cultivar trial and baseline testing with onion (collaborations with Texas Tech).
- Track root zone microflora of salad crops.
- Prepare and coordinate ALS planning workshop projecting research goals for next 5 years.

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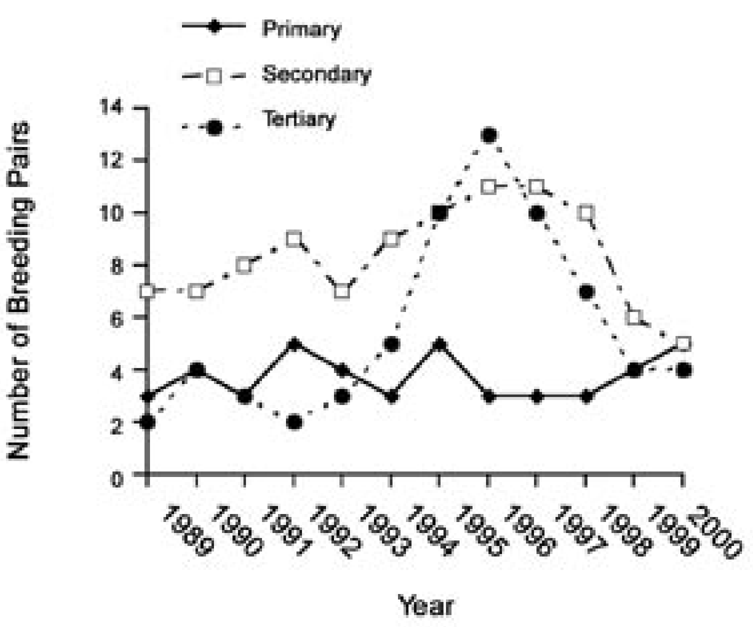
Participating Organizations: Dynamac Corporation (Dr. G.W. Stutte and N.C. Yorio), Utah State University (Dr. B. Bugbee), Cornell University (Dr. D. DeVilliers, Dr. C.F. Johnson, and Dr. R.L. Langhans), Rutgers University (Dr. H. Janes), Tuskegee University (Dr. D. Mortley), and Texas Tech University (Dr. E. Peffley)

Florida Scrub-Jay Habitat and Population Studies

The uplands of KSC and the adjacent Cape Canaveral provide one of the four largest populations of the threatened Florida scrub-jay species. This is an indicator of scrub ecosystem integrity. Space program construction projects and operations directly influence the habitat and its management. Although it is possible to estimate annual changes in population size, these estimates produce confidence limits that are too great to describe annual variation that is influenced by stochastic natural processes (rainfall) and deterministic factors (changes in habitat quality). Censusing the entire population to detect annual trends is not feasible, but it is possible to quantify habitat quality of the entire area and to predict population trends based on habitat-specific demography and dispersal relationships developed from samples of the landscape. Understanding these habitat-specific relationships also allows the formulation of KSC impact evaluation, minimization, and compensation techniques, as well as recovery actions used across the species range.



This figure shows population changes among potential habitats from 1989 to 2000 near Tel-4 at Cape Canaveral Air Force Station. Study years begin on April 1 and end on March 31. The number of breeding pairs remained stable in primary habitat and fluctuated most in tertiary habitat because of a flux of immigrants in 1995. Density-dependent reductions in demographic success associated with crowding effects greatly reduced population size following this event. Extensive wildfires in 1998 also reduced habitat suitability for the short term but increased habitat suitability across the long term. Reproductive success and survival improved greatly in 1999 and 2000 as population density declined and scrub oaks recovered from fire.

Testing ecological theories facilitates model construction to extrapolate data from the uniquely colorbanded birds at the territory scale (8 hectares [ha]) and apply it to the scale of the larger population. Habitat potential of scrub-jay territories is ranked into three classes of scrub oak cover (primary, secondary, and tertiary) that result from variation in soils and topography. Territory quality also varies with fire history categorized by four classes of shrub height arrangement: all short (less than 1.2 meters), short and optimal mix (1.2 to 1.7 meters), tall mixed, and all tall (greater than 1.7 meters). Sequences of aerial photography are evaluated to quantify annual changes in territory quality using Markov Chain models that describe different habitat management scenarios. Territories on primary and secondary ridges are usually population sources, provided they have a mixture of short and optimal scrub and no tall scrub. Population sources have reproductive success that exceeds mortality and have emigration that exceeds immigration, making them net exporters of individuals to populations sinks. Territories on tertiary ridges and territories with all short, tall mix, or all tall scrub are population sinks because mortality exceeds reproductive success. Territories in many areas are becoming unoccupied because habitat is of poor quality and there are too few immigrants to sustain them. Thus, improving habitat quality provides a mechanism to compensate for habitat losses associated with facility construction. However, Florida scrub-jays have short dispersal distances and a reluctance to colonize vacant territories, so sociobiology must be considered to allocate habitat management in an optimal geographical context. These calculations are complex and best performed using a spatially explicit, individual-based population model, which is being linked to a landscape change model. These studies were published in a dozen scientific journal articles. Future field studies will continue demographic monitoring and quantify how habitat quality, population density, and distance to vacant territories influence dispersal.

Key accomplishments:

- 1991: Developed habitat maps of the most important areas on KSC.
- 1992: Developed a scrub restoration and monitoring program.
- 1995: Developed techniques to map habitat suitability.
- 1996: Developed models to predict demographic success using maps.
- 1997: Tested the ability of maps and models to predict populations.
- 1998: Developed procedures to include uncertainty into decisionmaking.
- 2000: Developed procedures to project landscape changes.
- 2001: Developed an approach to link habitat and population dynamics.

Key milestones:

- 1995: Summarized population and habitat status trends.
- 1996: Developed scrub-jay population recovery strategy. Published habitat analyses procedures.
- 1999: Published population risk modeling procedures.
- 2001: Expanded studies to investigate larger-scale population processes.

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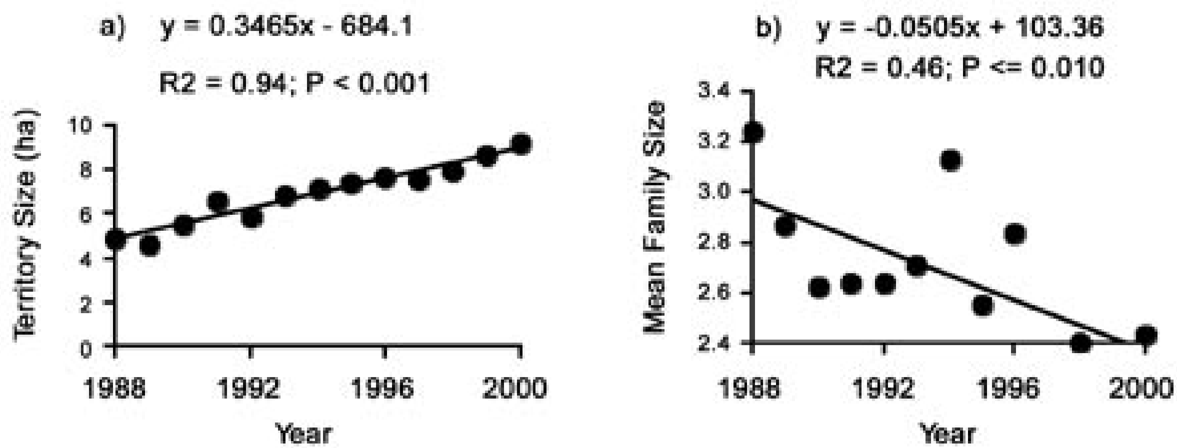

These graphs demonstrate population changes at Happy Creek from 1988 to 2000. The overall population has been declining because mortality exceeds reproductive success in most territories that either have too much tall scrub or too little scrub at optimal height. Increasing territory size and decreasing family size represent the decline. Florida scrub-jays have a cooperative breeding system in which the young remain with their parents for several years if nearby breeding vacancies are saturated. These nonbreeders help their parents spot predators and feed future generations of young. Total population size is subject to stochastic environmental variation that influences mean family size. Actual breeding pair densities (represented by territory size) are most influenced by deterministic factors, such as habitat quality, but these are evident only after many years of investigation. More severe population declines are masked by immigration that occurs because Happy Creek is of better habitat quality than many areas that surround it. These patterns can only be recognized because individuals are uniquely colorbanded.

Remote Video Monitoring of Florida Scrub-Jay Nests

One objective of ongoing demographic studies of Florida scrub-jays (*Aphelocoma coerulescens*) on KSC is to identify principal predators of eggs and nestlings. Studies have shown that failure of scrub-jay nests can be particularly high in degraded, overgrown scrub. On KSC and in scrub habitat throughout the state, fire suppression has degraded scrub-jay habitat. A previous study of an inland population of scrub-jays revealed that diurnal snakes and birds were the principal predators of scrub-jay nests. However, the scrub habitat on KSC differs from inland scrub in several respects, and nest predation may differ as well.

This study utilizes a relatively new technique – remote video monitoring. A small camera is concealed in vegetation near the nest. The camera operates in both visual and infrared wavelengths for 24-hour monitoring. The camera is connected to a time-lapse videocassette recorder by a 75-meter cable so that observer activity (i.e., changing video tapes) does not disturb the birds. Time-lapse videos are recorded at × 6 real time to allow a full day of recording to fit on a single VHS tape. Video monitoring is an effective way to study nest predation because it allows for identification of predator to species and for observation of behavioral patterns of the nesting species.

Preliminary results of this study implicate the yellow rat snake (*Elapheobsoleta quadrivittata*) as an important predator of scrub-jay nests on KSC. Unlike the inland study mentioned earlier, predation events typically occurred at night. Continuing studies may modify these results. Other observed predators include black racer (*Coluber constrictor*), corn snake (*Elaphe guttata*), and spotted skunk (*Spilogale putoris*). Also, all observed predations were successful (i.e., predator was not repelled by adults).

Female nest activity was also examined by comparing the frequency of leaving and arriving at the nest. Activity around the nest may attract predators, and activity levels may vary from nest to nest depending on habitat features or individual behavior. Preliminary results indicate that nest activity is similar during egg and nestling stages of the nesting cycle (figure 1). However, activity levels do appear to have a diurnal pattern (figure 2) that is probably related to ambient temperature (figure 3). Activity is lower during hot midday hours.

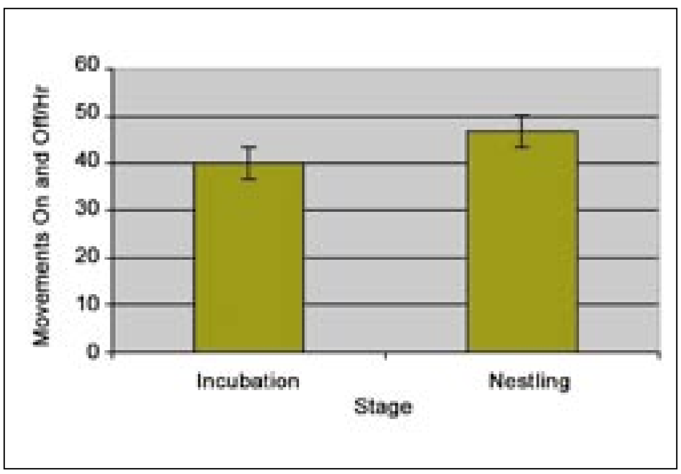

Figure 1. Female Nest Activity During Incubation and Nestling Stage (Mean female nest activity rate [frequency of movements on and off the nest per hour] during egg and nestling stages of nesting cycle; n=6; error bars are ± 1 standard deviation.)

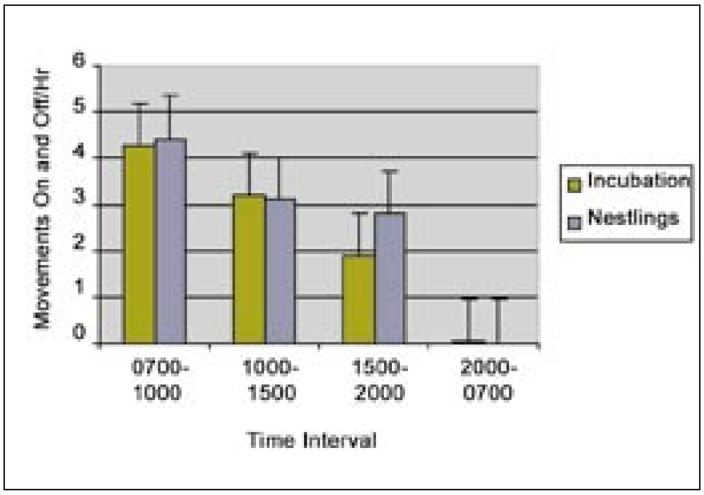

Figure 2. Female Nest Activity Rate (Mean female nest activity [frequency of movements on and off the nest per hour] during 4 time intervals of a 24-hour period beginning at 0700 hours; n=11; error bars are 1 standard deviation.)

This project is ongoing and will continue for at least one more breeding season. The data gathered during this study will be helpful in ascertaining the predator regime of Florida scrub-jay eggs and nestlings on KSC. Preliminary results have already contradicted previous knowledge.

Key accomplishments:

- Captured over 4,800 hours of video footage from 14 scrub-jay nests.
- Documented 10 predation events.

Key milestone:

- Continue to monitor nest predation, ascertaining the predator regime of Florida scrub-jay eggs and nestlings on KSC.

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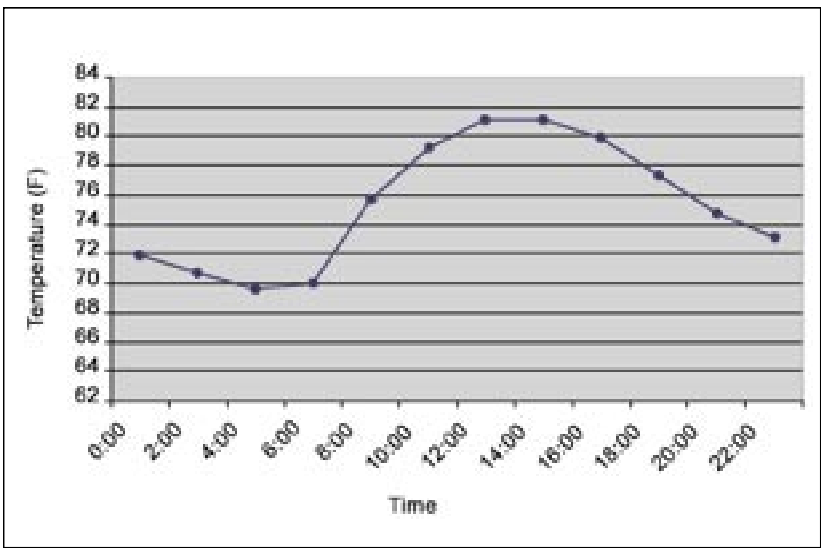


Figure 3. Daily Fluctuation of Mean Air Temperature in May on KSC

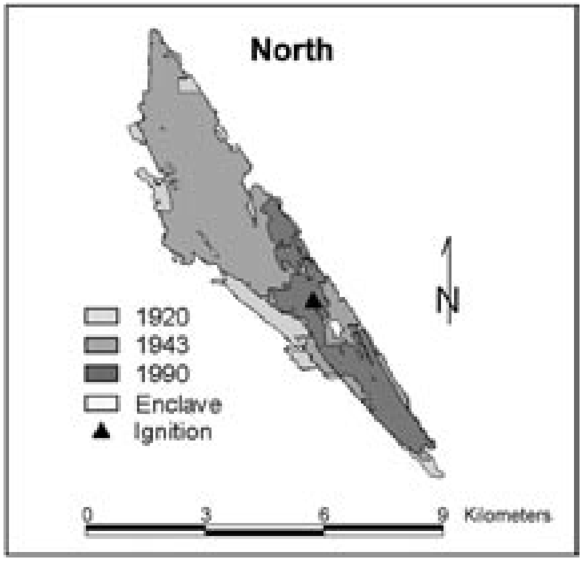
Land Use History and Anthropogenic Influences on Natural Fire Regime

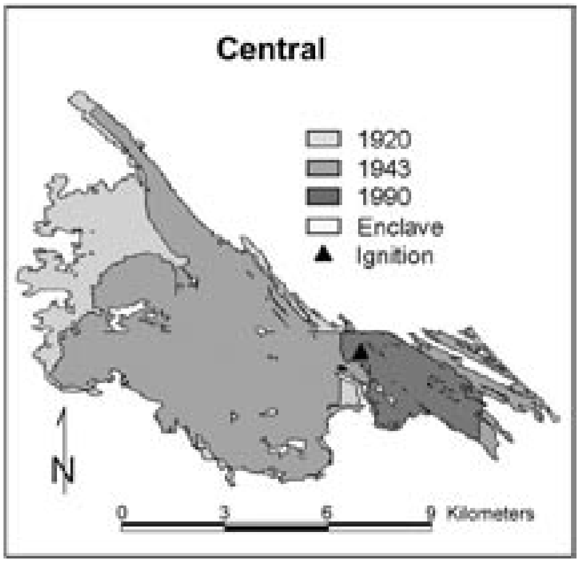
Scrub communities in Florida are well adapted to fire and other natural disturbances. Historically, in an undisturbed environment, frequent lightning ignitions maintained natural scrub in a low, open stature. European settlement brought open range management for ranching and scrub clearing for citrus groves. Fires were used annually to encourage herbaceous growth and improve range for cattle. Open range management continued in Brevard County until 1925 and in Volusia County until 1947 when cattle had to be fenced in and fires were restricted to ranchers' property. Fire was viewed as a threat to timber resources, which led timber industries to propose wildland fire suppression in the early 1940's. Organized wildland fire suppression in Brevard County began in the 1950's.

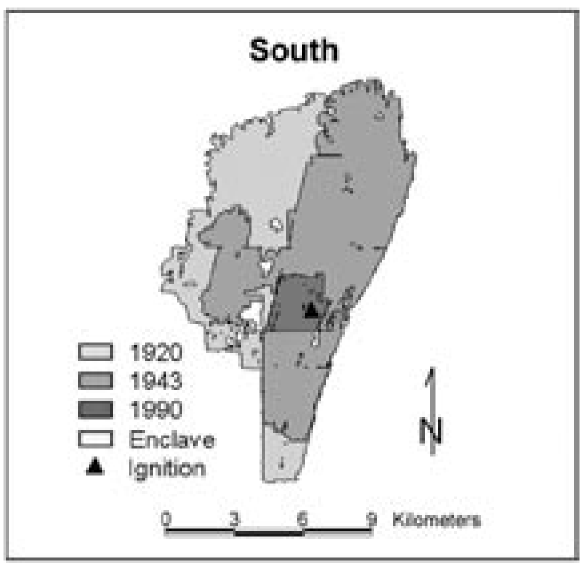
NASA began acquiring land in early 1962 on north Merritt Island, along the east coast of Central Florida. KSC is now the largest undeveloped land holding on the east coast of Florida. After NASA acquired the land, fire suppression remained in effect on KSC until 1981, when catastrophic wildfires became a safety and operations problem. The first fire management plan was developed in 1981 to reduce dangerous fuel levels and prevent future fuel buildup on KSC. The realization that scrub communities were becoming degraded and concern for wildlife species led to fire being used as a tool for restoring and maintaining scrub on KSC.

Restoring fire to the pyrogenic communities of KSC is very important for maintenance of natural biophysical processes and overall health of the region. To understand the effects of anthropogenic change on spatial fire behavior, we modeled historic and current fire spread across KSC. During the modeling, we held all variables constant with the exception of fuels, which represented different time periods. This approach isolated the differences between natural and anthropogenic fuel conditions, providing valuable perspective on baseline burning conditions for land managers.

The results show that anthropogenic influences have affected scrub and flatwoods fuel continuities and flammability, causing a reduction in fire extent (see the figure). The simulations show that in 1920 fires would burn until the fuels were exhausted or meteorologic conditions became unfavorable. In 1943, fires began to be confined by anthropogenic features on the landscape and were even more restricted by these features in 1990. Fragmentation, however, is not the only anthropogenic obstacle for fire. Past fire suppression policies altered land cover and, hence, fuels in several ways. The absence of fire in this fire-maintained ecosystem has allowed scrub to grow to unnatural heights, excluding fire in all but the most extreme meteorologic conditions. Exotic and hardwood species invasion of swale marshes has increased with fire suppression policies, reducing flammability across the KSC landscape.







Extent of Simulated Fires for 1920, 1943, and 1990 by KSC Region

The ignition locations are indicated for the Northern, Central, and Southern regions.

The results presented here help to quantify anthropogenic effects on fire behavior. The fires simulated on the relatively natural 1920 landscape burned freely until fuels or meteorologic condition became unfavorable. The 1943 and 1990 simulations show that fires have become much less governed by natural variables, such as fuels and meteorological conditions, but rather by human-imposed barriers, even in the absence of active fire suppression.

Key accomplishments:

- 1997: Developed study to investigate spatial historic land cover trends on KSC.
- 1998: Developed and applied method for mapping 1943 land cover for Indian River Lagoon watershed.
- 1999: Developed and applied method to model 1920 land cover pattern for Indian River Lagoon watershed.
- 2001: Developed historic fuel models for KSC.

Key milestones:

- 1999: Published study investigating historic land management and land cover trends.
- 2000: Published paper on modeling spatial reference conditions for southeast landscapes.
- 2001: Developed modeling framework for quantifying historic fire patterns.

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Participating Organization: Dynamac Corporation (B.W. Duncan)

Spatial Rainfall Monitoring and Analysis at KSC and CCAFS From 1989 to 2000

NASA and various agencies have monitored rainfall at KSC since 1983 to evaluate long-term trends in precipitation, deposition, weather forecasting, and tropical storms. These sites have been operated and maintained by:

- NASA Goddard Space Flight Center since 1988 (Tropical Rainfall Measuring Mission).
- Dynamac Corporation since 1983 (as part of the National Atmospheric Deposition Program and an area just south of Launch Pad 39A).
- NASA Weather Office since 1982 (a site at the Shuttle Landing Facility).

KSC is located on the Merritt Island National Wildlife Refuge (MINWR) on north Merritt Island, Florida, and Cape Canaveral Air Force Station (CCAFS) is located to the east of MINWR. The 10-year mean spatial rainfall pattern at KSC and CCAFS (total area including lagoonal waters of this barrier island complex) from 1989 to 1995 and from 1998 to 2000 is 631.3 square kilometers. Cape Canaveral and Merritt Island are recently-formed dune systems, and the Banana and Indian Rivers are submerged terraces inundated by brackish water. The physical influences that shaped the present topography of Cape Canaveral and Merritt Island include the longshore current, the onshore/offshore breezes, and natural land-building processes.

The spatial rainfall patterns on KSC are important for a variety of reasons. The lagoonal volumes are controlled by direct precipitation on their surfaces plus runoff and surface input from point and nonpoint source discharges, plus or minus groundwater seepage, minus evapotranspiration, plus or minus flow through Haulover Canal, plus or minus tidal exchanges with the Atlantic Ocean. The rainfall patterns will have to be considered in the further growth on KSC for roads and facility siting criteria and runoff patterns of the major watersheds. This could impact the outfall of stormwater runoff to the Banana River, Indian River, and Mosquito Lagoon, which border the east, west, and north of KSC. This freshwater could impact the salinity and nutrient levels of the rivers, which could influence the sea grass distributions. This could impact the fish nurseries and the feeding grounds of the endangered manatees. The rainfall patterns on the land could also affect the primary production of biomass and food for other endangered species (Florida scrub-jay and indigo snake). Another effect could be on the fine-fuel moistures on the various prescribed burn units for any given year, which might hinder the necessary burn cycles for proper habitat maintenance.

Key accomplishments:

- 2001: Draft paper written, spatial analysis completed using ArcView Spatial Analyst. Paper being edited for submission to *Journal of Climate* after internal review.

Key milestones:

- 2000: Performed data analysis, estimated missing data, and produced spatial maps using ArcView Spatial Analyst.
- 2001: Reviewed literature, wrote and started editing draft paper, and selected journal for submission.
- 2002: Finish editing, submit for internal review, and submit for publication in *Journal of Climate*. Begin work on second paper on non-normal rain years (extremely wet or dry).

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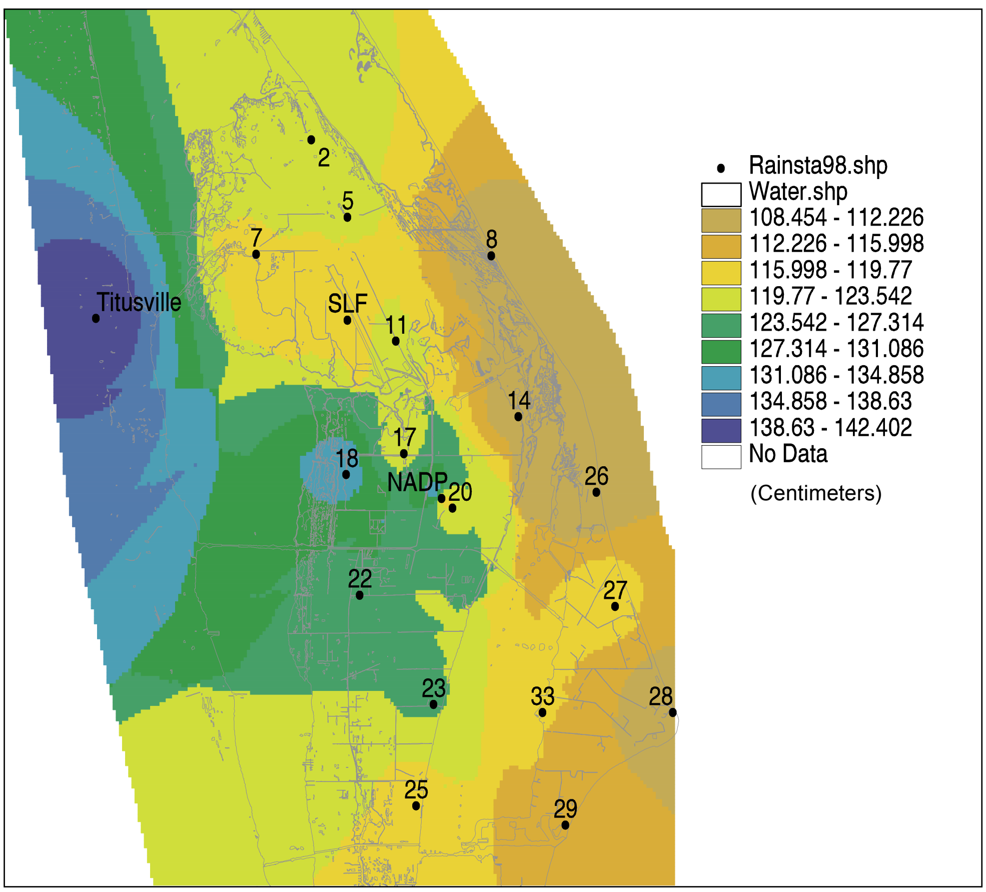

Mean Spatial Rainfall Pattern at KSC and CCAFS 1989 to 1995 and From 1998 to 2000

Scrub Restoration on Kennedy Space Center

KSC and Merritt Island National Wildlife Refuge (MINWR) have collaborated on scrub restoration and monitoring since 1992. Scrub restoration is directed towards improving habitat conditions for the Florida scrub-jay. KSC/MINWR supports a core scrub-jay population important to the species survival. Fire suppression (1962-1981) and landscape fragmentation allowed some scrub to reach size structure that was fire-resistant under prescribed burning conditions. Unburned scrub becomes unsuitable as scrub-jay habitat, and demographic success declines even if the habitat is still occupied.

Areas that had the potential to be optimal habitat but could not be restored by prescribed burning alone were selected for restoration. Mechanical treatment combined with prescribed burning was used to restore vegetation structure that could then be maintained by prescribed burning. Mechanical equipment and techniques used include Brown tree cutter, V-blade, K-G blade, Kendall tree cutter, and roller-chopper. Sites were burned within about 6 months of cutting. Vegetation was monitored using permanent 15-meter transects established before treatment and sampled periodically after cutting and burning. The responses of scrub vegetation to mechanical treatment and burning were compared to burning only using data from transects in scrub in Happy Creek that burned in 1986 and were sampled at least annually thereafter. Data shown here are illustrative of a large amount of data from numerous sites.

Scrub height in restoration stands in Happy Creek (Stand 3, $N = 5$; Stand 5, $N = 7$) and Shiloh (Stand 1, $N = 10$; Stand 6, $N = 10$) exceeded considerably the height of periodically burned scrub before treatment. Height growth of cut and burned scrub equaled or exceeded (sometimes by 50 percent or more) that of scrub burned without mechanical treatment (figures 1a and 1b). Regrowth of oaks and ericads was similar between cut/burned and burned-only stands. Mechanical treatment reduced saw palmetto cover (figures 1c and 1d). In burned stands, saw palmetto cover returned to preburn values within 1 year and remained at those levels. Saw palmetto cover in cut/burned stands was still reduced 7 to 8 years postburn (figures 1c and 1d). Figure 2 shows the treatment and recovery of one transect in the Happy Creek study site.

With careful application, these techniques can produce acceptable vegetation recovery. All mechanical treatments cause some decline in saw palmetto cover. Saw palmetto is the most flammable element in scrub of Merritt Island, and excessive loss can reduce the ability to burn the scrub in the future. Lack of fuel continuity can result in fires no longer spreading through sites, degrading habitat quality. The growth rates of long-unburned scrub after restoration suggest that restored scrub may have to be burned on relatively short intervals during a restoration period. Thus, it is critical to retain the ability to burn scrub frequently. In the historic landscape, openings in scrub were common, but they disappeared during decades of fire suppression, and prescribed burning has not reestablished openings in many landscapes. Where fuels are uniform, regrowth may be dense with no persisting openings. Piled fuels produce local hot spots that kill the roots and rhizomes of sprouting species. These openings close slowly from clonal growth of oaks and ericads. Such strategies should be used with care, because it is also important that the scrub matrix burn in order to top-kill shrubs, reduce litter and duff, and volatilize and recycle nutrients.

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Participating Organizations: Dynamac Corporation (P.A. Schmalzer and T.E. Foster) and Merritt Island National Wildlife Refuge (F.W. Adrian)

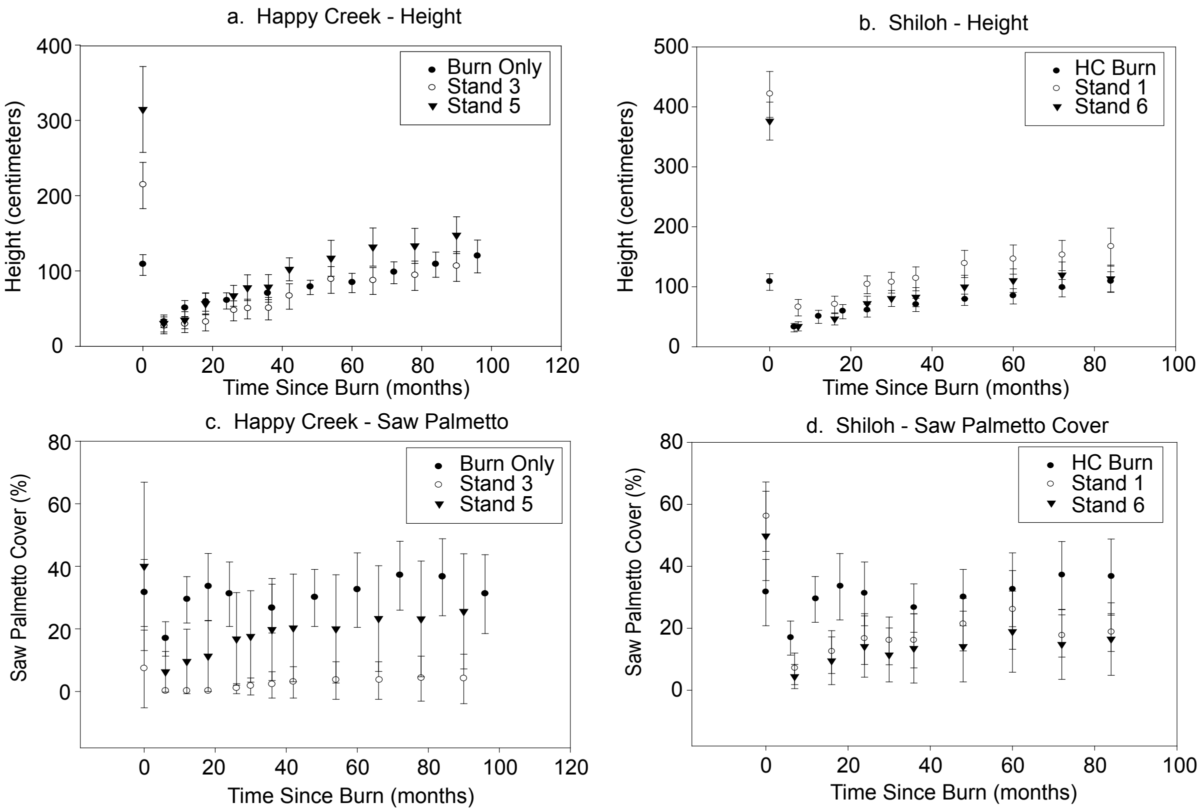


Figure 1. Height and Saw Palmetto Cover in the Restoration Sites

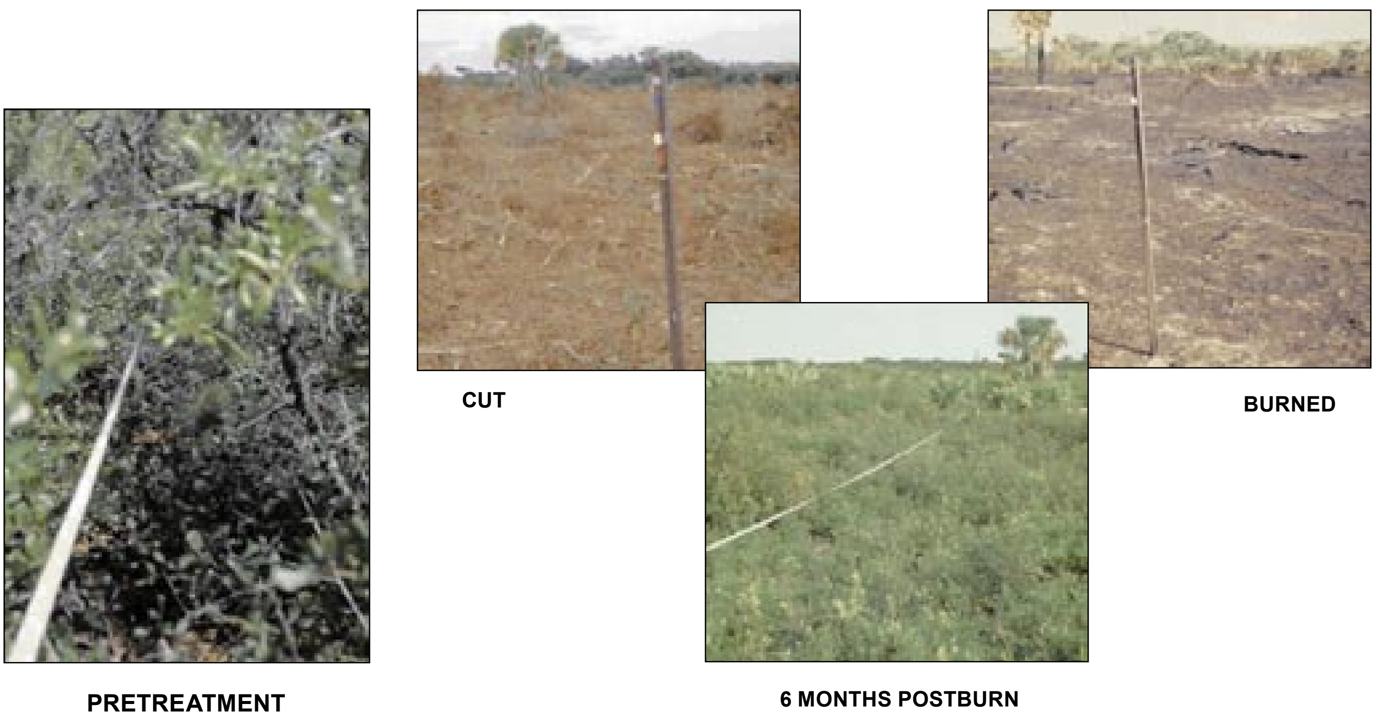


Figure 2. Treatment and Recovery of One Transect in the Happy Creek Study Site

Physiological Responses of Scrub Species With Varying Management Regimes

Scrub, a major upland system, occurs on approximately 1,600 hectares (ha) of KSC. This xeromorphic shrub community occurs on infertile, well-drained, sandy soils and is dominated by clonal, evergreen oaks. Ericads and *S. repens* (saw palmetto) also are prevalent species in Florida scrub. This system is pyrogenic and adapted to high-intensity, stand-replacing fires. The soils supporting scrub vegetation are excessively to moderately well-drained sand and are extremely nutrient-poor.

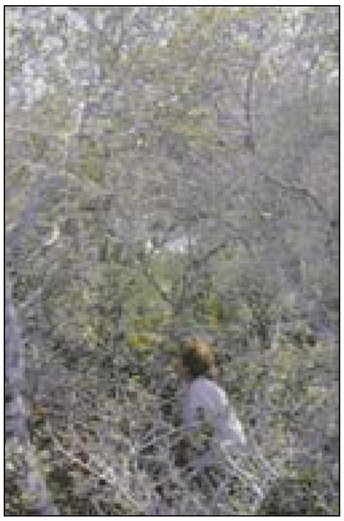
Four types of scrub communities are present on KSC: sand pine scrub, oak and oak-saw palmetto scrub, scrubby flatwoods, and coastal strand and scrub. Oak and oak-saw palmetto scrub are the most abundant community type (909.2 ha), occurring mainly in the inland portion of Merritt Island on well-drained, acidic soils that are low in nutrients and dominated by shrub species that resprout after fire. This typically includes three evergreen oaks (*Quercus chapmanii, Q. geminata,* and *Q. myrtifolia), S. repens*, and ericads (*Lyonia ferrigenea, L. fruticosa, L. lucida,* and *Vaccinium myrsinites*). Herbaceous species are not a major component of oak-saw palmetto scrub on Merritt Island.

Oak-saw palmetto scrub was subject to at least 20 years of fire suppression on KSC until prescribed burning was initiated in 1981. Active restoration of scrub habitat was begun in 1992. This restoration includes prescribed burning and, on the more overgrown sites, mechanical treatment followed by prescribed burns. Scrub at KSC and the Merritt Island National Wildlife Reserve (MINWR) is managed for structural characteristics that benefit the threatened Florida scrub-jay (*Aphelocoma coerulescens*), which include keeping the height around 1.7 meters and maintaining sandy openings. Scrub at KSC/MINWR was found to grow more quickly than at other locations, and the number and size of openings greatly decrease by 3 years postburn. Therefore, the fire return interval for scrub at KSC/MINWR needs to be no longer than 10 years.

Long-term studies to determine how management regime affects species composition and structure of scrub are continuing. However, this was the first study to examine whether a species physiological response was altered by management regime (prescribed burning, mechanical treatment, and fire suppression). Ten physiological parameters were measured on three individuals of eleven scrub species at three prescribed-burn plots, three mechanically treated plots, and three fire-suppressed plots.

Management regime did not affect a species physiological response (figure 1). Similar relationships were found among all management regimes. Species responses did not vary among the three management regimes. For example, the carbon-to-nitrogen (C:N) ratio for *Galactia elliottii* and *Smilax auriculata* remained low (20 to 30) regardless of management regime, while the oaks and *S. repens* maintained C:N in the range of 30 to 40. This does not mean that manage-

Mechanically Treated Scrubs



Fire-Suppressed Scrubs

Prescribed-Burn Scrubs

ment regime has no impact on the scrub system – ecosystem function (e.g., water exchange with the atmosphere) is determined by both the physiology of the different species or groups of species and the ecosystem composition of those species along with the total amount of transpiring leaf area. Although physiological responses of a particular species remain the same among the management regimes, species composition does not. Compositional changes with altered management are not unusual because management regime often acts as a disturbance on the system, and disturbance may be associated with a change in composition. Therefore, management regime has possible implications on ecosystem functioning in terms of carbon and nitrogen in water:

- In mechanically treated scrub, *S. repens* returns to only about 50 percent of its preburn cover, whereas the regrowth of trees and shrubs is similar to that of burned scrub.
  - *S. repens* is unique among the scrub species in its physiological response.
  - Loss of a large percentage of *S. repens* may lower the amount of carbon gained per water lost for the system, particularly if the loss of *S. repens* is not associated with a change in cover of the other functional groups.
- In fire-suppressed scrub, total vegetation doubles.
  - The percent cover of the trees more than doubles, approaching approximately 80 to 90 percent of the cover.
  - The percent cover of *S. repens* is approximately one-third of that found in burned scrub.
  - The total cover areas of the shrubs are approximately equal although species differ between the burned and fire-suppressed scrub.
  - By doubling the vegetation cover, more water will be lost because of transpiration.
  - More carbon may be assimilated because of the increase in tree cover, which has high rates of photosynthesis when compared to *S. repens*.

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Participating Organization: Dynamac Corporation (T. Foster)

Systems Impact of Waste Processing

Everything that is shipped into space is likely to become waste of one kind or another. This project looked at waste processing options and their impact on life support. About 40,300 kilograms (kg) of life support commodities are required for a crew of six for a year (yr). This is a lot of mass to supply and generates a similar mass of waste to be disposed of. Fortunately, much of this waste mass is recoverable, though at a cost of requiring some additional resources to process the waste. One example of a recoverable resource is water. Water is resupplied to the International Space Station (ISS) at a rate of approximately 3,500 kg/yr in its current configuration.

This project developed a model that calculated system impacts for varying mission types. System impacts are estimated in mass units as equivalent system mass (ESM). Estimates of initial and time-dependent ESM and break-even times for different life support options are shown in table 1 for a Mars surface mission with a crew of six people. The picture is less clear for ISS itself, in low Earth orbit, because much of the water is supplied from the Shuttle fuel cells and would otherwise be dumped.

Using ALS technologies, the time-dependent mass would be about 18,800 kg/yr. About 16,700 kg/yr of this would appear as waste that would have to be dealt with during the mission. This waste would be of a variety of types, including expended (ORU's), gases (notably carbon dioxide [CO2]), liquids (waste hygiene water, urine), and solids (trash, feces).

Our models and resulting analyses were used to produce the official ALS Research and Technology Development (R&TD) Metric (Drysdale and Hanford, 2002, JSC 47787, and earlier revisions) released by NASA Johnson Space Center (JSC). The metric used is calculated by dividing the ESM for a specified mission using ISS technology (ESM_{ISS}) by the ESM for the same mission using ALS technology (ESM_{ALS}): metric = ESM_{ISS} / ESM_{ALS}. The values of the metric for the missions considered are given in table 2.

For some mission scenarios, inedible biomass is a significant issue. A biomass production estimate was developed with Dr. Raymond Wheeler, YA-E4, for biomass and waste production for each of the selected ALS crop plants. From this crop model and the design of the plant production system for the BIO-Plex (Barta, 1996), the cost effectiveness of each of the crop plants was calculated. Using the diets given in the Baseline Values and Assumptions Document (BVAD), excluding those crop plants that were shown to be not cost-effective and using crop production rates from the BVAD, a plant waste data model for a crew of six was developed. The food closures (dry-weight basis) for the missions considered were calculated to be: Mars transit, 13 percent; Mars surface exploration mission, 13 percent; and a Mars base, 29 percent.

The waste model (draft for Mars missions) is summarized in table 3. The missions are further defined in Stafford, Levri, and Drysdale (2001), the ALS SIMA Reference Missions Document, JSC 39502.

Table 1. Initial and Time-Dependent ESM and Break-Even Times

Option	Initial ESM (kg)	Time-Dependent ESM (kg/yr)	Break-Even Time (yr) Compared to Open Loop
Open Loop	8,000	40,300	
ISS Technology	9,910	25,600	0.12
Advanced Life Support (ALS) Technology	11,000	18,800	0.16

Table 2. ALS Project Mission Metrics

Mission/Vehicle	ISS Technology ESM (kg)	ALS Technology ESM (kg)	ALS R&TD Metric
ISS Upgrade	122,513	92,866	1.32
Independent Exploration Mission	92,648	72,210	1.28
Mars Transit	27,966	20,711	1.35
Descent/Ascent Lander	12,721	9,122	1.39
Surface Habitat	51,961	42,377	1.23

Table 3. ALS Waste Model for Mars Missions

ALS Subsystem or Interface	Mars Transit ALS		Mars Descent/ Ascent Lander		Dual Lander Mars Surface ALS		Mars Base	
	Mass (kg)	Volume (m_3)	Mass (kg)	Volume (m_3)	Mass (kg)	Volume (m_3)	Mass (kg)	Volume (m_3)
Air	7.50	0.57	0.37	0.00	6.07	0.01	0.37	0.00
Biomass	0.61	0.00	0.00	0.00	1.19	0.00	1.41	0.00
Food	4.46	0.01	4.95	0.01	3.71	0.01	77.87	0.09
Thermal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waste	2.29	0.00	5.77	0.01	3.64	0.01	2.29	0.00
Water	0.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crew	35.31	0.03	30.32	0.03	35.31	0.03	35.31	0.03
EVA	0.00	0.00	12.71	0.03	7.26	0.03	7.26	0.03
Human Accommodations	52.60	0.07	12.71	0.03	52.60	0.07	52.60	0.07
TOTAL	103.75	0.69	66.84	0.12	109.79	0.16	177.10	0.03

Key accomplishments:

- Numerous publications and reports identifying model results were generated and presented (publication list available upon request).
- Plant waste models for ISS missions and Mars missions were calculated.

Key milestones:

- Results of this work are being presented at international conferences, including the International Conference on Environmental Systems (San Antonio, July 2002) and the Committee on Space Research (COSPAR) conference (Houston, August 2002).

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Participating Organization: Boeing (A.E. Drysdale and S. Maxwell)

Cost-Effective Methods of Onsite Wastewater Processing for Removal of Phosphorus and Pathogens

The expertise in plant-based waste processing systems generated during the past 15 years as part of the KSC/Advanced Life Support missions has been leveraged to solve terrestrial concerns with wastewater treatment. Leach fields used to treat septic tank effluent can lead to contamination of groundwater and surrounding surface water, particularly in sites with limited land area and either impermeable or overly porous soils. Nutrient leaching is a significant concern in the Florida Keys where increased development has been associated with decreasing water quality in the near-shore areas. These coastal areas can no longer use stand-alone septic tanks because of capacity limitations; therefore, the wastewater must be treated prior to its being released directly to the groundwater. Current treatment methods are time-consuming and costly. The objective of this project is to evaluate a cost-effective method using a conventional septic tank "front end" followed by a subsurface flow "garden" designed for zero-discharge (uptake of wastewater by plants that transpire clean water to the atmosphere).

The concept employs a closed plant bed for evapotranspiration treatment of all blackwater effluent. The goal of the project is to develop a system that is simple to operate, requires no pretreatment other than the septic tank, minimizes or eliminates moving parts, and is low-maintenance. An ancillary goal is to ensure the system is a desirable landscape element using common landscaping plants to capitalize on the landowner's interest in gardening/horticulture. The landscape plants were selected in relation to transpiration rates, nutrient removal capacity, maintenance issues, and salt tolerance for use in the subsurface "flow" garden. The first-generation trials evaluated the water processing rates and plant growth responses of four 50-square-foot test beds planted with 4 common tropical horticultural species. Each bed is receiving 5 gallons of septic tank effluent per day or about a half-person estimated toilet flow. The septic tanks used an ersatz blackwater composed of urine salts analog and vegetarian dog food to simulate feces. After 105 days of testing, plant growth appears vigorous and plants show no acute phytotoxic responses. Plant evapotranspiration rates were approximately 40 percent of projected average yearly levels, which is consistent with expected transpiration during winter months and early plant establishment.

Key accomplishments:

- Completed the first-generation system design.
- Deployed and performed proof-of-concept testing of system at experimental onsite location.
- Performed 105-day experiment.
- Completed analysis of system performance.
- Monitored water quality.
- Evaluated acute phytotoxicity issues.

Key milestones:

- Modification of design for optimization.
- Long-term operation testing (6 to 9 months) of second-generation design.
- Deployment of system in Florida Keys (Phase III).

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Participating Organizations: Dynamac Corporation (J.L. Garland, N.C. Yorio, P.A. Fowler, and V.J. Krumins), Azurea Inc., and Childs Enterprises (P. Childs)

Bed With Liner Gravel Encased Collection Pipe

Crushed Coquina Layer

Emitter on Top of Sand Layer

Crushed Coquina Around Emitter

Final Prototype Evapotranspiration Bed

Plant Growth as of March 12, 2002

Atmospheric Management in Variable-Pressure Environments

Reducing the atmospheric pressures for a closed plant growth system (greenhouse) will allow significant reductions in structural mass of the greenhouse and gas leakage and increase the potential for finding a thin, transparent material that can be used for a greenhouse, thus allowing direct capture of ambient light for photosynthesis. However, the reduced pressures pose considerable challenges; for example, thermal and humidity control capabilities are altered, as well as the operation of pressure-sensitive water delivery systems and maintenance of acceptable dissolved oxygen levels. A thorough understanding of plant growing system performance under reduced pressures is needed to assess these issues, along with monitoring and control capabilities for temperature, carbon dioxide, humidity, and dissolved oxygen levels over a range of operating pressures.

The focus of the project includes the testing and management of the internal environment of an approximately 1-square-meter greenhouse at relatively low pressure (about 10 kilopascals or 0.1 atmosphere). Obviously a 1-square-meter greenhouse could not provide much total oxygen and food for human life support, but it represents a first step toward testing the environmental management system, structural and materials systems, and plant growth in an integrated testbed. Results from this project can then be used to design and deploy a working module for a future Mars mission, as well as provide information for designing and building larger greenhouses to support more autonomous human colonies in space.

Figure 1. Lexan Dome Greenhouse for Testing in Low-Pressure Environments

Critical to the concept of using greenhouse structures designed for low pressures is the assumption that plants will grow and develop acceptably in these environments. Short-duration tests with lettuce plants showed that transpiration rates increased as pressure decreased. This result was consistent with other observations from low-pressure tests but was complicated by the difficulties in maintaining constant humidities at the different pressures. Subsequent tests to track weight loss from pans of water (direct evaporation) at different pressures but with better humidity and vapor pressure deficit control showed that evaporation rates increased as pressures decreased. This response is likely related to increased gas diffusion rates at lower pressures and in part can explain the increased transpiration observed with plants at reduced pressures.

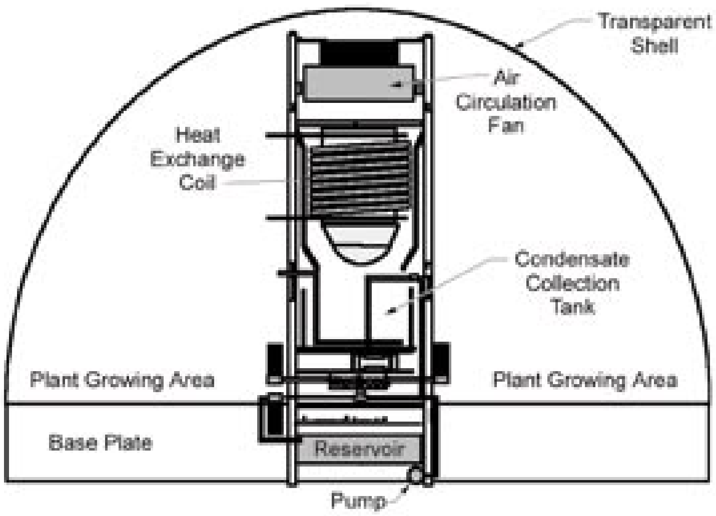

Figure 2. Atmospheric Control System for Small Greenhouse To Be Tested in Low-Pressure Environments

In a related series of tests, water vapor saturation pressures at different pressures were studied. To measure this, a water source was enclosed in a small, dark vacuum chamber, and the atmosphere was pumped down. The change in pressure was then observed as the chamber humidity was allowed to rise to approximately 100 percent. As expected, saturated humidity pressures were a strong function of temperature but were not affected by the total pressure. In several tests, rapid drops in pressure resulted in boiling of liquid water in the test chamber, which in turn caused a pressure increase.

Future activities include performing tests to determine whether low-pressure environments with only oxygen, carbon dioxide, and water in the atmosphere are acceptable for plant growth. A Lexan structure (1-meter-diameter dome) for growing plants was developed (see figure 1), which will be placed in a vacuum chamber and pressurized to approximately 10 kilopascals against an external pressure of approximately 1 kilopascal of carbon dioxide. The dome includes a cooling and humidity control system using externally supplied chilled water, condensed water recirculation system to the plants, air circulation, oxygen removal membrane, and the ability to add carbon dioxide as a pressurizing gas (see figure 2). Lighting would be provided externally to simulate Mars irradiance levels.

The goal is to grow candidate crops for Advanced Life Support Systems through a typical production cycle.

Key accomplishments:

- Performed environmental sensing and control tests at low pressures (humidity, carbon dioxide, and dissolved oxygen).
- Completed evaporation tests at various pressures.
- Successfully modified and tested high-pressure sodium lamps for use in a vacuum chamber.
- Completed construction of transparent dome for simulated deployable greenhouse testing in a vacuum chamber.
- Performed wind velocity characterization tests and thermal boundary layer tests at varying pressures.

Key milestones:

- Perform comparison tests (operating characteristics) of different-gauge thermocouples at low pressures. Conduct comparison of candidate oxygen-sensing approaches at different pressures. Repeat wet/dry bulb tests to assess psychrometry performance at different pressures.
- Perform psychometric measurements of plant water potentials at different pressures.
- Initiate long-term plant growth verification tests.

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Participating Organizations: Dynamac Corporation (Dr. P.A. Fowler), University of Florida (Dr. V.Y. Rygalov), and University of Guelph (Dr. M.A. Dixon)

Range Technologies

Range Technologies consist of unique technologies used in the range support facilities and equipment required to provide control, supply measurement data, and ensure safety of launch and test operations. Examples of these technologies include range safety analysis data processing equipment, telemetry reception and processing equipment, command destruct systems, weather systems, radar systems and displays, optical tracking and recording equipment, control centers, and communications centers. Significant capital investment is required to build this capability, and as a result, these assets have traditionally been slow to modernize. In addition, the costs associated with this infrastructure are difficult to quantify. Future spaceport operations will require flexible range technologies to accommodate the latest technological advances. These technologies must also be able to adapt to different space flight hardware designs and reduce the degree of customization required. Range technologies will also be needed to support multiple vehicles and multiple spaceports simultaneously. The ultimate goal of this technology thrust area is to create range technologies that provide for integrated range operation of all spaceports at lower costs and higher safety than is currently possible.

Technology focus areas include the following:

- Weather Instrumentation
- Range Surveillance Technology
- Tracking and Telemetry Technology
- Decision Modeling and Analysis
- Range Safety and Traffic Management

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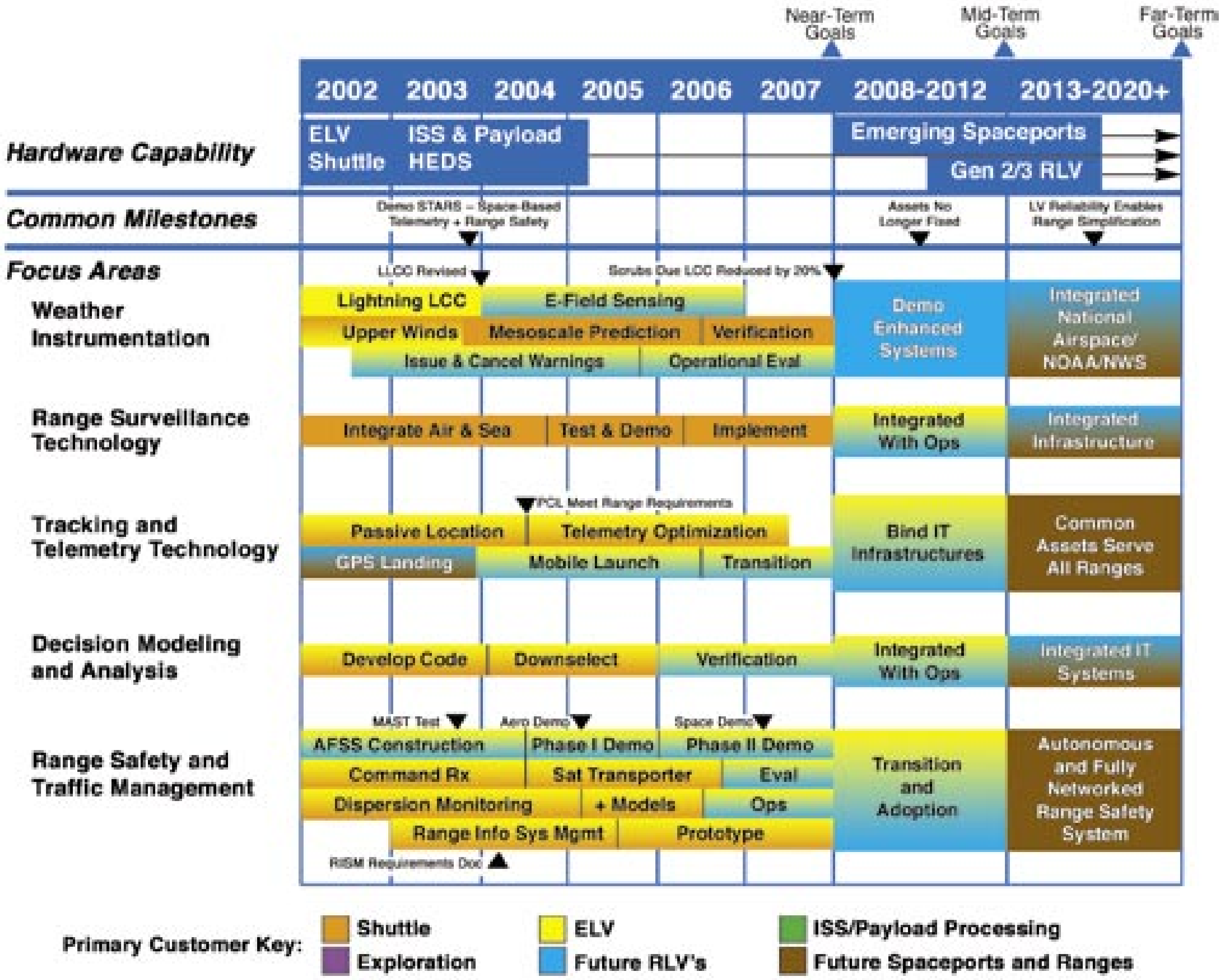
KSC Range Technologies Roadmap



Goals Specific to Focus Areas

- Improve safety and responsiveness (support more launches, reduce lead and turnaround time, and reduce delays)
- Reduce variable costs
- Reduce total cost of fixed infrastructure

Operational Forecasting Tool To Improve Predictions of Thunderstorm Anvil Clouds

Electrified anvil clouds extend the threats of natural and triggered lightning to space launch and landing operations at KSC and Cape Canaveral Air Force Station (CCAFS) well beyond the immediate vicinity of thunderstorms. Generated by deep convective updrafts and transported by upper-level winds, anvil clouds emanating from thunderstorms over the Gulf of Mexico can reach the KSC/CCAFS space launch/landing complexes in 2 hours or less. Launch Weather Officers of the 45th Weather Squadron (45 WS) and forecasters at the Spaceflight Meteorology Group (SMG) have identified anvil forecasting as one of the most challenging tasks when predicting the probability of Launch Commit Criteria (LCC) and Space Shuttle Flight Rule (FR) violations. An objective technique for forecasting the potential horizontal extent of anvil clouds is needed to assist forecasters in predicting the probability of a triggered lightning LCC violation.

During 2000, the Applied Meteorology Unit (AMU) established the technical feasibility of developing an anvil forecast tool on the basis of a 45 WS pilot study and a review of the most recent theoretical and applied research on the topic. The pilot study indicated a significant statistical relationship between upper-level wind speed and the length of mature thunderstorm anvil clouds. The anvil cloud layer was found to exist between the 300- and 150-millibar pressure levels, about 31,000 to 46,000 feet. An effective transport lifetime of 2 hours was estimated from a limited sample of anvil clouds on 17 days.

During 2001, the AMU expanded the pilot study by observing the life cycle of 167 anvil clouds on 50 days during the months of May, June, and July. A statistical analysis of the database confirmed the basic results of the pilot study. Further information on the variability of the transport lifetime and the correspondence between upper-level wind direction and the propagation of anvil clouds was added. The statistical parameters were needed for the formulation of an objective, observations-based forecast tool.

The AMU developed a prototype anvil forecasting tool for use on the Meteorological Information and Data Display System (MIDDS) and successfully tested it on the AMU MIDDS. The forecaster invokes the tool with a one-line command on MIDDS, which includes a user-selected location, such as the Shuttle Landing Facility, Launch Complex 39A, or a transoceanic abort landing site. Routine, global upper-air observations are automatically queried and the average wind speed and direction in the anvil layer are computed. The tool then automatically plots an anvil threat corridor on a satellite or radar image, providing the forecaster with a quick visual interpretation of regions from which anvil clouds could threaten the space launch and landing facilities on KSC, CCAFS, or the user-selected site. Several command options and an on-line help function are available.

Figure 1 shows a satellite image on the morning of May 13, 2001, prior to the onset of thunderstorm activity.

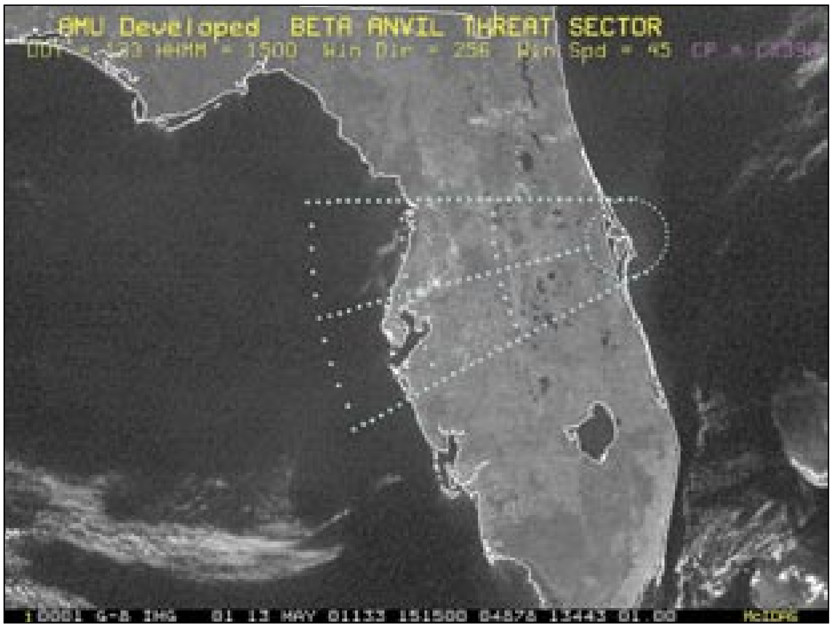


Figure 1. A Visible Satellite Image of the Florida Peninsula at 1515 Local Time on the Morning of May 13, 2001 (The threat corridors indicated that anvil clouds generated by thunderstorm activity in Central Florida would be transported over the Cape within less than 2 hours after formation.)

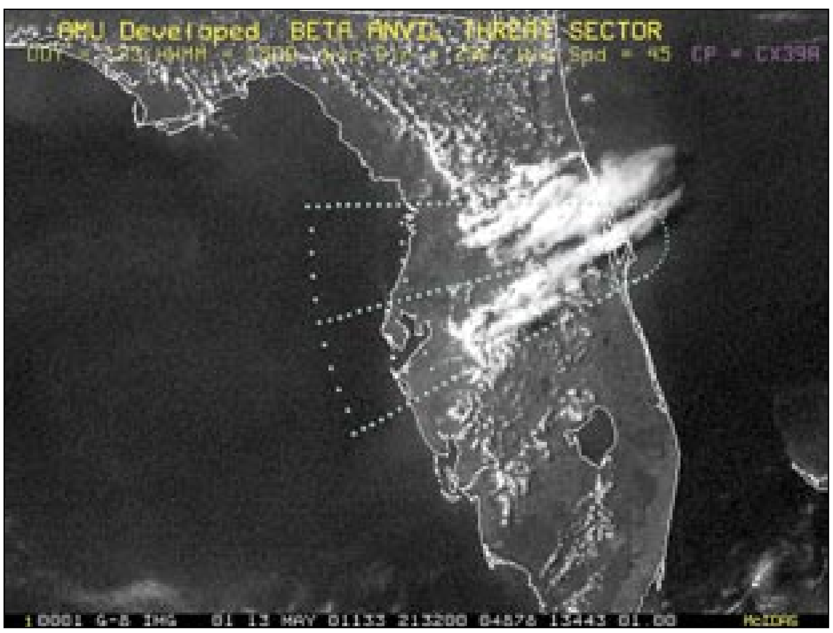


Figure 2. A Visible Satellite Image of the Florida Peninsula at 1632 Local Time on the Afternoon of May 13, 2001 (The anvil clouds were generated around 1430 local time by thunderstorm activity in Central Florida and transported 90 nautical miles east-northeast within 2 hours, as predicted by the anvil forecast tool.)

An anvil threat corridor is plotted for Launch Complex 39A using upper-wind data from the CCAFS weather station. The threat corridor originates from a 20-nautical-mile stand-off circle and includes 3 upstream arcs that would be traversed by anvil clouds within 1, 2, and 3 hours (outer arc). Figure 2 shows a satellite image for the afternoon of May 13, 2001. Thunderstorm activity over Central Florida generated several long, narrow anvil clouds that were transported east-northeastward over the KSC/CCAFS area, consistent with the guidance provided earlier in the day by the anvil forecast tool.

Key accomplishments:

- 2000: Established technical feasibility of developing an observations-based forecast tool from analysis of pilot study and literature search.
- 2001: Derived statistical parameters of forecast tool from anvil data archive and developed prototype forecast tool. Tested forecast tool on MIDDS in the AMU. The tool is designed for operational use and is invoked by a single command line.

Key milestone:

- 2002: Implementation of the anvil forecast tool on the operational MIDDS in the Range Weather Operations facility.

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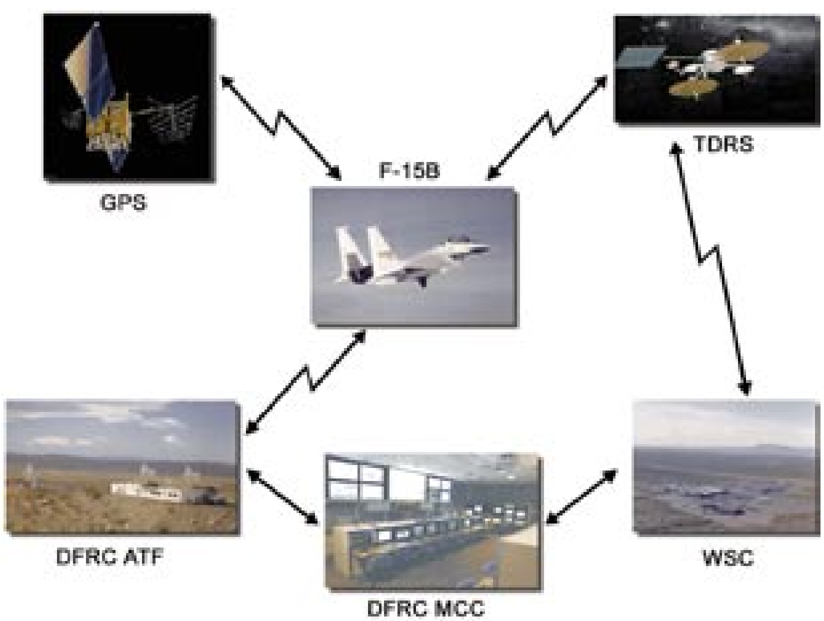
Participating Organizations: ENSCO, Inc. (W.C. Lambert, D.A. Short, and M.M. Wheeler) and 45th Weather Squadron (J.E. Sardonia)

Space-Based Telemetry and Range Safety (STARS)

The current Range Systems rely almost exclusively on a network of aging ground-based assets for tracking, communications, and flight termination system (FTS). Space-Based Telemetry and Range Safety (STARS) is a multifaceted and multicenter project to determine the feasibility of using space-based assets, including the Tracking and Data Relay Satellite System (TDRSS) and Global Positioning System (GPS), to reduce operational costs and increase reliability.

STARS is divided into the Range Safety and Range User systems. Innovations on the Range Safety side include GPS for metric tracking, a versatile low-power multichannel transceiver (LPT), digitized FTS commands, and a state-of-the-art flight processor. The Range User side uses broad-bandwidth communications to provide information about the vehicle health and audio and video data.



Flight Demonstration 1 Overview Configuration

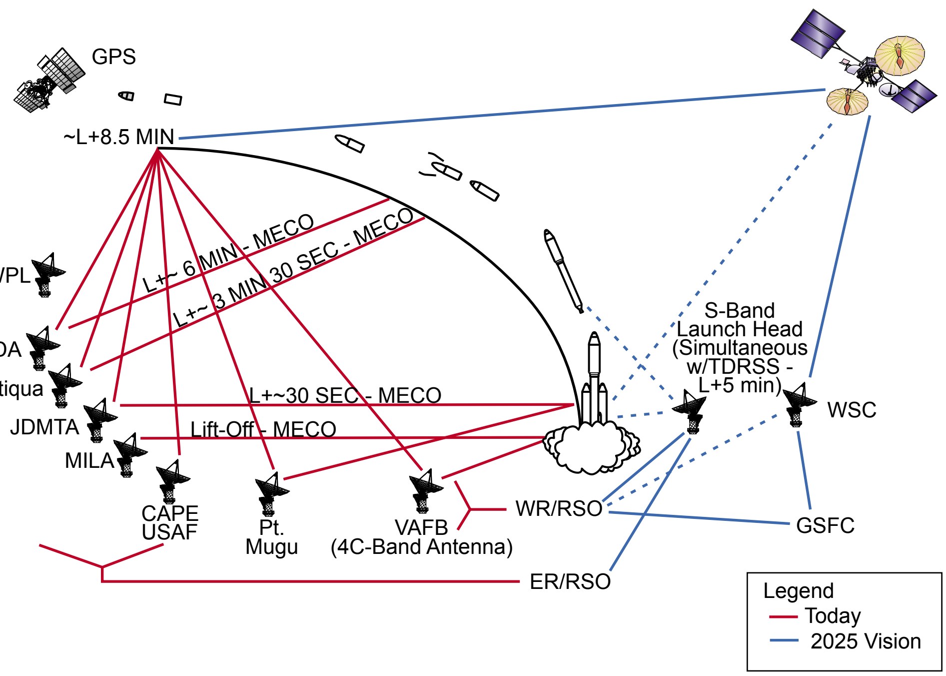
The primary NASA Centers and their roles in STARS are:

- Kennedy Space Center: Program management, engineering support, postflight analysis, and coordination with Cape Canaveral Air Force Station and the Eastern Test Range.
- Goddard Space Flight Center (GSFC): Flight hardware, TDRSS, and communications support.
- Wallops Flight Facility (WFF): Engineering support.
- Dryden Flight Research Center (DFRC): Flight hardware integration, configuration control (vehicle and range), range support, flight test and postflight analysis, coordination with Vandenberg Air Force Base (AFB), Edwards AFB, and the Western Test Range.

