NASA Technical Memorandum 103811

Research and Technology 1990 Annual Report of the John F. Kennedy Space Center

FOREWORD

As the NASA Center responsible for assembly, checkout, servicing, launch, recovery, and operational support of Space Transportation System elements and payloads, the John F. Kennedy Space Center is placing increasing emphasis on its research and technology program. In addition to strengthening those areas of engineering and operations technology that contribute to safer, more efficient, and more economical execution of our current mission, we are developing the technological tools needed to execute the Center's mission relative to future programs. The Engineering Development Directorate encompasses most of the laboratories and other Center resources that are key elements of the research and technology program, and is responsible for implementation of the majority of the projects in this Kennedy Space Center 1990 Annual Report.

Thomas M. Hammond, Technology Utilization Officer, PT-PMO-A, (407) 867-3017, is responsible for publication of this report and should be contacted for any desired information regarding the Center-wide research and technology program.

Forrest S. McCartney
Director

AVAILABILITY INFORMATION

For additional information on any individual report, contact the person identified following the article. Commercial telephone users can dial the listed extension preceded by area code 407. Telephone users with access to the Federal Telecommunications System can dial the extension preceded by 823.

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Materials Science

Materials science investigations are conducted in two well-equipped and well-staffed laboratories at the John F. Kennedy Space Center (KSC).

Microchemical Analysis Laboratory

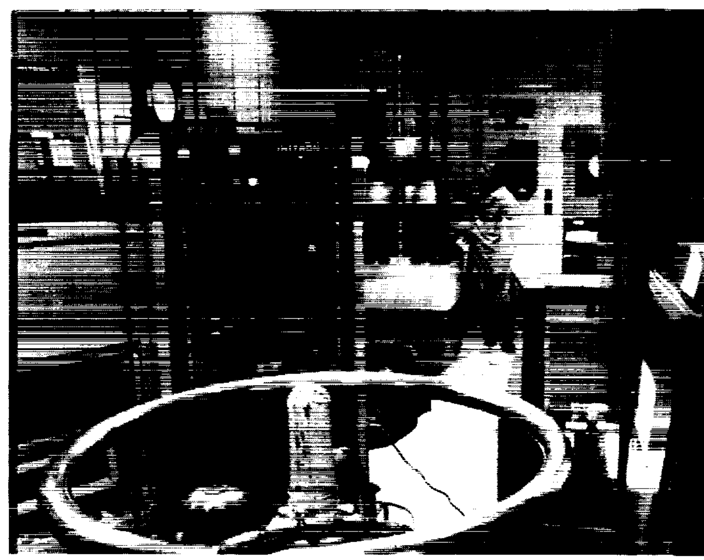
The Microchemical Analysis Laboratory employs high technology instruments, such as the electron microprobe, scanning electron microscope, infrared spectrophotometer, and mass spectrometer/gas chromatograph, as well as classical analytical methods, to identify a variety of materials. One basic function of the laboratory is to chemically identify any fluid or solid material down to the parts-per-billion range. A second basic function is to provide the investigative effort necessary to understand and solve chemical problems associated with the selection and application of materials in aerospace systems. Typical subjects for analysis are the Shuttle thermal protection system, aerospace materials (such as alloys and soft goods), and any contamination found on or in flight hardware or facilities.

Failure Analysis and Materials Evaluation Laboratory

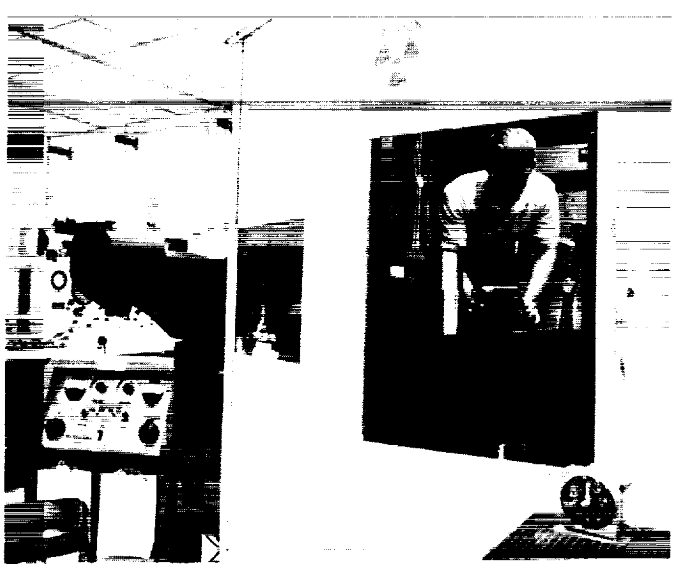
The failure analysis portion of this laboratory provides the investigative capability to determine, on a rapid turnaround basis, the causes of failures related to ground support equipment and flight hardware. The failure analysis process is conducted in the electrical/electronics, mechanical/fluid, metallurgical, and metrological laboratories, with supporting expert services within each of these areas. After the completion of an investigation, the engineer or physicist makes recommendations for preventing similar occurrences and, if necessary, devises a research program with the goal of preventing future failures.

The materials evaluation portion of this laboratory includes materials and environmental testing facilities, a liquid oxygen impact testing facility, and an environmental exposure test site along the Atlantic Ocean. This section of the laboratory provides the investigative effort necessary to understand and solve technical problems associated with the selection and application of materials (such as plastics, elastomers, metals, and lubricants) used in flight hardware, ground support equipment, and facility systems.

Microchemical Analysis Laboratory



Materials Evaluation Laboratory



Failure Analysis Laboratory

Conductive Organic Polymers as Corrosion Control Coatings

Electrically conductive polymers are being synthesized and formulated as protective coatings for ground support equipment and structures at Kennedy Space Center (KSC). The disadvantage of the current zinc-rich coatings used on launch structures is that the high concentrations of hydrochloric acid released during a Space Shuttle launch attack the zinc portion of the coating. The search for a coating with resistance to hydrochloric acid and to corrosion has focused on conductive polymers--materials with the electronic and magnetic properties of metal but with properties such as flexibility and chemical resistance of polymers.

The objective of the conjunctive research effort involving KSC and the Los Alamos National Laboratory (LANL) is to develop coatings from conductive organic polymers that will provide galvanic protection to steel surfaces. These organic coatings should be formulated to provide easy application, repair, and long-term resistance to the KSC launch environment. The launch environment consists of a marine, severe solar, and intermittently high acid-elevated temperature environment. The high acid-elevated temperature conditions are generated during vehicle launches using solid rocket motors.

Historically, the field of electrically conductive polymers has produced materials that have virtually no processibility. However, in the last few years, it has been discovered that aniline, the 3-substituted thiophenes, and pyrroles can be synthesized and polymerized to high-molecular-weight materials. In the research effort involving KSC- and LANL, the nature of the substituents has been carefully controlled, resulting in polymers readily soluble in common organic solvents and ones that can be melt-processed below decomposition temperatures. Thus, feasibility has been demonstrated for making processible polymers that are electrically conductive.

In the past year, several conductive polymers have been synthesized, and solutions of sufficient viscosity for casting films have been prepared. Solvents, casting techniques, and drying conditions have been developed for coating steel coupons with pinhole-free films of pi-conjugated polymers. The most promising materials at present are poly(alkylthiophenes) and polyaniline. Blending agents have been used in combination with the conductive polymers to increase film strength and adhesion to steel substrates.

The table "Properties of Processible Conductive Polymers" summarizes the properties for the most promising of the conductive polymers and conductive polymer blends. For suitability of any material to provide the desired corrosion protection, the material must demonstrate good/excellent properties in several categories: (1) ease of preparation and processing, (2) dopability (i.e., increasing conductivity by ionic additives), (3) electrical conductivity, (4) environmental stability, (5) mechanical integrity of film, and (6) adhesion to steel.

Adhesion to steel seems to be a limiting factor for the materials investigated. Although many of the polymer films adhere well to steel in water, the presence of acids lifts the films from the substrate. One method used to prevent the peeling problem was to treat the steel surface prior to coating. Coupling agents were used to covalently bond the polymer coating to the steel surface. Such treatment was especially

Properties of Processible Conductive Polymers

	P3HT	P3TEA	PAn	P3HT/Hyp	PAn/Hyp	PAn/Epo
Dopability, I_2	a	d	a	a	a	b
Dopability, acid	a	b	a	a	a	b
Ease of preparation	b	b	a	b	a	a
Ease of processing	b	b	a	b	b	b
Atmospheric stability	b	a	a	b	a	a
Processing of films with no pinholes	a	a	a	a	a	a
Film elasticity	b	d	c	b	d	d
Adhesion: H_2O	b	a	b	b	d	a
$NaCl/O_2$	b	b	b	b	d	-
HCl	d	d	d	d	d	c
Maximum conductivity	b	c	b	c	c	c
Permeability: H^+	Yes	Yes	Yes	-	-	-
Cl^-	?	Yes	Yes	-	-	-
Fe^{n+}	?	?	?	(No iron detected after exposure to steel coupon in corrosive environment)		

Notes: *a = Excellent*, *b = Good*, *c = Average*, *d = Poor*

P3HT = Poly (3-hexylthiophene)
P3TEA = Poly (3-thienylethylacetate)
PAn = Polyaniline
Hyp = Hypalon
Epo = Epon 828 epoxy

effective in marine environments. Samples were immersed in sodium chloride aqueous solutions with vigorous oxygen bubbling. Under these conditions, the polymer films adhered strongly to the steel coupons and the polymer-coated steel remained uncorroded even upon prolonged exposure. However, this surface treatment utilizing coupling agents has not been found effective in acidic environments. The polymer films remained adhered to steel coupons in a 1-molar hydrochloric acid solution for 24 hours with no corrosion under the coating, but the coatings wrinkled and peeled off when rinsed and dried.

A second strategy for improving adhesion of polymer coatings to steel is to blend epoxy materials with the polymer. Composites of various epoxy systems with conductive polymers were formulated, varying the mix ratios. The choice of curing agent is a very important aspect in obtaining conductive polymer/epoxy composites with a desirable balance of physical properties and electrical conductivity. Therefore, a range of composites was prepared with different curing agents. The conductivities achieved thus far are in the semiconducting range.

Current work is producing improved composite coatings with higher conductivities. Such efforts will continue, and properties of the coatings will be evaluated. Investigations will include corrosion testing in both salt water and hydrochloric acid solutions. Electrochemical evaluation of the conductive polymer coating/steel interface will also be carried out, using alternating current impedance techniques. Steps have been undertaken to locate a coatings institute to produce the most promising coatings in large batches.

Contact:
K. G. Thompson, 867-4344, DM-MSL-22

Participating Organization:
Los Alamos National Laboratory (B. Benicewicz)

NASA Headquarters Sponsor:
Office of Space Flight

Environmentally Compliant Coating Systems for the Shuttle Launch Sites

In 1986, a test program was started to evaluate protective coating systems on carbon steel surfaces exposed to simulated solid rocket booster (SRB) effluent. Test panels were coated with materials then available, exposed to the environment at a beach-side corrosion test site, periodically sprayed with a simulated SRB acid effluent, and evaluated after 18 and 36 months. The coating systems were based on solvent-thinned, inorganic, zinc-rich primers and various solvent-thinned topcoat systems.

The findings of this study were that, in general, the thick-film topcoat products provided better chemical and corrosion resistance than the thin-film counterparts when exposed to the simulated SRB acid effluent. However, in recent years, environmental regulations have sought to restrict the use of paints and coatings with a high concentration of solvent, which could include many of the coating systems tested in this study.

The use of the solvent-based, inorganic, zinc-rich primers tested and approved in the 1986 study could be prohibited at the Kennedy Space Center (KSC) in the near future due to their volatile organic content (VOC) levels. These materials all have VOC levels above 450 grams per liter (3.75 pounds per gallon), whereas the maximum levels allowed in some areas (such as California, some counties of Florida, and many other urban areas of the United States) are 420 grams per liter (3.5 pounds per gallon). Furthermore, legislation has dictated that this level be reduced to 350 grams per liter (2.8 pounds per gallon) by 1993. Therefore, the possibility that the inorganic, zinc-rich primers and topcoat systems presently approved at KSC will be prohibited and unavailable for use is very real.

In response to this circumstance, the current study will be conducted to search for inorganic, zinc-rich coating systems that provide superior protection to KSC launch structures and ground support equipment and fully comply with environmental regulations. Currently, the protective coating manufacturing industry is producing environmentally compliant, inorganic, zinc coatings such as high-volume solids and

KSC Corrosion Test Site

water-based systems. New systems are also being developed to conform to the anticipated strengthening of environmental air quality standards.

After application of these environmentally compliant coating systems, the test panels will be exposed to atmospheric contaminants at the KSC beach corrosion site with concurrent applications of an acid slurry made of hydrochloric acid (HCl) and alumina (Al_2O_3). To simulate the worst-case scenario experienced at the launch sites, the slurry will be applied to the test panels with no subsequent washdown.

The exposure test will be conducted for 5 years to determine the suitability of the coating systems. The test panels will be inspected for performance at 1, 3, 6, 12, 18, 36, and 60 months and will be formally rated in accordance with ASTM D610 at 18, 36, and 60 months. During this 5-year period, there will be approximately 130 applications of the acid slurry.

Contact:
L. G. MacDowell, 867-2906, DM-MSL-2

NASA Headquarter Sponsor:
Office of Space Flight

Stress Testing of Engineering Materials

Stress corrosion cracking (SCC) of metallic alloy materials can have a devastating impact on the safety and reliability of all types of structures, mechanisms, and high-pressure gaseous systems. Many times, this type of failure is unexpected and occurs at the worst possible moment in a schedule or critical operation of a system. Obviously, when dealing in high technology areas such as Shuttle launch and space travel, exotic metallic materials are used because of their high strength and lower weight. Typically, these types of materials are the most susceptible to the SCC phenomenon.

In response to this potential problem, work is underway to determine the SCC behavior of 50 of the most commonly used alloys at the Kennedy Space Center (KSC). These materials range from many stainless steels to the more exotic nickel-based and aluminum alloys. As a result of this work, materials with lower susceptibility to stress corrosion will be identified for use on facilities and systems at KSC.

The work is currently being conducted under contract to Florida Atlantic University by the Department of Ocean Engineering. The materials are being tested using the slow strain rate technique (SSRT) or constant extension rate technique (CERT) in a corrosive solution that simulates the Space Transportation System (STS) launch environment. The SSRT test has been accepted as a reliable method to judge a material's SCC resistance in a short time. The alloys are stressed to failure at a slow strain rate (10^{-6} inch per inch per second) in air and then compared to identical specimens that have been tested in the corrosive solution. Differences in fracture surfaces, stress levels, and times to failure of the specimens between the two environments are interpreted as variations in susceptibility to SCC.

The study is approximately 80 percent complete, and the findings will be available in the near future. The failed specimens are being analyzed using scanning electron microscopy (SEM) and the results will be sent to KSC for publication. These results will help to prepare a list of engineering materials that have specific resistance to SCC in the STS launch environment.

Contact:
L. G. MacDowell, 867-2906, DM-MSL-2

NASA Headquarters Sponsor:
Office of Space Flight

Accelerated Testing of Inorganic, Zinc-Rich Primers

Inorganic, zinc-rich coatings are used for corrosion protection of carbon steel structures at the Kennedy Space Center (KSC). To be considered for use at KSC, a primer must successfully withstand exposure at the beach corrosion test site. Primers are periodically rated for rusting on a scale of 1 to 10 in accordance with ASTM D610, with a rating of 10 being the best. For preliminary approval, primers must receive a rating of 9 or better after 18 months of exposure. For final approval, primers must continue to maintain a rating of 9 or better after 60 months. Unfortunately, this process requires a considerable amount of time to place new products on the approved list.

Alternating current impedance measurement techniques, also known as electrochemical impedance spectroscopy (EIS), are being studied as a possible method for determining the corrosion resistance of inorganic, zinc-rich primers for use at KSC. The goal of this test program is to develop an accelerated method for screening zinc-rich primers before exposing them to long-term testing at the beach corrosion test site. A reliable accelerated laboratory test method such as EIS could save time for preliminary approval of primers (see the figure "Electrochemical Corrosion Testing System").

For this method, primers are sprayed on test coupons for use in the laboratory experiments. These coupons are immersed in seawater, which is obtained from the Atlantic Ocean close to the beach corrosion site. The seawater is aerated during the test to provide the oxygen necessary for corrosion reactions. Test results should yield information on polarization resistance (R_p), which is a measure of a material's resistance to corrosion in a particular electrolyte. It is hoped that a correlation can be found between these laboratory results and the long-term field results.

This test program was started in November 1989. Results at this point are encouraging but preliminary. Tests are being conducted on primers that have already been exposed at the beach site for 52 months. Laboratory test results will be compared with these field results. The new-generation, zinc-rich primers now starting evaluation will also be tested to predict their field performance.

Electrochemical Corrosion Testing System

Contacts:
L. G. MacDowell and C. Ontiveros, 867-2906, DM-MSL-24

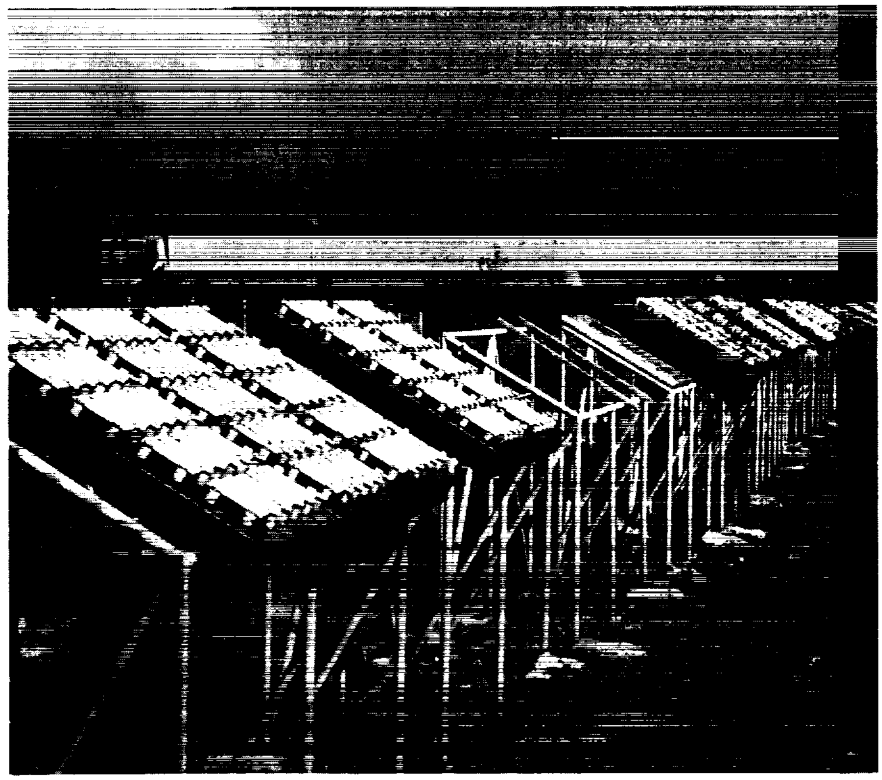
NASA Headquarters Sponsor:
Office of Space Flight

Protective Coating Systems for Repaired Carbon Steel Surfaces

In the past, maintenance repair of corroded carbon steel surfaces required the use of abrasive blasting to adequately clean and prepare the metal surface for application of protective coatings. Recent advances in coating technology promise acceptable protective coating performance when surface preparations are less than perfect. The present study focuses on new products and techniques that may reduce the level of surface cleanliness required for corrosion protection in many areas at Kennedy Space Center (KSC).

The coatings being tested in this study include epoxy mastics, moisture-cured urethanes, chemical conversion coatings, and any other type of repair coating identified during the course of the program. The study compares the performance of previously rusted panels that have been mechanically prepared using four methods and two initial conditions. The four mechanical methods used are power wire brush, pneumatic needle gun, sanding disk, and course wheel grinder. The two initial conditions used are to prepare the panels with water washing or without water washing prior to mechanical cleaning.

The initial screening of the many products was accomplished by exposing the prepared panels to 2,000 hours in the salt fog chamber. The results of this screening procedure indicate varying performances of the coatings of the same generic type. This result has considerably reduced the final list of products to be tested. Further results show that the "rust converter" type coatings provide little protection in an aggressive atmosphere and should not be considered for use at KSC.



Proximity of the Beach Corrosion Test Site to the Launch Pads

The materials identified by the screening procedure have been used to prepare panels for exposure at the KSC beach corrosion test site (see the figure "Proximity of the Beach Corrosion Test Site to the Launch Pads"). The panels were prerusted at the beach site for 6 months and then brought to the laboratory for surface preparation and application of the coating systems. The completed panels were installed at the beach corrosion site in July 1990.

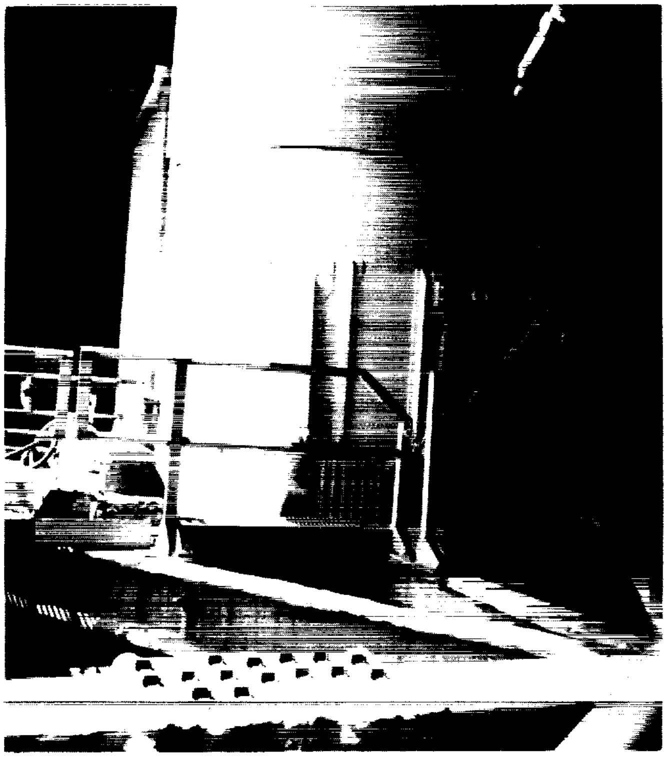
Panels exposed at the beach corrosion site will undergo solid rocket booster (SRB) effluent testing to simulate the conditions at the launch site. The SRB effluent tests will be accomplished by spraying simulated effluent onto two-thirds of the panels every 2 or 3 weeks. Panels at the beach will be inspected after 1, 3, 6, 12, 18, 36, and 60 months and rated for rusting on a scale from 1 to 10 in accordance with ASTM D610. An expanded test plan is available under document number MTB-144-88.

Contact:
L. G. MacDowell, 867-2906, DM-MSL-24

NASA Headquarters Sponsor:
Office of Space Flight

Study of Thermal-Sprayed Metallic Coatings for Potential Application on Launch Complex 39 Structures

The objective of this study is to evaluate candidate thermal-sprayed metallic coatings for potential application on the Zone 1 (high-temperature rocket motor blast) structures at Launch Complex 39 at the Kennedy Space Center. Tests are being performed to determine if the candidate coatings will protect the structure from the abrasive blast, heat, and acid-rich environment associated with



Mount Plate With TSC Composite Test Panels on the Titan Transporter Prior to Launch

the solid rocket booster (SRB) exhaust during Shuttle launches.

Launch Complexes 17 and 40 have been utilized to test the coatings. Both the Delta (Launch Complex 17) and the Titan III (Launch Complex 40) are powered by solid rocket motors (SRM's) and provide a launch environment similar to SRB exhaust.

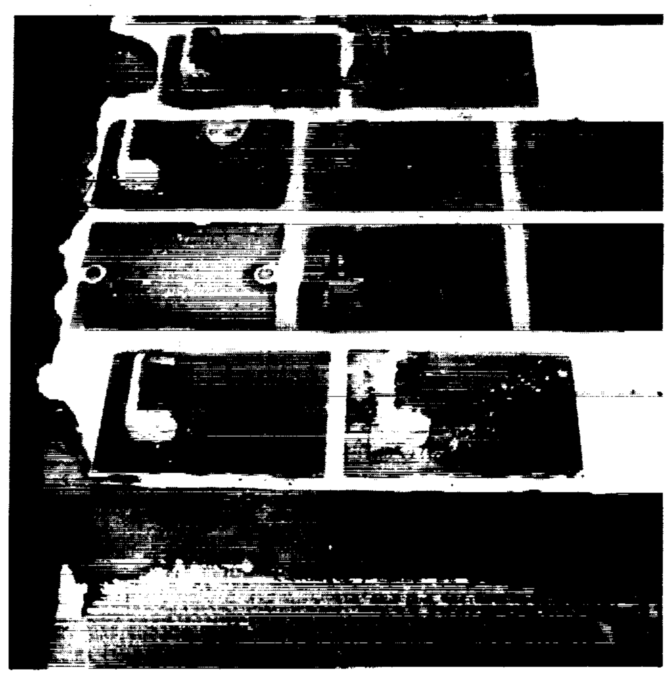
A group of thermal-sprayed coating (TSC) test panels were set out at the beach corrosion test site on April 15, 1987. Periodically, the panels were rinsed with a slurry of alumina (Al_2O_3) powder and hydrochloric acid (HCl) to simulate the effects of the SRB exhaust residue.

Most of the TSC alloys applied by either plasma or hypersonic flame spray processes are more noble than the low-alloy steels. In the case of these exotic, noble alloys, the carbon steel structure becomes the sacrificed anode that corrodes. This undesirable phenomena was illustrated after 2-1/2 years of beach exposure testing.

The testing in the launch environment has illustrated the problems of porosity and exfoliation due to thermal shock. The use of the exotic TSC's to protect launch structures appears to be impractical.

Only the relatively low-cost, aluminum TSC, which provides some cathodic protection for steel, appears to be a practical candidate for further investigation.

The aluminum TSC panel with several of the other materials will be subjected to the alumina/hydrochloric acid slurry rinse at the beach corrosion test site.



Mount Plate With TSC Composite Test Panels on the Titan Transporter After Launch

Contact:
P. J. Welch, 867-4614, DM-MSL-2

Participating Organization:
Martin Marietta Manned Space System Launch Support Services

NASA Headquarters Sponsor:
Office of Space Flight

Corrosion of Convoluted Metal Flexible Hoses

Various cryogenic supply lines and hypergolic lines at the Shuttle launch site use convoluted flexible hoses and bellows constructed of type 304L stainless steel. The extremely corrosive Space Transportation System (STS) launch environment, composed of sodium chloride (NaCl) and hydrochloric acid (HCl), has caused rapid pitting and failure of these flexible hoses; this leads to a loss of vacuum with a resulting high boiloff of the cryogenics.

In 1987, a project was initiated to identify a more corrosion-resistant alloy for this service. After testing 19 corrosion-resistant alloys for pitting resistance, the study quickly focused on the nickel-based alloys such as Hastelloy and Inconel. These alloys were chosen on the basis of their reported resistance to acid/chloride environments.

The first-year results were published under document number MTB-325-87A. Several alloys, such as Inco G-3, Inconel 625, and Hastelloy C-4, C-22, and C-276, performed well. After evaluation of all mechanical data and corrosion tests, Hastelloy C-22 was determined to be the most acceptable alloy for use in the STS launch environment (see the figure "Metal Bellows Repair Using Hastelloy C-22"). Samples of all alloys continue to be exposed at the beach corrosion site to gain valuable long-term exposure data.

During the summer of 1990, testing continued on the 19 alloys using alternating current impedance techniques to assess corrosion resistance. The alloys were tested in 3.55 percent NaCl and 0.1 normal HCl at varying immersion times. The acidic electrolyte was used to simulate conditions that exist in the STS launch environment. Preliminary data analysis suggests that this

Metal Bellows Repair Using Hastelloy C-22 technique may prove to be a valuable tool to rapidly screen metal alloys for their relative corrosion resistance. The data was published under document number MTB-610-89A.

Contact:
L. G. MacDowell, 867-2906, DM-MSL-24

NASA Headquarters Sponsor:
Office of Space Flight

Thermal-Sprayed Cathodic Protection for Steel Structures

Throughout the world, hundreds of steel structures have been metalized with thermal-sprayed coatings (TSC's) to provide long-term cathodic corrosion protection. Several of the structures date back to the 1930's.

Studies conducted by the thermal spray industry indicate that although the initial cost of a TSC system is more expensive than painting, the extended useful service life of the TSC makes it potentially less expensive as a long-term investment.

A study is underway to evaluate the cathodic TSC systems in the tropical marine environment of the Kennedy Space Center (KSC) and the chloride-rich environment at Launch Complex 39. The TSC's will be compared to the current protection coating system. Inorganic zinc paints are presently used to provide cathodic protection of steel structures. The test panels in this study will not be subjected to Zone 1 (high-temperature rocket motor blast) conditions.