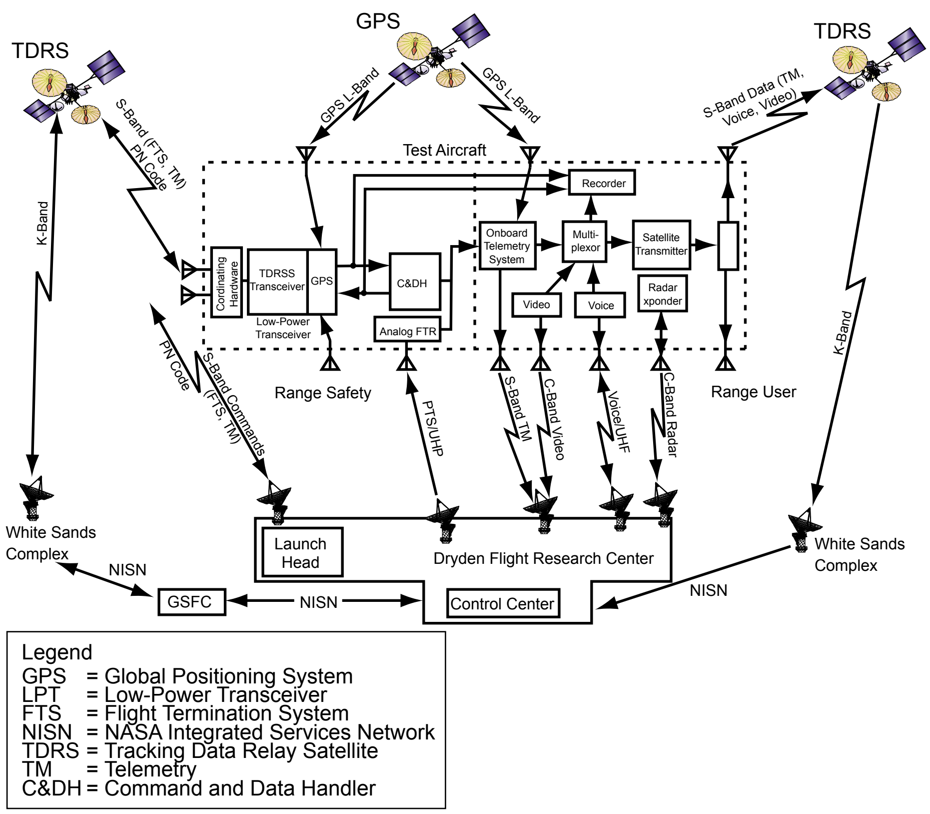
Supporting Centers include Glenn Research Center (GRC), providing research and analysis, and White Sands Complex (WSC), providing TDRSS and communications support.

Key accomplishments:

- 2001: Proposals by KSC/GSFC and DFRC combined, accepted, and funded (January). Demonstration Concept Study by GRC (October).
- 2002: STARS Flight Demo 1 Critical Design Review (CDR) (February). Flight processor Interface Control Document (February). LPT CDR (March). Hardware procurements initiation.



Space-Based Range and Range Safety Concept



Flight Demonstration Overview Block Diagram

Key milestones:

- 2002: Flight Demo 1 on an F-15B at DFRC.
- 2004: Flight Demo 2 on an F-15B at DFRC with redesigned antennas.
- 2005: Flight Demo 3 on a hypersonic vehicle.

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Participating Organizations: Dynacs Inc. (R.B. Birr), GSFC (T.C. Sobchak), DFRC (R.D. Sakahara, D. Whiteman, and D.K. Randall), WFF (W.R. Powell and S.N. Bundick), GRC (D.R. Hilderman), WSC (J.M. Gavura), and ITT Industries (M. Harlacher and S. Castell)

Autonomous Flight Safety System (AFSS) – Phase II

An automated flight safety decision process enables a flight vehicle itself to make real-time decisions on if/when/where/how to safely abort a mission or terminate the flight. It can serve as an advisor to mission flight control and the flight crew, a backup in case of a breakdown in communications or other elements of the infrastructure, and a fully autonomous onboard capability that is insensitive to any potential infrastructure breakdown.

The feasibility of automating the flight safety decision process was verified with the successful completion of AFSS Phase I (see Research and Technology 2000/2001 Report for details). Wallops Flight Facility (WFF) is providing funding for Phase II of AFSS under a Defense Micro-Electronics Agency (DMEA) contract. WFF and KSC are jointly managing Phase II in order to leverage work completed on Phase I and provide synergism to obtain a prototype AFSS.

The representative Expendable Launch Vehicle (ELV) mission chosen for this phase of AFSS is the Kodiak Star Athena I. The mission rules identified in the flight safety plan for this mission are representative of the rules for other classes of ELV's.

Phase II is broken into two primary components. The first one is software development and the subsequent verification and demonstration of the software. Lockheed Martin in Huntsville, Alabama, is performing this under the DMEA contract. The configuration for performing this task is shown in figure 1.

The objective of testing the AFSS software is to verify and demonstrate that it works as designed and implements flight termination limits properly. The software emulation of the human-in-the-loop system performance will also be verified at this stage. Once this is accomplished successfully, then the incorporation of the software into a flight computer will proceed. Figure 2 shows the configuration to be utilized in the laboratory for verifying the software will perform satisfactorily on a flight computer. The AFSS Flight Computer Configuration is partitioned into 3 sections:

1. Global Positioning System (GPS) Section: This includes two GPS units, a GPS constellation simulator, trajectory simulation files for driving the constellation simulator, and a capability for simulating anomalous trajectories on one or both GPS data streams.
2. Flight Computer Section: This includes the flight prototype computer with operating system (OS) software, any support computer and software needed for configuring the flight computer OS for AFSS and for compiling and loading the AFSS software and limits data onto the flight computer, along with compatible interface ports.

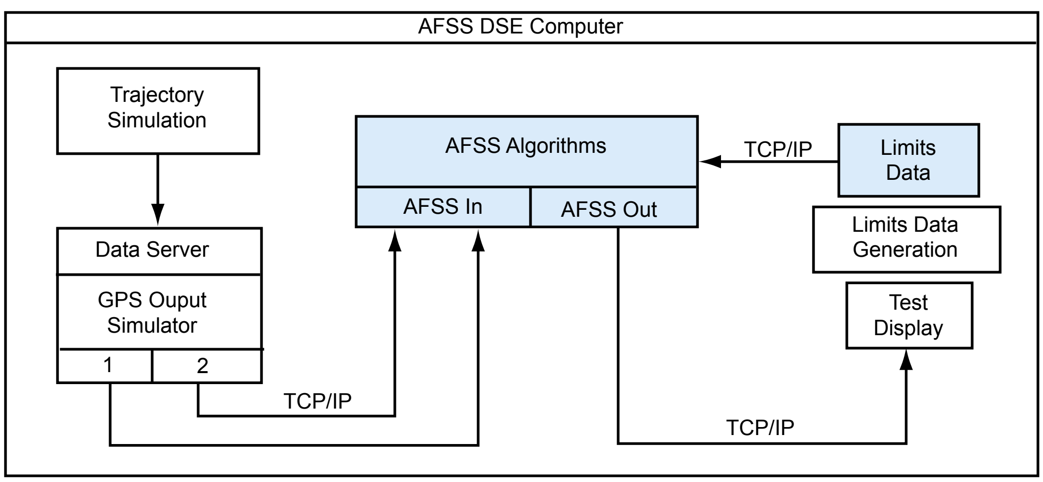

Figure 1. AFSS Software Development and Verification Configuration

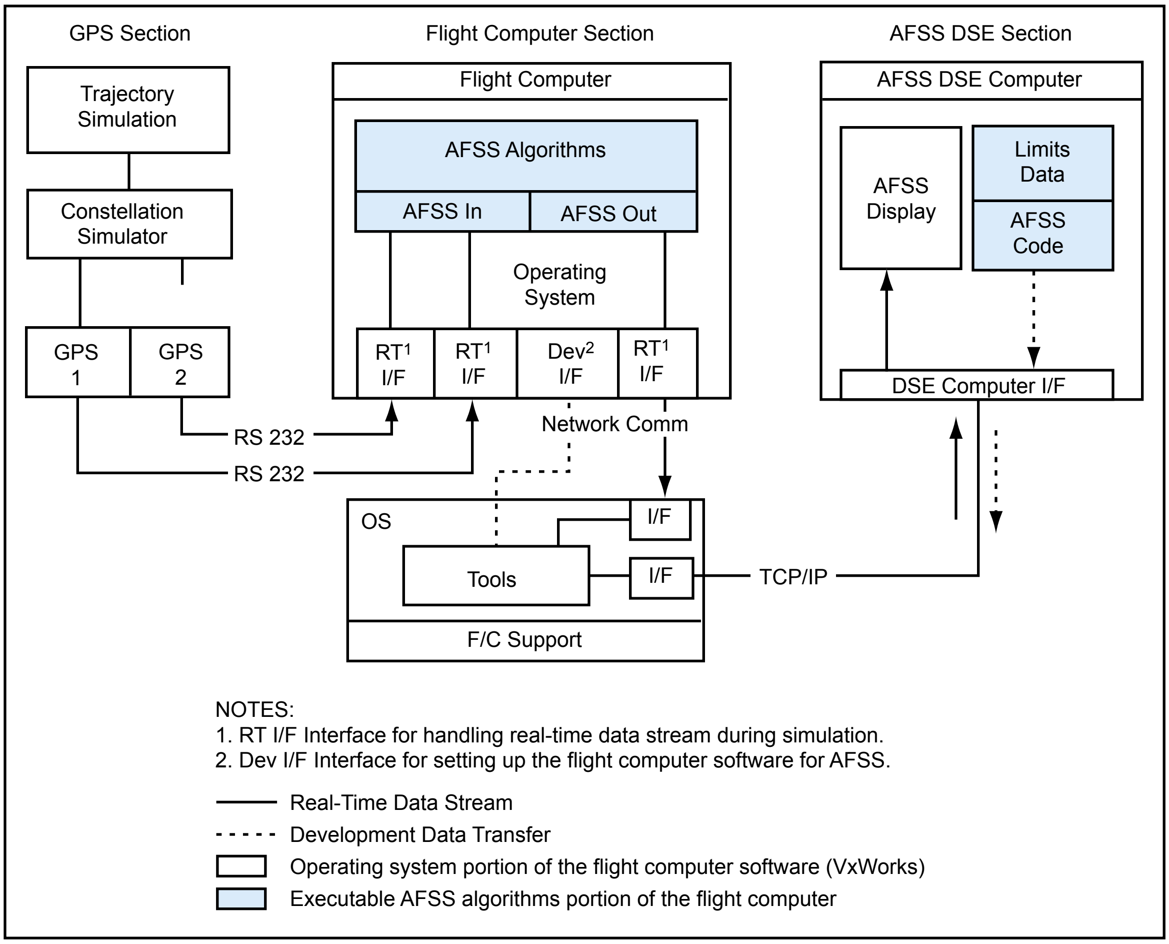

Figure 2. AFSS Flight Computer Configuration

3. AFSS Development Support Equipment (DSE) Section: This includes the computer on which the AFSS algorithms are developed and coded, the software for the real-time AFSS graphic display, and the AFSS algorithm code and limits data to be supplied to the flight computer support computer.

All elements verified in the software development configuration will be rechecked to ensure operational capability on the flight computer. In addition, a valuation of effectiveness and responsiveness will be performed at this time.

The AFSS concept for range safety offers many advantages. It provides global coverage and supports both the ascent and return-to-Earth flight phases. It improves safety by ensuring a comprehensive decision process predicated upon complete knowledge of the vehicle state and abort capabilities. Furthermore, it improves safety and reduces operations cost by eliminating dependence on radar and other dedicated assets.

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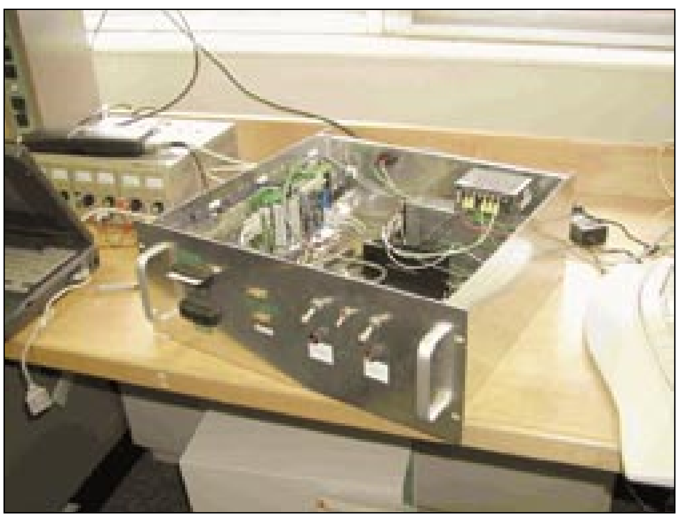
Participating Organizations: Wallops Flight Facility (J. Hickman, W. Powell, M. Patterson, J. Lanzi, and B. Bull), Lockheed Martin (S. Haley), and YA-D2 (S.A. Santuro)

Iridium Flight Modem

Flight modem demonstrates feasibility of "launch vehicle as a node" for real-time tracking using commercial satellite-based positional data without traditional ground and flight telemetry infrastructure. The flight modem uses commercial off-the-shelf (COTS) equipment capable of full duplex communications at 2,400 baud to augment or replace low-bandwidth telemetry tracking and control (TT&C) mission requirements. The flight modem can be combined with an onboard global positioning satellite (GPS) receiver as a vehicle locator and effectively eliminate the need for downrange radar tracking.

The flight modem has an onboard iridium modem that can either work as a dial-up modem to a landline or can call another iridium modem. If the dial-up method is used, the modem can be used to access the Internet and the delay will be about 2 seconds. If two modems are used, the propagation delay can be as little as 100 milliseconds. The iridium modem is tied to an onboard GPS receiver via a PC-104 computer. The iridium modem will answer incoming calls and automatically start sending GPS data to the call modem that initialized the call.

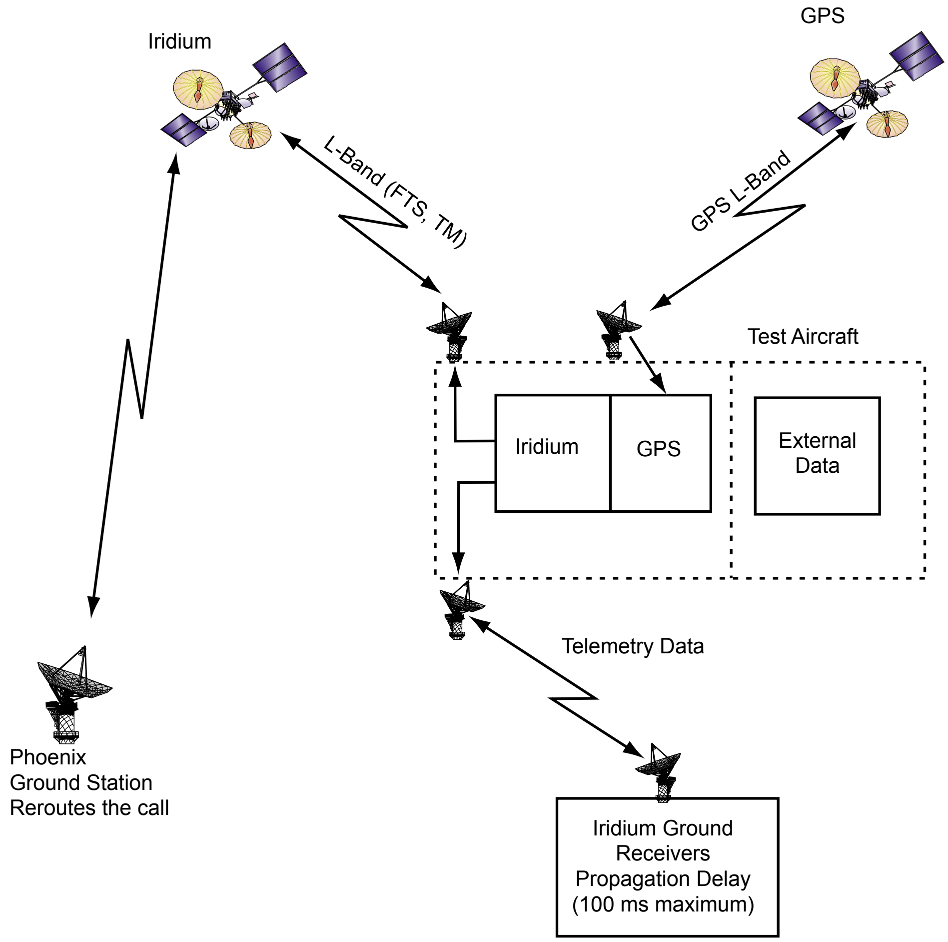


Iridium Flight Box

The benefits of the flight modem include reduced ground station infrastructure; elimination of inherit scheduling conflicts, sustaining engineering, and antenna equipment costs; reduced mission costs by an order of magnitude; drastic reduction in logistical issues; and worldwide access to low-rate TT&C data.

The iridium flight modem will use sounding rocket-related activities as a springboard to prototype GPS launch support systems. Other vehicle test platforms include balloons, unmanned aerial vehicles (UAV's), and aircraft. The technologies and processes involved include data communications, support hardware and software, safety and launch support processes, GPS, mission modeling, and analysis.

Ongoing development efforts include combining two iridium modems to increase the data rate to 4,800 bits per second, using one antenna for both iridium and GPS instead of two separate antennas, and developing a Sounding Rocket Antenna. The technologies involved in this project are the commercial satellite data services; the GPS receiver and potential other sensors (e.g., accelerometers); the Internet protocol (IP) communications and software tools; and the compact COTS bus architecture and local Ethernet ports.



Iridium Flight Modem Showing Test Flight Configuration

Benefits of this project include:

- Reduction and possibly elimination of radar dependence.
- Easy configuration of ground hardware.
- Easy addition of new monitoring sensors or payload data interfaces.
- Easy configuration of inexpensive Internet-based ground software.
- Elimination of inherent scheduling conflicts on satellites.
- Reduction of ground station infrastructure and antenna equipment tracking costs.

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Participating Organization: Dynacs Inc. (R.B. Birr and R. Chiodini)

Passive Coherent Locator for Range Safety

NASA is currently dependent on a costly range radar infrastructure to support range safety requirements. Less expensive alternatives being investigated include Passive Coherent Location (PCL).

Silent Sentry is a PCL technology developed by Lockheed Martin for all-weather surveillance and tracking of aircraft and missiles. Unlike conventional radar, PCL does not mechanically scan a volume of space or actively radiate a radio frequency signal. Instead, it passively listens for reflections of electromagnetic signals already in the environment from sources such as commercial television and FM radio.

PCL is capable of tracking multiple objects above a threshold detection size with accuracies purportedly comparable to C-band radar. Although PCL requires high-speed parallel processing to extract the targets from the received signals, its advantages are reduced operational and maintenance costs because of its mechanical simplicity and no interference with payload electronics or environmental impact because of its passive approach.

An onsite demonstration during the launch of STS-103 in December 1999 was the first phase of a NASA plan to assess the application and feasibility of implementing PCL technology as a primary or supplementary tracking and surveillance source for future and existing space launch vehicles.

A followup phase consisted of software and modeling modifications based on lessons learned from the onsite testing.

Key accomplishments:

- 2000: Identified critical tracking and surveillance requirements for Space Shuttle and Solid Rocket Boosters (SRB's). Onsite test during launch and landing of STS-103.
- 2001: Algorithmic and system improvements, including tracker upgrades, motion compensation, independent SRB tracking, multiple receiver nodes, and range safety display integration.

Key milestones:

- 2002: A baseline Silent Sentry System will be installed at Kennedy Space Center, and its ability to replace current range safety infrastructure will be evaluated by the Air Force Research Laboratory. Tentative plans call for PCL to be used during several Space Transportation System and Expendable Launch Vehicle operations by early 2003.

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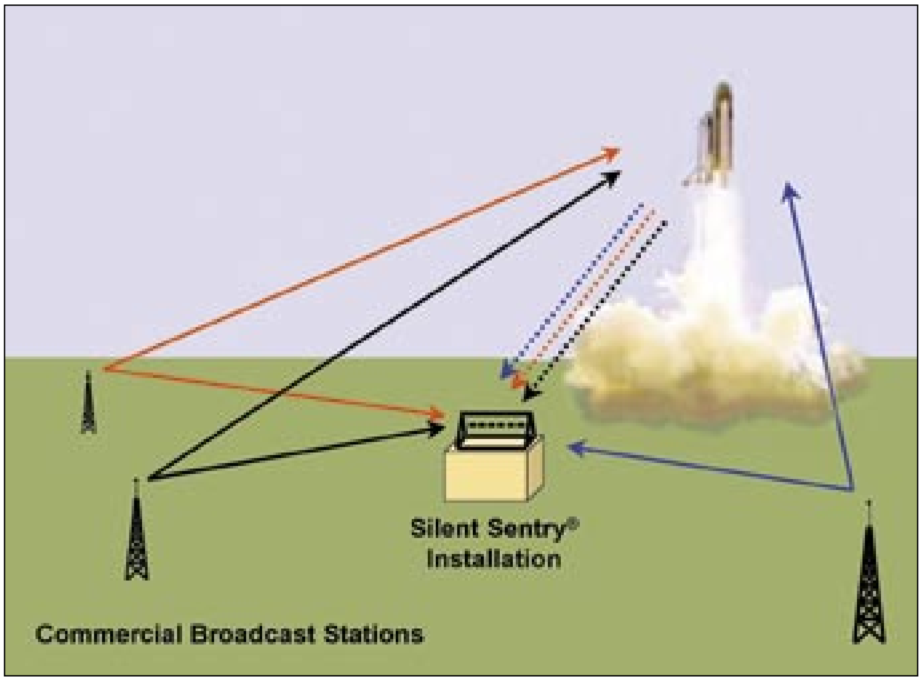
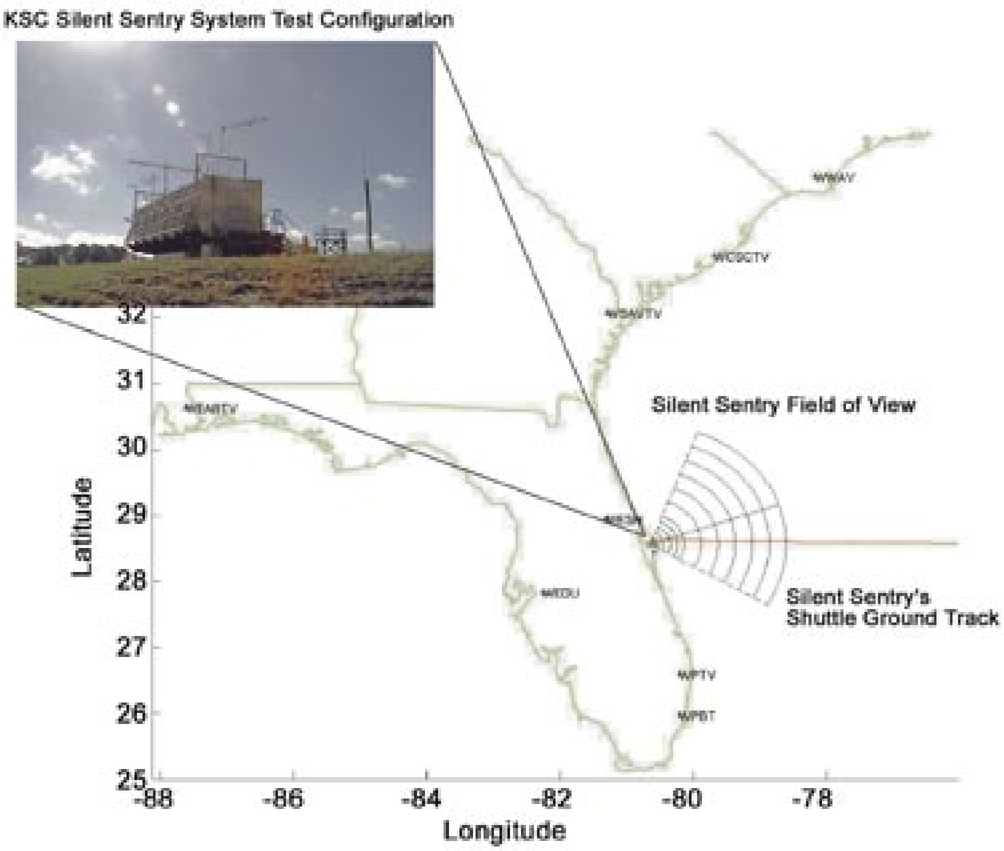
Participating Organization: Lockheed Martin Mission Systems (W. Underwood)



Silent Sentry System Concept



1999-2000 Phase 1 Test

Spacecraft Nutation Growth Rate Determination Using the Spinning Slosh Test Rig (SSTR)

Until recently, spinning spacecraft nutation growth rates have been difficult to predict accurately. Analysis was used in the past, but the predictive models used were typically conservative because of unknowns in the behavior of fluids sloshing in the propellant tanks. The conservative results from these models may not have the fidelity required by some spacecraft projects to predict the stability of their spacecraft both during upper-stage flight and post-upper-stage separation. Obviously, if a spinning spacecraft were to become critically unstable during third-stage flight or after spacecraft separation, the mission could be lost.

Several experimental testing methods have been used by various organizations to predict nutation growth rates. Many of these methods require large resources and facilities. Others, such as drop-tower testing, have utilized small-scale models and high spin rates, but scaling factors must be used and these types of tests are typically more applicable for propellant tanks with either rigid internal propellant management devices or no internal propellant management devices at all. Propellant tanks with flexible, bladder-type propellant management devices have been difficult to scale.

NASA/KSC has developed a predictive computer simulation to analyze nutation growth rates of spinning spacecraft. The simulation can use either a pendulum or rotor mechanical analogy to model propellant tank fluid motion and energy dissipation. Several pendulum or rotor parameters must be determined before the simulation can successfully predict nutation growth rates. To obtain the highest prediction fidelity possible, propellant behavior test data are required to populate the model parameters.

To provide accurate test data for the simulation, NASA/KSC and the Southwest Research Institute (SwRI) have developed a new spinning slosh test facility to obtain the propellant force and torque measurements necessary to derive the model parameters. This facility is called the Spinning Slosh Test Rig (SSTR) (figure 1). The facility is owned by NASA/KSC and operated by SwRI. The first use of the SSTR was in support of the Genesis mission, which was launched on a Delta II on August 8, 2001.

After the Genesis tests were completed, the SSTR dynamometer was redesigned to improve the fidelity of the data obtained, incorporate the lessons learned from the Genesis tests, and increase flexibility to accommodate various tank sizes. NASA/KSC utilized the redesigned dynamometer to obtain data in support of the CONTOUR spacecraft project launched on a Delta II on July 3, 2002. Figure 2 shows the CONTOUR test tank mounted to the SSTR.

With the improved force sensors of the redesigned SSTR dynamometer, SwRI was able to detect a previously unsuspected fluid resonance in the CONTOUR propellant tanks. NASA/KSC and SwRI revised the simulation to incorporate additional mechanical analogies to account for the resonance. The improved force sensors and revision of the NASA/KSC simulation greatly improved the accuracy of the simulation results for the CONTOUR mission. Figures 3.a and 3.b illustrate a sample of the data output from the CONTOUR tests. The fluid resonance in the Y-torque can be seen clearly in figure 3.b.

For both the Genesis and CONTOUR missions, the data obtained from the SSTR testing and subsequent simulation results provided much higher confidence in the nutation growth rate values. This higher confidence allowed the respective spacecraft projects to determine that no modifications to their spacecraft or upper stage were required to mitigate the risk of a nutation growth rate problem.

Future use of the SSTR includes testing a soon-to-be-fabricated generic propellant tank with various configurations of an internal, nonrigid propellant management device. The goal of the generic tests is to build a database populated by

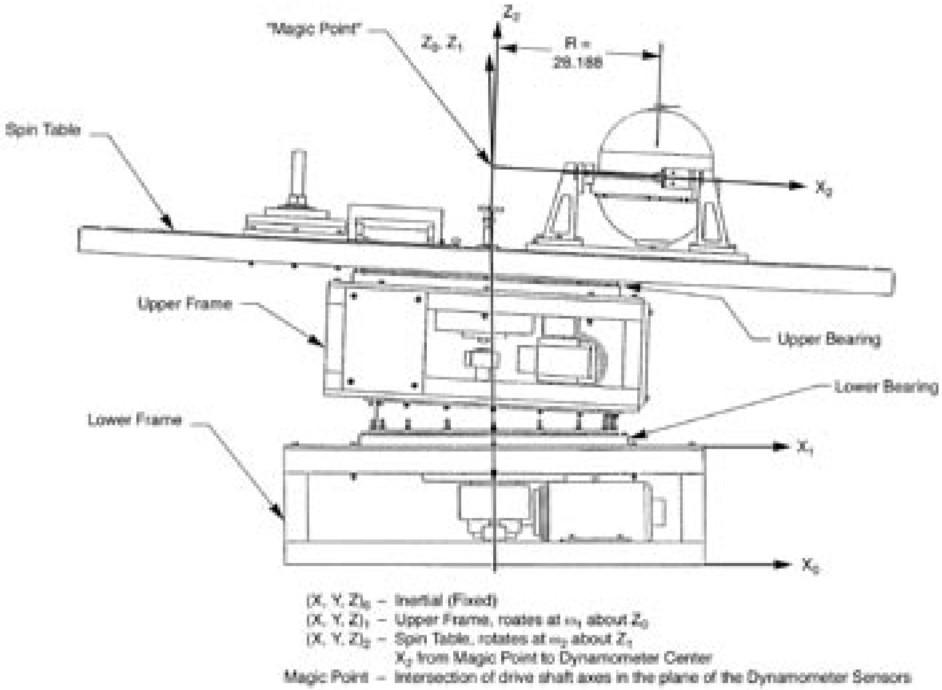


Figure 1. SSTR Hardware

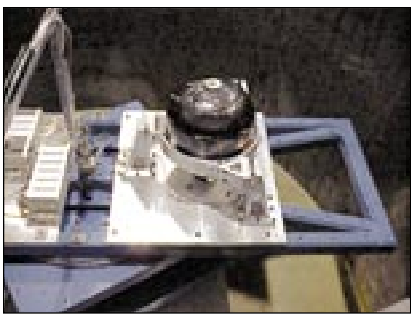


Figure 2. CONTOUR Test Tank on the SSTR

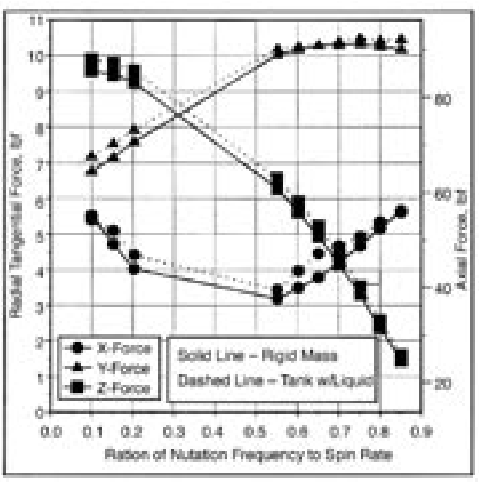


Figure 3a. Measured (Raw) Forces, for 51-Percent Fill at 110 Revolutions Per Minute

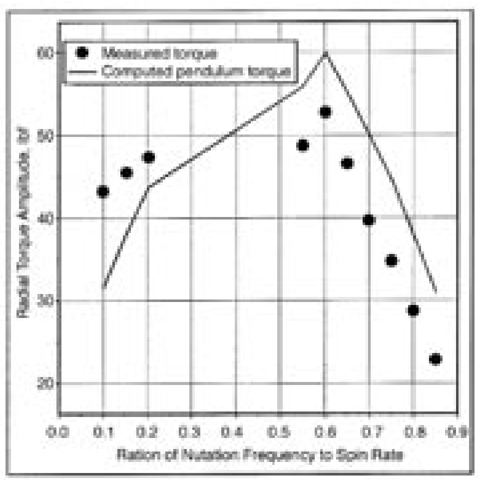


Figure 3b. Measured (Raw) Torques, for 51-Percent Fill at 110 Revolutions Per Minute

nutation growth rate values for various bladder configurations, tank placements relative to spacecraft centerline, and multiple fluid levels. Additional spacecraft projects have expressed interest in utilizing the NASA/KSC nutation growth rate analysis capability to obtain accurate nutation growth rate information.

Key accomplishments:

- 1999: Concept study.
- 2000: SSTR fabrication, assembly, and test; Genesis propellant tank tests.
- 2001: Dynamometer redesign; CONTOUR propellant tank tests.

Key milestones:

- 2002: Generic test tank tests.
- 2003: Spacecraft propellant tank tests.

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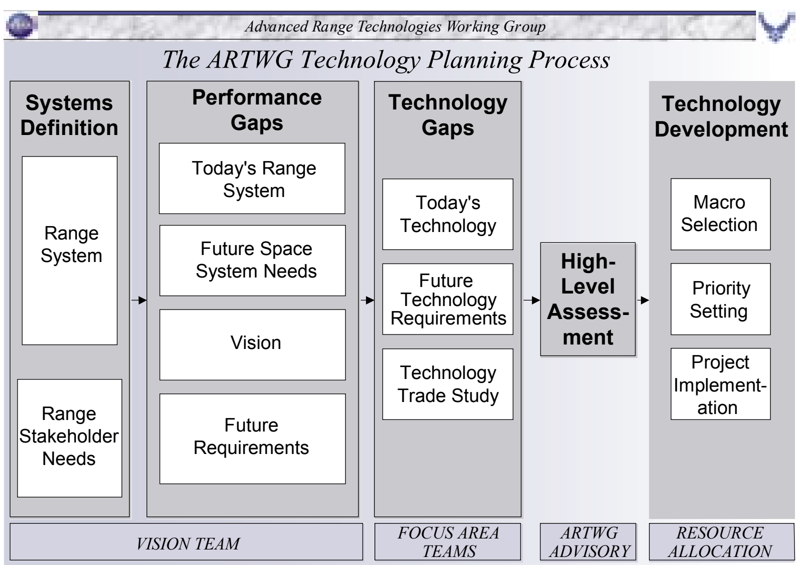
Participating Organizations: VB-A3 (J.E. Suderman), Analex (D. Griffin), Southwest Research Institute (Dr. F. Dodge and S. Green), and Boeing (A. Findley and K.J. Betty)

Advanced Range Technologies Working Group (ARTWG) Formation

In the spring of 1999, the Assistant to the President for National Security Affairs and the Assistant to the President for Science and Technology formed an Interagency Working Group (IWG) to review the future management and use of the primary U.S. space launch ranges. In February 2000, the IWG produced a report. Among its findings, the IWG found that there was no coordinated program focused on next-generation range technology development that would support lower costs and improve mission support capabilities. Their recommendation was to have the U.S. Air Force and NASA develop a plan to coordinate, develop, and demonstrate next-generation range technologies. In response to that recommendation, NASA and the Air Force formulated a Memorandum of Agreement (signed January 2002) and established the Advanced Range Technologies Working Group (ARTWG) to serve as the forum for U.S. parties who have an interest in range technology development. The ARTWG will produce nationally recognized roadmaps of next-generation range technologies to be developed. These roadmaps will be maintained and updated annually. The working group is cochaired by NASA KSC and the Air Force Space Command.



The following steps were identified to gain national recognition credibility and to ensure roadmap development:

- Staff the subgroup leadership team (7 subgroups with 14 cochairs) and the subgroup membership with nationally recognized experts in their respective fields who have strong leadership skills and reflect the very different backgrounds and experiences of all the range users.
- Select candidates that reflect the diversity of the range technology development organizations (academia, industry, NASA, Air Force, Federal Aviation Administration [FAA], and other Federal agencies).
- Develop an implementation plan and process that ensures participation and synergistically interacts with other range technology development initiatives (e.g., Range Standardization).
- Develop a schedule that pushes the project along but allows for reprioritization to permit much-needed technology debate.
- Continue to refine and update the roadmaps annually.

KSC has made significant progress in all areas. All 14 subgroup cochairs have been appointed. They represent many of the range user organizations and were appointed because of their leadership skills and technical abilities. The cochairs are from industry (aerospace and consultant companies), NASA, Air Force Space Command, Air Force 45th Space Wing, FAA, and Air Force Florida Air National Guard. In addition, the subgroups included membership from academia, FAA, state government, and other Federal agencies. An agreed-upon implementation plan and process (see the figures) were developed. The subgroup cochairs will lead their individual teams (Weather Systems, Telemetry Systems, Tracking and Surveillance, Scheduling and Coordination of Assets, Decision Making and Modeling, and Range Command and Control) through a series of activities. They will perform a system definition, a performance gap assessment, and a technology gap assessment, followed by the high-level trades needed to identify the candidate technologies. These assessments will create the candidate technology projects that will be used to develop the national road map. Over the next several months, these plans will be developed and the milestone schedule will be further refined.

Key milestones:

- Fully staff the subgroups and planned integration committees.
- Refine the overall ARTWG process.
- Continue to build the membership and coalition.
- Develop the National Range Technologies Roadmap.

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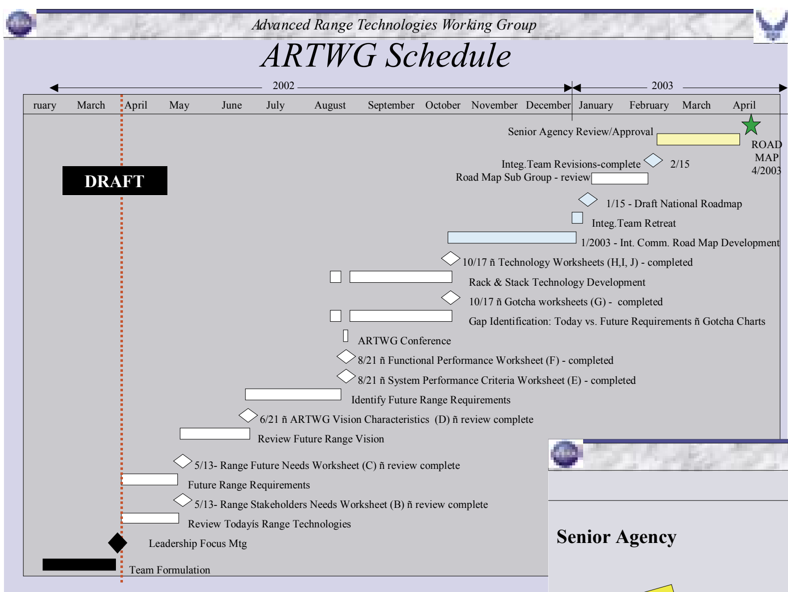
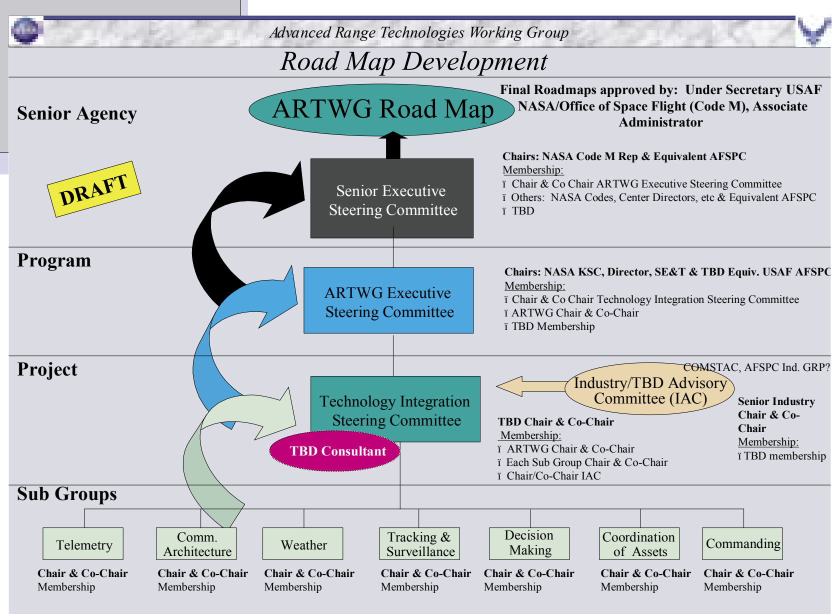
Participating Organizations: NASA: VB (J.M. Shaver), PH (S.J. Swichkow), TA (R.A. Turner), and YA (E.C. Denson and J.T. Madura); U.S. Air Force (Maj. D. Buck); Florida Air National Guard (Lt. Col. R. Schofield); Air Force Research Laboratory (Dr. S. Slivinsky and R.F. Ogrodnik); Aerospace Corporation (M. Fallon); Alaska Space Authority (P. Ladner); Air Force Space Command (Maj. D. Fogle and Maj. S. Van Sant); Booz, Allen, Hamilton (V. Villhard); and FAA (R. Heuwinkel)





Spaceport Structures and Materials

Advanced structures and materials are critical to achieving the goals of reduced costs, increased reliability, and higher flight rates for future spaceports. Spaceport structures and materials technology development areas include corrosion abatement, static charge dissipation, nondestructive evaluation (NDE), and nonflammability. Sources of corrosion and material degradation include humid saltwater environments surrounding launch structures and aggressive ozone and hard radiation environments of Earth orbit. Static charge buildup on payloads, spacecraft, and launch structures can present significant safety issues for personnel and equipment. Advanced flammable materials are desirable to enhance the safety of crew and ground personnel during operations. NDE technologies are critical to obtaining rapid status analysis of flight hardware. Since materials are ubiquitous in spaceflight, the reach of this technology thrust area will encompass launch structures, payload processing, spacecraft design, and vehicle maintenance.

Technology focus areas include the following:

- Launch Structures and Mechanisms
- Corrosion Science and Technology
- Electromagnetic Physics
- Materials Science and Technology
- Nondestructive Evaluation

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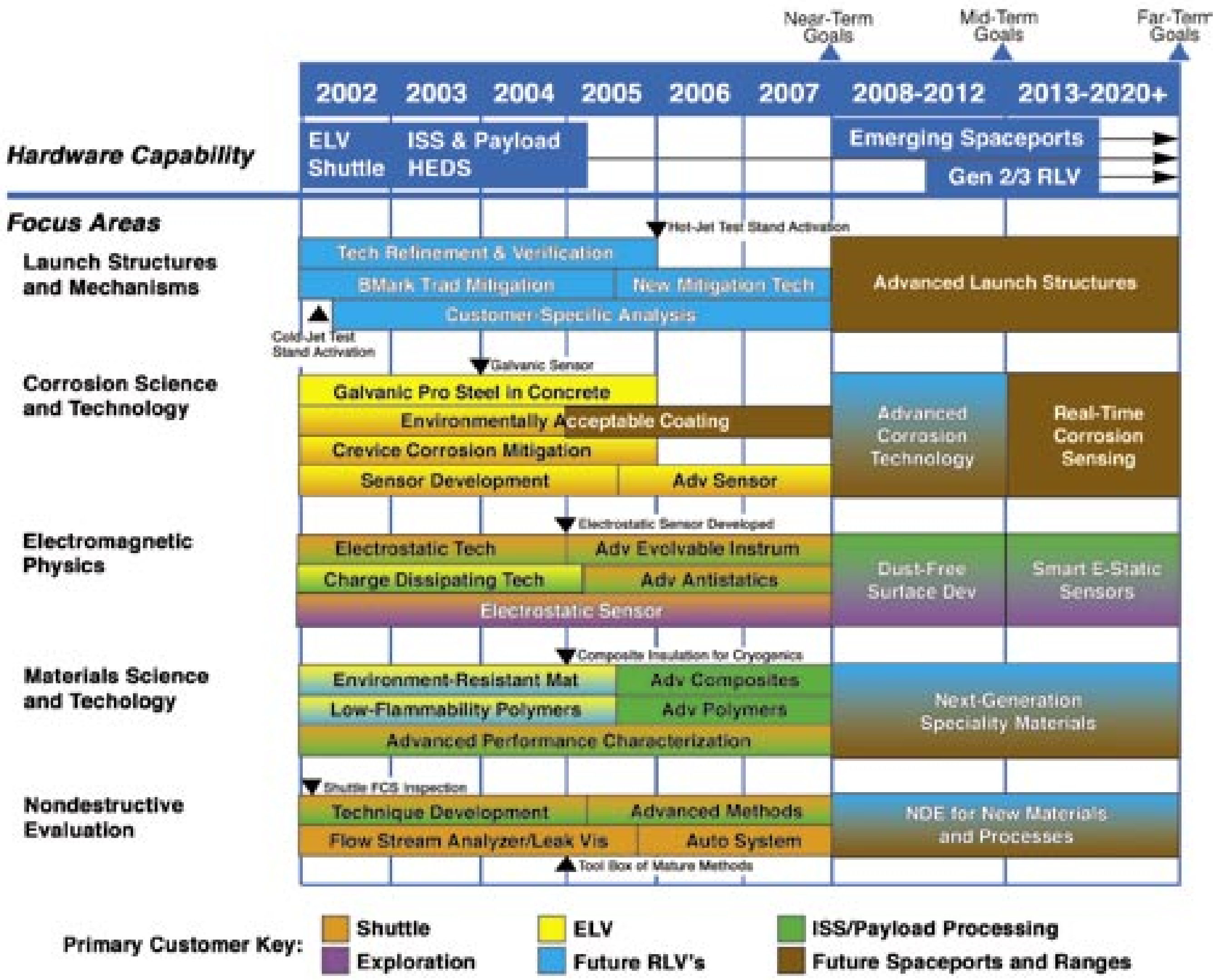
KSC Spaceport Structures and Materials Roadmap



Goals Specific to Focus Areas

- Ensure safe, efficient, and reliable structures techniques
- Enhance reliability and reduce maintenance cost of infrastructure
- Improve safety and reliability of operations through detection, mitigation, and prevention of electrostatic generation on equipment
- Develop specialty materials in support of future structures and materials initiatives

Launch Systems Testbed (LST) Capability Development

The Launch Systems Testbed's overall mission is to reduce costs and increase safety, availability, and maintainability of launch structures and mechanisms exposed to rocket launch environments.

The LST consists of the following four major components:

- Test Analysis Personnel – with specialized skills in structural dynamics, launch environments, fluid dynamics, and thermodynamics.
- Launch Environments Database – a knowledge reservoir of launch data from over 100 rocket launches.
- Scaled Test Facility – liftoff trajectory simulation capability with single or multiple supersonic flow nozzles.
- Basic Research Access – cooperative network of researchers around the world interested in future spaceport technologies development.

Significant effort has been directed toward planning and design/building activities leading to the development of LST infrastructure: a Trajectory Simulation Mechanism (TSM) and an LST Control Room. These are located inside the NASA Kennedy Space Center Industrial Area at the Launch Equipment Test Facility (LETF). Whereas the TSM is used to simulate a nonstationary scaled launch-induced environment, the LST Control Room is the nerve center for the control of TSM parameters and acquisition of acoustics, vibration, and related environmental data.

Current plan calls for the development of innovative schemes for launch exhaust management. The initial work will characterize the covered and uncovered duct with a J-deflector as a baseline for comparison and define the acoustic and rocket plume flow fields. Candidate schemes will be developed, and a subset will be selected for further study. These exhaust management schemes will be modeled, studied, and ranked using field testing and analytical techniques.

LST activities have a common goal of enhancing the research and development of vibroacoustic and structural analysis in the launch environment. They encompass the following key areas:

- Benchmark Traditional Mitigation – assess conventional method used to mitigate launch environments such as water deluge and covered ducts.
- Newer Mitigation Tools – develop traditional techniques to mitigate rocket-induced environments such as nontraditional duct geometrics, resonators, and diffusers.
- Customer-Specific Analysis – apply techniques to solve launch-induced environment issues for launch system developers and rocket engine test manufacturers and facilities.
- Technique Refinement and Verification – develop advanced analysis and design techniques verified with test or launch data, with subsequent prediction of the launch

Trajectory Simulation Mechanism

environment and its effect on launch structures/mechanisms.

- Advanced Launch Structures – develop with partners the next-generation launch structures to lower overall space transportation costs.

Future missions will derive benefits by avoiding active systems like igniters and water suppression systems; lessen possibility for hydrogen entrapment; reduce the acoustic environments at the payload, vehicle, and ground systems; and eliminate sound suppression water disposal issues.

In addition, KSC personnel, in concert with other Government organizations, academia, and the space industry, will attempt to contribute innovative launch exhaust management ideas to future pad architectures, static rocket engine test stands, and launch service providers.

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Participating Organization: Dynacs Inc. (Dr. R.N. Margasahayam)

Electrochemical Analysis of Chloride Rinse Agents on Aircraft Alloys

The purpose of this project is to analyze the effects of several chloride rinse agents (CRA's) on aircraft alloys using electrochemical techniques. This analysis is being carried out in parallel with the "Army Corrosion Retardant Additive Testing" that is being conducted by NASA and Dynacs at the Beach Corrosion Test Site at Kennedy Space Center.

The study analyzes the corrosion behavior of eight different metal alloys (listed in the table) immersed in six different solutions and in demineralized water. The solutions include four commercially available chloride rinse agents along with seawater and 3.5-percent sodium chloride (NaCl). The seawater and the demineralized water are being included as controls. The 3.5-percent NaCl solution was included because it is often used as a substitute for seawater and because of the availability of data on the corrosion behavior of materials in this environment. The commercially available rinse agents are being diluted in accordance with the manufacturers' specifications.

The study being conducted includes measurement of the open-circuit potential for an hour, linear polarization, potentiodynamic scans (PDS's), and cyclic polarization scans. The series of experiments is being conducted at different immersion times to monitor the performance of the metal with immersion time. An electrochemical flat cell designed to expose 1 square centimeter of metal to the rinse (electrolyte) is being used in the investigation. The data obtained will be analyzed to determine the corrosion rate, the susceptibility of the metal to pitting corrosion, and the magnitude of recovery.

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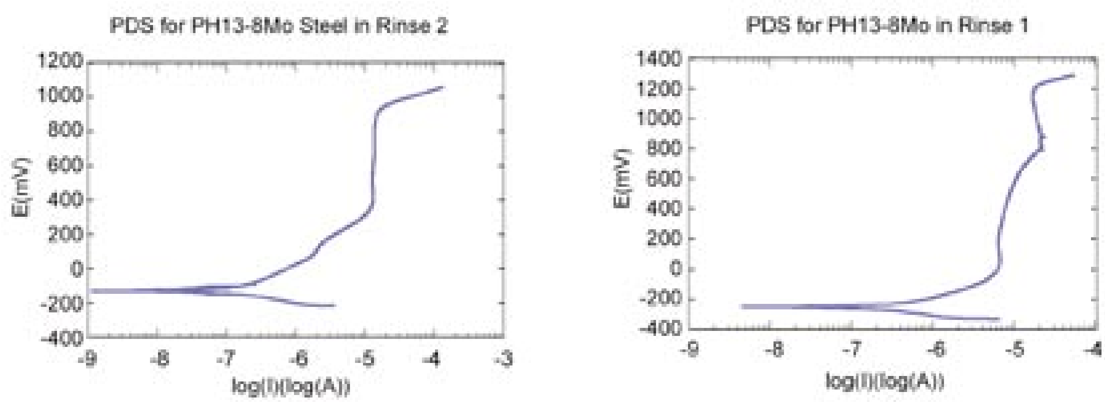
Participating Organization: Dynacs Inc. (R.D. Vinje and J.J. Curran)

Metals, Rinses, and Techniques Used in the Electrochemical Analysis of Chloride Rinse Agents on Aircraft Alloys

Metal Alloys		Rinses*	Electrochemical Techniques*
Aluminum	Al 2024 T3	Rinse 1	Corrosion Potential
	Al 7075 T6	Rinse 2	Linear Polarization
Steel Alloy	4340	Rinse 3	Potentiodynamic Scan
High-Strength Steel	PH13-8Mo	Rinse 4	Cyclic Polarization
	C 250	Seawater	
	AM 350	Demineralized Water	
Titanium Alloy	Ti-6Al-4V	3.5% NaCl	
Magnesium Alloy	AZ31B-H24		
** All rinses and electrochemical techniques are used on each metal.*			

Electrochemical Instruments and Laboratory Setup



Potentiodynamic Scans Recorded During Preliminary Experiments

Characterization of Experimental Primerless Silicone Coatings by Electrochemical Impedance Spectroscopy

NASA and other space organizations face the difficult challenge of protecting launch pad structures from corrosion. Thin-gauge stainless-steel and aluminum structures, such as protective bellows around drive mechanisms, flex repeatedly and thus require highly flexible and adherent coatings. The aerospace industry has traditionally used paints having high volatile organic compound (VOC) content for protecting vehicles and support structures. Flexible paints employ highly solvated rubber binder resins that render the products highly volatile and difficult to apply by spraying. Silicone-based paints are formulated to yield temperature- and weather-resistant coatings that prevent corrosion by forming effective electrolyte barriers. However, silicones are normally delivered from organic solvents and exhibit poor adhesion to unprimed metals.

Waterborne elastomeric anticorrosion coatings are being developed for the corrosion protection of metals such as aluminum and stainless steel in corrosive environments. These coatings consist of aqueous dispersions of silicone resins, stabilized with polymeric surfactants and pigmented with nontoxic anticorrosive additives. The latter silicone-modified polymers yield emulsions that adhere the coating to metal surfaces. By forming a topcoat-bound primer layer in situ, low-VOC coatings having simple application properties can be formulated. The ultimate goal in developing the coatings is to provide an effective, environmentally sound method for protecting the surfaces of aluminum and stainless steel without introducing additional pretreatment and priming steps.

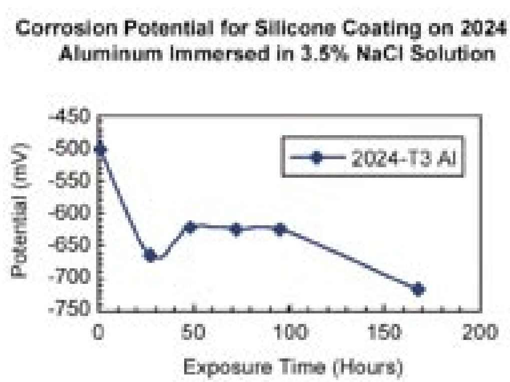


Figure 1. Open-Circuit Potential as a Function of Immersion Time in 3.5% NaCl for Silicone Coating on 2024-T3 Aluminum

A formulation of a VOC-compliant primerless silicone coating for corrosion control was characterized by Electrochemical Impedance Spectroscopy (EIS) and open-circuit potential measurements. The test samples used in this investigation consisted of panels of 2024-T3 aluminum, 316 stainless steel, and cold-rolled steel 1010 coated on one side with the experimental primerless silicone coating. Panels of the bare alloys, as well as an aluminum panel and a 304 stainless-steel panel coated with Aerocoat 7 (AR-7), were also tested. AR-7 was used as a control coating because of its excellent corrosion protection performance during 18 months of exposure at the Kennedy Space Center Beach Corrosion Test Site. Each sample was placed in an electrochemical cell and studied at various immersion times for up to 1 week in an electrolyte solution that consisted of aerated 3.5-percent salt (weight-by-weight) (NaCl). The cell

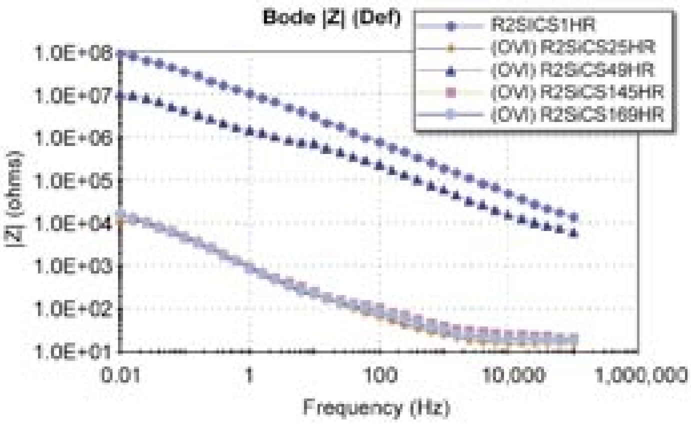


Figure 2. Bode Magnitude Plots for Silicone-Coated Carbon Steel at Different Immersion Times in 3.5% NaCl

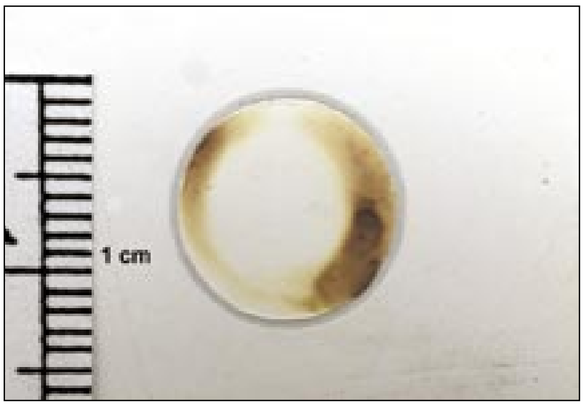


Figure 3. Silicone-Coated Cold-Rolled Steel Panel After 168 Hours of Immersion in 3.5% NaCl

Figure 4. Silicone-Coated Al 2024-T3 Panel After 168 Hours of Immersion in 3.5% NaCl

is designed to expose a circular area of 1 square centimeter to the electrolyte.

Open-circuit potential, as well as impedance measurements and visual observations, indicated that the newly developed primerless silicone coating provided effective corrosion protection of 316 stainless steel but was ineffective on aluminum 2024 T3 and cold-rolled steel. The failure was greater in the case of the cold-rolled steel. It was also determined that AR-7 provides a better degree of corrosion protection on aluminum 2024-T3 than on 304 stainless steel.

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Participating Organization: Dynacs Inc. (R.D. Vinje)

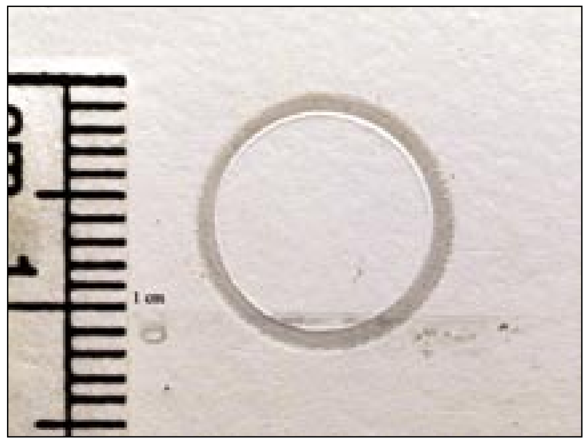


Figure 5. Silicone-Coated 316 Stainless-Steel Panel After 168 Hours of Immersion in 3.5% NaCl

Figure 6. AR-7 Coated 304 Stainless-Steel Panel After 168 Hours of Immersion in 3.5% NaCl

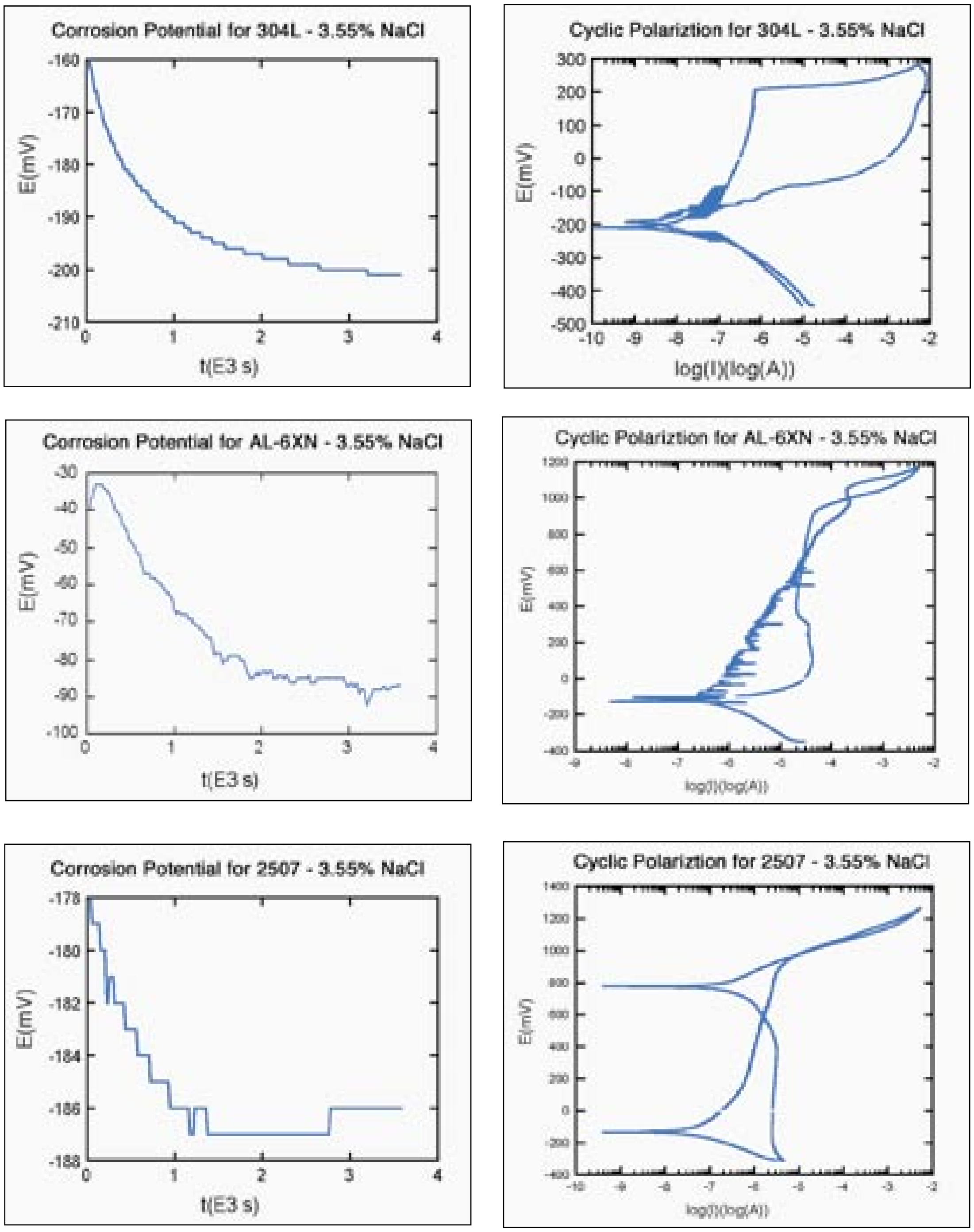
Electrochemical Characterization of Tubing Alloys in Simulated Space Shuttle Launch Pad Conditions

The 304L stainless-steel (304L SS) tubing is used in various supply lines that service the Orbiter at the KSC launch pads. The atmosphere at the launch site has a very high chloride content caused by the proximity of the Atlantic Ocean. During a launch, the exhaust products from the fuel combination reaction in the Solid Rocket Boosters include concentrated hydrochloric acid. The acidic chloride environment is aggressive to most metals and causes severe pitting in some of the common stainless-steel alloys. The 304L SS tubing is susceptible to pitting corrosion that can cause cracking and rupture of both high-pressure gas and fluid systems. The failures can be life-threatening to launch pad personnel in the immediate vicinity. Outages in the systems where the failure occurs can affect the safety of Shuttle launches. The use of a new tubing alloy for launch pad applications would greatly reduce the probability of failure, improve safety, lessen maintenance costs, and reduce downtime losses.

The objective of this investigation was to study the electrochemical behavior of 10 corrosion-resistant tubing alloys to replace the 304L SS tubing at the Space Shuttle launch sites. The alloys included 317L, 316L, 2205, C-276, 625, 254 SMO, C-2000, AL-6XN, AL29-4C, and 2507. For comparison purposes, 304L SS was included in the study. The specimens were flat panels of various sizes obtained by cutting the tubes and flattening them. Three electrochemical techniques were used to evaluate the performance of the materials: corrosion potential, polarization resistance, and cyclic polarization. The samples were placed in an electrochemical cell designed to expose a metal surface area of 1 square centimeter to the electrolyte solution. These solutions emulate conditions that are less aggressive than, similar to, and more aggressive than those found at the launch pads at KSC.

Analysis of the electrochemical data showed that the nickel-based alloys C-2000, C-276, and 625, along with the iron-based alloys 254 SMO and 2507, exhibited a corrosion resistance superior to the other alloys included in this investigation. The 304L, 316L, and 317L alloys exhibited the lowest resistance to corrosion. No conclusive cyclic polarization data were obtained for AL29-4C, but the corrosion potential and the polarization resistance measurements indicated an intermediate resistance to corrosion among the alloys tested. AL-6XN and 2205 also showed intermediate resistance to corrosion.

A comparison between the results from electrochemical measurements under conditions emulating those found at the launch pad and those from long-term atmospheric exposure revealed a strong correlation between the predictions based on cyclic polarization measurements and actual performance under atmospheric exposure. It was also determined that the area of the hysteresis loop was the best parameter to predict the actual performance of the tubing alloys.



Corrosion Potential and Cycle Polarization in 3.55% NaCl

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Participating Organization: Dynacs Inc. (R.D. Vinje)

Advanced Multisensor for Electrolytic Characterization

This effort is directed toward the development of a multisensor device that is capable of characterizing the conductive and corrosive nature of a medium. More specifically, a device is being developed and tested with the intent of identifying electrolytes in both the aqueous and solid states, as well as to develop the methodology needed to analyze and interpret the data. Ultimately, the integration of the sensor into a subsurface explorer probe aims to determine the feasibility of (1) grounding experimental devices on Martian soil, (2) utilizing the soil as an electrical return path, and (3) using the experimental data to design materials that will prevent the corrosion of devices that come into contact with Martian soil. While the focus of the research centers upon the development of a device to study interplanetary surfaces, commercial applications are feasible and anticipated. These may include but are not limited to agricultural, biological, and geological analyses.

To accommodate these goals, a device was constructed that consists of three major components (figure 1). The first is an ion selective electrode (ISE) array, which has the potential of determining individual ions in solution based upon the potentiometric analysis across a carrier-based polymeric membrane. The second constituent of the device aims to complement the first technique by using anodic stripping voltammetry (ASV). ASV is an analytical method in which analytes are preconcentrated on the surface of a working electrode for a specific duration. Through an anodic potential scan, the analyte is then stripped from the working electrode and is oxidized back to its original form, with a voltammetric determination indicating the ions present in solution. The final element of the device consists of a galvanic

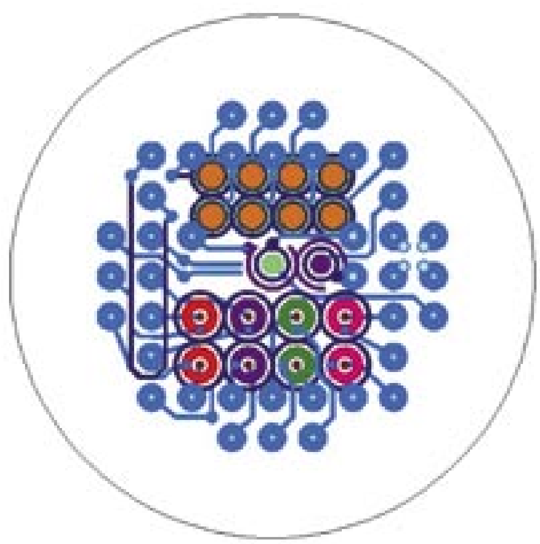

Figure 1. Diagram of Sensor Based on Electrochemical Techniques To Detect and Identify Ions in Solution

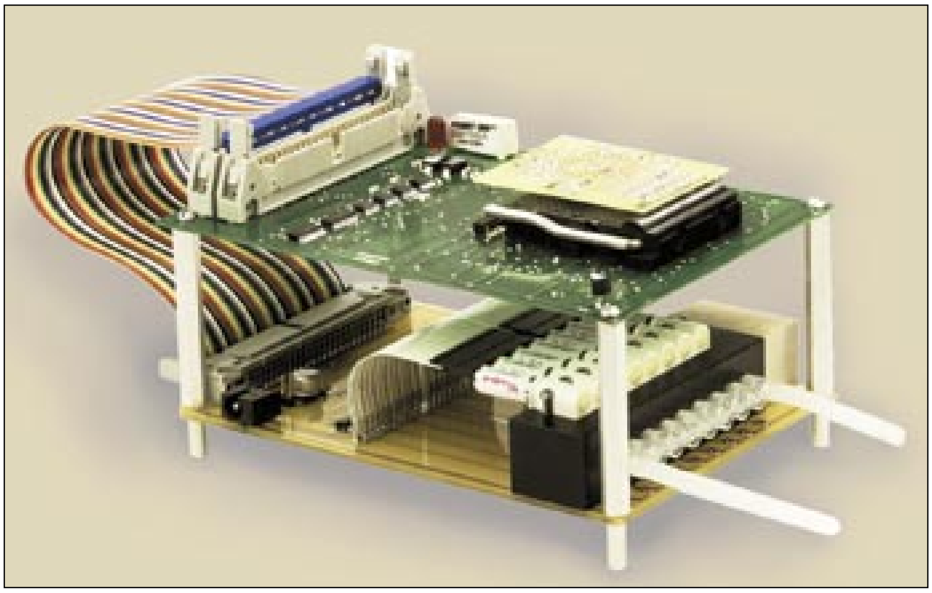

Figure 2. Fluidics Board

cell array. Using this methodology, the galvanic couples are arrayed, and the current is measured between differing anodic and cathodic metals. While in contact with an electrolyte, the short-circuit current generated between the galvanic couples is then monitored. Through the use of pattern recognition techniques, an investigation will ensue to analyze the electrolyte present in solution. In essence, the galvanic cell array will then be used to determine the conductive and corrosive nature of the matrix in question.

Most beneficial to the development of the multisensor is the choice of differing methods of analysis. Specifically, while individual analytes may be difficult to discriminate using one technique, the multiple processes may allow for the determination of ionic species in a multicomponent solution at concentration limits unobtainable with any one technique by itself. In response to this need, a prototype device was built by the Jet Propulsion Laboratory (JPL) and delivered to KSC in December 2001. This prototype is shown in figure 2. In order to determine whether the complex device is working properly, a resistor card was employed to test and improve the device in the acquisition of data. Initial studies have centered upon the concentration dependent analysis of individual ions present in solution, with multianalyte determinations employed to represent real-world conditions.

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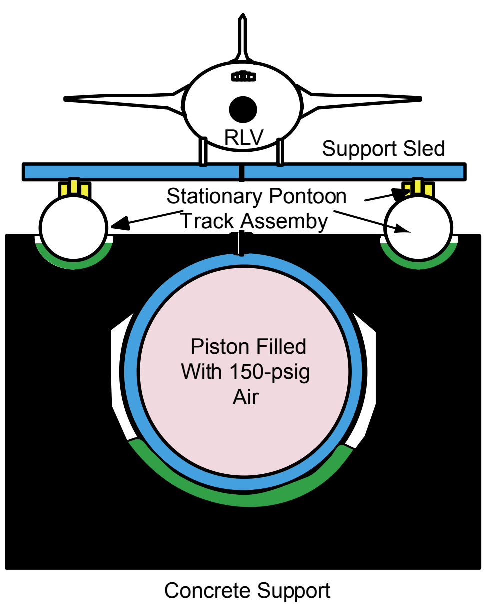
Participating Organizations: NASA/JPL (Dr. M.G. Buehler), NASA/KSC (N.P. Zeitlin), Swales Aerospace (Dr. M.R. Kolody), and Tufts University (Dr. S.P. Kounaves)

CELT Pneumatic Launch Assist

This proposal would develop pneumatic propulsion for a launch assist system. The Closed-End Launch Tube (CELT) system uses an elevated air pressure to push a moving piston down a cylinder. The piston is coupled to a low-friction sled riding directly above the cylinder, with the sled carrying the payload Reusable Launch Vehicle (RLV). The CELT system would be propelled by medium-pressure (150 pounds per square inch gage [psig]) air storage chambers, both stationary and on the moving piston, to raise air pressure directly behind the piston. Commercially available compressors can fill the air storage chambers in less than 2 hours. We would propose to start the RLV's engines to gain additional thrust and confirm proper engine operation prior to activating the launch assist system.

The system is attractive because of its highly efficient energy utilization employing existing technology and materials. The technique can be scaled to much larger payloads by simply increasing the diameter of the cylinder. The design incorporates fail-safe low-g abort by venting the gas supply behind the piston, combined with a preset closed chamber ahead of the piston to develop gas pressure and brake the vehicle without excessive g loading. The CELT can reduce operational costs and complexity and can provide significant payload increases on RLV's without the long, expensive development of other launch assist projects.



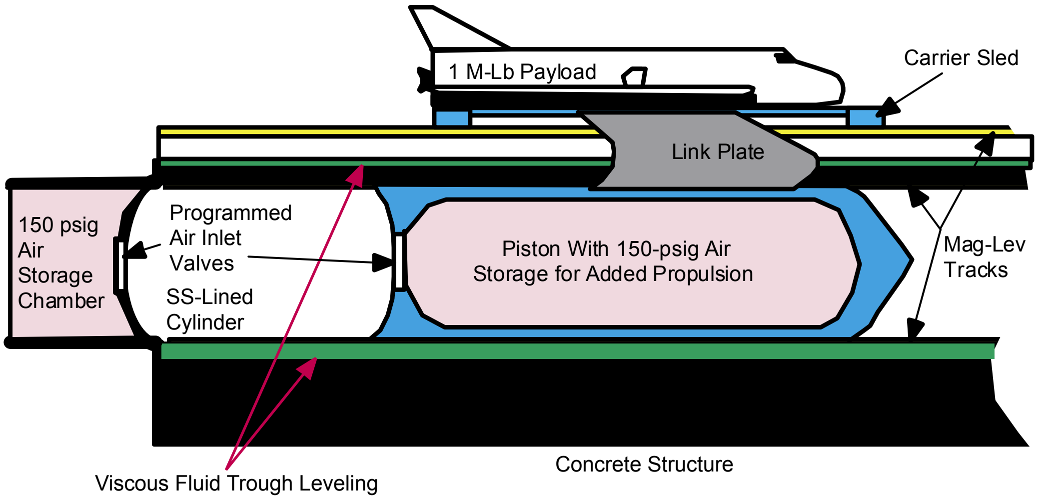
Cross-Section View

The rates of gas introduction, along with the rarefaction produced behind the moving piston and the compression wave in front of it, are challenges to the concept. The current project will advance the technology by modeling the system fluid dynamics and forces and testing the model against a laboratory-scale pneumatic tube.

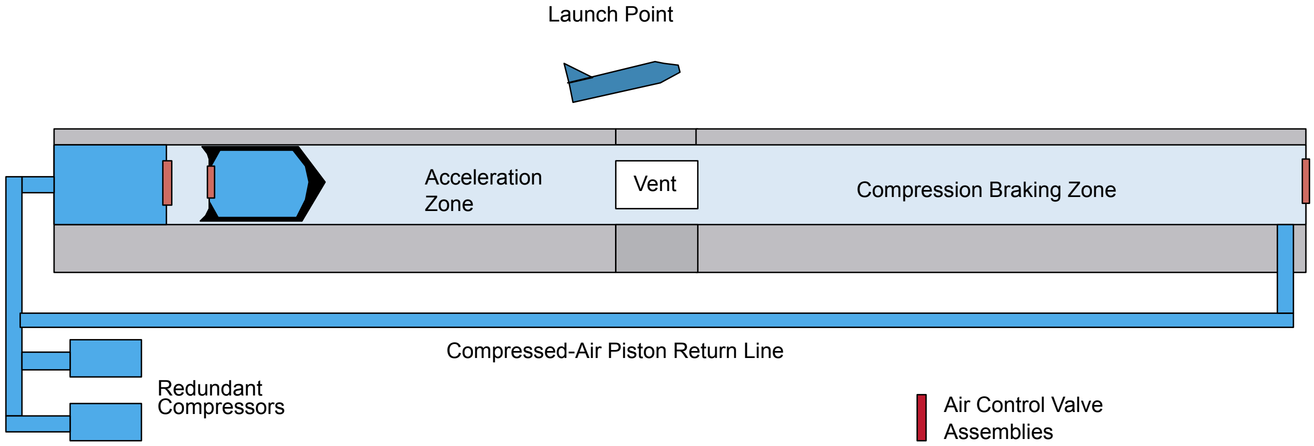
A 3-inch-diameter, 1000-foot system is being designed and constructed to allow direct experimental verification of the tradeoffs for evacuation of the tube ahead of the piston, the effects of gas injection from the piston, and gas composition and temperature effects on terminal velocity in a practical pneumatic drive system. Telemetry from the piston will record acceleration and cylinder pressures near the piston, while pressure transducers and optical sensors on the pneumatic tube provide far-field pressure, position, time, and velocity information.

The acceleration tube is constructed from commercial sanitary tubing, with the inside surface polished to a 20-microinch finish. The acceleration and braking gas storage containers are standard ASME 200-psig compressed-air vessels. The controls are pneumatic with electronic initiation via a LabView data acquisition and control system. During the expected 2-second experiments, the 16 pressure transducers and 14 optical sensors will provide continuous pressure data and discrete position and velocity data versus time.

Results will be used to verify and upgrade the model, benchmark the numerical solutions, and predict the performance of the 1-percent demonstrator and the full-scale system. Selection would be made for the best terminal velocity design for a practical, scalable system.



Longitudinal Cut-Away View



CELT System Design Concept

Key accomplishments:

- Published paper detailing feasibility, costs, and development schedules.
- Submitted proposals to both Gen 2 and Gen 3 programs.
- Design and ongoing construction of a 3-inch × 1000-foot prototype CELT track (1-percent scale model) that will test the key functions of the proposed launch assist system:
  - Long-tube pneumatic acceleration effects.
  - Piston gas release for propulsion.
  - Pneumatic gas braking.
  - Need for and degree of tube evacuation.
  - Ability to achieve 600 miles per hour.
- Design of both dumb and "smart" (instrumented) prototype projectile to be launched in test track.
- Construction of noninvasive sealed clamp assembly to hold transducers.
- Construction of data acquisition system to measure gas pressure and projectile velocity at 15 positions.

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Participating Organizations: YA-D1 (B.R. Hardman, M.J. Lonergan, and B. Vu), YA-D2 (J.M. Perotti and G.A. Hall), and Dynacs Inc. (Dr. C.D. Immer, J.J. Randazzo, and A.J. Eckhoff)

Chromate Coating Replacement for Aircraft

The objective of this project is to expose approximately 960 coupons to a harsh, outdoor marine environment at the NASA Kennedy Space Center Beach Corrosion Test Site (BCTS) while tracking the deterioration of the surface pretreatments and coatings. This study is to determine the effectiveness of protection of environmentally compliant replacement technology for chromate-inhibited coatings for aluminum materials on military aircraft.

The 960 coupons form a matrix of 4 materials having 9 pretreatments, each of which have 5 paint systems, all in sets of 3 or 5 coupons. Each coupon is scribed and will be evaluated in accordance with ASTM D 1654, Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments. The coupons will remain at the BCTS for at least 1 year. Those coupons showing little or no degradation at the end of the 1-year period may be exposed for a longer period of time. Baseline data has been collected, and further evaluations will include periodic visual inspections and photo documentation at predetermined monthly increments.

Key accomplishments:

- Built racks to hold 960 nonstandard-sized coupons.
- Installed approximately 960 coupons at the BCTS.
- Completed initial photo documentation.
- Developed a portable camera stand for taking consistent coupon photographs in place at the BCTS.

Key milestones:

- A 6-month summary of results.
- A 12-month report of the test evaluation.

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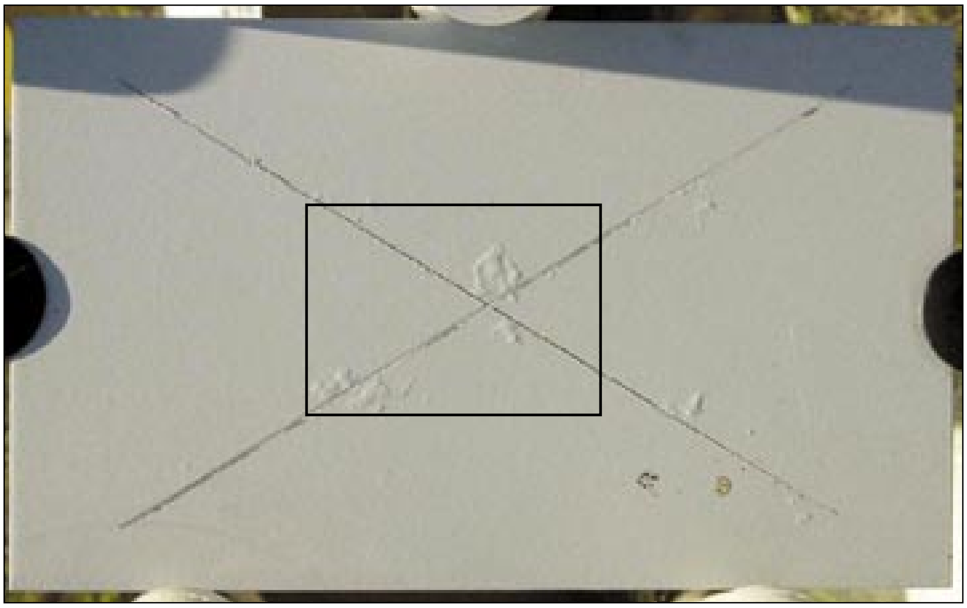
Participating Organization: Dynacs Inc. (J.J. Curran, T.R. Hodge, and J.P. Curran)

Coupon Racks at the BCTS



Typical Coupon
That Has Started To Blister

Closeup of Coupon Blister

Development of Liquid Applied Coatings for Protection of Steel in Concrete

Corrosion of reinforcing steel in concrete is an insidious problem facing KSC, other Government agencies, and the general public. These problems include damage to KSC launch support structures, such as transportation and marine infrastructures, as well as building structures. Because of these problems, the development of a galvanic liquid applied coating (LAC) system would be a breakthrough technology having great commercial value for the following industries: transportation infrastructure, marine infrastructure, civil engineering, and construction. The present effort to develop this type of system is directed at several goals:

- Phase I concentrated on the formulation of coatings with easy application characteristics, predictable galvanic activity, long-term protection, and minimum environmental impact. These new coating features, along with the electrical connection system, will successfully protect the embedded reinforcing steel through the sacrificial cathodic protection action of the coating.

- Phase II improved on the formulations, included optimizing metallic loading, and incorporated a humectant for continuous activation. In addition, development of optimum electrical connections will continue.

- Phase III will incorporate improvements from the previous phases to the test blocks.

- Phase IV will incorporate the final upgrades onto large structures that are heavily instrumented (figure 1).

Figure 1. Phase IV Test Slab

Laboratory testing has demonstrated the commercial potential of this technology. Presently, testing is being conducted at the KSC Materials Science Beach Corrosion Test Site with positive preliminary results (figure 2) demonstrating that the coating meets the National Association of Corrosion Engineers criterion for effective cathodic protection. In addition, the data is being collected and remotely accessed from offsite locations (figure 3).

Successful development and continued optimization of this breakthrough system would produce great interest in NASA/KSC Corrosion Technology Testbed Facilities. Commercial patents on this technology would enhance KSC's ability to attract industry partners for similar corrosion control applications and establish the Corrosion Technology Testbed as a leader in solving corrosion problems.

Key accomplishments:

- Proved the feasibility of using liquid applied coatings for protection of embedded reinforcing steel in concrete.
- Determined the optimum mix ratio for specific liquid applied coatings.
- Determined that the addition of moisture attractors shows little or no benefit to coating performance.
- Developed improved electrical connectivity between the coating and the internal reinforcing steel.

- Added intensive embedded instrumentation in new simulated concrete structures for monitoring corrosion protection.

Key milestones:

- 2001/2002: Move the liquid applied coatings testing from small-size samples (11 × 6 × 4.5 inches) to larger structures (4 feet × 4 feet × 7 inches). The new structure concrete design mix will include chlorides to simulate a contaminated reinforced concrete structure.

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Participating Organization: Dynacs Inc. (J.J. Curran and J.P. Curran)

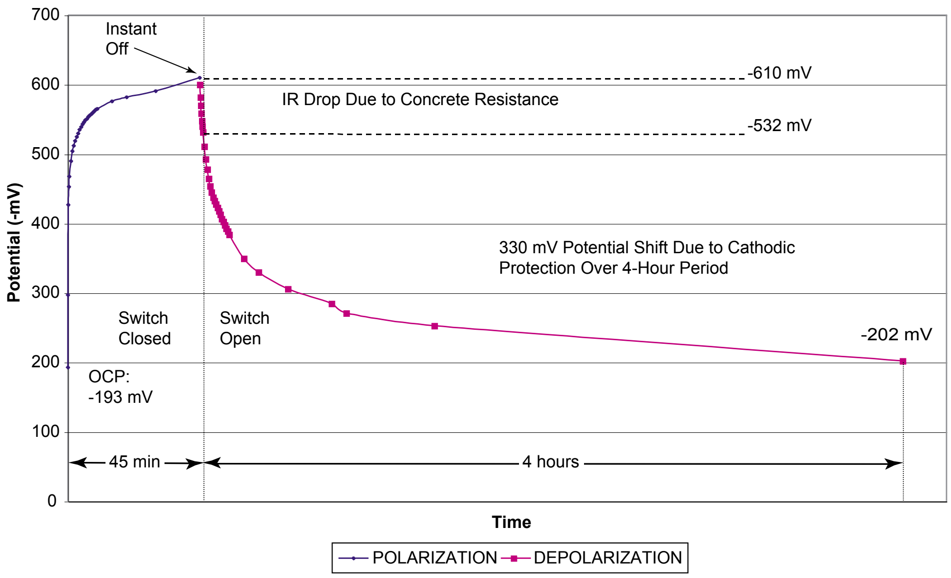


Figure 2. Polarization/Depolarization of LAC Test Block 2 1/11/2002

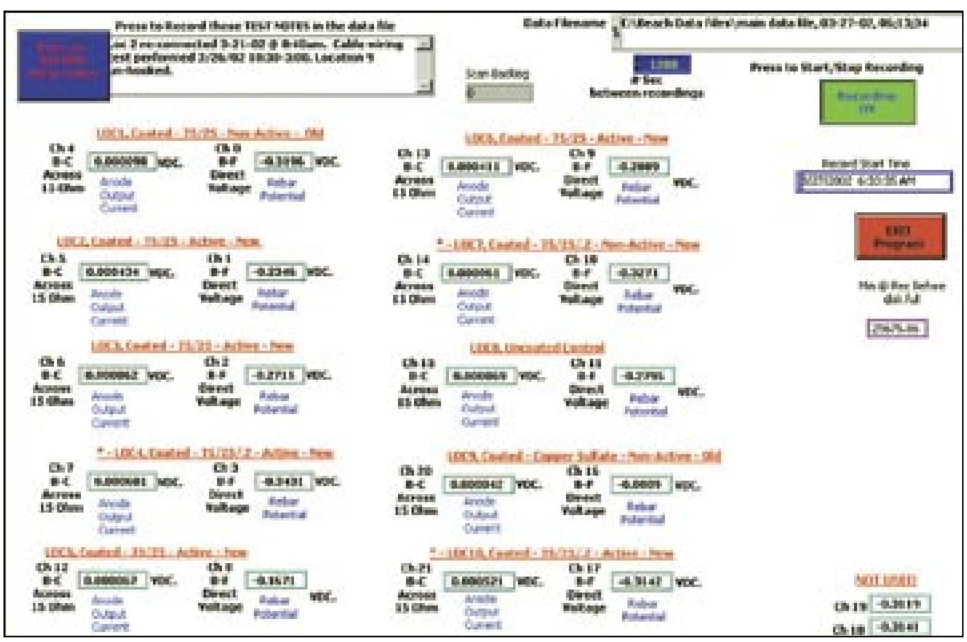


Figure 3. Remote Data Acquisition for Test Blocks

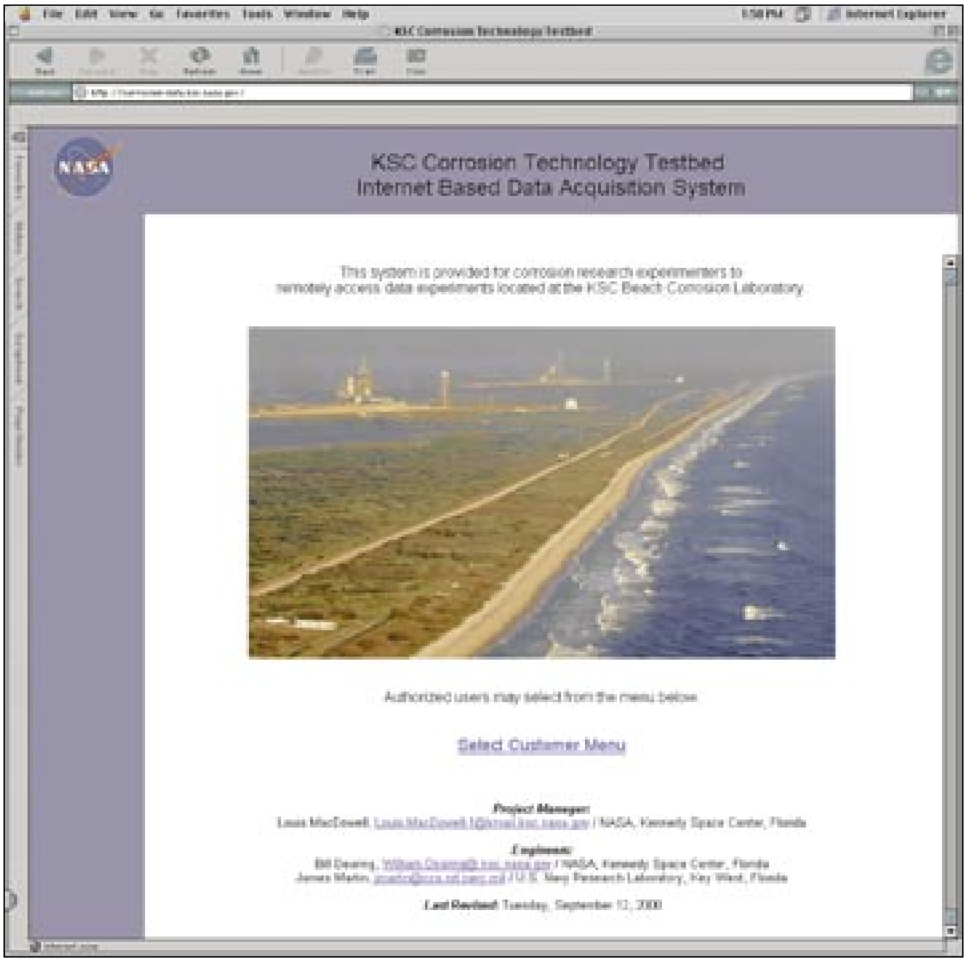
Remote-Access, Internet-Based Data Acquisition System

Current outreach efforts for KSC's Beach Corrosion Test Site require all experimentation and data collection be conducted by onsite personnel on a real-time basis. This restricts the amount of work conducted at the site because of personnel constraints. A Remote-Access, Internet-Based Data Acquisition System will establish a basis for the Corrosion Technology Testbed to allow personnel and customers to conduct their experiments from remote locations using the Internet.

This state-of-the-art pathfinder acquisition system could be utilized as a model for other NASA and KSC laboratories to directly develop their capabilities without the resulting impact to personnel and travel expenses. In addition, successful development and continued optimization of this system will produce great interest in NASA/KSC for corrosion research, corrosion exposure contracts, and industry partnerships. The benefits of this project include:

- Showcasing NASA/KSC's outreach efforts through interactivity and state-of-the-art innovative technologies.
- Establishing a Corrosion Technology Testbed for use by other NASA laboratories.
- Allowing direct outreach of the KSC Beach Corrosion Test Site to customers around the country and around the world.
- Allowing customers to conduct corrosion research without the travel requirements to the exposure site.
- Allowing business expansion at the site without the direct need for additional personnel.
- Developing network solutions to allow remote operation of experiment and data collection systems.
- Developing software with security features that allow outside customers to have data access at a KSC site.
- Testing the resulting systems to prove feasibility and optimize user interface and expansion capabilities.

This interactive system will have significant commercial applications for outreach to corrosion research laboratories, the corrosion control industry, Government laboratories, paints and coatings industries, and the marine technology industry.



Key accomplishments:

- Developed and approved a detailed security plan for this project for use at KSC.
- Completed fiber-optic network upgrades at the Beach Exposure Test Site that provide the level of network service required for this project. Installed a network rack to consolidate equipment and save space in the trailer.
- Installed indoor and outdoor webcams for use by corrosion site customers. These systems can be controlled remotely via a Web browser and include pan-tilt-zoom features. The webcams are currently accessible off-site by Corrosion Testbed customers from Government and industry. Access to these cameras is password-protected and allows customers to remotely view the current condition of their atmospheric exposure samples.
- Installed a 50-data-channel network from the exterior exposure site to the interior of the KSC Beach Corrosion Test Site for monitoring remote-access corrosion experiments.
- Created a Web site to interact with the KSC Beach Corrosion Test Site experiments.
- Integrated software and hardware to provide a secure and reliable system to monitor and control data acquisition computers.
- Developed data acquisition software to interface with the Internet.
- Collected data from 15 remote experiments proving the concept.
- Developed a prototype client application that will provide access to data acquisition systems from outside KSC. This application will have built-in security features that allow the customer to control a research experiment without presenting a significant computer security risk to KSC.

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Participating Organization: Dynacs Inc. (J.B. Crisafulli and J.J. Curran)

Surface Characterization of Polyimide Foams After Exposure to Oxygen Plasma

Because polyimide films like Kapton are used extensively in space applications such as low Earth orbit (LEO), their performance properties in space conditions are well characterized. Polyimide foams, on the other hand, have not been particularly studied and characterized in this environment. Recent advancements in high-temperature polymeric materials at NASA Langley Research Center have led to the development of new polyimide foam systems with attractive properties. These new polyimide foam systems have potential space applications because of their light weight, their relatively high operating temperature, and their cryogenic properties.

Before utilizing polyimide foams in the aggressive environment of LEO, it is important to understand and predict performance characteristics and the mechanisms of degradation. This information is also important to the protective measures that might be required in the utilization of these materials.

The atmosphere at LEO altitudes has a composition that is essentially the reverse of that in the troposphere, 20-percent nitrogen and 80-percent oxygen. Without the overlying atmosphere to filter short-wavelength ultraviolet (UV) radiation (less than 243 nanometers), the molecular oxygen present is largely photo-dissociated to atomic oxygen (AO). Atomic oxygen is highly reactive and thus is prone to rapidly oxidize materials exposed to it. Making the situation more extreme is the fact that structures in LEO are typically moving rapidly, as fast as 8 kilometers per second, to maintain the orbit. Moving at that speed, it is typical for structures to collide with atomic oxygen with energy of as much as 5 electronvolts and to encounter 10^{15} oxygen atoms per square centimeter of surface area per second. In this study, an oxygen plasma generator was utilized to produce an atmosphere of atomic oxygen that would simulate the atmosphere of LEO. The oxygen plasma was generated with an SP1 Plasma Prep II plasma etcher. The effective atomic oxygen flux was determined using ASTM E2089-00, Standard Practices for Ground Laboratory Atomic Oxygen Interaction Evaluation of Materials for Space Applications.

Comparative surface analyses of samples seen in figure 1 (the first letter after TEEK indicates the series and the second letter indicates the density) were performed with a Kratos XSAM X-ray photoelectron spectrometer (XPS). XPS is a surface analysis technique that looks at the upper atomic layers of a solid surface. In XPS, electrons are ejected from a sample surface with a particular binding energy characteristic of the elements present. Shifts in binding energy can be related to oxidation or chemical states.

The mass loss data indicate that chemical structure, then density effects, followed by surface area appear to have the greatest influence on atomic oxygen resistance for the HH, HL, LL, and CL series, with resistance in decreasing order CL>LL>HH>HL (figure 2). The XPS

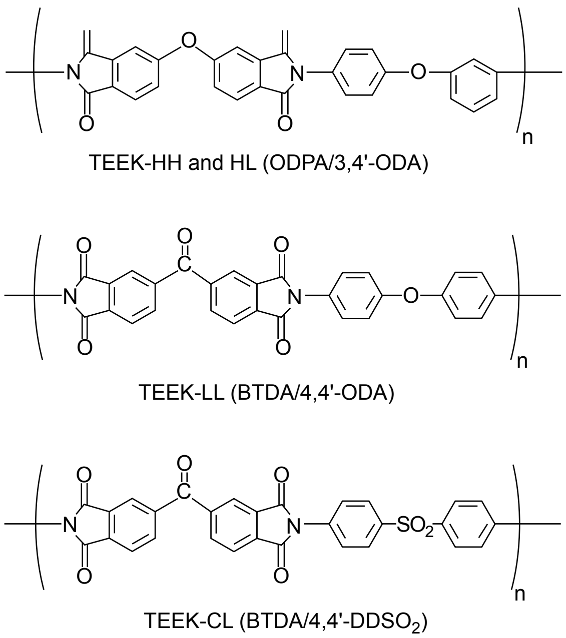

Figure 1. Chemical Structures of Foams

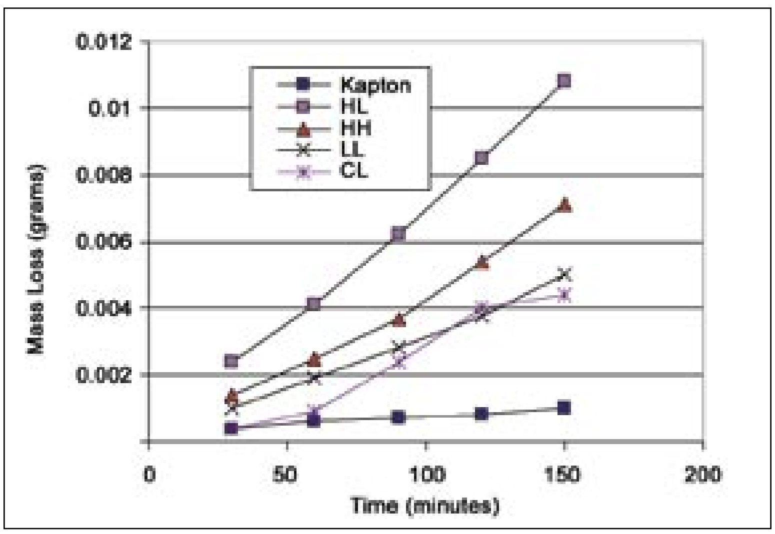

Figure 2. Mass Loss of TEEK HL, HH, LL, CL, and Kapton Tape

data indicate an overall oxidation of the foams. The data presented on the HL, LL, and CL foams showing an increase in carbonyl after atomic oxygen exposure correlate with the data previously reported on polyimide films. The higher-density HH series showed a decrease in the carbonyl group. This seems to indicate that the plasma is reacting with this group preferentially over atoms in the ring structure, resulting in some volatile products.

Key accomplishments:

- First surface chemistry study to evaluate the new polyimide foams systems performance characteristics with atomic oxygen for space applications.
- A technical paper was accepted for presentation and publication at the National American Institute of Aeronautics and Astronautics (AIAA) Meeting 2002.

Key milestones:

- A related study on the surface characterization of the weathering degradation of polyimide foams is currently in progress, and a technical paper was accepted for presentation at the 2002 National Meeting of the American Chemical Society.
- Several more publications and presentations on related research were made in 2001.

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Participating Organizations: Langley Research Center (E.S. Weiser), University of Central Florida (Dr. M.D. Hampton), Florida Institute of Technology (G.L. Nelson), and North Carolina Agricultural and Technical State University (S. Brown, KSC co-op)

A Study of the Degradation of High-Performance Polyimide Foams Using Infrared and Raman Spectroscopy Techniques

High-performance polyimide foams belong to a class of polymers characterized by strong thermal and chemical stability and resistance to degradation. At high densities they have strong mechanical properties as well. Recent advancements in high-temperature polymeric materials at NASA Langley Research Center have led to the development of new polyimide foam systems with attractive properties that allow for applications such as thermal and acoustic insulation and flame-retardant panels. They also have applications as insulation for the cryogenic fuel tanks for the next generation of reusable launch vehicles. It is therefore critical that we possess a thorough understanding of the behavior of these materials in extreme conditions and of their degradation processes. These studies can predict utilization parameters and could potentially enable early warning of impending material failure and greatly help failure analysis studies. In this study, select polyimide foams were thermally degraded to different extents under controlled conditions and then examined with both infrared (IR) and Raman spectroscopy in an effort to qualitatively and potentially to quantitatively describe the degradation processes.

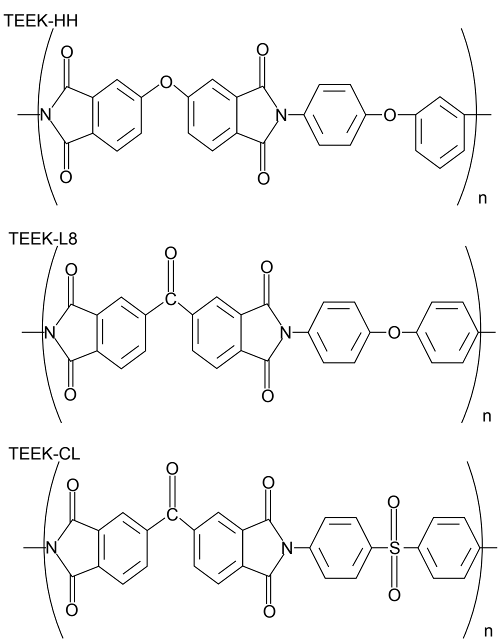

Figure 1. Molecular Structures of the Monomers for the Foam (All are aromatic, cyclic imide structures.)

The polyimides used in this study were all aromatic, cyclic imide polymers. The chemical structures can be found in figure 1. The select polymer foams analyzed were TEEK-HH, TEEK-L8, and TEEK-CL. The foam samples of different compositions had varying densities, though that was not a factor in this study.

The various foam samples were present in both degraded and virgin, or nondegraded, states. Thermal degradation of the foams was carried out by exposure to a radiant panel flame at a set distance. Multiple samples, each with a different flame exposure distance, were examined in an effort to observe changes in the foam throughout the degradation process. Samples of the foam materials were analyzed using a Bio-Rad 575C FT-IR spectrometer in combination with an FT-Raman accessory and a UMA 500 microscope.

Analyses of the samples' spectra were done both qualitatively in Bio-Rad Win-IR and semi-quantitatively in Microsoft Excel. Prior to studying changes in the spectra with degradation, it was necessary to correlate major functional groups with the IR and Raman spectra of the foams. Initially, the TEEK-HH structure was correlated, and then it was used as a guide in examining the other spectra. All of the samples were easily differentiated in the IR and Raman. The IR and Raman spectra of the TEEK-HH series are correlated in figure 2.

A definite increase in the OH-NH/CH ratio in the IR was observed with degradation between the TEEK polymers, with the degradation mechanisms similar. The OH-NH band peak at 3,631 cm^{-1} corresponds to O-H and N-H bonds in the molecular structure of degraded polyimide material; there are no such bonds in the original molecular structure. The IR of the degraded samples has primarily only shown changes in peak intensity and no major structural changes with degradation. The ratios, though, do seem to have great potential in gauging the degradation of the foam. The OH-NH/CH increase with degradation indicates the formation of a polyamic acid. It had proved more difficult to monitor degradation in the Raman. It is believed that the response in Raman is decreased significantly because of the weak response of Raman overall and the actual polymer per area in the charred samples. Also, Raman is a surface scattering technique and, in the case of charring, the surface is coated with char after exposure. This appears to be represented in the Raman for direct exposure. For exposure removed directly from the flame, Raman spectra show a decrease in overall intensities as was observed in the IR. The ratio increased by a factor 2.52 in the TEEK-HH foam from virgin to degraded, 1.58 for the TEEK-L8, and 10.70 for the TEEK-CL polymer. Note in the last case there was an unusual marked difference between the thick and thin samples examined, resulting in a high (approximately 28 percent) standard deviation in the ratio values. Most standard deviations were below or around 10 percent.

Key accomplishments:

- Ability to correlate IR and Raman spectroscopic data to degradation of polyimide foam samples.
- Sample handling and preparation for Raman analysis.

Key milestones:

- Better understanding of correlation between IR and Raman spectral analysis to degradation mechanisms of polyimide foams.
- Several more publications and presentations on related research were made in 2001, including an American Chemical Society book chapter.

Contacts: J.J. Palou (Jaime.Palou-1@ksc.nasa.gov), YA-F2-C, (321) 867-9404; and M.K. Williams, YA-C2, (321) 867-4554

Participating Organizations: Langley Research Center (E.S. Weiser) and Albion College (D. Holland)

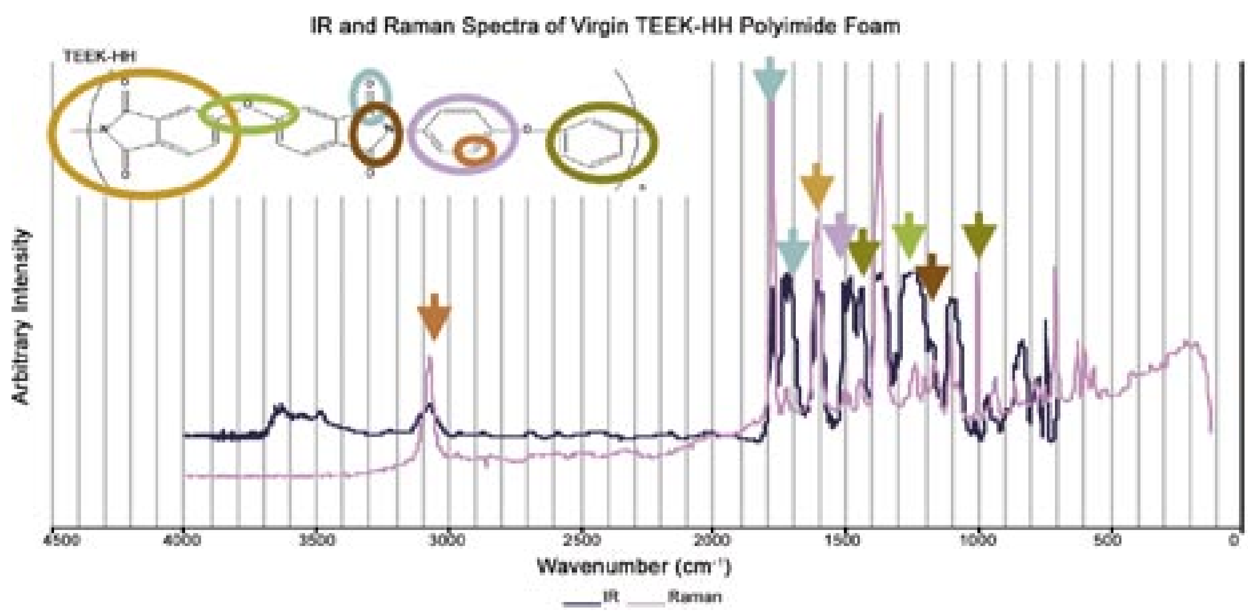

Figure 2. IR and Raman Spectra With Correlations for the TEEK-HH Polymer (From left to right, the circled components of the molecular structure correlate to an aromatic ring stretch for an aromatic cyclic imide; an ether; a carbonyl; a C-N-C structure in the imide, para, and meta aromatic substations; and a CH.)

Environmentally-Friendly Antifouling Coating Development

This project is a collaboration between NASA and the Naval Sea (NAVSEA) Systems Command. This antifouling program is an environmental program that seeks more environmentally benign antifouling coatings to satisfy the requirements of the Uniform National Discharge Standards (UNDS). UNDS is a partnership of Department of Defense (DoD), lead by the U.S. Navy; the Environmental Protection Agency (EPA); and the U.S. Coast Guard (USCG) to limit 25 targeted discharges from DoD and USCG vessels. One of the 25 targeted discharges is copper hull leachate. To limit this discharge, NAVSEA has proactively sought out new experimental antifouling coatings from industry that not only leach lower levels of copper but also provide performance sufficient to meet an extended dry-dock cycle of 12 years. In the past, only U.S. Navy and Coast Guard vessels were used as test platforms. Now, NASA has offered two Solid Rocket Booster retrieval vessels, the SS Liberty Star and SS Freedom Star, to participate in this coatings development program. The effort to apply patches of this experimental antifouling coating to SS *Liberty Star* and SS *Freedom Star* was funded by the Joint Group on Pollution Prevention (JG-PP) program. The JJ-GP program concentrates on funding projects designed to find solutions that reduce the amount of pollution created by certain waste streams common to several military and other Government agencies. Two 10- × 20-foot patches of experimental antifouling coating were applied to the starboard/aft and port/forward underwater hull sections of SS *Freedom Star* and SS *Liberty Star*. The coatings were applied in dry dock between October 5 and October 10, 2001. The ships returned to KSC in mid October and are being inspected for performance of the new antifoulants on a regular basis. Successful down-select of a new candidate coating will allow total recoat of the NASA and NAVSEA ships to significantly reduce hazardous leaching of copper into waterways where these ships dock.

Key accomplishments:

- Establishment of NASA and NAVSEA collaboration for antifouling coating development.
- Successful negotiation for the use of NASA Solid Rocket Booster recovery ships SS *Freedom Star* and SS *Liberty Star* to participate in the program.
- Application of test patches of experimental coatings on the SS *Freedom Star* and SS *Liberty Star*.

Key milestones:

- Periodically inspect the condition of the coatings on the ship hulls and document conditions.
- Send condition results to NAVSEA for inclusion in the overall program documentation.

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Participating Organization: NAVSEA (M. Ingle)

S.S. Liberty Star Booster Recovery Ship

Antifouling Patch

Corrosion-Resistant Tubing for Space Shuttle Launch Sites

The existing 304 and 316 stainless-steel tubing and fittings at the Launch Complex 39 launch pads are susceptible to pitting corrosion. This pitting corrosion can cause cracking and rupture of both high-pressure gas and fluid systems. The failures can be life-threatening to launch pad personnel in the immediate vicinity. Outages in the systems where the failure occurs can affect the safety of Shuttle launches. Improved corrosion-resistant tubing systems will greatly enhance both personnel and Shuttle safety concerns. These new-generation materials will require less maintenance over their lifetime and significantly reduce costs associated with these systems.

A range of materials was selected for testing to include stainless steels (austenitic, low-carbon, Mo-alloy, superaustenitic, duplex, and super-ferritic), Ni-Cr-Mo alloy, Ni-Mo-Cr-Fe-W alloy, and austenitic Ni-base superalloy. Four separate conditions that could be experienced at the launch facilities are being tested: normal seacoast unsheltered, normal seacoast sheltered, acid environment unsheltered, and acid environment sheltered. Two of the four racks are sprayed once every 2 weeks with an acid slurry to simulate Solid Rocket Booster (SRB) deposits accelerating corrosion rates. One of the acid-rinsed racks, as well as a nonrinsed rack, has a protective roof (cover) to simulate partial shelter. Each test article contains a series of 90-degree bends, 37-degree tube flairs, and an orbital weld.

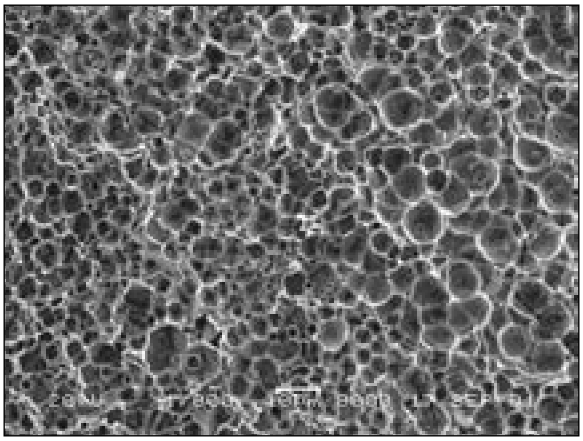
Tubing failures occurred in the 300-series control tubing assemblies after only 10 months under acid rinse conditions. The majority of the remaining high-alloyed steels showed little or no corrosion damage. All failures were identified as pitting corrosion failures. Other tubing test articles are subject to inspection of specific areas such as clamp points, wire loop contact points that retain identification tags, and orbital weld sites. Areas inspected are compared to those of the 300-series tubing brought in because of tube failure. These areas are of concern because of the increased corrosion potential caused by crevice corrosion and in heat-affected zones of welded areas.

Benefits of this project include the following:

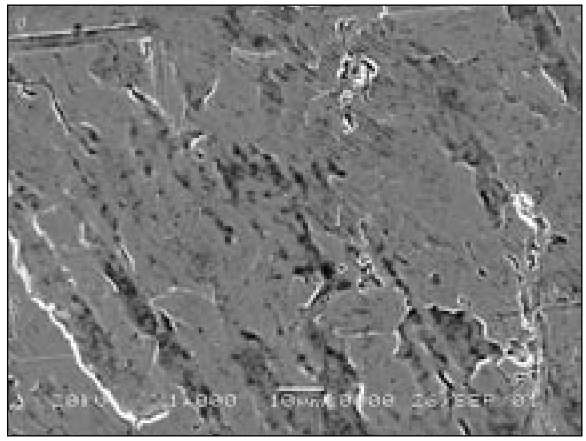
- Corrosion-resistant tubing in launch pad applications would greatly reduce the probability of future pitting corrosion failures.
- Improved safety, increased reliability, reduced downtime, and lower maintenance costs would result from using the more corrosion-resistant alloys.

Key accomplishments:

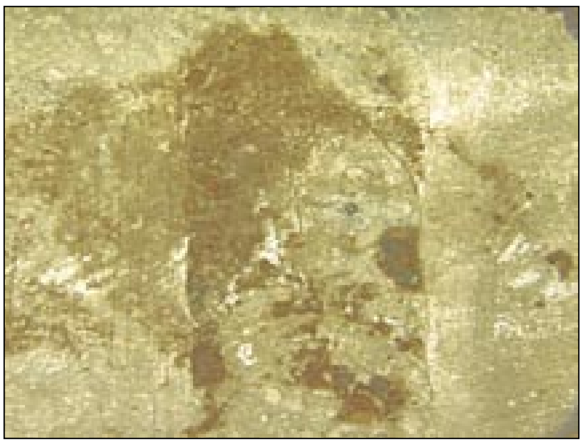
- Analyzed first-year failures.
- Compared the different alloys at critical corrosion sites such as clamp points and wire loop contact points that retain identification tags.
- Performed orbital welds.



SEM, Exposed 316L SS Tubing



SEM, Unexposed 316L SS Tubing



300-Series SS Weld (Failure Point)

Superaustenitic SS Weld

Key milestones:

- Determined performance/cost benefits to recommend new material for Launch Complex 39 applications.
- Presented paper at the NACE 2002 Conference.
- Completed progress report.

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Participating Organization: Dynacs Inc. (J.J. Curran and T.R. Hodge)

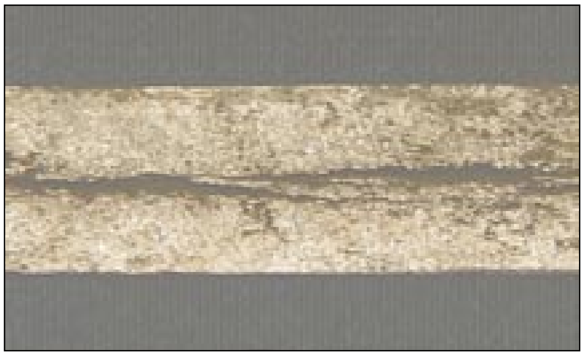
Army Corrosion-Retardant Additive Testing

The objective of this project is to test and evaluate chloride rinse agents (CRA's) for effectiveness of cleaning typical aviation metals. These metals pertain to Army aircraft, missile, and ground vehicle systems and components. NASA and the Engineering Development Contractor, Dynacs Inc., are testing the effectiveness of four separate CRA's to prevent or reduce corrosion of metals exposed to salt spray. Nine different metals specified by the U.S. Army are presently experiencing a harsh, outdoor marine environment at the NASA Kennedy Space Center Beach Corrosion Test Site (BCTS). Solutions of CRA's and control solutions are sprayed onto metal coupons each week. The coupons are being observed for corrosion activity for a period of 2 years. Comparison testing of products and recommendations will be reported at the 1- and 2-year points. Four chloride rinse agents shall be compared to seawater, demineralized water, and no rinse as controls. The nine materials/coatings that were selected for testing are:

- Aluminum 2024-T3 with 8625 coating.
- Aluminum 2024-T3 with 5539 coating.
- Aluminum 7075-T6.
- Magnesium 4377 with 3171 coating.
- Steel 4340.
- PH 13-8 Mo high-strength steel.
- AM-355 CRT high-strength steel.
- C-250 maraging high-strength steel.
- 6Al-4V (Ti-6Al-4V), UNS R65400.

Corrosion ratings will be based on weight loss for the 4340 steel, and

Coupon Cleaning (left to right, Ray Springer, Jerry Curran, and Jan Surma)



Exfoliation Seen on a 0.063-Inch Aluminum 7075 Coupon After 1-Year Exposure

Pitting Corrosion on a 1-Square-Centimeter Area of a Magnesium Coupon After 1-Year Exposure

pitting characteristic ratings will be applied to all other alloys.

Key accomplishments:

- Completed 1-year exposure of coupons.
- Cleaned and evaluated 8 of 9 coupon material sets at the 1-year point. The C-250 arrived late and will be tested at its 1-year deployment anniversary.
- Completed and delivered 1-year progress report.
- Presented 1-year data at DoD Tri-Services Conference.

Key milestones:

- Complete 2-year exposure of coupons.
- Clean and evaluate 2-year coupons.
- Prepare and deliver final report and associated coupons.

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Participating Organization: Dynacs Inc. (J.J. Curran, Dr. R.G. Barile, T.R. Hodge, J.M. Surma, J.P. Curran, and R.W. Springer)

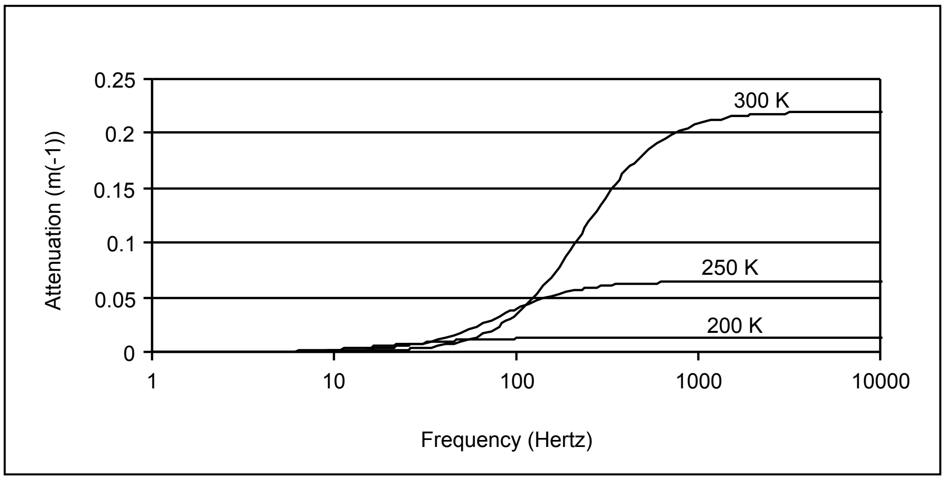
Vibrational Nonequilibrium Effects in the Martian Atmosphere

Carbon dioxide, the primary constituent of the Martian atmosphere, has low-energy vibrational modes that are significantly populated at typical temperatures on both Mars and Earth. When changes in temperature occur, the relative populations of these modes change correspondingly, but this population redistribution is slow because the probability of transferring energy between the kinetic energy of a carbon dioxide molecule and a vibrational state during a collision is very small. Hence, a large number of collisions, resulting in a long period of vibrational nonequilibrium, may be required to distribute the energy between these states.

Herzfeld and Rice first described vibrational nonequilibrium in 1928 to explain observed sound wave absorption and dispersion effects in various gases. Experimentalists reported, contrary to prediction, that sound waves in many gases showed anomalous frequency-dependent attenuation. Herzfeld and Rice showed that if there was a slow energy exchange between translational and internal degrees of freedom (slow compared to the mean collision time), the experimental results could be explained. Low-frequency sound waves provide enough time for energy equilibrium to be achieved, and hence the waves propagate as predicted by Stokes. However, high-frequency sound waves do not allow energy equilibrium to be achieved. In this case, energy exchange between the translational and internal degrees of freedom is delayed with respect to the traveling sound wave and results in attenuation of the wave.

For several years after Herzfeld and Rice's paper, gas relaxation effects were treated as separate from the standard continuum mechanics treatment of gas phenomenon. It was not until 1942, in an intriguing paper by Tisza, that a theoretical link between these two fields was proposed. Tisza recalls that there are two viscosity coefficients, a shear viscosity and a bulk viscosity, in the standard continuum mechanics development and that it is normally assumed that the bulk viscosity is small and can be neglected (for an ideal gas the bulk viscosity is equal to zero). He then went on to show that, by including the bulk viscosity term and including it in a description of sound wave propagation, the results of Herzfeld and Rice can be derived. Accepting this result provides a direct process whereby gas relaxation parameters can be merged into the Navier Stokes relation and used to predict aerodynamic effects.

Over the next 20 years, hundreds of papers in this field were published. Researchers realized that, by measuring the sound propagation characteristics of a gas, information on the internal degrees of freedom of that gas could be found. The field flourished and achieved impressive results as described by several review papers and books published in the 1950's and 1960's. But, with the advent of more sophisticated and precise methods of examining molecular degrees of freedom, the attractiveness of this field declined. By the 1970's, the extensive body of information achieved in the field of gas relaxation phenomenon was rarely mentioned in typical graduate or undergraduate



Predicted Plot of the Sound Attenuation Versus Frequency for a Dry Carbon Dioxide Atmosphere at a Pressure Similar to That on Mars (700 Pascals)

sequences. By the 1990's, few scientists were familiar with this phenomenon and its possible impact on Martian aerodynamics was ignored.

In the Earth's atmosphere bulk, viscosity effects can be ignored, but this is probably not the case within a carbon dioxide atmosphere or on Mars. In a pure carbon dioxide atmosphere, the magnitude of the bulk viscosity at standard temperature and pressure is about 2000 times larger than the shear viscosity, and in even routine aerodynamic problems has a larger effect than the shear viscosity. On Mars, the introduction of other atmospheric constituents and the combination of lower pressure and temperature can increase the bulk viscosity even further.

Based upon the papers in the field of gas relaxation and the extensive studies carried out on sound propagation in carbon dioxide from the 1920's to 1960's, it is possible to make quantitative and defensible assertions concerning sound propagation on Mars (see the figure). This is interesting and has some impact on human exploration of Mars, but the more important questions that remain are:

- What is the impact of a potentially large bulk viscosity on a wide variety of aerodynamic interactions?
- How does this affect weather formation, wing design, or inlet and fan operation?
- Will it affect the launch trajectory of a future Martian ascent vehicle?

Effort is underway to understand this phenomenon and to predict its impact on Martian aerodynamics.

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Electromagnetic Physics Laboratory (EMPL)

The EMPL at the Kennedy Space Center has developed capabilities for the study and evaluation of the electrostatic properties of films and bulk materials as well as powders and granular materials. NASA scientists in the laboratory, partnering with Swales Aerospace, Dynacs Inc., and the Florida Institute of Technology, have been applying their expertise to enhance the research and development efforts in the electrostatics of materials. International collaborations with universities in Japan and the United States, as well as with NASA's Jet Propulsion Laboratory, make the EMPL a unique environment for these studies.

The Environmental Thermal Vacuum Chamber, developed primarily for the simulation of the Martian environment, is also used in electrostatic studies and testing in support of the Space Shuttle and the International Space Station. This chamber is 2 meters in length and 1.3 meters in diameter and has a volume of 1.5 cubic meters (figure 1). The Environmental Thermal Vacuum Chamber has a vacuum depressurization time of 20 minutes and a controlled repressurization time of 10 minutes. It can be repressurized in an emergency in 10 minutes. The Environmental Thermal Vacuum Chamber can operate at temperatures ranging from -90 to +200 degrees Celsius (°C). It was outfitted with an automated control system with a graphical user interface for complete automation of pressure control, atmospheric control, and temperature control.

Figure 1. Environmental Thermal Vacuum Chamber

The Triboelectric Test Robot (TTR) instrument was recently completed in the EMPL to measure both the electrostatic generating potential and the electrostatic discharge time of films, clothing materials, space suits, solid foams, gloves, paints, and coatings (figure 2). The TTR is capable of testing 6 samples at a time and operates in the Environmental Thermal Vacuum Chamber under various atmospheric gases and at atmospheric pressures ranging from 0.2 to 1,000 millibars, temperatures ranging from -90 to +200 °C, and humidities ranging from near 0 to 100 percent.

An advanced multisensor electrometer (figure 3) is currently being developed to measure the surface charge deposited onto a surface by means of dust transport. This electrometer is suited to test materials exposed to powders and dusts at high speeds under various environ-

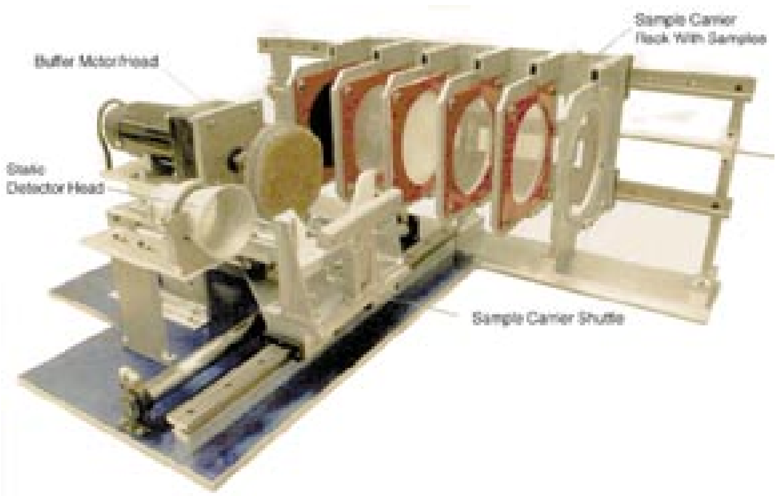

Figure 2. Triboelectric Test Robot

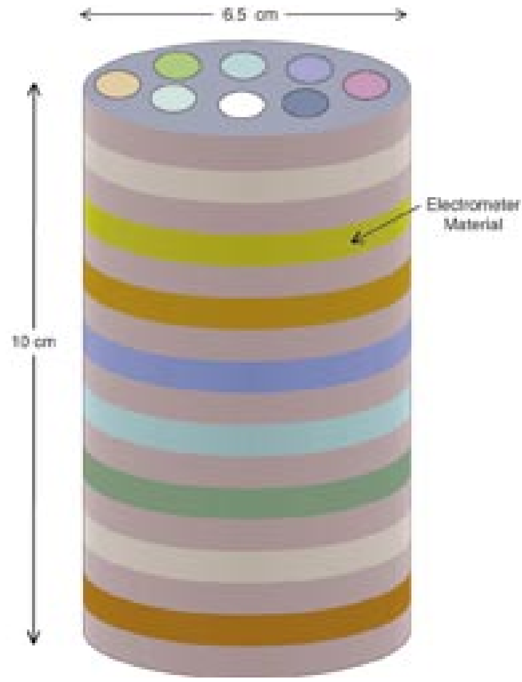

Figure 3. Advanced Multisensor Electrometer

mental conditions to measure the charge buildup as particles come in contact with it. The instrument can be used to test not only a material's response to charge accumulation but also a material's ability to keep dust from adhering to it.

Besides controlling the atmospheric conditions (temperature, pressure, and gases), the EMPL has the capability to reproduce windy conditions to disperse powders and dusts onto different materials. This need derived from the inability of convection to occur at low pressures. Since convection alone cannot propel dust at low pressures (approximately 1 millibar), the Low-Pressure Dust Impeller was developed to systematically disperse an amount of dust onto a surface at speeds up to 30 meters per second at low pressures (figure 4).

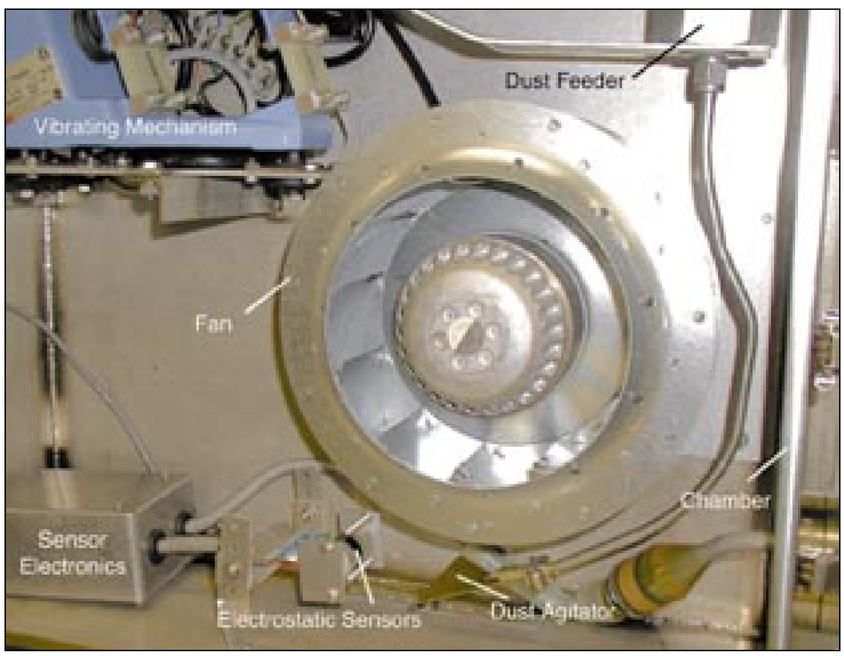

Figure 4. Low-Pressure Dust Impeller

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Participating Organizations: YA-C2-T (Dr. R.H. Gompf, E.E. Groop, and M.D. Hogue), Florida Institute of Technology (Dr. J. Mantovani), Swales Aerospace (Dr. C. Buhler), Dynacs Inc. (A.W. Nowicki), and YA-F1-T (P.F. Richiuso)

Charge Decay Properties of Martian Regolith Simulant Particles

The Electromagnetic Physics Laboratory at KSC focused recently on testing and understanding the electrostatic properties of the Johnson Space Center Mars-1 Martian regolith simulant for future robotic missions to Mars. In a dry environment such as that of Mars, electrostatic discharge can become hazardous; therefore, characterization of this phenomenon is crucial for mission success.

To characterize this phenomenon, experiments were designed to measure the charge decay characteristics of the simulant. Measurements were performed in a simulated Martian environment under both moist conditions (12-percent relative humidity) and dry conditions (less than 1-percent relative humidity). For the experiments under dry conditions, the soil was baked out to remove excess moisture and was evacuated to pressures below 1 torr before each experiment was performed. Figure 1 shows the time it takes dry simulant to discharge once exposed to a high-voltage corona under normal simulated Martian conditions at different temperatures. At lower temperatures the soil decays more slowly indicating the higher resistivity of the simulant.

This behavior is understood in terms of the current-voltage (I-V) characteristics of the material. Tests of the I-V relationships (figure 2) show that the soil possesses nonohmic behavior when the soil is moist and ohmic behavior when the soil is dry. Using these forms of the I-V curves, theoretical relationships of the charge decay curves can be derived and match well with the experimental data in figure 3.

Analyses of the moist and dry simulant indicate that the most important mechanism behind the charge decay of the Martian regolith is the moisture content of the soil. Possible use of this mechanism in the search for water on Mars is being investigated.

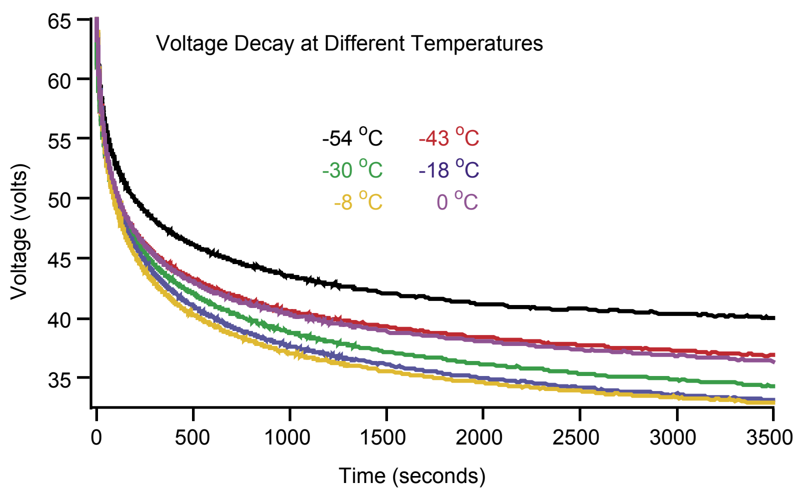

Figure 1. Average of Many Voltage Decay Curves at Low Temperatures Under Simulated Martian Conditions

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Participating Organizations: Swales Aerospace (Dr. C. Buhler) and Dynacs Inc. (A.W. Nowicki)

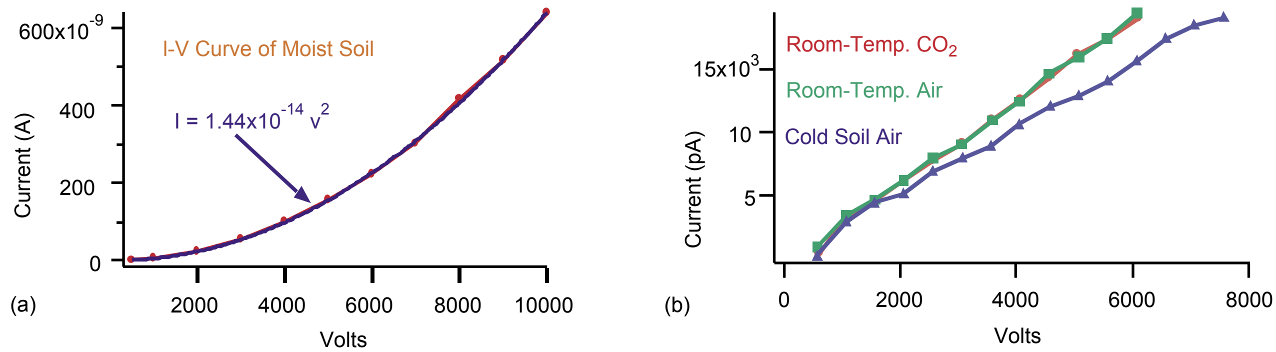

Figure 2. I-V Curve for (a) Moist Simulant (Red) Along With a Best-Fit Curve Shown in Blur and (b) I-V Curves of Dry Simulant

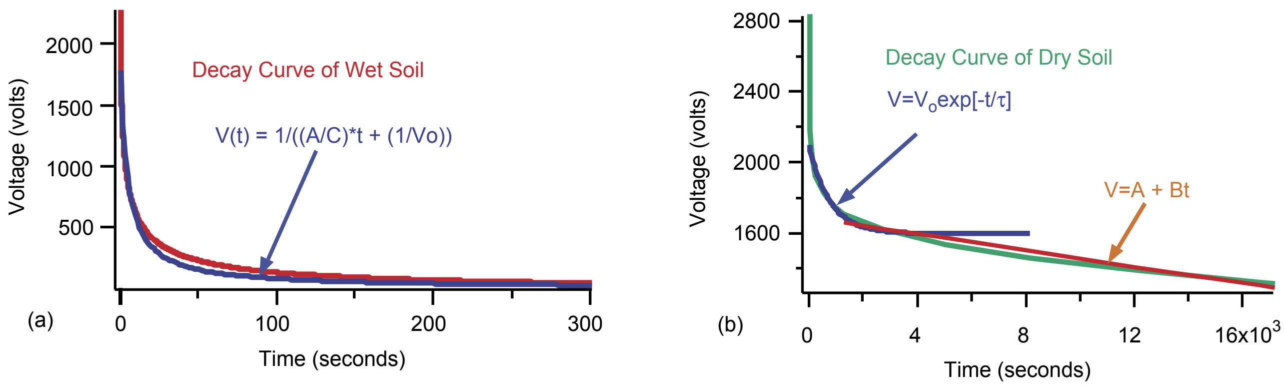

Figure 3. Decay Curve for Both (a) Wet (Red) and (b) Dry (Green) Simulant Along With Best-Fit Curves (The colors match the curves with their equations.)

Particle Charging at Simulated Martian Conditions

The mechanism for aolian transport of sand particles on Mars is still subject to some debate. It has been proposed that reptation, the ballistic injection of grains by impact of saltating grains and by nudging of surface grains into a creeping motion, is the prime mechanism of dust transport on Mars. During saltation, grains lifted into the atmosphere travel over a distance and land again on the surface (figure 1). Upon impact with the surface, the grains either bounce back into the atmosphere, roll, or kick out other particles. The entire frictional process whereby particles slide, roll, and impact themselves and other objects can lead to contact electrification. This phenomenon may be enhanced by the high frequency of dust devils, which were observed by the Pathfinder mission to occur daily. The choice of materials for future Mars missions needs to reflect a due consideration of the magnitude of the charge that these materials can acquire by moving airborne Martian dust particles.

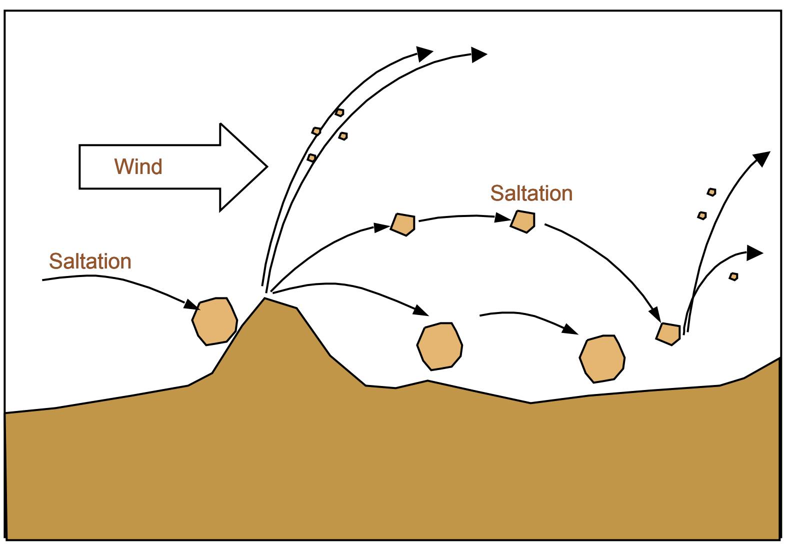

Figure 1. Saltation (Sand particles lifted into the atmosphere travel over a distance and land again on the surface.)

To simulate the saltation effect, an apparatus was devised to drop Martian simulant grains down a deflection board whose surfaces were coated with either Rulon, Lexan, Teflon, fiberglass-epoxy G-10, acrylic, or acetate (figure 2). These experiments were performed in a 9-millibar atmosphere to simulate the average pressure on the surface of Mars. The particles, under the force of gravity, bounced, rolled, slid, and were deflected until finally falling into a Faraday cup for charge measurement. It was speculated that corona fields can affect the electrostatic charging of the simulant grains. To study this phenomenon, the particles were allowed to fall through either an AC, +DC, or –DC corona field. In all cases, the simulant was dropped directly through the field before bouncing down the deflection board. Background runs with no corona fields were obtained for benchmark.

Figure 3 shows the percent change in simulant charging over no corona for the three corona cases. Further experiments will look at the corona field's effect on neutralized simulant and will compare the magnitude of the simulant electrification at extremely low humidity values.

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Participating Organizations: Florida A&M University/Florida State University College of Engineering (Dr. F. Gross, S. Joshi, and R. McCown)

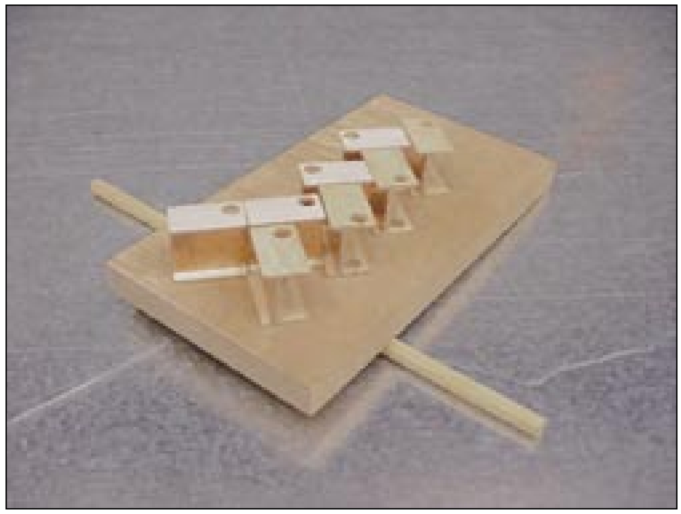

Figure 2. Deflection Board Assembly

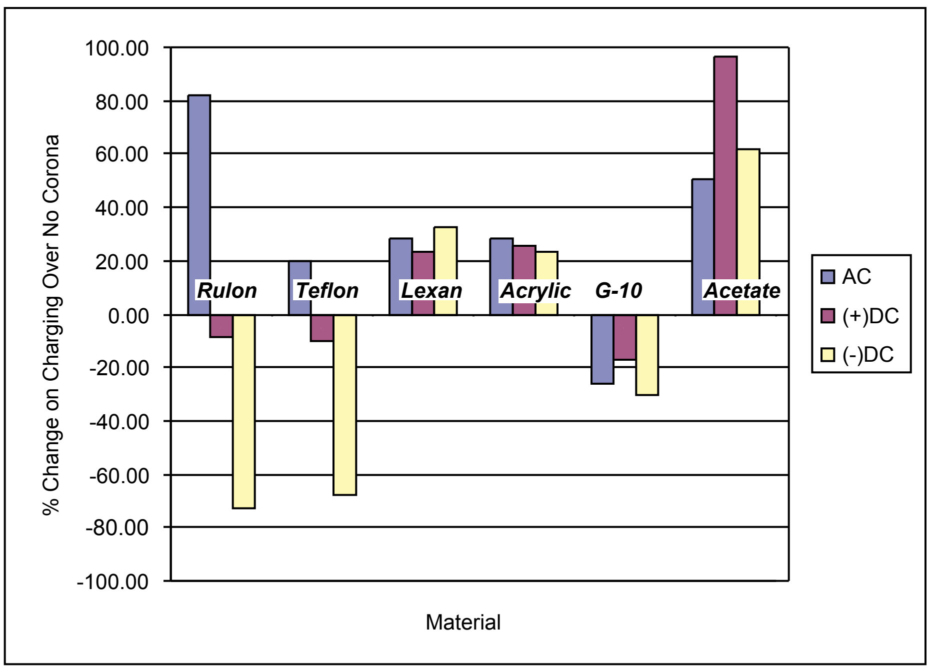

Figure 3. Percent Change in Charging Over No Corona for Various Corona Cases

Aerodynamic Multisensor Electrometer

Atmospheric dust electrification is a highly probable phenomenon in the Martian atmosphere. To gain a more thorough understanding of the potential for electrostatic discharge of different materials on Mars, the Electromagnetic Physics Laboratory at KSC developed an aerodynamic electrostatic multisensor that will measure the electrostatic and triboelectric properties of Martian atmospheric dust (figure 1). This knowledge will provide necessary information for the design of landers, rovers, and habitation facilities in future missions to the planet.