The three cathodic-type TSC systems commonly used in industry are being evaluated. The TSC materials are aluminum (Al), zinc (Zn), and a zinc/aluminum alloy. All the TSC's were applied to the test panels by a combustion-spray system. The test panels with the three TSC materials and the inorganic zinc paint system will be exposed to the environment at the KSC beach corrosion test site, Launch Complex 39, and the KSC Industrial Area.

Contact:
P. J. Welch, 867-4614, DM-MSL-2

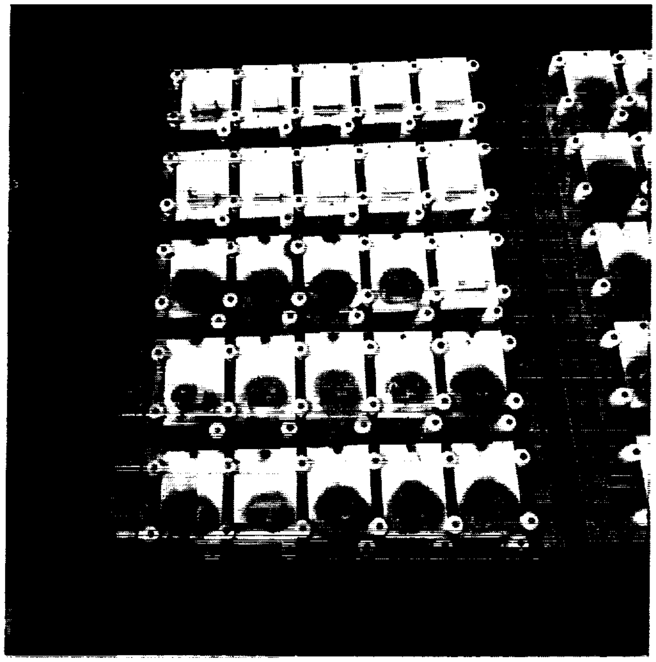
NASA Headquarters Sponsor:
Office of Space Flight

Protective Top Coating Systems for the Space Transportation System Launch Environment

Zinc-rich coating systems exposed to the Space Transportation System (STS) launch environment at the Kennedy Space Center (KSC) have been suffering premature failure due to the highly acidic residue produced by the solid rocket boosters. Early attempts at topcoating these zinc-rich coatings with a thin film to increase their chemical resistance have produced only marginal results.

Topcoat systems are being tested to improve coating performance for exposure to KSC's harsh environment (see the figure "Coating Evaluation of Test Panels at the Beach Corrosion Test Site"). The present study focuses on using thicker film topcoats over the zinc-rich primers to improve the chemical resistance to a marine atmosphere and to highly acidic residues.

In 1986, 119 materials producing 67 coating systems were exposed to atmospheric contaminants at the KSC beach corrosion site with concurrent applications of an acid slurry made of hydrochloric acid (HCl) and



Coating Evaluation of Test Panels at the Beach Corrosion Test Site

alumina (Al_2O_3). To simulate the worst-case scenario experienced at the launch sites, the slurry was applied to the test panels with no subsequent washdown.

The current test will be conducted for 5 years to determine the suitability of the topcoat systems. The panels have been judged for performance at 6, 12, 18, and 36 months. The last evaluation will occur at 60 months, which will be followed by a final report. During this 5-year period, there will have been approximately 130 applications of the acid slurry.

The panels are approaching the 52-month point of exposure. The results of the 18-month evaluation were published in February 1988 under document number MTB-268-86B. The 36-month evaluation revealed that topcoat performance was generally poorer than the untopcoated condition; the results were published in September 1989 under document number MTB-268-86C. Several manufacturer's topcoat products are, however, performing very well. This result has prompted consideration to prepare a list, for incorporation into KSC-STD-C-0001, that includes approved topcoat products for use when topcoats are required and specified for launch structures and ground support equipment at KSC.

Contact:
L. G. MacDowell, 867-2906, DM-MSL-24

NASA Headquarters Sponsor:
Office of Space Flight

Aqueous Precision Cleaning

NASA's policy is to conserve and reduce the usage of the chlorofluorocarbons (CFC's) and Halons identified in the Montreal Protocols. In addition, it is planned to phase-out the use of these materials by 1995.

NVR Analysis by Attenuated Total Reflectance

NVR Analysis by Surface Tension

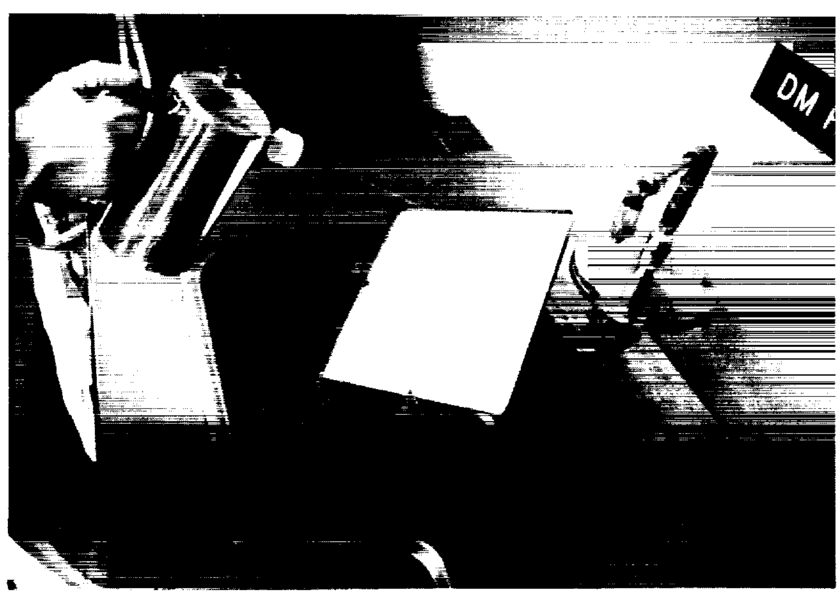
One of these materials, CFC-113, commonly referred to as Freon 113, is used for precision cleaning at the Kennedy Space Center (KSC). CFC-113 is the test solvent of choice specified in KSC-C-123, Specification for Surface Cleanliness of Fluid Systems.

A Kennedy Integrated Team (KIT) of NASA and KSC contractors was formed to find an environmentally acceptable replacement fluid for the precision cleaning process. The team, the CFC Replacement Study Team, is working toward the goal of using water for precision cleaning.

KSC-C-123 identifies CFC-113 as the test solvent used for cleanliness verification. Cleanliness verification consists of particulate analysis and nonvolatile residue (NVR) analysis. Wiltech, Inc., and the NASA Microchemical Analysis Branch personnel at the KSC Component Cleaning and Refurbishment Facility have been performing most of the research and development work with some assistance from the University of Central Florida.

Most of the work to date involves contaminated witness plates that are sampled by the conventional technique, CFC-113, and by the proposed method using deionized water. The greatest challenge is posed by performing the NVR analysis with water. After performing initial literature searches, market research, and screening tests, two techniques were selected for test and development. The first method is fluid surface tension by dynamic contact angle (DCA) analysis, and the second is infrared spectrometric attenuated total reflectance (ATR) analysis.

The CFC Replacement Study Team is working with the other NASA Centers in this effort to solve this environmentally sensitive problem.



Sampling of Witness Plate Technique Used in the Aqueous Precision Cleaning Study

Contact:
P. J. Welch, 867-4614, DM-MSL-2

Participating Organizations:
Wiltech, Inc.
University of Central Florida

NASA Headquarters Sponsor:
Office of Space Flight

Development of New Flooring Materials for Clean Rooms and Launch Site Facilities

NASA utilizes one of two different static-dissipating floor coverings in Shuttle assembly areas: flexible polyvinyl chloride (PVC) tiling or poured epoxy flooring material. Both have disadvantages associated with their use. PVC fails NASA's outgassing test due to the plasticizer component in the formulation. The plasticizer can volatilize at room temperature and then recondense on sensitive optical surfaces. Although there are static-dissipating PVC tiles commercially available, none have qualified that have been subjected to the outgassing test. The poured epoxy flooring also performs poorly and is difficult to maintain, repair, and clean.

A Small Business Innovation Research (SBIR) project identified chemically resistant polymers, conductive fillers, flame-retardant additives, and stabilizers that could be used to formulate floor tiles which meet NASA's requirements. Sample formulations, based on high-density polyethylene and PVC, have passed outgassing and fluid compatibility tests at the Kennedy Space Center (KSC). Dispersion problems with the conductive fiber filler have been solved. Final evaluation of the materials is underway, and testing of suitable adhesives has begun. Test floors of each material will be installed for the durability and wear tests at KSC.

Contact:
C. J. Bryan, 867-4344, DM-MSL-2

NASA Headquarters Sponsor:
Office of Space Flight

Development of a New Chemical-Resistant Fabric for Protective Clothing

A program was initiated to identify a fabric for the next generation of clothing to protect workers using hazardous chemicals at the Kennedy Space Center. The hazardous chemicals of interest include hydrazine, monomethylhydrazine, nitrogen tetroxide, hexane, toluene, sodium hydroxide, citric acid, 1,1,1-trichloroethane, methyl ethyl ketone, 2-propanol, and two hydraulic fluids (MIL-H 5605 and MIL-H-83282).

Tuskegee University is the prime contractor for this program. TRI/Environmental, Inc., has been subcontracted to contact various manufacturers for information concerning new barrier materials that may be suitable for use in protective clothing. Samples of the more promising materials will be obtained, and the physical properties and gross chemical resistance evaluated by TRI. TRI will further evaluate the candidate materials for ease of fabrication into garments. Tuskegee University will perform permeability and degradation tests with the hazardous chemicals to determine the best material for the new chemically protective suit.

Contact:
C. J. Bryan, 867-4344, DM-MSL-2

16NASA Headquarters Sponsor:
Office of Space Flight / Office of Equal Opportunity Program

Compatibility of Corrosion-Resistant Alloys With Aerospace Fluids

Nineteen corrosion-resistant alloys were evaluated several years ago for corrosion resistance in the Kennedy Space Center launch environment. Five of these alloys that exhibited outstanding corrosion resistance were identified in this evaluation. These alloys, Inco G-3, Inconel 625, and Hastelloy C-4, C-22, and C-276, were selected for evaluation of their compatibility with oxygen, hydrogen, hydrazine, monomethylhydrazine, and nitrogen tetroxide. Promoted combustion tests in oxygen showed these alloys to be resistant to ignition at pressures twice as high as those required for consumption of the 300-series stainless steel alloys evaluated. Rubbing friction tests also ranked these alloys more resistant to ignition than the 300-series stainless steel in oxygen. Particle impact tests in oxygen are still pending.

A test chamber is being designed to perform slow-strain-rate, stress-corrosion cracking tests on the five alloys in hydrazine, nitrogen tetroxide, and monomethylhydrazine. Hydrogen embrittlement susceptibility will be evaluated by a slow-strain-rate method and by static pressurization of a thin disk after the establishment of steady-state hydrogen permeation through the disk.

Contact:
C. J. Bryan, 867-4344, DM-MSL-2

NASA Headquarters Sponsor:
Office of Space Flight

Fracture Susceptibility Study of Corrosion-Resistant Alloys

Advancement of technology puts stricter performance requirements on materials. Metallic materials are exposed to more corrosive environments and higher mechanical stresses. A combination of the two conditions makes metals uniquely susceptible to fracture failures; therefore, new alloys are continuously developed to meet the increasing performance demand.

A joint research program was established between the Mechanical Engineering Department at the University of Central Florida (UCF) and the Materials Science Laboratory of Kennedy Space Center (KSC). The main goal of this program is to broaden the knowledge base for fracture resistance of metallic materials in the highly corrosive, salt-bearing KSC environment.

The KSC effort focuses upon the stress corrosion cracking and corrosion fatigue of recently developed alloys in the natural KSC environment. Quantification of the KSC atmosphere and simulation in the laboratory are planned. A trailer was acquired for a mobile field laboratory, and a servohydraulic testing machine will be purchased.

The UCF effort emphasizes the provision of mechanistic interpretations for crack propagation processes. A hydrogen embrittlement study in a cathodically charging environment was initiated. A microscopic crack propagation study has been in progress based upon fractography and laser interferometry.

Together, UCF and KSC have a full line

of analytical instrumentation to assist the corrosion-enhanced fracture studies, including Auger electron spectroscopy, X-ray photoelectron spectroscopy, scanning electron microscopes, X-ray fluorescence, Fourier transform infrared spectroscopy, and electron microprobe.

Contact:
R. U. Lee, 867-3400, DM-MSL-22

Participating Organization:
University of Central Florida

NASA Headquarters Sponsor:
Office of Space Flight

Hazardous Emissions and Contamination Monitoring

The John F. Kennedy Space Center (KSC) stores and pumps huge quantities of cryogenics, as well as lesser amounts of exotic fluids. The extreme toxicity and volatility of these fluids mandate a comprehensive safety program. Four development laboratories are responsible for implementing the specialized instrumentation hardware and systems that satisfy stringent safety requirements.

Hazardous Gas Detection Laboratory

The Hazardous Gas Detection Laboratory has the continuing task of implementing systems that are capable of measuring (in complex mixtures) gaseous components both qualitatively (specifically hydrogen, helium, nitrogen, oxygen, and argon) and quantitatively (parts-per-billion range). A typical hazardous gas detection system comprises a mass spectrometer, a sample and calibration gas delivery subsystem, and a data acquisition and control system. The laboratory projects now receiving the most attention are: (1) applying artificial intelligence/expert systems to aid in realtime diagnostics and troubleshooting, (2) operations monitoring and data interpretation, (3) developing a military specification, and (4) flight-qualified miniature detection systems for advanced launch systems.

Optical Instrumentation Laboratory

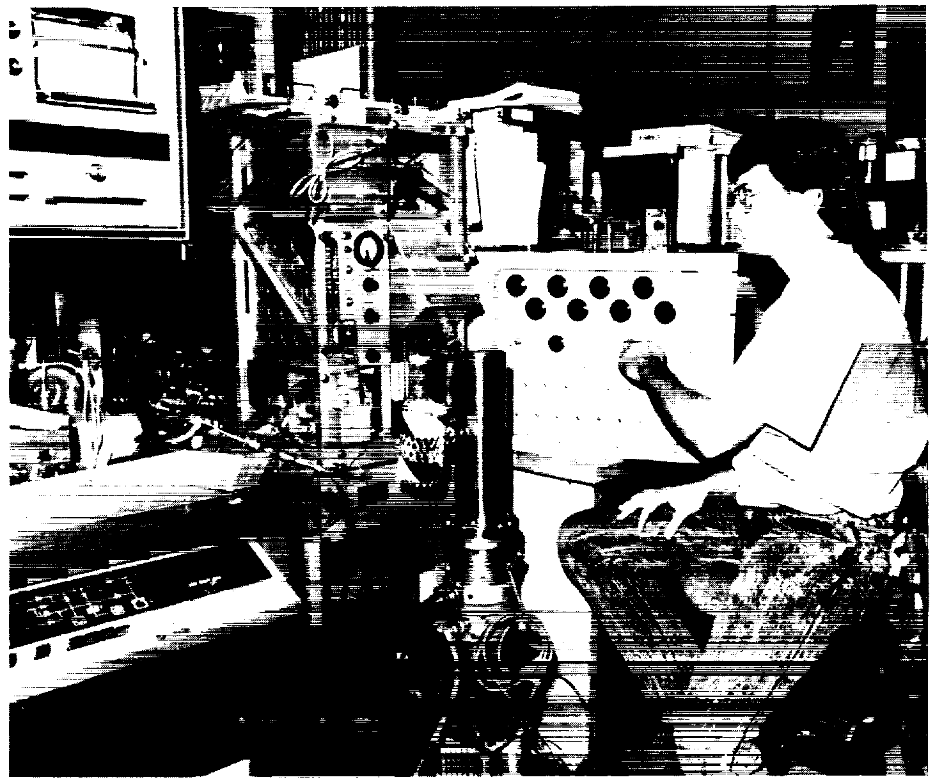
The Optical Instrumentation Laboratory develops and tests imaging systems for viewing phenomena that are undetectable to the unaided eye or by normal viewing techniques (for example, hydrogen fires and other thermal emitters and hydrogen and other gas clouds). A recent laboratory achievement is the design and demonstration of a multispectral television camera that is capable of unambiguously imaging and color coding fuel fires in the infrared and ultraviolet spectral emission ranges. The laboratory is equipped with an optical spectrometer for measuring the emission spectra of an extensive variety of radiating sources.

Toxic Vapor Detection Laboratory

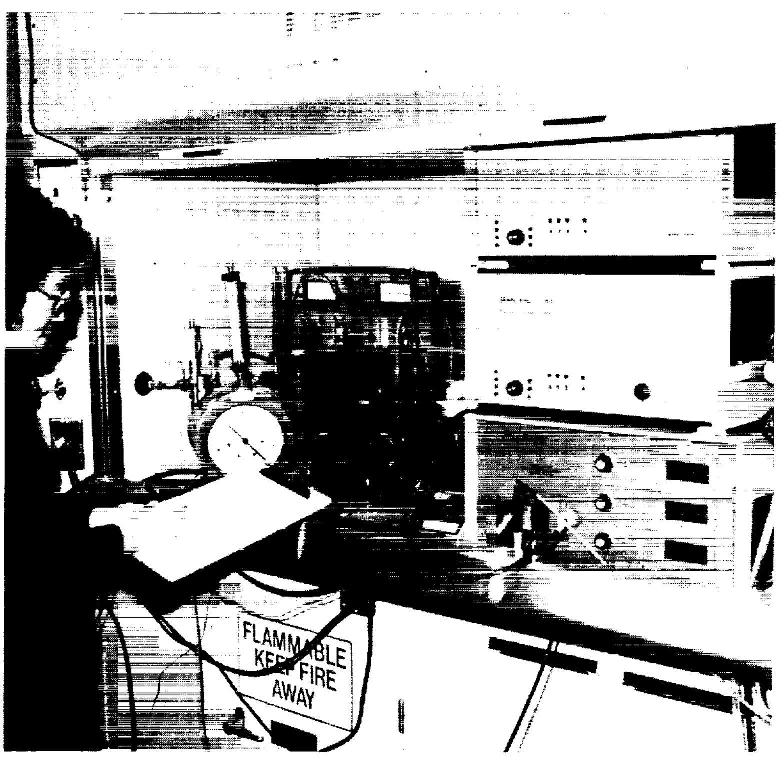
The Toxic Vapor Detection Laboratory (TVDL) is developing two new series of toxic vapor detectors because the commercially available instrumentation does not meet the current Government standards for measuring trace amounts of hypergolic fuels and concentrated ammonia vapors in an ambient background. The TVDL was established to perform research on detection techniques; to design, build, and test prototype and/or modified commercial detectors; and to evaluate new commercial instruments. All research and tests are performed utilizing the TVDL's unique capability to provide a wide range of toxic vapor concentrations at controlled flow rate, temperature, and relative humidity conditions. All tests are computer controlled to provide comprehensive qualitative and quantitative performance evaluations of every instrument tested.

Contamination Monitoring Laboratory

The Contamination Monitoring Laboratory was established to perform contamination monitoring research and development; to develop contamination measuring systems; to evaluate commercially available particle counters, hydrocarbon and nonvolatile residue monitors, and other instrumentation; and to advance the technology in the areas of realtime nonvolatile residue (NVR), realtime particle fallout monitoring, and contamination monitor calibration methodology. The laboratory is equipped with particle counter systems, personal-computer-based data acquisition and control systems, a pulse height analyzer, a research-grade Fourier transform infrared (FTIR) spectrophotometer, nondispersive infrared analyzers, an aerosol standards generation system, an optical microscope, and a normal complement of test and measurement instrumentation.



Hazardous Gas Detection Laboratory



Toxic Vapor Detection Laboratory

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Quick-Response Oxygen Analyzers

Objective

To evaluate and qualify quick-response oxygen analyzers for use in the planned Space Station Processing Facility (SSPF) at Kennedy Space Center (KSC). Large quantities of gases such as nitrogen and helium will be required for payload processing in the SSPF. These gases will be supplied by large-volume, high-pressure pipes that will run through an underground tunnel system. Since portions of these tunnels and other areas will have limited air circulation, the possibility exists that oxygen-deficient pockets could develop; due to leaks in these pipes, an oxygen deficiency monitoring system is required.

Approach

Personnel exposed to an oxygen-deficient atmosphere may suffer effects ranging from severe physiological impairment to unconsciousness within 15 seconds. Therefore, NASA Safety directed that the oxygen monitors used in the SSPF must have a response time of 10 seconds or less. Since this is a safety-related system, the design must be redundant.

Because none of the oxygen analyzers in use at KSC meet NASA's required response time, a market survey was needed to find a replacement. Analyzers based on a variety of technologies were purchased and evaluated for accuracy, linearity, time response, calibration drift, ruggedness, and reliability. Other factors included in the evaluation criteria were sensitivity to power surges, maintenance requirements, and the required frequency of calibration.

Accomplishments

After performing a market survey, instruments representing a variety of technologies, including electrochemical, paramagnetic, and zirconium crystal detectors, were procured. Qualitative analyses of ruggedness, reliability, maintenance requirements, frequency of calibration, and sensitivity to power glitches were performed.

Several instruments were identified that met the 10-second response time requirement in preliminary screening. These analyzers will be subjected to rigorous testing.

Contact:
P. A. Mogan, 867-4438, DL-ESS-24

Participating Organization:
McDonnell Douglas Space Station Company
(L. H. Allen and D. G. Garretson)

NASA Headquarters Sponsor:
Office of Space Flight

Integrated Environmental Monitoring System

Objective

To develop an instrumentation system for monitoring cleanroom environmental conditions in the planned Space Station Processing Facility (SSPF) and related structures at Kennedy Space Center (KSC). Quantities to be monitored include temperature, humidity, differential pressure, oxygen deficiency, and toxic vapors.

Background

Processing of flight hardware elements in cleanrooms at the SSPF will involve the use of toxic substances such as hydrazine propellants and ammonia refrigerant. An integrated system is required to monitor cleanroom conditions (air cleanliness, temperature, humidity, and differential pressure) and all toxic or flammable substances that may be present in each of the cleanrooms.

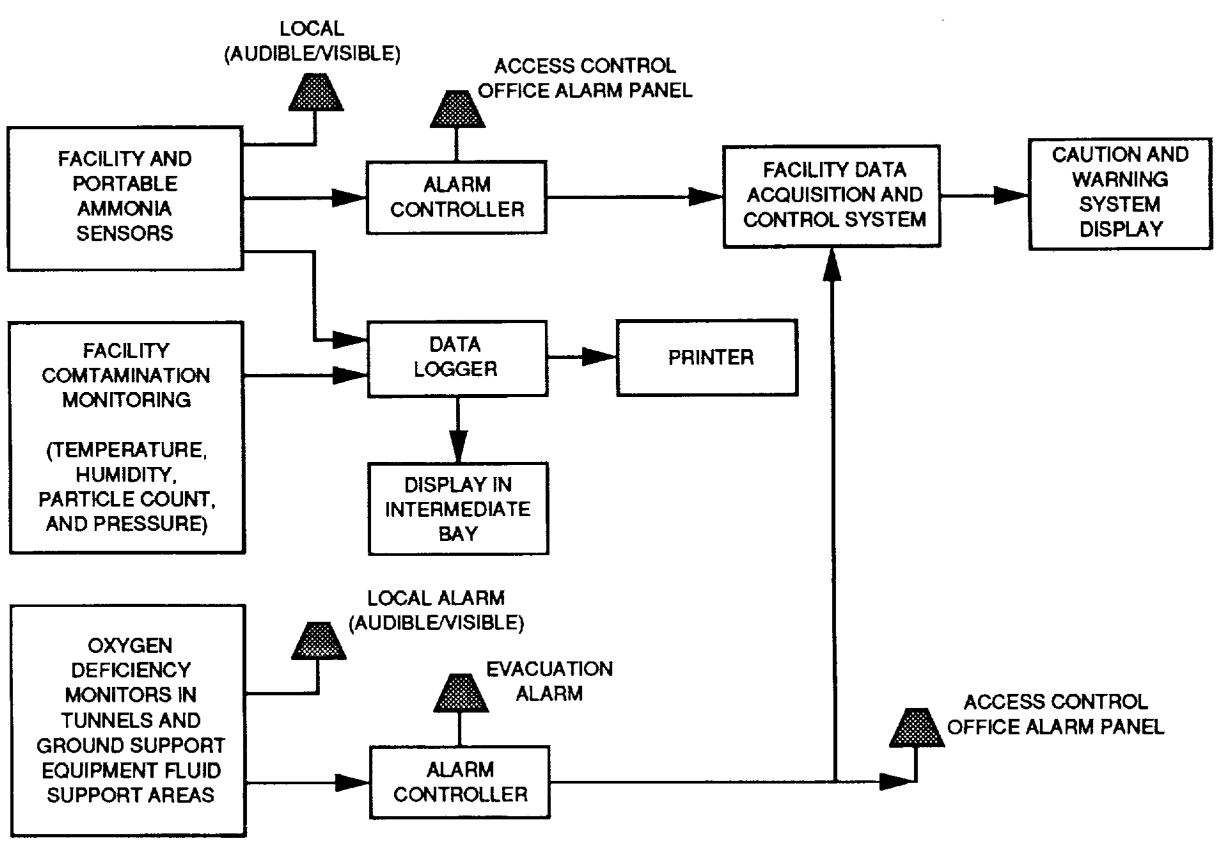
Approach

Various particle counters, ammonia detectors (for both low and high concentrations), and hydrazine detectors will be purchased and evaluated for use in the integrated environmental monitoring system. These instruments will be evaluated in terms of performance as well as reliability, ruggedness, maintainability and calibration requirements, and features such as alarm, health checks, etc. Data from these instruments will be multiplexed and transmitted to a central data station. A design trade study will be performed to determine both the type of computer and networking that are best suited for the monitoring system.

Since the toxic vapor detection functions of this monitoring system are safety related, the design must include redundancy in instrumentation, power, and alarms.

Accomplishments

A particle counter evaluation program has been accomplished and several viable instruments identified for use in the monitoring



Integrated Environmental Monitoring System

system. An appropriate differential pressure transducer is being qualified for use at KSC and temperature and humidity sensors have been selected.

A design trade study resulted in the selection of RS-422 networking. Evaluation of oxygen analyzers and ammonia monitors is in progress.

Contact:
P. A. Mogan, 867-4438, DL-ESS-24

Participating Organization:
McDonnell Douglas Space Station Company (L. H. Allen, V. V. Bukauskas, J. S. Francis, W. L. Gill, and D. G. Garretson)

NASA Headquarters Sponsor:
Office of Space Flight

Evaluation of a Dual Filter Photoacoustic Infrared Hypergolic Fuel Vapor Detector

Objective

To perform an in-depth evaluation of a candidate technology for use in the second-generation Hypergolic Vapor Detection System (HVDS II).

Background

In 1989, a preliminary evaluation of commercially available monomethylhydrazine (MMH) and hydrazine (N_2H_4) detectors was performed at the Kennedy Space Center Toxic Vapor Detection Laboratory (TVDL). The Bruel&Kjaer Model 1302 Toxic Gas Analyzer, although not included in the 1989 preliminary evaluation, was tested September 26 to 29, 1989. Model 1302 uses the infrared absorption principle. The broadband source is filtered by six narrow bandwidth filters. This feature enables Model 1302 to detect up to six gases (water vapor plus five more gases) simultaneously. Model 1302 has a photoacoustic infrared detector that measures pressure fluctuations induced by the temperature changes caused by infrared absorption in a sealed sample chamber.

During this abbreviated evaluation, Model 1302 showed very little relative humidity dependence from 0- to 90-percent relative humidity at 25 degrees Celsius and was able to distinguish between MMH, N_2H_4, and some of the expected interferent gases. Time response, temperature dependence, and long-term performance were not tested. Based on this abbreviated test, a decision was made to include a Bruel&Kjaer Model 1306 toxic vapor photoacoustic infrared detector (PAIR) in the extended test of the four selected technologies (electrochemical, photoionization, optical infrared absorption, and photoacoustic infrared absorption) in 1990. The difference between Model 1302 and the PAIR is that the PAIR sampled only two wavebands (water vapor and one gas) versus the six sampled by Model 1302. The wavebands used in Model 1302 are 2.5 microns and 11.6 microns.

Approach

The extended test consisted of four parts: (1) a basic test at the nominal test condition of 25 degrees Celsius and 45-percent relative humidity, (2) a long-term (30 day) test, (3) an environmental test (temperature/relative humidity extremes), and (4) a special test [including interference gases, N_2H_4 response, and MMH in nitrogen (N_2) response]. The linearity, accuracy, precision, response time, noise, and drift were evaluated throughout all except the special test.

The HVDS II technical requirements against which the PAIR was evaluated are shown in the table "HVDS II Technical Requirements."

Results

The PAIR's performance is summarized in the table "PAIR Performance Summary," and the results of the evaluation are:

1. Range and Accuracy/Linearity: The PAIR, via photoacoustic infrared technology, has the capability of providing several orders of magnitude of range without saturating the detector. The PAIR maintained linearity (see the figure "PAIR Linearity Over the 30-Day Test") and span accuracy (see the figure "PAIR Span Over the 30-Day Test") over the entire test.