The multisensor electrometer consists of an array of insulating materials with each material backed by a miniature electrometer. The instrument was designed to be exposed to mineral particles similar in composition to those in the Martian environment. To simulate a windstorm, mineral particles are propelled toward the instrument at speeds reaching 20 meters per second. The overall sensor array has an aerodynamic configuration to minimize turbulent flow. The electrometer sensor uses a simple reference capacitor design similar to the one used on the Mars Environmental Compatibility Assessment (MECA) Electrometer (figure 2), a flight-ready instrument designed by the Jet Propulsion Laboratory and KSC that includes five sensors in a line array with a resolution of 5 million elementary charges. The probe consists of a field-sensor electrode that is enclosed by a guard electrode, which in turn is enclosed by an electrically grounded shield (figure 3). The probe is embedded in a cylinder to within 2.5 millimeters of the surface. The overall gain of the electronic circuit is 0.25 picocoulomb per millivolt. The current version of the instrument contains six sensors to measure the electric field induced by any net charge on six different insulator surfaces. The charge develops through frictional contact between the cylindrically-shaped insulators and incident granular material.

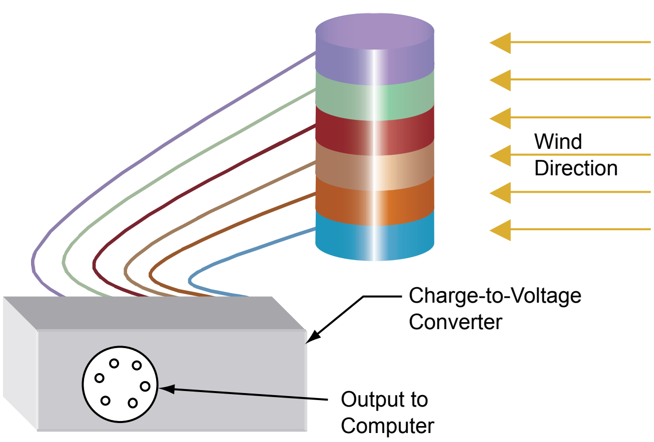

Figure 1. Diagram of the Prototype of the Aerodynamic Electrometer and Its Associated Electronic Housing With Sensor/Guard Probes Embedded in 6 Cylindrical Insulators

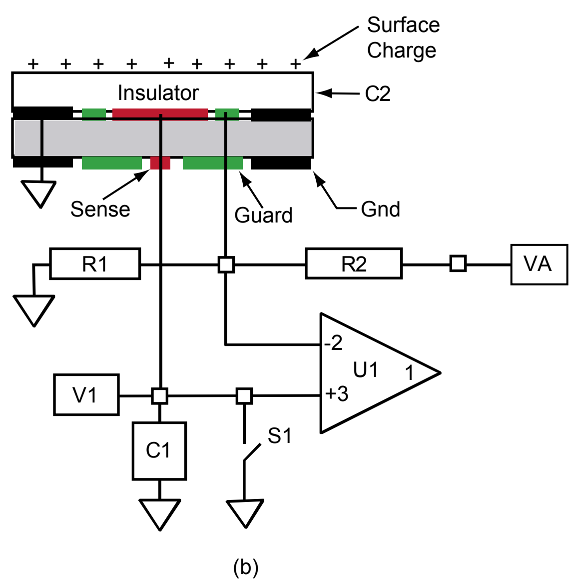

Figure 2. Circuit Diagram for Each of the Electrometer Probes

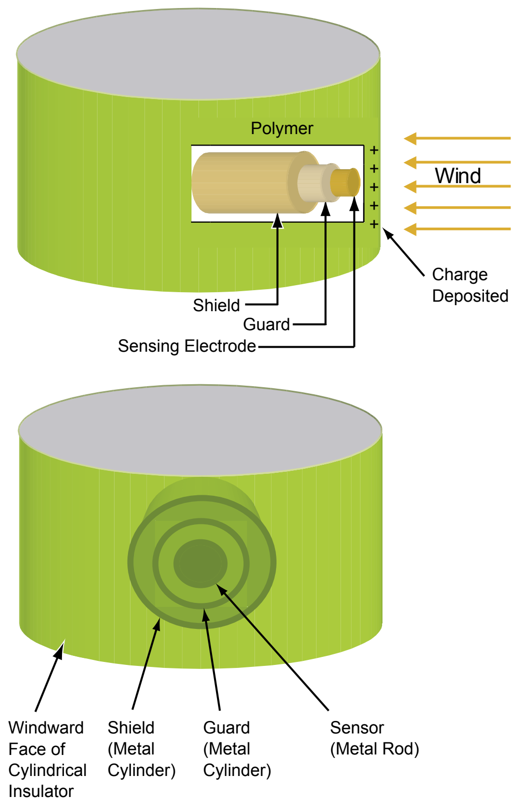

Figure 3. Diagram of One of the Electrostatic Probes Inside an Aerodynamically-Shaped Polymer (The shield, guard, and sensor electrodes are embedded below the surface of the windward face of the cylindrical insulator.)

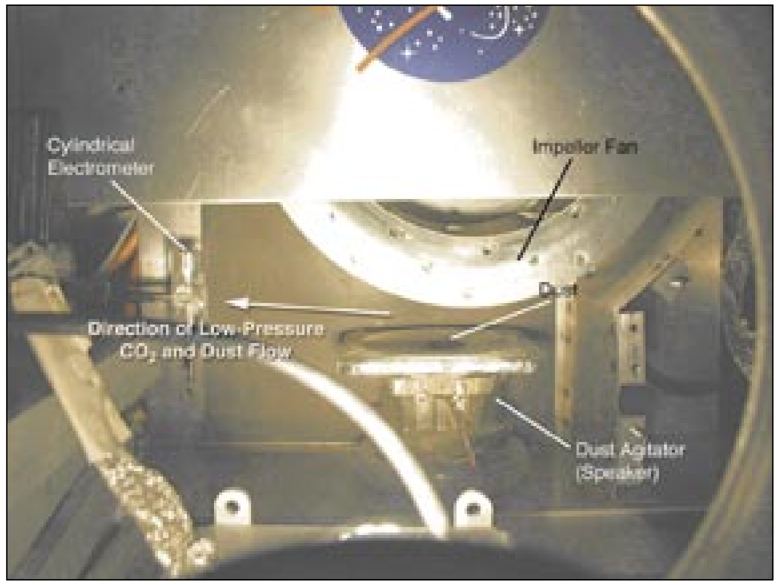

Figure 4. KSC Dust Particle Impeller Operates at Low Pressures and Is Capable of Propelling Dust Particles at Atmospheric Pressures and Pressures as Low as 7 Millibars

Windborne dust particles were generated using a dust particle impeller that was developed at KSC to simulate a Martian dust storm in a vacuum chamber (figure 4). Constant wind speeds of 20 meters per second were measured with the dust impeller operating at gas pressures ranging from 5 millibars to 1 bar.

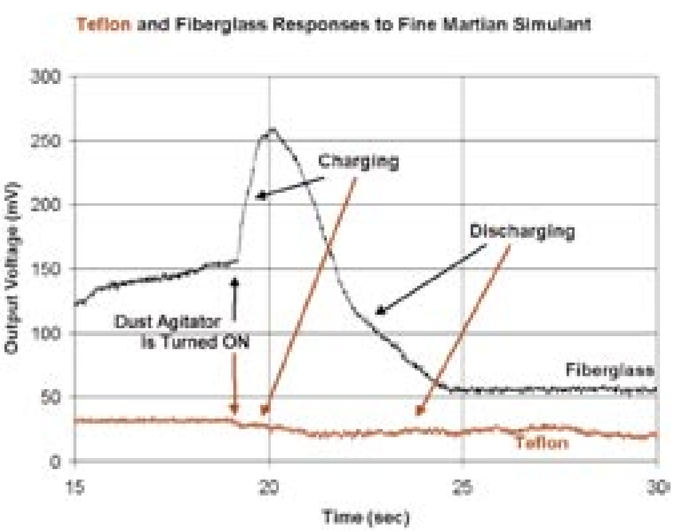

Figure 5. Martian Soil Simulant Particles Propelled to the Aerodynamic Electrometer With the Probe Embedded in Teflon and Fiberglass-Epoxy G-10 Cylinders

Figure 5 shows the electrostatic responses of polytetraflouroethylene (Teflon) and fiberglass-epoxy G-10 to Martian simlant dust particles. The cylinders were exposed to windborne dust particles in separate experiments. Data were taken in a vacuum chamber containing a room-temperature carbon dioxide (CO_2) atmosphere at 9 millibars. Other granular materials such as silicon dioxide (SiO_2), iron oxide (Fe_2O_3), and aluminum oxide (Al_2O2_2, found by Viking and Pathfinder instruments to be major components of the Martian soil, were also used in these experiments.

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Participating Organizations: Florida Institute of Technology (Dr. J. Mantovani), YA-C2-T (E.E. Groop), Swales Aerospace (Dr. C. Buhler), and Dynacs Inc. (A.W. Nowicki)

Electrostatics of Airborne Granular Material

Airborne granular material in the size range from about 1 micrometer up to 1 millimeter can acquire comparatively large electrostatic charges because of multiple contacts between particles and particle collisions with different surfaces. Highly charged particulate matter of this size can be attracted to surfaces. Dust control in clean environments can become difficult because of these charged particles. On the other hand, charged granular material has many beneficial applications. Devices such as electrostatic copiers, inkjet printers, powder-coating machines, injection moldings, and electrostatic precipitators depend on controlled charging of these small particles. The Electromagnetic Physics Laboratory at KSC is engaged in studies leading to a better understanding of the electrostatics of granular material.

Surfaces can become charged as a result of contact and separation between materials of different Fermi electronic energy levels. In a vacuum, these excess charges can remain on surfaces indefinitely. In a gaseous atmosphere, excess charge can leak away because of the presence of free charges in the gas, such as ions, electrons, or other heavily charged particles. At low atmospheric pressures, the number of free space charges is reduced, affecting the discharging characteristics of surfaces in specific ways.

To study charge exchange phenomenon in granular material, a KSC-designed low-pressure dust impeller is used together with an aerodynamic multisensor electrometer. Small particles ranging in size from about 5 to 17 micrometers are launched toward several cylindrical polymers in a dry carbon dioxide atmosphere at 9 millibars. Electrostatic sensors embedded in the aerodynamic multisensor measure the electrostatic charge generated on these polymers in real time. Figure 1 shows a simulation of

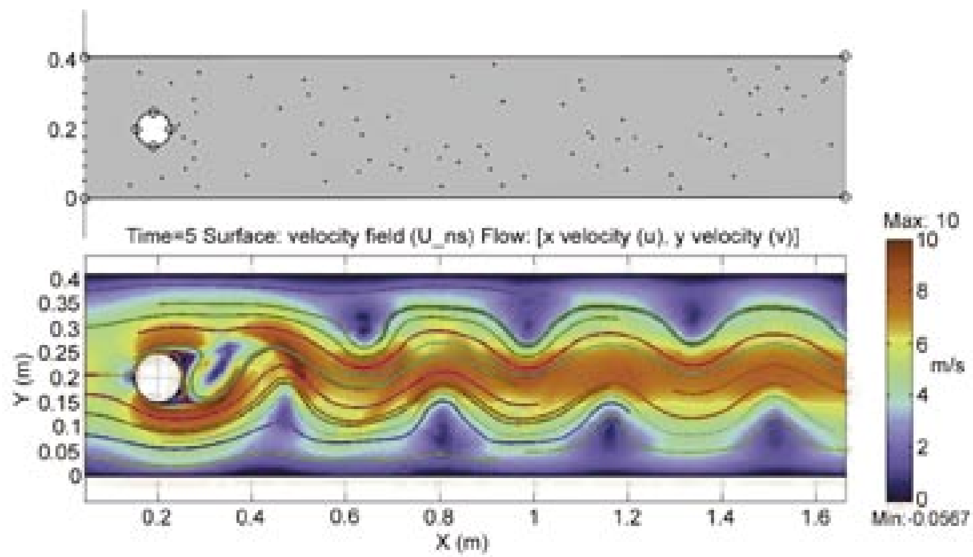

Figure 1. Computer Simulation of Particle Flow Around the Cylindrical Multisensor Electrometer

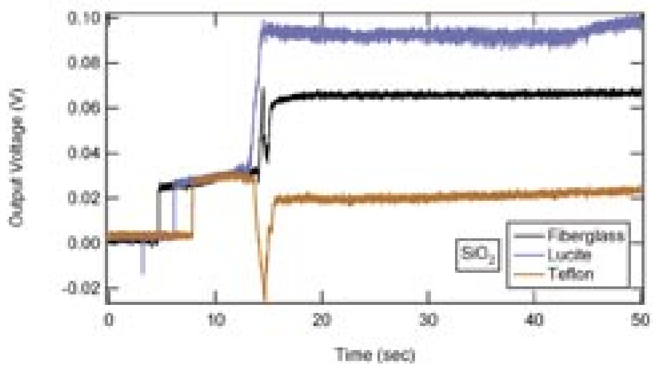

Figure 2. Electrometer Responses to SiO_2 Particles Striking Fiberglass, Lucite, and Teflon Cylinders

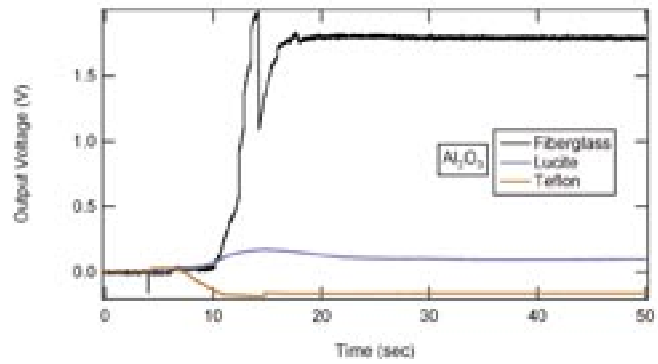

Figure 3. Electrometer Responses to Al_2O_3 Particles Striking Fiberglass, Lucite, and Teflon Cylinders

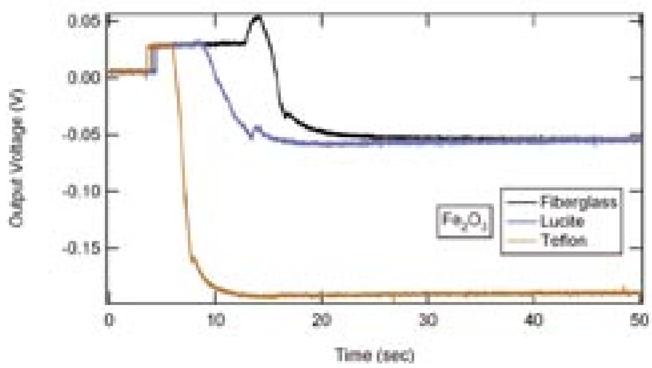

Figure 4. Electrometer Responses to Fe_2O_3 Particles Striking Fiberglass, Lucite, and Teflon Cylinders

Table 1. Triboelectric Series

Polymer	Granular Mineral
Most Positive	
	Iron Oxide (Fe_2O_3)
Lucite	
	Calcium Oxide (CaO)
	Aluminum Oxide (Al_2O_3)
	Silicon Dioxide (SiO_2)
Teflon	
Most Negative	

particle flow around the aerodynamic multisensor. In an initial attempt at characterizing this interaction, a triboelectric series was generated. In this series, the materials are ordered according to the relative positions of their electronic energy levels when brought into contact.

Figures 2, 3, and 4 show the electrometer responses to the charge exchanged between fiberglass-epoxy G-10, Lucite, and Teflon when in contact with silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3) particles. The table lists the ordering of the minerals and the polymers in a triboelectric series based on the data shown in figures 2, 3, and 4. The average electrostatic responses of the polymers to the granular minerals may allow us to observe consistent differences in behavior, which could lead to a possible identification of such minerals.

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Low-Pressure Dust Impeller

Laboratory studies of fast-moving, submillimeter dust particles at low atmospheric pressures such as those existing on Mars (5 to 9 millibars) require a mechanism for airlifting the particles into a rarified atmosphere while generating sufficient winds for moving the particles. Current studies rely on wind tunnels that move gases at the required speeds but are not suitable for small-scale experimentation with a small number of particles.

The Low-Pressure Dust Impeller was designed at KSC's Electromagnetic Physics Laboratory to accelerate dust without direct contact. The instrument is designed to operate at pressures ranging from about 5 millibars to 1 bar. It uses either a vibrating membrane or a vibrating feeder to levitate dust particles, mechanically separating them and placing them under fluidized conditions. Once the particles are separated, conductive impeller blades move the atmospheric gas molecules to thrust the particles onto a target at velocities up to 22 meters per second, simulating the Martian winds. The dust impeller is small and was designed as a self-contained low-temperature vacuum system.

The impeller provides for a simple simulation of a dust storm at many different environmental conditions. More important, it allows for the simulation of a dust storm at the low atmospheric pressures existing in the Martian atmosphere.

The instrument has applications in the manufacture of spray-dried products and the production of pigments, as well as in the application of pesticides. The application of aerosols administered in the treatment of respiratory diseases may be more readily studied with this impeller. An understanding of the properties of aerosols is of great practical importance. Since this instrument disperses dry powders without the physical contact of the particles, it avoids the buildup of electrostatic charge on the dust particles, a common problem to many commercially available dry-dispersion dust generators.

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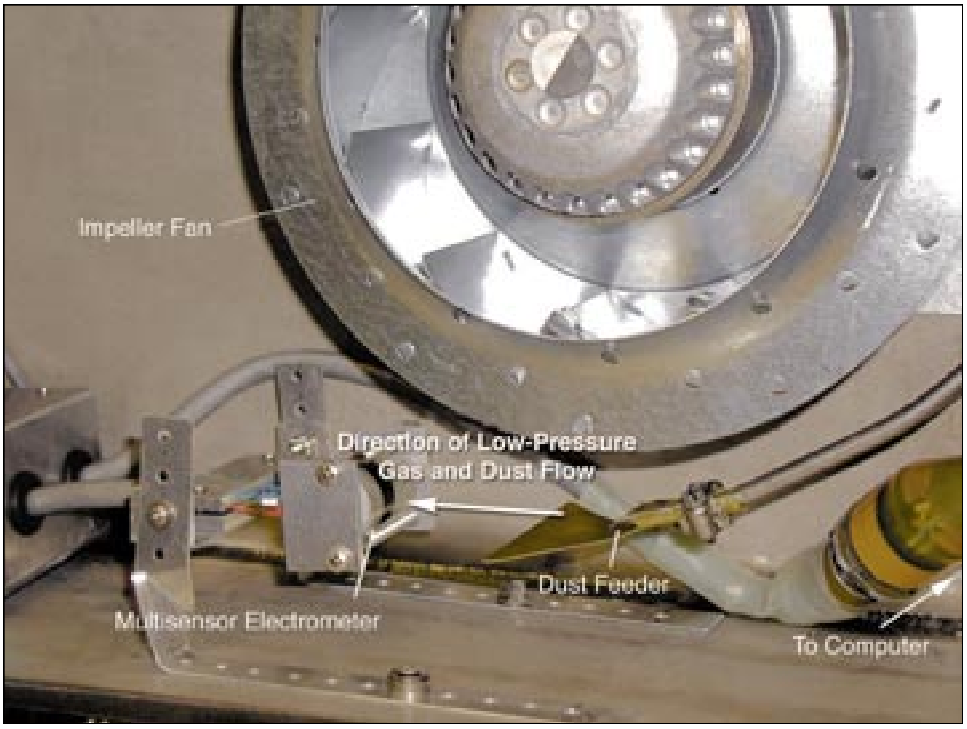

Low-Pressure Dust Impeller With Vibrating Membrane
To Propel Dust at Low Pressures

Command, Control, and Monitoring Technologies

Command, Control, and Monitoring (CCM) Technologies form the lifeblood of spaceport operations. These technologies span the gamut from preparing a spacecraft for launch to simulating procedures to ensure accurate process execution. The CCM Technologies Product Lines also focus on monitoring the status of space flight hardware to ensure safety for crews and ground personnel. CCM technologies lead to increased intelligence in spacecraft and more advanced network infrastructures to support the intelligence systems embedded in the vehicles. The ultimate goal is to create an integrated system that provides seamless connectivity between ground and avionics capabilities. Automation of CCM functions reduces costs by accessing expert intervention as needed. The higher level of automation also provides for more accurate status updates and targeted maintenance to ensure optimum performance of launch structures and vehicles.

Technology focus areas include the following:

- Advanced Control System Technologies
- Chemical Detection
- Field Inspection and Measurement
- Advanced Data Processing and Distribution
- Smart Sensors and Acquisition
- Spaceport System Health Management
- High-Reliability Software Development

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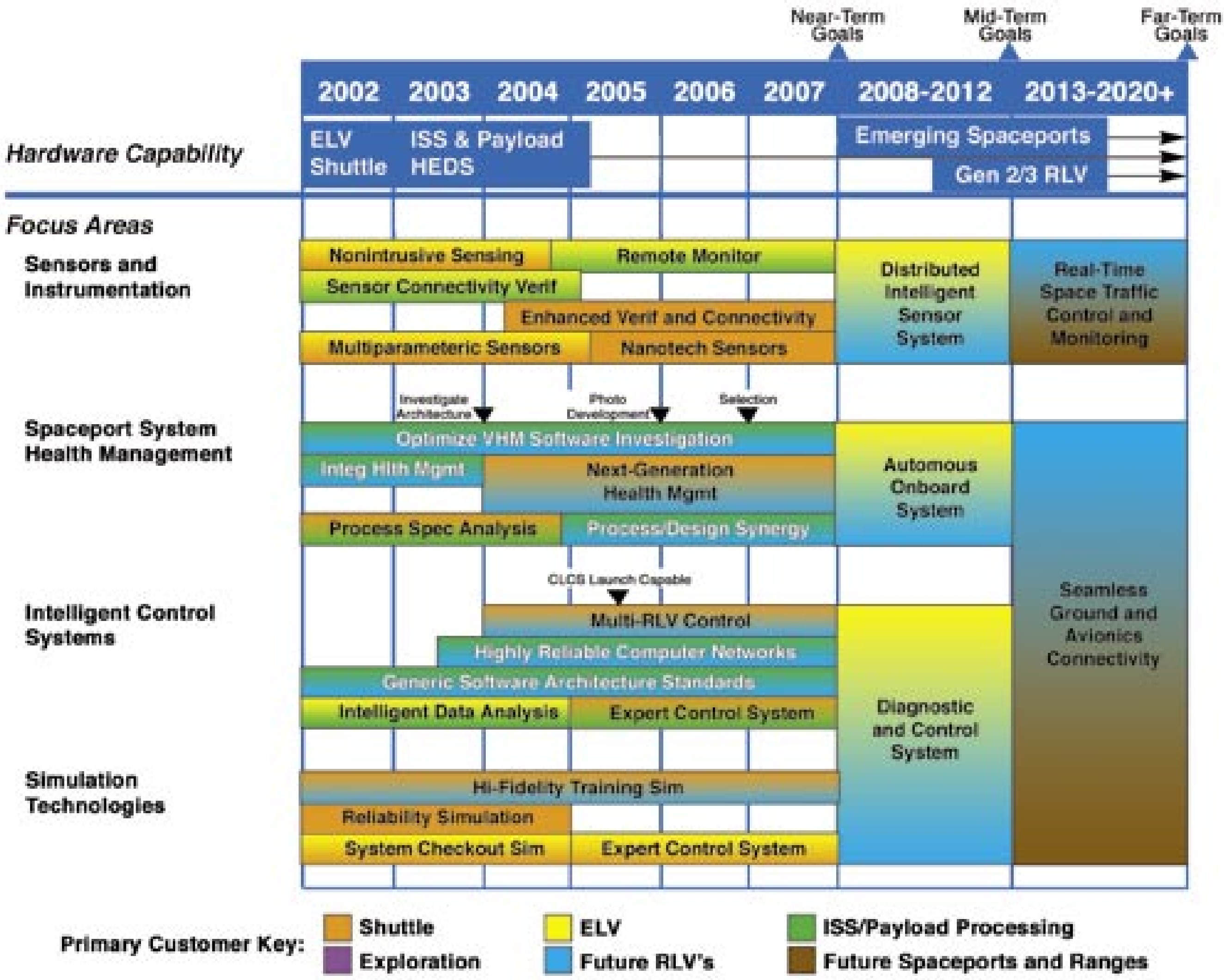
KSC Command, Control, and Monitoring Technologies Roadmap



Goals Specific to Focus Areas

- Reduce contribution of CCM systems to the cost per pound of payload to orbit
- Increase safety by improving monitoring and sensing of critical systems and improving CCM system reliability

KSC Real-Time Simulation Interface (RSI)

The RSI is the result of an effort to both enhance performance and modernize the KSC Launch Processing System's Simulation Interface to the firing rooms (refer to the Research and Technology 1999 Annual Report). The RSI is a replacement and complete redesign of the Video Simulation Interface (VSI), which has performed as the simulation interface to the firing rooms since the start of the Shuttle era. The RSI was designed not only to meet and exceed current VSI specifications but also to incorporate maximum flexibility to meet future requirements. The core design of the RSI incorporates a highly compliant architecture, which will facilitate future enhancements. One of the primary goals in the new design was to remove dependencies upon specific hardware whenever possible. To that extent, the VxWorks operating system was chosen for its broad-based hardware compatibility. Primary data communication between the various elements of the RSI utilizes a 13-megabyte-per-second optical fiber transport between reflective memory PCI bus cards. This feature allows daisy chaining and system expansion to multiple chassis for scalable functionality. As shown in the figure, the RSI core is based on a 21-slot VME chassis that contains a hybrid mix of boards. A Force Sparc CPU-50 VME Single Board Computer (SBC) running Solaris is used as the system controller. There is also a second Force Sparc VME board, which functions as the Simulation Executive (KSC Simulation System Sim-Engine), running under Solaris. This board contains a Reflective Memory (RM) PCI Mezzanine Card (PMC) for the Simulation Executive and Model communication to the other RSI elements in the chassis. These elements consist of a set of Simulator Processor Units (SPU's) that are running the VxWorks operating system on Motorola PowerPC's. Each of these SPU's, in turn, can host up to six PMC's, one of which is an RM card. The RM allows data sharing and coherency between the SPU's and the Simulation Engine. The other five cards on each SPU are Generic Simulator Cards (GSC's), which perform Shuttle and ground system data flow emulation. Each GSC is dynamically configurable to emulate a Shuttle Downlink pulse code modulation (PCM) stream, Ground Data Bus (GDB), or Launch Data Bus (LDB). The RSI can also function as a Shuttle PCM Uplink simulator using a Berg Bit-sync VME board. Lastly, each GSC is based on a TMS320 Digital Signal Processor (DSP), which enables the card to be programmed to emulate data protocols to support future vehicles, payloads, and even nonspace-based systems.

Essentially, the RSI is a portable, self-contained simulation interface with a built-in simulation engine. The RSI can interface to the firing rooms, as well as function within a hardware-in-the-loop simulation environment such as the Kennedy Avionics Test Set (KATS). In this type of environment, the RSI is used to handle data transmission to and from real hardware such as the Shuttle General Purpose Computers (GPC's). In this mode of operation, the RSI has been designed to handle commands and requests for data from the GPC's in as little as 5 microseconds.

Real-Time Simulation Interface (RSI), 21-Slot Chassis

Key accomplishments (2000 – 2001):

- Completed the proof-of-concept investigation of real-time Linux.
- Moved into full capability development with VxWorks for device drivers.
- RSI connected to the Checkout, Launch, and Control System (CLCS) Gateway for hardware testing. (RSI was connected to a Gateway [a new CLCS firing room element] test fixture and successfully displayed correct data from an RSI-generated 128-kbit/sec PCM telemetry stream containing Orbiter Instrumentation bus-formatted data.)

Key milestones (2002):

- RSI GDB and LDB elements 90-percent complete.
- RSI validation scheduled for July 2002.
- Deployment of the first elements of RSI scheduled for September 2002.

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KSC Checkout and Launch Control System (CLCS) Gateways

Gateway development is part of an overall effort to replace the existing Kennedy Space Center Launch Processing System (LPS) Checkout, Control, and Monitoring Subsystem (CCMS) in firing rooms that support processing and launch of the Space Shuttle. The CLCS is made of several components, including the Gateway subsystems. Gateway subsystems are similar in function to the CCMS front-end processors (FEP's) and provide interfaces between CLCS, the Space Shuttle, and ground support equipment (GSE). The existing CCMS was designed and built in the 1970's with custom hardware and assembly language prior to establishment of industry standards commonly used in real-time data processing systems today. One of the Gateway's primary functions is to perform link protocol conversion between the nonstandard Shuttle/GSE interfaces and the industry standard 100BaseT network interface. This allows Gateways to communicate with other CLCS subsystems. Gateways also perform data conversion, calibration, command routing, command authentication, measurement change checking, measurement time stamping, and link health monitoring.

Processing commands and data for the Space Shuttle and GSE requires CLCS to be able to support communication via complex Pulse Code Modulation (PCM) data streams (uplink and downlink), Orbiter's Launch Data Bus (LDB) (a variation of MIL-STD-1553), the Ground Data Bus (unique to KSC), serial interfaces (RS-232), and Ethernet for recently modernized ground systems such as the Hazardous Gas Detection System 2000. Although computing power available in today's high-speed embedded real-time computers permits a single subsystem to process data and commands for all interfaces, safety and redundancy considerations require the deployment of separate Gateway subsystems to support each specific link. In a launch processing environment, there are six Gateway types: GSE, LDB, PCM Downlink, PCM Uplink, Space Shuttle Main Engine, and Consolidated Systems. In order to maximize reuse of hardware and KSC-developed software in the various Gateway types, an open systems architecture based on the VersaModule Eurocard (VME) standard was chosen as the hardware platform. Each Gateway consists of a 6U VME Chassis, two high-speed single-board computers (Gateway Control Processor [GCP] and Front-End Process Controller [FEPC]), disk drive, IRIG-B Interface Board, 100BaseT network interface board, and a special interface board depending on which link a particular Gateway Subsystem is required to support. A separate Signal Conditioning Chassis contains custom KSC-developed circuit boards used to sum and split LDB, GSE, and PCM signals. Figure 1 shows a single GSE Gateway subsystem VME chassis and components.

Figure 1. CLCS GSE Gateway Subsystem

To support Space Shuttle launch countdown, 21 Gateways will be used for the large number of different Shuttle/GSE interfaces and to satisfy redundancy requirements for LDB, GSE, Consolidated Systems, and PCM Downlink Gateways. Redundant Gateways are configured as "Active Standby Pairs." If the Active Gateway fails, CLCS will automatically switch to the Standby. In the case of the GSE Gateway, the switch time can be as little as 20 milliseconds with no loss of commands. Two Gateway groups that will eventually support launch countdown are currently deployed in the CLCS Operations Control Room One (OCR-1). One of these Gateway groups is shown in figure 2.

Initial development on 10 Computer Software Configuration Items (CSCI's) for CLCS Gateways

Figure 2. CLCS OCR-1 Gateway Group

Figure 3. Gateway Maintenance User Interface

is complete. As with the hardware, a software architecture was developed to facilitate a high level of code reuse. Wind River's VxWorks operating system was chosen for Gateway subsystems for its symmetrical multiprocessing features, priority-preemptive scheduling support, and deterministic context switch times required for real-time command and control systems such as CLCS Gateways. The Common Gateway Services (CGS) CSCI runs on the GCP single-board computer and is present in all Gateway types. CGS controls Gateway initialization and termination sequences and continuously performs critical subsystem integrity checks on all executing software tasks. The CSCI also provides all command and measurement interfaces between Gateways and upstream CLCS subsystems. There are nine end-item-specific CSCI's developed to meet requirements unique to each different interface. The end-item-specific CSCI's run on the FEPC and communicate with CGS via the operating system's symmetrical multiprocessing capabilities. In order to improve poor operator interfaces typically associated with embedded systems, a Web-based Maintenance User Interface (MUI) was developed. The MUI provides a user-friendly interface for operations, maintenance, and troubleshooting activities. The MUI consists of HTML and Java software. An example MUI Web page is shown in figure 3.

Key accomplishments and milestones:

- 2002: GSE, LDB, PCM Downlink, Space Shuttle Main Engine, and PCM Uplink Gateways successfully supported CLCS system tests at KSC facilities, including the Kennedy Avionics Test Lab, Shuttle Simulation System, GSE at the Hypergolic Maintenance Facility, and with Shuttle Hardware at Shuttle Avionics Integration Laboratory (SAIL) at the Johnson Space Center in Houston, Texas. Over 175 Gateway subsystems are now deployed in several locations including the Launch Control Center OCR-1, Hypergolic Maintenance Facility, SAIL, Cargo Integrated Test Equipment (CITE) in the Space Station Processing Facility, and various CLCS development environments located in the Launch Complex 39 area.

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Small Mass Spectrometer System Onboard High-Altitude Research Aircraft WB-57

Variation in gas concentration near active volcanoes could provide valuable information about the state of the internal activity beneath the Earth's crust. Compounds such as acetone (C_3H_6O), sulfur dioxide (SO_2), and carbon dioxide (CO_2) in the atmosphere could be used as key indicators to predict when the volcanic eruption would occur. In an effort to promote scientific cooperation among NASA, the United States Air Force, and the University of Costa Rica, KSC is in the process of developing a small mass spectrometer system to be flown onboard a research aircraft known as WB-57 (figure 1) for in situ gas sample collection. The goal of this joint project is to determine the correlation between in-flight gas concentration data and the states of various volcanoes during their evolution process in order to provide early warning of the volcanic activity to the local residents. This will be the first time that a mass spectrometer is used in a high-altitude (approximately 50,000 feet), low-pressure (150 torr), and low-temperature (-50 degrees Celsius [°C] or -58 degrees Fahrenheit) environment. The instrument has to be small enough to fit into a dedicated compartment of the aircraft, light enough so that it will not exceed the aircraft's overall load limit, and rugged enough to withstand the g-force during takeoff and landing. Above all, it should be operational continuously and autonomously during the entire estimated

Figure 1. WB-57 Research Aircraft

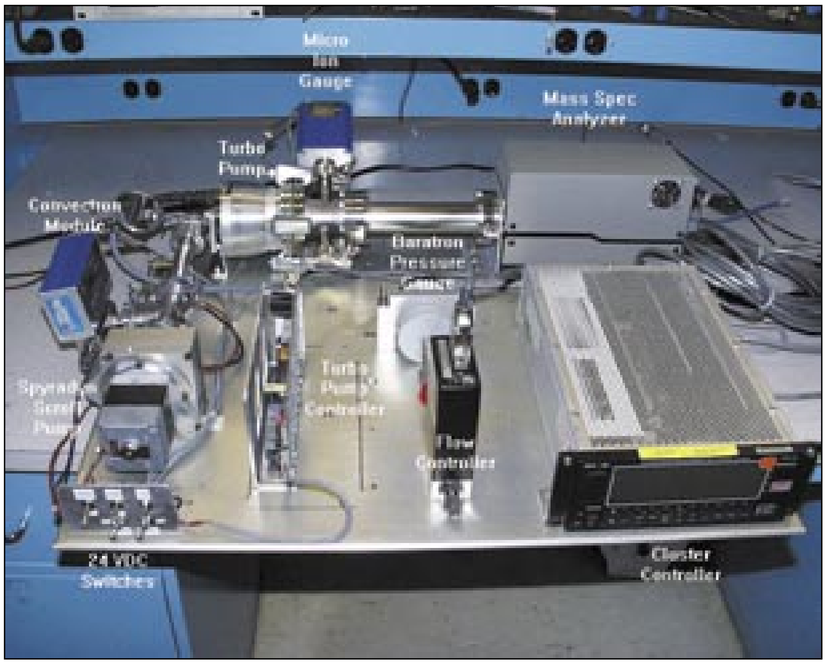

Figure 2. WB-57 Test Components

7-hour flight. Success of this test flight would be crucial for future hardware development of the advanced hazardous gas detection system onboard the Space Shuttle.

Figure 2 depicts the major components of the mass spectrometer system to be tested before flight: an SRS RGA 100 quadrupole analyzer; an Alcatel ATH 30+ Turbo molecular pump; an Alcatel ACT 200 Turbo Pump controller; a 24-volt direct-current, dual-stage Spyradyn Scroll pump; a Granville-Phillips Ion Gauge Module; a Granville-Phillips Convectron Gauge Module; an MKS Mass Flow Controller; an MKS Baratron Pressure Gauge; and an MKS Cluster Controller. The entire unit weighs about 90 pounds and is currently being assembled in the Engineering Development Laboratory at KSC. Preliminary environmental testing on the system indicates that most of its components appear to be functional nominally at 150 torr, but some of its components, especially the turbo molecular pump, may require heaters to keep them warm and operational at -50 °C. Vibration tests will also be performed to ensure the system's functionality in the presence of shock and vibration during takeoff, landing, and in-flight turbulence.

Key milestones:

- Complete system design and buildup.
- Complete system test at low pressure. All components performed nominally.
- System test at low temperature is still in work. Some components require heaters.
- Vibration test will follow after environmental test.
- Transport to Johnson Space Center for WB-57 flight.

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Participating Organization: Dynacs Inc. (Dr. CR. Arkin, W.D. Haskell, and G.R. Naylor)

Product Data Management (PDM) and Checkout and Launch Control System (CLCS)

The CLCS project is deploying a PDM system (Autotrol's Centra-2000) to meet many of its configuration management requirements. In particular, CLCS is using Centra-2000 to perform the following functions:

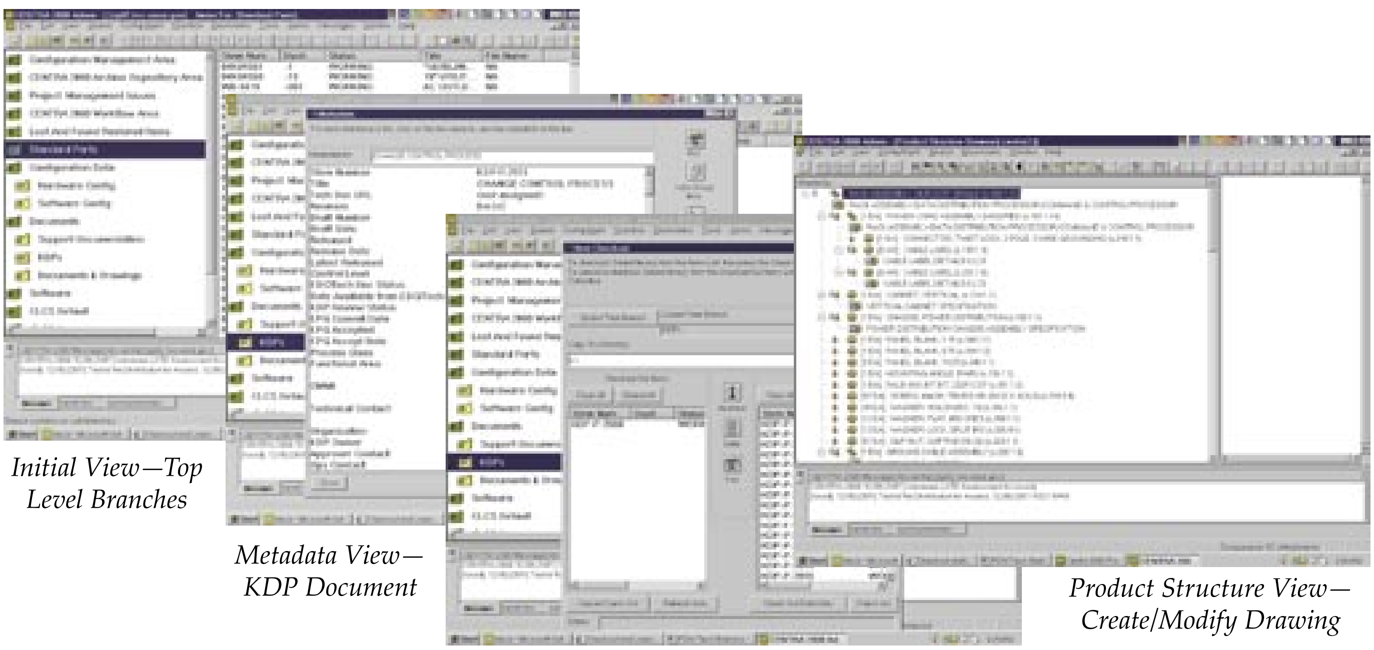
- Electronic Data Management (EDM)
- Parts and assembly management
- Product structuring
- Documentation control (including drawings)
- Change Management (including Engineering Support Requests [ESR's])
- Workflow (automated process management)

CLCS documents and drawings are maintained and controlled on-line. The EDM function of Centra-2000 keeps a full history of documents and drawings. Each revision is saved and associated with the change request. The documents are maintained using change management functions of Centra-2000.

Parts and their corresponding specifications and/or drawings are described and represented in Centra-2000. Parts are then linked to each other in a hierarchical relationship to represent assemblies. Assemblies are also linked together to form products. In addition, parts can be linked together to represent substitute and/or alternate part relationships. Parts are also linked to their corresponding drawings, specifications, and associated change request. There is a two-way relationship between the parts, drawings, specifications, and change requests. This allows a user to know the complete pedigree of any part. Attributes are defined for parts, documents, and drawings and are used to track key pieces of information, such as vendor name, part number, alternate part, file type, and release status.

Changes to items in Centra-2000 are tracked using a custom change request form. The changes are classified as levels 3, 4, and 5, with level 3 indicating the highest level of control. Level 3 changes affect items that are operational and require project management approval. Level 4 changes affect items that are not operational but are in the formal test cycle. Department or panel heads approve level 4 changes. Level 5 changes affect items in development and may be approved by the responsible project member.

An additional feature of Centra-2000 is the capability to implement a workflow. A workflow can



Initial View—Top Level Branches

Metadata View—KDP Document

Product Structure View—Create/Modify Drawing

Item Checkout View—KDP Document

be thought of as automated process management. It is a pictorial and functional representation of a process complete with decision blocks, approval stages, reading lists, electronic notification, parallel paths, and alternate paths. Workflows may be used to enforce existing processes such as document reviews, ESR reviews and approvals, and changes to controlled items such as parts and assemblies. ISO processes may be represented and tracked by Centra-2000.

CLCS is also using Centra-2000 to provide structure to unstructured data. Centra-2000 facilitates the storage and retrieval of unstructured data. Some examples of unstructured data are overhead presentations, briefs, white papers, schedules, project directives, assessments, and position papers. This data is often shared among the project members in meetings and is typically stored on a file server without revision control. Centra-2000 provides both revision control and a hierarchical structure to this data. Change control can also be applied to this data if necessary.

Key accomplishments:

- November 2001 – Completed Generation 0 – Hardware/software procurement of Centra-2000 PDM system, initial configuration, team training, pilot setup of hardware parts, assemblies, product structuring, and documents.
- April 2002 – Completion of Generation 1 – HMF parts, assemblies, product structuring, documents, drawings; all CLCS KDPs; full version control.

Key milestones:

- September 2002 – Partial completion of Generation 2 – ESR tracking and basic change management for parts, assemblies, documents.

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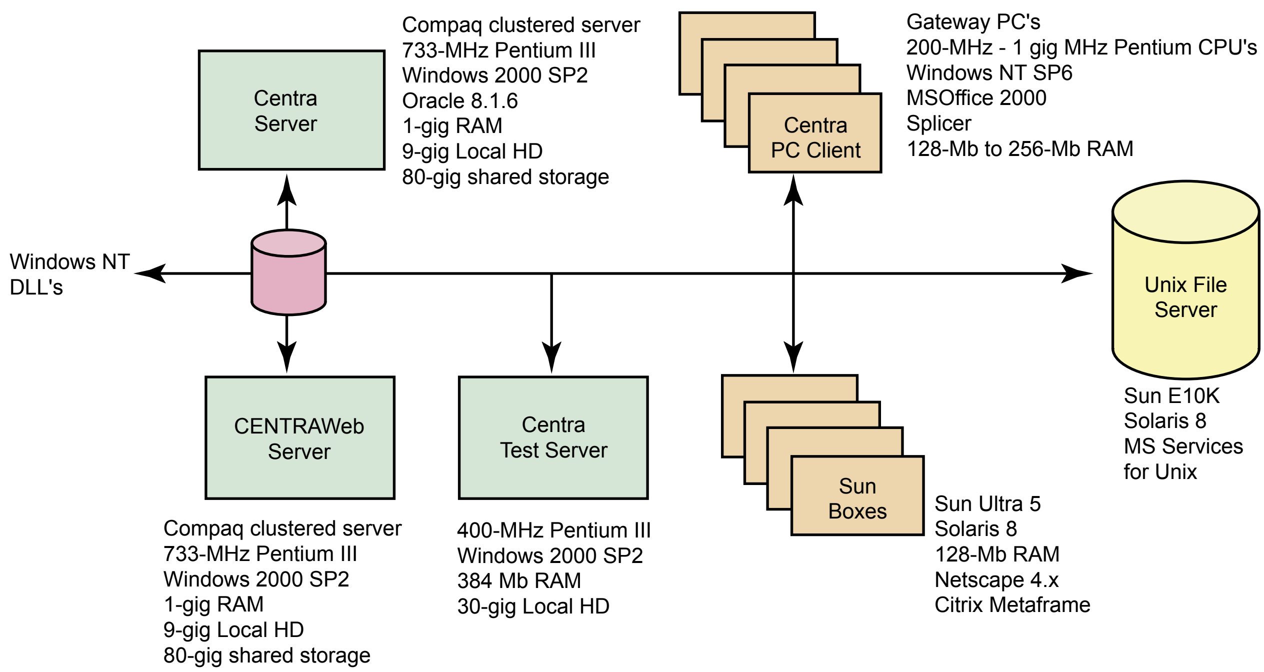

Note:
This picture shows the HW configuration of the PDM system. CLCS selected Centra 2000 from Autrotrol technologies as the PDM system. The configuration includes two clustered servers for the Centra 2000 software, a shared drive for the custom software, a test server, shared storage with a Unix file server for backups, and PC's running Splicer for viewing of drawings and documents.

PDM (Centra 2000) HW Configuration

Signal Conditioning Amplifier Recorder (SCAmpR)

The SCAmpR architecture is a new approach to high-end data acquisition. As the name suggests, each amplifier in the system has memory for storing data. In addition, each amplifier has a microprocessor that configures the amplifier for different requirements and calibrates, communicates, and processes the data. In short, each amplifier is a stand-alone data acquisition system.

A SCAmpR channel communicates using a standard network protocol conforming to American National Standards Institute/Institute of Electrical and Electronics Engineers (ANSI/IEEE) STD 802.1. This enables the system to be integrated using standard network distribution equipment. The system is commanded and data is retrieved from the SCAmpR channels through an isolated network using a simple software application written for a personal computer (PC) running Windows. This application can be adapted to other computer platforms.

SCAmpR Prototype Chassis Showing 16-Channel Power Module

The intent of this architecture is to time-tag and record the data at the amplifier in nonvolatile memory. This greatly increases the reliability of the system by eliminating the possibility of failures in peripheral components that are required for recording data in traditional systems. With SCAmpR, the data is archived at the source and can be retrieved at any time. Even if there is a failure while retrieving the data, the retrieval process can, at worst, just be repeated. The system is designed with bandwidth that allows for data snapshots to be acquired by the host PC while receiving health status from the SCAmpR channels. In fact, the data files in their entirety can be transferred while recording for a 200-channel system operating at 10,000 samples per second per channel.

The system is designed around ANSI/IEEE 1014, specifically referencing the 6U VersaModule Eurocard (VME), 21-slot mechanical standard. This makes standard VME hardware suitable for the chassis buildup. This standardization greatly reduces cost and ensures continued availability of chassis parts through numerous vendors. A single chassis will contain 64 SCAmpR channels and mount in a standard 19-inch rack. The backpanel of the chassis will have the sensor cable interface connectors. These can be built to integrate with existing systems. The prototype chassis is shown in the figure.

The system is scalable to the limits of the network equipment. The individual SCAmpR channels communicate at 100 megabits per second. The chassis is configured to interface with a single network cable. This greatly reduces infrastructure costs.

The system in no way adheres to the electrical VME standard. The chassis uses the backplane for power distribution to the SCAmpR channels. The two end slots on both sides of the chassis contain modularly designed power cards that provide power for 16 SCAmpR channels through the backplane. The chassis can be configured to require a single 120-volt alternating current power cable or accept a 28-V direct current power source. Any power slot can receive any power module.

The 6U form factor allows space for four SCAmpR channels to be located in a single card slot. The channels share no hardware though they reside on the same circuit board. This ensures that a failure of any one channel will be isolated and affect no other channel.

The approach to the SCAmpR channel is also modular. Though the processor, communication, and memory will be the same, it is anticipated that different requirements will necessitate the design of specialized amplifier sections. A section of the circuit board is reserved for varying measurement requirements. It will be relatively inexpensive to integrate a specialized requirement into the basic modular design.

The final card slot of the chassis is reserved for a certification card. This system will not require a separate certification station. A single command from the host PC will initiate a certification cycle that will confirm the health of the chassis and its contents. This feature will save considerable labor. The system will not have to break configuration to achieve the required annual calibration of the amplifiers. A periodic calibration of the certification card is all that will be required.

The SCAmpR architecture was created with the intent of breaking the pattern of increasingly short-duration obsolescence associated with electronic systems. This system can adapt readily to changes in network equipment. With a simple software application revision, computer equipment and operating systems can be replaced without major cost or time impact to the system. SCAmpR will continue the tradition of state-of-the-art data acquisition at KSC while reducing costs for operation and maintenance to a fraction of that required in current systems.

Key accomplishments:

- Developed system requirements.
- Prototyped power module, SCAmpR module, backplane, and chassis.
- Tested and demonstrated the system prototype.

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Participating Organization: Dynacs Inc. (Dr. P.J. Medelius, J.D. Taylor, J.A. Rees, Dr. C.T. Mata, J.J. Henderson, and T. Erdogan)

Hydrogen and Oxygen Point Sensors

This is a continuing work toward the development of leak detection point sensors for cryogenic propellants in the presence of purge gases including helium and nitrogen. Both commercial sensors and sensors designed in-house were tested in the Gas Detection Sensor Test Station (GDSTS) (figure 1), developed by YA and the Engineering Support Contractor, Dynacs Inc. These sensors will be used for locating leaks in ground support equipment, the Space Shuttle, and future-generation spacecraft. The goals of this work include the following:

- Maintain a state-of-the-art sensor test station and capabilities.
- Test new, promising propellant sensors, designed to operate in air or purged environments, at room or cryogenic temperatures, and at ambient or high-altitude pressures.
- Develop in-house sensors where commercial sensors are lacking.
- Ultimately shorten vehicle processing time.

Figure 1. Gas Detection Sensor Test Station Located in Engineering Development Laboratory

The GDSTS was validated as a sensor test station using the Detronics combustible gas sensor presently utilized on the Shuttle launch pads for hydrogen leak detection. Test station performance parameters were monitored during the tests that included wide variations of hydrogen concentrations, pressures, and temperatures. After successful validation, the GDSTS was used to simultaneously validate the performance of a group of five Detronics combustible gas sensors from the supply batches currently used at Shuttle launch pads for outdoors and in purged area leak detection. Another test apparatus was constructed to perform quick screening tests of propellant sensors required to operate at very low temperatures (figure 2).

Promising hydrogen sensors to be used in purged areas and in very cold environments are being developed by a partnership between Glenn Research Center, Makel Engineering, and Case Western Reserve University (figure 3). The first generation of these devices, based on palladium alloy deposited on a micro-hotplate, was tested in the GDSTS and its performance was reported to the developers as feedback for the next generation. Ultimately, NASA intends to qualify these sensors for ground support equipment and flight hardware.

A commercial oxygen sensor was recently tested in the GDSTS and found to be of very superior design

Figure 2. Cryostat Apparatus for Screening Propellant Sensors Required To Operate at -180 Degrees Celsius

Figure 3. Glenn Research Center, Makel Engineering Corp., and Case Western Reserve University Hydrogen Sensor

Figure 4. Oxygen Sensors Qualified at -150 Degrees Celsius in GDSTS

and performance. Packaging issues are already solved for this zirconia-hydrate-based sensor, which is housed in a standard transistor package (figure 4). By testing in the GDSTS, this sensor was found to operate successfully in an environmental range of temperatures well below the manufacturer's specifications.

Part of the development process is to search for and partner with research or commercial entities willing to join with NASA and codevelop sensors that meet NASA requirements. A number of these arrangements are being pursued:

- Florida Institute of Technology, Electrical Engineering, fiber-optics hydrogen sensor (in place).
- Florida Solar Energy Center, hydrogen-sensitive optical fibers and devices fabrication using state-of-the-art microdevice equipment.
- SNECMA, a French company that has a hydrogen sensor reported to be qualified for cryogenic temperature operation deployed on the Ariane rocket.
- Advanced Magnet Lab, a Florida research company that has proposed a low-temperature hydrogen sensor based on nuclear magnetic resonance concepts.
- National Institute of Standards and Technology (NIST) Laboratory in Washington, D.C., provided NASA technical support and micro-hotplates that will be coated in-house with palladium alloys sensitive to hydrogen.

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Participating Organization: Dynacs Inc. (Dr. R.G. Barile, J. Dominguez, M.A. Bertucci, S.J. Stout, D.P. Schmidt, C.B. Mattson, J.G. Gates, and A.J. Eckhoff)

External Tank Center of Alignment System (ETCAS)

When the External Tank (ET) is mated to the Solid Rocket Boosters (SRB's), it is necessary that the ET be precisely positioned. The ETCAS is a tool that assists personnel in this operation by providing an automated measurement of the distance that separates the ET from each SRB. The ETCAS also provides a laser line that assists personnel in aligning the ET such that the two SRB's and the ET have the same centerline (see figure 1).

The current ETCAS uses two sensor units that each contain an acoustic sensor and a laser crosshair. These are connected to a central display unit by long, stiff cables that provide power to the sensors and a path for the measurement data. The sensor units are attached to the SRB by magnets. These acoustic sensors require frequent calibration and are suspect at temperature extremes.

A replacement for this system is in development. The new system uses a new commercial off-the-shelf (COTS) laser distance sensor to measure the distance between the SRB and the ET and to provide a line for the centerline adjustment. Laboratory testing will characterize the sensor's performance over the required temperature range, and a temperature measurement will be made along with the distance measurement to compensate for environmental changes.

The new system will use wireless technology to communicate. A core wireless system has been in development for several years in the Engineering Development Laboratory (EDL). This wireless system will be integrated with the laser distance sensor, a custom control and power circuit, and a battery pack to create the sensor unit. This new sensor unit package (see figure 2) will be magnetically attached to the SRB as before.

The new user interface will have a small, color, liquid crystal display (LCD) touch-screen panel that will show the relative position of the ET to the SRB both numerically and graphically.

The new ETCAS will have a number of advantages over the current system. The laser distance sensor will provide greater accuracy

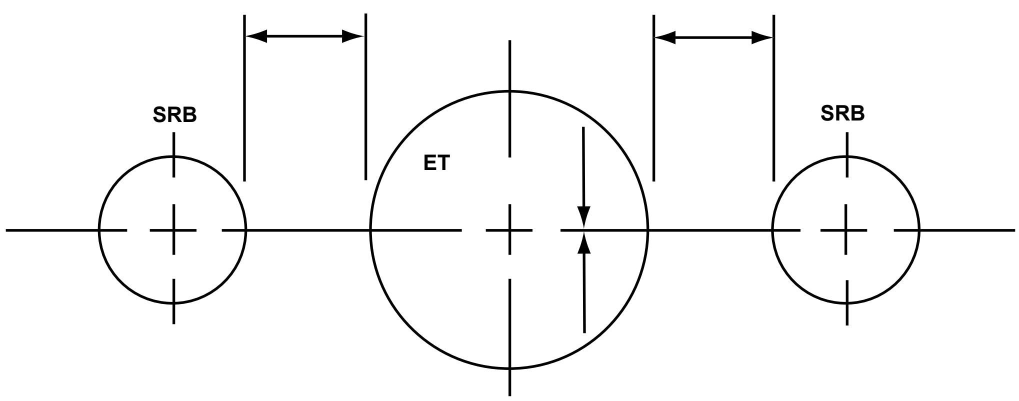

Figure 1. Graphical Representation of the SRB and ET Cross Section With Alignment Axes

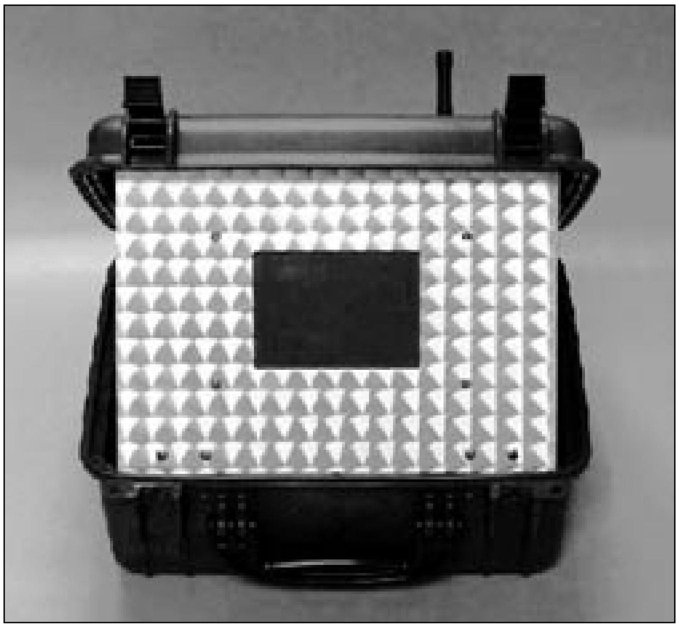

Figure 2. ETCAS User Interface Prototype

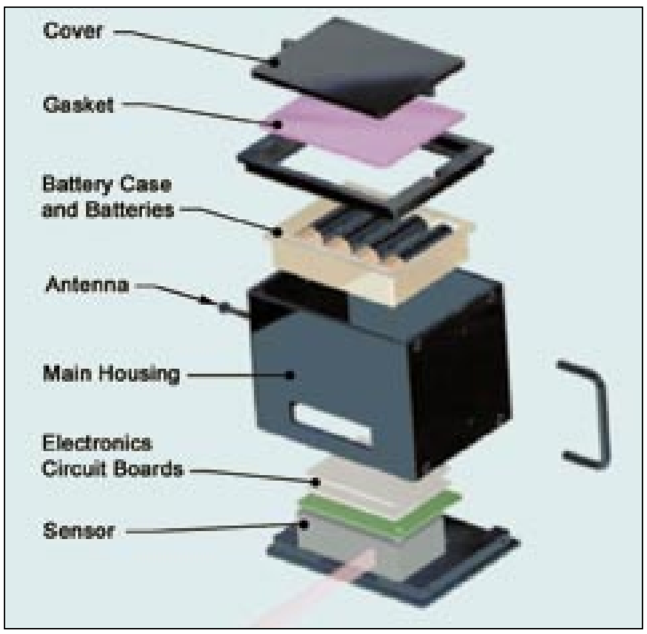

Figure 3. ETCAS Sensor Unit

and will not require calibration. The entire system will fit in a case the size of a deep briefcase. Eliminating the cables to the remote units, the wireless ETCAS will allow the operator using the interface display to direct the alignment from a safe and effective distance.

Key accomplishments:

- Characterized and tested prototype sensor.
- Developed custom interface hardware and software.
- Integrated the EDL modular wireless system with COTS technology to gain utility and save money.

Key milestones:

- Final design of sensor hardware and display.
- Testing and debugging of user interface software.
- Approval and field use of the developed hardware.

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Participating Organization: Dynacs Inc. (Dr. C.T. Mata, J.J. Randazzo, B.M. Burns, N.N. Blalock, J.D. Taylor, and A.J. Eckhoff)

Electronic Nose for Space Program Applications I: Monitoring for Low-Level Chemical Vapor Contaminants in Spacecraft

The ability to monitor the air quality in a closed environment, such as the Shuttle, the International Space Station (ISS), and future human missions to Mars or the Moon, is important to ensure health and safety of astronauts. Postmission analyses of grab air samples from the Shuttle have confirmed the occasional presence of onboard contaminants. Accordingly, a need exists for a lightweight, low-power, miniature instrument that can monitor contaminants at trace levels in real time. One promising technology is the Electronic nose (E-nose). Commercial E-nose instruments are now available, and several are being evaluated at the Kennedy Space Center for space program applications (figure 1).

An E-nose consists of an array of nonspecific vapor sensors. Typically, each individual sensor responds to a broad range of chemicals, albeit with a unique sensitivity relative to the other sensors. Upon exposure to a test vapor, the pattern and magnitude of response across the sensing array is compared to previously stored response patterns. The E-nose is selective because individual vapors induce unique response patterns. Representative response patterns for hypergolic fuels (i.e., hydrazine [HZ] and monomethylhydrazine [MMH]) are presented graphically in figure 2. Although chemically similar, the patterns for HZ and MMH are clearly distinct. The collection of data for the E-nose library and the development of mathematical models for using that data for identification of a test vapor are known as “training.” A properly trained E-nose could provide notification of sudden adverse events, such as leaks, spills, or even fire. The program at KSC is evaluating the E-nose technology for monitoring organic vapors and other chemicals in breathing air.

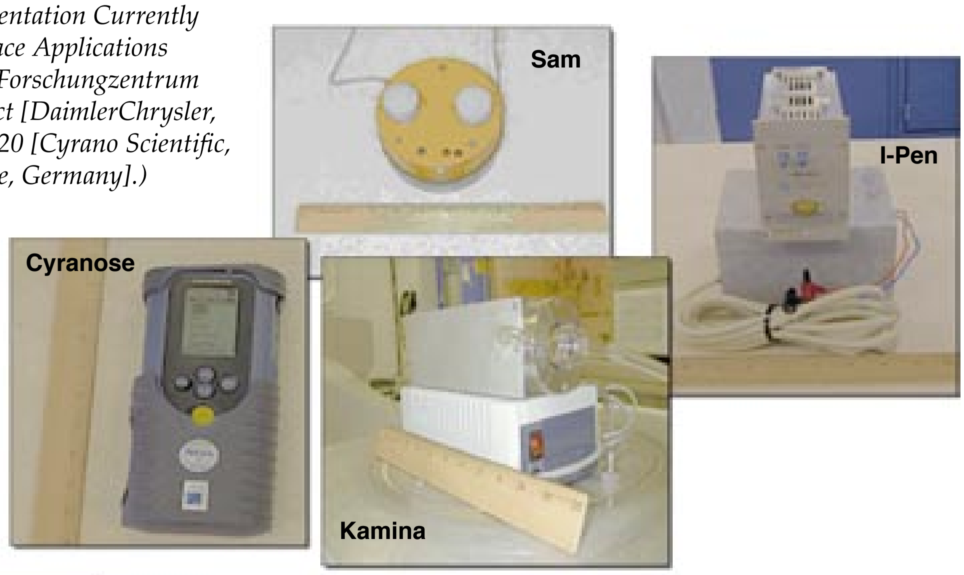
One critical parameter for space applications is the detection and identification of hypergolic fuel. Present allowable vapor levels in breathing air are set at 10 parts per billion (ppb). One particularly challenging application is the detection of hypergols in the Shuttle airlock at these levels. During space walks, the Orbital Maneuvering System is controlled by a Hypergolic Propulsion System. Prior to reentry to the crew quarters cabin through the airlock, it is important to verify that no residual vapor is present. This must be done at the operating pressures of the airlock, which range from about 3 to 15 pounds per square inch (psi). Although numerous monitors exist for hypergolic fuel vapors at higher concentrations, few technologies have been identified that reliably respond at this low concentration. Thus far, the Kamina is the only commercial E-nose technology that can readily respond to hypergolic fuels at this level (figure 3).

To train the Kamina E-nose to hypergolic fuels, over 50 individual exposures were performed at pressures ranging from 3 to 14.5 psi and relative humidity ranging from 5 to 80 percent for concentrations in the 10- to 1,000-ppb range. Using the vendor-supplied modeling software to perform a principal component analysis (PCA) followed by linear discrimination analysis (LDA), a model was created that assigned individual compounds to well-defined regions in two-dimensional space. This demonstrates that the Kamina should identify these vapors. In addition to developing models using vendor-supplied software, there is an active in-house program to develop algorithms to identify which sensor elements within the array provide the most information, to identify the best procedure to extract information from the data, and to determine the best classifier for the application.

Key accomplishments:

- Evaluated four commercial E-nose technologies for low-level detection of hypergolic fuels and identified at least one instrument (Kamina) that can readily detect HZ and MMH at 10 ppb.
- Using the Kamina E-nose, collected a training set composed of over 50 independent hypergolic fuel (HZ and MMH) measurements at concentrations ranging from 10 to 1,000 ppb. The effects of ambient relative humidity (5 to 85 percent)

Figure 1. Various E-Nose Instrumentation Currently Being Evaluated by KSC for Space Applications (Instruments include the Kamina [Forschungzentrum Karlsruhe, Germany], the Sam Detect [DaimlerChrysler, Aerospace, Germany], the Cyranose 320 [Cyrano Scientific, USA], and the I-Pen [AirSense, Germany].)



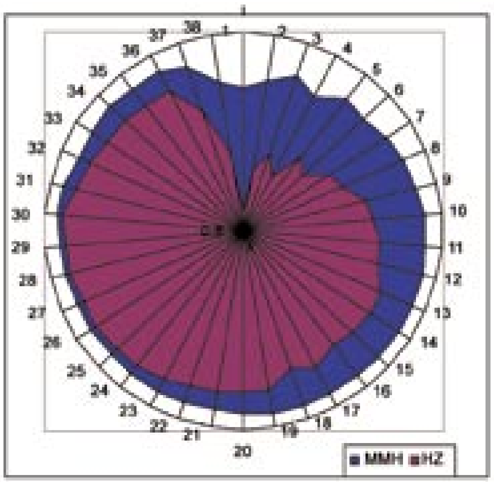


Figure 2. Response of the Sensor Array Used in the Kamina E-Nose to HZ and MMH (Unique response patterns obtained for 200-ppb HZ and 200-ppb MMH.)

and pressure (3 to 15 psi) were included in the training set.

- Developed criteria to extract analytically significant information (e.g., features) from the training set to develop models with improved identification efficiencies. Using the newly developed feature extraction method, self-validation of the training set predicts an improved probability of identification near 90 percent.
- Obtained comparable identification efficiencies with a second training set composed of five common volatile organic compounds.
- Demonstrated that both short-term and long-term exposures provide similar identification information.

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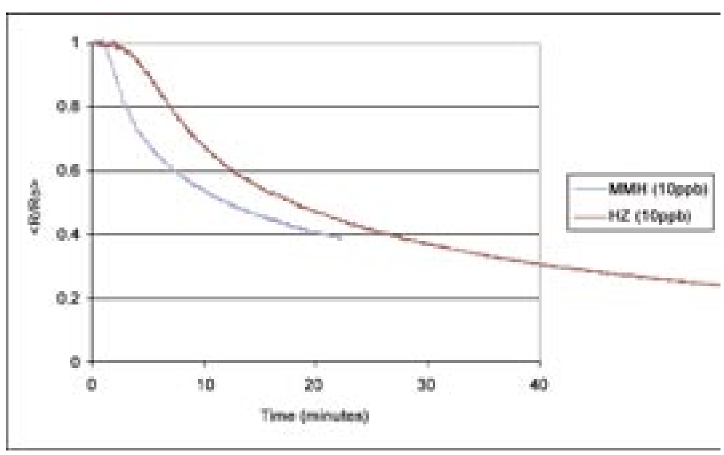
Participating Organization: Dynacs Inc. (Dr. W.J. Buttner and Dr. B.R. Linnell)

Figure 3. Real-Time Response of the Kamina Sensor Array to 10-ppb HZ and MMH (The array was exposed with clean air for approximately 60 seconds followed by exposure to the HZ or MMH vapor. The average of the 38 sensors is plotted as R/Ro, where R is the sensor response at any point in time and Ro is the response of the sensor in clean air.)



Electronic Nose for Space Program Applications II: Precombustion Fire Alarm

Frequently, one of the earliest indicators of a pending electrical fire caused by equipment failure is the overheating of wires. Wires and other electrical cables are usually encased in a plasticlike insulating material. Modern wire insulation is made from organic polymers. One common insulation material is polyvinyl chloride (PVC). For the Shuttle and other space applications, a higher-grade insulation is typically used such as Teflon or Kapton. As the wires heat up, chemical vapors are emitted from the insulation. These compounds consist of residues left over from the fabrication process (e.g., solvent residues, additives, low-molecular-weight oligomers) and of thermal degradation products of the insulation itself. Since the chemical composition and fabrication process differ for the various insulating materials, each wire type will have a unique profile for its thermally generated vapors. This chemical distribution is indicative of the insulation material itself. Vapor outgassing begins before the development of smoke or soot. Thus, chemical monitoring for selected signature vapors can provide notice of a pending fire prior to actual combustion. This in turn can provide warning to allow shutdown of operations before major damage can occur.

The observation of selected chemical signatures would indicate a thermal excursion in electrical circuitry. The task is not so much to identify the signature compounds but to observe their presence and to confirm their uniqueness to the system under study. Figure 1 illustrates the experimental apparatus for the thermal generation of vapors from various wire types. As the wire heats up, gaseous products are generated. Electronic nose (E-nose) instruments installed within the chamber detect the generated vapors. Figure 2 shows the response pattern of the Kamina E-nose to the thermal vapors of various wire types. Clearly, each wire type induced a unique response. The Sam Detect E-nose also exhibited an equally impressive response to vapors generated from heated wires. Modeling of the Sam Detect data resulted in well-separated 2-dimensional projections indicating that thermal degradation of the various wire types can be identified via chemical monitoring.

Key accomplishments:

- Designed and built the apparatus for the controlled thermal outgassing and degradation of various wire types. This system was interfaced with the E-nose technologies.
- Tested two E-nose instruments (Sam Detect and Kamina) and identified promising technologies for continued developments.
- Modeled data that confirms a degree of selectivity.

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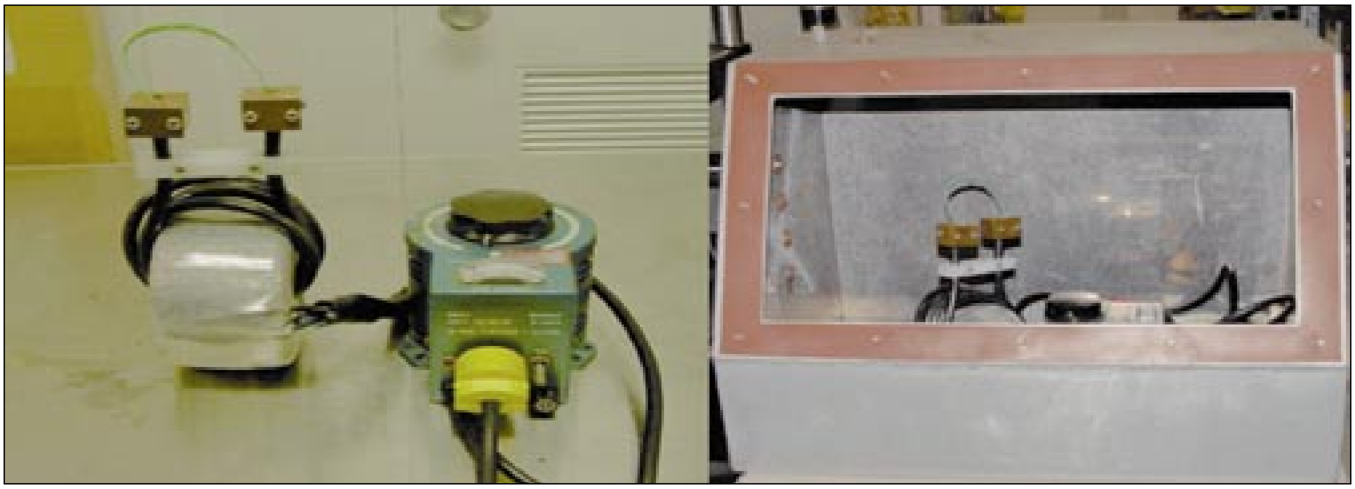
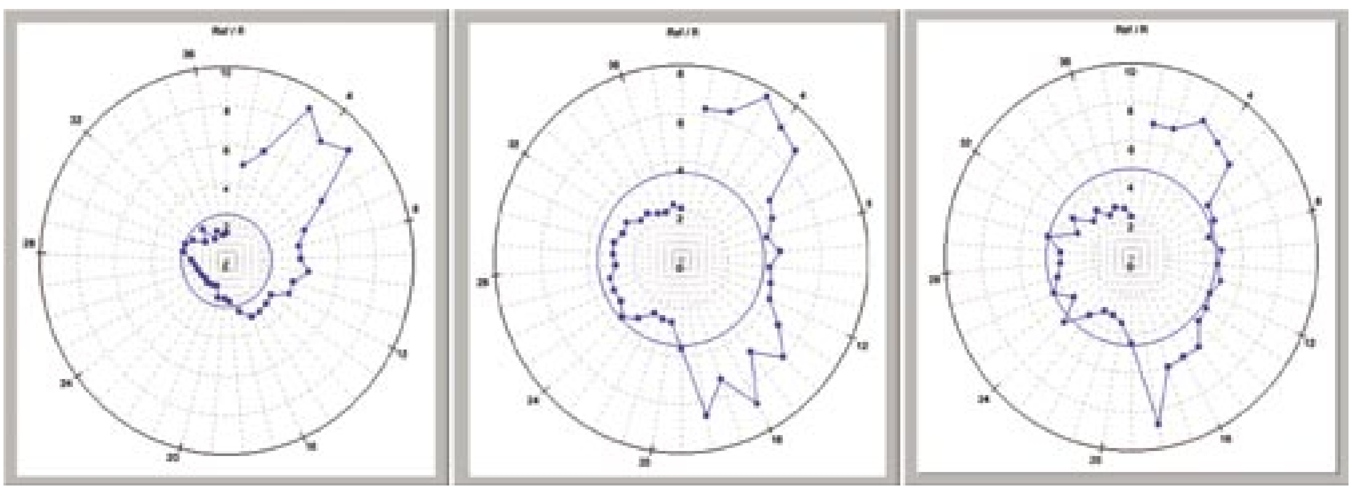


Figure 1. Experimental Apparatus for the Thermal Generation of Vapors From Various Wire Types

(The wires are heated via a power transformer. This process is typically carried out in an enclosure to allow access to the vapors by an E-nose. Various E-nose technologies (not shown) were used in this study and were mounted within the chamber during the heating process.)



PVC **Kapton** **Teflon**

Figure 2. Response Patterns Induced by Thermally Generated Vapors for Various Wire Types Observed on the 38-Sensor Array Used in the Kamina E-Nose

(Data is presented as a radial plot in which the response for each of the 38 sensors is plotted as a distance from the origin. Vapors are identified by comparing the response patterns of a sample vapor to previously measured patterns stored in memory. The pattern for PVC is readily and easily distinguishable from Kapton and Teflon. Although similar, there is sufficient difference between Teflon and Kapton for identification of the wire type.)

Solenoid Valve Electromechanical Model

The purpose of this work was to develop a simplified electromechanical model of a solenoid valve used in the Space Shuttle's fuel system. The primary goal of this math model is to characterize and predict the valve's current signature. A current signature is simply a plot of the current flowing through the valve's electromagnet versus time.

It has been proposed that a detailed analysis of current signature can provide critical information about valve health (see "Solenoid Valve Status Indicator," KSC Research and Technology [R&T] 1999 Annual Report). Health monitoring in this context implies that failures can be avoided by observing subtle changes in the current signature, which correspond to deterioration of the valve system. From this point of view, early detection of current signature anomalies could be used to avoid a catastrophic valve failure.

There are several prominent features of the current signature belonging to the solenoid valve, as discussed in the 1999 R&T Report. When the valve is energized, a sizeable dip in current occurs in the general vicinity of the midpoint of the exponential rise of the current curve. Similarly, a large dip occurs in the midpoint vicinity of the current decay. The precise shape and position of these energized and deenergized current dips are thought to yield information about the electromechanical state of the valve, which is linked to the question of valve health.

It is presently believed that the basic shape of these current dips (or spikes) is primarily caused by a back-EMF generated by the time derivative of inductance L. In conventional circuits involving inductive elements, the total time derivative of L is zero, since L is a constant. However, in the Shuttle solenoid valve, inductance is a function of the poppet-plunger assembly displacement x. The displacement is also a function of time, so that total time derivative of L is nonzero.

The dependence of valve inductance on other system parameters can lead to detection of valve performance degradation by analyzing the current signature. One of the most common failure mechanisms is contamination of the valve's O-rings with foreign debris. Other less common failures might be related to cracks in the casing or the spring and spring-mounting assembly. Debris blocking the plunger-solenoid gap could also lead to valve failure. It is hoped that a good understanding of working characteristics using a simplified electromechanical valve model will enhance our ability to utilize current signature analysis. Valve current signature monitoring and analysis should, in the end, be able to provide critical information about valve health and performance and hopefully provide a means of detecting the onset of common failure modes well before catastrophic failure occurs.

Key accomplishments:

- Developed a lumped-parameter electromechanical model that helps explain the current signature of a Space Shuttle solenoid valve.
- The deenergized portion of the

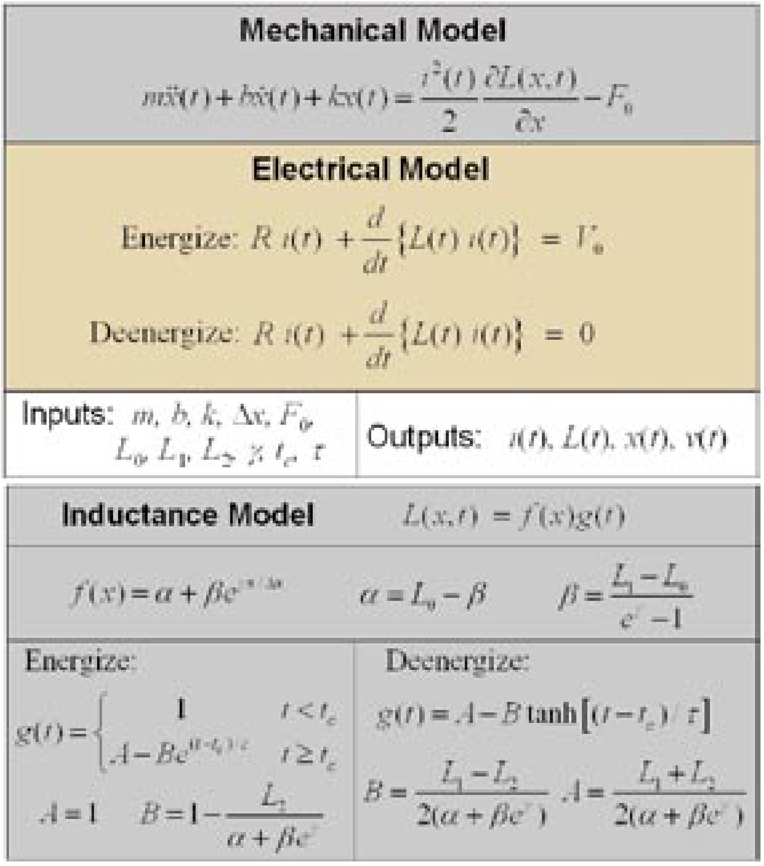


Figure 1. Valve Electromechanical Model

model seems to fit the measured data with reasonable accuracy.

- The energized portion of the present model fits well but only if all parameters are unconstrained (more work is needed in this area).

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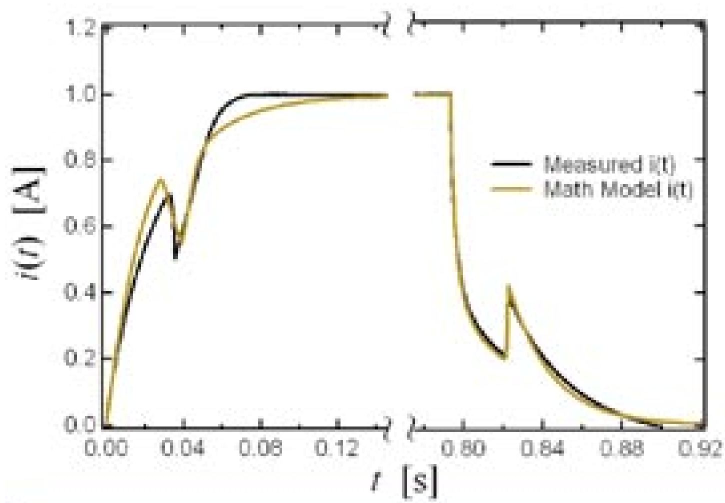

	γ	L_0	L_1	L_2	b	τ	t_c	F_0
Energize	1.182	0.514	0.862	0.608	122.52	0.00522	0.0422	114.07
Deenergize	7.067	0.514	1.140	0.446	75.40	0.00601	0.794	114.07

Figure 2. Model Versus Measured Data

Solenoid Inter-Force (SIF) Calculator

The Lorentz force is the well-known force exerted on a charged particle of charge q and velocity $\mathbf{v}$ in a magnetic field $\mathbf{B}$:

$$\mathbf{F} = q\mathbf{v} \times \mathbf{B} \tag{1}$$

When a charged particle, such as an electron or proton with a linear velocity, encounters a magnetic field, the Lorentz force results in a spiral trajectory, where the circular portion of the path is perpendicular to the **B** field.

The integral form of the Lorentz force equation is:

$$\mathbf{F} = \int \mathbf{J} \times \mathbf{B}\, dx^3 \tag{2}$$

Equation (2) is useful in describing a solenoid coil configuration. This is the case in figure 1, where the bottom coil (coil 1) is stationary and has a steady-state current of I_1. The upper coil (coil 2) in figure 1, which has a steady-state current I_2, slides along a vertical rod, maintaining axial symmetry.

A form of the force equation that lends itself to evaluation by computer is:

$$\mathbf{F} = \frac{2\pi I_2}{A_2} \sum_{k=1}^{N} a_k \mathbf{e}_\phi \times \mathbf{B}_k A_2 \tag{3}$$

where I_2 is the current and A_2 is the cross-sectional area of coil 2 wire, a_k is the radius of the kth wire loop of coil 2, and $\mathbf{B}_k$ is the field at the position of the kth wire loop of coil 2. The position of the kth wire loop is specified by $\rho = a_k$ and $z = z_k$.

Now sum the simple analytic expressions for the magnetic field of a circular current loop over all loops of the solenoid (see "Solenoid Inductance and B-Field Calculator," KSC Research and Technology 2000-2001 Report):

$$B_\rho(a_k, z_k) = \frac{\mu_0 I_1}{2\pi} \sum_{j=1}^{M} \frac{z_{jk}}{\alpha_{jk}^2 \beta_{jk} a_k} \left[(a_j^2 + a_k^2 + z_{jk}^2) E(\varphi_{jk}^2) - \alpha_{jk}^2 K(\varphi_{jk}^2) \right] \tag{4}$$

The final force formula given in figure 2 is found by combining Equations (3) and (4). This is the force that pushes coil 2 above coil 1 while balancing gravity. The levitation height h is dependent on the product of the currents in both coils (I_1 and I_2) as well as the mass of coil 2. Note that if the currents I_1 and I_2 flow in the same direction, the force is attractive. In order to levitate, the currents must be in opposite directions.

The height h in figure 1 was measured for several values of current. For this data, currents were equal and opposite. This data is shown in the plot of figure 3 as circles. Results are also plotted from the SIF calculator for the same range of current values (figure 4). Even though the calculated and measured values are not exactly lined up, the correlation suggests that the SIF calculation produces reasonable results.

Key accomplishments:

- Developed an analytic formula to calculate the levitation height between two solenoids constrained to move in the axial direction.
- A Windows calculator was developed that evaluates levitation height based on input coil parameters, as well as estimates of coil temperature.
- Using similar analytic methods, a formula that computes the approximate current leading to mechanical failure (coil implosion) was derived.

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Participating Organization: Dynacs Inc. (Dr. J.E. Lane and Dr. C.D. Immer)

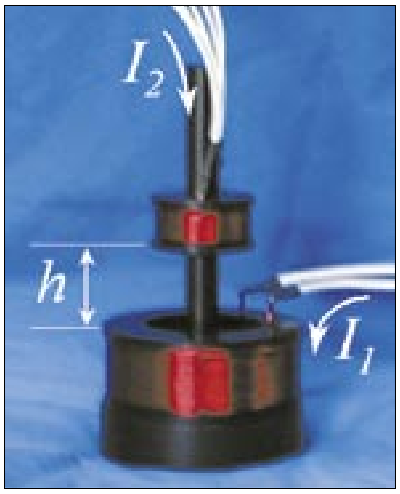

Figure 1. Lorentz Levitation Test

$$F_z = -\mu_0 I_1 I_2 \sum_{k=1}^{N} \sum_{j=1}^{M} \frac{z_{jk}}{\alpha_{jk}^2 \beta_{jk}} \left[\left(a_j^2 + a_k^2 + z_{jk}^2 \right) E(\varphi_{jk}^2) - \alpha_{jk}^2 K(\varphi_{jk}^2) \right]$$

- The summation is over all current loops of radius a_j of coil 1.
- $\alpha_{jk}^2 \equiv a_j^2 + a_k^2 + z_{jk}^2 - 2a_j a_k$
- $\beta_{jk}^2 \equiv a_j^2 + a_k^2 + z_{jk}^2 + 2a_j a_k$
- $\varphi_{jk}^2 \equiv 1 - \alpha_{jk}^2 / \beta_{jk}^2$
- $z_{jk} \equiv z_k - z_j$

Figure 2. SIF Analytic Formulas

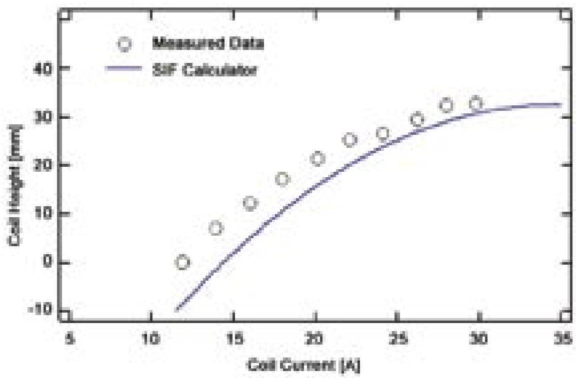

Figure 3. Measured Versus Calculated Data

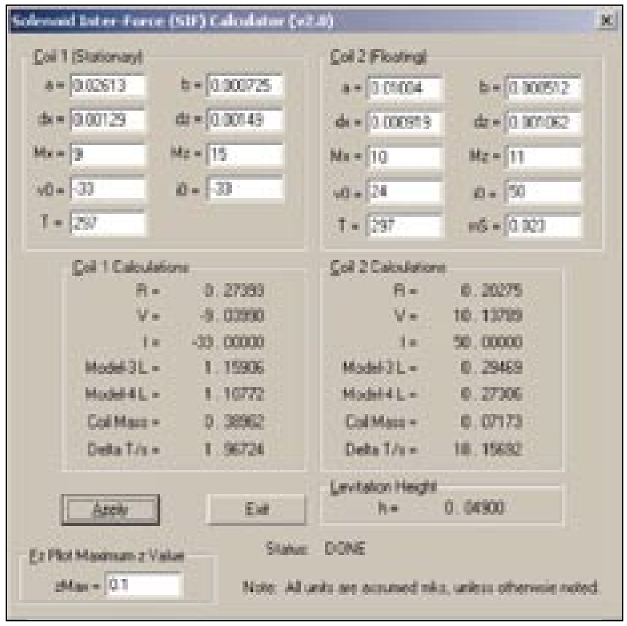

Figure 4. SIF Windows Panel

Block Convolution Mask for Position Measurement

A special-purpose convolution filter was developed that converts a printed target composed of black and white squares into a pattern of dots. The output image consists of mostly a black background and a pattern of white dots, corresponding to the intersection points of the black and white squares. The result is an output image that requires less processing than the original input image of black and white squares against an unknown background. Printed targets are much easier to fabricate than other types of targets since they can be created and modified with a computer drawing utility and a standard office printer.

The Block Convolution Mask (BCM) filter transforms a printed target into a set of pinpoints that can in theory be single pixel points. The uniqueness of this innovation is the ability to minimize dimensional error associated with imaging a target for positioning or measurement applications.

BCM can be defined as a type of image gradient operator or edge detection filter. Most gradient operators and edge detection filters are square arrays (or filter masks) of size $N \times N$ where N is an odd number. The BCM described herein is also a square $N \times N$ filter mask, where N is now even.

By imaging targets, information can be obtained from a two-dimensional (2-D) camera image, thus providing the x, y, z position of the target in the camera coordinate system. The formulas that transform a 2-D image to 3-D position x, y, z are based on a pinhole camera model (figure 1), where m and n are pixel locations (integer values) in the x and y image direction; L_x and L_y are the physical dimension of the target (or distance between targets) in the x and y direction; s_x, s_y, and s are "scale factors" in the x and y direction and the RMS value; m_0 and n_0 are the center x and y location of the target in the image; m_c and n_c are the pixel locations of the center of the image; and α is a value that must be determined by calibration of the camera/lens system. Note that f is the focal length of the lens.

Applications for the printed target and convolution filter include those calling for accurate position measurements. The sharpness of dots in the

$$s_x = \frac{L_x}{m_2 - m_1} \qquad s_y = \frac{L_y}{n_2 - n_1} \qquad s = \sqrt{\frac{s_x^2 + s_y^2}{2}}$$

$$x = s(m_0 - m_c) \qquad y = s(n_0 - n_c) \qquad z = \alpha s + f$$

Figure 1. Position Formulas Based on Pinhole Camera Model

$$F = \begin{pmatrix} -1 & -1 & 1 & 1 \\ -1 & -1 & 1 & 1 \\ 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & -1 \end{pmatrix}$$

Figure 2. Example 4 × 4 BCM

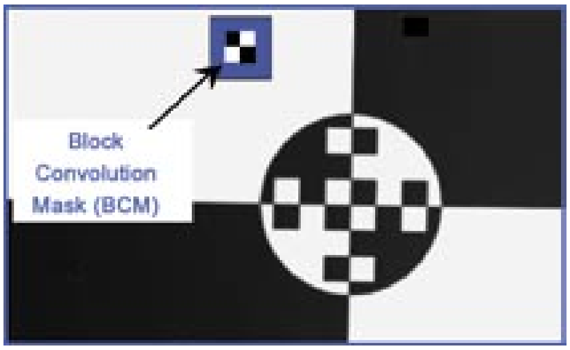

Figure 3. Input: BCM and Target Image

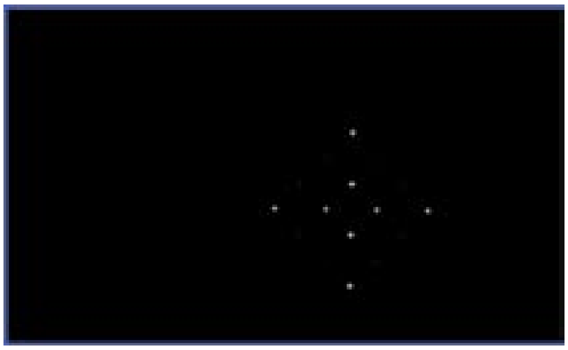

Figure 4. Output: Filtered Target Image Using BCM

filter output image is dependent on the size of the convolution filter. For example, an 8 × 8 filter produces a sharper image of dots than a 4 × 4 filter. However, as the filter size increases, so does the million-instructions-per-second (MIPS) requirement of the image processing system.

Key accomplishments:

- Developed a spatial convolution filter mask for applications requiring precise position measurement using a digital camera system. This technique may be used in applications requiring a high-accuracy measurement of 3-D spatial coordinates where direct physical measurement is not practical.
- The block convolution filter designed for this application converts a printed target of alternating squares (checkerboard) to a set of pinpoints, thus minimizing dimensional error in the object being imaged.

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Figure 5. Precision Position Measurement Application Using a BCM and 2-D Image Filter

Surveying With a Digital Camera System

Position measurement of flight hardware components, such as Solid Rocket Boosters, External Tank, and Shuttle Orbiter, is a critical step in the stacking and processing flow of the Shuttle Space Transport System. Surveyors who deal with land, construction, and highway surveying often deal with similar position measurement problems. Even though the surveying techniques used to locate Shuttle components and launch support equipment make use of similar mathematical techniques (based on the fundamentals of trigonometry and plane geometry), the instrumentation used by NASA and United Space Alliance (USA) in these kinds of operations greatly surpasses the measurement precision capabilities of typical surveying equipment.

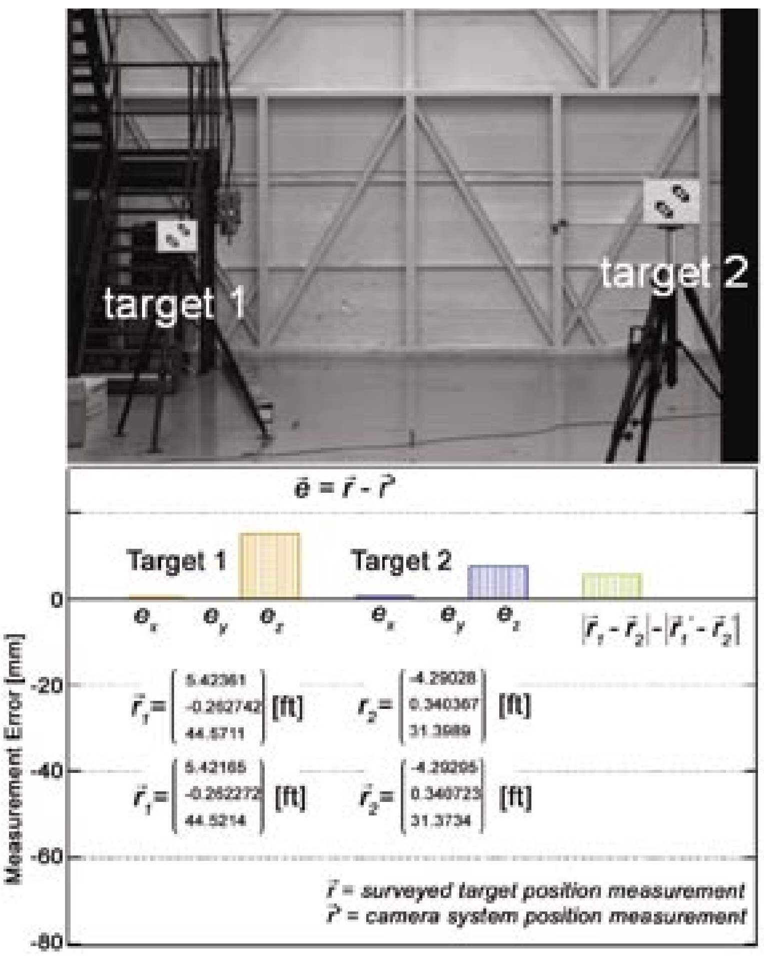

Figure 1. Example Survey Results of Two Targets

A low-cost alternative to expensive laboratory-grade surveying instrumentation was proposed and evaluated by the Engineering Development Contractor, Dynacs Inc., at KSC. This alternative is a digital vision system, composed of a digital camera, computer, and flat black and white targets. Figure 1 shows an example of relative error between true target positions and measured positions during a test of the vision measurement system. True target positions were determined by a precision survey performed by the NASA and USA Optics Group, using an array of high-quality laboratory-grade theodolites (see figure 2). The measurement error of the NASA/USA survey is less than 1 millimeter (mm).

In our test of the camera position measurement system, the camera coordinate system's origin is a point on the camera axis at a distance f in front of the charged couple device (f is the focal length of the lens). The z-axis is positive in front and away from the camera origin. The x-axis is horizontal and positive to the left of the camera origin. The y-axis is vertical and positive up from the camera origin.

The formulas described in figure 3 estimate the camera position measurement resolution limit. Note that the numerical values give error in millimeters with z in feet. The x, y, z error can be larger than that predicted by the equations in figure 3. Lens distortion may be the primary cause. An example of y error, shown in figure 4, is approximately within the theoretical error, since the target positions in this test were all near the y-axis, where lens distortion has minimal effect. As shown in figure 4, the z measurement resolution is usually much lower than the x and y measurement resolutions. However, at close range (distance between camera and targets), the z resolution can surpass the x and y resolution.

Figure 2. One of Four High-Precision Theodolites Used To Locate True Position of Targets

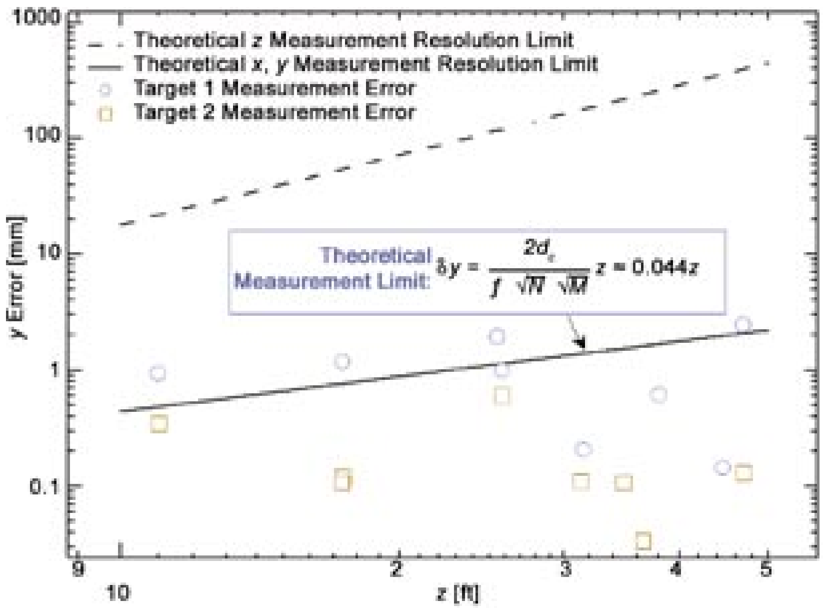

Figure 4. y Measurement Error Versus z

x, y Theoretical Measurement Limit:	$\delta x = \delta y = \frac{2d_c}{f\sqrt{N}\sqrt{M}} z \approx 0.044z$	
z Theoretical Measurement Limit:	$\delta z = \frac{2d_c}{Lf\sqrt{N}\sqrt{M}} z^2 \approx 0.18z^2$	
d_c = 9 µm	width of CCD pixel	
f = 25 mm	lens focal length	
L = 3.2 in	target width	
N = 8	convolution filter mask size ($N \times N$)	
M = 3	number of target point sets measured	

Figure 3. Theoretical Measurement Limits for a 1024 × 1024 Pixel Digital Camera

The low-cost advantage of the digital camera vision position measurement system may offset the lower position resolution disadvantages in many applications.

Key accomplishments:

- Developed and demonstrated vision system algorithms for independently locating *x*, *y*, and *z* positions of multiple targets, as well as measuring the relative distance between target pairs.
- Derived a set of formulas, which approximates the limit of measurement precision of a camera surveying system. These formulas relate the vision system (camera, lens, and target) parameters to the best measurement resolution that can be expected.

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Participating Organization: Dynacs Inc. (Dr. J.E. Lane and Dr. C.D. Immer)

Payload Ground Handling Mechanism (PGHM) Vision Measurement System

For installation of payloads into the Orbiter cargo bay while at the pad, the payload is delivered to the launch pad in a canister. The Rotating Service Structure (RSS) at the launch pad is retracted and the canister is mated with the Payload Changeout Room (PCR). The payload is transferred from the canister into the PCR, the canister is removed, and the RSS is then mated with the Shuttle. The payload is then transferred into the payload bay of the Shuttle Orbiter. The mechanism responsible for manipulating the payload, the PGHM system, consists of a set of movable J-hooks that lifts the payload by its trunnions.

Successful, safe integration of the payload requires careful position measurement of the J-hooks relative to the payload trunnions and the payload relative to the Orbiter payload bay. Typically, the ground support equipment involved is complexly structured, oddly shaped, and large in scale so that standard toolboxes of methods for distance measurements (theodolites, rulers, laser ranging, etc.) are neither cost-effective, practical, nor efficient. Currently, because of the complex nature of the geometry involved with the flight hardware, rulers are the best way to take these relative position measurements; however, measurement with rulers is difficult, time-consuming, and relatively inaccurate.

The PGHM Vision Measurement System seeks to alleviate this measurement problem by using a standard, inexpensive RS-170 monochrome camera coupled with digital image processing to measure these relative positions accurately in real time to 0.025 inch in x, y, and z. The hardware mounting bracket attaches to the PGHM using existing screw holes and consists of a camera, light-emitting diode (LED) for illumination, and a breakout box. The system is shown in figure 1.

With the data acquired during STS-108, algorithms were developed sufficient to meet the requirements of 0.025-inch accuracy at the working distances of the PGHM. Data acquired by the PGHM Vision Measurement System during STS-108 is shown in figure 2.

This Vision Measurement System consists of inexpensive commercial off-the-shelf (COTS) hardware components and custom-designed software using standard image-processing algorithms. To provide robustness in the initial systems, it is necessary to affix small paper targets to the hardware to measure position. These targets are acquired using highly specialized convolution filters. Development of more advanced pattern matching schemes will eventually lead to acquisition of “landmarks” in the field of view (such as those outlined with the red circles shown in figure 2) instead of targets. Enhancements to the target acquisition software algorithm can easily take place without modification of any hardware.

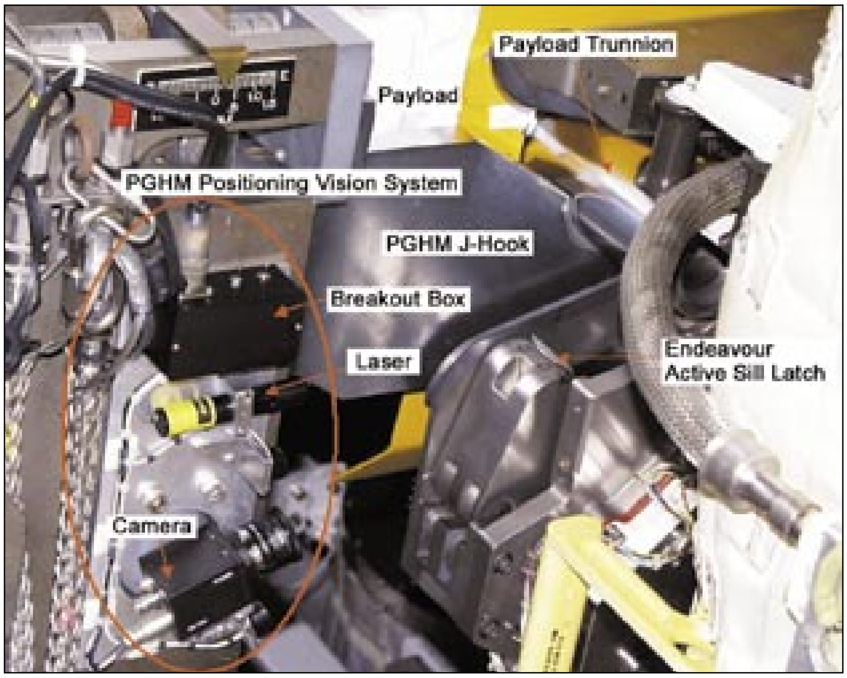

Figure 1. PGHM Vision Measurement System Installed To Acquire Data During Loading of Payload Into Endeavour for STS-108

Key accomplishments:

- Selection and design of hardware compatible with PGHM system using COTS components that require no modification of the PGHM system for integration.
- Development of geometric equations to calculate position of targets and/or landmarks from images.
- Real-time image acquisition, target tracking, and position calculations with accuracy of 0.025 inch at 30 samples per second.
- Successful testing of system including acquisition of image data during STS-108.

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Participating Organization: Dynacs Inc. (Dr. J.E. Lane, Dr. C.D. Immer, S.L. Parks, and W.D. Haskell)

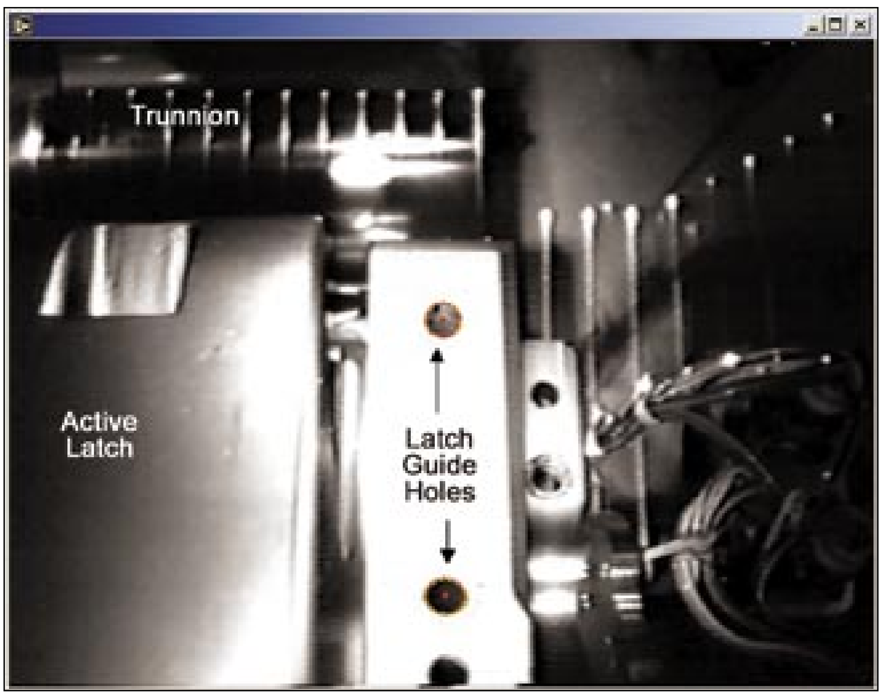


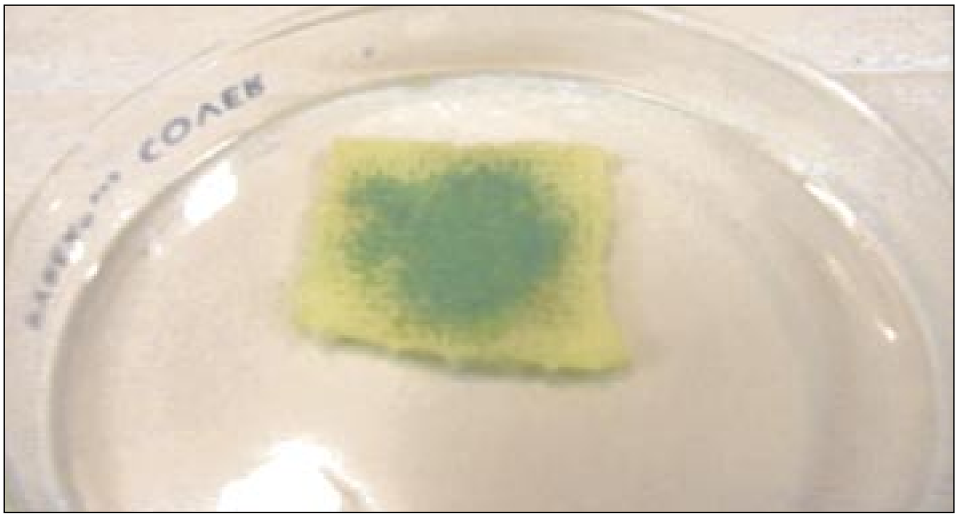
Figure 2. Data Acquired by PGHM Vision Measurement System During STS-108

Color-Indicating Wipe for Detection of Hydrazine and Monomethylhydrazine on Space Suits

In March 2000, NASA Human Exploration and Development of Space (HEDS) independent assessment report JS 0024, "Adequacy of Intravehicular Detection and Removal of Hypergolic Propellant Contamination Following Extravehicular Activity," documented a need to detect and remove hypergolic propellant contaminants in the airlock after an extravehicular activity (EVA). Contamination may occur when an EVA astronaut brings dangerous levels of hypergolic propellant into the airlock. When the airlock is pressurized, the contaminants may be released in the airlock chamber, thus potentially contaminating the airlock and the breathing environment of the Space Station and Shuttle and causing a critical risk to crew and vehicle safety. In 1995, the American Council of Governmental and Industrial Hygienists (ACGIH) adopted a more stringent Threshold Limit Value (TLV) of 8-hour time-weighted average at 10 parts per billion (ppb). Because there is no sensor system that adequately provides real-time, early warning of the hazardous conditions in the space and airlock environment, the EVA crewmember must undergo rigorous, time-consuming procedures to remove any contaminants. Such activities include scrubbing the space suit with a brush and baking off any remaining contaminants in the sun prior to entering the airlock. It is not desirable to repressurize the airlock to purge contaminants because of a limited supply of oxygen. As a result, the report indicated a need to develop a small, real-time, lightweight, and power-efficient sensor to detect very low levels of contaminants in the airlock environment. An ion mobility spectrometry sensor was developed for monitoring hypergolic fuel in the airlock. However, because of its high maintenance cost, downtime, and inability to detect 10 ppb, the sensor is no longer in use. Currently, several detectors are in development in hope of meeting the safety requirement. These instruments use paper tape, mass spectrometer, or electronic nose technologies. It can cost millions of dollars to develop, implement, operate, and maintain an instrument. None of the instruments can remove the contaminants on the space suit. An instrument may be successfully developed to monitor the airlock; however, it will not work in space since the hypergolic fuels are in liquid form and cannot be pumped into the instrument for detection.

Our approach was to develop a wipe that can effectively detect and remove hypergolic propellants before the astronauts enter the airlock. The method is to coat an absorbing wipe with an indicator that will change color when exposed to hypergolic fuel. In addition, it will remove hypergolic fuel from the space suit.

A market search indicated a microfiber material made of 70-percent polyester and 30-percent nylon that can absorb liquids 8 times its weight. After subjecting the material to ignition and reactivity tests with hydrazine and monomethylhydrazine, the material was deemed safe for use. The ignition test consisted of measuring temperature change when a 2-inch square of material is in contact with 0.5 milliliter (mL)



Wipe Doped With 0.5 mL of 10% Universal Indicator and Drops of Hydrazine

of propellants for 10 minutes. The reactivity test consisted of soaking a 4-inch square of material with 1 mL of propellants for 10 minutes. A 10-percent aqueous solution of the universal indicator was prepared. This solution was also deemed safe. Test wipes consisted of 1-inch squares of the microfiber material. They were first submerged in deionized water and ultrasonically washed for 1 hour with 3 changes of deionized water. They were block-dried and then air-dried. Then 0.5 mL of the 10-percent indicator was added to the dried squares. The wipes were ready to use. To test the function of the wipes, 0.5 mL of hydrazine was added to a wipe, and an instant change of color to bright green was observed. The tests also consisted of wiping a piece of clean space suit material with a few drops of hydrazine on it and observing color change and absorption. To determine how much hypergolic fuel could be absorbed, drops of hydrazine were added to the wipe. It was found that a 1-inch-square wipe could absorb 2.5 mL of liquid. The reacted wipes were stored in plastic bags.

The universal indicator consisted of a combination of pH indicators, each of which changes color at a certain pH value. For example, bromophenyl blue changes from yellow to blue at pH 3.0 to 4.6 and phenolphthalein changes from clear to pink at pH 8.2 to 10. Since the universal indicator is a combination of pH indicators, it shows a distinct color for each pH value. Hypergolic fuels hydrazine and monomethylhydrazine are basic (pH greater than 7); the universal indicator will show a green/blue color.

Once the wipes are doped with universal indicator and stored in a plastic bag, there are ready to use. There is no maintenance required. The operation of the wipes is very easy – just wipe the surface of the space suit and observe a color change. This can be done before the astronauts return to the airlock. If there is no color change, there is no exposure of liquid hypergolic propellants. The used wipes can be stored in a sealed plastic bag for disposal at a later date. Results are shown in the photo.

The application of a wipe to detect and remove contamination of the space suit can be extended to commercial applications on the ground, such as developing color-indicating protective garments and color-indicating wipes.

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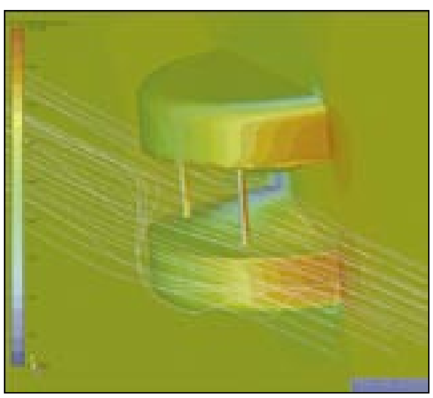
Extreme-Velocity Wind Measuring System: 3-D Venturi

The current wind sensors used at remote KSC locations for wind speed detection are deficient in two main areas. First, rotating cup-and-vane-type anemometers have a high maintainability because of the wear and tear of their moving components. Second, there is a high degree of failure associated with such systems because of damage from extreme wind conditions. A key reference is Hurricane Andrew in 1993, when no ground-based wind sensors survived the path of the storm. Hence, there are no verifiable measurements of the highest winds generated by Andrew.

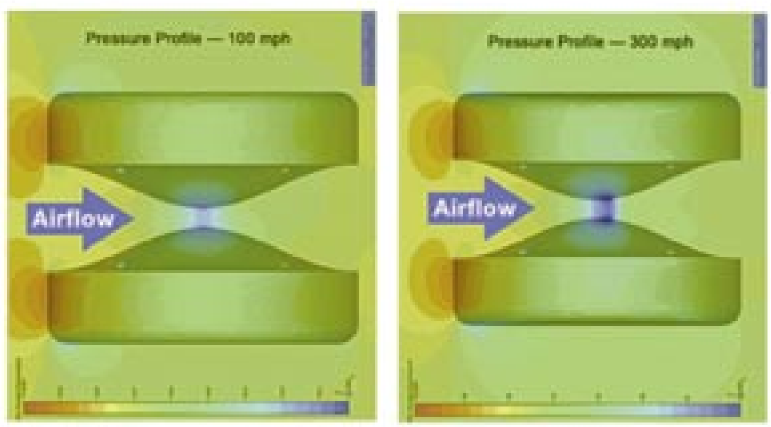
The three-dimensional (3-D) Venturi wind sensor was developed to provide measurements of extreme winds at various locations around KSC. The 3-D Venturi wind sensor is a device for the measurement of wind speed through the use of pressure measurements across a known shape. The basic form is that of a typical streamlined venturi profile (a double-inflection curve) revolved 360 degrees about an axis passing vertically through the center of the profile. The profile has a series of instrumented ports located near the center and periphery to allow for pressure measurements along the surface. The wind speed is calculated by applying Bernoulli's law to the pressure change created between the ports. (Eqn. $P = ½ \rho * k * V^2$). Wind direction is derived from the pressure profile distributed over the surface. In addition, temperature and relative humidity measurements are incorporated into the design.

A conceptual approach was devised to create a surface wind profile (wind velocity and direction) sensor by combining pressure measurements and smart software algorithms and incorporating the knowledge developed using Computational Fluid Dynamics (CFD) simulation.

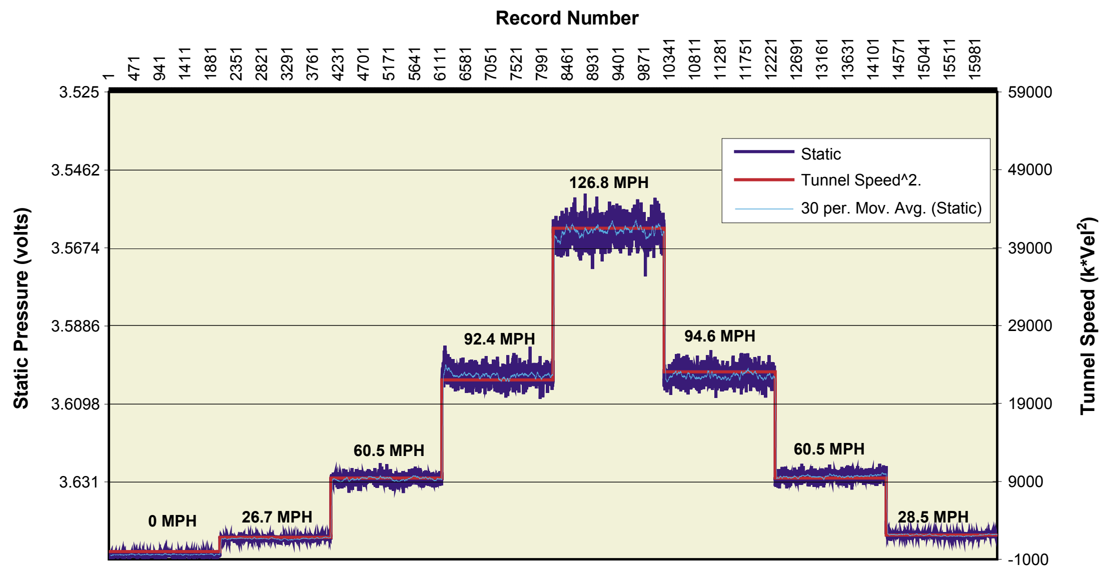
The result is a design that incorporates many beneficial qualities that make the 3-D Venturi an attractive alternative to the current equipment. The 3-D Venturi has a relatively small profile and no moving parts. It has a fast response, wide dynamic range, and short recovery time and incorporates both speed and directionality of wind, an inherent advantage over cup-and-vane anemometers. Further-



Flow Pattern and Pressure Pressure Profile (100 mph)



Wind Tunnel Test of 3-D Venturi (Static Pressure Time Series)



Wind Speed Test Results at Embry-Riddle Aeronautical University

3-D Venturi Prototype at Embry-Riddle Aeronautical University

more, the design will be capable of autonomously acquiring and storing data during a storm for further analysis.

Key accomplishments:

- 2000: First prototype built and tested in low-speed wind of approximately 127 miles per hour (mph). Validation of design concept.
- 2001/2002: Modeling, analysis, and simulation of design at high wind velocities using CFD software.

Key milestones:

- Validate design at extreme wind velocities to 300 mph.
- Conceptualize and integrate methodology for wind direction determination.
- Optimize port locations to achieve best sensitivity and dynamic response.
- Optimize design to provide a remote, stand-alone system capable of autonomously acquiring, recording, and storing storm information.
- Ruggedize the design for field deployment.
- Field-deploy and test system.

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Participating Organization: Dynacs Inc. (J.J. Randazzo, A.J. Eckhoff, and N.N. Blalock)

Micro-Wireless Instrumentation

As part of its Command, Control, and Monitoring Technologies development efforts, the Kennedy Space Center is working in partnership with the Johnson Space Center and a commercial partner (Invocon Inc.) to develop a suite of stand-alone Micro-Wireless Instrumentation devices for space applications. This system addresses several major problems facing the United States aviation and space efforts including the following:

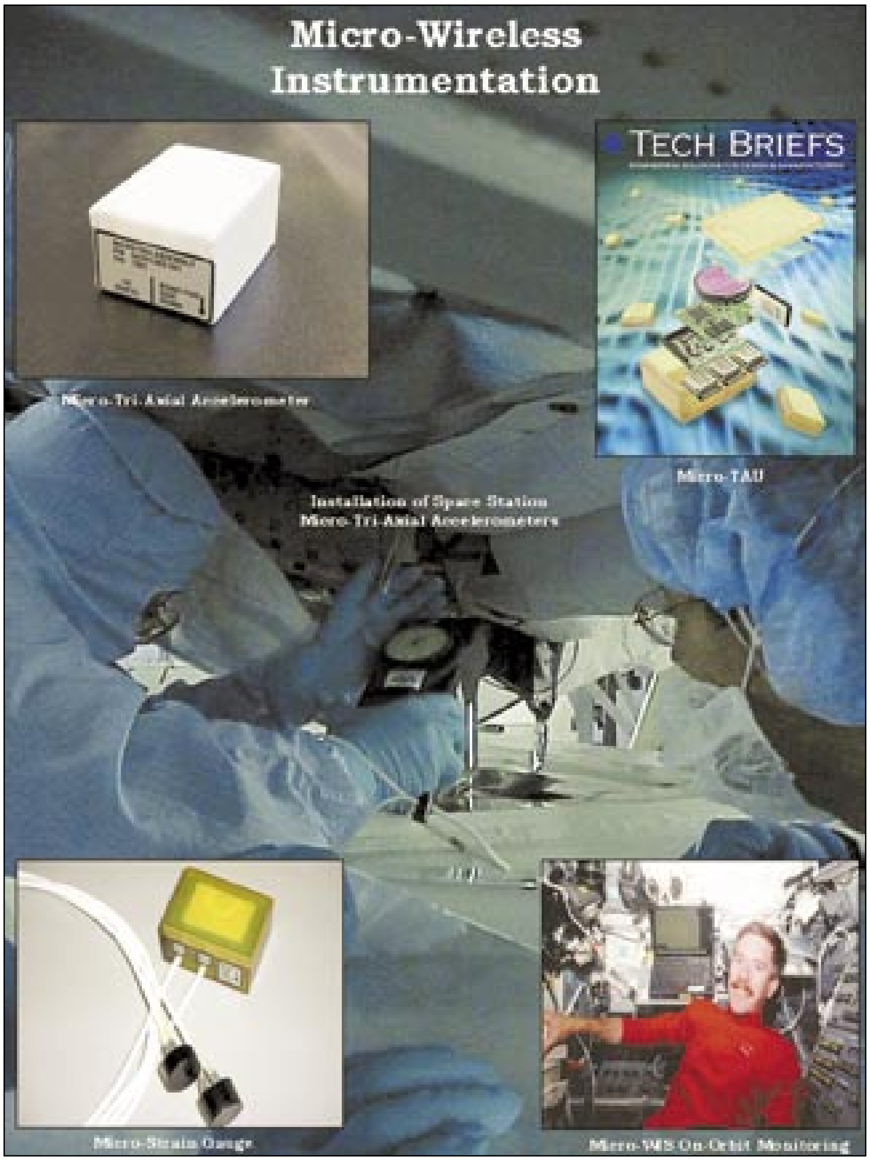
- Instrumentation is critical for spacecraft; however, it has been expensive to add instrumentation to the Space Shuttle because of the high integration costs of interfacing with existing Shuttle systems. For example, adding a single sensor may require power and data wiring to be installed from the sensor to a central instrumentation system some distance away. Each zone the wire crosses results in significant labor costs to update drawings, revise existing procedures, and modify Shuttle flight software.
- Wiring on aircraft and spacecraft has been a cause of numerous anomalies and failures. For example, a Space Shuttle wiring short circuit 5 seconds into the flight knocked out computer buses interfacing with two of the three main engines. As an aviation example, the crash of a Swissair MD-11 near Halifax, Nova Scotia, in September 1998 was attributed to wiring damage.
- Wiring adds significant weight to a spacecraft or aircraft (approximately 230 miles of wire per Shuttle, 300 miles per DC-9 airplane). Reducing weight is key to more-efficient and less-expensive air and space travel.

The partnership developed a Micro-Wireless Instrumentation System (Micro-WIS) consisting of the following components:

- The Micro-Wireless Temperature Sensor System is a small, self-contained, battery-operated sensor system that measures temperature at a programmable sample rate and transmits the data to a receiver unit in real time.
- The Micro-Strain Gauge Unit is a small, self-contained, battery-operated, two-channel strain measurement system that can be programmed (via radio frequency [RF] link) to wake at a predetermined time or strain level and begin recording strain data. The recorded data can be downloaded via RF at 916-megahertz (MHz) and 1-milliwatt (mW) output power.
- The Micro-Tri-Axial Accelerometer Unit (TAU) is a small, self-contained, battery-operated, three-axis acceleration measurement system that can be programmed (via RF link) to wake at a predetermined time or acceleration load and begin recording data. The recorded data can be downloaded via RF at 916-MHz and 1-mW output power.

Key accomplishments:

- Utilization of the wireless instrumentation system has reduced the cost of adding temporary instrumentation to the Space Shuttle and International Space Station (ISS) by an order of magnitude.
- Inexpensive instrumentation was successfully provided in support of several space missions:



– Space Shuttle Air Revitalization System (ARS) troubleshooting.
– Forward Reaction Control System (FRCS) feed line design environments.
– Recertification of Space Shuttle Main Engine thrust structure.
– Environmental data for payload customers (Spacehab-Oceaneering Space System [SHOSS] Box, MACH 1).
– ISS airlock temperatures.
– ISS Multipurpose Pressurized Logistics Module (MPLM) acceleration monitoring.

Key milestones:

- July 2002: RF Node allowing Integrated Vehicle Health Monitoring (IVHM) of wireless data at KSC. Extended-life Micro-WIS (sensors with 10-year battery life reduces ground operations) at JSC.

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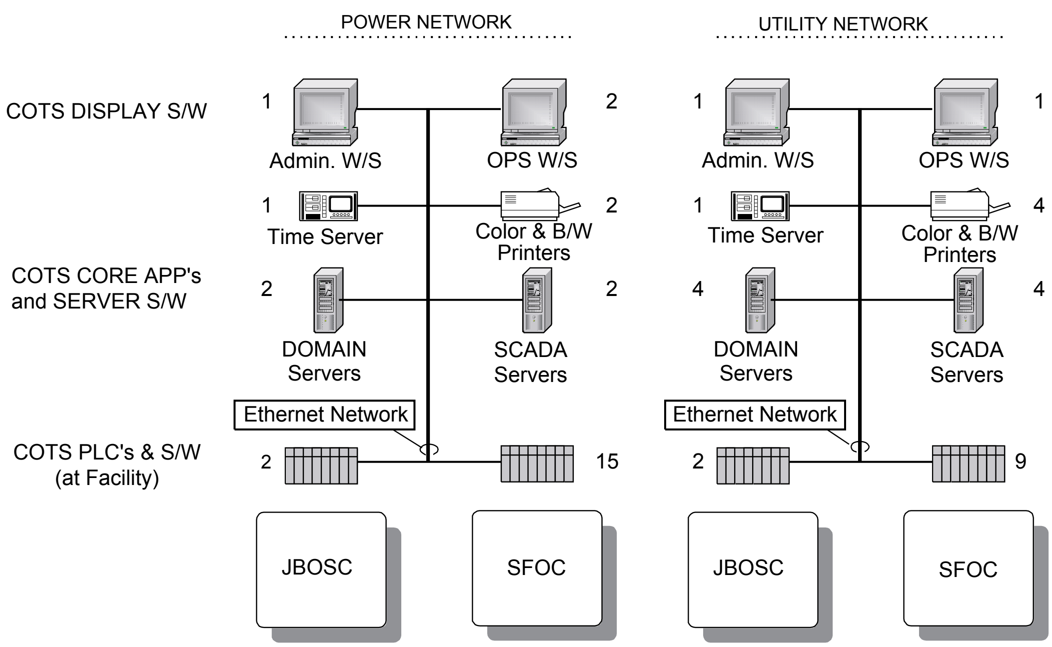
KSC Facility and Utility Control and Monitoring System Replacement

The Kennedy Complex Control System (KCCS) is a replacement for KSC's Complex Control System (CCS), which controls and monitors power, HVAC, potable water and wastewater, compressed gas distribution, and other facility- and utility-related systems throughout KSC. The existing CCS was derived from NASA's Launch Processing System and is based on custom hardware developed in the 1970's that can no longer be maintained except by cannibalization. KCCS is a powerful, highly robust, and flexible system based entirely on commercial off-the-shelf (COTS) hardware and software and offers significant cost savings to NASA over attempting to maintain the old system.

When complete, KCCS will have replaced CCS in approximately 30 facilities throughout KSC and transferred approximately 11,000 measurement control points with SquareD/Modicon programmable logic controllers (PLC's) and PC-based servers. These PLC's communicate via a redundant ATX Ethernet to servers located at the Launch Control Center. These servers run redundant Supervisory Control and Data Acquisition (SCADA) software, input/output servers, data trending servers, alarm servers, and report generators. The result is a system that is extremely robust and tolerates network failures, software glitches, and computer hardware failures without losing data.

The COTS-based KCCS was also selected for its ability to communicate with newer technology sensors and "smart" devices using a large variety of communication formats including Ethernet, LONWORKS, MODBUS, MODBUS/TCP, PROFIBUS, DEVICENET, SERIPLEX, and other common industrial field buses. The system can also communicate with equipment made by Andover Controls. In addition, the system can accept existing commercial instrumentation outputs such as analog voltages, current loop, contact closure, and other standard quantities.



KCCS System Block Diagram

KCCS Monitoring Console

KCCS Programmable Controller Installation Example

KCCS File and Data Servers

Currently there are approximately 10 active installations of KCCS.

Key accomplishments:

- 1998: Design trade study and requirements definition.
- 1999: Market survey and hardware selection.
- 2000: Activation of first installation.
- 2001: Resolution of issues with SCADA and redundant trend servers.

Key milestones:

- 2002: Design/installation and activation of numerous sites.
- 2003: Conversion of measurements for launch pad fire sprinkler and water deluge systems. Activation of all sites.
- 2004: Facility modifications to Launch Control Center.

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Shuttle Tire and Strut Pressure Monitor (TPM)

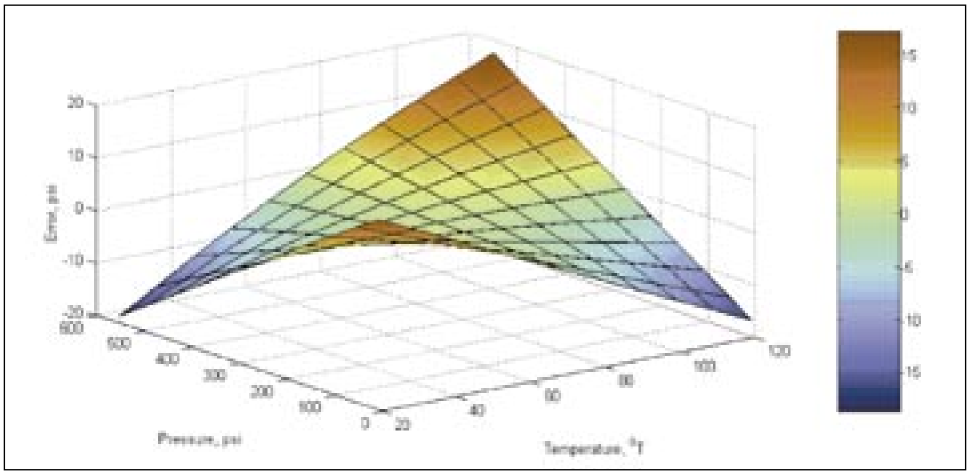
Present Shuttle Operations requirements call for performing pressurization and pressurization decay tests to validate the Shuttle Orbiter tires and struts for flight. It is necessary to identify any leak paths during processing before the Orbiter is ready for flight. To achieve this task, an instrumentation system capable of working at 450 pounds per square inch absolute (psia) and detecting 0.1-psi changes at that high pressure is required. Currently, the configuration and acquisition of these measurements is time-consuming, involving the setup of long, pressurized, flexible tubing and significant warmup time of the measurement system. Among other concerns, there are safety issues related to having long pressurized lines. The TPM project goal was to design a handheld system to accurately measure Orbiter tire and strut pressure and temperature, thus removing the need for the large and unwieldy system presently in use.

The approach was to place pressure and temperature sensors as close to the tire or strut measurement location as possible, allowing the user to make accurate measurements rapidly, to minimize the length of high-pressure lines, and to allow reasonable distance between the tire or strut and the operator. Ideally, the pressure and temperature sensors should attach directly to the pressure supply/relief valve on the tire and/or the strut, with the necessary electronics contained in a handheld enclosure connected by a 6-foot instrumentation cable. Therefore, the project team set out to select small, highly accurate pressure and temperature sensors, to design the optimum mechanical interface between the tire/strut valve and the sensors, and to design a compact, handheld electronics unit that provides rapid, reliable pressure/temperature data display.

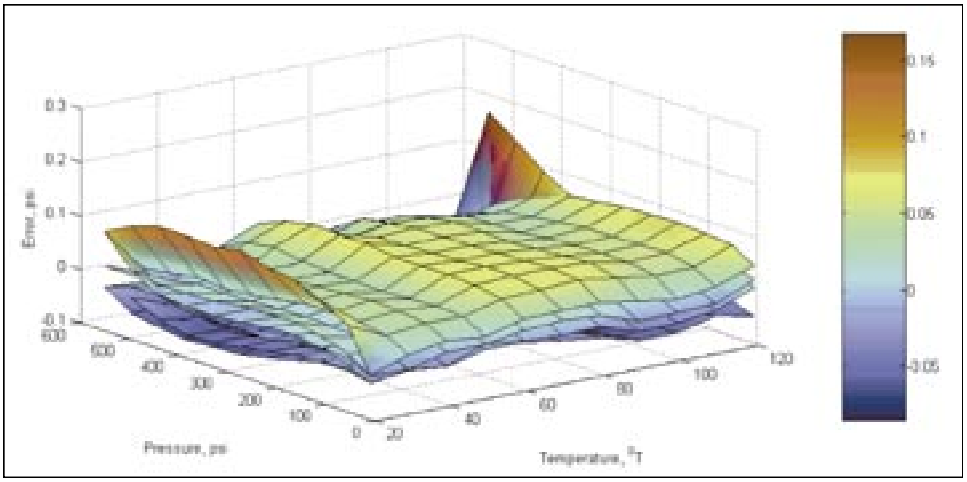
Field-Grade Prototype of TPM

The system was designed to have a sensing unit connected by instrumentation cable to the data acquisition and display unit. The pressure measurement portion of the proposed system centers on a small, highly accurate pressure sensor. The commercially available sensor is capable of delivering pressure measurements repeatable to within 0.03 psia. Temperature compensation and correction are required to maintain this tight tolerance throughout the wide operating temperature range. The complete pressure sensor assembly, housed in a stainless-steel enclosure, contains the pressure sensor, a temperature sensor and electronics for precise excitation to the pressure sensor, and amplification of pressure and temperature measurements. The sensing unit housing and fittings and unit's orientation were designed to allow for easy installation and removal by technicians.

The TPM user interface is a handheld device that can be powered by 12-volt (V) alternating current or by 9-V direct current batteries. The handheld device provides voltage to the sensing unit electronics, as well as low-pass filtering and analog-to-digital conversion of sensors measurements. The system includes a smart software algorithm embedded in a microcontroller, utilizing complex conversion equations developed from pressure and temperature sensor calibration data; the system is capable of optimizing measurement accuracy at any given operating temperature. Because of the developed software algorithm, the system is capable of maintaining the required accuracy throughout the required temperature range. The handheld electronics provide the user with an



First-Order Approximation – Error Curve



Second-Order Approximation – Error Curve

easily read visual display of pressure/temperature or the streaming of pressure/temperature data via an RS-232 interface.

Designed to operate in a temperature environment anywhere from 20 to 120 degrees Fahrenheit, this new measurement tool will enhance Shuttle Operations tire and strut pressure measurements. Sensor accuracy, electronics design, and a simple user interface will allow operators quick, easy access to required measurements. Coupled with a laptop computer, this new measurement system can provide users with automated data recording and trending, eliminating the chance for data hand-recording errors. In addition, calibration software will allow for calibration data to be automatically utilized for the generation of new data conversion equations, simplifying the calibration processes that are so critical to reliable measurements.

Key accomplishments:

- Developed, fabricated, and preliminarily tested sensing unit and handheld display unit.
- Delivered prototype unit to United Space Alliance Operations for field testing.

Key milestone:

- Automated calibration station is being developed to support required accuracies.

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Participating Organization: Dynacs Inc. (Dr. C.T. Mata, A.J. Eckhoff, R.T. Deyoe, J.J. Randazzo, B.M. Burns, and N.N. Blalock)

Advanced Data Acquisition System (ADAS)

Current and future requirements of the aerospace sensors and transducers field call for the design and development of highly reliable, cost-effective data acquisition devices and instrumentation systems. New designs that incorporate self-health, self-calibrating, and self-repair capabilities allow for greater measurement reliability and extended calibration cycles. With the addition of power management designs and components, state-of-the-art data acquisition systems allow data to be processed and presented with increased efficiency and accuracy.

A smart signal conditioning amplifier was designed incorporating these requirements. This device provides increased reliability by utilizing techniques to automatically reroute signals through different paths when the processor identifies a component malfunction.

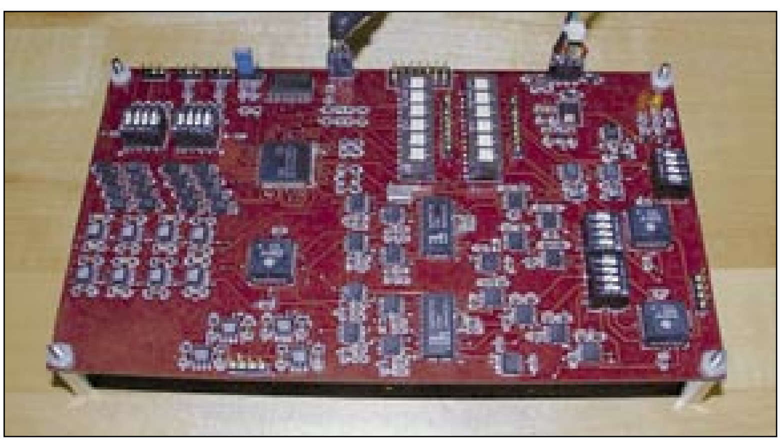
The analog signal path design architecture presented addresses the issues of signal redundancy and signal integrity without taking the traditional approach of providing total hardware redundancy for every channel and every function block of a data acquisition system.

In addition to signal redundancy issues, the need for self-calibration verification capability has also played a major role in defining the approach followed by this project when formulating its architecture. Data acquisition systems such as those used in spacecrafts need the ability to calibrate automatically without external intervention. Furthermore, the quality of the measurement provided by the system is directly related to the system's ability to ensure a proper calibration through the life of the process being monitored.

Finally, the capability of the data acquisition system to perform system health checks, failure detection, and failure prediction, as well as automated self-repair, plays a paramount role in systems for which operator intervention is not an option. Again, deep space spacecrafts require the ability to automatically reconfigure their data acquisition systems as failures are identified.

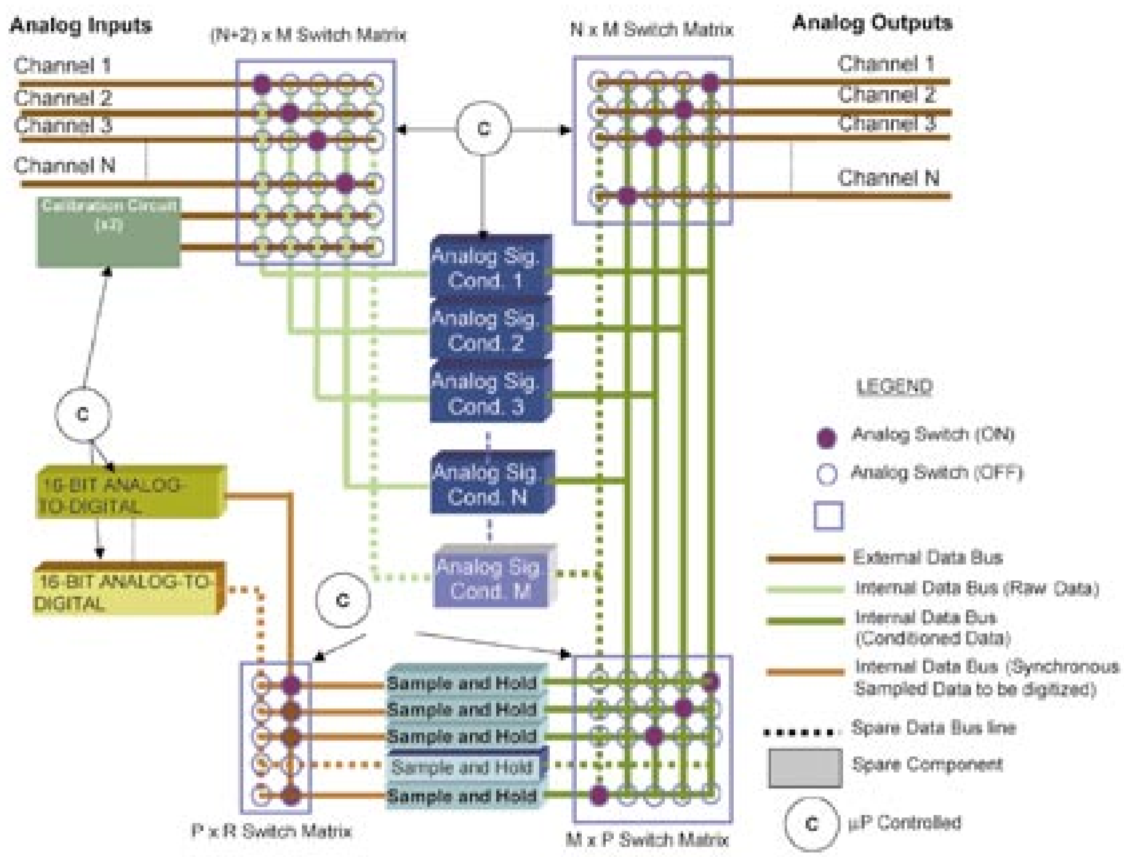
The traditional approach has basically provided systems with total hardware and software redundancy to overcome failures (two complete, independent redundant channels for every measurement required). This approach usually is very costly and adds significant weight, size, and power requirements to the systems it is supporting. All these characteristics are undesirable when dealing with aerospace systems.