2. Precision, Sensitivity, and Noise: The PAIR has a low signal-to-noise ratio because the signal change due to absorption by MMH at the low parts per million (ppm) level is very small relative to the baseline signal. Because of this, the PAIR failed both the sensitivity and noise specifications and could only marginally pass the deviation part of the precision specification.

HVDS II Technical Requirements

Test	Criteria
Range	0 to 30 ppm
Accuracy/linearity	Within ±20 percent or 0.5 ppm of actual
Precision	Span ±10 percent, maximum deviation ±10 percent
Noise	0.3 ppm peak-to-peak (zero and span)
Response time	10 to 90 percent in < 60 seconds
Humidity	Delta span within ±20 percent from 10- to 90-percent relative humidity
Temperature	Delta span within ±20 percent from 0 to 50 degrees Celsius
16-hour zero drift	Zero drift less than ±1 ppm
30-day drift	Span and zero drift less than ±1 ppm
Interferent	Rejection ratio ≥ 500:1
N_2H_4	Measure ±20 percent of actual concentration
MMH in N_2	Measure ±20 percent of actual concentration
Calibration cycle	No calibration for 90 days mandatory (180 days desired)
Maintenance time	No maintenance for 90 days mandatory (180 days desired)
Zero and span	Adjustment present

3. Time Response: The PAIR failed the time response specification. Due to the need to exchange the volume of the test cell, seal the cell, and then measure the sample, the PAIR's average sample cycle time was about 65 seconds. The PAIR's system response time is measured in minutes rather than in seconds. The failure of the PAIR to meet the time response specifications is a limitation of the photoacoustic infrared technology and its implementation.

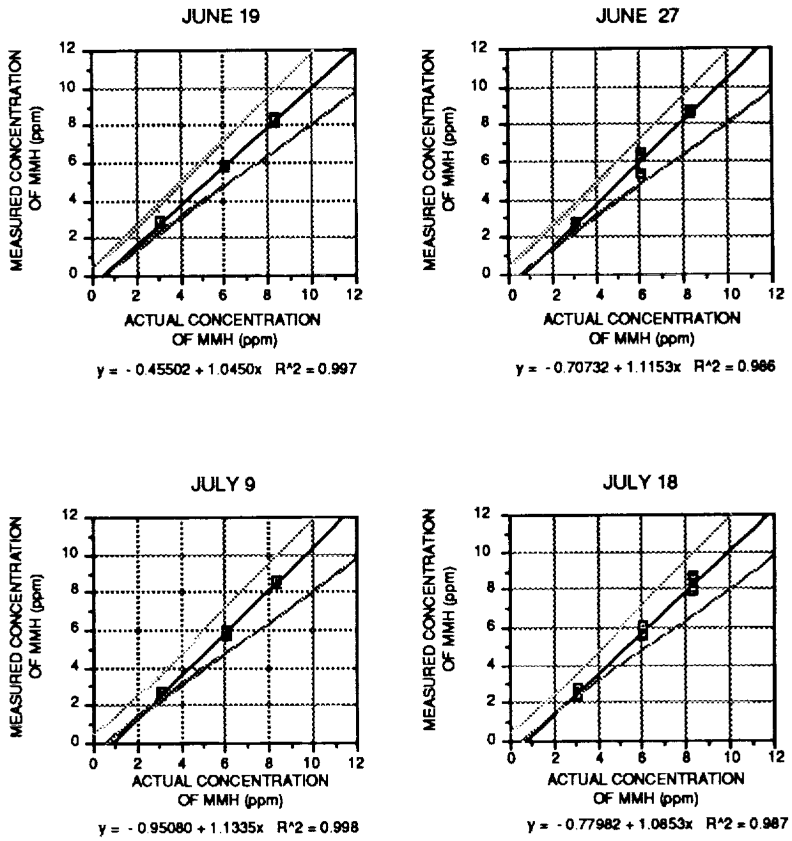
4. Humidity, Temperature, and Drift: An inherent problem in infrared technology is that water vapor absorbs infrared in many wavelengths. However, the PAIR measured water vapor and then subtracted the water vapor contribution to eliminate relative humidity dependence. Readings for three MMH concentrations with relative humidity from 0 to 90 percent are shown in the figure "PAIR Span as a Function of Relative Humidity." The PAIR measurements varied with temperature but only to the extent expected due to the change of the molar volume with temperature (a 10-percent-high reading at -5 degrees Celsius and a 7-percent-low reading at 45 degrees Celsius).

5. Interferents, N_2H_4, and MMH in Gaseous Nitrogen (GN_2): The PAIR failed

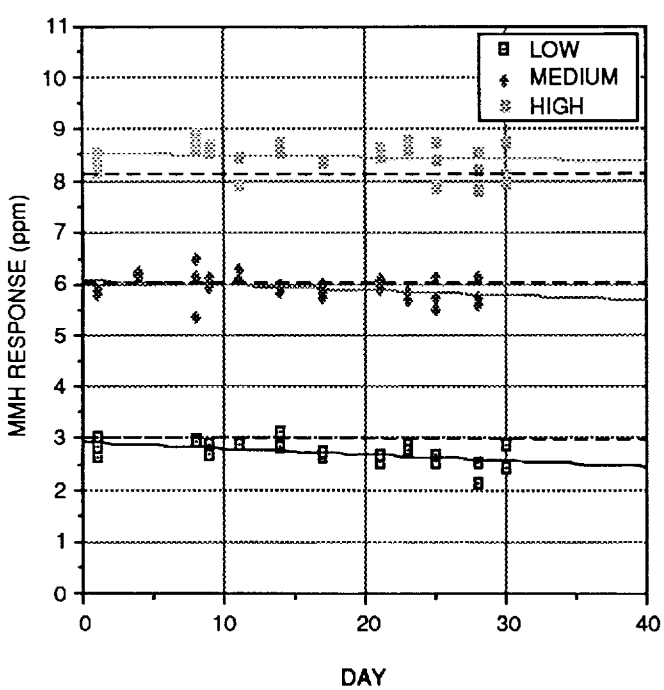
PAIR Performance Summary

Test	Result*	Performance
Range	P	PAIR capable of orders-of-magnitude range
Accuracy/linearity	P	Excellent throughout all tests
Precision	P	Kept span accurately but exceeded deviation limits periodically over time and at high temperatures
Noise	F	Failed the noise specification for the entire test; noise became more than 3 ppm at 50 degrees Celsius
Response time	F	Failed all time response specifications
Humidity	P	Met the specifications on all three relative humidity ramp tests
Temperature	P	Passed for all temperatures
16-hour zero drift	P	Drifted < 0.1 ppm in 16-hour drift test
30-day drift	P	Span drift < 0.4 ppm, zero drift < 0.5 ppm
Interferent	F	Failed all except Freon 114
N_2H_4	F	Failed; average N_2H_4/MMH ratio equaled 0.25
MMH in N_2	P	Passed for entire range
Calibration cycle	P	No re-span/re-zero needed for duration of test
Maintenance time	P	No maintenance performed for duration of test
Zero and span	P	Via remote computer control

**P = Pass; F = Fail*



PAIR Linearity Over the 30-Day Test

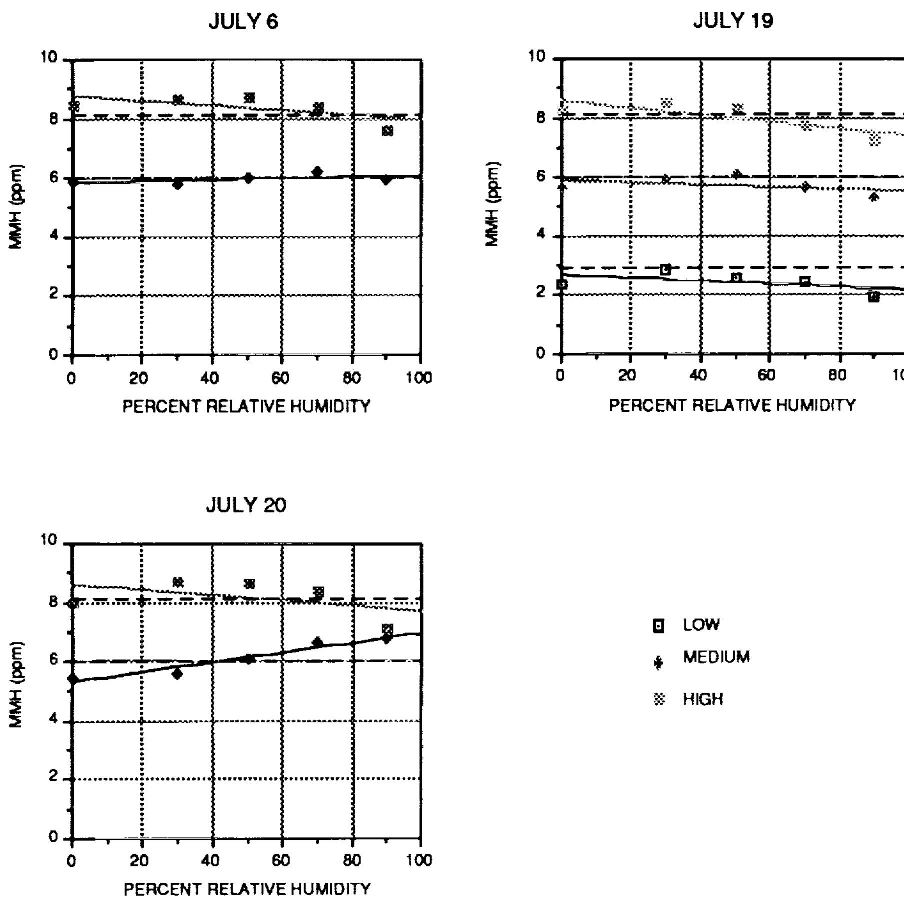


PAIR Span Over the 30-Day Test

the interferent test because most of the gases tested had absorbance peaks that overlapped the MMH peak. The PAIR did not measure N_2H_4 the same as MMH because their absorption is different at 11.6 microns. The PAIR read MMH in GN_2 almost equal to MMH in air because GN_2 is not an infrared absorber.

Conclusion

The PAIR meets the HVDS II specifications, with the exception of the time response, interferent, and N_2H_4 specifications. Of these three deficiencies, the time response is the most difficult to solve because of the relatively long sample cycle required for the photoacoustic infrared



PAIR Span as a Function of Relative Humidity

technology. The time required to exchange and measure the sample makes it nearly impossible for the PAIR to meet the desired time response specifications. The other two shortfalls can be overcome by returning to the Model 1302 detector to provide detection of several discreet wavebands to permit interferents to be removed from the actual sample measurement.

Contact:
R. C. Young, 867-4438, DL-ESS-24

Participating Organization:
Boeing Aerospace Operations, Engineering Support Contract (Dr. T. A. Hammond)

NASA Headquarters Sponsor:
Office of Space Flight

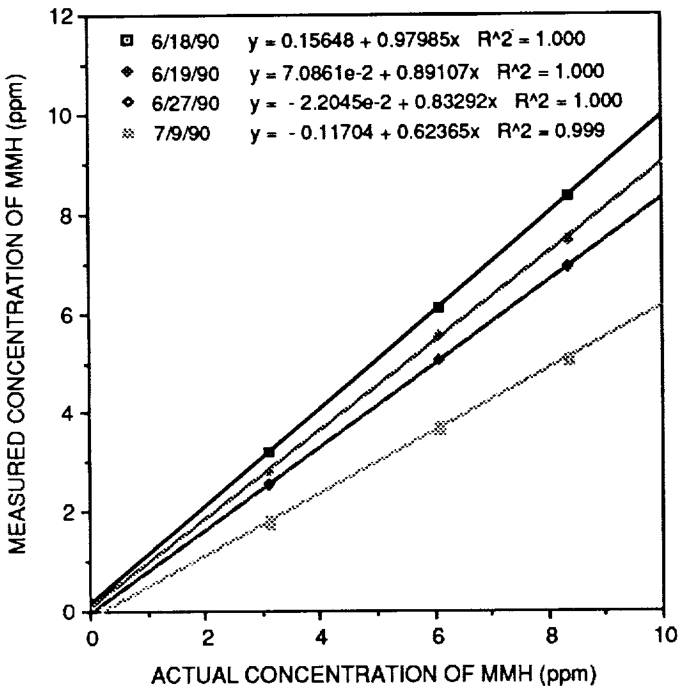
Evaluation of the Interscan RLD Electrochemical Sensor for Hypergolic Fuel Vapor Detection

Objective

To evaluate the Interscan RLD monomethylhydrazine (MMH) electrochemical cell for possible implementation in the second generation of the Hypergolic Vapor Detection System (HVDS II) at Launch Complex 39, Kennedy Space Center.

Background

The current HVDS utilizes an Ecolyzer 7000 Series Draeger three-electrode



Interscan Electrochemical Cell Linearity Over Time

electrochemical cell with an unsupported diffusion membrane and an aqueous caustic (potassium hydroxide) electrolyte. Numerous membranes have ruptured during operation, causing component contamination from the caustic. The constant failures, more importantly, have lowered the level of confidence in the detection system.

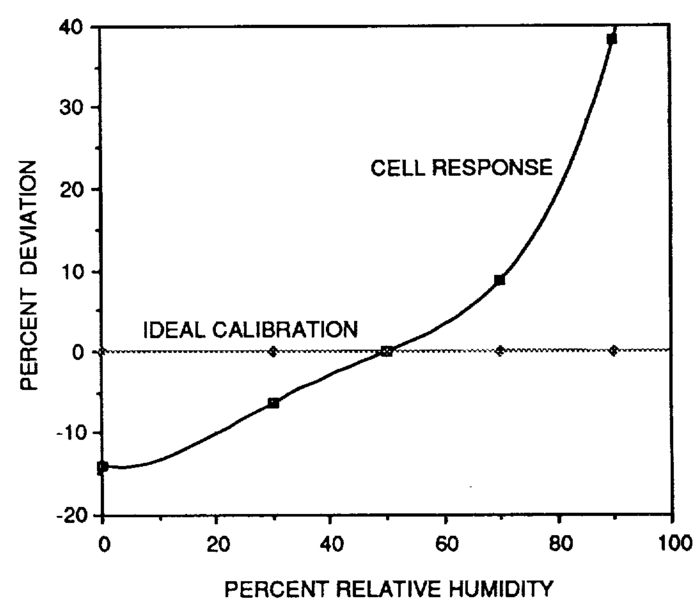
The Interscan RLD electrochemical cell was chosen for evaluation from several other types of electrochemical systems. One factor for the decision was that the cell is constructed so that the diffusion membrane is supported by a nylon mesh and a matrix material of glass wool impregnated with an electrolyte. The cell has a refillable reservoir of deionized water that utilizes a wicking mechanism to wet the upper cell matrix. Another advantage of the system is the two-electrode design (as opposed to the three-electrode Draeger cell), which has demonstrated more stable zero readings.

Approach

The Interscan RLD sensor was tested in a controlled environment to examine its response to various temperatures and relative humidities while exposed to several concentrations of MMH. The electrochemical cell's response to these conditions was characterized over a 30-day drift test. The results were compared to operational parameters for evaluating the HVDS II.

Results

The Interscan RLD demonstrated stable zero and noiseless signal throughout the test. The cell proved to have extremely linear responses but was plagued with continual loss of sensitivity even within 1 day of its calibration. The sensitivity was lowered to below the 20-percent instrument criteria within 14 days.



Interscan Electrochemical Cell Response to Relative Humidity Changes

The Interscan electrochemical cell displayed a slight increase in sensitivity, although within the 10-percent criteria, while the temperature was increased from 15 to 45 degrees Celsius. When the temperature was lowered to -5 degrees Celsius, the sensitivity dropped drastically to 60 percent of the original value, although at -5 degrees Celsius, the deionized water reservoir did not freeze.

The most drastic effect of the cell was its response to MMH at various relative humidities. The lowest response was seen at 0-percent relative humidity and the highest at 90-percent relative humidity. The cell had a tendency to dry out at a lower humidity. When exposed to 0-percent relative humidity overnight, the reservoir would lose up to 15 percent of its water content. During the 30-day drift test at an average of 45-percent relative humidity, the reservoir needed refilling after 3 weeks.

An interference test using various gaseous commodities was performed using a cell calibrated with MMH. The cell did not respond to isopropyl alcohol, Freon 114, Freon 113, and Freon 21, each at a 1000-parts-per-million level. The cell had a greater than 900-to-1 rejection ratio to ammonia. The only commodity that did show a significant response was hydrogen sulfide, with a 33-to-1 rejection ratio.

Conclusion

As it was tested, the Interscan RLD electrochemical cell would not be a viable choice for use in the HVDS II, which requires continuous operation of 90 days without calibration or maintenance. However, changes may be made to ensure more efficient wetting of the electrode, thereby lessening the effect to relative humidity. An automatic refilling device may be used to refill the water reservoir to prevent cell dry out at low relative humidities. With these corrections, the cell may be able to maintain a stable sensitivity to meet the requirements for use in the HVDS II.

Contact:
R. C. Young, 867-4438, DL-ESS-24

Participating Organization:
Boeing Aerospace Operations, Engineering Support Contract (M. J. Beers)

NASA Headquarters Sponsor:
Office of Space Flight

Monomethylhydrazine Active Sampler Using Vanillin Chemistry

Objective

To test and evaluate the vanillin chemistry when used as an active sampler for monomethylhydrazine (MMH) at low concentrations.

Background

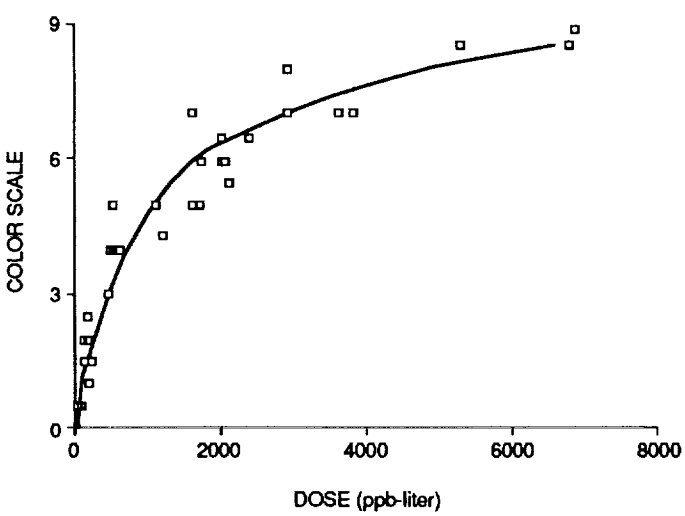
Hydrazines are employed by NASA as hypergolic fuels. The health hazards associated with these chemicals mandate that work areas be monitored to ensure exposures of personnel remain within safe limits. The Naval Research Laboratory (NRL) and GEO Centers, Inc., personnel developed a vanillin chemistry colorimetric badge for the passive sampling of hydrazine vapors under NASA/Kennedy Space Center sponsorship. Recently, the American Conference of Governmental Industrial Hygienists proposed that the threshold limit values of the hydrazines be dropped to 10 parts per billion (ppb) by May 1992. The passive badge responds to hydrazine and MMH at 10 ppb within 45 minutes. In some cases, a faster response is required, so active sampling with a personal sample pump is described here.

Approach

Small cellulose filter disks were coated with a vanillin solution and allowed to dry. Each disk was individually placed in a plastic cassette that allowed the vapor to be drawn through the disk at the rate of the sample pump. Several doses were tested and the disks were evaluated using a color wheel dose estimator. Two sample pump rates were used, 1 and 5 liters per minute. MMH concentrations between 3.2 and 170 ppb were tested.

Results

A good correlation between the MMH dose and the intensity of the yellow color was observed for the tests as shown in the figure "Color Badge." The results were independent of the sample rate, indicating that if the results are needed five times faster, the rate could be increased by five. This is a rapid way to detect a low concentration. One application is to be used to determine if an area is safe for entry. The technology could be adapted in an automated instrument such as a paper tape instrument.



Color Badge

Contact:
R. C. Young, 867-4438, DL-ESS-24

Participating Organization:
Naval Research Laboratory (S. Rose-Pehrsson)

GEO Centers, Inc. (P. Carver)

NASA Headquarters Sponsor:
Office of Space Flight

Multispectral Imaging of Hydrogen Flames

Objective

To develop a room-temperature imaging system using multispectral television (MTV) techniques that can detect and display hydrogen flames, discriminate them from other infrared sources, and interface compatibly with the existing Launch Complex 39 Operational Television System (OTV).

Background

A better instrument that can reliably detect and display the presence of a hydrogen fire has been on the Shuttle program's "want list" for some time. When the Shuttle's STS-14 launch aborted with a "cutoff" after "main engine start," the existing hydrogen fire detectors went into alarm. This condition signals a hydrogen fire on the launch pad. With the current detectors, the exact location and intensity of the fire was indeterminable. The launch team had insufficient information to react adequately to the problem and quickly ensure the safety of the crew, associated flight systems, and ground support equipment. As a result of this event, efforts were initiated to develop a solution that would provide information about not only the presence but also the location and intensity of a hydrogen fire. MTV is one of these efforts.

Approach

As reported in the Research and Technology 1989 Annual Report and summarized here, a multispectral imaging system was conceived. The system used two infrared regions and the visible region, the theory being that most of the light emission from a hydrogen fire exists in the middle-to-far infrared regions. Additionally, the visible image provides background information to establish the field of view. Although some emission exists in the ultraviolet region and originally was considered as an input to the imaging system, testing showed that the amount of usable information from the ultraviolet signal was minimal. Therefore, the ultraviolet spectrum was removed as a considered input to the system.

Results

The fundamental concept and general principles were demonstrated using a first-generation prototype. This initial effort proved the proposed approach for detecting and imaging hydrogen fires was achievable. It represents a viable method for developing an aerospace quality instrument for use in launch operations.

The accomplishments thus far have included designing, producing, and testing a second-generation prototype. This design featured measuring three specific infrared wavelengths through the application of lenses and a rotating filter wheel. The selected filters in the wheel permitted viewing in three spectral regions: (1) one region where the presence of water vapor exists, (2) a second spectral region where carbon dioxide exists, and (3) a third spectral region located between regions one and two.

The information from the infrared detectors was converted to video and the three signals fed to the red-green-blue (RGB) inputs of a video genlock converter. A charge-coupled device (CCD) camera was configured to provide background visual information of the identical area viewed by the infrared lens. A genlock converter mixes the CCD video and the RGB video and displays them on a color monitor. Although testing on this second-generation unit was successful in detecting and discriminating hydrogen flames among varied background effects, the results revealed some typical development problems. Simple lenses led to both spherical and chromatic aberration effects. The system experienced stability problems in the frame buffers. Conversion and mixing of the RGB input with the CCD video, although acceptable, required excessive circuitry to achieve compatibility.

As a result of these accomplishments and test results, a third-generation design has begun. This design will provide a comprehensive system prototype demonstrating the new designs, such as beam-splitting techniques and improved video processing that will eliminate the problems experienced thus far during the development.

Future Plans

The next series of efforts will have two parts. Part one will complete the design and development of the third-generation camera system. Part two will construct a prototype for testing and demonstration to the potential users and managers of the system. The third-generation unit will be a field-usable, digital version. A special effort will be required to design, develop, and fabricate an infrared zoom lens to include this performance feature in the camera. Once the performance of the third-generation prototype has proven acceptable to the customer, documentation for acquiring a first-production MTV article will be prepared. Fabrication of the unit will be achieved by an outside contract.

Contact:
J. D. Collins, 867-4449, DL-ESS-24

Participating Organization:
Boeing Aerospace Operations, Engineering Support Contract (Dr. R. C. Youngquist and Dr. S. Gleman)

NASA Headquarters Sponsor:
Office of Space Flight

Color Chemistry for Nitrogen Dioxide Detection

Objective

To investigate the use of color chemistries as indicators for realtime colorimetric detection of nitrogen dioxide (NO_2). The chemistry will be applied for the development of NO_2 dosimeters.

Background

NO_2 is the oxidizer employed in the Space Shuttle program. Large quantities of NO_2 are stored at Kennedy Space Center and carried on the Shuttle for each mission. Due to the toxicity of NO_2 at high concentrations, a short-term exposure limit (STEL) of 1 part per million (ppm) has been established by the American Conference of Governmental Industrial Hygienists. To minimize risk, monitoring of employees and their work environments is necessary.

Approach

Initial investigations identified several promising chemistries for NO_2 detection, including benzidines, amines, naphthalenes, benzoic acids, and phenols. Most of the compounds proved to have a high sensitivity to ambient concentrations of NO_2. After initial testing was completed, ortho-tolidine (3,3-dimethylbenzidine) was selected for further evaluation. Ortho-tolidine has the needed sensitivity and little ambient NO_2 response over an 8-hour period. Ortho-tolidine exhibits a sunlight sensitivity that is being pursued at present.

The reaction that occurs between ortho-tolidine and NO_2 yields a green color. Several materials (filter paper, woven absorbent substrates, and Amberlite cation exchange resin) were investigated as substrates for the ortho-tolidine. Filter paper is convenient and performs well. It will be used for continued laboratory evaluations.

Results

Laboratory investigations indicated good correlation between dose and color intensity. A visual indication is noted almost immediately upon exposure to 0.5 part per million (ppm) of NO_2. Badges exposed to low doses of NO_2 develop pale mint green to mint green-blue colors. Exposure to doses up to approximately 15 ppm-min gives grey-green shades. Higher doses give olive-toned colors. Badges exposed to 200 ppm-min develop forest green and brown shades.

Initial interference tests indicated that ozone is a potential interferent. Exposure to ozone caused the badges to quickly develop a golden tan color. Subsequent exposure to 15 ppm-min of NO_2 indicated that the badge still reacts with the NO_2. It developed a grey-green color over the initial tan shade. When badges were exposed to 300 ppm-min of ammonia (NH_3) after exposure to 15 ppm-min of NO_2, they developed a sand brown color. However, exposure to NH_3 alone was not an interferent and did not hinder subsequent color development upon exposure to NO_2. Exposure to 270 ppm-min of NO after exposure to NO_2 did not cause a shift in color. Exposure to NO prior to NO_2 caused badges to develop a very pale yellow-green discoloration but did not impede the development of color from a subsequent exposure to NO_2.

Contact:
R. C. Young, 867-4438, DL-ESS-24

Participating Organization:
Naval Research Laboratory (S. Rose-Pehrsson)

NASA Headquarters Sponsor:
Office of Deputy Administrator

Evaluation of Realtime Portable Nitrogen Dioxide Detectors

Objective

A comparative evaluation of four nitrogen dioxide (NO_2) detectors was undertaken for the purpose of finding a new and reliable portable detector to support hypergolic oxidizer operations at the Kennedy Space Center. A new instrument is required to meet the Occupational Safety and Health Administration (OSHA) short-term exposure limit (STEL) of 1.0 part per million (ppm) because the approved Ecolyzer Model 6300 is no longer manufactured and spare parts may soon become unavailable.

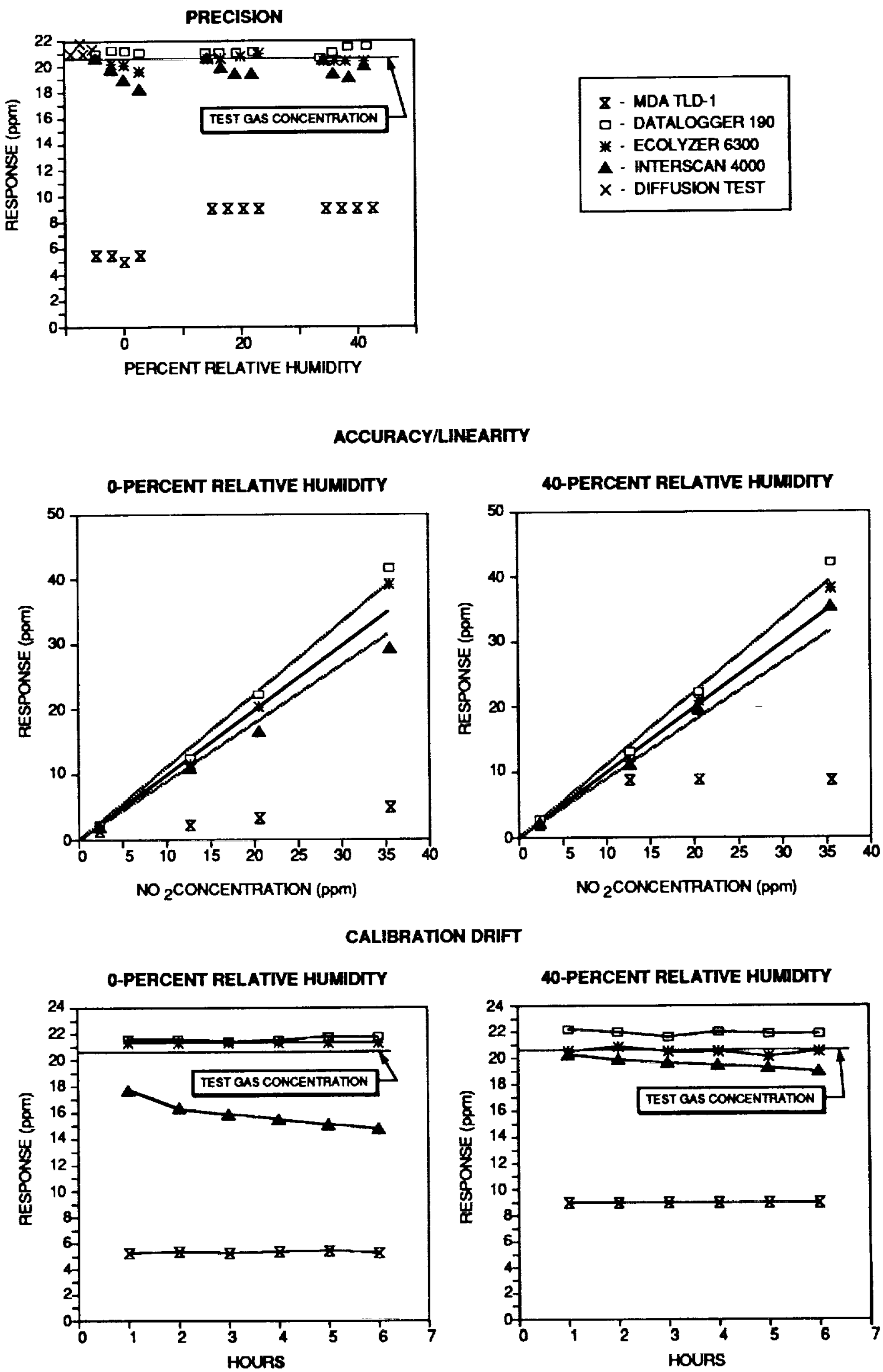
Background

Hypergolic nitrogen tetroxide (N_2O_4), used for propulsion in the space program, is not only highly energetic but also very toxic. A reliable detector is essential to ensure that the environments in work areas such as the Orbiter Processing Facility (OPF), the Hypergolic Maintenance Facility (HMF), hypergol storage areas, and Launch Pads 39A and 39B do not contain N_2O_4 vapor exceeding the STEL of 1.0 ppm. Personnel must work in these areas for extended periods of time.