The approach taken by the KSC Sensors Group is based on a concept we call "spare parts – tool box." As with any process that has identifiable critical components, we identified and assessed areas of the data acquisition system's analog signal path with specific reliability problems. An initial reliability assessment based on data acquisition system exposure to external conditions was implemented. Data acquisition system areas such as signal inputs and outputs were considered high-risk areas, while internal areas of the system not exposed to external environment were considered lower risk areas. A more detailed assessment that includes component reliability assessment (mean time between failures, etc.) will be implemented when specific components are baselined for the design.



ADAS Prototype System

Based on the reliability rating given to these areas, we have provided the system with a "tool box" with *n* number of "spare parts" (components) necessary to ensure continued operation of the system. The



ADAS Architecture

number of "spare parts" of each type and the different types of "spare parts" contained in the "tool box" will not have to be the same for each identified area of the system. Areas with higher probability of external abuse (by customer or environment) will be assigned a greater number of "spare parts" than areas well protected by the system. These "spare parts" will be capable of replacing any similar part within the system regardless of the location (channel number).

The technology described here presents innovative solutions to problems associated with traditional data acquisition methods. Key ADAS features include:

- Electronic health self-check: Continuous health checks allow failures to be detected and corrected within seconds.
- Device/system self-calibration: The calibration method, based on a highly accurate and stable voltage reference, allows continuous self-calibration of the system thus providing accurate measurements even under diverse environmental conditions.
- Electronics and function self-repair: Intelligence built into the microcontroller code allows the system to reroute signals as required to maintain an accurate and stable measurement.
- Failure detection and prediction: The current state of the system is continuously compared with its historical database (stored locally within the system). Real-time analysis results in the prediction of components faced with imminent failure, as well as longer degradation trends.
- Power management for reduced power consumption: Smart power management is used to reduce unnecessary power consumption.

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Piecewise Linearization of Analog-to-Digital Converters for Highest Accuracies

A novel software algorithm to maximize the accuracy of high-resolution analog-to-digital (A/D) converters is presented. Implementing this approach, the data acquisition system is required to use only one hardware voltage reference as an input of the A/D converter. The value of this reference used by the software algorithm is optimized for narrow input ranges. The transfer function (TF) of the A/D converter is linearized locally, and the result is an overall error of approximately 1 least significant bit (LSB), greatly improving existing systems. When wide input voltage ranges are desired, the algorithm is used to derive a piecewise, software-compensated approximation of the transfer function of the A/D converter.

High-end data acquisition systems generally use at least one stable, high-accuracy voltage reference to compensate for temperature drifts on the TF of the A/D converter and associated circuitry (a general block diagram of a data acquisition system is shown in figure 1). The accuracy of the A/D converter over the temperature range is dominated by the drift performance of the voltage reference. Among the other sources of errors that affect A/D converter accuracy are noise of the voltage reference, integral linearity error, differential linearity error, transition noise, full-scale error, and full-scale error drift. Because of all these errors, it is extremely difficult to obtain accuracies better than a few LSB's when using existing approaches.

As an example, in a 16-bit A/D converter, it is acceptable to have 12 bits of accuracy. Normally, the device could have a resolution of 1 to 2 LSB's, but when issues like noise, drift, and nonlinearity are considered, the accuracy of the A/D converter is not much better than 12 of 16 bits. When 12-bit accuracy is not sufficient and speed requirements do not allow the use of higher-resolution A/D converters, some algorithms may be used to increase the effective accuracy by 1 or 2 LSB's. Yet, accuracies of 14 bits or better are very hard to achieve with existing 16-bit A/D converters and existing software algorithms.

When narrow input voltage variations are expected, the TF of the A/D converter may be locally linearized to achieve the highest accuracy within that narrow voltage range. Figure 2 better describes the concept.

The locally linearized, software-compensated TF of an A/D converter using a single hardware voltage reference and ground for compensation is given by (1):

$$V_{out} = \frac{\hat{V}_{in} - \hat{V}_{off}}{\hat{V}_{ref} - \hat{V}_{off}} \times V_{ref} \qquad (1)$$

where $\hat{V}_x$ is the number of counts (quantization levels) of its respective voltage, V_{ref} is the value of the voltage reference used in software (variable we want to optimize), and V_{out} is the software-calculated representation of V_{in}. Note from figure 2 that the error between the linearized TF and the actual TF [ε_2] is greater than the error between the locally linearized TF and the actual TF [ε_1] for a given input voltage $V_z \in \{V_1, V_2\}$.

Following the same approach, we may define an array of voltage references to provide maximum accuracy through a piecewise linearization over a wide input voltage range (see figure 3). The value of the voltage reference used in software will be determine by the input voltage and by the simple software rule given by (2):

$$V_{ref_i} = V_{ref_n} \forall V_{in} \in \{V, V_{n+1}\} \qquad (2)$$

Key accomplishment:

- Successfully implemented algorithm on Shuttle Tire and Strut Pressure Monitor (TPM) with greatly improved measurement accuracy.

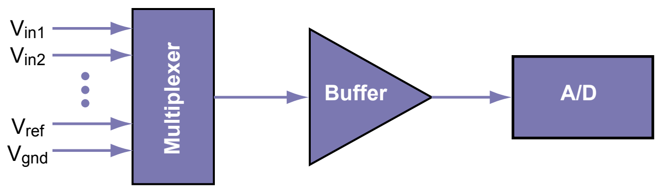

Figure 1. General Data Acquision Block Diagram

Key milestone:

- Formalize software algorithm for implementation in several existing projects.

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Participating Organization: Dynacs Inc. (Dr. P.J. Medelius, Dr. C.T. Mata, and B.M. Burns)

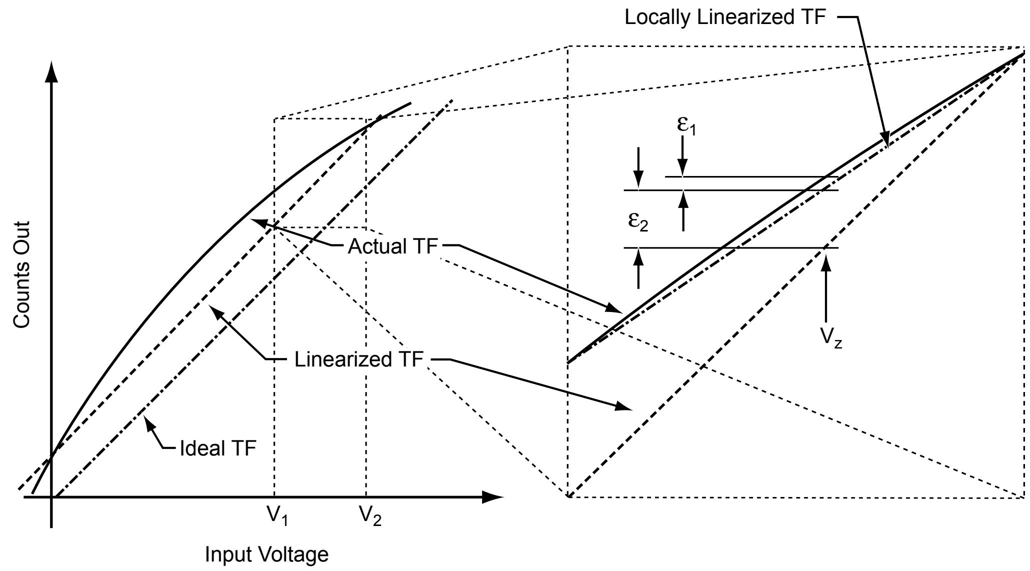


Figure 2. Transfer Function (TF) of an A/D Converter Showing the Ideal TF, the Actual TF, the Linearized TF, and the Locally Linearized TF

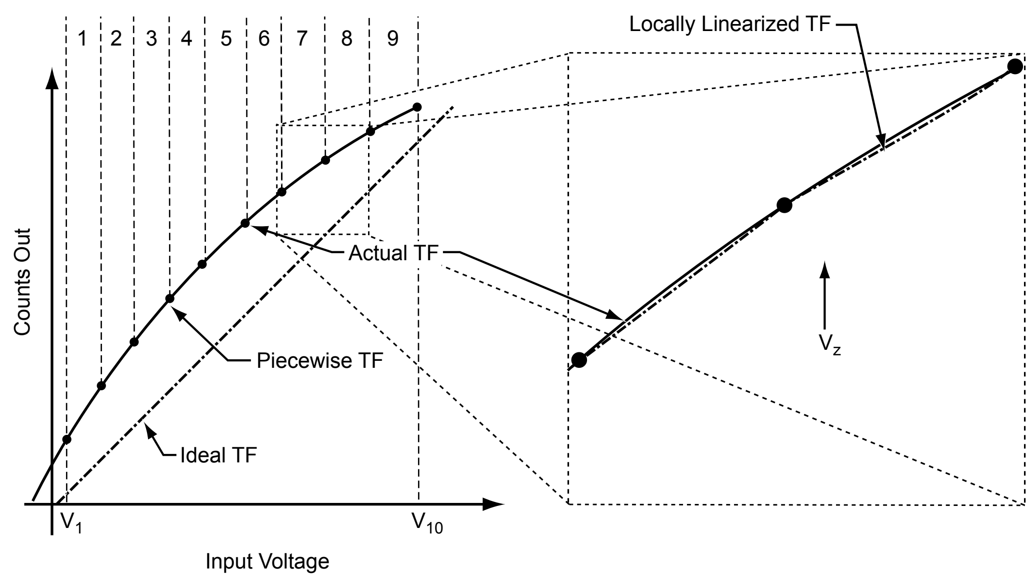


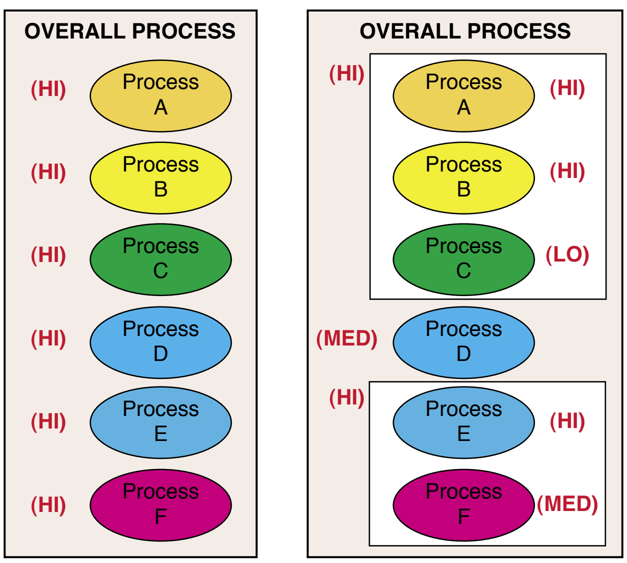
Figure 3. Transfer Function (TF) of an A/D Converter Showing the Ideal TF, the Actual TF, and the Locally Linearized TF

Embedded Knowledge in Wireless Sensors

Instrumentation systems are mainly used to monitor and control processes, which may be either very simple in nature (e.g., controlling the temperature of a room) or very complex (e.g., preparing, fueling and launching rockets in space). In general, complex processes can be broken into a series of interrelated smaller processes. But depending on the complexity and the number of processes monitored, traditional centralized decisionmaking entities (e.g., control room computers) are heavily loaded with data. Most of the time, these processes are stable and "in control," meaning that, although large amounts of data are being analyzed, usually it is not necessary for the centralized entity to make a decision. This equates to a large tangible cost (in manpower resources and/or computational time) to analyze the "nominal data."

Creating decentralized systems, capable of monitoring and controlling smaller, simpler processes and sharing information among them, is highly desirable. These systems can utilize information to make determinations regarding the overall process stability. By decentralizing the decisionmaking process, the system becomes less complex and more cost-effective and aids in eliminating single points of failure in the process.

The following steps minimize the disadvantages of centralized decisionmaking:

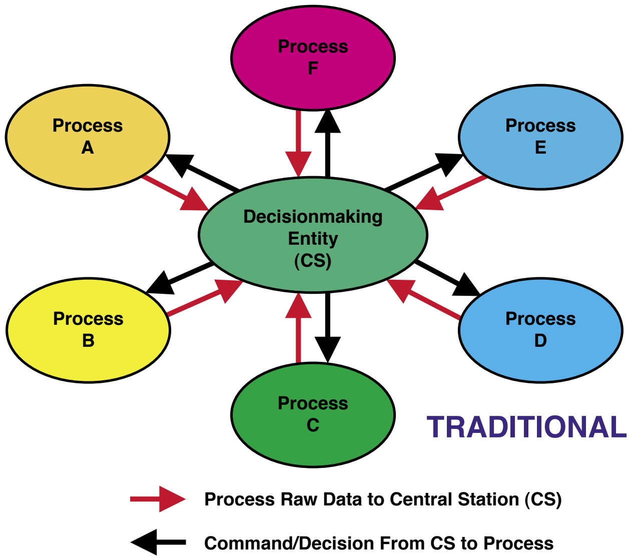


Overall Process Importance Assessment (Traditional Versus Proposed)

- Break down complex processes into simpler, smaller processes and their relationship rules with respect to the overall process (calculate process-importance weights for each simpler one).
- Define the basic knowledge rules to govern these simpler processes.
- Incorporate these basic knowledge rules at the sensor level (embed knowledge rules in sensors).
- Utilize the properties of wireless communication to share process knowledge and process information among the sensors, transducers, and controlling equipment (Wireless Sensor Network).
- Decentralize the process decisionmaking capabilities and locate these capabilities remotely at the site of the physical process.
- Using the relationship rules defined above, verify control of overall process by verifying control of simpler processes and by sharing process information among simpler processes.
- Monitor the health of associated sensors involved in the process. Validate sensors measurement outputs by applying process knowledge rules embedded in the sensors.
- Minimize raw data transfer by emphasizing transfer of process information (processed data at the sensor level) versus processing raw data, optimizing the communication bandwidth.
- Ultimately, decentralize overall process control by creating a distributed Smart Wireless Sensor Network. The control of the overall process is shared among the different process field entities and the centralized entity. Control of lower-level processes is performed at the process-specific location. Information is shared among entities. The centralized entity performs an overall supervisory function by receiving, processing, and coordinating process information, not raw data.

The proposed architecture will develop a Smart Wireless Sensor Network that utilizes the unique characteristics of wireless communication to monitor and control a specific process. Each sensor (from now on also referred as Remote Station [RS]) will have the following architecture:

- A wireless communication section composed of a low-power radio frequency (RF) transceiver system and a microcontroller.



- An analog section composed of sensor excitation and signal conditioning circuitry.
- A power supply section composed of battery, associated power management, and protection circuitry.
- A digital/control section composed of a microprocessor (microcomputer or similar), storage memory, and analog-to-digital conversion circuitry.
- Adaptive software algorithms to provide hardware configuration and control capability, as well as process-specific knowledge rules and smart monitoring capabilities.

A typical RS will contain not only information to monitor and control its individual functions but also knowledge related to other RS's associated with the process being assigned. Process information will be downloaded into the process control microcontroller through the RF link.

On a typical operation scenario of the Smart Wireless Network System, RS x will be polled by the Base Station (BS) for information. RS x will acquire data from the sensor, verify the acquired data is within expected range or exceeds defined limits, and broadcast results back to the base stations. RS's associated with RS x by their embedded knowledge information will decode the information sent by RS x and validate the received information by applying the process-specific rules. As soon as the BS completes a monitoring cycle, each RS has acquired information not only about its own sensor but also from the associated RS's for that monitoring cycle. At that time, they have validated not only their own data by applying knowledge rules contained in memory but the information of other associated RS's independently. By doing this, the proposed architecture can detect failures (like instrumentation failures) and flag them to the base station. The architecture can also independently assess the state of the assigned process (process in control or out of control) and validate it with the base station. Eventually, when enough confidence is built in the RS's, process control could be delegated to the RS's, relieving the base station of this responsibility.

Key accomplishments:

- 2002: Established system requirements, preliminary conceptual design, and software architecture. Implemented laboratory demonstration prototype.

Key milestones:

- 2003: Implement field prototype.

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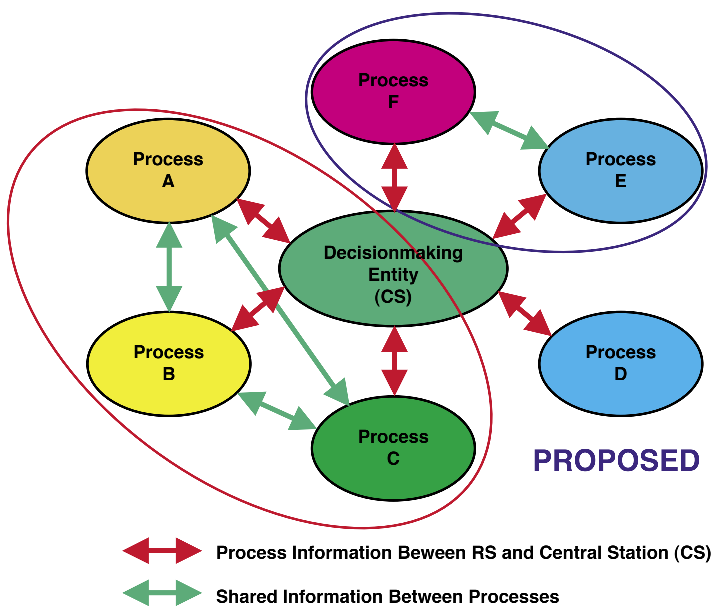
Participating Organization: Dynacs Inc. (Dr. P.J. Medelius and Dr. C.T. Mata)

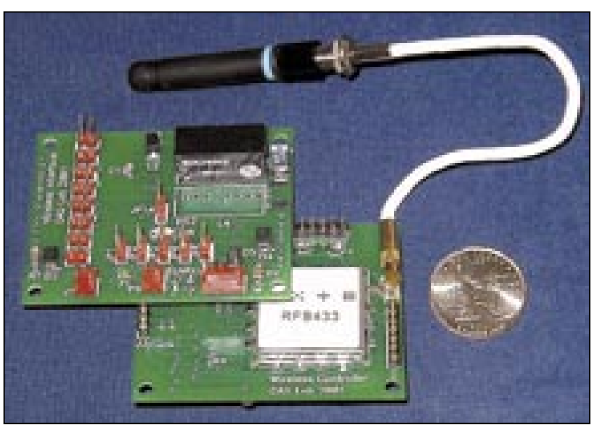


Wireless Vacuum-Jacketed (VJ) Line Sensors Network

The Space Shuttle uses liquid hydrogen (LH_2) and liquid oxygen (LOX) as propellants for its main engines. To maximize the amount of propellant in the Space Shuttle's External Tank (ET), these propellants are stored in liquid form. To prevent boiloff of these commodities, the Space Shuttle's Main Propulsion, LH_2, and LOX systems on the ground and in the vehicle need to be kept at very low temperatures, insulated from the external environment. Insulation is accomplished using special thermal insulating materials and vacuum lines.

The liquid propellants are stored at the pad's hydrogen and oxygen storage tanks until fueling of the Space Shuttle starts approximately 10 hours prior to launch. At that time, they are pumped to the ET using vacuum-jacketed (VJ) lines. These transfer lines are several hundred feet long, and they reside at the pad area and Mobile Launcher Platform (MLP). A loss of vacuum in the VJ lines will cause the propellant to boil off, a condition that is not desirable.

Thermal vacuum gages are used to measure the conditions of these transfer lines. These gages are permanently installed in the VJ lines. United Space Alliance (USA) personnel perform periodic checks of the vacuums in these lines. When loss of vacuum is detected, the line needs to be pumped back to the desired level. Periodically, an operator manually measures the vacuum in these lines. A signal-conditioned meter is connected to each of the vacuum gages, and a reading is obtained and recorded. Since tens of these gages are located throughout the pad and MLP, this is a very labor-intensive operation.



Remote-Station Wireless Module

The designed system consists of a network of sensors (remote units), located on the VJ cross-country lines and in and around the MLP VJ lines. This sensor network connects to the existing thermal vacuum gages permanently installed in the VJ lines. Each remote station provides current excitation to the vacuum gage, signal conditioning of the signal coming from the vacuum gage, and wireless transmission to a central (base) station. The sensor network utilizes the benefits of wireless communication, and batteries or solar energy powers it. The designed system provides the following characteristics:

- Signal conditioning and data acquisition capability in situ to each VJ line sensor.
- Measurement trending analysis capability.
- Capability to independently monitor the vacuum in the line and notify user if preset limits are exceeded.
- Data relay capability for inaccessible areas, allowing remote read capability (e.g., in trenches, under gratings on the pad surface, and in tunnels on the MLP).

Requirements of the Space Shuttle program prompted the implementation of several innovative ideas. First, there is a requirement to maintain electromagnetic compatibility (EMC) and to keep radio frequency (RF) interferences to a minimum at the pad. To do that, RF output power was kept to a minimum (10 milliwatts). Since data availability was also a requirement, an innovative software (Lost Station Algorithm) approach was created to allow alternate communication routes for the sensors (embedded intelligence in the sensors) in case of interferences or loss of communication. In addition, capability to use remote stations as data relay stations was necessary because of the long distances to be covered. Finally, an innovative power

Remote-Station Test Stand

management algorithm was created to support operations at the pad for 2 years before replacing batteries.

Each remote unit of the Wireless Sensors Network consists of a transducer module (providing excitation and signal conditioning), a controller, radio transceiver, antenna, power supply (battery-powered), and a weather-protective enclosure. All measurements are transmitted back to a central (base) station and then sent to the central data-gathering equipment or processed through a host computer.

The central (base) station runs the polling algorithm that acquires, stores, analyzes, and distributes the VJ information to the users. The “Master Configuration Window” display controls all remote station selection, configuration, data summary, and status information. When a remote station is selected, the “Remote Station Window” display opens to allow configuration of data scaling/engineering unit conversion and sample rate. A list of active remote stations is contained in the “ID Data Units Window,” along with actual data received and the applicable engineering units. The “Summary Window” display allows for a summarized assessment of the number of active remote stations (e.g., 7 remote stations active). The “Status” window provides a summarized assessment of the condition of the system and remote station communication (e.g., 4 lost stations exist, 2 stations not responding).

Key accomplishments:

- Designed and tested RF transceiver module.
- Designed and tested analog module.
- Developed and tested software for remote and base stations.

Key milestone:

- Development of a field-grade 10-station network for the pad.

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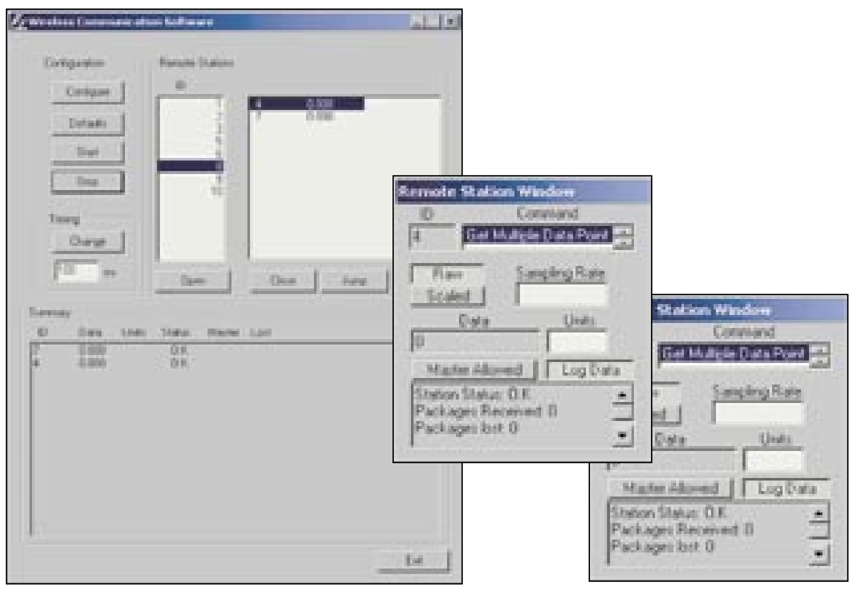

Windows User Interface Software

Fluid System Technologies

Fluid System Technologies form the foundation of the modern spaceport and will continue to have a prominent place in spaceport operations for the foreseeable future. The fluid systems used on spacecraft include propellants, gases and other vehicle servicing fluids, heat transport and firex, and fluids for crew. The large amounts and wide variety of fluids required by modern spacecraft dictate flexibility and efficiency in fluids operation. Fluid System Technologies will seek to develop the means to reduce thermal losses associated with cryogenic fuels, minimize maintenance and process monitoring costs, and provide for safe operation of the spaceport. The ultimate goal of this technology thrust area is to create efficient technologies that can be quickly adapted to the changing fluid needs of future spacecrafts residing at the spaceport.

Technology focus areas include the following:

- Storage, Distribution, and Servicing Systems
- Production, Recovery, and Disposal Management Systems
- Vehicle Interface Systems
- Safety Systems
- ELV/RLV Thermal/Fluids Environments and Management

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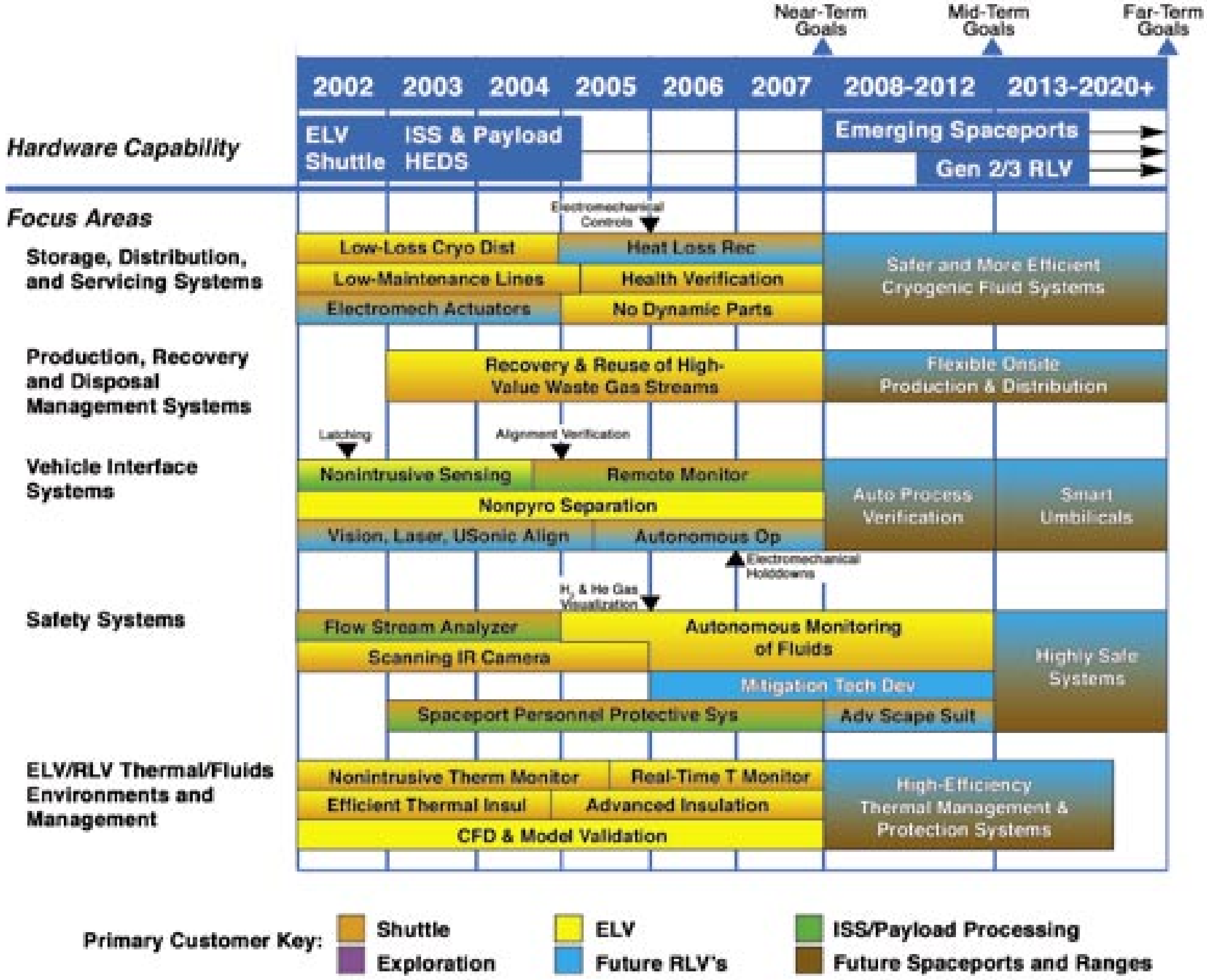
KSC Fluid System Technologies Roadmap



Goals Specific to Focus Areas

- Reduce human oversight of servicing systems by 20% near-, 60% mid-, and 85% far-term
- Reduce waste streams by 30% near-, 60% mid-, and 75% far-term
- Reduce hazardous operations for vehicle interfaces by 50% near-, 85% mid-, and 100% far-term

Thermal Performance of Cryogenic Piping Multilayer Insulation in Actual Field Installation

A standardized way of comparing the thermal performance of different pipelines in different sizes is needed. Vendor data for vacuum-insulated piping are typically given in heat leak rate per unit length (watt per meter [W/m]) for a specific diameter pipeline. An overall apparent thermal conductivity – k-value – for actual field installations (k_{oafi}) is therefore proposed as a more generalized measure for thermal performance comparison and design calculation. The total system includes the inner piping, the insulation material layers, the outer piping, and other items such as spacers and getters. The k_{oafi} provides a direct correspondence to the k-values reported for insulation materials and illustrates the large difference between ideal multilayer insulation (MLI) and actual MLI performance.

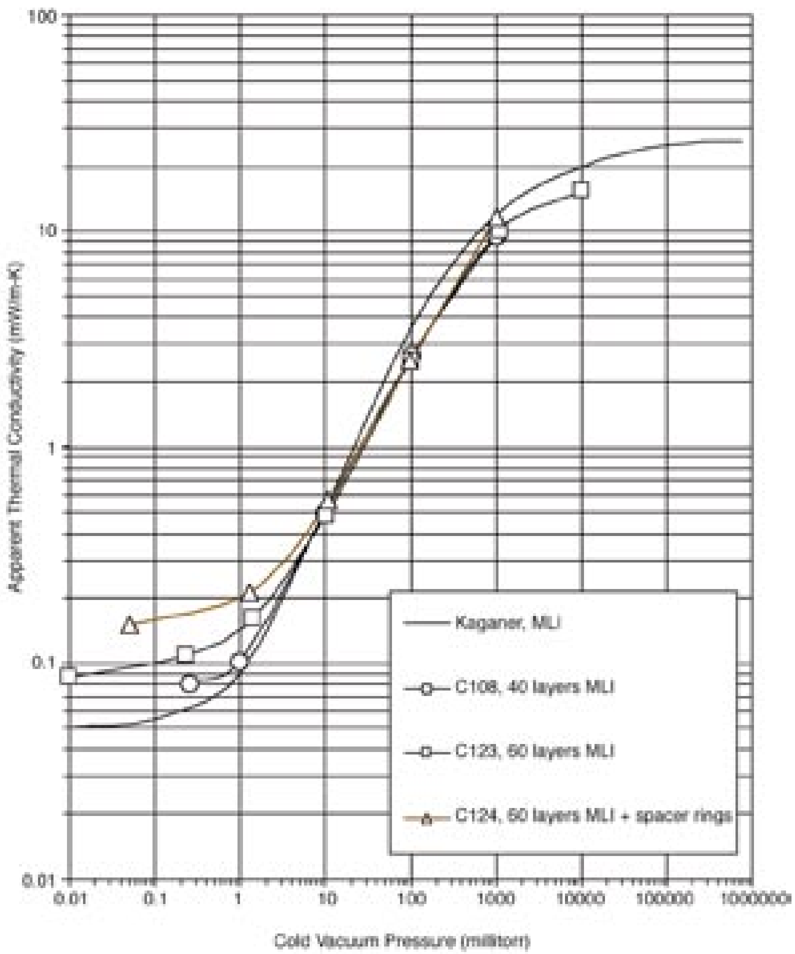


Figure 1. Variation of Apparent Thermal Conductivity With Cold Vacuum Pressure, Spacer Simulation Results

Ambient heat transfer into a cryogenic pipeline comes through several paths including valves, connectors, instrumentation, and insulation. A common type of thermal insulation system is MLI. MLI systems come in many varieties and must be tailored to the specific application. The performance of MLI is known to be sensitive to localized compression effects and trapped residual gases produced by the combined mechanical influences of bending and spacers. Bending-type mechanical effects come from four sources: bending, as in handling and installation; thermal contraction and expansion; line pressure reaction forces; and the weight of the line (sagging). Spacers are employed in the design of vacuum-jacketed lines to keep the inner line concentric within the outer line during manufacturing and to counteract these mechanical effects during operation. Spacers are made from low-thermal-conductivity materials to minimize heat conduction.

In this experimental research study, a section of insulated piping was tested under cryogenic vacuum conditions, including simulated spacers and bending. Several different insulation systems were tested using a 1-meter-long cylindrical cryostat

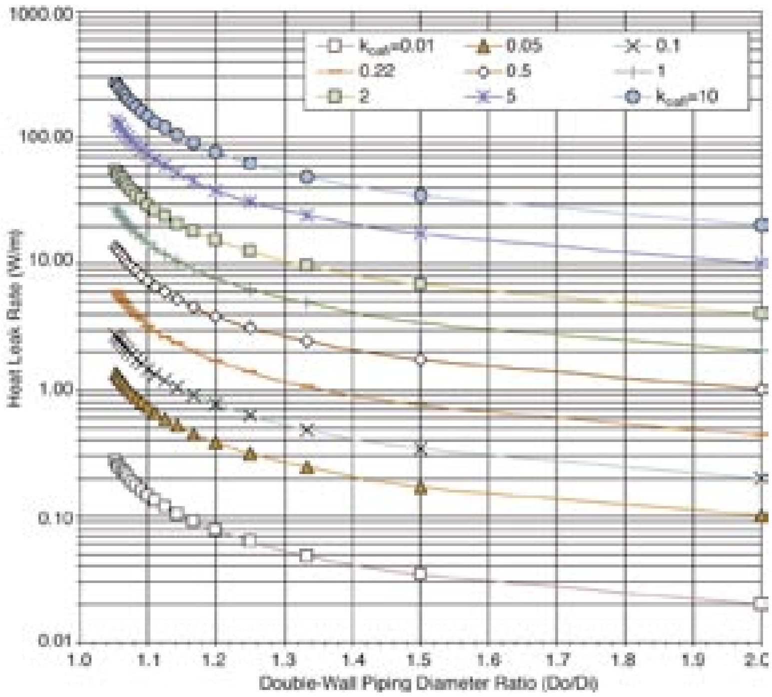


Figure 2. Variation of Heat Leak Rate With Diameter Ratio (Do/Di) for k_{oafi} From 0.01 to 10 mW/m-K and Boundary Temperatures of 300 K and 77 K

test apparatus. The simulated spacers tests showed significant degradation in the thermal performance of a given insulation system. The results of the simulated spacers test are given in figure 1. The spacer simulation shows a significant increase in the rate of heat transfer for the high-vacuum tests. For C123 in comparison to C124 the k-value increased from 0.09 to 0.15 milliwatt per meter-kelvin (mW/m-K) (a 67-percent increase in heat transfer).

Figure 2 provides a convenient design tool for estimating heat loads (W/m) for different line sizes and different k_{oafi}. The experimental laboratory data can be compared with manufacturers' typical data for a 60- × 110-mm line: 2.30 W/m (flexible) and 0.75 W/m (rigid). Converting these typical heat leak values into their thermal conductivity equivalents, we obtain k_{oafi} of 0.99 mW/m-K (flexible) and 0.32 mW/m-K (rigid). The k_{oafi} method is being used by the Cryogenics Test Laboratory to provide practical engineering information for specific system designs and applications.

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Participating Organization: Dynacs Inc. (Dr. S.D. Augustynowicz)

Heat Transfer Study for HTS Power Transfer Cables

Power transfer cables using high-temperature superconducting (HTS) materials are currently being developed for utility demonstration projects. The initial urban retrofit applications may employ lengths from 100 to 1,000 meters or longer. Cryogenic refrigeration systems are required to maintain these cables at their operating temperature range from about 70 to 80 kelvin (K). Thermal losses are a key factor in the successful application of HTS power cables. The phase I project, Thermal Insulation Performance of Flexible Piping for Use in HTS Power Cables, in collaboration with the Department of Energy and Oak Ridge National Laboratory, was completed at the Cryogenics Test Laboratory in 2001. A series of heat transfer tests under cryogenic vacuum conditions using flexible corrugated piping (simulated thermal insulation system for an HTS power cable) was performed. The mechanical effects created by bending and effects of insulation compression created by spacers were simulated. Over 90 tests of 12 different thermal insulation systems, including standard multilayer insulation (MLI) and the new layered composite insulation (LCI), were tested and evaluated.

Existing HTS power cable prototypes rely on the use of vacuum jacketing with MLI systems inside to reduce the ambient heat leak rates to manageable levels. MLI systems are subject to large variations in actual performance. The small space available for the thermal insulation materials makes the application even more difficult because of bending considerations, mechanical loading, and the arrangement between the inner and outer piping. Each of these mechanical variables affects the heat leak rate. For all applications, it is critical that the thermal insulation and vacuum enclosure be robust. For any MLI to function properly, the vacuum level must be maintained below 0.0001 torr cold vacuum pressure (CVP). Furthermore, a maintenance-free insulation system (high-vacuum level for 20 years or longer) is a practical requirement. Overall heat leak targets of around 1 watt per meter (W/m), depending on the diameter of the cable, are achievable, but manufacturing and maintenance can be a problem because of the high-vacuum requirement.

This experimental research study of flexible piping for HTS power cables shows three basic levels of thermal performance: ideal MLI, MLI on rigid piping, and MLI between flexible piping. The thermal performance varies widely with both the vacuum level and the materials. The performance of ideal MLI is defined as a k-value of 0.05 milliwatt per meter-kelvin (mW/m-K) for a vacuum level below 0.0001 torr and boundary temperatures of 80 and 293 K. At a high-vacuum level, the k-values of MLI on rigid piping were about 0.09 mW/m-K. Under similar conditions, the k-values of MLI between corrugated piping were 0.19 mW/m-K. The new LCI, on the smooth sleeve or between the corrugated piping, performed as well as MLI at high vacuum and much better than MLI at soft vacuum (only 3.1 mW/m-K at 1 torr). The total insulating effectiveness of an insulation system is the key factor when considering the cryogenic refrigeration requirements for an HTS power cable. The simulated spacers tests and the simulated bending tests showed significant degradation in the thermal performance of a given insulation system (typically greater than 50 percent) at high vacuum conditions. A typical k-value of 1.0 mW/m-K, based on commercial double-wall flexible piping, for thermal loss calculations appears reasonable for a well-executed MLI construction operating at the high vacuum level.

The results from the study begun at NASA Kennedy Space Center will be used to decrease the refrigeration load for HTS power cables. Soft-vacuum systems have much lower vacuum burden costs, which is key to lowering the overall cost of building, operating, and maintaining long, flexible power cables as part of a utility infrastructure. The plan for continuing this work includes the construction and testing of a long flexible cryostat to address basic heat transfer and fluid flow questions. In this approach we can leverage the ongoing insulation material development work and the existing test infrastructure of the Cryogenics Test

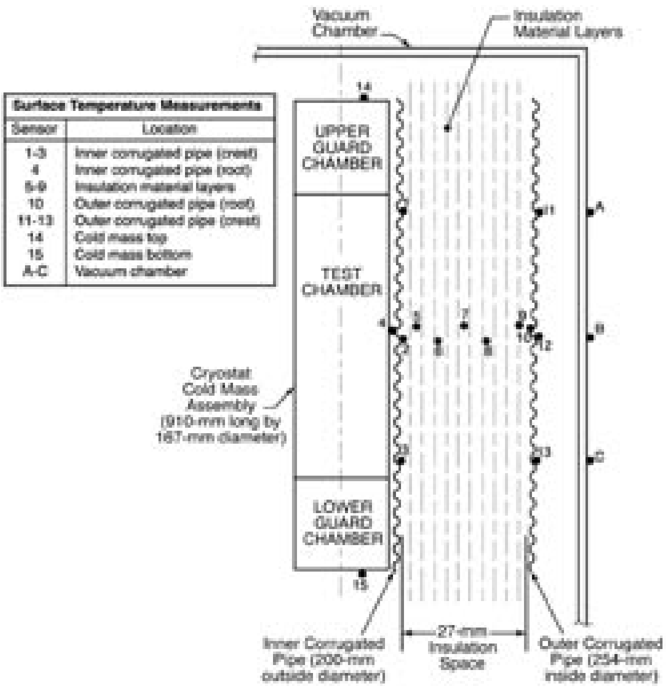

Figure 1. Configuration of Corrugated Piping and Location of Temperature Sensors

Figure 2. Test Apparatus Showing Outer Corrugated Pipe

Laboratory including our 18-meter-long Cryogenic Pipeline Test Apparatus. The target is to be able to make flexible piping with thermal performance approaching that of rigid piping to help make energy-efficient HTS power cables become an industrial reality.

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Participating Organizations: Dynacs Inc. (Dr. S.D. Augustynowicz, Z.F. Nagy, and K.W. Heckle) and Oak Ridge National Laboratory (Dr. J.A. Demko)

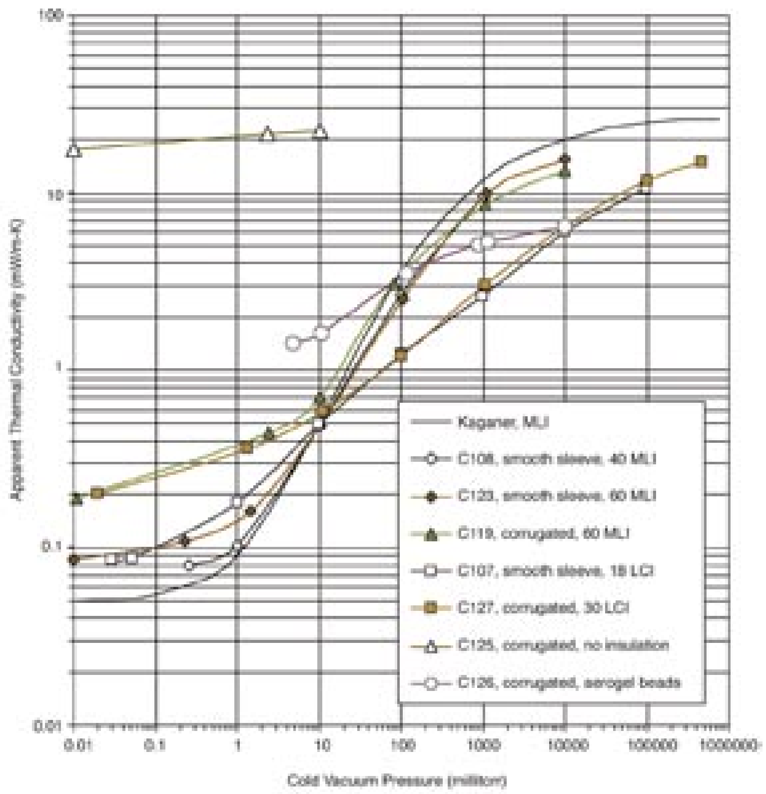

Figure 3. Variation of k-Value With CVP for Different Cryogenc-Vacuum Thermal Insulation Systems

Thermal Performance Testing of Insulation Panels for CBAT

The Cryogenic, Conformal, Composite, Common-Bulkhead, Aerogel-Insulated Tank project, or CBAT, is part of the development of Airframe Technologies for Advanced Space Transportation. Demonstration of all these technology elements (cryogenic, conformal, composite, common, and aerogel) together in one engineering development unit (EDU) is the overall objective of this project, which is being led by the Marshall Space Flight Center (MSFC). A key part of the prototype launch vehicle tank-set is the thermally insulating structural panel between fuel (kerosene) and oxidizer (liquid oxygen) tanks. Thermal performance testing of candidate insulation panels under cryogenic vacuum conditions was performed at the Cryogenics Test Laboratory of the NASA Kennedy Space Center.

The steady-state liquid nitrogen boiloff method of calorimetry was used to determine the apparent thermal conductivity (k-value) of the test specimens. Cryostat-4, a flat-plate insulation test apparatus for comparative k-value measurement, was used for all tests. A liquid nitrogen cold mass maintained the cold boundary temperature (CBT) at approximately 78 kelvin (K). The warm boundary temperature (WBT) was maintained at approximately 293 K using an external heater. The mean temperature was therefore about 186 K (-87 degrees Celsius). Vacuum environments included the following three cases: high vacuum (HV), soft vacuum (SV), and no vacuum (NV). Nitrogen was the residual gas within the vacuum chamber.

The 8-inch-nominal-diameter test specimens, shown in figure 1, include evacuated, nonevacuated, and krypton-filled insulation panels manufactured by NanoPore Inc. The core material is Nanogel, a trademark of Cabot Corporation. Values for thickness and density for the installed condition are given in the table. A summary graph of the calibrated k-value as a function of CVP is presented in figure 2. The curves for polystyrene and aerogel beads are shown for reference. The evacuated panel tests, test series F102 and F106, show that the compressive load of approximately 50 pounds per square inch causes a significant increase in the heat transfer rate. The krypton-filled panel F104 shows remarkably good performance relative to the air-

Installed Thickness and Density for Insulation Panels

Series	Description	Thickness (mm)	Density (g/cm^3)
F102	Evacuated	11.5	0.253
F103	Air-filled	13.0	0.221
F104	Krypton-filled	11.6	0.266
F105	F103 w/o edge	12.8	0.224
F106	F102 compressed	10.2	0.285

Figure 1. Test Specimens F102 (Evacuated), F103 (Air), and F104 (Krypton)

filled panel F103 as expected because the thermal conductivity of krypton is much lower.

Although the KSC task for CBAT has concluded, the research work continues in a related area. Plans for 2002 call for working with Technology Applications, Inc., to develop structural insulating panels for cryogenic piping. The core material for this insulation system will be glass microspheres for their excellent combination of mechanical, thermal, and low-mass properties. Potential applications include thermal protection system for reusable launch vehicles, common bulkhead propellant tanks for spacecraft, underwater fuel transfer lines, shipping containers for frozen foods or biological tissues, refrigerated transport, replacement for conventional cellular glass or foam insulants on liquid oxygen piping and tanks, and cold boxes for manufacturing processes.

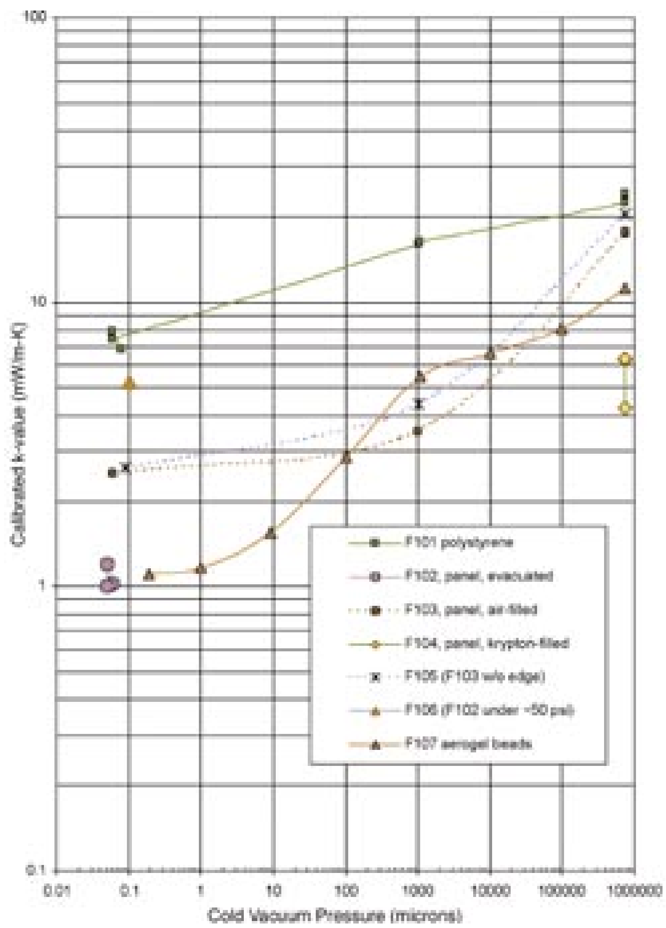

Figure 2. Variation of Calibrated k-Value With Cold Vacuum Pressure

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Participating Organizations: Dynacs Inc. (K.W. Heckle) and NASA MSFC (G. Smithers)

Aerogel Beads as Cryogenic Thermal Insulation System

A technology focus area of the Cryogenics Test Laboratory is thermal insulation systems. The development of cost-effective, robust cryogenic insulation systems that operate at soft-vacuum level is a primary target from the energy and economics point of view. This applied research and development work includes the test, evaluation, characterization, and application of silica aerogel beads produced by Cabot Corporation. The aerogel bead material has many potential applications for cryogenic and other higher-performance insulation needs in industry. Evaluation activities include novel composite constructions and larger-scale applications such as cold boxes. The material has been proposed for insulating cryogenic umbilical connections for new commercial launch platforms, retrofitting perlite-insulated storage dewars, and insulating a miles-long cryogen transfer line. Over 100 liquid nitrogen boiloff tests of the aerogel products using research cryostats have been performed. Characterization information, such as evacuation, outgassing, and ease of use, is also being obtained. The thermal performance data are being used in the preliminary development of future space launch and exploration applications.

The aerogel beads have a bulk density of about 80 kilograms per cubic meter (kg/m^3) and a mean particle diameter of 1 millimeter (mm). The typical pore diameter of the particles is about 120 angstroms. Production of the aerogel beads employs a continuous spray process of manufacturing. The ambient drying step replaces the costly supercritical drying step characteristic of most aerogels produced by solution-and-gelation (sol-gel) methods. The beads are treated to remain hydrophobic, but a hydrophilic (untreated) product is also available for oxygen service. The properties of aerogel beads are given as follows:

Properties of Aerogel Beads

Property	Value
Nominal Diameter	1 mm
Bead Density	140 kg/m^3
Bulk Density	80 kg/m^3
Surface Area	650 m^2/g
Pore Volume	3.17 cm^3/g
Outgassing	Less than 1% to total mass loss
Flammability	Noncombustible
Minimum Ignition Temperature	400 °C

Steady-state liquid nitrogen boiloff methods were used to characterize the thermal performance of aerogel beads in comparison with conventional insulation products such as perlite powder and multilayer insulation (MLI). Test articles are heated and evacuated to below 10^{-5} torr to begin a test series. The cold vacuum pressure (CVP) is adjusted for the desired vacuum level using nitrogen as the residual gas. A thermal shroud maintains the insulation outer surface (warm boundary temperature [WBT]) at approximately 293 K. (See figure 1.) The cold mass (cold boundary temperature [CBT]) is kept at approximately 80 K. After coincident stability of the vacuum level, all layer temperatures, and the evaporation (boiloff) rate are achieved, the apparent thermal conductivity (k-value) is determined from Fourier's law of heat conduction for a cylindrical wall.

The materials tested were aerogel beads (81 kg/m^3), opacified aerogel beads (94 kg/m^3, carbon black R300), perlite powder (115 kg/m^3, 50 × 50 mesh), and MLI (92 kg/m^3, 60 layers aluminum foil and fiberglass paper). All test specimens were made in a cylindrical configuration at a typical thickness of 25 mm. A summary graph of the k-value as a function of CVP is given in figure 2. The experimental curves for perlite and MLI compare well with similar thermal performance data from the literature. The aerogel beads gave superior performance for all CVP's above 0.1 torr. The carbon black opacifier improved the performance of the aerogel beads for CVP's below 10 torr. The high-vacuum (1×10^{-4} torr) performance of the plain white aerogel beads is approximately 1.1 milliwatts per meter-kelvin (mW/m-K), while that of the opacified specimen is approximately 0.6 mW/m-K. The added radiation shielding effect of the opacifier yielded almost 50-percent improvement. The k-values for the aerogel beads were found to be comparable to the performance of other aerogel-based products under similar cryogenic vacuum conditions. The results showed the performance of the aerogel beads was significantly better than the conventional materials in the soft-vacuum to no-vacuum range. Opacified aerogel beads performed better than perlite powder under high-vacuum conditions.

The results of this experimental research study of aerogel beads show that this new product offers several performance advantages in comparison to the more conventional thermal insulation products currently available for cryogenic applications. The following characteristics are some key advantages of the aerogel beads: free flowing, fill small cavities, minimal dusting, nonsettling, do not compact, no preconditioning needed, and can be molded or formed using binders. Thermal performance for the actual use conditions between liquid nitrogen temperature and room temperature was determined to be approximately 11 mW/m-K at no vacuum and 1.1 mW/m-K (0.6 mW/m-K, opacified) at high vacuum. Further studies for material optimization and system application are in progress.

Looking for cost-effective solutions to insulation problems is fundamental to the energy-intensive field of cryogenics and, in general, to the endeavors of space travel. A successful production chain for the aerogel beads and similar nano-technology materials will be an important part of these efforts. Maturation of the production processes can then lead to wide-scale usage in practically all refrigeration industries including food processing, storage, and transportation; air conditioning and environmental control; medical and biological applications; and manufacturing processes.

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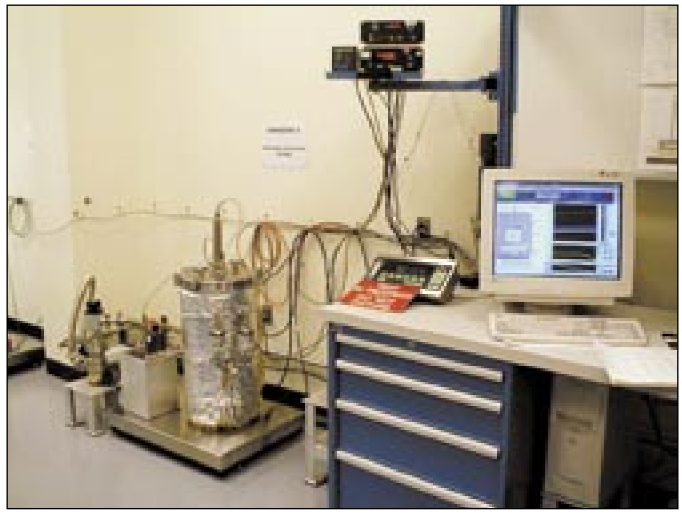

Figure 1. Overall View of Insulation Test Cryostat Apparatus

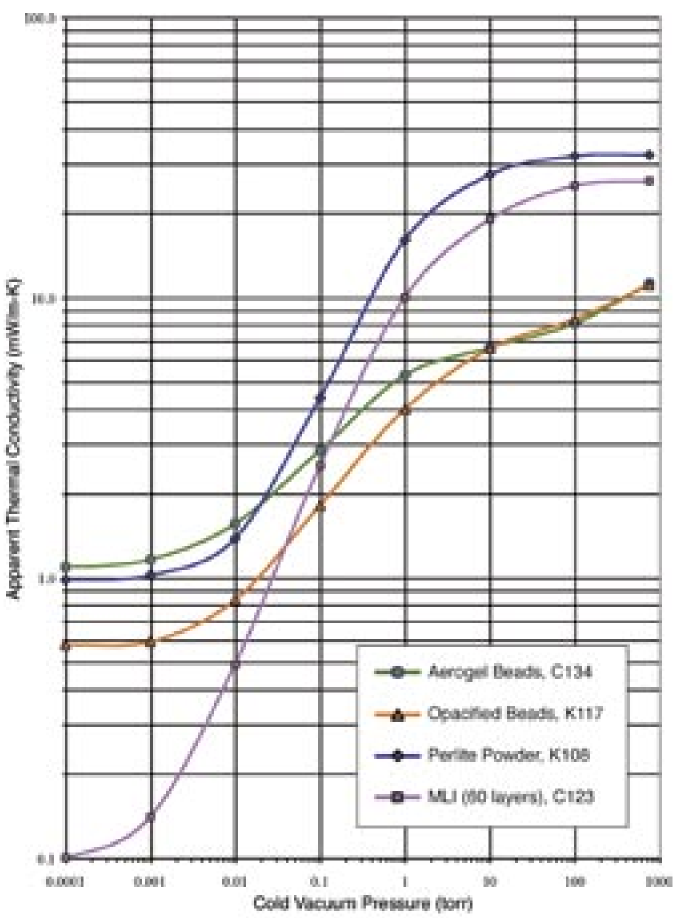

Figure 2. Variation of k-Value With CVP for Different Insulation Materials

Performance Characterization of Perforated Multilayer Insulation (MLI) Blanket

A perforated MLI blanket system is targeted for a number of large-scale cryogenic facilities. Space applications and particle accelerators are two fields concerned with the thermal shielding of devices used at cryogenic temperatures. Because radiation heat transfer varies with T^4 insulation, systems operating between the boundary temperatures of 300 and 77 kelvin (K) are of prime importance. The heat transfer in this range is the dominant portion of the total heat transfer, even for devices operating with a cold boundary temperature as low as 2 K. Systems operating under conditions of degraded vacuum levels are also a key consideration because of heat transfer by residual gas conduction.

An experimental study of a perforated MLI blanket was performed in 2001. The blanket, manufactured by Jehier (Chemille, France), is a cryogenic thermal insulation system composed of perforated double-aluminized Mylar separated by polyester net spacers. Two blankets of 15 layers each were installed on the cylindrical cold mass of the research cryostat as shown in figure 1. The total thickness of the 30 layers was 7 millimeters (mm). Complete characterization of the blanket thermal performance between 300 and 77 K using a steady-state liquid nitrogen evaporation method was produced using Cryostat-1. A summary graph of the variation of apparent thermal conductivity (k-value) with cold vacuum pressure (CVP) is given in figure 2. The k-value at the high vacuum condition of 0.01 millitorr was measured to be 0.029 milliwatt per meter-kelvin (mW/m-K). (The equivalent R-value per inch is 5,000.) Comparison of experimental data for other types of MLI systems is also presented. Layer temperature profiles for the different vacuum levels are presented in figure 3.

The testing was performed at the Cryogenics Test Laboratory of NASA Kennedy Space Center as part of a comparative study of cryogenic vacuum insulation systems. Basic heat transfer questions and practical methods of application regarding the performance of high-performance MLI blankets continue to be addressed. A target is to develop thermal insulation systems that can operate effectively for large-scale, energy-efficient industrial application on Earth and in space.

Figure 1a. Installation of MLI Blanket

Figure 1b. Completed Installation Showing Lower Closeout of Cold Mass

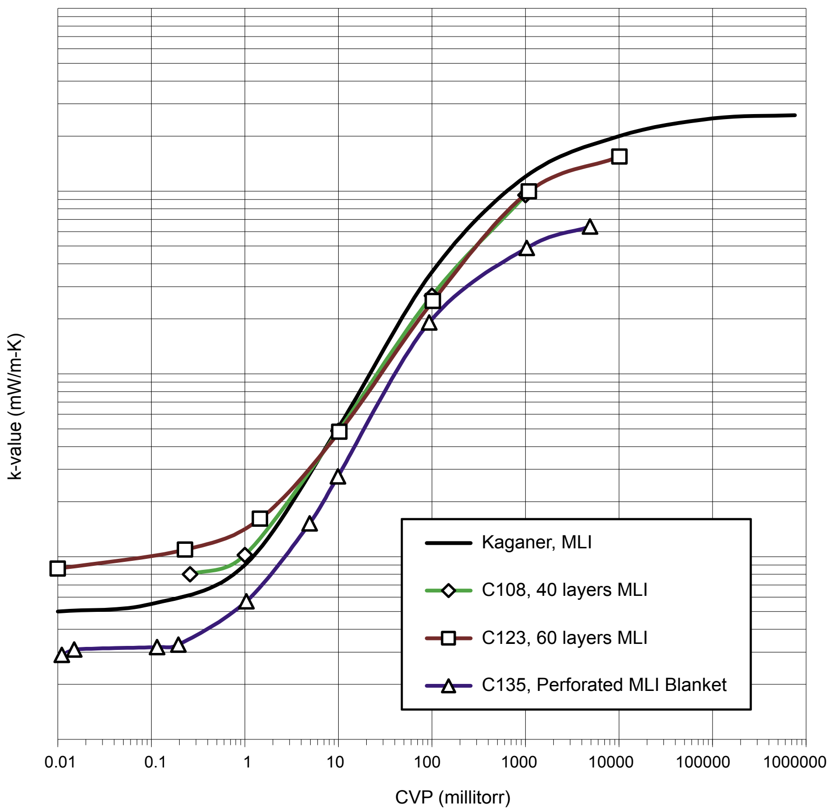

Figure 2. Variation of k-Value With CVP's for Different MLI Systems

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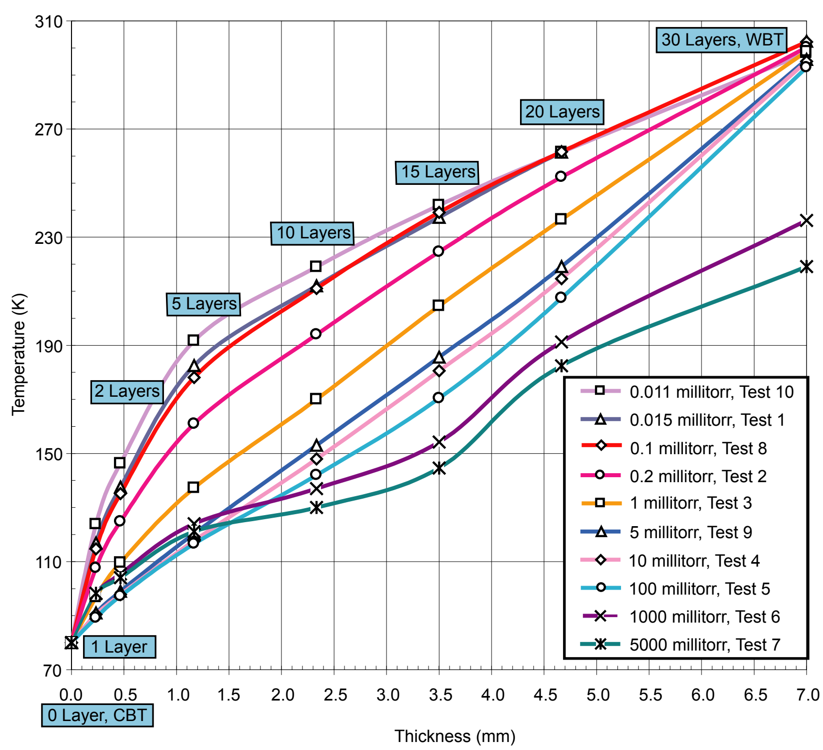

Figure 3. Layer Temperature Profiles as a Function of Blanket Thickness for Different CVP's

Improvements and Modeling of the RWGS Process

The Reverse Water Gas Shift (RWGS) reaction, which has been known since the mid-1800's, has been combined with water electrolysis (WE) to provide a testbed for the development of autonomous control software to produce data to model the RWGS/WE system and to develop process improvements at Kennedy Space Center. The RWGS reaction combines carbon dioxide (CO_2) with hydrogen (H_2) over a copper catalyst at 673 kelvin (K) in an endothermic reaction ($\Delta H = 37.6$ kJ/mol) to produce water (H_2O) and carbon monoxide (CO). The H_2O is electrolyzed to produce oxygen (O_2) and H_2, which is recirculated to the RWGS reactor. This system would be a useful tool on Mars where atmospheric CO_2 is a convenient raw material. The system is important even if water is present on Mars, since it provides not only O_2 but also CO, which is a useful raw material for metal oxide reduction and production of hydrocarbons and other organic materials. Therefore, we have continued to develop our understanding of the RWGS/WE system, with primary objectives to reduce the system complexity and improve the overall efficiency of the process.

The baseline data for the system are given in the table, which provides a matrix of operating parameters, including the reactor feed to raw material (RM) feed ratio with the compressor. Several trends in the RWGS reaction are shown by the data. For example, as the total flow rate increases (runs 1, 2, and 3), the conversion is almost unchanged; as the ratio of CO_2 to H_2 increases (runs 2, 4, and 5), the conversion increases; as the reactor temperature increases (runs 2, 6, 7, 8, and 9), the conversion increases; as the pressure in the reactor increases (runs 2, 10, and 11), the conversion remains unchanged; and as the reactor feed to RM feed ratio increases, the conversion appears to go through a maximum. These data in the table will be used to select the optimum operating conditions for the system.

Test Matrix for the RWGS Baseline

Run Number	CO_2 (sLpm)	H_2 (sLpm)	Temperature (°C)	Pressure (psia)	Reactor Feed / RM Feed	Conversion CO/CO_2 (%)
1	0.5	0.5	400	45	Single Pass	20.5
2	1.0	1.0	400	45	Single Pass	22.1
3	3.0	3.0	400	45	Single Pass	19.8
4	1.0	2.0	400	45	Single Pass	15.0
5	2.0	1.0	400	45	Single Pass	30.2
6	1.0	1.0	350	45	Single Pass	16.9
7	1.0	1.0	375	45	Single Pass	19.8
8	1.0	1.0	425	45	Single Pass	23.7
9	1.0	1.0	450	45	Single Pass	24.7
10	1.0	1.0	400	16	Single Pass	22.2
11	1.0	1.0	400	30	Single Pass	22.3
12	1.0	1.0	400	45	12.5	52.5
13	1.0	1.0	400	45	14.0	63.3
14	1.0	1.0	400	45	12.8	95.8
15	1.0	1.0	400	45	11.0	99.1
16	0.5	0.5	400	45	22.5	66.6
17	0.5	0.5	400	45	13.4	100.0

RWGS Testbed Developed at KSC

One of the initial problems with the design of the reactor was illustrated by the temperature differential across the bed, which ranged from 40 to 50 degrees Celsius. Since the bed was heated from the outside and the reaction is endothermic, it was difficult to transfer heat across the bed. This difference is made worse by the insulating characteristics of the catalyst bed, which is copper-impregnated γ-alumina. To correct the problem, copper turnings were added to the catalyst, and the temperature difference dropped to less than 10 degrees. Other changes in the initial design include a change in the method of analysis (from a mass spectrometer to a gas chromatograph). The gas chromatograph used two detectors for the analysis, eliminating the need to switch carrier gas for analysis. In the final analytical method, CO and CO_2 were analyzed with a thermal conductivity detector and H_2 was analyzed with a helium ionization detector.

Additional changes are planned for the RWGS system that could eliminate the recycle loop and reduce the complexity of the process. The primary change under investigation is to remove water directly from the reactor, thus shifting the equilibrium so the reactants are consumed before they leave the reactor.

Key accomplishments:

- Improved the temperature control reactor by adding copper turnings and a proportional integral derivative (PID) control on the heater.
- Added a gas chromatograph to analyze the composition of the reactions and products at critical control points.

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High-Accuracy Heat Flux Rate Measurements for Launch Vehicles

Knowledge of aerothermally induced convective heat transfer and plume-induced heat transfer loads is essential to the design of thermal protection systems (TPS's) for launch vehicles. Aerothermal and radiative models are typically calibrated via the data from in-flight heat flux sensors. The most commonly used sensor for this purpose is the Schmidt-Boelter gauge because it is easy to install, gives a rapid transient response, and has an analog output proportional to the incident heat flux. There are errors involved with these instruments, however, that can lead to indicated measurements twice as high as actual environments under common launch vehicle flight conditions. Correcting these errors will reduce thermal protection materials used and associated processing and allow for the use of more materials that cannot meet the current conservative-design thermal loads.

The standard Schmidt-Boelter gauge is made largely of copper or aluminum but also uses epoxy and a thermopile. The sensors are cylindrical, with the sensing end of the cylinder flush-mounted to the exposed surface of the launch vehicle and thus exposed to the external thermal and velocity boundary layers as well as thermal radiation. Schmidt-Boelter gauges take advantage of the one-dimensional Fourier's law to measure the incident heat flux, with the thermopile analog output proportional to the incident heat flux. When surrounded by low-conductivity insulation, the sensor has an exposed surface temperature significantly lower than the insulation and this leads to two types of measurement errors.

One error is experienced only in convective heat transfer and is induced by the disturbance of the thermal boundary layer. This is caused by the lower-temperature calorimeter surrounded by the higher-temperature insulation and results in a higher-incident heat flux on the gauge than on the surrounding insulation. The second type of error is caused by heat conduction from the surrounding insulation radially into the cylindrical calorimeter. This is manifested in the gauge reading as an indicated heat flux higher than the incident heat flux on the sensing surface.

An effort is currently underway to model the heat flux gauge under typical flight conditions that includes an installation surrounded by high-temperature insulation. The goal is to correct the measurements to reflect the local heat flux on the insulation had the instrument not been present. The three major components of this effort include: (1) a three-dimensional computational thermal math model including the internal conduction heat transfer details of a Schmidt-Boelter gauge; (2) a computational flow dynamics (CFD) analysis to determine the effects on measurement of the rapidly changing thermal boundary layer over the near-step changes in wall temperature; and (3) testing performed on flat plates exposed to an aerothermal environment in the Marshall Space Flight Center (MSFC) Improved Hot Gas Facility (IHGF).

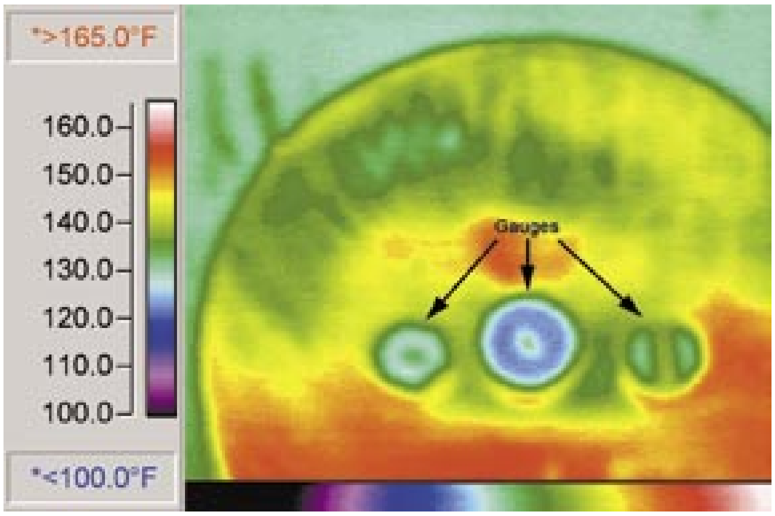

Figure 1. Infrared Image of Schmidt-Boelter Gauges Surrounded by Stainless Steel Under a Mach 4.1 Aerothermal Environment at MSFC IHGF

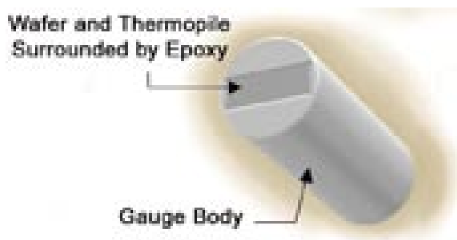

Figure 2. Simple Diagram of Schmidt-Boelter Gauge

This work improves on previous work in three ways: (1) it models radial energy error components, including both as-built and as-installed factors; (2) its CFD model more precisely accounts for property changes of the supersonic stream and their impact on the dynamic boundary layer; and (3) it provides data that will be used to calibrate the models.

Key accomplishments:

- Completed three-dimensional conduction model for radial heat transfer.
- Completed CFD code for analysis of thermal boundary layers.
- Collected initial data from aerothermal facility.

Key milestones:

- 2002: Collected final data. Calibrated three-dimensional conduction model and CFD model.
- 2003: Establish applications for corrections to in-flight instrumentation.

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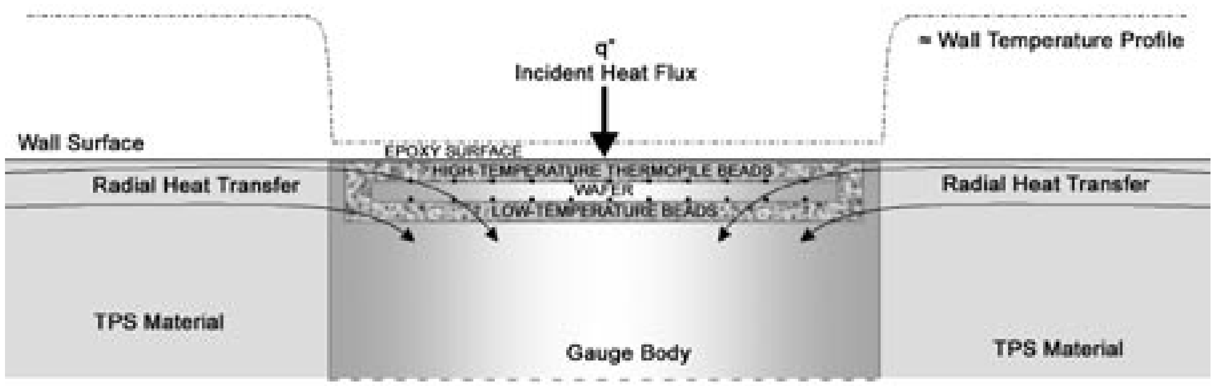

Figure 3. Heat Transfer Diagram of Schmidt-Boelter Gauge

An Application of Overset Grids to Payload Fairing Internal Flow CFD Analysis

Spacecraft often include instruments that are sensitive to contamination or may be composed of lightweight components with a limited ability to withstand high flow rates past component surfaces. For a typical expendable launch vehicle, prelaunch air-conditioning and purge requirements generally entail injection of air or gaseous nitrogen (GN_2) at high flow rates into the payload fairing (PLF) once the spacecraft has been encapsulated. A computational fluid dynamics (CFD) analysis was carried out to characterize the resulting flowfield (velocity, pressure distributions, and flow streamlines) and to investigate flow-induced effects and possible contamination sources and dispersions over spacecraft surfaces.

Overset (or embedded) grids are becoming increasingly popular in CFD applications for the prediction of flowfields about complex three-dimensional geometries. In the last decade, overlapping grids were mostly applied to problems of high-speed aerodynamics, and their applications to low-speed internal flow are relatively few. This report summarizes the application of overset grids for the analysis of PLF/spacecraft internal flow.

Overlapping grids were generated for two PLF/spacecraft configurations. Various grid topologies were utilized for the component grids. Collar grids were considered for defining the intersection regions. The collar grids provide the communication between the intersecting grids, as well as the necessary resolution for viscous flow computation.

The steady-state flowfield is obtained with the aid of a three-dimensional Navier-Stokes code, OVERFLOW, developed by NASA. The code has the capability to handle chimera overlapped grids. Turbulent flow is modeled with the aid of the Spalart-Allmaras one-equation turbulence model governing turbulent kinetic energy. Initially, fluid is set at rest in the entire system; that is, all the velocity components are set to zero. Appropriate boundary conditions have been imposed, including the solid wall and inflow and outflow boundaries. Inflow velocity profiles (and mass flow rate) are specified at the pipe inlet. Because of the subsonic nature of the flow, the static pressure at the outflow boundary needs adjustment for providing the necessary mass flow rate. Convergence is achieved using time-stepping scheme, multigrid cycling, and low Mach number preconditioning. Steady-state solution for this grid system was obtained for pipe Reynolds number of 2.4E5 (based on pipe diameter) and a Mach number of 0.04.

An examination of the steady-state flowfield indicated the complex three-dimensional flow is characterized by areas of vortex flow, flow separation, high degrees of swirl, and reverse flow. Streamline traces from various sources (typical of access and vent openings on the PLF and launch vehicle) suggest the possibility of particle dispersion both upstream and downstream of the sources.

Figure 1 displays the streamline traces emanating from the air-conditioning (AC) pipe/fairing junction.

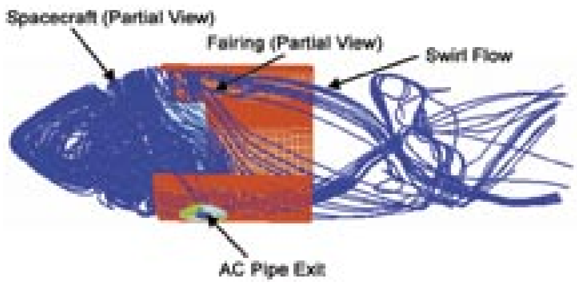

Figure 1. Streamline Traces Emanating From the AC Pipe Exit

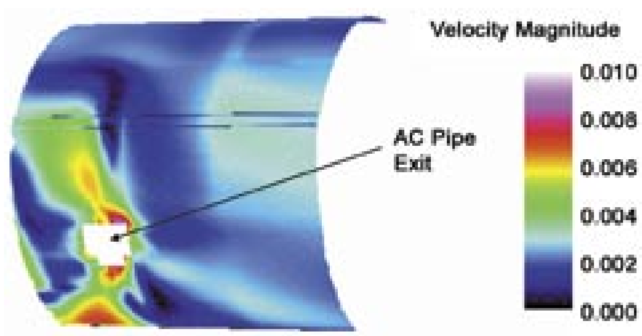

Figure 2. Contours of Velocity Magnitude in the Fairing

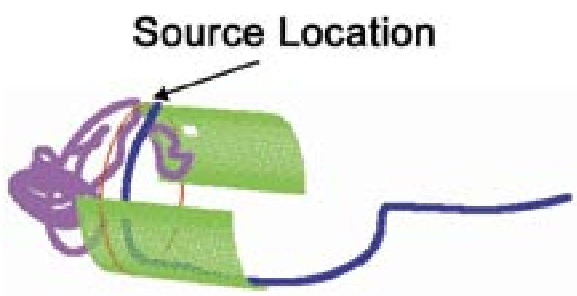

Figure 3. Streamlines Emanating From Sources at Accesss Openings

The velocity magnitudes within the fairing are exhibited in figure 2. A typical source streamline from an access opening is displayed in figure 3.

Key accomplishments:

- Developed grid systems and flow solutions to define internal flow-fields for two PLF/spacecraft configurations for an expendable launch vehicle.
- Provided detailed characterization of the internal flowfields of encapsulated spacecraft during prelaunch operations.

Key milestone:

- Analyze and test a simulated PLF/spacecraft configuration to provide empirical data for model correlation and calibration.

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Space Habitat Carbon Dioxide Electrolysis to Oxygen

Oxygen production via the direct electrochemical reduction of carbon dioxide (CO_2) is being investigated. This technology has direct applications for ongoing space missions (e.g., the International Space Station [ISS], Shuttle) and for Human Exploration and Development of Space (HEDS) missions as a means to remove CO_2 generated from human respiration in space cabins during long-term missions. No room-temperature system has been identified that can sustain CO_2 electrolysis, although one possible approach (i.e., the ionic liquids) is being investigated. At least two high-temperature systems were shown to electrochemically convert CO_2 into oxygen; these are the solid oxide conductors and the molten carbonate (MC) cells. The MC cell has several advantages over solid oxide conductors. The main advantage is that it operates at considerably lower temperature than the solid oxides (550 degrees Celsius [°C] versus 700 to 900 °C). In addition, the MC system is a mature technology in the fuel cell industry and exhibits both high throughput and long lifetime. Accordingly, many of the technical problems associated with high-temperature operation were addressed and solved for the MC fuel cell. The electrochemical process can be envisioned to proceed via either an oxide ion or a carbonate ion intermediate:

Oxide Anion Intermediate	Carbonate Anion Intermediate	Reaction
$2CO_2 + 4e^- \rightarrow 2CO + 2O^=$	$4CO_2 + 4e^- \rightarrow 2CO + 2CO_3^=$	Cathode
$2\,O^= \rightarrow O_2 + 4e^-$	$2CO_3^= \rightarrow 2CO_2 + O_2 + 4e^-$	Anode
$2CO_2 \rightarrow 2CO + O_2$	$2CO_2 \rightarrow 2CO + O_2$	Net Cell

It should be noted that in the presence of carbon dioxide, oxide ions would be in equilibrium with carbonate ions ($CO_2 + O^= \leftrightarrow CO_3^=$), the main mobile anion in the molten carbonate cell. Accordingly, CO_2 reduction in molten carbonate could proceed via a carbonate intermediate, although mechanistically the actual electrochemical reaction could be via either the oxide ion or carbonate ion.

This general reaction scheme was demonstrated experimentally. Figure 1 illustrates the production of oxygen during CO_2 electrolysis using two platinum electrodes immersed in a bulk reservoir of molten carbonate at an operating temperature of 550 °C. The anode was partially surrounded by an inert tube to facilitate collection of the vapor products. The anode vapors were transferred to a gas chromatograph using a helium sweep gas and analyzed for oxygen and carbon dioxide. The observed oxygen concentration as measured by the gas chromatograph correlated nicely to the oxygen concentration as predicted by Faraday's law. The reaction scheme also predicts that the anode gas should consist of two parts of CO_2 for each part of oxygen. This was experimentally confirmed.

The excellent correlation between the observed oxygen and carbon dioxide levels in the anode gases confirms the viability of using the molten carbonate system to generate oxygen via the direct electroreduction of CO_2. Bulk reservoirs of molten

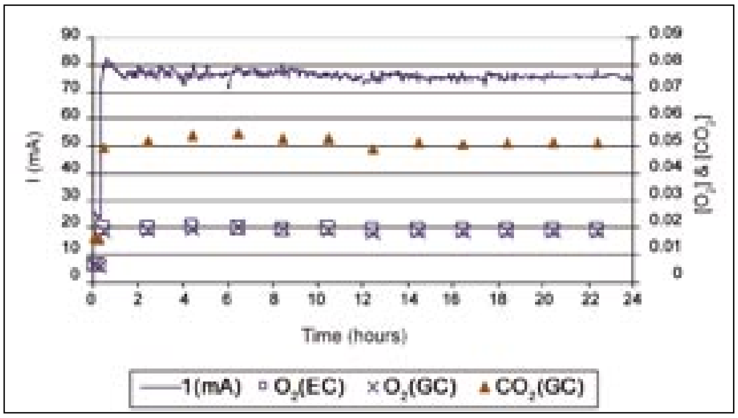

Figure 1. Oxygen Production Via CO_2 Electrolysis on a Platinum Anode and Cathode in a Bulk Reservoir of Molten Carbonate at 550 °C. (The anode vapors were collected in a helium sweep gas and analyzed by a gas chromatograph (GC). The oxygen concentration as measured by the GC [□] was nearly idential to the oxygen concentration as predicted by Faraday's law. Direct reduction of CO_2 predicts that the composition of the anode gases consists of two parts of CO_2 for each part oxygen. GC analyses confirm this level of CO_2 [▲]. Results are shown for 7 days of continuous operation; no significant loss in response was observed during this time.)

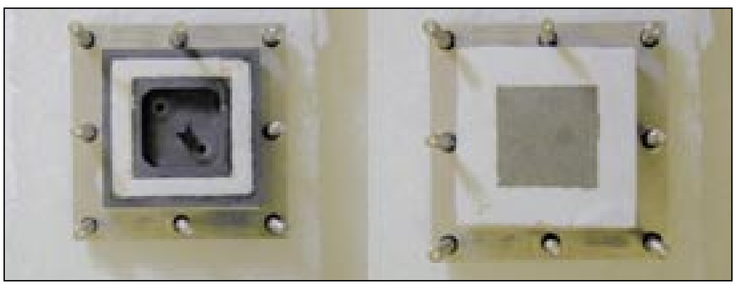

Figure 2. Prototype MC Wafer Cell (The MC wafer consists of a thin-film platinum electrode on both surfaces of a ceramic substrate or two substrates mounted on top of each other, while the bulk ceramic is impregnated with carbonate salt. The wafer is mounted in a cell. At operating temperature, a carbonate melt forms. A liquid seal isolates the internal cell chamber from the external environment. CO_2 electrolysis to oxygen was demonstrated, but work is still required for obtaining a reliable liquid seal.)

electrolytes are not amenable for deployment in space applications. Instead, wafer-electrolyte configurations, similar to those developed by the fuel cell industry, are being developed. Electrodes on porous ceramic wafers saturated with the carbonate electrolyte are being developed for the molten carbonate electrolysis cell. Figure 2 shows a prototype design for the wafer cell. Tests demonstrated that oxygen can be generated via the direct CO_2 electrolysis using this cell configuration. Improvements in the robustness of the cell design and integrity of the seals remain to be accomplished.

Key accomplishments:

- Developed a test system that allowed the evaluation of CO_2 electrolysis in MC with the capability of collecting the anode gases for independent analyses. This demonstrated a high Faradaic efficiency for the generation of oxygen via the electrochemical reduction of CO_2 in a bulk electrolyte at 550 °C.
- Identified ceramic substrates for developing a wafer electrode/electrolyte structure and made prototype systems that confirm similar electrochemical behavior for the wafer cell as the bulk electrolyte system.

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Rayleigh Doppler Technique for Location of Hydrogen and Helium Leaks

When electromagnetic radiation is emitted, scattered, or reflected from an object moving toward or away from an observer, the observed wavelength is shifted (the Doppler effect). The molecules of a gas will scatter electromagnetic radiation (Rayleigh scattering). Thus, radiation that is Rayleigh-scattered from a gas may be shifted in wavelength because of the velocity of the scattering molecules.

The distribution of velocities will vary with the composition of the gas, so when light of a single frequency is scattered from a gas, the frequency spectrum of the scattered light is broadened (Doppler broadening). The degree of broadening will depend upon the velocities of the molecules, which in turn depend upon the composition of the gas. Therefore, it is possible to determine the composition of a gas by measuring the Doppler broadening of Rayleigh-scattered light.

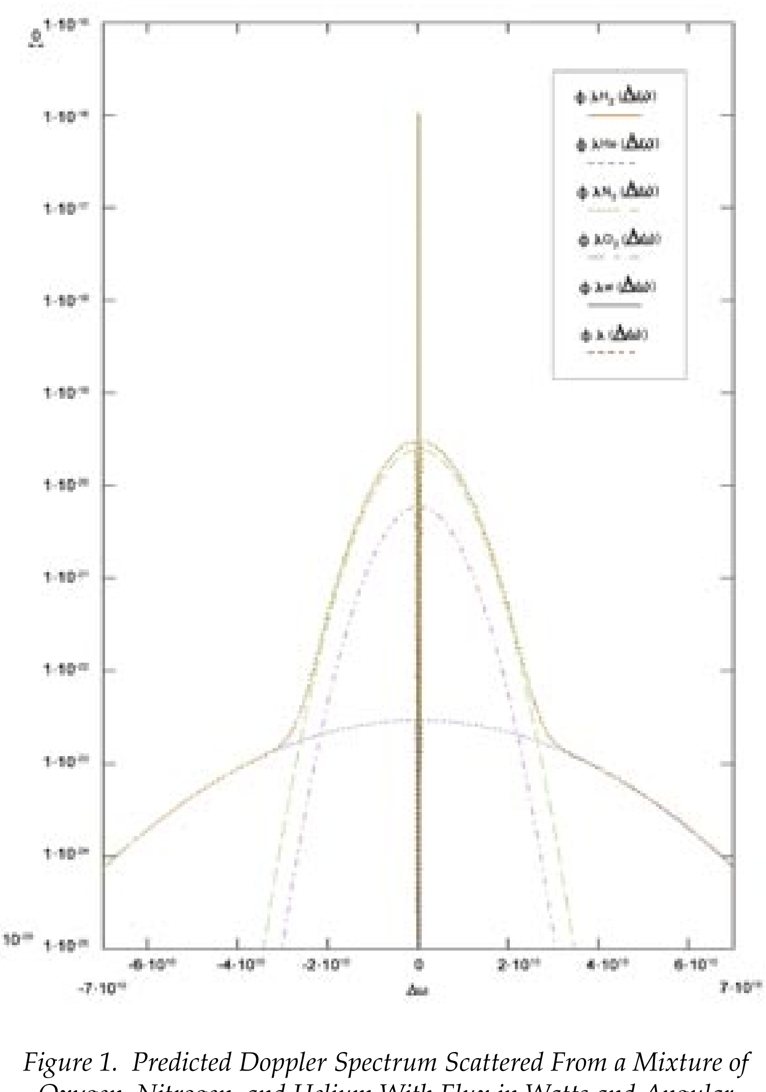

Figure 1. Predicted Doppler Spectrum Scattered From a Mixture of Oxygen, Nitrogen, and Helium With Flux in Watts and Angular Frequency in Radians/Second

A theoretical model was developed that predicts the spectrum of the Doppler-broadened light and the signal-to-noise ratio for this technique as a function of the key design parameters. This model includes both direct detection and heterodyne detection approaches. An example of predicted spectrum is shown in figure 1.

Five approaches to implementation of this technique were considered singly and in combination as candidates for a proof-of-principle experiment:

- Homodyne detection.
- Offset homodyne detection.
- Heterodyne detection.
- Vapor absorption filter.
- Fabry Perot interferometer.

A survey of the key technologies for the laser, detector, modulator, filter, and frequency discriminator indicated that two approaches may be currently feasible for a proof-of-principle experiment: homodyne and a combination of vapor absorption filter and Fabry Perot. Analyses using the model developed in this phase indicate that both of these techniques are expected to provide signal-to-noise ratios suitable for proof-of-principle experiments. Designs for these two experiments are outlined in figures 2 and 3. The next step in development after proof of principle will be to add a scanning system to enable acquisition of a two-dimensional image of the distribution of the leaking gas.

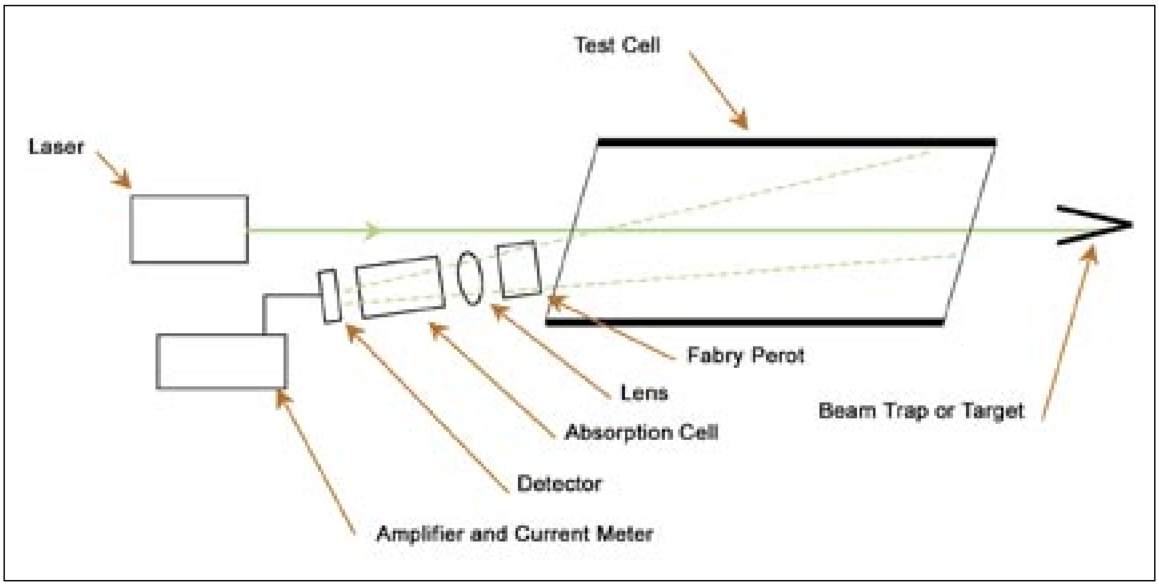

Figure 2. Direct Detection Experiment

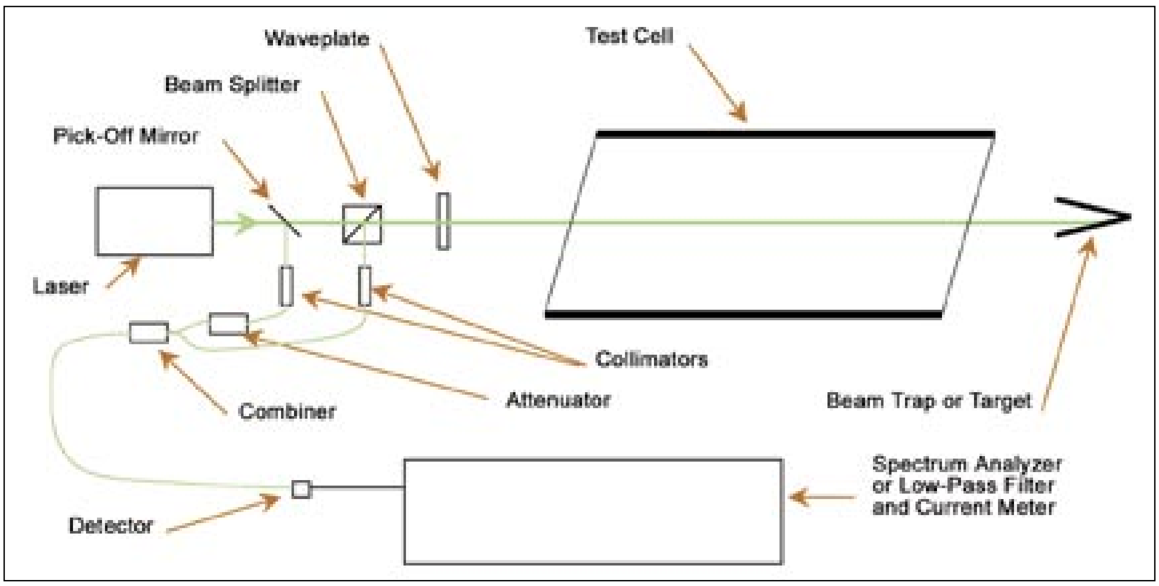

Figure 3. Homodyne Detection Experiment

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Participating Organization: Florida Space Institute (G. Sellar)

Cryogenic Piping Networks for Energy-Efficient Launch Sites

Future launch sites need a new approach for the supply of propellants and gases. Services will be built around thermally efficient, system-integrated concepts supplied by centralized plants for both energy conversion and cryogenic production. Piping networks to deliver the cryogenic fluids (helium, hydrogen, nitrogen, and oxygen) across long distances are a key element of a low-maintenance, economic, energy-efficient launch site. The Cryogenics Test Laboratory is seeking to explore and develop cryogenic transfer and distribution networks that greatly reduce recurring cost by reducing hardware and support subsystems, increasing thermal performance, and improving system dependability.

A three-way approach will leverage the development of new materials and existing insulation test technology infrastructure of the Cryogenics Test Laboratory:

- Energy and Economics: Explore key factors for providing energy-integrated fluid systems and cost-effective operations.

- Advanced Engineering: Address cryogenic piping design with respect to cost, maintenance, and thermal performance.

- Novel Materials: Exploit new insulation materials including layered composite insulation (LCI), aerogels, polyimides, and composites.

Accurate measurement of thermal performance will be accomplished by using the Cryogenic Pipeline Test Apparatus and directly comparing the results with those from commercial pipelines. The 18-meter-long cryostat (see figure 1) is now in operation at the Cryogenics Test Laboratory for conducting accurate thermal performance tests using the liquid nitrogen evaporation method. An example of the measured heat transfer data for several test runs of two commercial pipelines is given in figure 2.

Key accomplishments:

- 2001: Completed system calibration and the testing of commercial pipelines.

Key milestones:

- Produce concepts for efficient storage, transfer, distribution, and control networks.
- Build prototype 18-meter pipelines based on efficiency targets relative to overall launch site architectures and novel thermal insulation system materials now available.
- Perform accurate thermal performance testing of the prototype lines using Cryogenic Pipeline Test Apparatus.
- Perform cost analysis to compare the new technology with the standard vacuum-jacketed multilayer insulation transfer line technology.

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Participating Organization: Dynacs Inc. (Dr. S.D. Augustynowicz and Z.F. Nagy)

Figure 1. Overall View of Cryogenic Pipeline Test Apparatus

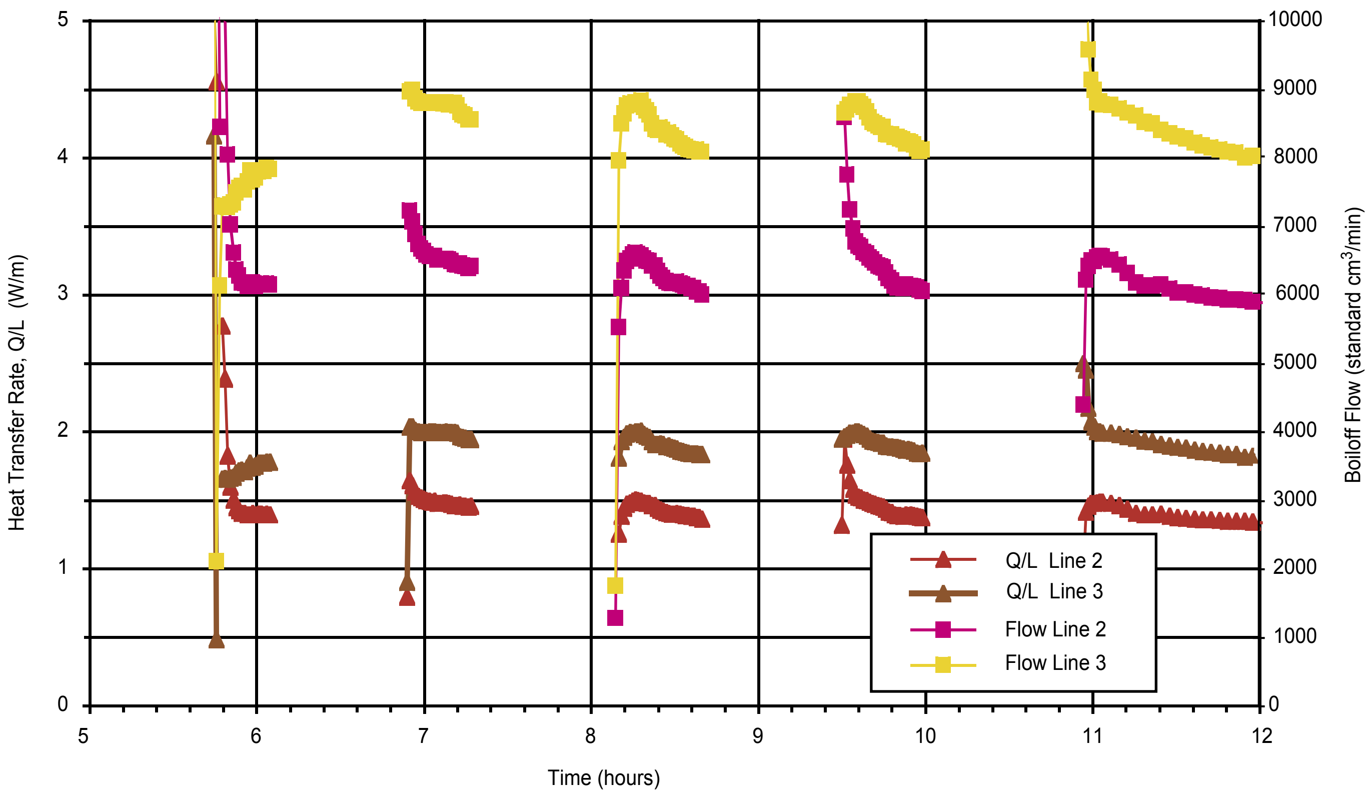

Figure 2. Example of Heat Transfer Measurement Data for Two Commercial Cryogenic Pipelines Tested in Parallel

Thermal Conductivity of High-Performance Polyimide Foams

A new class of material is now being developed for cryogenic thermal insulation systems for the next-generation reusable launch vehicles, commercial and defense marine ships, commercial aircraft, and numerous industrial applications. Recent advancements in high-temperature polymeric materials at the NASA Langley Research Center have led to the development of new polyimide foam systems with attractive properties for applications in thermal and acoustic insulation. To understand the performance parameters of these new foam systems at low temperatures and pressures, experimental studies are being conducted at the Cryogenics Test Laboratory. Liquid nitrogen cryostats developed by the Cryogenics Test Laboratory are being used to perform detailed thermal characterizations of these novel materials under full-range cryogenic vacuum conditions. Although common polymeric foams such as polyurethane have outstanding properties, they have been limited in their applications by temperature, poor fire resistance, and their susceptibility to thermal cycling and ultraviolet light exposure. These new high-performance foam systems of cyclic imide polymers have excellent structural integrity, fire resistance, thermal aging resistance, and thermal cycling properties.

In general, thermal conductivity of foamed systems is the lowest of any solid materials and is determined by the gaseous conduction within the pores, conduction via the solid structure of the foam, convection through the cells, and radiative heat transfer. This research allows for all of these parameters to be studied, including density, surface area, and open- or closed-cell content effects. In closed-cell foams, the heat transfer coefficient in the cell will change as the blowing agent is replaced by air with time. In open-cell foams, the overall thermal conductivity of the system will increase because of the open transfer of air into the cells through convection. This pioneering work involves never-before-investigated parameters for these foam systems and has led to important technology development for the NASA Space Launch Initiative/2nd Generation Launch Vehicles Program. The research and development are now being extended for the future utilization of novel polyimide composite materials in both aerospace launch systems and a number of industrial cryogenic equipment applications.

Key accomplishments:

- Pioneering work involved never-before-studied thermal conductivity parameters for polyimide foams and composite systems.
- A total of 104 cryogenic tests of 12 different materials was performed in 2001.
- A new flat-plate cryogenic insulation test apparatus was constructed.
- Baseline research led to important work for the Space Launch Initiative/2nd Generation Launch Vehicles Program.
- Research led to a Shuttle launch site equipment project proposal that addresses replacement of cryogenic insulation for ground systems.

Insulation Test Articles of Polyimide Foam Materials

Key milestones:

- Cryogenic performance information of polyimide foams was provided to support Phase I technology development work for the Space Launch Initiative.
- A number of publications and presentations on related polyimide foam research, including an American Chemical Society book chapter, were made in 2001.

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Participating Organizations: NASA Langley Research Center (E. Weiser) and Dynacs Inc. (Dr. S.D. Augustynowicz and K.W. Heckle, Sr.)

Buffer Gas Preparation From Cryogenic Collection

Buffer gases to blend with oxygen to produce breathing air are a requirement for Mars exploration. Before the recent announcement that water appears to exist in the Martian soil, the preferred source of oxygen was the Martian atmosphere. The Martian atmosphere, which contains approximately 95.3-percent carbon dioxide, 2.7-percent nitrogen, and 1.6-percent argon, is the source of the buffer gases. The source of oxygen would be from water electrolysis, either produced by the reactions of hydrogen with carbon dioxide, or water present on the surface of Mars. The need for carbon dioxide to produce fuels and other useful materials still exists, which means that it must be captured and separated from the nitrogen and argon. If it is assumed that carbon dioxide is captured by freezing at 193 kelvin (K), then a typical composition of gases in the chamber would be 30-percent carbon dioxide, 44-percent nitrogen, and 26-percent argon, which is the feed composition used in these studies. The target concentration of carbon dioxide in the buffer gas was 600 parts per million (ppm), the initial temperature was assumed to be 230 K, and the pressure was 1 kilopascal (kPa).

A test fixture was developed that allowed control of the feed gas composition, flow rates, and temperature. Pressure controllers were used to control the pressure drops across the membranes, and the volumetric flow rates of the permeate and raffinate were measured with wet test meters. When gas mixtures were used, a gas chromatograph measured the composition. Sufficient data were collected so mass balances could be calculated.

Preliminary tests with pure gases (carbon dioxide, nitrogen, and argon) were performed with four different commercial membranes over a temperature range from 230 to 298 K and pressure drops across the membranes that ranged from 0 to 28 kPa. The permeate flux and pressure drop data were used to calculate the pressure-normalized flux at different temperatures. The pressure-normalized flux, usually expressed in gas permeation units (GPU's), was plotted versus temperature to show the temperature dependency of the membranes for various gases. Since the membrane film thickness was not known, the relative selectivity, which is the ratio of the GPU's, was calculated for each of the gases as a function of temperature. Finally, mixtures of gases were passed through the membranes and the changes in composition were measured by gas chromatography. These data were then input to a solution-diffusion model and the design of a membrane system was generated. The final design used two hollow-fiber membranes produced by Air Products. These membranes are produced from brominated polysulfones and sold under the trade name Permea Prism Alpha Separators. The model used for the final design was the Permea PPA-22, Prism Alpha Separator, which has a surface area of 22 square feet. The results of the modeling are shown in the table and the system design is given in figure 1.

Performance Data Generated by the Enerfex Model for 230 K

Stream	1	2	3	4	5	6
% Carbon Dioxide	30.00	27.62	56.53	8.06	0.06	20.04
% Argon	26.00	26.90	15.84	34.37	37.72	29.37
% Nitrogen	44.00	45.48	27.61	57.56	62.22	50.59
Liter/Hour	12.77	16.78	6.77	10.01	6.00	4.01
Torr	780	780	6	780	780	6

Stream 1 is the initial feed to the membrane and stream 5 is the product, which has a carbon dioxide concentration of 600 ppm and a flow rate that is approximately 50 percent of the feed.

The membrane system, shown in figure 2, has a capacity that is approximately 12 times the flows used in the example given in the table or a product output at stream 5 of 1.2 standard liters per minute. Figure 2 shows the two membranes, pump required for stream 6, pressure controller for stream 6, and gas mixture supply.

Key accomplishments:

- A membrane system was designed that could remove carbon dioxide from a mixture of argon and nitrogen in two steps starting with 30 percent and ending with 600 ppm.
- The losses of buffer gases removed from the carbon dioxide capture chamber were only 50 percent of the initial feed.

Key milestones:

- 2001: Collection of data and design of a multimembrane system.
- 2002: Testing of the prototype membrane system to confirm capacity and purity of the product.

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Participating Organizations: Dynacs Inc. (L. Fitzpatrick, J.M. Surma, and T.R. Hodge), Florida Institute of Technology (P. Jennings and Dr. J. Whitlow), and Enerfex (R. Callahan)

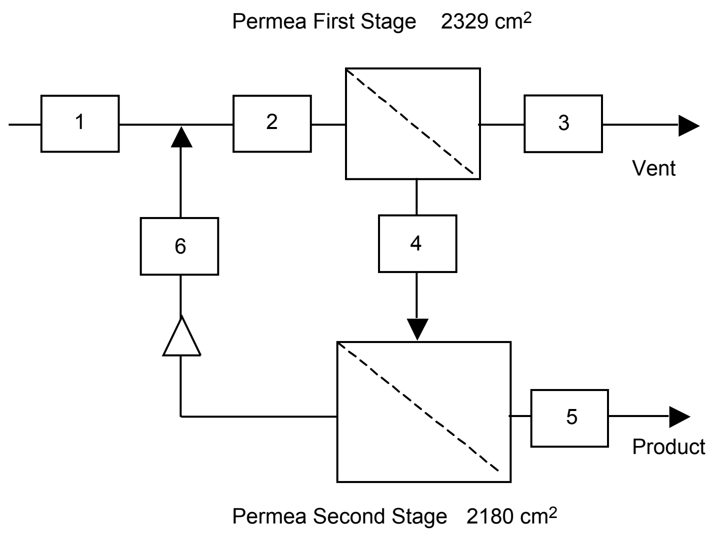


Figure 1. Membrane Purification of Feed From the Capture of Carbon Dioxide

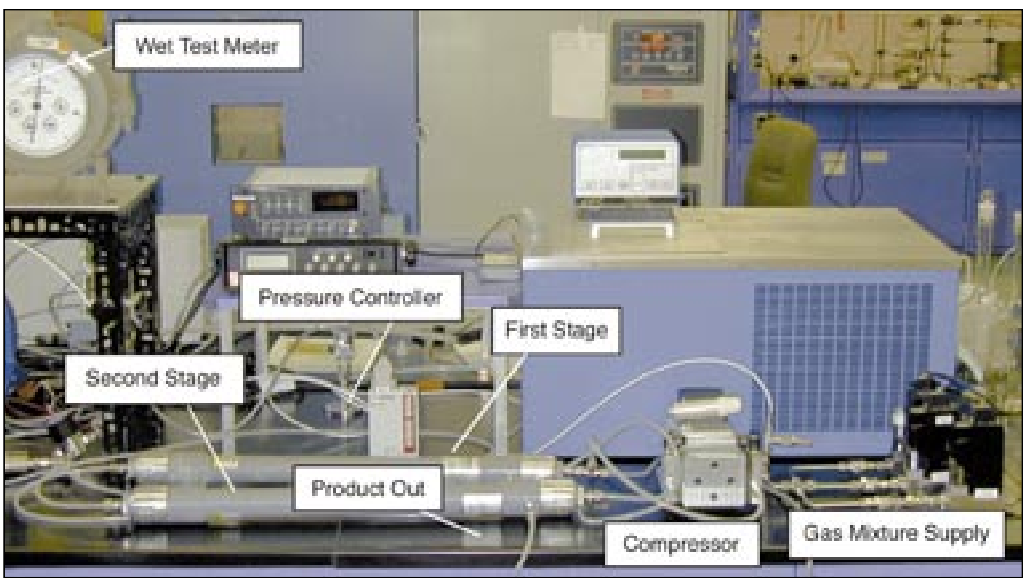


Figure 2. Laboratory Setup for the Gas Purification System, Shown Connected to the Testbed Used To Measure the Performance

Process and Human Factors Engineering

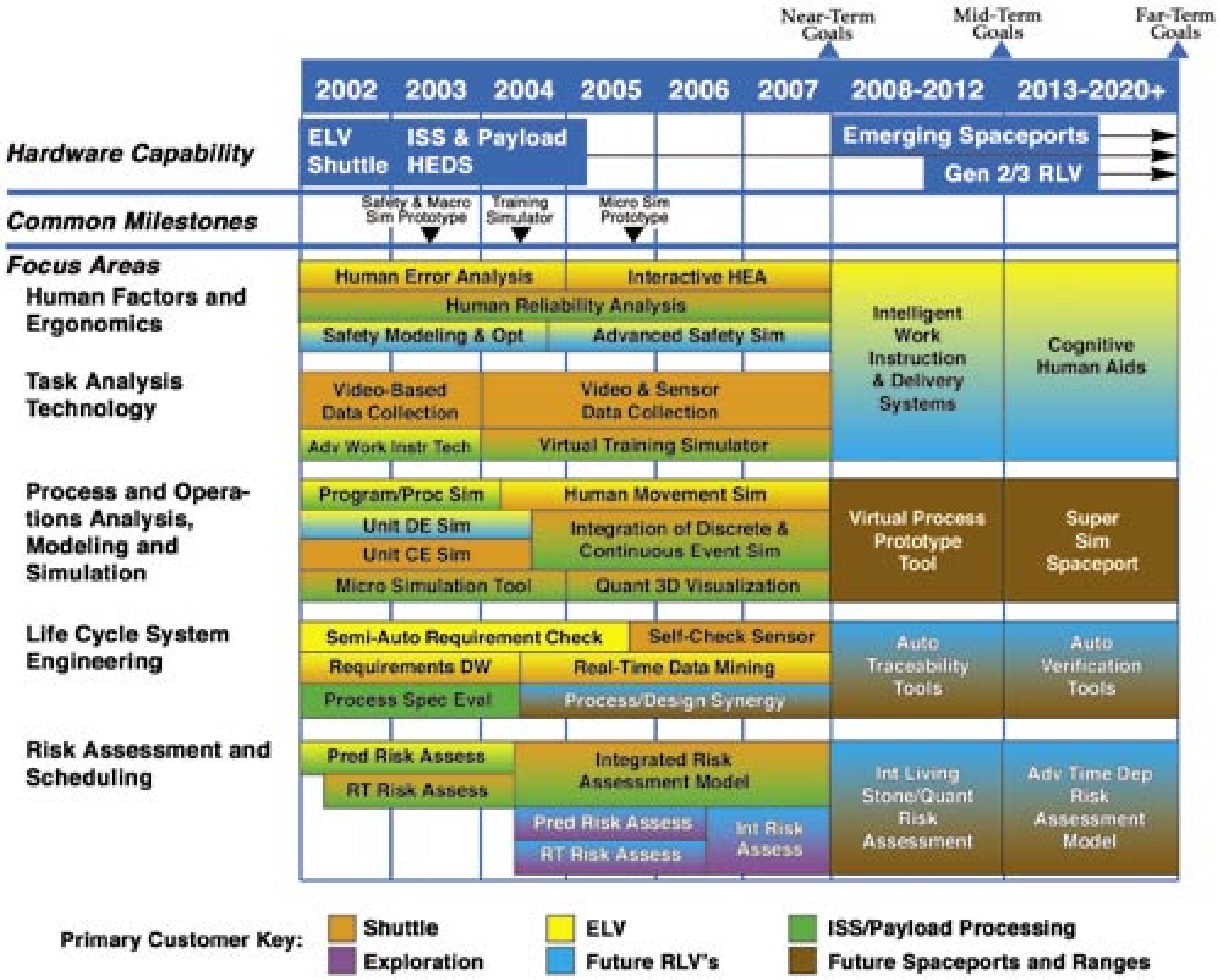
Process and Human Factors Engineering within the context of spaceports covers research on process efficiency, overall system performance, risk assessment, and life cycle engineering. Process Engineering for spaceports also focuses on the human aspects of process engineering, including ergonomics, human factors, human error analysis (HEA), and human reliability analysis (HRA). Process and Human Factors Engineering activities focus on benchmarking and improving existing processes used in spaceport activities, using a combination of simulation, human factors analysis, and process data collection. The ultimate goal is to create efficient processes that can be quickly adapted to the changing needs of future spaceports.

Technology focus areas include the following:

- Human Factors and Ergonomics
- Task Analysis Technology
- Process and Operations Analysis
- Modeling and Simulation
- Life Cycle System Engineering
- Risk Assessment and Scheduling
- Scheduling and Risk Assessment Technology

For more information regarding Process and Human Factors Engineering, please contact Dr. Deborah Carstens, (321) 867-8760, Deborah.Carstens-1@ksc.nasa.gov; or Dr. Gena Baker, (321) 867-4261, Gena.Baker-1@ksc.nasa.gov.

KSC Process and Human Factors Engineering Roadmap



Goals Specific to Focus Areas

- Decrease hours of work-related injury or illness
- Reduce processing times in impacted areas
- Increase number of processes optimized

Ablative Test Tracking Interface

The Materials and Processes Laboratory, located in the Vehicle Assembly Building (VAB), supports External Tank (ET), Solid Rocket Booster (SRB), and Orbiter efforts with in-process testing for a variety of materials, including adhesives, foams, ablatives, and films.

Pulling things apart has been a traditional source of parental disapproval for quite some time. However, at the Materials and Processes Laboratory, it is their job. The lab uses a Tinius-Olsen (T-O) 10,000-pound Universal Testing Machine to evaluate tensile strength. This "evaluation" is destructive testing: the T-O machine literally rips various materials apart and records the points at which they fail.

One of these materials is RT-455, a trowelable thermal ablative compound used for Thermal Protection Systems on the SRB's. During SRB flight set processing, technicians make approximately 500 tensile samples, one for each gallon of material mixed. It is extremely important to accurately record the sample identification, type of failure, and the exact force at which the sample failure occurs. The Ablative Test Tracking software performs this task. The lab previously used DOS-based software for its RT-455 ablative tracking requirements, but that software was technologically obsolesced by both the passage of time and the introduction of Windows.

The software team and design team chose Oracle Forms on a Microsoft Windows platform for the user interface. This provided current database technology. However, Oracle Forms did not provide the special-purpose communication functions this effort required. In response, the software team embedded C++ function calls within the form. This allowed the user to simply press an on-screen button to initiate two-way communication with the Tinius-Olsen via a serial port. This digital interface to an analog device allowed the software to automatically direct the operation of the T-O machine and receive the test values in return.

The C++ functions significantly extend tracking capabilities. These on-screen objects provide real-time display of T-O operational values and display dialog boxes for direct user interaction as required. Although they automatically initiate the T-O and start testing, the software still preserves all manual backup capabilities. There is also an on-screen abort button to immediately terminate a test if necessary.

Advances in communication technology make the direct interface of a test process and its tracking software both convenient and practical. It avoids the duplication of effort (and errors) involved when using a human being and keyboard to interface an analog device to a database.

The Ablative Test Tracking software provides the Materials and Processes Laboratory with a convenient and accurate way to automatically record and report their tests. It gives better support to SRB processing with automatic recording of values from

Figure 1. Tinius-Olsen 10,000-Pound Universal Testing Machine

Figure 2. RT-455 Ablative Sample (SRB) Undergoing Tensile Test

Figure 3. Close-Up of RT-455 Sample After Cohesive Failure

the test-generating device directly to the tracking and reporting software. Testing performed includes ablative application tensile strength and density, spray-on foam insulation tensile and density, troubleshooting of material-related problems, and Orbiter lap-shear testing of adhesives and films.

Key accomplishment:

- 2002: Integration of C++ communications modules into Oracle Forms.

Key milestone:

- 2002: Program designed, coded, and fully implemented.

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Participating Organization: United Space Alliance (S.M. Schneider, A.M. Foderousky, G. Lebovitz, and A. Beckus)

Process Analysis and Modeling: Using Expert Knowledge To Augment Simulation-Based Operational Analysis of Space Transportation Concepts

NASA's long-term goals include dramatic reductions in the cost of space transportation. Achieving this goal requires innovative technologies and new approaches to vehicle design, development, manufacturing, and operation. Among the innovations needed is the development of design assessment models that enable the analysis of all life cycle activities for space transportation system concepts, from development to operations.

Operations models (ground operations or spaceport operations) are an important part of the assessment of new vehicle architectures since they reflect a large portion of the system's recurring costs and will determine the vehicle flight rate capability. The recurring costs and the flight rate are the result of tasks or activities that are required during ground operation (for example, the preparation of a payload for integration with the vehicle). Typically the cost and task duration assessments of these processes are performed by experienced engineers who employ their knowledge of production and operations technology, methods analysis, and engineering economics to predict the probable cost and production time of a product – in this case a ground operation activity.

This research focuses on the development and evaluation of new techniques for automating the operations assessment of future space transportation systems by using a combination of activity-based costing and simulation modeling. The approach translates vehicle design parameters into a set of activities and a related process map in a domain (operations characteristics of future space vehicle concepts) where there is limited knowledge. This approach is innovative because it will, for the first time, combine activity-based cost modeling (which is known to work well in well-defined environments) with expert knowledge to estimate the activities, cost, and time characterizations associated with proposed space transportation concepts. A critical element of this research is the gathering of data and expert opinions in order to develop "knowledge engines" for major vehicle subsystems. The knowledge engines capture existing and futuristic approaches to a vehicle subsystem and link those to an activity set, time, cost, failure characterizations, and process map.

Key accomplishments:

- Created the initial framework for the knowledge engines.
- Developed a preliminary knowledge engine for the Thermal Protection Systems (TPS).
- Prepared an initial prototype tool to support the process of "knowledge capturing."

Key milestones:

- Complete the knowledge engine for TPS.
- Develop a working tool that automates the translation of design variables into activities and process map using the developed TPS knowledge engine.
- Create a knowledge engine for a second subsystem.
- Integrate the second knowledge engine into the working tool.

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Participating Organization: University of Texas El Paso (Dr. A. Ruiz-Torres) and Command and Control Technologies Corp.

Markov Random Field Approach to Region Extraction for Hypothesis Support Using Tabu Search

The ultimate goal of computer vision is image understanding, in other words, knowing what is within an image at every x and y point. A complete computer vision system should be able to segment the image into homogeneous portions, extract regions from the segments that are single objects, and finally output a response as to the locations of these objects and what they are.

The framework for image understanding consists of three not necessarily separate processes. A representative computer vision system is shown in figure 1. In the first process of figure 1, image segmentation is performed. Image segmentation consists of dividing the image into homogeneous portions that are similar based on a correlation criterion. In this document, image segmentation will also be known as the low-level vision (LLV) process. In figure 1, the second or intermediate-level vision (ILV) process performs region extraction. Region extraction may receive the results obtained during an LLV process or the original image itself. With this information, the ILV process attempts to represent image objects from hypothesized objects. Subsequently, the third process of figure 1 performs image understanding operations based on the extracted regions provided as input. The hypothesized image understanding operation will be known as the high-level vision (HLV) process.

Most computer vision research for approximately the past 30 years has focused on LLV processes. Only recently has some attention been devoted to furthering the knowledge of ILV processes, primarily using LLV methods. These LLV techniques work well if the image properties are uniform or homogeneous (e.g., same gray level, texture). However, these methods are inapplicable for regions whose image properties are nonuniform or heterogeneous. Therefore, what is needed is a new technique specific to the ILV goal that will extract regions of nonuniform image properties.

Accordingly, the main focus of this research was on the ILV process. Hence, an energy minimization technique is provided that recognizes compact-closed objects represented in polar coordinate form. These compact-closed objects are used to characterize a Markov Random Field (MRF), which is incorporated into an energy minimization function. An initial high-level hypothesis is provided by a simulated HLV process (i.e., image analyst or human). A combinatorial optimization technique, known as tabu search, then provides the means for

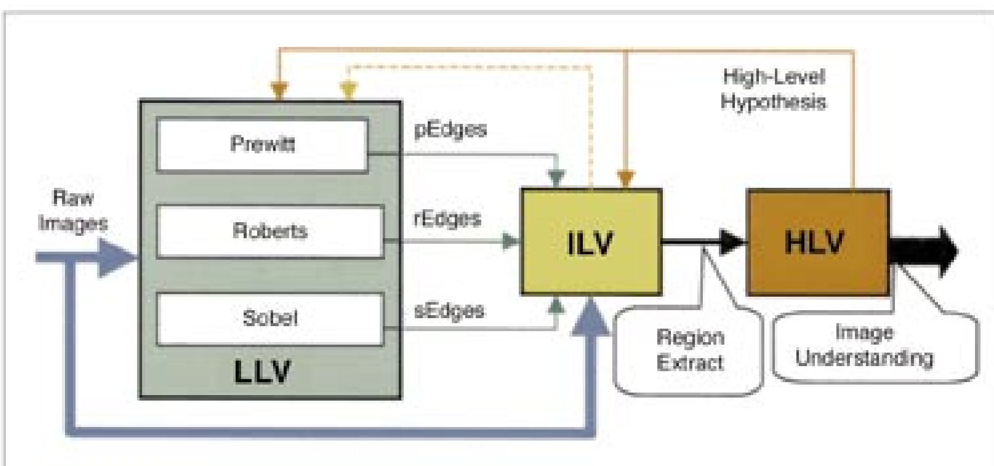

Figure 1. Computer Vision System Protomodel

driving the energy function to its minimum state. This research also showed how the minimum energy state corresponds to an MRF state of highest probability (i.e., Gibbs Distribution).

A smaller set of results is provided showing the algorithm's capability to extract a quadrilateral region from an image. In one case, the quadrilateral region is a synthetic representation of a building. In the other two cases, the quadrilateral region is a real-world object in the form of a building. Figure 2 is the synthetic case used for experimentation. Figures 5 and 7 are the real-world cases used for testing.

Key accomplishment:

- Project completed April 20, 2001.

Key milestone:

- Research presented at Florida Tech's Sigma Xi Paper Conference on March 30, 2001.

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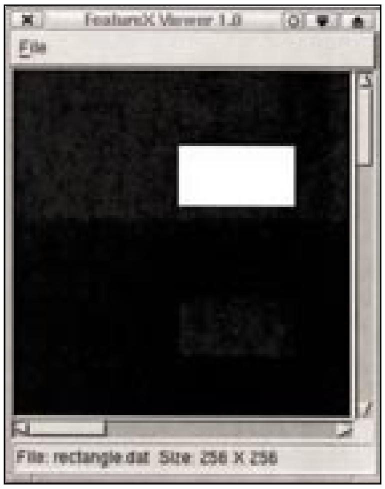

Figure 2. Rectangle.jpg Image

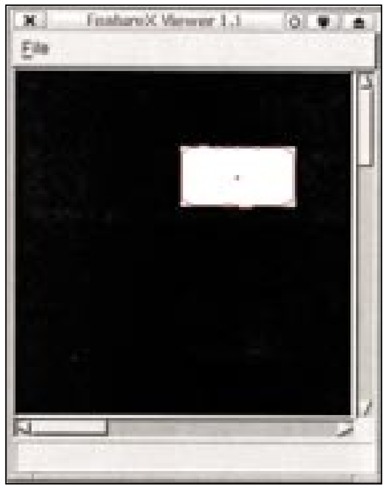

Figure 3. 20×20 Result

Figure 4. Aerial.jpg Image

Figure 5. 20×20 Hypothesis

Figure 6. 20×20 Result

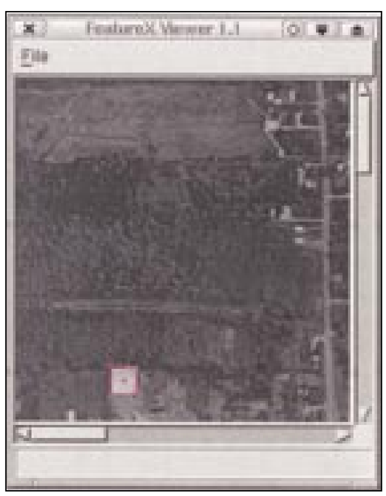

Figure 7. 25×25 Result

Hypothesis Support Mechanism for Mid-Level Visual Pattern Recognition

A novel method of performing the task required by an intermediate-level vision (ILV) process was derived. This new technique is based on the Hough Transform, specifically, the generalized version. The novel method solves problems of rotation-invariance and scale-invariance plaguing the generalized Hough Transform while providing a technique that solves the ILV problem and meets the goals of this research.

The use of the Hough Transform, in the case of hypothesis testing, is valid as shown by prior disclosures. When testing the hypothesis of an object in an image, a considerable number of subhypotheses are generated in order to extract a correct region in an image. This makes the problem of region extraction similar to combinatorial optimization. Although region extraction could be considered as a global optimization problem (if there were only a single region in the image), the problem of region extraction itself is not congruent with that of global optimization.

There exist many combinatorial optimization techniques that have been used to solve this problem, including genetic algorithms, simulated annealing, and tabu search. None of these methods guarantee finding the correct or exact solution, only the best possible one (after a number of iterations of the given algorithm.) Therefore, prior investigations have shown the value of these combinatorial optimization techniques should be reexamined, in addition to stating that the Hough Transform is a better search space strategy and ultimately more efficient. Consequently, this reexamination should be done by considering the Hough Transform, its generalized version, its properties, and the overall usefulness as a hypothesis support mechanism.

Unlike the methods previously listed, the novel version of the generalized Hough Transform, called the Pose-Invariant Hough Transform (PIHT), does not require the generation of numerous subhypotheses locating the desired region for extraction. Instead, by using a new version of the R-Table, called the J-Table, rotation-invariance and scale-invariance are built into the table (i.e., hypothesis). The novel PIHT method

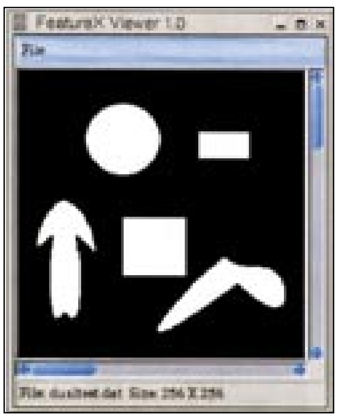

Figure 1a. DUALTEST

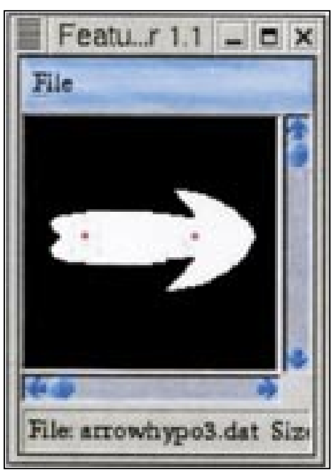

Figure 1b. Template

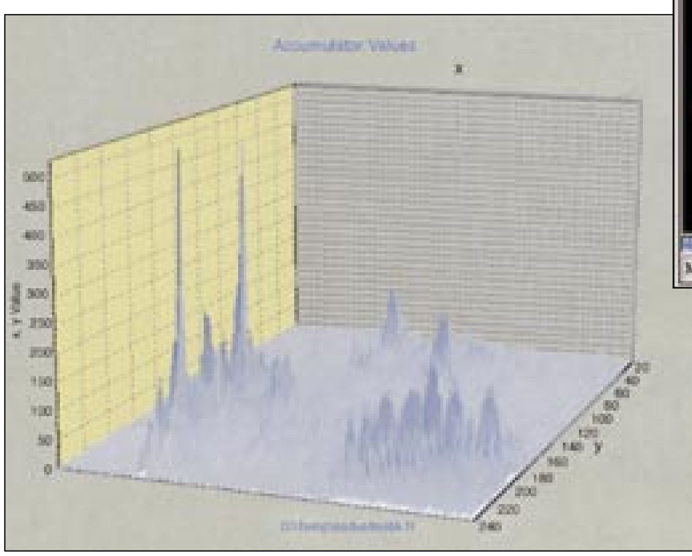

Figure 1c. Surface Plot

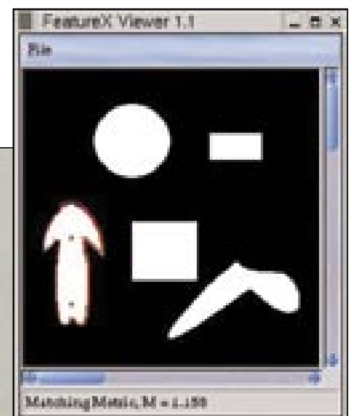

Figure 1d. Result 2

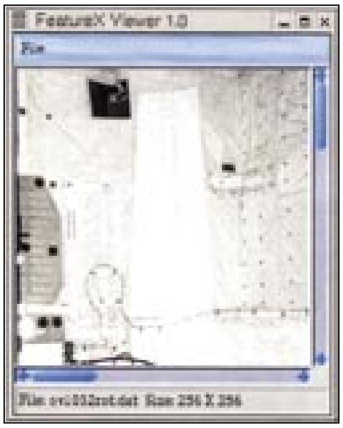

Figure 2a. Rotated-Unscaled

Figure 2b. Template

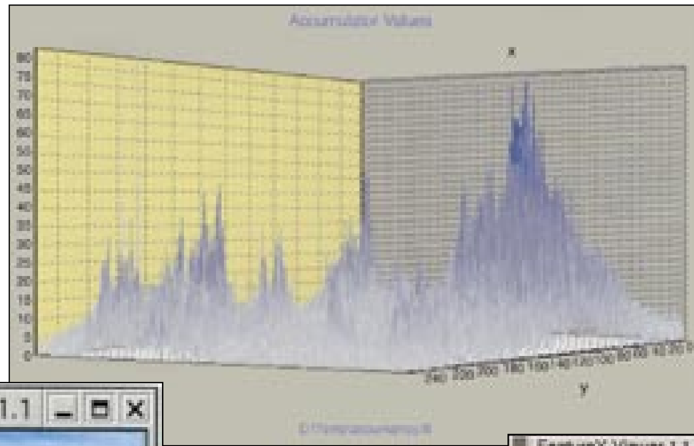

Figure 2c. Surface Plot

Figure 2d. Result 2

with its new J-Table is invariant to rotation or scale differences of the desired object in the image. This alleviates the need of generating subhypotheses and eliminates the associated complexities.

Nonetheless, the PIHT (and the generalized Hough Transform) alone does not provide the desired region extraction or contour identification required by the ILV process. What is needed is a scheme using the results of the PIHT and performing the region extraction or indicator-of-match required. Hence, an entirely new technique was developed, called the Inverse-Pose-Invariant Hough Transform (IPIHT), which executes the indicator-of-match.

It should be palpable that the efficiency of the PIHT/IPIHT framework depends on several factors, including quality of segmentation, accuracy of gradient determination, and validity of Hough Transform capabilities. To determine if any or all of these factors affect performance of the framework, it becomes necessary to experiment on individual functions and analyze their performance.

The results shown are from the ILV implementation and were collected for binary and real-world images under two categories, quadrilateral (i.e., rectangular) and arbitrary shapes. Consequently, these two categories had six different test cases performed against them – Unrotated-Unscaled, Rotated-Unscaled, Unrotated-Half-Scale, Unrotated-Double-Scale, Rotated-Half-Scale, and Rotated-Double-Scale. The rotation used in all these test cases was 90 degrees or $\pi/2$ radians. See figures 1 and 2 for the test results of the DUAL-TEST and real-world arbitrary cases.

Key accomplishment:

Project completed on November 16, 2001.

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Expert Seeker: A People-Finder Knowledge Management System To Seek Experts at Kennedy Space Center

The NASA Faculty Awards for Research (FAR) is funding the development of Expert Seeker, an expertise-locator Knowledge Management System. Knowledge Management studies at KSC have confirmed the need for a centerwide repository, which will provide KSC with intranet-based access to experts with specific backgrounds. This system still is under development; however, version 3.0 is now available through KSC's intranet (figure 1). A version containing only test data resides at Florida International University, Knowledge Management Laboratory (FIU-KM Lab); this version is used for development purposes.

Expert Seeker aims to help locate intellectual capital within the Center at all educational levels. Expert Seeker maintains records of various competencies available within the organization including items that are not typically captured by the Human Resources (HR) applications, such as completed past projects, training, career summaries, and other relevant knowledge. This expertise-locator will be especially useful when organizing cross-functional teams.

The main interfaces on the query engine in Expert Seeker use text fields to search the proposed data for keywords, fields of expertise, names, or other applicable search fields. The application processes the end user's query and returns the pertinent information. The information is collected from a conglomeration of multimedia databases and then presented as queried.

Figure 1. Expert Seeker Graphical User Interface

The purpose of the Expert Seeker is to unify myriad data collections into a Web-enabled repository that could easily be searched for relevant data. Prior to this project, there was no single point of entry into a unified repository that allowed identification of employees based on specific skills. Expert Seeker allows KSC experts more visibility and at the same time allows interested parties to identify available expertise within KSC. This system will help to identify a researcher's expertise within a discipline and to facilitate communication with a point of contact.

The tools used to develop Expert Seeker are:

- Coding and programming using ColdFusion 4.5, JavaScript, and Active Server Pages (ASP).
- Database implementation with Microsoft SQL Server 7.0.
- Search capabilities provided by Verity.
- Graphical user interface (GUI) design with Adobe Photoshop 5.0.
- HTML and other Web development tools.

The development of Expert Seeker required the utilization of existing structured data as well as semi-structured information as much as possible. Figure 2 represents the architecture of Expert Seeker:

ASTAR: This HR database view provides the experts' in-house training courses.

Annual Training and Development Survey (ATDS): This HR database view provides the experts' workshops and academic classes employees are planning to take.

X.500: This database view provides the experts' general employee data such as name, phone, organization, fax, and e-mail address. X.500's unique identifier is also used to cross-reference employees in different databases.

Skills Database: This database view provides a set of skills and subskills used by Expert Seeker to index the expertise search. The KSC Core Competency team defined this set of skills and subskills as a refinement to a previous Centerwide skills assessment.

NASA Personnel and Payroll System (NPPS) Database: This HR database view provides the experts' formal education, including professional degrees and the corresponding academic institutions. NPPS also provides the employee's department, used by the directorate search mode. The contents of this database were also used to initially populate the career summary section table.

KPRO: This database view will be populated with project participation information through a new project management system under development at NASA KSC.

Goal Performance Evaluation System (GPES): The GPES is a system created at KSC. This database view serves as the data source for profile information such as staff achievements. GPES will replace the Skills Database since GPES will also be populated with KSC's strategic competencies and levels of expertise.

User-Specified Data: This database view is provided to support optional user-supplied data. For example, experts can opt to provide career summaries that will be used by Expert Seeker to augment the expertise search. A database table to hold this information was created and linked to the system, initially populated from the NPPS Human Resources database. Other user-supplied data could include pictures, publications, patents, hobbies, civic activities, etc.

Data Mining: Expert Seeker expertise search is augmented through the use of data-mining algorithms, which build an expert's profile based on information published by employees on their Web pages. Similarly, a document repository could be mined for expertise using these algorithms.

Searchable Answer-Generating Environment (SAGE): SAGE is an expertise-locator system developed and hosted at the FIU-KM Lab to identify experts within Florida's universities. Expert Seeker users can define the search scope to be within KSC or to expand it to universities in Florida. The latter means that Expert Seeker would launch an expert search to SAGE, and the results of this search will be integrated into one output at the Expert Seeker GUI.

Recognizing that there are significant shortcomings of self-assessment, we propose to use an increased reliance in technology to update employee profiles and thus place less reliance on self-assessed data. For example, we are proposing the use of GPES, an in-house performance evaluation tool, to mine employee accomplishments and automatically update their profiles. Typically, employees find it difficult to make time to keep their resumes updated. Performance evaluations, on the other hand, are part of everybody's job. We therefore seek to use this tool, augmented with appropriate queries, to inconspicuously keep the employee profiles up to date.

Key milestones (2002):

- Implementation of the system prototype.
- Testing of the system prototype.
- Rollout.

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Participating Organization: Florida International University (Dr. I. Becerra-Fernandez)

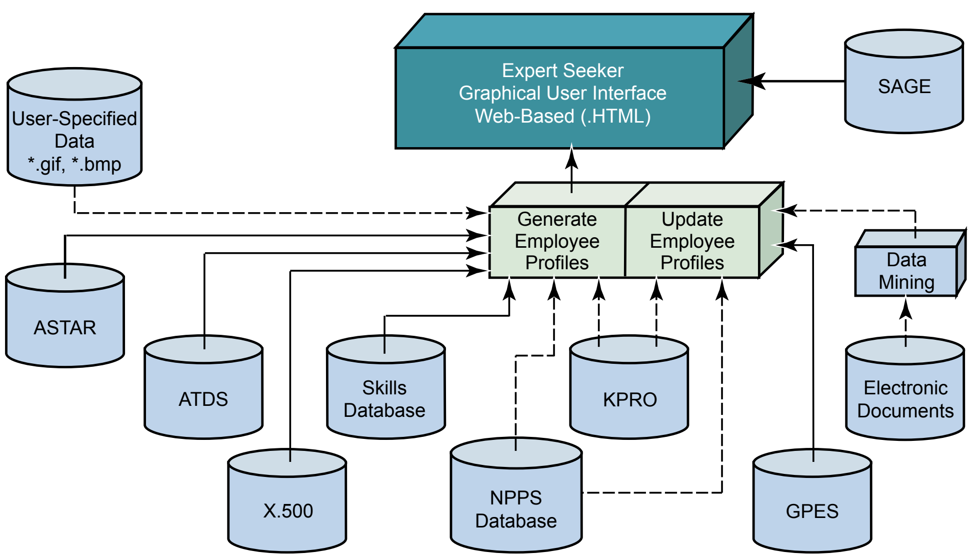


Figure 2. Expert Seeker Architecture

Portfolio Analysis Tool (PAT)

A key characteristic that will distinguish successful enterprises of the next millennium will be the ability to respond quickly, proactively, and aggressively to unpredictable change. Robust methods and tools to facilitate change management are therefore an essential requirement for the modern enterprise. This project targets key technology gaps and challenges associated with strategic change management:

- Lack of scientific methods for strategic change management.
- Lack of information-integrated software tools to support the change management process.
- Lack of knowledge management mechanisms that capture, store, and leverage corporate knowledge for strategic planning and control.

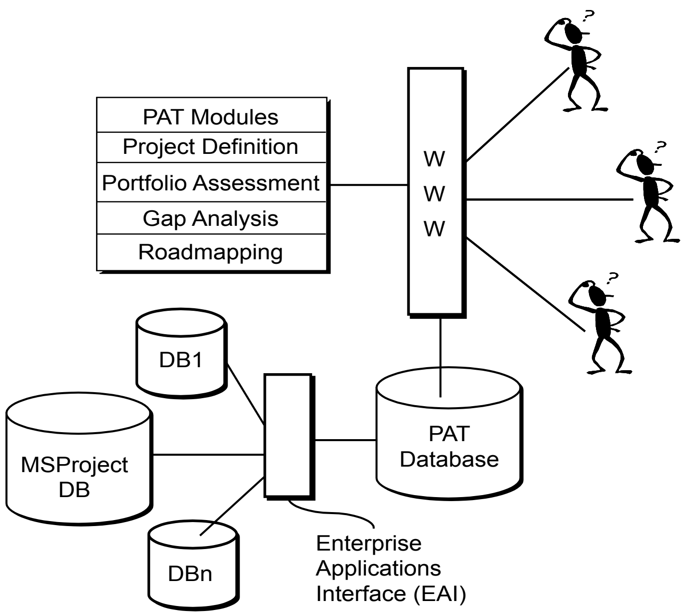
We have developed and demonstrated a Portfolio Analysis Tool, a Web-based software tool that facilitates strategic change management. Key functional requirements addressed by PAT include the following.

- Provide technology investment decision information: PAT provides decisionmaking information to facilitate strategic planning.
- Facilitate identification of technology gaps: A direct result of the portfolio analysis is to assist the precise identification of technology gaps.
- Promote technology roadmap development: The portfolio gap analysis results provide information to construct a time-phased technology development approach/roadmap.
- Facilitate decisionmaking over distributed teams: PAT facilitates the collaborative/distributed decisionmaking processes associated with strategic planning and change management.