Approach

Laboratory evaluations were conducted on four instruments: the Ecolyzer Model 6300, the National Draeger Datalogger Model 190, the Interscan Model 4000, and the MDA Model TLD-1. The TLD-1 employs a photo-optical system to measure the degree of color change on a chemically impregnated paper tape cassette. The Ecolyzer, Datalogger, and Interscan models use electrochemical cells to measure the change in current occurring at the electrodes.

The Ecolyzer, Interscan, and TLD-1 use an internal pump to transport the sample to the detector, whereas the Datalogger works on the passive diffusion principle. All four units are battery powered. The Ecolyzer, Interscan, and Datalogger were calibrated in the laboratory at a midrange of 20.6 ppm (approximately 20 percent fullscale) and at a near STEL concentration of 1.24 ppm. The



High-Range Calibration

TLD-1 provides no calibration adjustment; it was calibrated by the manufacturer. The parameters tested were accuracy/linearity, precision, calibration drift, response time, and humidity effects at 0-, 20- and 40-percent relative humidity.

Results

The responses of the Ecolyzer, Interscan, and Datalogger were more accurate over the entire range when calibrated at the higher concentration of NO_2. A change in relative humidity did not appear to affect the responses. The response of the TLD-1 was less accurate and appeared to become more sensitive to an increase in relative humidity.

The precision of the Interscan improved with an increase in relative humidity, while the precision of the other units did not exhibit any significant effects due to changes in relative humidity.

The Ecolyzer and Datalogger showed minor negative drift, but neither was significantly affected by a change in relative humidity. The TLD-1 responses were consistent, but an increase in the readings was noted as the relative humidity increased. The Interscan exhibited a decrease in the magnitude of drift with an increase in relative humidity. This was due to the capillary action of the matrix material employed by the Interscan cell as a means of keeping the sensing electrode "wet" during operation of the unit.

The TLD-1 is preset to update the reading every 30 seconds and did yield a final stable reading for the high-calibration gas concentration after 30 seconds; however, it took two reading cycles or 60 seconds for a stable value at the low concentration. The response time to 90 percent of the final reading was 15 seconds or less at the calibration gas concentrations for the Ecolyzer, Interscan, and Datalogger.

Contacts:
R. C. Young, 867-4438, DL-ESS-24
A. R. Thurow, 867-0512, WT

NASA Headquarters Sponsor:
Office of Space Flight

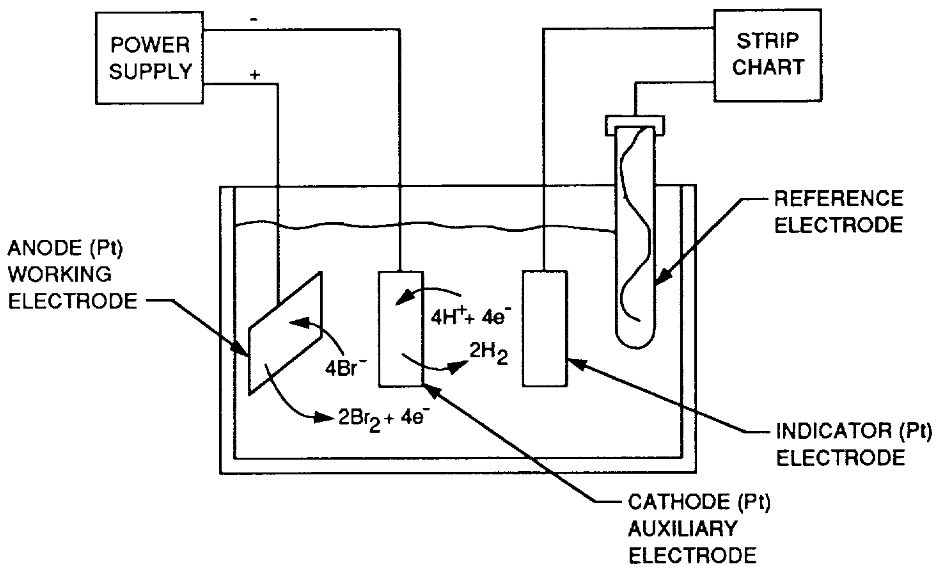
Detection of Parts-Per-Billion Concentrations of Monomethylhydrazine Vapor in Air by the Coulometric Method

Objective

To evaluate the vapor scrubbing system and the coulometric analysis procedure used at Kennedy Space Center (KSC) for detecting low parts-per-billion (ppb) concentrations of monomethylhydrazine (MMH) vapor in air.

Background

MMH is used as hypergolic propellants for the inflight Shuttle maneuvering systems. MMH vapor is highly toxic and has been shown to cause mutagenic activity. The American Conference of Governmental Industrial Hygienists has proposed to reduce by 1992 the acceptable threshold limit value of MMH to 10 ppb from the current 200 ppb. A coulometric analysis procedure has been in use for many years at KSC for the detection of parts-per-million concentrations of hydrazines. The KSC Toxic Vapor Detection Laboratory conducted an experiment to evaluate the feasibility of using the coulometric analysis procedure for ppb-level detection.



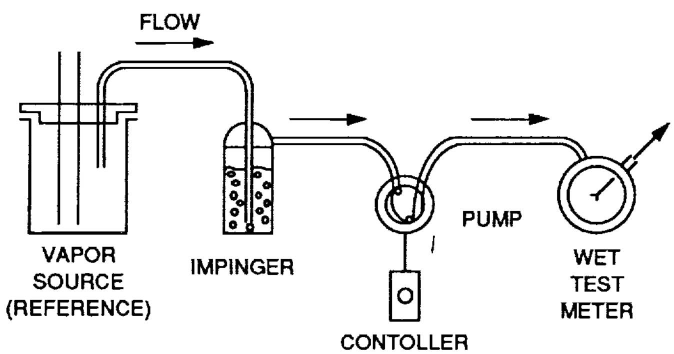
Typical Standard Coulometric Titration System

Approach

The test vapors are generated by using a Kin-Tek Span Pac 361 precision standard vapor generator in conjunction with a Miller-Nelson HCS-301 flow-humidity-temperature control system. The Span-Pac consists of three permeation devices housed individually in three temperature-controlled ovens. Each permeation device is a stainless-steel Dewar containing a coil of polymeric capillary tubing submerged in MMH. Nitrogen flows through the polymeric tubes at all times, carrying MMH vapor which permeates through the polymeric tubing. Standard vapors at various relative humidities may be generated by diluting the MMH-nitrogen mixture with conditioned air from the Miller-Nelson unit. By activating the SPAN or ZERO mode in conjunction with activating a combination of channel switches of the permeation devices on the Kin-Tek vapor generator, zero air and various concentrations of MMH vapor may be generated at a required percent relative humidity. This experiment used MMH vapors 3 to 149 ppb at approximately 80-percent relative humidity.

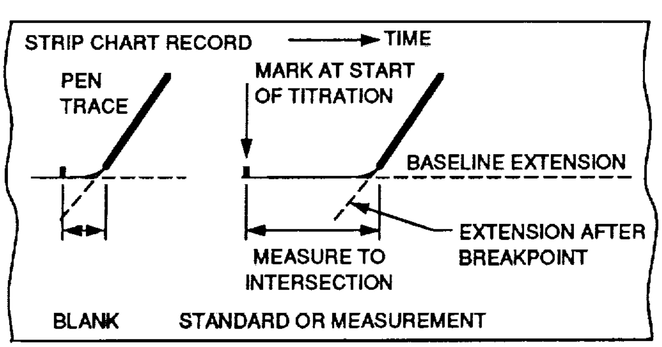
The circuits of the coulometric analysis system are shown in the figure "Typical Standard Coulometric Titration System." The oxidant generator circuit consists of a platinum anode (+), an auxiliary platinum cathode (-), and a constant-current power supply. The potential monitoring circuit contains a platinum indicator electrode, a reference electrode, and a strip-chart recorder. Quantification of MMH is obtained by counting the electrons produced by the oxidation of the analyte since each mole of MMH produces 4 moles of electrons. The electrons produced enter an electric circuit and are counted by integrating the electric current as a function of time, since time and current are related to the number of electrons by the Faraday constant (96,484.56 ampere-seconds per mole). In other words, the time or net recorder chart distance required for reaction is directly related to MMH concentration in the scrubbed solution.

MMH vapors were scrubbed through a straight glass tube impinger containing 25 milliliters of 0.1-Molar sulfuric acid (H_2SO_4) as the scrubbing solution at 0.8 to 1 liter per minute. A wet test meter monitored the volume of the MMH vapor passing through the impinger. For all vapor concentrations studied, 15 liters of the MMH vapors were scrubbed, except for concentrations less than 10 ppb, where 30 liters were scrubbed in order to have sufficient response above the background reading. Most of the scrubbing used a single impinger. Two impingers in series were used only for the determination of the absorbing efficiency of the scrubbing solution. The standard laboratory sampling setup is presented in the figure "Vapor Collection System Setup."



Vapor Collection System Setup

For the analysis of the scrubbing solutions, approximately 0.4 gram of potassium bromide (KBr) crystals were dissolved in the scrubbing solution. A direct electric current passing through the solution electrolyzed the KBr at the anode to produce bromine (Br_2), which immediately oxidized the MMH present in the scrubbing solution. The time required to complete the reaction (see the figure "Measurement of Coulometric Titration Length") corresponded to the amount of MMH present in the solution. Proper coulometric operation was checked by reacting with a standard solution of MMH.



Measurement of Coulometric Titration Length

MMH vapor concentration was calculated using the following formula:

ppb (in air) = [net titration length in centimeters x 0.38 x 10^3] / [chart speed (centimeters per minute) x liters of vapor scrubbed]

where

0.38 = [(10^{-4} amperes) x (60 seconds per minute) x (24.5 liters per mole) x (106 microliters per liter)] / [(9.65 x 10^4 ampere-seconds per mole-electron) x (4 mole-electrons per mole)]

No volume correction was applied since all the MMH vapor scrubbing was done at 23 to 25 degrees Celsius and at 1 atmospheric pressure.

Results

1. Efficiency of the Vapor Scrubbing Solution

   The efficiency results obtained for the various MMH vapor standards are presented in the table "Efficiency of the Vapor ScrubbingSolution." There was no carryover of MMH vapor into the second impinger except for the 149-ppb MMH standard, where a slight carryover was observed. A higher scrubbing volume (during an overnight run) resulted in a carryover into the second impinger for the standards at 42 ppb. The data indicate that scrubbing volumes of 15 liters for vapors above 10 ppb and 30 liters for vapors under 10 ppb are optimal and that the 0.1-Molar H_2SO_4 is an efficient medium for absorbing the MMH vapors at low-ppb levels without any carryover losses.

*Efficiency of the Vapor Scrubbing Solution**

MMH Vapor Standard	Liters of Vapor Scrubbed	Average MMH in First Impinger (ppb)	MMH in Second Impinger (ppb)
Std-7.5	30	2.7	-
Std-20	15	7.2	-
	15	8.0	-
	30	5.7	-
Std-79	15	21.0	0
Std-158	15	42.0	0
	831	38.0	<1
Std-316	15	78.0	0
	836	84.0	2
Std-632	15	149.0	2

**Notes:* *Temperature: 23 to 25 °C*
Relative humidity: 80 to 81 percent
Scrubber volume: 25 milliliters
Scrub rate: 0.8 to 1 liter per minute

2. Precision of the Analytical Procedure

The precision study of the analytical procedure included the sample collection system as well as the coulometric analysis. Data obtained for a series of MMH vapor standards are presented in the table "Precision of the Analytical Procedure." The variation for most of the vapor standards was found to be approximately 10 percent or less.

3. Coulometer Response to MMH

The net chart distance obtained in centimeters at a chart speed of 2 centimeters per minute in the coulometric analysis versus the MMH vapor concentration is presented in the figure "Instrument (Coulometer) Response to MMH." The curve demonstrates the consistency in the coulometric response in determining MMH in the absorbing solution. It also demonstrates a linear response to the MMH vapor concentrations, ranging from 3 to 149 ppb, analyzed in accordance with the prescribed laboratory test procedure.

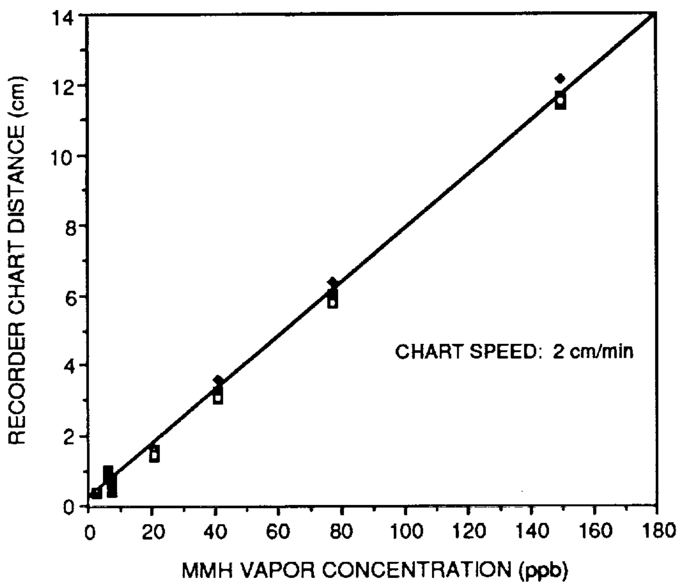
4. Spiking of the Scrubbing Solution Containing MMH

Spiking of the various MMH vapor standards was performed using 0.1-Molar H_2SO_4 scrubbing solutions containing 72- and 7.9-ppb MMH. The purpose of

Precision of the Analytical Procedure
(Sample Collection and Coulometric Analysis)

	Std-7.5	Std-20	Std-20	Std-79	Std-158	Std-316	Std-632
Run 1 (ppb)	2.2	7.6	6	22	42	79	146
Run 2 (ppb)	2.5	8.2	5.4	22	47	82	156
Run 3 (ppb)	2.5	7.6	6.3	20	43	75	150
Run 4 (ppb)	2.9	8.2	5.7	22	41	79	147
Run 5 (ppb)	2.5	8.2	6	19	41	77	147
Run 6 (ppb)	2.9	8.2	5.1	19	39	74	147
Run 7 (ppb)	2.9	-	5.4	-	42	-	-
Run 8 (ppb)	2.9	-	5.9	-	44	-	-
Average (ppb)	2.7	8	5.7	21	42	78	149
Variation (ppb)	2.7+0.2 2.7-0.2	8+0.2 8-0.4	5.7+0.6 5.7-0.6	21+1 21-2	42+5 42-3	78+4 78-4	149+7 149-3
Percent variation	7	3 to 5	11	5 to 10	7 to 12	5	2 to 5
Standard deviation	0.27	0.31	0.4	1.51	2.39	2.94	3.76
Percent coefficient of variation	10	3.9	7	7.2	5.7	3.8	2.5

***Note:** 15-liter vapor scrub volume data used for all standards, except 30-liter vapor scrub volume data used for Std-20 and Std-7.5.*



Instrument (Coulometer) Response to MMH

this study was to determine the amount of spiked MMH vapor that could be recovered. Data obtained are presented in the table "Recovery of Spiked MMH Vapor." The results reflect that the average percent recovery for all of the standard MMH vapors spiked into the scrubbing solution containing a known amount of MMH was in the range of 81 to 113 percent, except for the 15-liter Std-20 runs, where the average percent recovery was 71 percent. However, the 30-liter Std-20 runs yielded 105 and 103 percent recovery for scrubbing solutions containing 72- and 7.9-ppb MMH, respectively.

5. Detection Limit of the Analytical Procedure

The detection limit of an analytical procedure is normally a factor of the baseline noise in any analytical instrumentation. In coulometric analysis, the type of baseline information obtained is a line trace. It was decided to use the detection limit equal to the line trace obtained by running the blank scrubbing solution through the coulometric titration procedure. The blank solution yielded an average chart distance of approximately 0.4 centimeters at a chart speed of 2 centimeters per minute, which when calculated equated a value of approximately 5 ppb; hence, 5 ppb was selected as the theoretical detection limit of the analytical procedure.

6. Detection Limit of the Overall Method

The detection limit of the overall method is the amount of MMH spiked that allows recovery equivalent to the detection limit of the analytical procedure. It was decided to evaluate if it would be possible to go below 5 ppb as the detection limit of the overall procedure. A set of six absorbing solutions containing 2.1-ppb MMH were spiked with a 2.7-ppb MMH vapor standard using 30 liters of the scrubbing volume. The MMH concentrations recovered are presented in the table "Detection Limit and Reliable Quantitation Limit for MMH." The detection limit of the overall procedure is less than 5 ppb.

7. Reliable MMH Quantitation Limit

The reliable quantitation limit is the smallest amount of MMH that can be quantified with at least 75-percent recovery and better than plus or minus 25-percent precision. The data (see the table "Detection Limit and Reliable Quantitation Limit for MMH") obtained for spiking 30 liters of 5.7-ppb MMH vapor into six absorbing solutions containing 7.9-ppb MMH were used to calculate the reliable quantitation limit.

Recovery of Spiked MMH Vapor

MMH Vapor Standard	MMH in Solution (ppb)	MMH Spiked (ppb)	MMH Found (ppb)	Percent Recovery	Average
Zero gas	72	0	72+1 72+0 72+1		
Std-20	72	7.2	72+5.1 72+5.1 72+5.1	71 71 71	71
Std-20	72	5.7*	72+5.7 72+6.3	100 111	105
Std-79	72	21	72+17 72+15 72+20 72+16	81 71 95 76	81
Std-158	72	42	72+39 72+38 72+33 7.9+18 7.9+18 7.9+18	93 91 79 86 86 86	88
Std-20	7.9	7.2	7.9+8.9 7.9+7.6 7.9+7.6 7.9+8.2	124 106 106 114	113
Std-20	7.9	5.7*	7.9+6.3 7.9+6.0 7.9+5.3 7.9+5.7 7.9+6.0 7.9+6.0	111 105 93 100 105 105	103
Std-79	7.9	21	7.9+19 7.9+18 7.9+18 7.9+18	91 86 86 86	87
Std-158	7.9	42	7.9+36 7.9+36 7.9+37 7.9+36	86 86 88 86	87
Std-316	7.9	78	7.9+78 7.9+77 7.9+79 7.9+77	100 99 101 99	100

****30-liter spikes; all others were 15-liter spikes***

Detection Limit and Reliable Quantitation Limit for MMH

MMH in Solution (ppb)	MMH Spiked (ppb)	Run	MMH Recovered (ppb)	Percent Recovery
7.9	5.7	1	6.3	111
7.9	5.7	2	6.0	105
7.9	5.7	3	5.3	93
7.9	5.7	4	5.7	100
7.9	5.7	5	6.0	105
7.9	5.7	6	6.0	105
		Average:	5.9	103
Standard deviation: 6.1 Precision at 1.96 standard deviation = ±12 percent				
2.1	2.7	1	2.9	107
2.1	2.7	2	2.5	93
2.1	2.7	3	2.2	81
2.1	2.7	4	2.2	81
2.1	2.7	5	2.2	81
2.1	2.7	6	2.2	81
		Average:	2.4	87
Standard deviation: 10 Precision at 1.96 standard deviation = ±20 percent				

The average percent recovery of six runs was 103 percent and the precision was plus or minus 12 percent. Since the precision obtained was better than required by the Occupational Safety and Health Administration methodology, it was decided to use the data for spiking 30 liters of 2.7-ppb MMH vapor into six absorbing solutions containing 2.1-ppb MMH. The average percent recovery was 87 percent and the precision was plus or minus 20 percent; hence, it is appropriate to consider 3 ppb as the reliable quantitation limit of the method.

<u>Conclusion</u>

The experiment demonstrates that the MMH vapor scrubbing system and the coulometric analysis procedure can be utilized for reliably detecting MMH vapor in air as low as 3 ppb. The estimated sampling and analysis time required per sample is approximately 30 minutes.

Contact:
R. C. Young, 867-4438, DL-ESS-24

Participating Organization:
University of Puerto Rico
(Dr. N. K. Mehta)

NASA Headquarters Sponsor:
Office of Deputy Administrator

Hydrogen Dispersion Nozzle Testing

During cryogenic loading of the Space Shuttle Columbia, leak detectors measured excessive hydrogen leakage in the 17-inch

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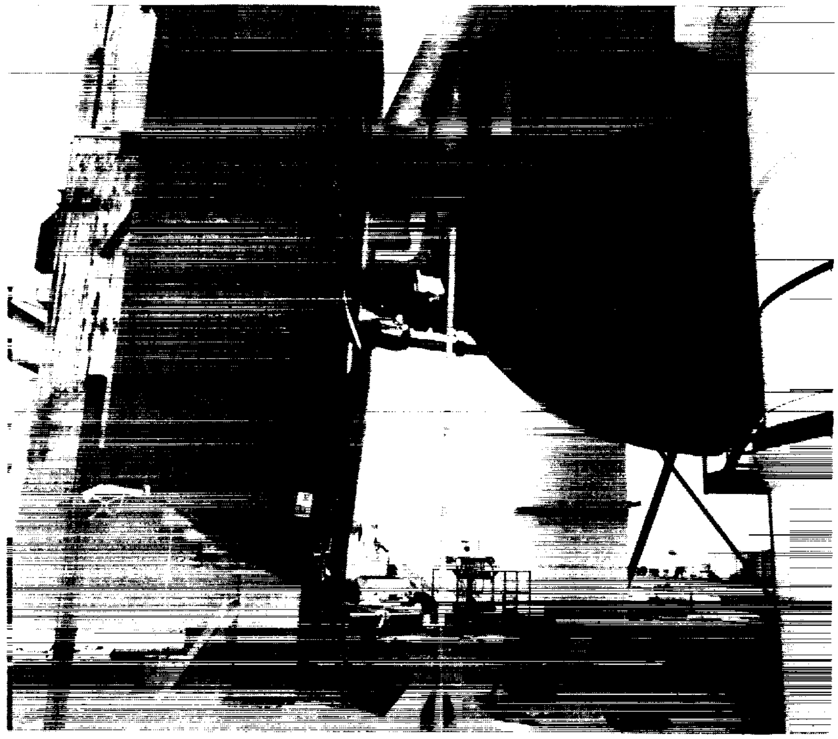
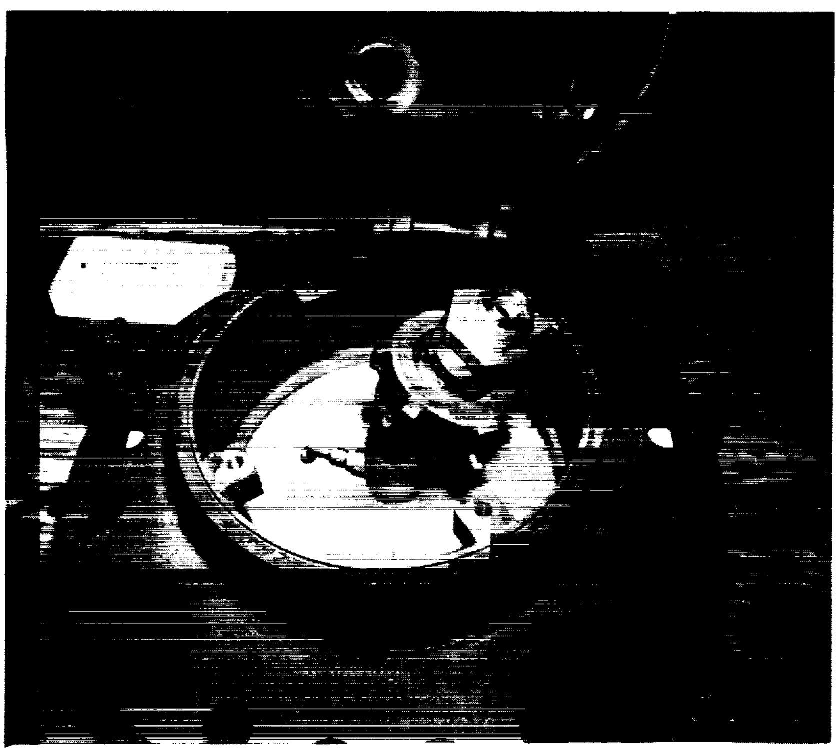
line between the external tank and the Orbiter. This problem continued through several liquid hydrogen loading tests conducted to determine the location and cause of the leakage.

In an effort to disperse hydrogen leaks if they occur, a hydrogen dispersion nozzle, shown in the figure "Hydrogen Dispersion Nozzle," was designed to blow high-pressure nitrogen gas from under the external tank to the hydrogen leak area. A test was performed at Kennedy Space Center's Launch Equipment Test Facility with full-size mockups of the external tank, solid rocket motors, a portion of the Shuttle wing, and the connecting piping setup as shown in the figure "Hydrogen Dispersion Nozzle 17-Inch Disconnect Leak Test Setup." The nozzle is shown at the bottom of the left side of the left solid rocket motor.



Hydrogen Dispersion Nozzle 17-Inch Disconnect Leak Test Setup



Hydrogen Dispersion Nozzle

The supersonic nozzle was designed for a 750-standard-cubic-foot-per-minute gaseous nitrogen flow with a 125-pound-per-square-inch inlet pressure. Hydrogen leakage was simulated by chilling gaseous hydrogen with a liquid nitrogen heat exchanger and passing the cold hydrogen to the simulated leak area through a 1/4-inch tube with orifices sized for 10-, 5-, and 2-standard-cubic-foot-per-minute leak rates. Hydrogen leak data was taken around the 17-inch line disconnect at the

Orbiter mockup and the 48-bolt flange line. Hydrogen leak detectors with 14 channels of continuous sampling at 1 sample per second were used. A mass spectrometer with eight channels manually selected was also used. Wind velocity was measured using three axis propeller anemometers.

Wind was simulated using a large fan to produce 20-knot winds. Tests were also run to determine if the nozzle would blow the ice or debris particles against the Orbiter wing by dumping ice and debris on the nozzle.

Tests were successful in determining that the nozzle is effective in partially dispersing hydrogen leakage. A nozzle has been installed on Mobile Launcher Platform 2.

Contact:
F. S. Howard, 867-4181, DM-MED-11

Participating Organization:
Boeing Aerospace Operations, Engineering Support Contract

NASA Headquarters Sponsor:
Office of Space Flight

Evaluation of an Optical Infrared Hypergolic Fuel Vapor Detector

Objective

To perform an in-depth evaluation of an optical infrared detector for use in the second-generation Hypergolic Vapor Detection System (HVDS II)

Background

A preliminary evaluation of commercially available monomethylhydrazine (MMH) and hydrazine (N_2H_4) detectors was performed at the Kennedy Space Center NASA Toxic Vapor Detection Laboratory (TVDL) in 1989. None of those instruments was able to satisfy the desired performance objectives for the HVDS II; therefore, four technologies (electrochemical, photoionization, optical infrared absorption, and photoacoustic infrared absorption) were selected for refinement and further testing in 1990. The Foxboro Miran 101 Specific Vapor Analyzer with an 11.3-micron filter was the infrared detector selected for engineering modification.

Two deficiencies in the Foxboro Miran were uncovered during the preliminary evaluation: (1) the detector output signal took a long time to stabilize and (2) the zero output drifted significantly, especially with respect to temperature change. The Optics Instrumentation Laboratory of the Engineering Design Laboratory modified both the optics and the electronics modules to remove these deficiencies. The modified detector was redesignated, and the Dual Element Digital Sampler (DEDS) was used in the extended test.

Approach

The DEDS was tested with three other instruments: the Interscan electrochemical detector, the IO photoionization detector, and the Bruel&Kjaer (B&K) photoacoustic infrared detector. The extended test consisted of four parts: (1) a basic test at the nominal test condition of 25 degrees Celsius and 45-percent relative humidity, (2) a long-term (30 day) test, (3) an environmental test (temperature/relative humidity extremes) and (4) a special test [including interference gases, N_2H_4 response, and MMH in nitrogen (N_2) response]. The linearity, accuracy, *HVDS II Technical Requirements*

Test	Criteria
Range	0 to 30 ppm
Accuracy/linearity	Within ±20 percent or 0.5 ppm of actual
Precision	Span ±10 percent, maximum deviation ±10 percent
Noise	0.3 ppm peak-to-peak (zero and span)
Response Time	10 to 90 percent in < 60 seconds
Humidity	Delta span within ±20 percent from 10 to 90 percent relative humidity
Temperature	Delta span within ±20 percent from 0 to 50 degrees Celsius
16-hour zero drift	Zero drift less than ±1 ppm
30-day drift	Span and zero drift less than ±1 ppm
Interferents	Rejection ratio ≥ 500:1
N_2H_4	Measure ±20 percent of actual concentration
MMH in N_2	Measure ±20 percent of actual concentration
Calibration cycle	No calibration for 90 days mandatory (180 days desired)
Maintenance time	No maintenance for 90 days mandatory (180 days desired)
Zero and span	Adjustment present

precision, response time, noise, and drift were evaluated throughout all except the special test. The DEDS was evaluated against the HVDS II technical requirements as shown in the table "HVDS II Technical Requirements."

Results

The DEDS performance is summarized in the table "DEDS Performance Summary" and the results of the evaluation are:

1. Range, Accuracy/Linearity: The DEDS, via optical infrared technology, provides several orders of magnitude or range without saturating the detector. The DEDS maintained linearity (see the figure "DEDS Linearity Over the 30-Day Test") and the ability to read a differential span (see the figure "DEDS Span Over the 30-Day Test") over the entire test. The differential span is the average actual span reading minus the average actual zero reading immediately prior to the change of concentration. This value was necessary because the zero drifted upward continuously due to the gradual degradation of the mirors in the DEDS gas cell. The deterioration of the mirror caused the amount of infrared light reaching the detector to decrease, which was interpreted as an MMH response. The deterioration of the mirrors did not change the differential

span reading because the MMH concentration is measured by the change of transmittance from the established zero value.

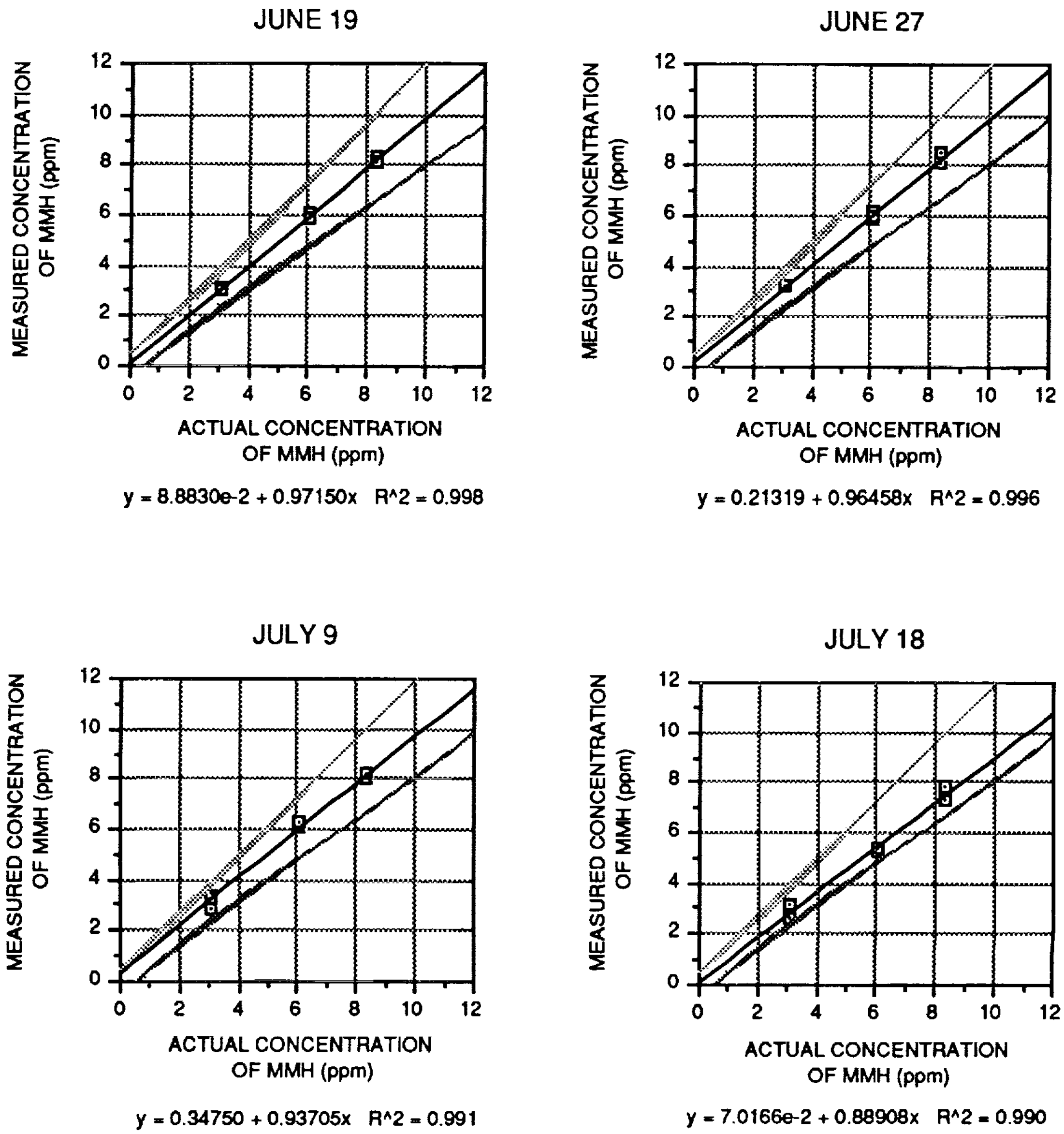
2. Sensitivity and Noise: The DEDS failed the sensitivity and noise specifications because it had a very low signal-to-noise (S/N) ratio. The low S/N ratio is due in part to the infrared technology but was significantly decreased further by the poor initial and continually degraded condition of the gas cell mirrors. The sensitivity and noise of the DEDS were marginal at the start of the test. The noise increased by about 150 percent by the end of the test.

3. Time Response: The DEDS was marginally able to meet the time response specification. Prior to the test, the relationship of the time response to sample flow rate through the instrument was investigated. As expected, an increased flow rate improved the time response. A sample flow rate of 10 liters per minute was fast

DEDS Performance Summary

Test	Result*	Performance
Range	P	DEDS capable of orders-of-magnitude range
Accuracy/linearity	P	Excellent except at elevated temperatures
Precision	P/M	Kept span accurately but exceeded deviation limits periodically over time and at high temperatures
Noise	F	Failed the noise specification for the entire test; noise became more than 3 ppm at 50 degrees Celsius
Response time	M	Met the delay specifications, but met the rise time specification only about 40 to 70 percent of the time (function of relative humidity and temperature)
Humidity	P	Met the specifications on all three relative humidity ramp tests
Temperature	F	Failed at 35 and 45 degrees Celsius
16-hour zero drift	P	Drifted 0.8 ppm in 16-hour drift test
30-day drift	P/F	Span drift less than 0.8 ppm; failed zero drift
Interferent	F	Failed all except Freon 21
N_2H_4	F	Failed; N_2H_4/MMH ratio equaled 0.42
MMH in N_2	P	Passed for entire range
Calibration cycle	P/F	No re-span needed; multiple/re-zeroing needed
Maintenance time	P	No maintenance performed for duration of test
Zero and span	P	Via remote computer control

**P = Pass; F = Fail; M = Marginal*



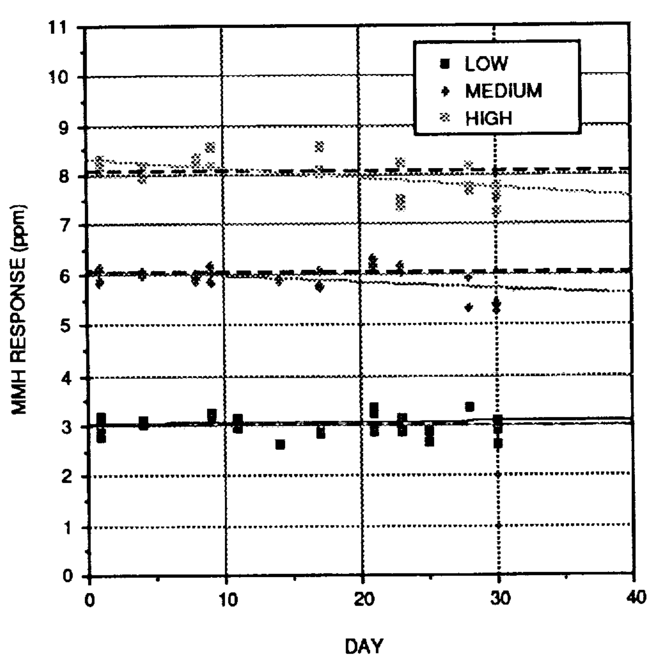
DEDS Linearity Over the 30-Day Test

enough for the DEDS to meet the time response criteria without drawing too large a sample flow from the MMH flow generation system. Thus, the marginal performance on the time response specifications is an implementation problem rather than a technology limitation.

4. Humidity, Temperature, and Drift: The DEDS did not measure the absolute value of the MMH accurately over the range of relative humidities, but it did read the differential of span and zero correctly. Because water vapor absorbs infrared light, a detector will interpret increased relative humidity as an increase in the concentration of the target gas. The DEDS was able to read the correct delta above the elevated zero at high relative humidities, indicating that

relative humidity compensation may be a viable fix to the relative humidity problem. The DEDS failed to meet the specifications at high temperatures. Some error was expected due to the change of the molar volume as a function of temperature (a 10-percent high at -5 degrees Celsius and 7-percent low at 45-degrees Celsius). However, the DEDS errors were far greater than that and are probably due to the degraded mirror surface or mirror alignment change with temperature. The DEDS passed the short-term drift test but failed the long-term drift test. The failure in the long-term test is again attributed to the degradation of the mirrors.

5. Interferents, Hydrazine, and MMH in GN_2: As expected, the DEDS failed the interferent test. The only way to eliminate interferents is to detect absorbance in multiple wavebands and then subtract out the unwanted compounds. Also as expected, the DEDS did not measure N_2H_4 the same as MMH because MMH and N_2H_4 absorbance peaks are different. Again as expected, the DEDS read MMH in GN_2 very nearly equal to MMH in air.



DEDS Span Over the 30-Day Test

Conclusion

The DEDS, with some additional engineering development, can meet the HVDS II specifications, with the exception of the interferent and N_2H_4 response requirements. The other shortfalls can be overcome with two reasonable changes to the DEDS. The first and by far most important change would be to use a new gas cell to eliminate the problems caused by the poor mirrors. A gas cell with properly aligned, high-efficiency mirrors would reduce the deficiencies noted in the sensitivity, noise, precision drift, and temperature tests. The second change would be to add relative humidity compensation. An alternative to adding relative humidity compensation would be to zero the instrument at ambient conditions just prior to use. This would be adequate for most sampling operations because gross changes in relative humidity do not normally occur quickly. These two relatively simple modifications should permit the DEDS to meet all but the interferent and N_2H_4 testing requirements.

Contact:
R. C. Young, 867-4438, DL-ESS-24

Participating Organization:
Boeing Aerospace Operations, Engineering Support Contract (Dr. T. A. Hammond)

NASA Headquarters Sponsor:
Office of Space Flight

Evaluation of Photoionization Detectors for Hypergolic Fuel Vapor Detection

Objective

To evaluate photoionization detectors (PID's) for potential use in the second generation Hypergolic Vapor Detection System (HVDS II).

Background

PID's are used widely in gas chromatographs and as portable detectors for organic vapor detection. These detectors use an ultraviolet light source to ionize the sample and an electric field to collect the ion pairs and to measure the ion current and convert it to a voltage signal. The output voltage is then determined by the type of vapor and the vapor concentration.

Prior to the extended test, five different PID's were evaluated: the HNU 52a gas chromatograph detector, the HNU IPSI-101 portable detector, the Photovac Tip 1 portable detector, the Photovac Autotip 1 area monitor, and the O.I. 4430 gas chromatograph detector. The two Photovac instruments used a radio-frequency-excited lamp while the other instruments used direct-current-discharge lamps of approximately 1000 volts direct current. A 10.0-electron-volt lamp was chosen as the best performer for monomethylhydrazine (MMH) detection. Signals from both HNU instruments were quenched significantly by humidity and were also prone to lamp window fouling. In addition, for the HNU 52a, both the lamp and the ion chamber were powered from the same circuit board, so that brightening the lamp lowered the ion chamber voltage, resulting in poor operational characteristics. Since the Photovac Tip 1 units were unreliable and quickly malfunctioned, they were dropped from the test. Testing was resumed on a Photovac Autotip 1; however, this instrument had been modified, and it did not perform properly even after multiple efforts to return it to its original configuration.

The O.I. unit was the top performer in the initial screening test and was selected as the best system for modification and further testing. The modified O.I. photoionization detector (OIPID) incorporated active humidity compensation to remove signal quenching due to the presence of water vapors, a nitrogen sweep gas to prevent the lamp window from fouling, and a heated sample chamber to prevent moisture condensation. The OIPID was controlled by a Macintosh II computer operating the National Instrument Corporation's Labview 2 virtual instrument software.

Approach

The OIPID was tested with the three other instruments: the Interscan electrochemical detector, the Bruel&Kjaer photoacoustic infrared detector, and a laboratory-modified Foxboro Miran 101 infrared detector. The extended test consisted of four parts: (1) a basic test at the nominal test condition of 25 degrees Celsius and 45-percent relative humidity, (2) a long-term (30 day) test, (3) an environmental test (temperature/relative humidity extremes), and (4) a special test [including interference gases, hydrazine (N_2H_4) response, and MMH in nitrogen (N_2) response]. The linearity, accuracy, precision, response time, noise, and drift were evaluated throughout all except the special test.

Results

The OIPID initially performed well, but its performance degraded throughout the test. It was discovered later that dust and fibers had formed a small ball about 2 to 3 millimeters in diameter which had lodged in the sample chamber. This contamination caused erratic signals over the duration of the test.

The OIPID signal exhibited very little noise under normal operating conditions, remaining stable throughout the test at 0.2 to 0.3 parts per million peak-to-peak. The zero value drifted only minimally; there was no need to reset the zero during the test. Span noise gradually increased throughout the test, due most likely to the dust and fiber contamination. Noise increased at high relative humidities but did not vary significantly with temperature. As a result, the OIPID easily met the precision and noise specifications.

The humidity compensation worked satisfactorily, resulting in a response that was accurate and linear over a wide range of relative humidities. However, the OIPID accuracy dropped out of the acceptable range at elevated temperatures due to two factors. First, the OIPID compensated for water vapor effects by using relative humidity rather than absolute humidity. The actual number of water molecules, the absolute humidity, causes the decrease of signal. The number of water molecules at a given relative humidity increases with temperature, resulting in more signal decrease than can be compensated. Second, the nitrogen sweep gas flow controller failed, which greatly reduced the number of photons in the ionization region.

The OIPID was the most responsive of all the instruments tested. Rise times were somewhat concentration dependent but were less than 60 seconds for all conditions tested. Increased humidity significantly slowed the OIPID's response, but the response was still within specifications. Fall times are generally longer than rise times, and the OIPID could meet the fall time specification only sporadically.

The OIPID responded to several of the interferents tested, but it had reasonable rejection ratios for all. The interferents (with the rejection ratios shown in parentheses) tested are: hydrogen sulfide (18:1), isopropyl alcohol (18:1), ammonia (45:1), Freon 21 (1061:1), Freon 114 (>2000:1), and Freon 113 (>1000:1).

The OIPID detected N_2H_4 vapors. Using a detector calibrated with MMH, it registered readings 36 percent below the actual N_2H_4 concentration. The OIPID detected MMH with more efficiency in gaseous nitrogen (GN_2) than in air. The increased sensitivity is due to the absence of the ultraviolet absorbing oxygen. The OIPID did not meet the MMH in nitrogen accuracy test, but it was functional for detecting MMH in a nitrogen atmosphere.

Conclusion

The OIPID performed better than any other PID tested at the NASA Toxic Vapor Detection Laboratory. However, several minor improvements would greatly enhance its performance over extended periods and at high temperatures. First, and most important, a flow filter must be installed to prevent microscopic-size dust or debris from entering the ion chamber. No PID can function properly with debris in the electric field that can provide a possible short between the electrodes. Second, flow control should be changed from the Sierra flow controller to a simple, fixed-orifice flow regulator. This would provide more stable and accurate gas flow control under field conditions. Finally, the humidity compensation should be changed from the current relative humidity basis to an absolute humidity basis, so that the moisture quench would be accurately corrected. Overall, the OIPID demonstrated good performance and, with the modifications discussed above, it could be developed into a serviceable field device for MMH leak detection.

Contact:
R. C. Young, 867-4438, DL-ESS-24

Participating Organization:
Boeing Aerospace Operations, Engineering Support Contract (D. M. Blaies)

NASA Headquarters Sponsor:
Office of Deputy Administrator

Preliminary Evaluation of a Fourier Transform Infrared Spectrometer for Hypergolic Fuel Vapor Detection

Objective

To investigate the feasibility of using Fourier transform infrared (FTIR) spectroscopy to provide the basis for the prototype development of the second-generation Hypergolic Vapor Detection System (HVDS II).

Background

In 1989, a preliminary evaluation of commercially available monomethylhydrazine (MMH) and hydrazine (N_2H_4) detectors was performed at the Kennedy Space Center (KSC) Toxic Vapor Detection Laboratory (TVDL) (refer to KSC-DL-3382). None of those instruments was able to fully satisfy the desired performance objectives for the HVDS II program; therefore, sensors from four technologies (electrochemical, photoionization, optical infrared absorption, and photoacoustic infrared absorption) were selected for refinement and testing in 1990. In addition, on May 17 and 18, 1990, a preliminary study of an FTIR was conducted. The advantage of the FTIR over other infrared detectors is that the FTIR can calculate the concentration of the target gas by subtracting out the concentrations due to interferents. The spectral collection and analysis time is projected to be only seconds.

Approach

The FTIR tested was a standard Bomen Model MB 120, with a 10-meter gas cell. The FTIR was put through a limited number of tests to determine its ability to accurately and linearly measure a range of MMH concentrations at extremes of relative humidity and in the presence of several different interferents. The tests were done using a standard TVDL MMH vapor generation system similar to that used for the preliminary evaluation mentioned earlier. Spectra were taken for each of the tests and examined to verify qualitatively that the FTIR was detecting the MMH and other interferent gases. The spectra were then analyzed to determine how accurately and quickly the concentration of MMH could be quantified for each of the test conditions. Due to time limitations, no attempt was made to characterize the FTIR time response, its performance in a wide range of

HVDS II Technical Requirements

Test	Criteria
Range	0 to 30 ppm
Accuracy/linearity	Within ±20 percent or 0.5 ppm of actual
Precision	Span ±10 percent, maximum deviation ±10 percent
Noise	0.3 ppm peak-to-peak (zero and span)
Response time	10 to 90 percent in < 60 seconds
Humidity	Delta span within ±20 percent from 10- to 90-percent relative humidity
Temperature	Delta span within ±20 percent from 0 to 50 degrees Celsius
16-hour zero drift	Zero drift less than ±1 ppm
30-day drift	Span and zero drift less than ±1 ppm
Interferent	Rejection ratio ≥ 500:1
N_2H_4	Measure ±20 percent of actual concentration
MMH in N_2	Measure ±20 percent of actual concentration
Calibration cycle	No calibration for 90 days mandatory (180 days desired)
Maintenance time	No maintenance for 90 days mandatory (180 days desired)
Zero and span	Adjustment present

temperatures, or its ability to read N_2H_4 in air or MMH in nitrogen (N_2). The scope of the test was to investigate the most difficult performance requirements for the HVDS II. The HVDS II technical requirements are summarized in the table "HVDS II Technical Requirements."

Results

The spectra collected were analyzed by using four absorbance bands (at wavenumbers 929, 963, 1303, and 3016 cm-1), and by using only a single waveband (at wavenumber 1303). The analysis was done both ways to determine the decrease of accuracy due to using only the single waveband (to speed up the analysis process) versus the multiple waveband. The FTIR exhibited excellent linearity over the range of MMH tested (2 to 12 parts per million) in dry air by both analyses. The linearity degraded only slightly at the 80-percent relative humidity test condition using only the single waveband analysis. Based on this limited test, the FTIR was judged able to compensate extremely well for variations of relative humidity.

The remainder of the tests was directed toward measuring MMH in the presence of various interferents (isopropanol, methanol, Freon, ammonia, and combinations of these gases). A qualitative review of the data indicted that MMH absorbance peaks could be separated from the interferent peaks even when there were orders of magnitude more interferent than the MMH. As a result of the quantitative analysis, it was concluded that in no case was MMH identified as being present when it was not actually there and that the calculated MMH values were always close to the actual MMH vapor concentration in the presence of interferents. This performance was achieved in spite of the fact that the number of calibration spectra was limited. A summary of the FTIR's performance against the HVDS II requirements is presented in the table "FTIR Performance Summary."

Conclusion

The FTIR demonstrated the ability to detect and quantify concentrations of MMH below 1 ppm in dry air, in air at 80-percent relative humidity, and in the presence of massive amounts of interferents. The FTIR also demonstrated the ability to detect and quantify numerous interferents, separately and in combinations. A very important aspect of the FTIR is that once the spectrum is collected, analyses can be done to detect and quantify any molecule that absorbs infrared in the spectral region covered. Some of the potential candidates are of course MMH and N_2H_4, but also nitrogen dioxide, carbon monoxide, carbon dioxide, ethanol, methylene chloride, and acetone. This is not an exhaustive list, but indicates some of those gases that might be of interest at KSC. No tests were done to measure the FTIR's time response. However, it was estimated that the time to collect, store, and analyze each spectrum would be shorter than expected to

FTIR Performance Summary

Test	Result*	Performance
Range	P	FTIR capable of orders-of-magnitude range
Accuracy/linearity	P	Excellent at both 10- and 80-percent relative humidity
Precision		Not tested
Noise		Not tested
Response time		Not tested
Humidity	P	Met the specification at 10- and 80-percent relative humidity
Temperature		Not tested
16-hour zero drift		Not tested
30-day drift		Not tested
Interferent	P	MMH can be measured, and interferents can be identified and measured
N_2H_4		Not tested
MMH in N_2		Not tested
Calibration cycle		Not tested
Maintenance time		Not tested
Zero and span	P	Via remote computer control

**P = Pass*

meet the HVDS II specifications. Furthermore, no tests were done to characterize the FTIR's response to N_2H_4 in air or MMH in N_2, but no difficulties are envisioned in accomplishing these tasks. Based upon the results of this feasibility test and projected performance capabilities of the FTIR technology, further testing is warranted to explore the FTIR as a potential candidate for an HVDS II instrument.

Contact:
R. C. Young, 867-4438, DL-ESS-24

Participating Organization:
Boeing Aerospace Operations, Engineering Support Contract (Dr. T. A. Hammond)

NASA Headquarters Sponsor:
Office of Space Flight

Realtime Particle Fallout Monitor

Objective

To develop a low-cost, high-reliability, realtime monitor capable of qualifying and size-segregating particles larger than 20 microns for use in clean work areas at Kennedy Space Center (KSC).

Background

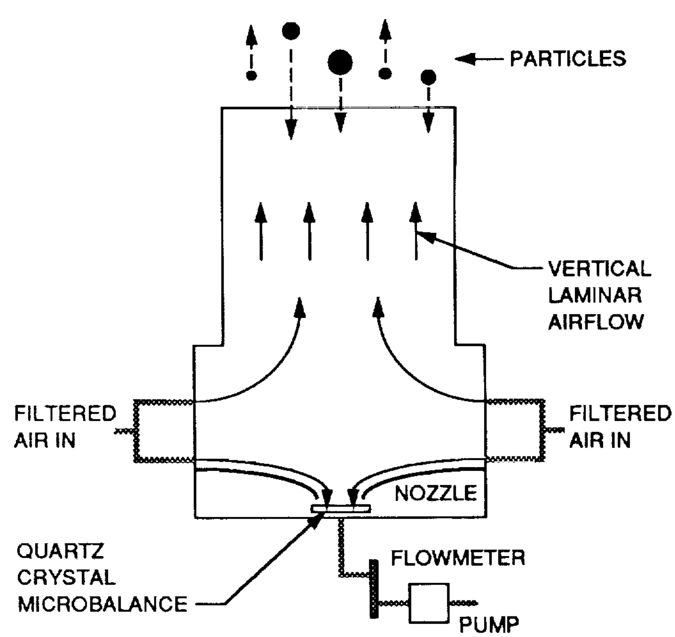
Particulate fallout levels are monitored in payload operations and storage areas at KSC because of the detrimental effects of this contamination on both optics and mechanical parts. The current method used at KSC involves collection of these particles on a gridded filter. The filter is taken to a laboratory and the particles counted under a microscope.

A realtime method for monitoring particulate levels is needed to establish control over events that produce contamination in cleanrooms. The instrument would also be used to study certain operations to determine what events cause payload contamination and how the operations can be modified to minimize contamination.

Approach

A Phase I Small Business Innovation Research (SBIR) contract was awarded to develop a realtime particle fallout monitor based on the principle of vertical elutriation to size-segregate particles and a quartz crystal microbalance for quantification. After development, testing and redesign, laboratory testing, and investigation of calibration procedures, a field test is required to ensure the instrument is comparable to the standard KSC gridded filter method.

Vertical elutriation uses a vertical lami-



Vertical Elutriation Principle of Operation nar airflow moving upward through a "chimney." Particles larger than a certain aerodynamic size will fall through the "chimney." These particles are subsequently drawn into a quartz crystal microbalance for measurement.

After the field testing at KSC, data will be analyzed to assess instrument performance. Further design improvements will be identified and discussed in the Phase II SBIR proposal.

Accomplishments

After the completion of the Phase I design and laboratory testing, the instrument was field tested for 2 weeks on Operation and Checkout Building Test Stand 3 at KSC. Phase I results identified several design flaws; solutions were presented in the Phase II proposal. Further work will be performed pending funding from NASA Headquarters.

Contact:
P. A. Mogan, 867-4438, DL-ESS-24

Participating Organizations:
Femtronics (Dr. W. D. Bowers)

McDonnell Douglas Space Systems Company (V. V. Bukauskas)

NASA Headquarters Sponsor:
Office of Space Flight

Advanced Hazardous Gas Detection System (AHGDS)

Objective

To develop a hazardous gas detection system that features high reliability, high accuracy, simple maintainability, and self-validation and permits operation with minimal human dependency.

Background

The Advanced Launch System (ALS) program requires an improved system for hazardous gas detection to meet its more stringent requirements. Also, the hazardous gas detection systems now used to support Shuttle operations are reaching their design lifetime. There is a strong need to upgrade the present systems due to the high maintenance requirements and the unavailability of spare parts.

Approach

As reported in the Research and Technology 1989 Annual Report and summarized here, existing mass spectrometers are being tested and evaluated in order to select the main element of the system. The mass spectrometer selected for this program is from the Central Atmospheric Monitoring System (CAMS I). The United States Navy developed this analyzer for use in measuring constituents in the "air" aboard submarines. CAMS I is a fixed-focus, fixed-collector, magnetic sector mass spectrometer. This analyzer will undergo extensive evaluation in different configurations to ascertain its full capabilities.

The remaining elements of the system, such as the sampling subsystem, the command and data subsystem, and the associated support equipment, are being defined and produced. The mass spectrometer evaluation and the testing of required components, such as turbomolecular pumps, flex lines, quick disconnects, vacuum components, and transducers, will take place concurrently. There will be a special effort for the development of using knowledge-based techniques to ease the operator interface and decision-making process.

Results

The AHGDS program experienced about six months of uncertainty due to ALS funding problems. Test plans for CAMS I characterization testings were prepared. Vibration testing of turbomolecular pumps was completed. An initial report has been prepared documenting the test results. In summary, the results showed that certain turbomolecular pumps can operate and survive in a vibration environment similar to that experienced at Complex 39 during Shuttle launches. A CAMS I mass spectrometer was modified to improve the helium detection limit. The modifications included employing different electrometers, replacing the ion pump with a turbomolecular pump, and admitting a sample gas into the roughing line. The Naval Research Laboratory tested these modifications. The first change had no effect, while the second and third brought about major improvements to the helium and hydrogen detection limits. The overall test results show that the modified CAMS I is a reliable system capable of performing the analysis requirements for a Kennedy Space Center gas detection system.