Intended PAT end users are strategic planners and project/technology portfolio managers. The PAT architecture includes a database server that provides persistent storage of the information managed by PAT. PAT also provides a Web-based user interface that facilitates distributed capture of key information required to perform portfolio analysis. A central function of PAT is to facilitate sound project/technology investment decisionmaking as part of strategic change management. Different types of outputs and visualizations are generated by PAT to accomplish this function, including: (1) Risk-Return Portfolio Analysis, (2) Gap Analysis, (3) Sensitivity Analysis, (4) Roadmap Generation, and (5) On-Demand Reports. Key innovations include novel adaptation and application of portfolio theory for strategic decision support and structured, knowledge-based method for strategic planning and change management. PAT is expected to significantly improve NASA's change management capability in the near term.

Key accomplishments:

- 2000: Selection for Phase II research and development. Definition of PAT requirements. Design of PAT architecture.
- 2001: Development of prototype Web-based portfolio analysis tool.



Portfolio Analysis Tool Functional Architecture

Completion of change management method. Completion of initial test data collection and tool testing.

Key milestones:

- 2002: Completion of Phase II Final Report. Completion of PAT testing and validation. Completion of PAT deployment at KSC and end-user training. Development of PAT Commercialization and Phase III planning.

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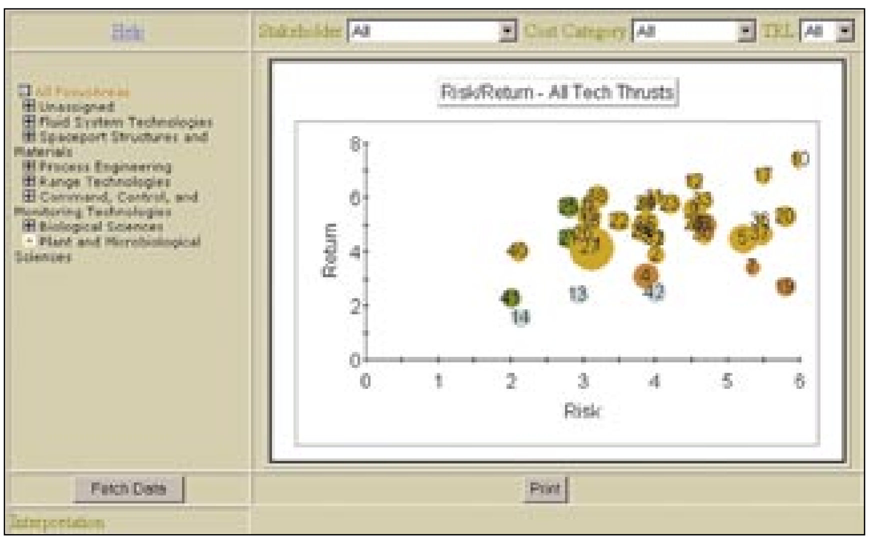
Participating Organization: Knowledge Based Systems, Inc. (Dr. P.C. Benjamin)



Example Risk Return Analysis Output

Toolkit for Enabling Adaptive Modeling and Simulation (TEAMS)

The increasing complexity of systems has enhanced the use of simulation as a decision-support tool. The popularity of simulation among competing quantitative tools can probably be attributed to the fact that it is both simple and intuitively appealing. It facilitates experimentation with real-world systems that would either be impossible or cost-prohibitive otherwise. Moreover, simulation is often the only scientific methodology available to practitioners for the analysis of complex systems. In spite of the advantages, however, only a small fraction of the potential practical benefits of simulation modeling and analysis has reached the potentially large user community because of the relatively high requirements of time, effort, and funding needed to build, maintain, and rapidly deploy simulation technology. TEAMS addresses key technical challenges associated with systems simulation, such as inadequate methods and tools for cost-effective simulation model development and deployment and inadequate methods and tools for cost-effective simulation model maintenance. TEAMS will provide current and future spaceport designers a knowledge-based infrastructure for quickly and easily developing, maintaining, and reconfiguring simulation models.

This project will design, develop, and demonstrate TEAMS, a decision-support tool that facilitates quantitative space transportation operations and maintenance process analysis. The technical approach involves the following tasks:

- Define TEAMS requirements.
- Design TEAMS architecture.
- Develop focused TEAMS demonstration application scenarios.
- Develop and demonstrate prototype TEAMS.
- Develop Phase II technology hardening and deployment approach.

TEAMS provides automated support for collaborative and distributed spaceport operations analysis. TEAMS will provide valuable decision information to spaceport stakeholders, analysts, and designers. Key functions provided by TEAMS include:

- Spaceport Knowledge Management: Browse, organize, and share knowledge about spaceports.
- Collaborative Spaceport Modeling: Facilitate collaborative and distributed spaceport operations and maintenance activity modeling.
- Collaborative Spaceport Analysis: Facilitate collaborative and distributed spaceport operations and maintenance activity analysis.

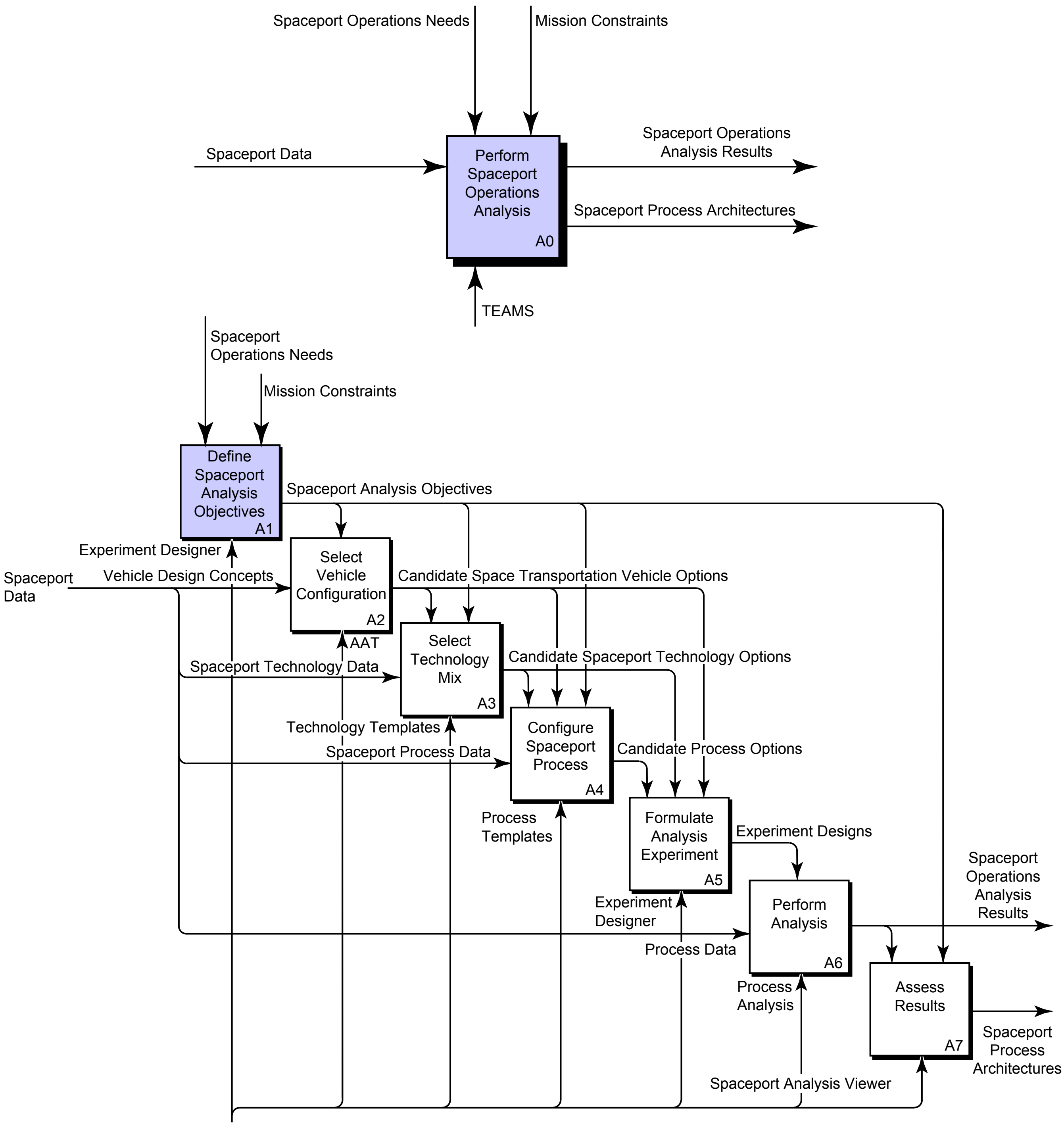
Potential TEAMS benefits include the ability to affordably explore a large number of spaceport decision alternatives, higher-quality spaceport designs, and reduced spaceport development, operations, and maintenance costs.

Key accomplishments:

- 2001: Start of Phase I project. Definition of TEAMS requirements.

Key milestones:

- 2002: Completion of TEAMS prototype software. Completion of Phase I Final Report. Formulation of Phase II technology development and deployment approach.
- 2003: Selection of KSC application areas. Refinement and hardening of TEAMS software. Development of focused TEAMS KSC application.



TEAMS Concept of Operation

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Participating Organization: Knowledge Based Systems, Inc. (Dr. P.C. Benjamin)

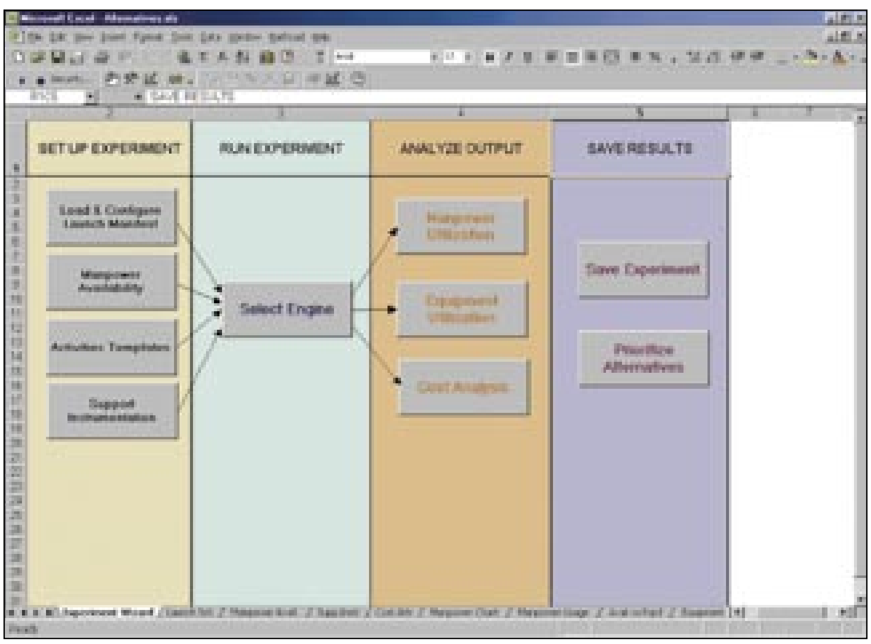
Range Process Simulation Tool (RPST)

The ability to respond quickly, proactively, and aggressively to unpredictable change will distinguish successful enterprises of the next millennium. Robust methods and tools to facilitate change management are therefore an essential requirement for the modern enterprise. Currently, there is a lack of robust and practical tools to quantitatively assess the impact of technology insertion on operational performance of space transportation systems. In particular, there is a need for new methods and tools for quantitatively assessing the impact of planned technology modernization/technology insertion on the operational performance metrics of the Eastern Test Range.

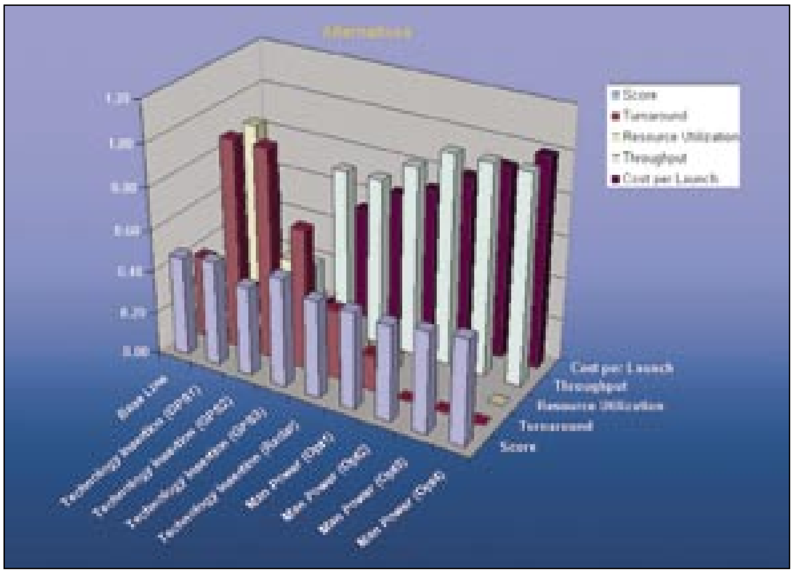
This project will design, develop, and demonstrate a Range Process Simulation Tool (RPST), a decision support tool that facilitates quantitative change impact assessment. The technical approach involves the following tasks:

- Define change impact assessment requirements.
- Design and develop RPST software.
- Develop baseline Range process models.
- Define focused test application scenarios.
- Acquire test application data.
- Test and validate RPST.

The RPST is intended for use by Range Planners and Range Technology Portfolio managers to quantitatively assess Range operational performance and assess the impact of Range technology changes/upgrades on operational performance. The RPST is an important first step toward deploying a realistic and robust Range change impact assessment capability. RPST also provides key enabling technology for modeling and analyzing future aerospace transportation spaceports. The key RPST innovations are a novel, model-based approach for change impact assessment and a component-based, scaleable, open-architecture approach that facilitates rapid tailorability and cost-effective deployment to varying spaceport application situations. The main RPST benefits include the ability to accurately and reliably predict impact of technology changes on space transportation systems and the ability to reduce the Range operational and maintenance costs through improved change management decision support.



RPST Experiment and Analysis Flow Architecture



Example RPST Output

Key accomplishments:

- 2000: Start of Phase II research and development. Definition of application focus areas. Development of preliminary simulation-based change impact assessment framework.
- 2001: Definition of RPST requirements. Development of preliminary RPST prototype. Identification of RPST test scenarios. Definition of a data collection and software testing approach.

Key milestones:

- 2002: Completion of scalable RPST prototype. Completion of test scenario data collection. RPST testing and validation. Development of technology transfer and commercialization approach. Completion of Phase II final report.

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Searchable Answer-Generating Environment (SAGE) Expert-Finder

SAGE is a repository of experts information within the State of Florida. The SAGE Expert-Finder Knowledge Management (KM) System creates an integrated database by masking multiple databases as if they were one.

SAGE has been on-line since August 1999 and can be found at *http://sage.fiu.edu.* (See figure 1.) Originally, SAGE unified the researcher databases from the State of Florida University System. Currently, SAGE has access to sponsored research data from private institutions as well, such as Florida Institute of Technology, Florida Memorial College, and Embry-Riddle Aeronautical University.

SAGE gives university researchers more visibility and simultaneously allows interested parties to identify available expertise within Florida universities. This application helps to identify a researcher's proficiency within a discipline and to facilitate a point of contact.

Benefits that SAGE provides include the following:

- SAGE helps locate researchers in Florida for collaboration with industry and Federal agencies, thereby increasing potential research funding to the Florida universities.
- SAGE combines and unifies existing data from multiple sources into one Web-accessible interface.
- SAGE incorporates a File Transfer Protocol (FTP) client, an application that will be resident at each of the participating universities to automate data transfer to the SAGE server.

In October 2001, the SAGE graphical user interface was completely redesigned to maintain the uniformity visible throughout all KM Lab-hosted Web sites. The new interface provides an enhanced flash capability as well as a basic html version. SAGE also includes a thesaurus, which is a collection of concepts forming an ontology that upon request can perform a search on similar words based on the keyword in use. A consistent taxonomy is applied to improve upon the usual keyword- and full-text-based techniques. It allows an end user to retrieve information using appropriate terminology and avoids problems of poor selectivity and quality of results caused by missing, inconsistent, or conflicting vocabulary.

The use of a thesaurus can extend the capability of the Web site by generating new keywords from an existing input provided by the user. The thesaurus provides a standardized means of organizing many kinds of information, including both conceptual and taxonomic. In other words, the thesaurus is a tool designed to aid users in finding their way around a vocabulary database. In addition to its traditional use as an authority for the terms used in indexing the database, it offers suggestions of terms the user might not even have considered.

The construction of the thesaurus is accomplished using Perl programming language because of its powerful text processing capabilities. The script uses an existing pool of information from Wordsmyth Educational Dictionary-Thesaurus (WEDT) that includes over 50,000 headwords and very precisely defined and hyperlinked synonyms. It retrieves an extended set of related terms or a set of synonyms. ColdFusion 4.5 is used to cache the results of the query. In addition, the new output is used in conjunction with the Verity Search Engine that utilizes a stoplist and stemming.

To achieve results, we use interprocess communication (IPC). When a user submits a search, the script will issue an http request to a remote server by communicating through a socket (connection). The http request queries an external search engine that resides on the remote server. The script retrieves the html document generated by the search engine, parses the document by using regular expressions, and retrieves the desired information. Basically, since it is issuing a request, the script is acting as Web client.

The script relies on the structure of the document, Web structure mining. In this case the document is a raw html document. To retrieve data from an html document efficiently, the document must have a uniform format or a "cue" for where to start looking for the necessary data. So the programming task is trivial.

With the goal of always trying to improve and facilitate the process of keeping the SAGE database updated, the latest development is the SAGE Automatic FTP Client version 3.0 (figure 2). SAGE Auto FTP Client version 3.0 allows the universities that are part of the SAGE community to transfer their researcher's information file directly from their servers to the SAGE server residing at the KM Lab in an easy and efficient manner. This data can be received in a variety of different formats, such as Excel or Access, and even in a tab-delimited text file. Once this data is obtained, the KM Lab members convert it to a standard format to be displayed in the SAGE Web site.

The SAGE Auto FTP Client version 3.0 offers a simple, user-friendly interface. It also contains a Help File where the user can find answers to frequently asked questions. Every university is provided with a unique password to ensure the accuracy of the transfer. The SAGE Auto FTP Client version 3.0 guarantees the SAGE database will have the most up-to-date information pertaining to researchers, their projects, and their funding all year long.

The current version of SAGE includes a Newsletter that allows the users to keep up to date with the information regarding existing and upcoming SAGE news. To subscribe, the user just clicks on the SAGE Newsletter icon that appears in the SAGE home page and provides a name and e-mail address. The user will periodically receive the latest information concerning SAGE (figure 3).

SAGE is hosted from the KM Lab, and it is available 24 hours a day, 7 days a week. Currently SAGE receives an average of 40 users per day. About 54 percent of the total hits that SAGE gets daily originate from commercial sites (.com and .net), 39 percent are from educational institutions (.edu), and 2 percent are from Government and military organizations (.gov and .mil). Visitors originate from the United States and around the world, including Japan, France, Austria, Switzerland, Bahamas, Mexico, and the United Kingdom.

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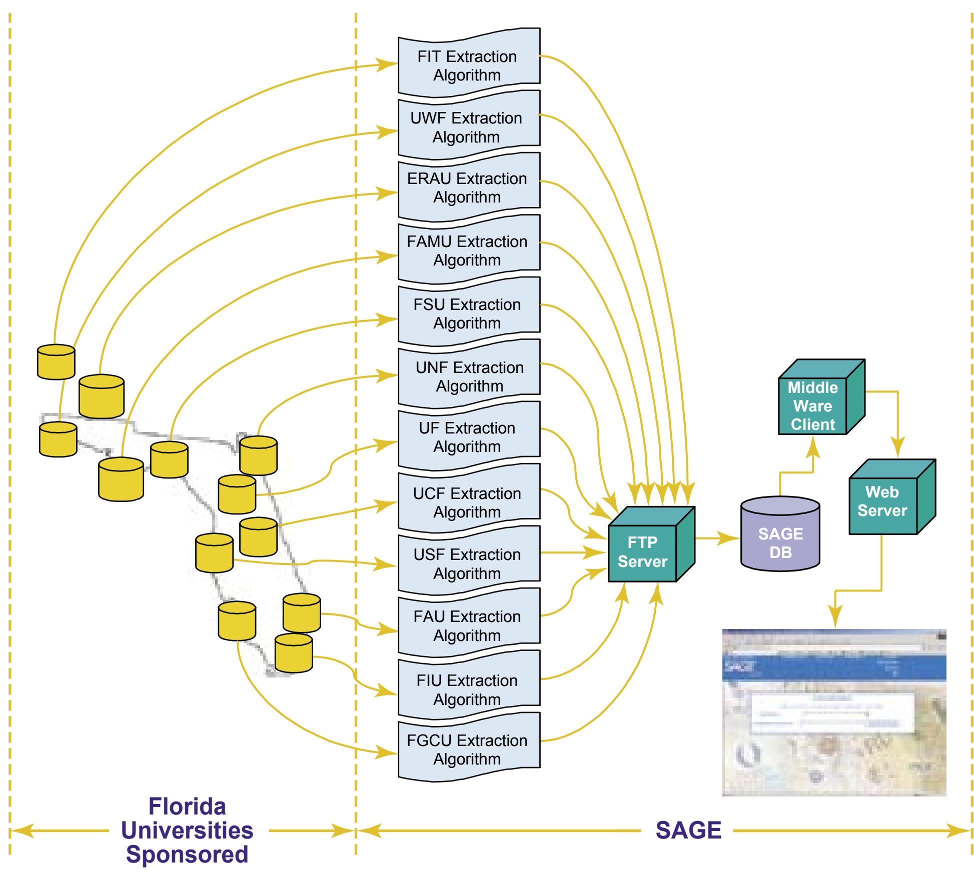
Participating Organization: Florida International University (Dr. I. Becerra-Fernandez)



Current SAGE Architecture

Competency Management System (CMS)

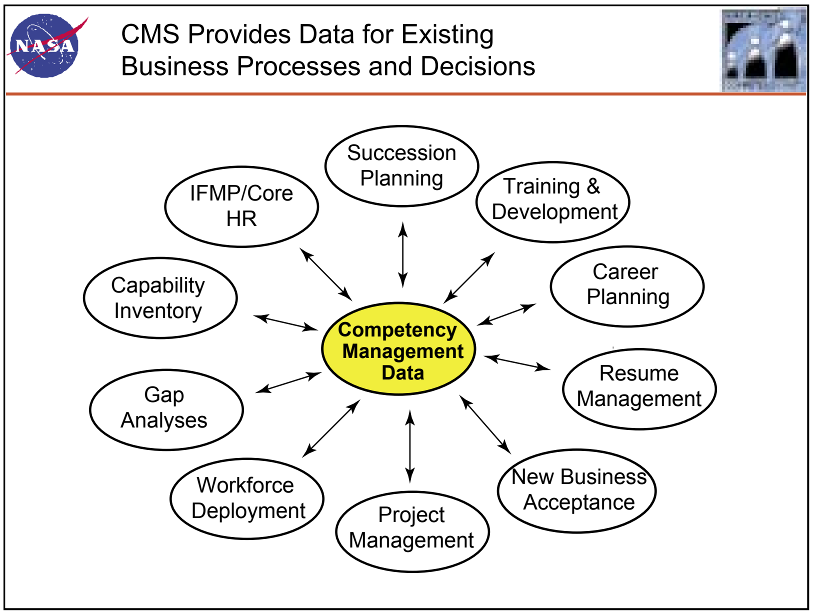
NASA is faced with the daunting task of maintaining and growing our technical capability to support our varied, dynamic, and growing business lines. We must meet the expectations of the public and industry to lead the exploration of our planet, the solar system, and deep space. This must be accomplished in an environment of downsizing of Government and shrinking Federal budgets. How can we manage our human capital so we retain and grow knowledge and apply it strategically to the products and services that meet our customers' needs?

Our approach was to catalog the specific knowledge areas that support the strategies to meet customers' expectations. This required meeting with organizational leaders in each directorate and the Center to determine the contribution of each to our strategy. Then subject matter experts (SME's) were interviewed to develop the identified knowledge areas into competency content. From these specific competencies, we can describe the knowledge required for the strategic functions carried out in each position in the organization. A Competency Management System and associated tool were then developed to (1) implement the system across the workforce, which determines a measurable gap between what we know and what we need to know, (2) meet our strategic goals, and (3) satisfy our customers' needs. An industry consultant, InterKnowledge Corporation, was instrumental in developing the model structure, ensuring a high-quality product, and assisting in the system deployment.

To capture and analyze the data, a Web-based tool was developed. All employees can easily participate by developing and maintaining their own portfolio of competencies, skills, and experiences. Supervisors utilize the system to manage the current and anticipated knowledge needs of the organization by setting the competency requirements for each job position. The resulting data is then provided to senior executives, managers, and the human resource department. With this key information, they are able to make more informed decisions in multiple related business areas, from budgeting training dollars to allocating workforce to developing requirements for hiring. The CMS enables effective and critical communication among the various related business processes to implement more strategic solutions to the human capital needs of the organization.

Key accomplishments:

- 2000: Completed the design of the KSC Competency Management Model and began the development of competency content with SME's.
- 2001: Completed the pilot project to design and deploy the CMS in the Spaceport Engineering and Technology Directorate. Deployed CMS in the Workforce and Diversity Management Directorate, modeling nearly 400 employees.
- 2002: Currently deploying CMS throughout the KSC civil service workforce. When completed, over 1,800 employees will be modeled. Model was modified to have an Agencywide appearance.



Competency Model Connection to Business Processes

Key milestones:

- 2000: CMS Team chartered by the KSC Human Resources Development Board to pilot a competency management model and associated implementation tool in the Spaceport Engineering and Technology Directorate.
- 2001: CMS development completed. System presented to NASA AA for Human Resources and Education.
- 2002: CMS presented to NASA Administrator, Sean O'Keefe. KSC to be fully modeled by mid fiscal year.
- 2003: Annual strategic realignment of model to begin.

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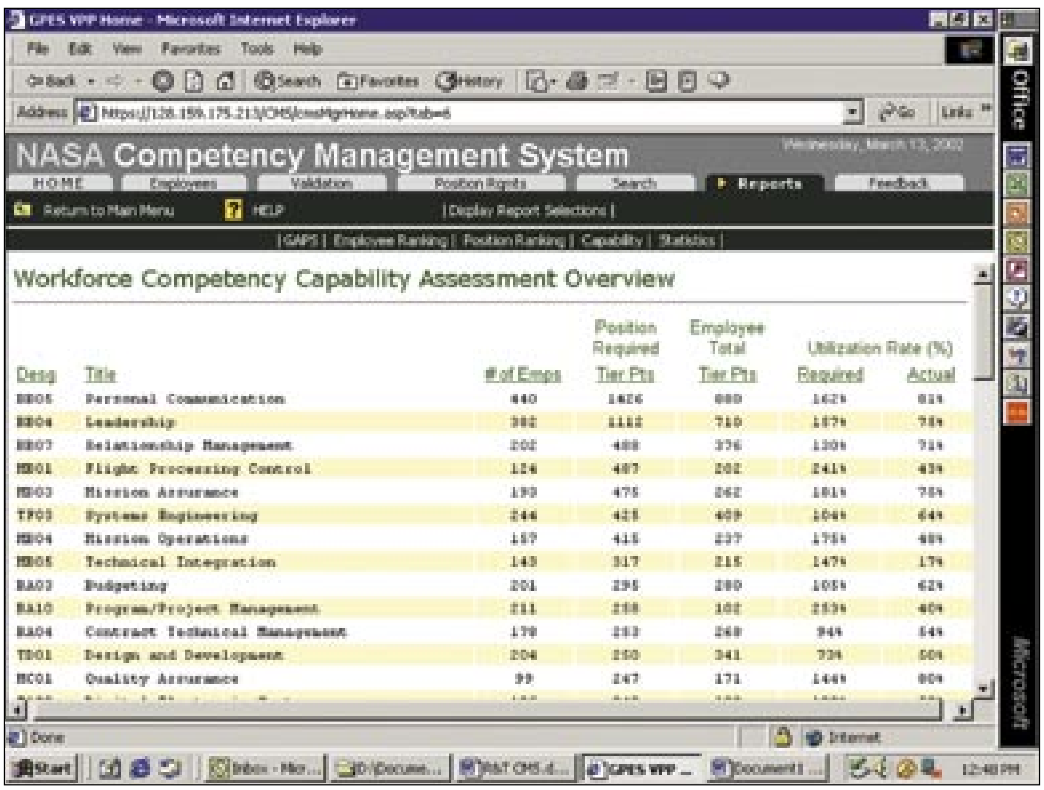
Participating Organization: InterKnowledge Corporation (D.T. Walsh)



System Screen View

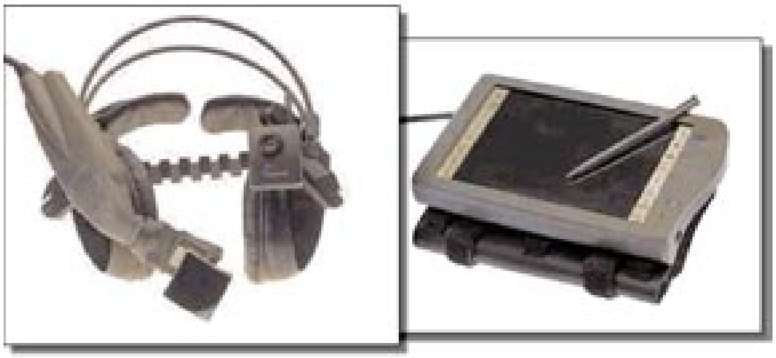
Work Instruction Delivery System

The primary objective of this project was to determine if body-wearable computers are a feasible delivery system for the Work Authorization Documents (WAD's) utilized in Shuttle processing operations. Body-wearable computers present an opportunity to develop a WAD delivery system that enables access while preserving the technician's mobility, safety levels, and quality of work done. More specifically, the goals of this project were to research, identify, and recommend specific brands of body-wearable computers available on the market and identify which areas of Shuttle processing may benefit from this technology. Fields tests were performed at the Space Shuttle Main Engine (SSME) shop for SSME receiving inspection, Thermal Protection System (TPS) thickness measurement at the Solid Rocket Booster (SRB) Assembly Refurbishment Facility (ARF), and a general usability test at the Orbiter Support Building (OSB).

Wearable computers are small-size PC's that differ from pocket PC's and personal data assistant (PDA) devices at the hardware level as well as the operating system level. Wearable computers are just like any desktop PC's or laptops and use the same operating systems, whether Windows, Windows NT, or Linux. Hence, they can run any application that regular PC's can run.

Field tests for SSME receiving inspection were conducted to determine if the technology could be successfully used to deliver the WAD of the SSME receiving inspection activity. Results indicated the SSME inspection job would not benefit significantly. However, there may be other WAD's in the area that could benefit substantially. An example of other activities is Shuttle landing SSME inspection. A networked wearable unit could allow technicians at the Shuttle Landing Facility (SLF) and engineers at other areas of KSC as well as in California to see the conditions of the SSME via an on-line camera.

Field tests for SRB sprayable ablative thickness measurement were conducted to establish the benefits of using a wearable computer to develop an integrated system that fully automates the TPS thickness measurement activity. This was a two-phase study. Phase 1 consisted of testing the integration of the KUDA sensor to a wearable computer for on-line data collection, avoiding the manual data entry step of the measuring thickness of the SRB TPS materials. Phase 2 was a usability test to decide the best way for the technicians to interact with the unit (via a belt or on a pushcart). The test showed that the integration of the KUDA sensor is feasible. In addition, PIExpert was used to analyze some historic measurements with the intent of investigating the possibility of reducing the number of observations needed. This complementary test proved that it is indeed possible to reduce the number of observations taken, resulting in significant time savings. It was clear that having the data on-line and using PIExpert would quicken some of the basic statistical analysis and allow more extensive analysis to be readily done.



Wearable Computer Devices

A test was conducted to establish the usability of wearable computers when carrying out normal computer functions such as entering data and reading text, graphics, and schematics. The test called for two different modalities of interaction:

- For data display → touch screen and heads-up display.
- For data entry → touch screen using JOT software and super-mini keyboard. Overall, 62.32 percent of the responses were in support of using this technology.

A final report was submitted with lessons learned and recommendations. In general, there is a positive attitude toward the technology, and the interaction with the unit seems to be acceptable. Wearable PC's provide a great degree of mobility and an excellent means to transmit and receive data. The introduction of the wearable computing technology requires that the WAD be in electronic form. Recommendations submitted included the technology be introduced in an incremental fashion and field tests continue especially as technology improves.

Key accomplishments (2001):

- Field-tested to determine if the technology could be successfully used to deliver the WAD of the SSME receiving inspection activity.
- Field-tested for SRB sprayable ablative thickness measurements to establish the benefits of using a wearable computer to develop an integrated system that fully automates the TPS thickness measurement activity.
- Tested the usability of wearing computers when executing normal computer functions.
- Submitted final report with lessons learned and recommendations.

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Participating Organization: Florida International University (Dr. M.A. Centeno)

AI Techniques for Payload and Vehicle Processing Scheduling

Preparing vehicles and payloads for launch is an extremely complex process involving thousands of operations for each mission. Each operation requires a number of resources (facilities, equipment, personnel). Since several missions are in preparation simultaneously, they all compete for scarce resources. Furthermore, since many of these resources are extremely expensive and limited in number (often operating at or beyond their capacity), optimal assignment and efficient use is critically important. There are also a number of additional constraints imposed by ground rules, safety requirements, and the unique needs of processing vehicles and payloads destined for space. These challenges are compounded by the endless changes to the schedule caused by late deliveries, delayed flights, and malfunctioning equipment. To resolve the many conflicts and predict possible problem areas, operators must use a number of rules of thumb specifying where things should happen, whether they will happen on time, and whether the requested resources are actually necessary.

Although there are a number of commercially available scheduling systems, the degree of domain knowledge required for decisions and the unusual set of constraints make these of limited use. Stottler Henke Associates, Inc. (SHAI) solved these problems by applying a combination of artificial intelligence (AI) techniques to produce Aurora, a system capable of rapidly completing a near-optimal schedule. Aurora is unusual in that it combines sophisticated scheduling mechanisms with domain knowledge

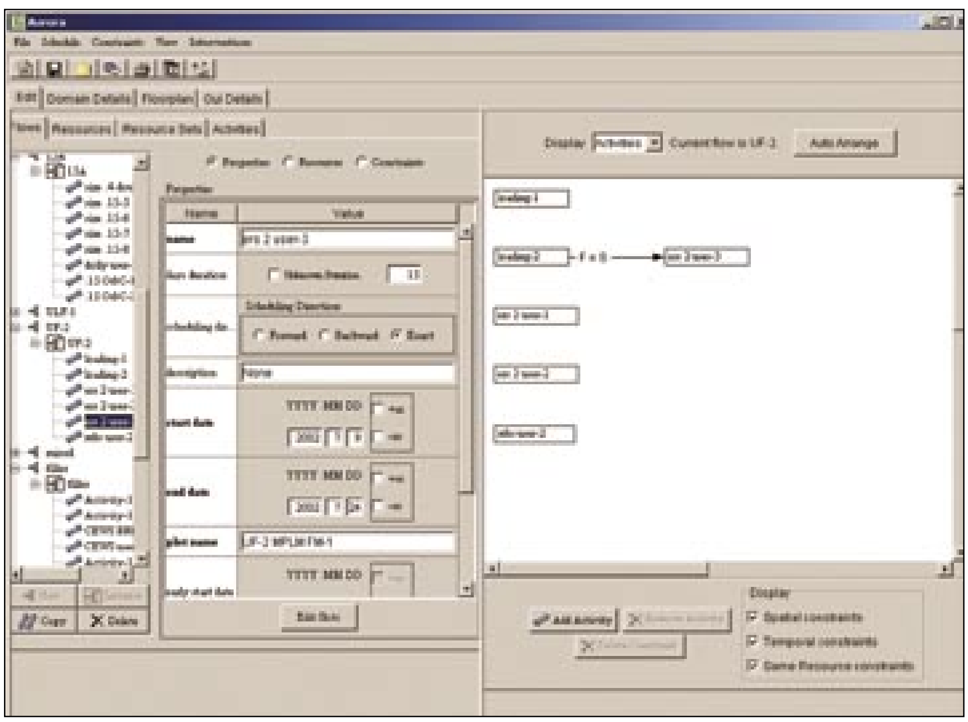

Figure 1. Aurora Flow Editing and Display Window

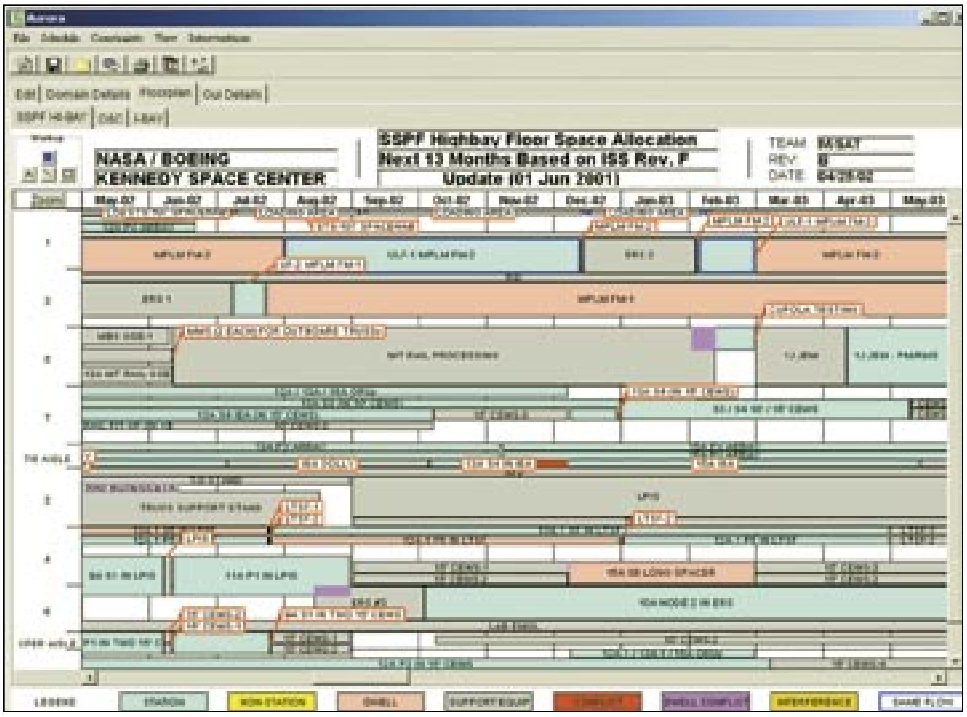

Figure 2. Floorspace Resource Allocation Display and Editor

and case-based expert conflict resolution techniques to solve the scheduling problem. It also takes into account a number of problems unique to KSC, such as the needs to schedule floorspace and maintain certain spatial relationships among the tasks and components, in order to obtain high-quality results.

Aurora then displays resource usage, floorspace usage, and the spatial relationships among different activities graphically. Scheduling experts can interactively modify and update the schedule and can request more information about specific scheduling decisions. This allows them to supply additional information or verify the system's decisions and override them to resolve conflicts, if necessary. In this last case, the program observes how the user resolves a given conflict and uses that cached knowledge in future scheduling to resolve similar conflicts. The interface uses comparable case-based reasoning techniques to automate repetitive tasks.

Key accomplishments and milestones:

- June 2001: Completed proof-of-concept prototype.
- April 2002: Released a scheduling system that provides support for spatial requirements and constraints as well as traditional scheduling needs.
- August 2002: Augmented Aurora with a sophisticated timeframe selection system based on resource load. Developed a case-based expert kernel to support less experienced users and automate repetitive tasks.

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Participating Organization: Stottler Henke Associates, Inc. (R. Stottler)

Advanced Protective Suit

Personnel at the Kennedy Space Center are required to handle highly toxic rocket propellant during ground operations. Fully encapsulated suits provide respiratory and skin protection. These suits, however, can cause significant heat stress during warm-weather operations. A supercritical air-supplied Environmental Control Unit (ECU) was designed and is being tested to replace the existing liquid air-supplied units in an effort to eliminate oxygen enrichment, attitude dependence, and lack of quantity measurement. An air distribution vest was also designed and is being tested as an improvement to the current air distribution system.

Air Vest Prototype

It is hoped that integration of both designs will enhance performance of this propellant handler's ensemble (PHE).

Key accomplishments:

- Supercritical air ECU operates in all positions, without oxygen enrichment.
- Supercritical air ECU provides air for 2-hour suited timeline.
- Air vest designed to concentrate available ECU cooling air on the torso.
- Testing accomplished on four subjects in 74- and 110-degree-Fahrenheit (°F) environments.
- Created a standard testing protocol for fully encapsulated garments.

Key milestones:

- Determine most efficient and supportable heat stress countermeasure for suit. This could be the existing hose manifold, the new air vest, or a liquid-cooled garment.
- Establish demand breathing to decrease weight of air carried and eliminate carbon dioxide.

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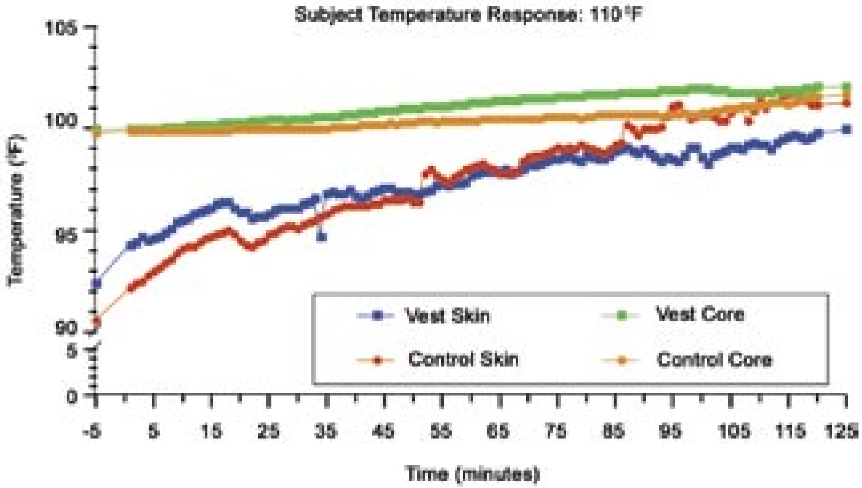
Participating Organizations: Bionetics Corp. (D.A. Ratliff) and Aerospace Design and Development Co.

Air Vest Worn Under PHE



Individual Subject Response to Simulated Work Tasks in 110 °F Wearing Air Vest and Standard Configuration

Supercritical ECU Prototype 1- and 2-Hour Design

Simulated Work Tasks in Category-1 PHE

Kennedy Space Center Projects and Resources Online (KPRO)

KPRO is a centralized project management information system tailored to the unique project management practices of NASA and KSC, building on the project management capabilities provided by the commercial off-the-shelf (COTS) application Microsoft Project 2002 Enterprise. KPRO will provide the following functionality:

- Schedule planning and tracking.
- Project portfolio analysis.
- Management of KSC resources (personnel) assigned to projects.
- Selection of resources based on skills and/or competencies.
- Fiscal and multiyear budget planning and tracking.
- Automated interfaces to the NASA accounting systems.
- Status reporting.
- Earned value management (EVM).
- Continuous risk management, including issues tracking and reporting.
- Document sharing.

KPRO supports the following levels of usage representing major classes of users with specific interface needs:

- Project: covers day-to-day project management and engineering activities.
- Management: covers most reporting and provides visibility for various interested parties across multiple projects and funding sources.
- Executive: covers multiyear and multiproject analysis, planning, and forecasting and provides high-level reporting.

KPRO provides a consistent environment that supports structured project management in accordance with NASA and KSC policies and procedures (including NPG 7120.5A, "Program and Project Management Processes and Requirements," and KDP-KSC-P-2600, "Project Management Overview"). The KPRO development team was a member of the Microsoft Joint Development Program. This program provided early access to MS Project 2002, dedicated Microsoft support (including onsite visits), and the means to provide input on features, deployment issues, etc., of MS Project 2002.

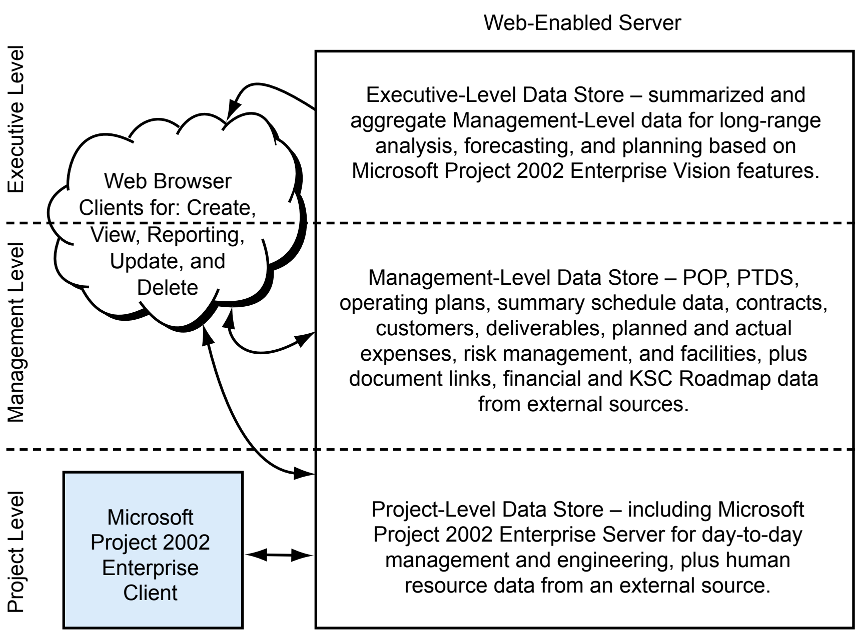
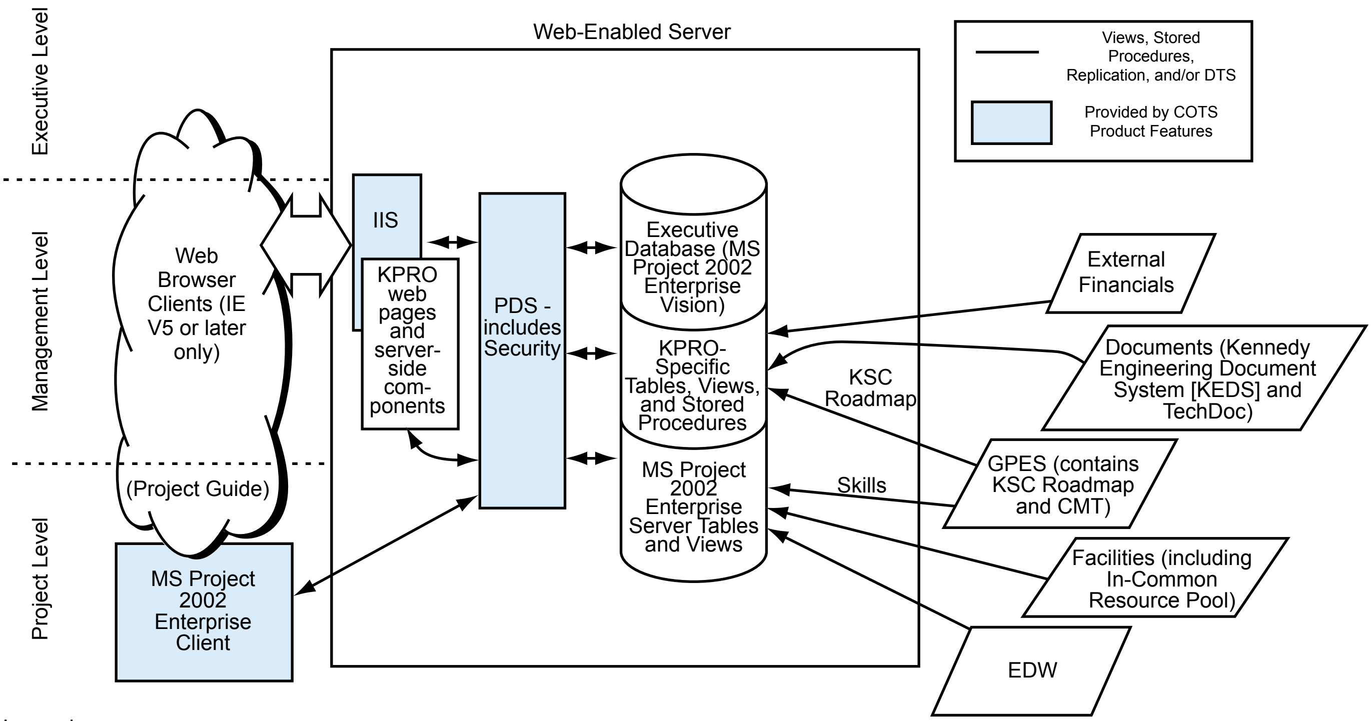


Figure 1. KPRO High-Level Architecture

KPRO will be deployed incrementally and is divided into four deliveries. Delivery 1 became operational in June 2002 after Microsoft's final release of MS Project 2002. Additional deliveries will be rolled out approximately every 6 months with release of Delivery 4 in September 2003.

Key accomplishments:

- Formulation/requirements phase complete. Planning, scheduling, and requirements baselined with the appropriate level of customer, stakeholder, and user participation and concurrence.



Legend

CMT	Competency Management Tool
COTS	Commercial off-the-shelf
DTS	Data Transformation Services
EDW	Employee Data Warehouse
GPES	Goal Performance Evaluation System
IE	Internet Explorer
KEDS	Kennedy Engineering Document System
MS	Microsoft
PDS	Project Data Service
POP	Program Operating Plan
PTDS	Project Task Description Sheet

Figure 2. KPRO Detailed Software Architecture

- Implementation phase ongoing since October 2001. Delivery 1 pilot testing (February 1, 2002).
  - Delivery 1 deployment (June 3, 2002).
  - Obtain actual expense data from NASA accounting systems.
  - Assign resources from a common resource pool.
  - Automate project control number.
  - Populate human resource pool from the KSC Employee Data Warehouse.
  - Standard scheduling tools.
  - Initial set of custom reports.
  - Evaluate COTS EVM capabilities.

Key milestones:

- Transition fiscal planning and reporting to KPRO; Delivery 2, November 2002.
- Transition multiyear planning and reporting; centralized risk management; incorporate information from the competency management system (CMS); Delivery 3, February 2003.
- EVM reports; interface with contractors reporting systems for expense and labor data; Delivery 4, September 2003.

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Aft Protection Process Improvement Team

The Aft Protection Process Improvement Team (PIT) was chartered to evaluate Orbiter vehicle (OV) aft compartment processing in the horizontal and vertical positions. The team emphasized the prevention of damage to flight hardware during processing. Attention was focused on aft processing when a vacuum-jacketed line was damaged at a critical point in the processing flow. As a result, senior management chartered a team to evaluate opportunities to prevent flight hardware damage.

The Aft Protection PIT was an intensive effort that assembled a dedicated cross-functional team composed of individuals who are involved in the processing in the Orbiter aft compartment. The team utilized Continues Improvement (CI) tools to evaluate aft compartment processing areas of concern, including access, flight hardware damage, high-traffic areas, fall protection issues, revising the aft training video, and the one-time entry form. The PIT was empowered by management to seek solutions and rapidly implement changes. The team included trained facilitators from the United Space Alliance (USA) Industrial Engineering and Human Factors department and was led by team leaders from shop and engineering.

The team assessed and provided improvements for:

- Initial Aft Access (Post OV-105 STS 99 Roll-In) – Initial entry into the Orbiter aft compartment after roll-in was evaluated.
- Potential collateral damage to adjacent hardware/systems – The team evaluated when flight hardware damage was occurring during processing.
- First-Time Entry Forms – One-time entry forms did not require a briefing and escort.
- Aft Access Training Video (OV-211-LSC) – Training video was outdated and did not reflect the current vehicle configurations.
- Lighting – Improve lighting and evaluate the use of cordless lights to prevent collateral flight hardware damage caused by electrical cords.
- Communication box and headset cord concerns – Engineering Support Request (ESR) written to evaluate wireless headsets to prevent damage caused by communication cords and Operational Intercommunication System-Digital (OIS-D) boxes.
- Emergency Egress Procedures – Evaluation performed of man loading on each specific platform area; developed man-loading standard for the horizontal and vertical platform sets.
- Fall Protection issues inside the aft compartment – Aft platform evaluated to study difficult access areas and those that put the technicians in a working-at-heights issue.

Key accomplishments:

- March 2000: Developed an Operational and Maintenance Instruction (OMI) that provides the initial aft access sequence. Revised first-time entry forms to require a briefing by shop management and an escort for the visitor.

- June 2000: (Horizontal Operations) Wrote ESR to improve access to the power-head platforms and to eliminate fall protection issues. Developed mitigation plan to eliminate fall hazards for technicians during engine installation and removal. Conducted platform fit checks for all aft platforms.
- December 2001: Updated Aft Access Training Video to reflect the requirement changes with an emphasis on flight hardware protection and personnel safety.
- March 2002: Evaluated wireless headsets for use inside the vehicle to eliminate the communication cords, which are a potential source of damage to flight hardware.

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Participating Organizations: United Space Alliance (J.D. Comer, J.G. Crews, J.R. Ewald, G.P. Floyd, T.G. Riley, D.L. Bilby, D.S. Mayer, W.M. McKenzie, J.L. Gerlach, J.J. Curtis, J.W. Garrett, and T.K. Amster), Rocketdyne (S.E. Keeler), and NASA PH

Orbiter Laser Alignment Spotting

Following an Orbiter vehicle landing or demate from the mate/demate device (MDD), the vehicle is moved to the Orbiter Processing Facility (OPF). Previously Orbiter towing, aligning, and spotting into the OPF high bays have been an inaccurate process. Moving a large vehicle into the OPF bays combined with a high-precision alignment requirement makes the task extremely challenging. The task is made more difficult because the tug design and task requirements limit the tug driver's field of vision. The tug driver depends on verbal directional instructions from the Orbiter Move Director (OMD). When the tug driver cannot see the towlines and misses the towpath, the driver must back up and start again. High variability in alignment and spotting made the process unreliable and dependent on the skills and luck of the tug driver and OMD. This time-consuming process can waste many valuable man-hours while OPF personnel wait for the OPF high bay to open for work. Accurate alignment of the Orbiter is also essential for the functional use of workstands on all levels throughout the entire OPF process flow, particularly those with flip-down plates and extensions. An Orbiter misalignment may require use of pic-boards in place of existing platforms later in the vehicle process flow to complete other tasks.

The solution was to provide an inexpensive and highly effective laser alignment and spotting system visible to the tug driver and OMD. United Space Alliance (USA) Optics, Corrective Action Engineering, Orbiter Handling Engineering, and Industrial Engineering/Human Factors formed a team to develop a process that uses two off-the-shelf laser theodolite digital transit units for alignment spotting. One laser is used for guiding the tug driver and the second is used for cross-checking the Orbiter Main Landing Gear (MLG) during roll-in. A translucent laser "target" was constructed and is used on the tug during this process. The first laser projects a dot on the target providing a directional reference for the tug operator towing the Orbiter. Simultaneously, a second laser projects a beam onto the MLG for the OMD to verify the Orbiter vehicle alignment accuracy.

Roll-in process time from Spacecraft Operator (SCO) change-out to final spot was previously as long as 4 hours. Improved roll-in process time and final spot is now 15 to 30 minutes. During the testing phase of the system in August 2001, Discovery was aligned and spotted in the OPF highbay 2 within 13 minutes. The new process has saved man-hours, and costly wear and tear on the tug, Orbiter nose wheel, and struts. In addition, this new process cuts back on Orbiter fuel cell usage and allows the Orbiter to be jacked and leveled sooner, which provides quicker access to time-critical ground support equipment. This also allows for interfacing to Power Reaction, Storage, and Distribution and securing facility cooling and ground power quicker, thus relieving the SCO in less time. Additional benefits include functional improvements throughout the entire OPF flow for workstand flip-down and extention platform access. The possibility of unecessary pic-board

Orbiter Tow Tug

First Laser Spot on Translucent Tug Target

Second Laser Spot on Main Landing Gear

installation for access, in place of an existing platform, has been reduced because of improved alignment accuracy of the Orbiter.

Key accomplishments:

- 2001: Researched laser systems and types for application. Met with stakeholders for customer interviews. Tested laser alignment prototype process in the Vehicle Assembly Building highbay 4. Formed continuous improvement project team. Tested laser alignment system in OPF. Purchased system components for OPF-owned laser package. Began tug driver process familiarization and training.

Key milestones:

- 2001: Began OPF technician hands-on training during roll-in. Completed laser operating system turned over to OPF ownership.
- 2002: Completed OPF technician laser training package.

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Participating Organization: United Space Alliance (C.R. Floyd, D.G. Sheriff, P.S. Dickey, M.W. McClure, and K.D. VanDyke)

General-Purpose Rigging – Annual Load-Testing Process Enhancement

KSC utilizes approximately 2,000 individual pieces of ground support lifting hardware that require annual load tests (nondestructive stress tests performed by loading the hardware and monitoring for deformation) in accordance with NASA documentation. This hardware includes all general-purpose rigging such as synthetic web slings, wire-rope, alloy steel chain slings, shackles, and d-rings controlled by individual shops or logistics. Historically, the United Space Alliance (USA) Heavy Equipment organization, located at KSC, conducted these load tests at its shop. The maintenance date was indicated on a dog tag attached to each item. The shop supervisors and technicians were responsible for ensuring the items were tested. Hardware items whose load tests were past due could not be used for processing and were verified through the Quality department. USA departments were using a variety of workflow processes to accomplish the load test and return the item to service, and little communication occurred between organizations.

An intense 4-day process improvement team investigation was initiated in October 2001 to analyze the process, identify problem areas, and develop countermeasures. The team documented the process flow used by the majority of the organizations' operations (figure 1), interpreted historical data, and found the average cycle time (from request for load testing to return of item) was 54 days with a 45-day standard deviation. Hardware could be tested much more quickly based on a processing emergency, but approval for expedited load testing was difficult to obtain. In response to long out-of-use periods, shops purchased hardware in duplicate and sometimes triplicate. Hardware was periodically lost or misplaced during the process, and tracking a request through the system was virtually impossible.

Though historical information was scant, the majority of items deemed to have failed load testing did so during a visual inspection performed before the actual load test. The team investigated the load

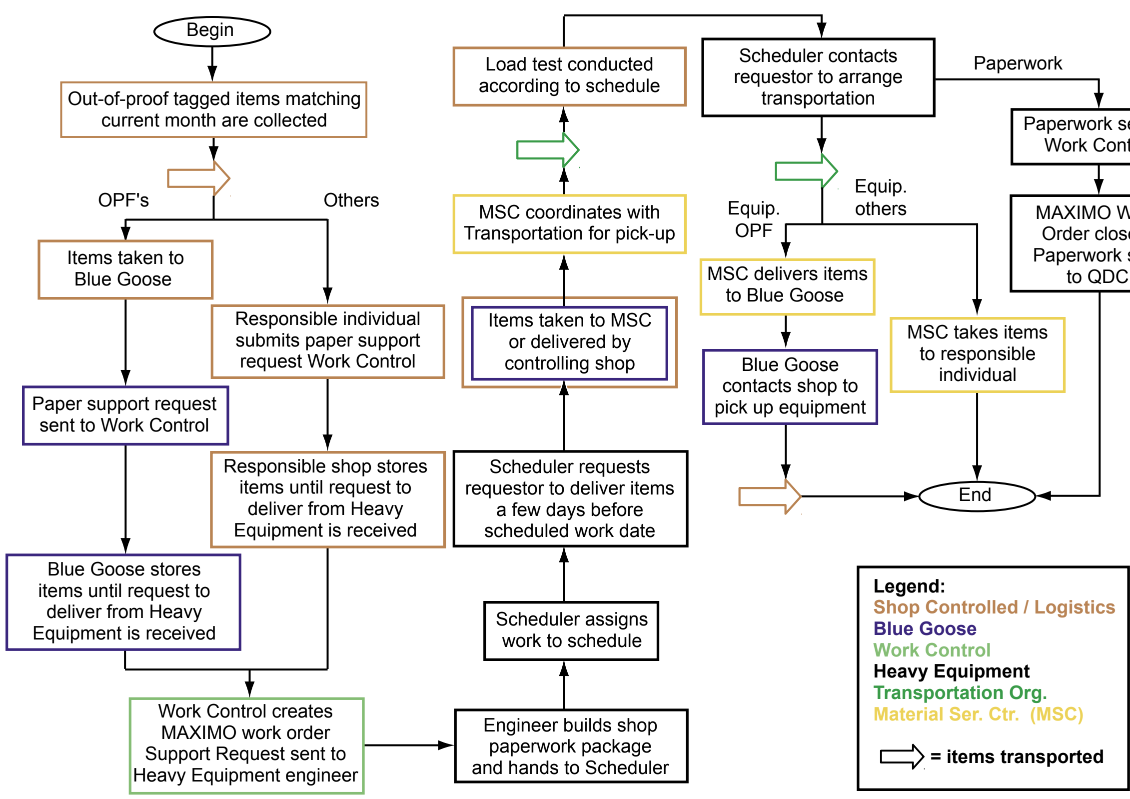

Figure 1. Old Workflow Process

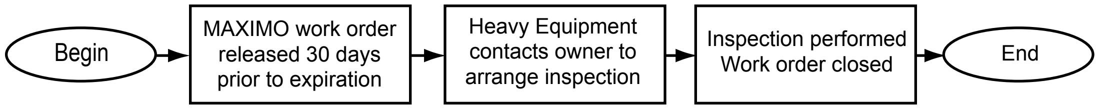

Figure 2. New Workflow Process

test requirements in NASA-STD-8719.9 and compared them to the "KSC List of Nonload Test Slings" in KHB 1710.2. Approval was obtained from the NASA KSC Lifting Devices and Equipment Manager to submit requests for addition to the exempt list.

The process improvement team recommended a new streamlined workflow (figure 2) and the following measures that were adopted and are nearing final implementation:

- Each organization will submit a list for approval to the "KSC List of Nonload Test Slings."
- USA Heavy Equipment will perform annual inspections at the owner's location in lieu of the load test and eliminate transportation.
- An off-the-shelf software package (MAXIMO) will automate the maintenance recall and track the visual inspection process. MAXIMO will initiate a work order directly to Heavy Equipment 30 days prior to the expiration date of each item.
- The maintenance dog tag on the hardware will indicate the item as exempt from load testing and will reflect a visual inspection date (figure 3).

The table depicts performance statistics of the old process compared to the new process.

Key accomplishments:

- Over 600 labor hours will be saved per year across several organizations.

Figure 3. Sling and Shackle Bearing New Maintenance Dog Tags

- Using the same expiration date for all of the items in a single location streamlines the inspection process and requires fewer inspectors.
- Onsite inspection prevents the possibility of lost hardware and dramatically reduces out-of-use time, thereby eliminating the need to stock excess equipment.
- Paper support requests and load-testing documentation are eliminated.
- The process is standardized for all organizations.

Table 1. Analysis of Old Versus New Process

	Old Process	New Process
Date Range for Data	11/20/98 to 09/10/01	N/A
Number of Requests per Year	60	20
Minimum Cycle Time (days)	1	1
Maximum Cycle Time (days)	196	1
Average Cycle Time (days)	54	1
Standard Deviation (days) (High variability shows process out of control)	45	1
Average Time Equipment Out of Service (days)	54	1
Approximate USA Labor Hours per Year	720	110

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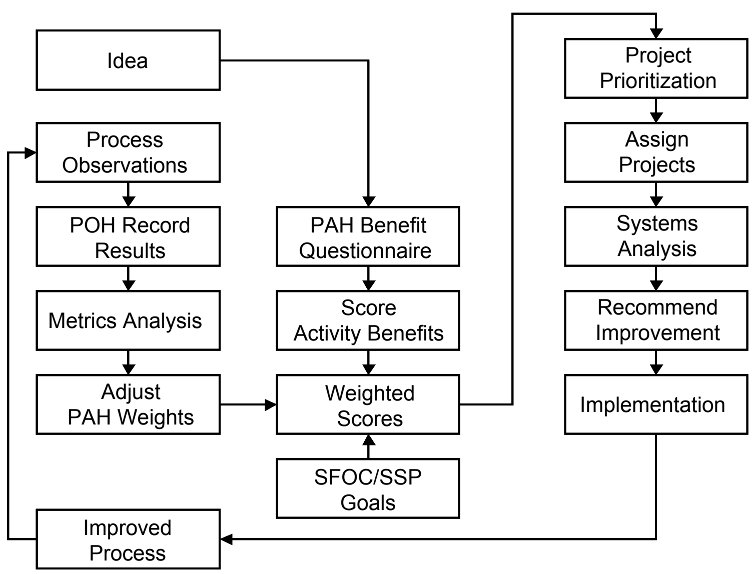
Participating Organization: United Space Alliance (K.P. Warren [team lead], J.R. Ewald, K.D. VanDyke, J.L. Bisbey, C. McCombs, T.L. Henderson, D.C. Smith, G. Garrett, L.A. Tripps, M. Chavez, and P. Cureton)

A Project Priority Assessment Tool

The United Space Alliance (USA) Industrial Engineering and Human Factors (IEHF) department of USA Florida Technical Services (FTS) supports Space Shuttle processing as part of the Space Flight Operations Contract (SFOC)/Space Shuttle Program (SSP). The objectives of IEHF are to reduce the potential for mishap and improve process efficiencies. These objectives are accomplished by applying scientific methodologies and techniques from both Industrial Engineering and Human Factors disciplines. By achieving the IEHF objectives, the department supports the USA goals to provide safe operations for all aspects of the business and to improve, grow, and diversify the business.

At KSC Ground Operations (GO), engineers and technicians closely involved with any Space Shuttle ground processing operation are trained to recognize the potential for accident mishaps during processing. Similarly, their experiences enable them to identify processing efficiency improvements. USA systems and procedures, such as Operational Area and Safety Improvement System (OASIS) and Risk-Associated Trouble Spots (RATS), are tools available to document accident reduction and process improvement ideas. The IEHF department may also be contacted. Opportunities assessed by IEHF analysts historically result in process efficiency improvements and reductions in the potential for mishaps to occur.



An engineer, technician, or manager of any process may contact the IEHF department with an idea to improve the process efficiency or reduce the potential for mishaps. General data is collected about the idea and is documented into a database. All ideas are categorized as potential IEHF activities that may take the form of projects or studies such as a systems analysis. A priority assessment questionnaire is completed to quickly assess the benefits gained by implementing a project improvement recommendation from the original idea.

Each IEHF activity has a set of boundaries. A priority assessment questionnaire defined by a priority assessment hierarchy (PAH) is used to assess each bounded system for potential benefits. The benefits, unrelated to risk assessment, represent the potential results of recommendations that may be implemented against the bounded system. The PAH is mapped to a process observation hierarchy (POH). The POH dictates a basis for collecting important Shuttle-related ground operations processing characteristics. Both the POH and the PAH are mapped to the risk assessment scorecard categories (RASC), which include safety, mission success, schedule, supportability, and cost.

The responses to the priority assessment questions reflect the potential benefits gained with respect to the risk assessment scorecard categories and the SFOC/SSP goals, if the proposed solutions of the IEHF activity are implemented. Each question is asked in a way that solicits a response to determine if the implementation of the proposed activity will have (1) positive impact, (2) no impact, or (3) negative impact to the bounded system with respect to the parent category or next level in the PAH. The question is assigned a value so a positive impact scores a high benefit in contrast to a negative impact that scores a low benefit. The scores noted for each question are multiplied by a weighting previously assigned to that question. These products are multiplied by specified weights of the RASC and in accordance with a predetermined mapping between the PAH and the RASC. The weighted products are summarized into a single weighted score that represents the benefit score of the IEHF activity.

All activities with weighted scores are compared and ranked in decreasing order where those activities with the highest score are expected to produce the greatest benefit. The activities with the highest scores are then assigned to an IEHF engineer or analyst as projects. Resources are applied to complete a systems analysis so when a recommendation resulting from the analysis is implemented, the process originally defined as an IEHF activity is improved. The expected improvement may be reported as a reduction in process anomalies from other process observations documented in POH records.

The following decision support process enables the IEHF department to prioritize activities:

- Document an idea to improve a process or reduce the potential for mishaps.
- Complete a priority assessment benefit questionnaire.
- Score activity attributes in accordance with the questionnaire.
- Adjust weights to reflect metrics and goals.
- Calculate the weighted activity score.
- Prioritize activities in order of weighted score.
- Assign high-scoring activities as projects or studies.
- Present, select, and implement recommendations.

The project priority assessment tool enables the IEHF department to rank ideas captured during Shuttle processing that may improve process efficiencies or reduce the potential for mishaps. Use of the tool assists the department manager in selecting ideas, among many, that will provide the greatest improvement to Shuttle processing and maximize the efficient utilization of department resources.

Key accomplishments:

- IEHF Integrated Data Management Process in place. Activity Priority Assessment Methodology implemented.
- Process observation hierarchy, record, and database completed. Improvements pending.
- Project priority hierarchy, benefit questionnaire, and database completed. Improvements pending.
- SFOC/SSP/goals hierarchy documented.
- Activity resource tracking database completed.

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Participating Organization: United Space Alliance (D.J. Frankos, E.P. Brown, L.S. McAuliff, K.D. Van Dyke, K.S. Stelges, J.J. Jacoby, and J.C. Guarino)

Standardization of Mishap Investigation Process

While prior efforts to enhance the investigative process at Kennedy Space Center focused on building analytical capabilities into the human factors mishap investigation, the lack of the structured approach to the investigative process fostered the possibility of incomplete and incorrect assessments of human error. A standardized method was necessary to provide investigators with a process that allowed for a comprehensive examination of the facts and circumstances of events, while providing a more efficient and effective method for investigating mishaps.

For the first time in the history of the U.S. Space Program, human factors mishap investigations at KSC are being conducted in a process consistent with the multimodal transportation investigative community. Sound, time-proven incident and accident investigation principles and procedures are being implemented for use by investigators to enhance their abilities to conduct thorough investigations of mishaps. The entire standardized process will facilitate easier identification of problem areas around KSC, promote a more efficient investigative process, provide a means to train investigators more easily, and promote the recommendation of comprehensive improvements and enhancements centerwide.

While the purpose of the investigative process is to determine causal and contributing factors that led to incidents and accidents, the goal of the investigator is to provide meaningful, achievable recommendations to prevent a recurrence of events and enhance safety. The standardized investigation process being implemented at KSC is the key to attaining that goal. The phased approach to implementation of various elements of the standardized process is underway and has already been successful in promoting the comprehensive, efficient, and effective methodology of investigating mishaps that was desired.

Key accomplishments:

- August 2001: Development of the Mishap Investigation Operating Procedure.
- October 2001: Development of Phase II, including Interview Protocol and Investigators Standard Glossary.
- December 2001: Successful completion and implementation of Phase I, including the Standardized Investigation Protocol, the Standard Investigation Report Format, the Human Factors Investigation Checklist, and the Investigation Kit list.

Key milestones:

- April 2002: Purchase and acquisition of all items on the Investigation Kit list.
- August 2002: Successful completion and implementation of the Mishap Investigation Operating Procedure.
- December 2002: Completion and implementation of all Phase II elements.

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