Future Plans

Long-term operational testing will be conducted on the pumps that successfully passed the initial vibration tests. The proposed subsystems and components that will comprise the AHGDS will be designed, acquired, and tested. This will lead to the integration, assembly, test, and demonstration of an operational AHGDS prior to September 1992.

Contacts:
W. R. Helms, 867-4438, DL-ESS-2
J. D. Collins, 867-4449, DL-ESS-24
R. Adams, 867-4449, DL-ESS-24

Participating Organizations:
Boeing Aerospace Operations, Engineering Support Contract (F. Luaces-Lorenzo, D. R. Wedekind, S. M. Simmons, and M. J. Blankenship)

Naval Research Laboratory (Dr. J. R. Wyatt and Dr. M. Ross)

NASA Headquarters Sponsor:
Office of Space Flight

Biosciences

The biosciences research and development effort at the John F. Kennedy Space Center (KSC) is supported by the Environmental Monitoring and Microbiological Laboratories, the Biomedical Research Laboratory, and the Life Sciences Support Facility.

Environmental Monitoring and Microbiological Laboratories

The Environmental Monitoring Laboratory provides monitoring support for air quality, water quality, and environmental impact analyses. Equipment includes a fully operational chemistry laboratory for sample analyses using an atomic absorption spectrophotometer, a Technicon autoanalyzer, an inductive coupled plasma analyzer, and gas chromatographs. A remote sensing/ geographic information system laboratory provides for use of satellite and aerial imagery in support of ecological research and environmental support to KSC operations. The Clinical and Environmental Microbiological Laboratories support all aspects of microbiological analyses at KSC. They are equipped with automatic microbiological identification systems, automatic plate counters, and a wide range of sampling equipment.

Biomedical Research Laboratory

The Biomedical Research Laboratory is a fully equipped and staffed facility capable of performing a wide range of physiological research related to human response to microgravity. The laboratory supports the preflight and postflight checkout of the Shuttle's bioinstrumentation and systems used in unique life sciences experiments. It also has the capability and skills to accomplish complete testing at temperature extremes on the full range of personnel protective equipment. A clinical laboratory operates within the research laboratory where radioimmunoassay and a variety of blood analyses are performed.

Life Sciences Support Facility

The Life Sciences Support Facility is involved in nonhuman life sciences flight experiments for the Shuttle program, inhouse and externally sponsored biological research, space biology research, and the Controlled Ecological Life Support System (CELSS) Breadboard project. The facility provides capabilities for receiving, housing, and caring for animals and growing plants. It contains plant growth chambers, analytical laboratories, preparation areas for food processing and waste studies, and the large CELSS growth chamber for closed system work. Supporting elements include flight animal isolation facilities, surgery and x-ray facilities, and data management and storage.

Environmental Monitoring and
Microbiological Laboratory

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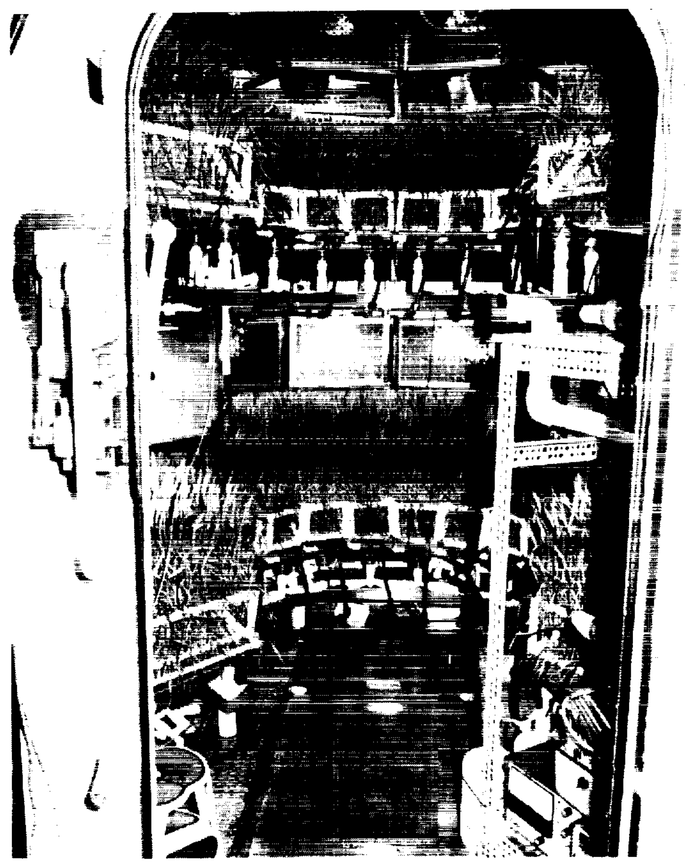


Life Sciences Support Facility

Biomedical Research Laboratory

Vegetation Studies and Biospherics Research

Analysis of the effects of fire on wetlands at Kennedy Space Center as a part of the NASA Biospherics Program continued with the completion of soil sampling through 12 months after the fire and the resampling of vegetation and biomass of the sites studied in conjunction with Langley Research Center. Chemical analyses of soil and biomass samples were completed. Preliminary results were presented in Williamsburg, Virginia, at the Chapman Conference on Global Biomass Burning. Also, work was initiated in the Biospherics area to evaluate ecological effects of elevated carbon dioxide in a joint study with the Smithsonian Environmental Research Center.

Work on the fire ecology of scrub vegetation continued with the resampling of permanent transects that burned in 1986 at 36 months after the fire. Data analysis and report preparation on this project are underway.

Preparation of vegetation studies summary reports continued with the completion of a report detailing the climate of the KSC area based on a climatological data base that includes nearly 100 years of data. A report including a revised floristic list and a list of threatened and endangered plants was completed as was a summary of geology and soils information.

Monitoring of launch effects on vegetation continued with the resampling of vegetation

A Control Burn in KSC Wetlands

and soils near Launch Pad 39A before resumption of launches there, extending the data base for examining long-term effects. Chemical analysis of these and previous soil samples from the launch impact areas is underway and has been completed for many parameters. Deposition patterns and vegetation effects were determined for launches of STS-31, STS-32, STS-33, STS-34, and STS-36 and were summarized in quick-look reports.

Contact:
W. M. Knott, Ph.D., 853-5142, MD-RES-L

Participating Organization:
The Bionetics Corporation (P. A. Schmalzer, Ph.D.)

NASA Headquarters Sponsor:
Office of Space Flight

Habitat Assessment Group

Environmental monitoring and research concerning endangered and potentially endangered wildlife within uplands and wetlands were consolidated to form the Habitat Assessment Group. Functions include the development of methods to interpret and predict the effects of ongoing and proposed operations at Kennedy Space Center (KSC) on wildlife and habitat. The species investigated are those most influenced by cumulative construction impacts, launches, and other NASA operations.

Habitat at KSC provides for the largest population of the Florida scrub jay, which occurs near many operations and sites for proposed facilities. Most scrub and slash pine at KSC is occupied by scrub jays but only a small portion is optimal habitat, based on criteria established elsewhere. Much of the population inhabits areas of marginal habitat suitability. Studies are performed to distinguish between conditions where reproduction exceeds mortality ("sources") and conditions where mortality exceeds reproduction ("sinks"). If suitable habitat conditions defined by other investigators apply at KSC, most areas may be population "sinks." Modeling studies by other investigators have shown that animal populations can be maintained by source populations that are a small percent (e.g., 15 percent) of the entire population so that it is critical to identify potential "sources" and manage them properly. Many "sink" habitats are still important because they enable the population to be more genetically diverse and able to withstand catastrophic events. Marked individuals and long-term demographic data are necessary because "sinks" can contribute to persistence of a population that is on a downward slide; such trends are not recognized by superficial study. To date, 354 Florida scrub jays have been banded in four areas at KSC and the adjacent Cape Canaveral Air Force Station. Two study sites in the Titan launch pad impact areas are used to evaluate launch effects. Studies on territory size and composition, reproductive success, and survival were performed in 20 territories in 1988, 40 territories in 1989, and 50 territories in 1990. A Geographical Information System (GIS) model was developed to identify areas that have the potential to be optimal for scrub jays. A draft habitat suitability model was also developed which, combined with the GIS model, will be useful for project planning, comparing alternative construction sites, and quantifying cumulative impacts. These models require long-term demographic data to test their accuracy before they will be accepted by regulatory agencies and the scientific community.

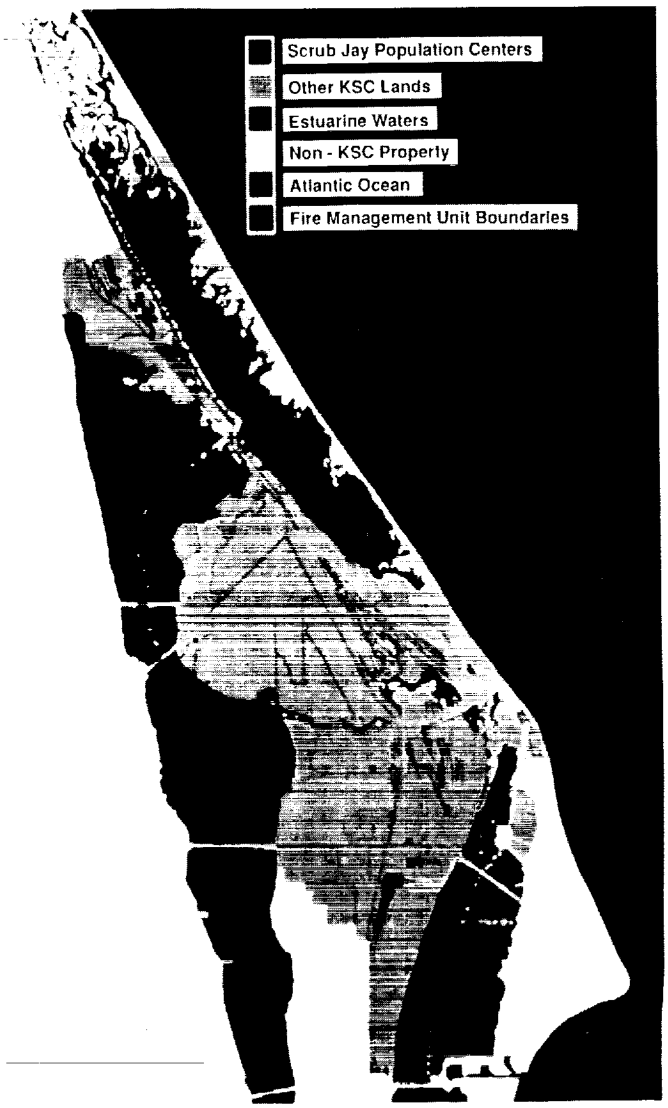
Wood Stork Nest at Bluebill Creek Colony South of Launch Complex 39A

Other protected species in scrub and slash pine areas at KSC are the bald eagle, gopher tortoise, and indigo snake. Collaboration with a University of Florida researcher studying bald eagles at KSC resulted in a GIS model that overlays areas important for nesting bald eagles and scrub jays. This model suggests that nearly half the areas important for bald eagles occur in places that are important to scrub jays. This is only a small portion of the total amount of area important for scrub jays. Where there is overlap, however, bald eagle nest sites are associated with poorly drained conditions, whereas the best areas for scrub jays are well drained.

Most construction projects occur in areas inhabited by gopher tortoises. Initial studies were funded by the Florida Game and Fresh Water Fish Commission to identify habitat preferences of the gopher tortoise and to develop procedures to evaluate impacts of projects in coastal scrub and slash pine. Results showed that a lower percent of burrows were occupied by gopher tortoises than would be calculated by a burrow-to-tortoise correction factor that was considered the regulatory standard, and that gopher tortoises were not restricted to well-drained areas as once believed. Radio tracking of 22 tortoises in two study areas has been done to further define habitat requirements and uses of correction factors.

Early studies north of KSC showed that indigo snakes require tortoise burrows within well-drained areas as winter den sites, whereas more recent studies south of KSC and on Florida's west coast showed that indigo snakes can use other habitat components as den sites. Radio tracking studies of indigo snakes are performed to investigate habitat use and movements and the importance of well-drained areas that comprise about 2 percent of all KSC lands. These areas are the most suitable for future development since much of KSC qualifies as wetlands. Eight animals from KSC have been tracked since the study began 3 years ago. In a cooperative study with the Merritt Island National Wildlife Refuge, two additional animals have been relocated to KSC and instrumented with transmitters. This will provide information regarding relocation and the ability of indigo snakes to live without access to well-drained ridges.

Wading bird surveys are performed to quantify the importance of different habitats



Prime Scrub Jay Habitat at KSC

for feeding, to evaluate seasonal and yearly variations in the number of wading birds using KSC, and to identify historical, current, and potential sites for nesting and roosting. Three years of data collection are used to address water management practices and the significance of areas influenced by operations. GIS applications are used to determine the types of habitat surveyed and the proportion sampled relative to the total at KSC.

Other Space Shuttle launch-monitoring activities include postlaunch site visits to investigate the direct effects on wildlife and before- and after-launch nest surveys of wood storks and other wading birds at colonies near launch pads.

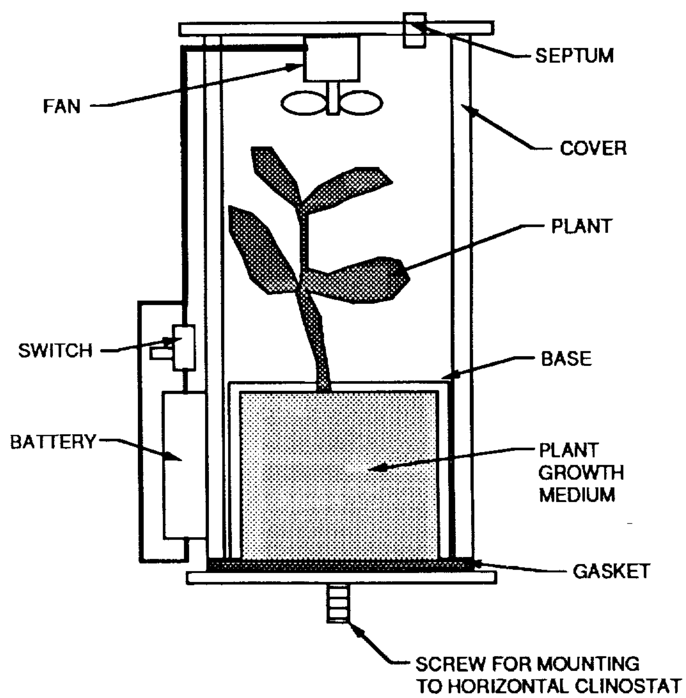
Contact:
W. M. Knott, Ph.D., 853-5142, MD-RES-L

Participating Organization:
The Bionetics Corporation (D. Breininger)

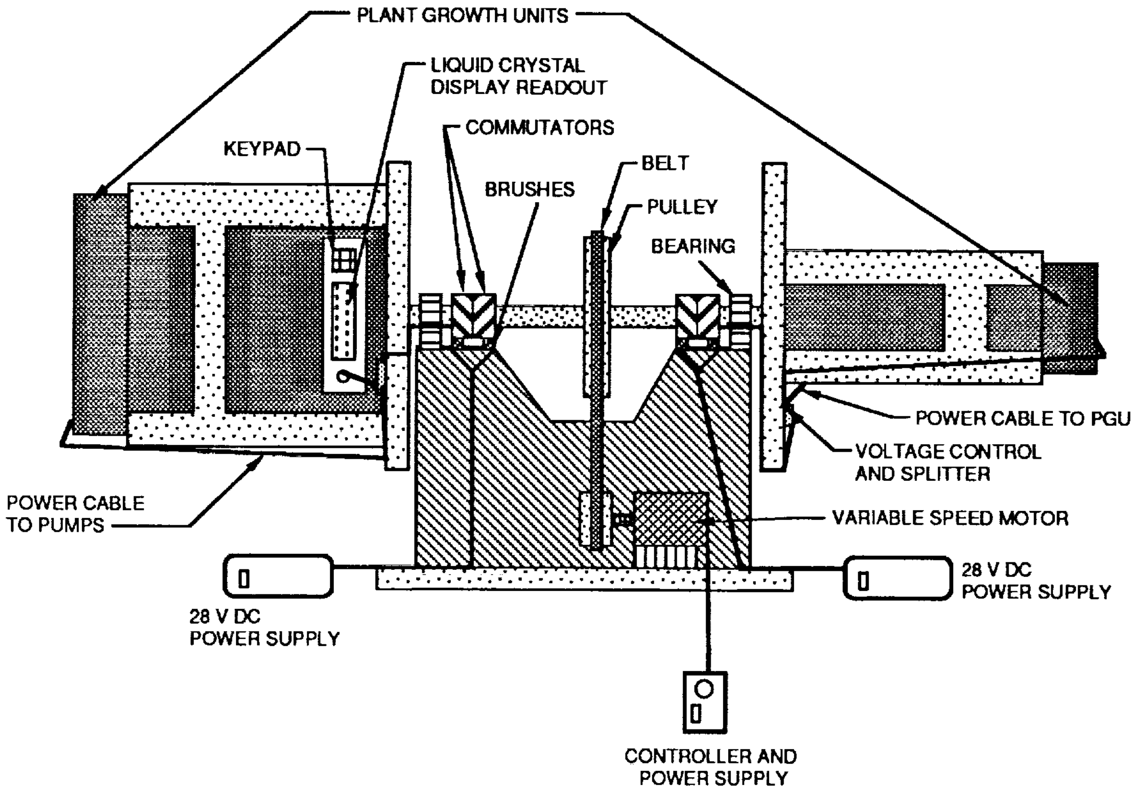
NASA Headquarters Sponsor:
Office of Space Flight

Plant Space Biology Program

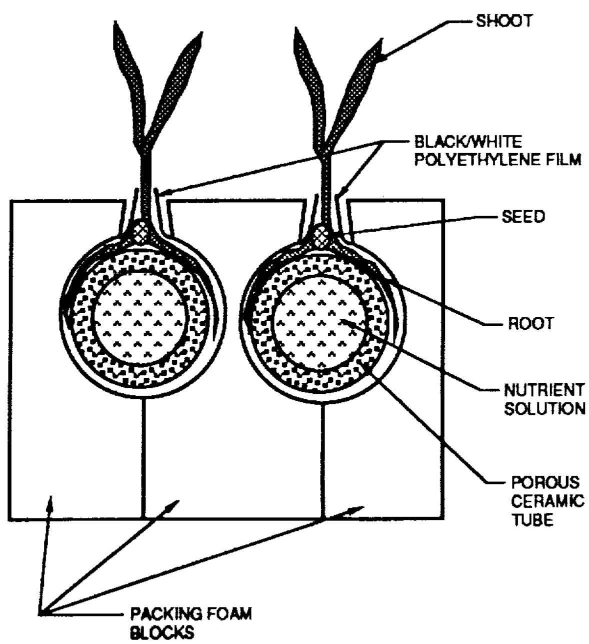
In an effort to try to examine the influence of gravity on higher plant photosynthesis and carbohydrate metabolism, technology development occurred along several fronts. Development of the Tubular Membrane System (TMS) for supplying water



Sealed Chamber for Plant Growth and Gas Exchange Measurements on a Clinostat



Clinostat for Rotating the Space Shuttle Middeck Locker Plant Growth Unit



Porous Tube Plant Growth Unit Cross Section

and nutrients to plants in altered gravity conditions continued this year. Advances were made in adapting the TMS for the middeck locker Plant Growth Unit (PGU). A number of miniaturized TMS units of varying pore sizes were designed and fabricated that fit into the small Plant Growth Chambers (PGC) that fit into the PGU. Comparative tests between the TMS units and other media have been initiated. Pump and reservoir modules have also been constructed and have been utilized within a mockup of the PGU. A clinostat, which can rotate two of these mockups, has been constructed and the TMS has supported plant growth for up to 2 weeks at a time under altered gravity conditions produced by the clinostat.

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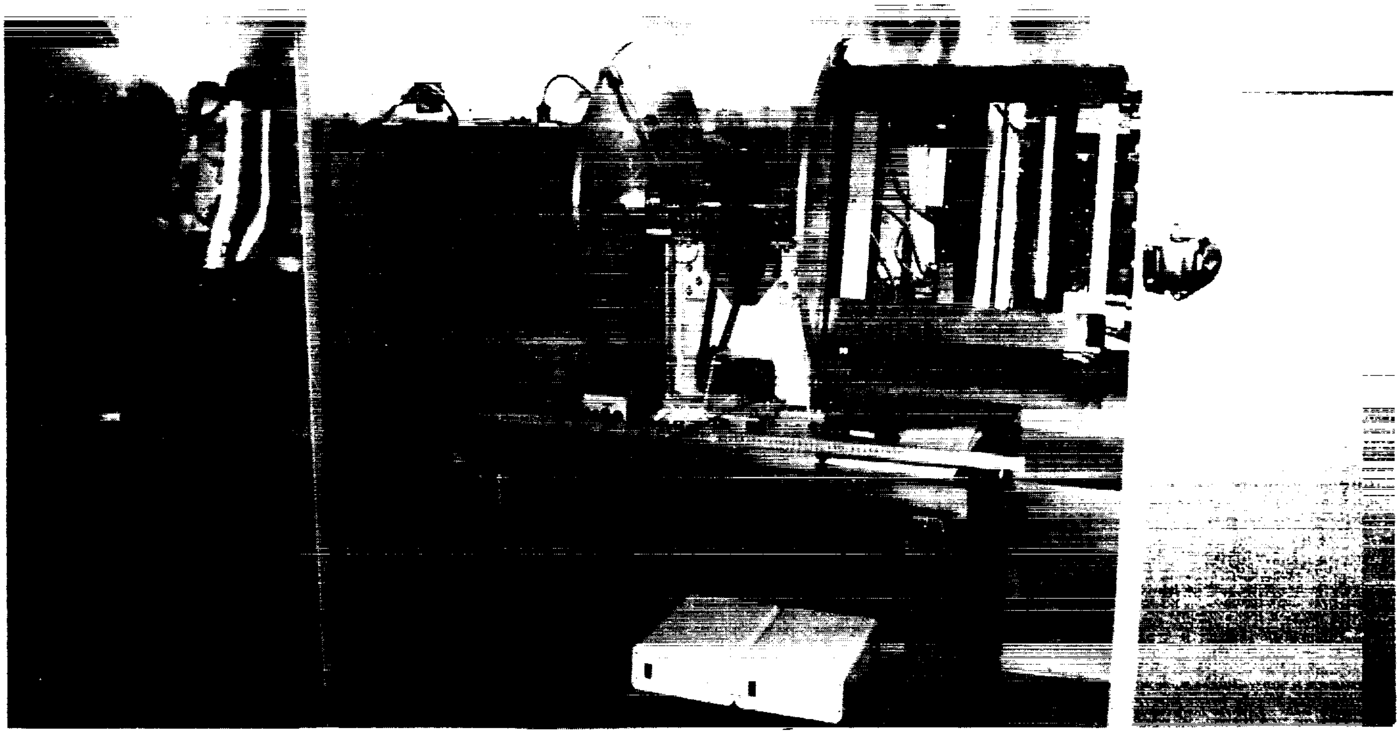


Clinostat for the PGU

Sealed Atmospheric Gas Exchange Chamber for Plants in Altered Gravity Treatments

Another advance this year was the development of a cylindrical chamber that can be atmospherically sealed and mounted on a small clinostat for measuring the effect of altered gravity on plant photosynthesis and respiration. Using this, it has been shown that horizontal clinorotation results in an increase in the photosynthesis/respiration ratio of pea and maize seedlings.

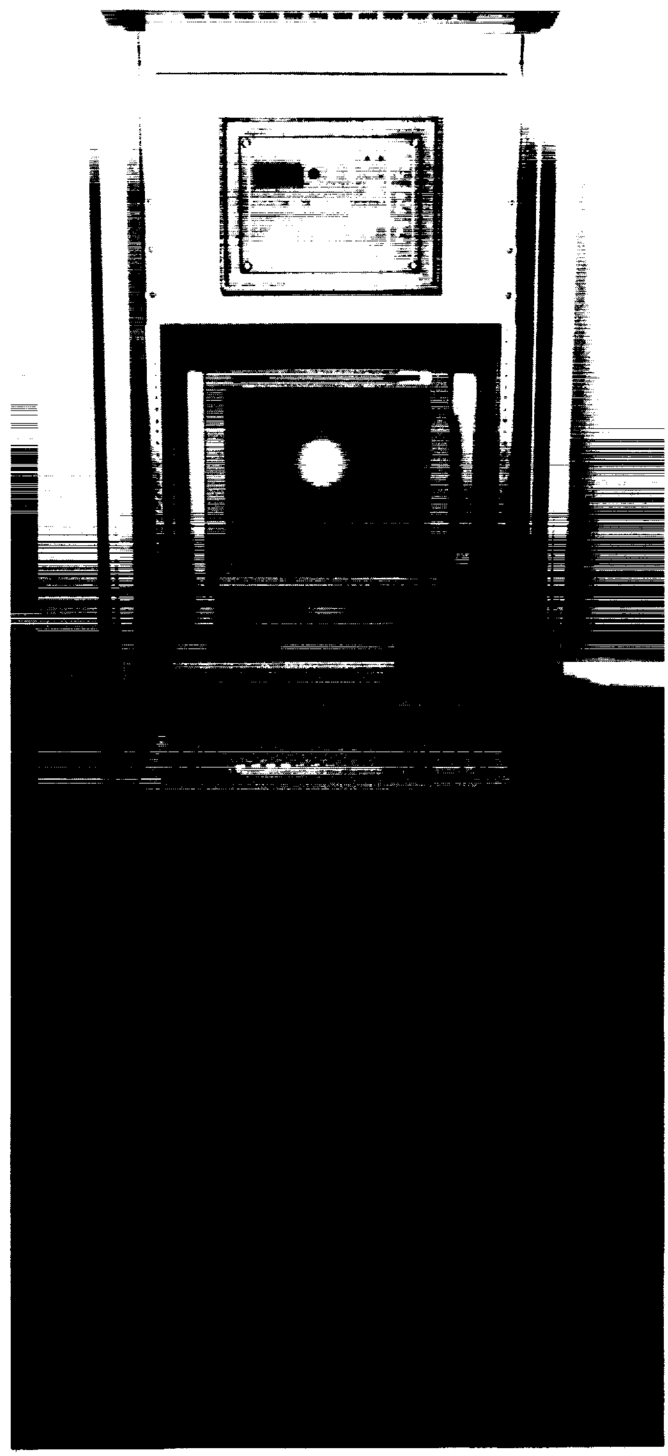
Contact:
W. M. Knott, Ph.D., 853-5142, MD-RES-L

Participating Organization:
The Bionetics Corporation (C. S. Brown, Ph.D.)

NASA Headquarters Sponsor:
Office of Space Sciences and Applications

Orbiter Environmental Simulator

The Space Shuttle temperature, humidity, and carbon dioxide levels are dynamic and mission specific. These environmental changes may introduce variables into flight experiments that cloud test results. The Orbiter Environmental Simulator (OES) was developed to resolve this problem by precisely duplicating mission-specific changes in temperature, relative humidity, and carbon dioxide levels in ground control experiments. The OES consists of a plant growth chamber modified to include dynamic control by a microcomputer. Orbiter Calibrated Ancillary System (CAS) data, archived from a particular mission, is loaded into the microcomputer which in turn controls the plant growth chamber to dynamically match Orbiter environmental conditions. This system has been successfully employed to support postflight ground control experiments for the Chromosomes and Plant Cell Division in Space Experiment (CHROMEX)



Orbiter Environmental Simulator Control Unit and the Characterization of Neurospora Circadian Rhythm (CNCR) Experiment that flew on STS-29 and STS-32, respectively. Efforts are underway to modify the OES to simultaneously support ground control experiments with flight experiments.

Contact:
W. R. Munsey, 867-4551, CP

Participating Organization:
The Bionetics Corporation (C. R. Hargrove)

NASA Headquarters Sponsor:
Office of Space Sciences and Applications

Human Physiology Research Projects: Blood Pressure Control

During the past year, the Life Sciences Research Office undertook two major research projects to determine the effects of spaceflight and exercise on the blood pressure control system in man. These studies were used as a testing ground for the development of new countermeasures designed to minimize the development of low blood pressure during standing (a condition known as orthostatic hypotension) following spaceflight.

In the first project, Kennedy Space Center researchers collaborated with a group of scientists from Simon Fraser University in British Columbia, Canada. In this study, positive pressure (LPP) was applied to the lower body to produce an increase in blood pressure during rest and exercise. This LPP-induced hypertension caused a significant increase in the response of a cardiovascular reflex, which is impaired during exposure to simulated or actual spaceflight and is associated with orthostatic hypotension. These results suggest that exposure to hypertensive stimuli (loading) of cardiovascular baroreceptors may be necessary to protect the normal function of blood pressure control. These data may also suggest that exercise may be a more effective countermeasure against postflight orthostatic hypotension than lower body negative pressure (LBNP), which is currently being tested in the Space Shuttle program and normally causes unloading of cardiovascular baroreceptors.

The second project was a joint bedrest study conducted at Ames Research Center (ARC) that lasted from late July through August. In this study, eleven men from 30 to 50 years of age underwent 7 days of continuous bedrest in a 6-degree headdown position to simulate the effects of exposures to weightlessness. The ARC bedrest study provided the opportunity to examine the effects of microgravity on specific cardiovascular alterations that have not yet been examined from controlled ground-based studies. The response of a sympathetically mediated baroreflex control of vascular resistance was measured in addition to the measurement of the vagally mediated carotid-cardiac baroreflex. These two measurements are important in assessing and understanding the adaptation of man to weightlessness since both may be associated with postflight fainting episodes in astronauts. The results demonstrated that the function of both sympathetic and parasympathetic autonomic control of blood pressure is significantly impaired following exposure to microgravity and that these adaptations should be considered in the development of countermeasures designed to mitigate postflight orthostatic hypotension.

Additional bedrest and exercise studies

Carotid-Cardiac Baroreflex Neck Pressure Chamber

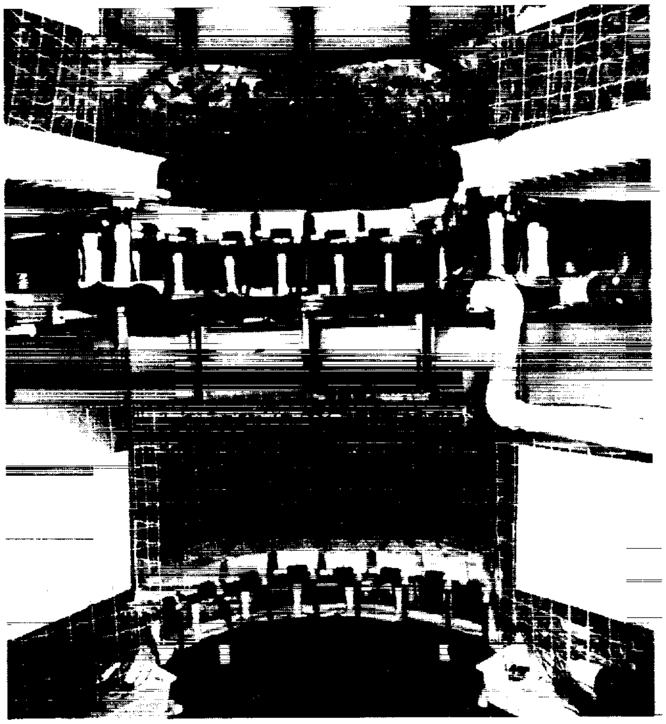
will be conducted during the next year. The results from present and future experiments should provide critical information about the human cardiovascular adaptations to spaceflight and needed development of countermeasures against adverse effects.

Contact:
V. A. Convertino, Ph.D., 867-4237, MD-RES-P
D. F. Doerr, 867-3152, MD-ENG

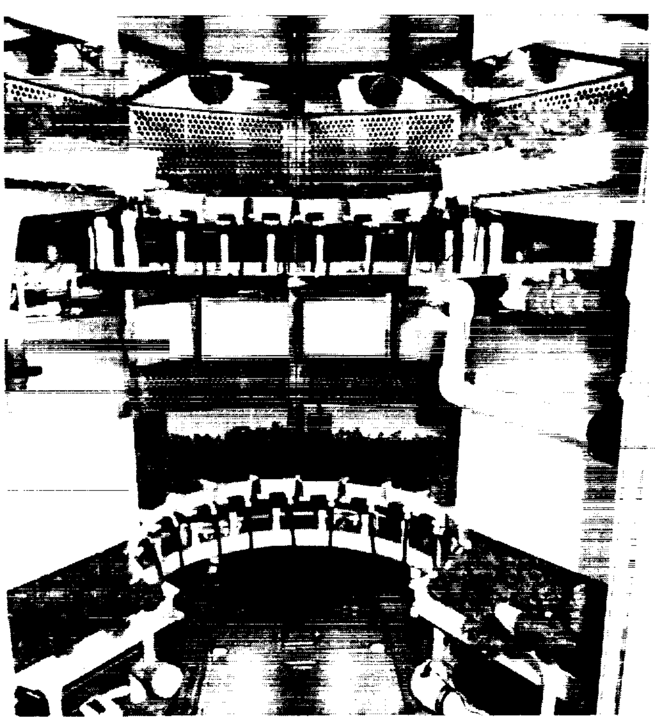
NASA Headquarters Sponsor:
Office of Space Sciences and Applications

Controlled Ecological Life Support System (CELSS) Biomass Production Chamber

Crop tests inside the CELSS Biomass Production Chamber (BPC) continued during the past year, including two tests each with soybean (*Glycine max*) and lettuce (*Lactuca sativa*). For each species, one test was conducted with high-pressure sodium lamps and one test with metal halide lamps. Little difference was noted between lettuce tests, but total biomass production for soybean was greater with high-pressure sodium in comparison to metal halide lighting. This was attributable to the higher amount of photosynthetically active radiation from the sodium lamps. As with previous tests with wheat, gas exchange data [carbon dioxide (CO_2), oxygen (O_2), and water (H_2O)] were monitored throughout development, as were atmospheric concentrations of ethylene, a gas known to have profound effects on the growth and development of most plants. CO_2 and O_2 exchange rates for both soybean and lettuce rose rapidly as the plant stands reached complete "ground cover," suggesting that stand photosynthesis in early development is limited by total light interception. Exchange rates for soybean peaked near 40 days after planting and then gradually declined with age (stands were harvested in approximately 90 days after planting). Lettuce plants were harvested at 28 days after planting (a typical growth cycle for loose-leaf-type lettuce). Maximum water exchange rates (from leaf transpiration) occurred with soybeans near 40 days after planting and totaled about 120 liters from the chamber per day. The rate of transpiration could be strongly influenced by absolute humidity of the chamber atmosphere as well as the atmospheric CO_2 concentration, which is known to affect leaf stomatal (pore) opening. Unlike previous



Soybeans Growing in the Biomass Production Chamber



Lettuce Growing in the Biomass Production Chamber

tests with wheat, ethylene levels did not exceed 20 parts per billion during growth for either soybean or lettuce.

Contact:
J. C. Sager, Ph.D., 853-5142, MD-RES-L

Participating Organization:
The Bionetics Corporation (C. L. Mackowiak)

NASA Headquarters Sponsor:
Office of Space Sciences and Applications

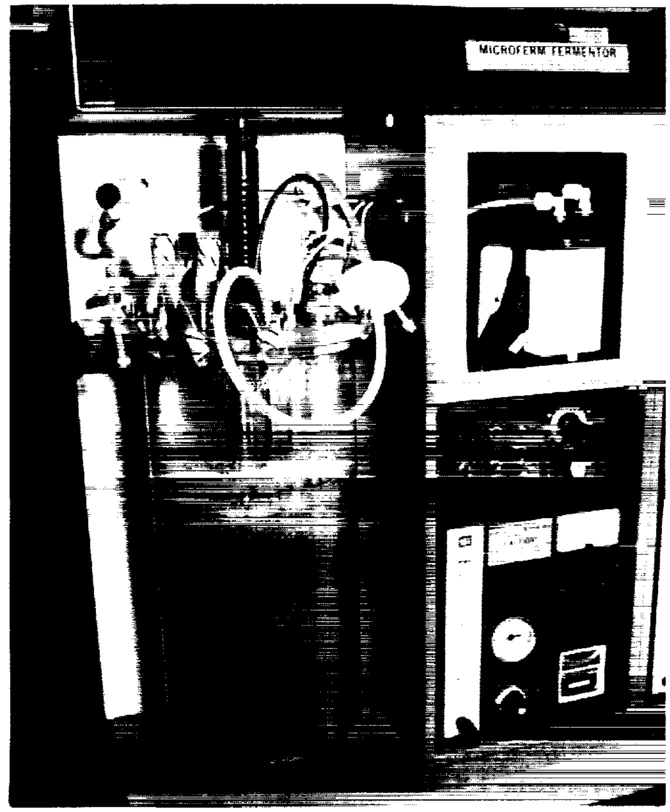
Biomass Processing Research

Integration of scaled-up biomass conversion processes into the Controlled Ecological Life Support System (CELSS) Breadboard Project has progressed. These processes had been selected to provide maximal conversion of Biomass Production Chamber (BPC) crop residues into either edible products or recycled crop nutrients. Efforts have continued to complete the design, procurement and/or fabrication, installation, and testing for each bioreactor. Completion of these tasks will provide operable, BPC-scale hardware and control systems for the processes selected.

Design and fabrication of a BPC-scale "leachate" reactor were completed this past year. This reactor will function to extract water-soluble organic and inorganic compounds from BPC crop residues in preparation for subsequent processes. Leached inorganics will be returned to the hydroponic nutrient solutions in the BPC, but the ultimate fate of the soluble organic compounds has yet to be decided. Researchers continue to examine the feasibility of converting these organic compounds into edible fungal biomass, such as vegetative mycelial cultures of the oyster mushroom, *Pleurotus ostreatus*. Research on this topic continued with a trial scale-up of the process from a 100-milliliter shake-flask culture to a 10-liter stirred, aerated fermentor. The process continues to provide intriguing possibilities for a CELSS application.

Optimization of cellulase enzyme production by *Trichoderma reesei* continued with an examination of crop residue extraction pretreatments that remove hemicellulose and lignin and expose more cellulose. Extraction processes that were tested included: (1) base, (2) base plus peroxide, and (3) dilute sulfuric acid. None of these pretreatments increased cellulase enzyme production. A system for maintenance of stock fungal cultures was implemented to provide a more reproducible preparation of inoculum for larger scale (e.g., 10-liter) fermentor and other studies. An inoculum preparation protocol was designed and implemented for the same reason. A small 1-liter (working volume) bioreactor/fermentor with antifoam and pH control and dissolved oxygen and off-gas carbon dioxide monitoring will be needed for inoculum preparation. Scale-up of cellulase enzyme production to handle BPC outputs of inedible crop residues continued. The design phase for a BPC-scale bioreactor for production of cellulase enzyme was completed and identified the operational scale needed. This process could be satisfied by modification of an existing 14-liter fermentor. Preliminary studies with this bioreactor were initiated to define potential operational problems.

The same extraction pretreatments studied for enzyme production were also applied to efforts to optimize hydrolysis of crop residue cellulose to glucose. These extractions, which remove hemicellulose and lignin and expose more cellulose, all resulted in increased cellulose conversion efficiency. The dilute acid extraction process was selected for further study because it will also hydrolyze the hemicelluloses into constituent monosaccharides without undesirable chemical modification of these products. Commercial sources of cellulase enzyme were compared with CELSS-produced enzyme complex produced onsite from wheat residues. The CELSS-produced source out performed the commercial sources. As with other processes, a BPC-scale bioreactor has been designed for enzymatic hydrolysis of crop residue cellulose. Procurement of a 19-liter stirred tank reactor with pH and temperature control (50 degrees Celsius needed) was initiated.



Ten-Liter Fermentor Culture of Trichoderma reesei

Involvement is expected during the next year with resource recovery through aerobic, and possibly anaerobic, microbial digestion of crop residues and with aquaculture through algal cultivation and production of microbial biomass suitable for fish diets.

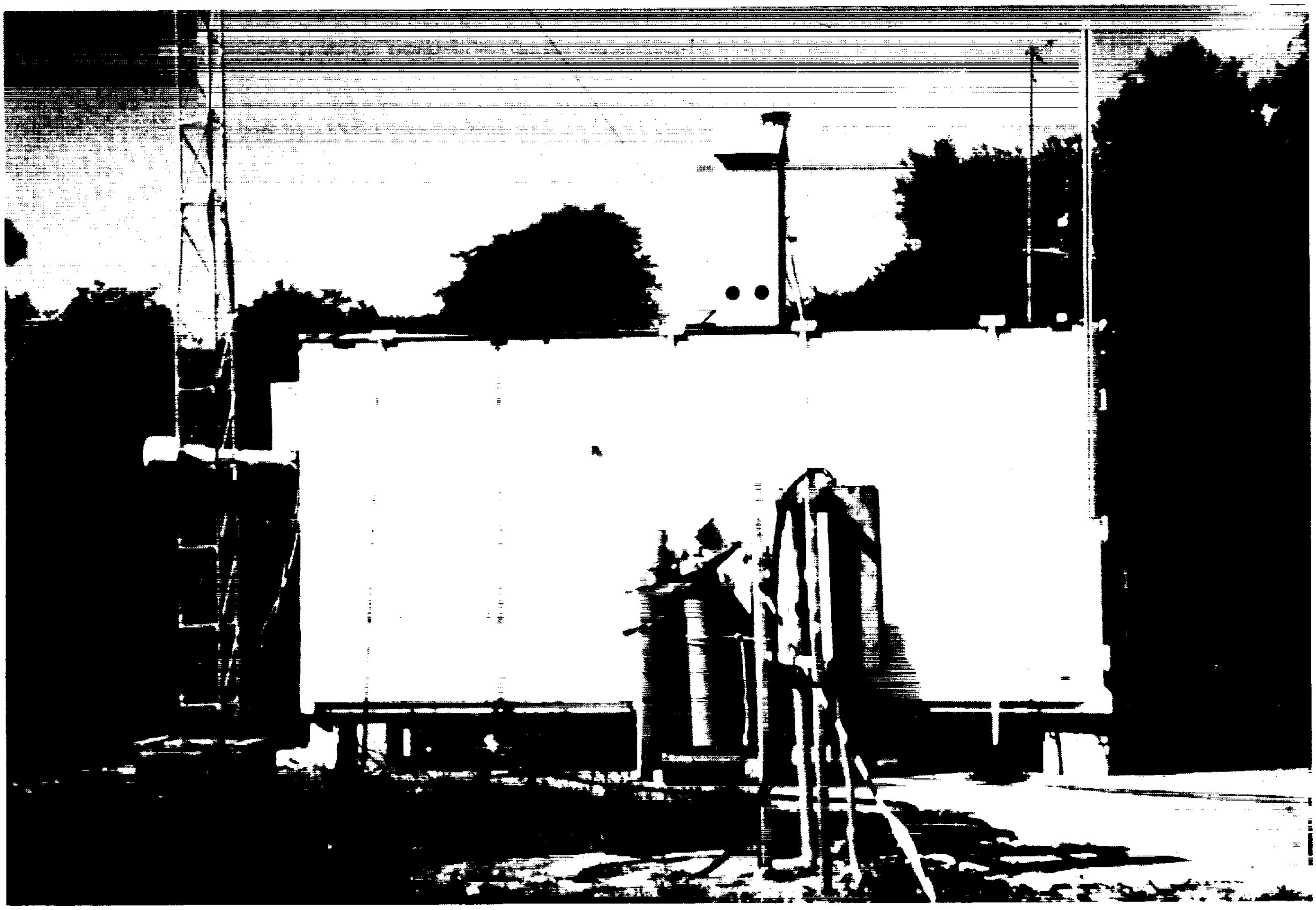
Contact:
W. M. Knott, Ph.D., 853-5142, MD-RES-L

Participating Organization:
The Bionetics Corporation (R. F. Strayer, Ph.D.)

NASA Headquarters Sponsor:
Office of Space Sciences and Applications

Air Quality Monitoring

Long-term ambient monitoring of the Environmental Protection Agency (EPA) and the Florida Department of Environmental Regulation (DER) priority pollutants (ozone, sulfur dioxide, carbon monoxide, nitrogen oxides, and particulates) as well as local meteorological conditions continued at the permanent air monitoring station (PAMS). Instrumentation used for sampling employs different analytical techniques including the following: ozone - gas chemiluminescence; sulfur dioxide - pulsed-ultraviolet fluorescence; carbon monoxide - gas filter correlation infrared absorption; and nitrogen oxides - gas chemiluminescence. The data is collected once per minute by a data logger tied via modem to an HP-9000 mainframe computer. The data is validated using the EPA and DER Quality Assurance guidelines. The



Permanent Air Monitoring Station

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

historic trend of increasing ozone levels continued during 1990 with one exceedance of the national ozone standard. This exceedance brings the theoretical number of expected exceedances to 2.0. There were no other exceedances during the year.

A new trailer was purchased to replace the old one and new equipment was purchased to measure ozone and nitrogen oxides. These instruments are microprocessor controlled to help eliminate older instrumentation problems such as zero and span drift.

Contact:
W. M. Knott, Ph.D., 853-5142, MD-RES-L

Participating Organization:
The Bionetics Corporation (J. H. Drese)

NASA Headquarters Sponsor:
Office of Space Flight

Raster Vector Integration

The Remote Sensing and Geographical Information Systems Laboratory has recently acquired the ability to integrate Earth Resources Data Acquisition System (ERDAS) raster data and Environmental System Research Institute (ESRI) ARCINFO Geographical Information System (GIS) vector data via the ERDAS LIVELINK software module. This allows a user to display raster data such as satellite data (e.g., Landsat 5) and integrate vector or point data, superimposing that information on top of the image. The image is georeferenced to the Florida state plane coordinates system by 100 ground control points. Vector data (representing such features as buildings, roads, and railroads) and point data (such as groundwater sampling stations) are digitized from existing Master Plan maps. In addition, observation records, such as those collected during aerial surveys of the Florida manatee occurring in KSC waters, can also be easily depicted on the screen. Tabular data for any information superimposed over the image can simultaneously be displayed. This ability to query any associated data base is made possible by the relational data base capabilities of ARCINFO GIS software.

Contact:
W. M. Knott, Ph.D., 853-5142, MD-RES-L

Participating Organization:
The Bionetics Corporation (M. Provancha)

NASA Headquarters Sponsor:
Office of Space Flight

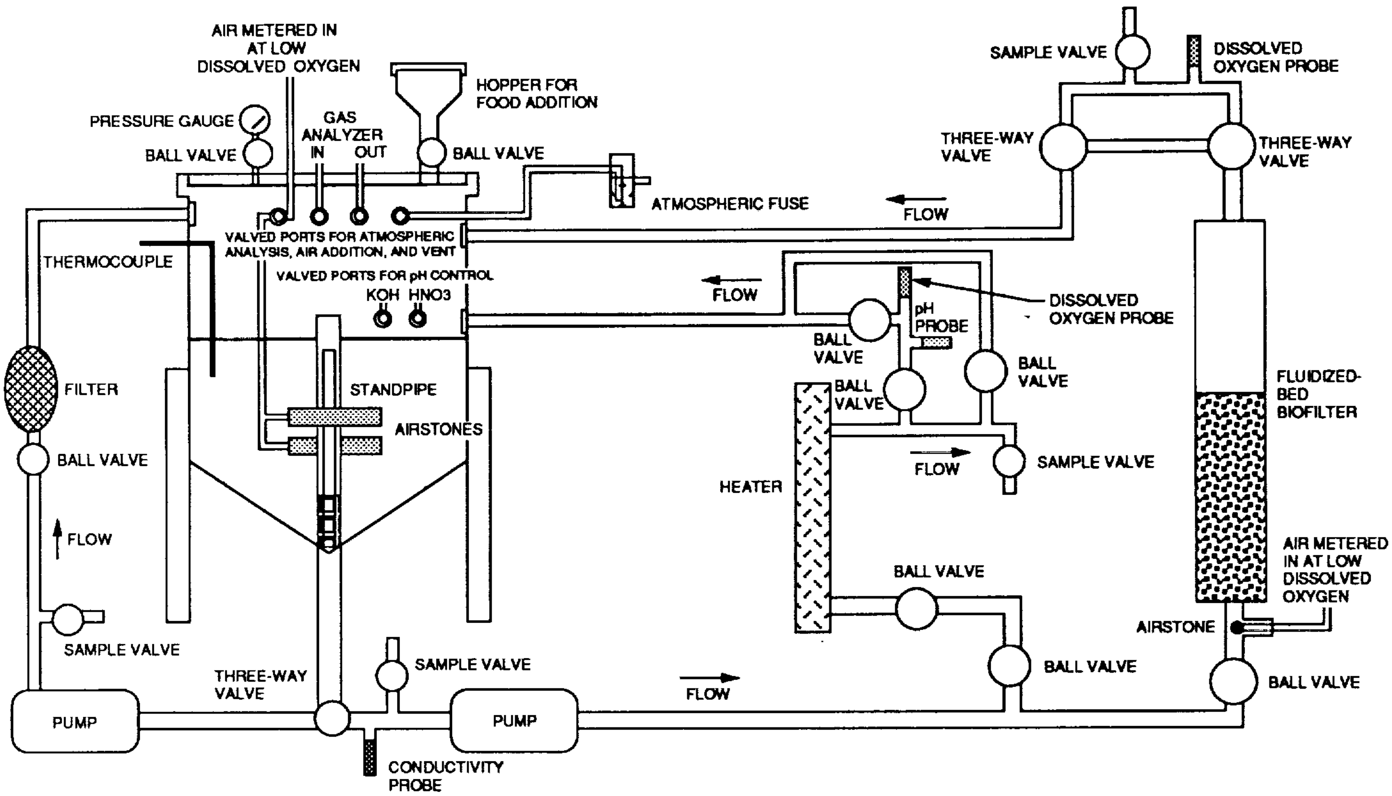
Aquaculture Research

The development of aquaculture as an integral part of the Controlled Ecological Life Support System (CELSS) biomass production and resource recovery efforts was continued. This project included the development and construction of a computer-controlled, atmospherically closed aquaculture system with a 500-liter fish culture tank and a fluidized-bed biofilter (for controlling toxic ammonia). This system will facilitate collection of critical data on mass flows through a controlled aquaculture system. The use of chemostats to culture unicellular algae is being investigated and shows a great deal of promise for providing supplemental food and oxygen for the fish.

Contact:
J. C. Sager, Ph.D., 853-5142, MD-RES-L

Participating Organization:
The Bionetics Corporation (T. W. Dreschel)

NASA Headquarters Sponsor:
Office of Space Sciences and Applications



Closed Aquaculture System for Carbon and Nitrogen Mass Balance

Biomass Production Research

Environmental response studies with various candidate crops for the Controlled Ecological Life Support System (CELSS) were conducted using standard plant growth chambers. As with the previous year, tests focused on the effects of lamp spectral quality and atmospheric carbon dioxide (CO_2) concentration on crop growth and development. Results from 4-week studies showed that soybeans develop leggy shoot growth under high-pressure sodium lighting at low to moderate irradiance, but this can be avoided by supplementing the sodium lighting with some blue light (e.g., from fluorescent lamps) or by increasing the overall irradiance from the sodium lamps alone. CO_2 tests with potatoes showed that no advantages in total growth were obtained when CO_2 enrichment (to 1000 parts per million) was used in conjunction with long photoperiods. In contrast, CO_2 enrichment with short photoperiods produced yields nearly as high as those obtained under regimes with higher total lighting.

Cultural procedure tests with wheat, sweet potatoes, and peanuts continued in preparation for growth chamber tests under controlled environments. Tests with tissue culture-propagated cuttings of potatoes were conducted in cooperation with the Biology Department at the Florida Institute of Technology. Results showed that cuttings could be kept short under wide-spectrum (white) or special phosphor blue fluorescent lamps, but became unmanageably tall with red phosphor fluorescent or low-pressure sodium lighting. Additional tests showed that enriching the atmosphere with CO_2 could substitute for the normal procedure of adding sucrose to the growing medium of the tissue culture plantlets. This indicates that plants can generate photosynthetic competence in tissue culture and may provide a means for avoiding the use of sugar for plant propagation schemes for a CELSS.

Contact:
R. M. Wheeler, Ph.D., 853-5142, MD-RES-L

Participating Organization:
The Bionetics Corporation (C. L. Mackowiak)

NASA Headquarters Sponsor:
Office of Space Sciences and Applications

Tubular Membrane Plant Growth Unit

The Tubular Membrane System (TMS) is a patented plant nutrient delivery system being developed for growing plants in microgravity. The ability to grow plants in microgravity is important for supplying food and regenerating oxygen for human presence in space. The testing of computer control for the TMS continued with a crop of a dwarf variety of tomato being grown. The TMS was also used for germination tests with the Long Duration Exposure Facility (LDEF) space-exposed tomato seeds and controls.

Dwarf Tomato Plants on the TMS

Contact:
W. M. Knott, Ph.D., 853-5142, MD-RES-L

Participating Organization:
The Bionetics Corporation (T. W. Dreschel)

NASA Headquarters Sponsor:
Office of Space Sciences and Applications

Development of a Method for Imaging Muscle Cross Section Using Magnetic Resonance

A method was developed for converting magnetic resonance images (MRI) collected on a medical MRI scanner to a format readable on the Macintosh personal computer. A program was written to view the images and calculate muscle cross-sectional areas. This method was used in a study of changes in muscle volume.

Contact:
P. Buchanan, M.D., 867-2585, MD

Participating Organization:
The Bionetics Corporation (D. Woodard, M.D.)

NASA Headquarters Sponsor:
Office of Space Sciences and Applications

The Important Role of Eccentric Muscle Actions in Exercise Countermeasures

Skeletal muscle not only develops force when it shortens and lifts a load at 1 g, it also resists stretch when lowering a load. An example of the latter activity would be walking down stairs. Muscles of the lower limbs are activated, develop force, and are stretched to control the descent. While lengthening muscle actions (so termed eccentric) are essential for most physical activity at 1 g, they seldom (if at all) occur in space because of the lack of gravity.

A research study has been conducted at Kennedy Space Center to determine if eccentric actions are essential for inducing optimal adaptive responses to resistance training. Subjects performed lower body exercise with concentric and eccentric actions or with only concentric actions for 19 weeks.

Training with both types of actions resulted in greater increases in strength than training with only concentric actions. This was also true after 1 month of detraining, which resulted in modest decreases. Training with both types of actions also caused greater muscle fiber hypertrophy, especially of fast-twitch, type II fibers. As with strength, modest atrophy occurred after 1 month of detraining. The metabolic cost of training with concentric actions was only slightly increased by adding eccentric actions to the exercises.

The results have several important implications for the development of exercise prescriptions and equipment for use in space. The exercises used to date in space have been mainly endurance in nature and have provided resistance during concentric actions. They have maintained functional capacity of the cardio-respiratory system, but have not maintained muscle strength or mass. Our results indicate that the lack of eccentric actions could, in part, explain their ineffectiveness. Moreover, the use of eccentric actions adds little to the caloric cost of resistance exercise, while optimizing increase in muscle size and strength. This is an important point considering the enclosed environment of a spacecraft, where food and oxygen, for example, are not in infinite supply.

The aforementioned results and concepts clearly indicate that eccentric actions should be incorporated into the exercise prescriptions to be used during space flight. This has not been done, in part, because commercially available equipment that provides loading during eccentric actions is not readily adaptable for use in the enclosed, energy-sparse environment of the space vehicles. The equipment requires electricity and uses fluid-filled cylinders to provide resistance for eccentric actions. A mechanical device that imposes resistance during eccentric and concentric actions, as evident at 1 g, needs to be developed. Research in this direction is presently being conducted.

Contact:
P. Buchanan, M.D., 867-2585, MD

Participating Organization:
The Bionetics Corporation (G. A. Dudley, Ph.D., and P. A. Tesch, Ph.D.)

NASA Headquarters Sponsor:
Office of Space Sciences and Applications

Autonomous Systems

Autonomous systems research and development efforts at the John F. Kennedy Space Center (KSC) are focusing on applying artificial intelligence and robotics technology to the Space Shuttle's ground processing and launch operations. The Artificial Intelligence Laboratory and the Robotics Applications Development Laboratory are engaged in this application process.

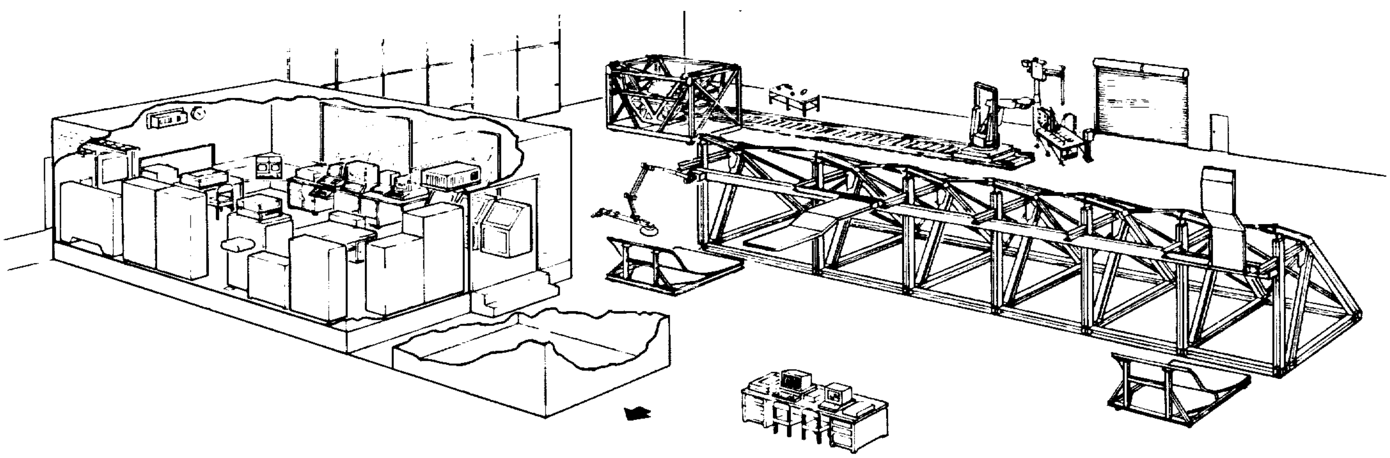
Robotics Applications Development Laboratory

The Robotics Applications Development Laboratory (RADL) is used for prototyping and testing of robotic systems that will be capable of performing many of the mechanical ground processing functions for the Space Shuttle and associated payloads. Elements in the design and evaluation stage include stereo and structured laser three-dimensional vision systems, realtime reactive and adaptive control systems, and a variety of force/torque and proximity sensors. The integrated RADL system is currently providing an easy-to-use testbed for NASA sensor integration experiments. Advanced target tracking development is in progress for mating of umbilicals used during space vehicle launch. Programmatic studies are underway to use laboratory capabilities to enhance the safety, productivity, and efficiency of KSC facilities for Shuttle and future ground processing operations. Projects are underway that should generate large operational cost savings through the integration of advanced technologies for ground processing operations, such as Orbiter tile and radiator damage assessment.

Artificial Intelligence Laboratory

The Artificial Intelligence Laboratory provides the capability to investigate and develop artificial intelligence/expert systems technology needed by the Space Shuttle program for streamlining checkout and launch operations. The laboratory serves as a working environment for systems domain experts and software programmers. It houses specialized computers (14 symbolic processors) and 16 general-purpose personal computers plus peripherals. The laboratory is involved in the analyses or development of an intelligent launch decision support system (launch feasibility management tool) and a knowledge-based autonomous test engineer (autonomous control, monitoring, fault recognition, and diagnostics for troubleshooting).

Robotics Applications Development Laboratory



Robotics Applications Development Laboratory

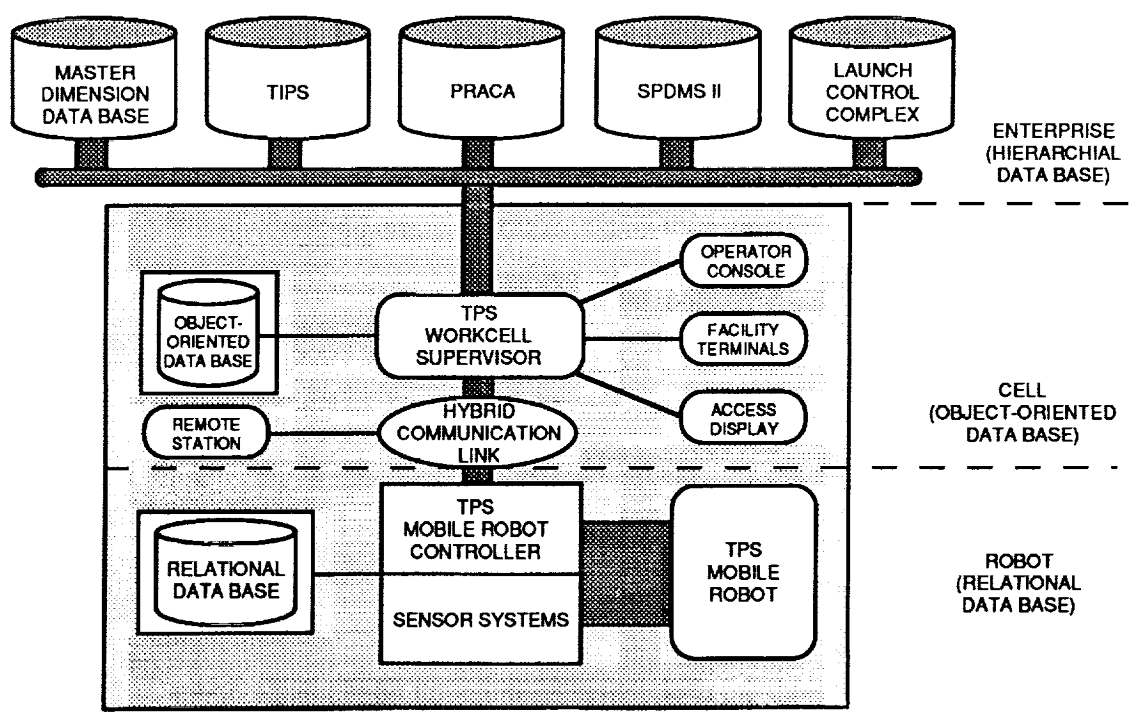
Artificial Intelligence Laboratory

Orbiter TPS Automation Study

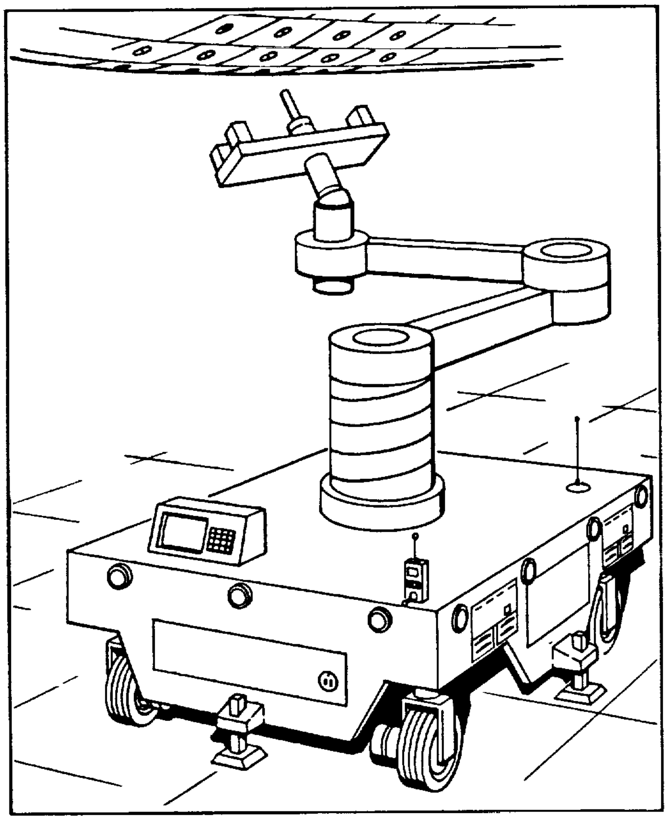
A comprehensive study was conducted to evaluate Orbiter maintenance procedures on the Thermal Protection System (TPS) and to select procedures that could be automated using available robot and sensor technology. The objectives of the study were to identify TPS tasks whose automation would be cost effective and could improve the Orbiter maintenance schedule and to integrate state-of-the-art robotic technologies into NASA's ground operations.

A list of all relevant tasks was compiled. This list comprised 132 processes from which 19 tasks were selected as candidates for automation. Preliminary evaluation of these tasks narrowed the list to seven tasks that could be justifiably automated with available technology. These tasks were then rank ordered, and the ranking selected the step-and-repeat tasks (tile rewaterproofing and TPS anomaly detection) as initial processes to be automated. Four of the remaining tasks can be added at a later date with software additions only; one task would require a specialized sensor to be developed under a different program.

The study resulted in a conceptual design for a robotic system capable of moving sensors and specialized tools to inject and inspect the lower surface tiles. Because the rewaterproofing tool has to be moved from tile to tile and because current sensor technology is incapable of viewing the entire Orbiter underside, a mobile base with an associated fine-positioning mechanism is required to move the tools and sensors around in a timely manner. The mobile base can be semi-automatically or automatically moved into various positions underneath the Orbiter and would be capable of being transported to the appropriate facility during the refurbishment cycle to perform work. The system will function by: (1) accepting user-defined data (e.g., tasks and regions to work on), (2) performing tasks in an autonomous fashion, and (3) automatically uploading the resulting data (e.g., inspec-



Automated TPS Control System Architecture



Automated TPS Processing Mobile Robot

tions, dimensions, pictures, maps, etc.) to the appropriate data base management systems.

A 3-1/2-year project plan was developed that would allow significant demonstrations of intermediate capabilities of the system throughout the development cycle. Early demonstrations will include operator interface displays and tile rewaterproofing and sensor capabilities. Intermediate demonstrations will include mobile-base move and fine-positioner capabilities. Early in the integration, demonstrations of system navigation, positioning, and sensor interaction will be made with realistic mockups. The robot will locate randomly selected tiles and the sensor data will be acquired and displayed. These and later demonstrations will directly support the final goal of complete integration of a production-qualifiable system.

The study team concluded that the system proposed for automating the selected tasks is technically feasible and cost justifiable. Initial labor hour savings are calculated to be 630 hours per flow and 2500 hours per flow on full implementation. Process efficiency savings of several weeks per flow will be realized for some automated tasks. Improvements to shop safety, TPS quality, and paperless documentation will also be significant.

This will be the first mobile robotic system used for Orbiter launch processing. Development of the system will result in a nontrivial integration of state-of-the-art technologies. System development will begin in January 1991.

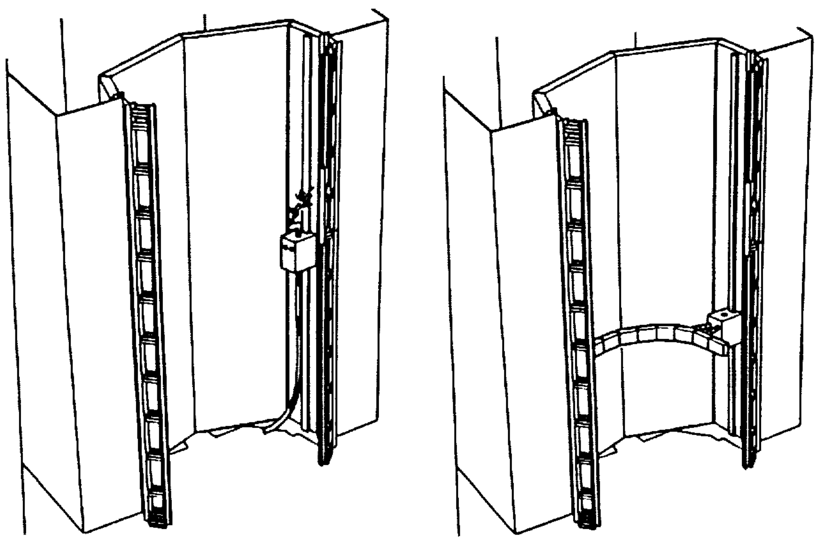
Contact:
T. A. Graham, 867-4156, DM-MED-12

Participating Organization:
Boeing Aerospace Operations, Engineering Support Contract, (J. R. Bledsoe and W. Spiker II)

NASA Headquarters Sponsor:
Office of Aeronautics and Space Technology

Payload Processing System Study

The Kennedy Space Center (KSC) is the operational support base for processing the Orbiter vehicle and its payloads (cargo) for the Space Transportation System (STS) to accomplish specific missions in space. Payload processing at KSC includes the preparation, final checkout, and loading of payloads into the Orbiter vehicle before launch and deintegration of payloads upon their return from space. A payload is the cargo



PCR Washdown Mechanism　　PCR Vacuum Mechanism

The InterClean Robot

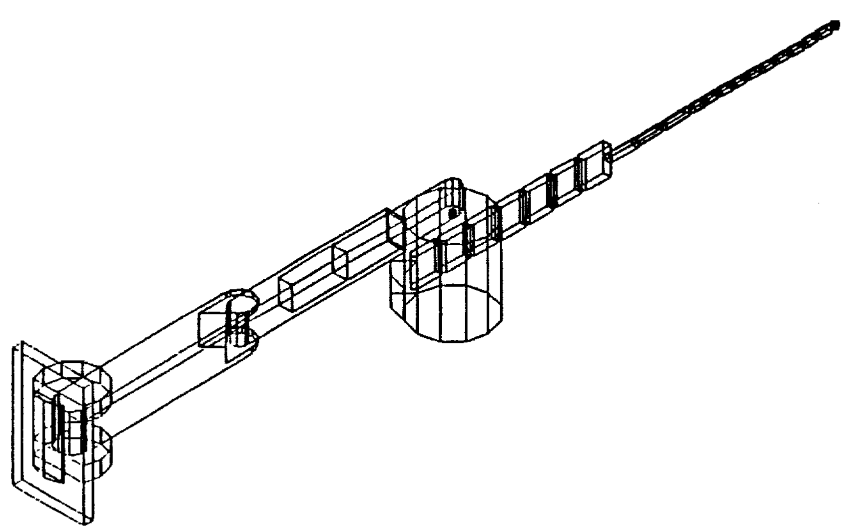
that is designed and built (usually by an owner other than NASA) specifically for integration into the Orbiter vehicle at the Payload Changeout Room (PCR) or the Orbiter Processing Facility (OPF) at KSC.

More specifically, the Payload Processing System study was targeted to determine the requirements and design solutions needed to support automated payload processing tasks. The perspective of the KSC study team was to identify and propose appropriate automation/robotic technologies and solutions capable of significantly improving payload processing for the optimum mix of human and machine resources for enhanced safety, productivity, cleanliness, and cost effectiveness.

Three robotic system solutions were identified and proposed: (1) the High-Efficiency Particle Accumulator (HEPA) Filter Aerial Inspection Robot (HAIR), (2) the Interstitial Area Cleaning (InterClean) Robot, and (3) the Multiple-Degree-of-Freedom Robot (M-DOF).

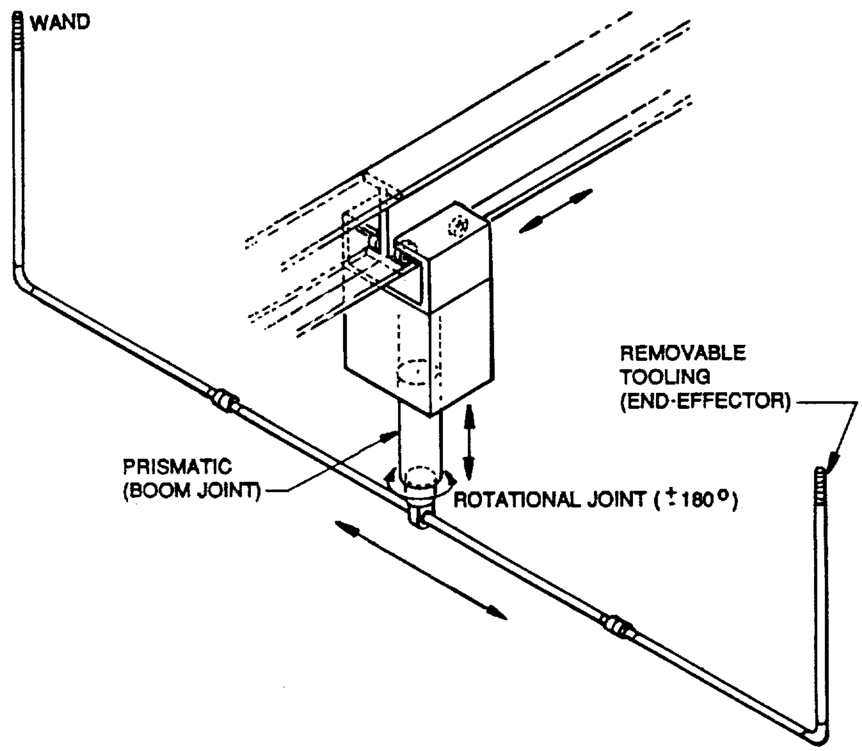
<u>HAIR</u>

The HAIR performs the inspection and certification of the clean air HEPA filters in the ceiling of the PCR. This is an essential step in preparing the PCR to meet the environmental parameters. The proposed system is a 4-degree-of-freedom (4-DOF) robot with three prismatic joints and one rotational joint (PPRP), designed to operate on the existing 5-ton bridge crane rails located at the PCR. This system will be equipped with sensors and feedback circuitry to autonomously or semi-autonomously control the 4-DOF robot to perform systematic filter efficiency and leak checks



M-DOF Robot Simulation

without damaging the filters or colliding with existing structures.



HEPA Aerial Inspection Robot (HAIR)

InterClean Robot

The InterClean robot performs both the exterior washdown of the main PCR doors and the removal of insects from the interstitial area between the Orbiter payload bay doors and the PCR main doors. This system will incorporate two vertically translational bases, permanently installed in the interstitial area and the washdown and vacuum end-effectors. The washdown InterClean is a 2-DOF robot with one prismatic joint and one rotational joint (PR). The vacuum InterClean is a 3-DOF with two prismatic joints and one rotational joint (PRP). The system will be equipped with adequate sensors, controls, actuators, and fail-safe features to autonomously clean the interstitial area.

M-DOF Robot

The M-DOF robot will perform a number of tasks that require light-duty manipulation and long reach into a highly restricted work space. The proposed design is a redundant (greater than 6-DOF) manipulator arm. This system will perform basic processing tasks such as inspection, insertion, and removal of small items. The configuration will consist of a positioning boom and a serpentine manipulator. The positioning boom will provide a base for the serpentine manipulator and is attached to the PCR strongback. The boom consists of three links: a rotary shoulder joint at the base, a rotary elbow joint between the first and second link, and a telescopic joint between the second and third link. This positioning mechanism will be responsible for positioning the serpentine manipulator close to a desirable access window into the payload. The serpentine manipulator will consist of three sections: a planar base arm, a planar midarm, and an end arm that consists of tubular links moving in three dimensions. The system will incorporate a number of advanced technologies in the area of sensing (skin), mechanisms, path planning, control, and user interface. The M-DOF will be a 5-year project with 2 years of research and development. At the end of 2 years, a feasibility review study is anticipated.

The M-DOF robot presents a tremendous opportunity to demonstrate advanced manipulation techniques in more complicated payload processing scenarios. Due to the fundamentally complex environments surrounding payloads and payload processing, a flexible robotic system capable of complex maneuvers in very constrained spaces will prove invaluable to inspection, checkout, light manipulations, and general processing of payloads at KSC. In addition to offering the advanced capability of redundant degrees of freedom into automated payload processing, the M-DOF system will no doubt provide a rich source of systems and components for technology transfer.

Contact:
R. Lewis, 867-4181, DM-MED-12

Participating Organizations:
Boeing Aerospace Operations, Engineering Support Contract (G. N. Maliotis)

McDonnell Douglas Space Systems Company

Carnegie Mellon University

NASA Headquarters Sponsor:
Office of Aeronautics and Space Technology

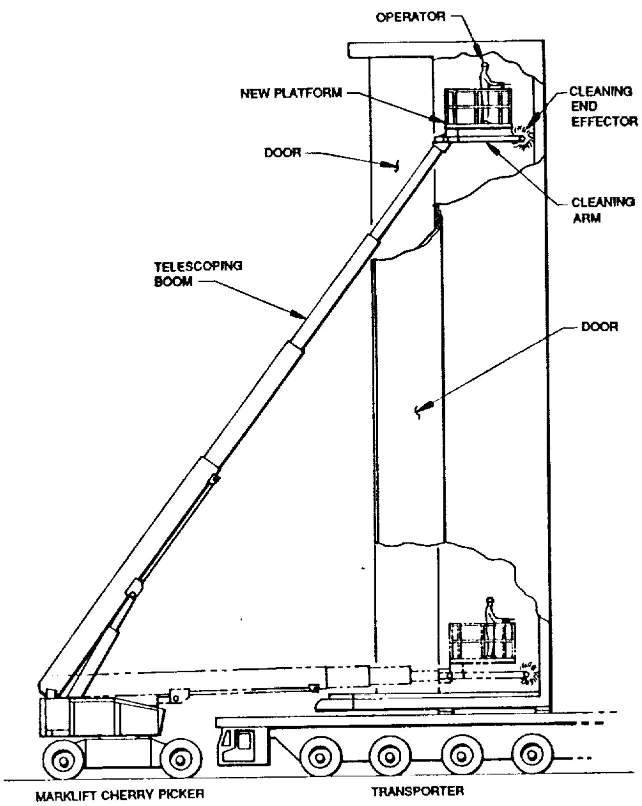
Automation of Payload Canister Cleaning

The payload canister is used for transporting mission payloads from several processing facilities at Kennedy Space Center (KSC) to the launch pad. The payload is then installed inside the Orbiter payload bay. The canister must maintain a clean interior environment around the payload throughout transportation. It is required that the canister interior walls and components be cleaned before a payload is installed. The canister is cylindrical in shape with a length of about 67 feet and a diameter of about 15 feet. Currently, this cleaning process involves the effort of three technicians working for approximately four days. The KSC Robotics Section has studied the feasibility of automating this process.

After a thorough search and data evaluation, it was determined that there were no commercially available robots to successfully perform the cleaning process. A number of conceptual designs for automating the process were investigated; several of these approaches could be implemented. As the study progressed, it became clear that canister cleaning should be approached as an automation process and not a robotics automation process. A program has been proposed that emphasizes development of an automated cleaning system using state-of-the-art technology.

This approach offers several advantages to KSC. There are many potential applications for an automated cleaning system, and this program will develop a generic system that will have the flexibility to be applied in other applications. The recommended approach (see the figure "Proposed Canister Cleaning Configuration") will minimize risk and shorten development time. This will result in a low-cost application that will be available in a short time frame. Operationally, this system should improve safety and shorten processing time.

In the next year, engineering design will commence on the mechanical, electrical, and control systems. Concurrently, cleaning end-effectors will be designed, built, and tested. By the end of the first year, all subsystems will be built and fabricated. After the first-year efforts, it is anticipated that another four months will be required to assemble, test, and certify the complete system.



Proposed Canister Cleaning Configuration

Contact:
R. Lewis, 867-4156, DM-MED-12

Participating Organization:
Boeing Aerospace Operations, Engineering Support Contract (A. C. Hiebert and R. P. Bennett)

NASA Headquarters Sponsor:
Office of Space Flight

Orbiter Radiator Damage Inspection

Background

NASA Kennedy Space Center (KSC) is working on a joint project with Lockheed (KSC and Palo Alto organizations). Lockheed is developing a sensor system to examine and inspect the Orbiter radiators for damage (delamination and meteorite dings) while NASA is developing a robotic mechanism to transport the Lockheed sensor over the complex contours and 10.5-foot by 60-foot surface of the radiators. A prototype production system and future production models will be tested, certified, and installed in the Orbiter Processing Facility (OPF) at KSC.

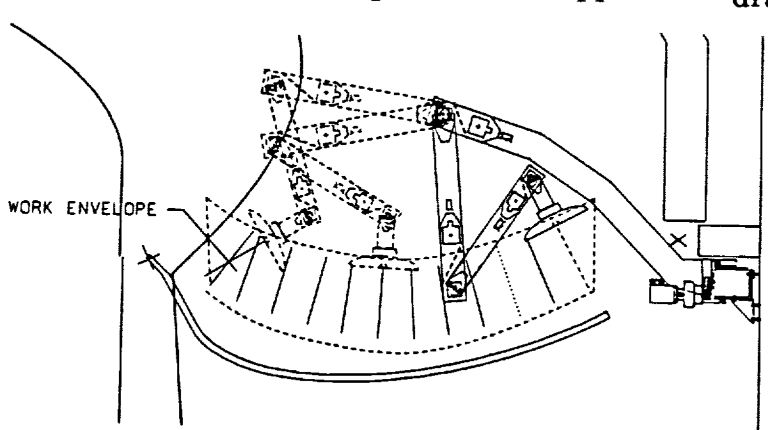
The objective of the project is to decrease the amount of time it takes to process an Orbiter before each mission. The efficiency of the radiators to dissipate radiant heat energy is dependent on their surfaces being clean and damage free. It presently takes 16 people 24 hours to inspect the Orbiter radiators to determine damage (e.g., dings, scratches, impacts, etc.) prior to continuing other work in the OPF. A robotic inspection system should reduce this to two people in three hours and provide accurate repeatable trend data and a quality inspection. Currently, the operation is performed with an XYZ mechanism over the Orbiter that moves "buckets" large enough to carry men and equipment. The buckets are driven by highly skilled personnel. The visual inspection is performed using the naked eye and observations are recorded on a log sheet. This does not provide an accurate permanent record of damages and their locations. Small imperfections may be overlooked. This is a very uncomfortable, task-intensive, repetitive job.

By automating this operation, most of the personnel would be relieved of their inspection duties so their talents can be used to perform other jobs more demanding of their skills. It would also provide a quickly accessible permanent record of radiator inspection data (damage assessment and precise location), reduce the amount of paperwork required to get the job done, minimize setup time to get ready for inspection, and provide expansion capabilities so that other functions could be performed on the radiators with the automated mechanism (e.g., cleaning). The overall goal is to achieve an efficient and less expensive operation.

Automatic Radiator Inspection Device (ARID)

The ARID mechanism was an evolutionary design culminating in a four-degree-of freedom robot (see the figure "Radiator Inspection Robot"). Lockheed originally envisioned that the ARID would be a camera traveling on a contoured beam shaped like the radiators, transported along two rails that lie along the edges of the Orbiter radiators.

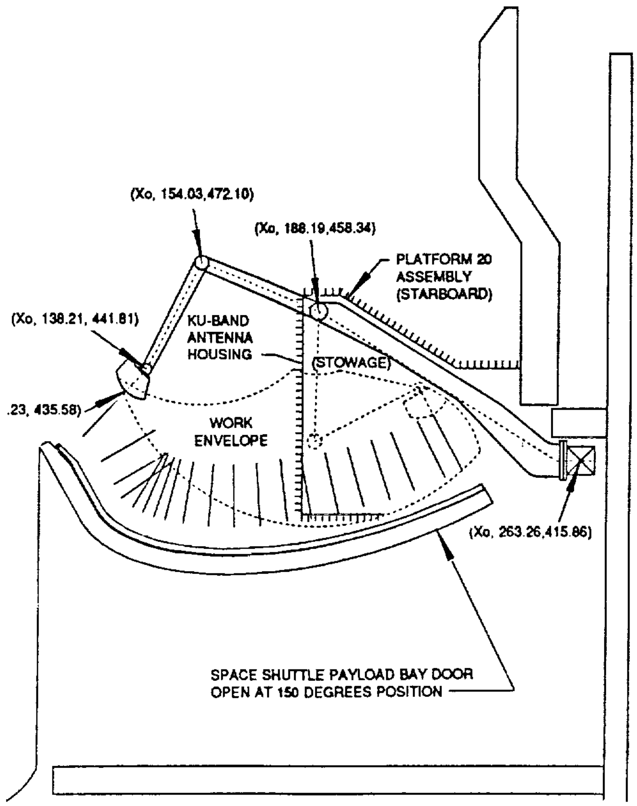
During the design, it became readily apparent that all these problems could be minimized through a flexible robotic mechanism that could: (1) provide a quick, software-programmed "frame shift operation" eliminating parking offset adjustments, (2) be cantilevered from under access platforms located adjacent to the radiator panels and moved out of the way when necessary so as to not impact facility operations, and (3) be reprogrammed or be expanded to support other future changes. This robotic flexibility will be advantageous for future update of the system to allow for cleaning of the radiators by the ARID rather than by men hanging over the sides of buckets. In the near future as the use of the robot becomes more of a standard operation, as people get more accustomed to using automation, and after the ARID proves itself to be reliable, a modification can be made so that it can actually clean the radiators by "hand rubbing" the delicate surface.



Radiator Inspection Robot

The first in-house mechanism concept (a PPRP robot) consisted of a 65-foot prismatic rail to traverse the length of the four radiator panels, a prismatic cart to reach from the outer edge of the door to the Orbiter's hinge, and another prismatic rack-and-pinion rail with a rotary joint to move the inspection device over the contoured surface of the radiators. However, this configuration required many closeup pictures and would have produced an excessive amount of data. The time to process this data would not have significantly reduced operational timelines. Therefore, the design quickly evolved into a PRRR mechanism (see the figure "24-Inch Inspection Work Space") in which the cables could be routed within an enclosed space (bending at the joints rather than being dragged over the width of the radiators). Seals can be installed on the joints to eliminate grease drippings.

Lockheed (the designers of the payload) requested that NASA KSC (the robot designers) investigate designing a mechanism that would allow taking photos from 6 feet away. This design would require that the upper access platforms be raised and another revolute joint be installed to lift the nose of the de-



24-Inch Inspection Work Space

vice; also, it would have made it difficult to design the robot to allow for later modification so it could reach the radiator surface for cleaning. However, a 6-foot inspection proved to be too far away to obtain reliable photos even with zoom lens. Also, since the designers did not want the device to hit and damage the radiators if it fell, it was determined that a 24-inch inspection distance would be the required sensing position above the surface of the radiators. The link lengths of the robot were then designed so the robot could transport the sensor over the work envelope without hitting the radiators at its extreme lower position. A mechanical stop keeps the robot within this work envelope. The link lengths were designed so the stops could be removed later and still be long enough to reach the surface of the radiators for any future tactile tasks.

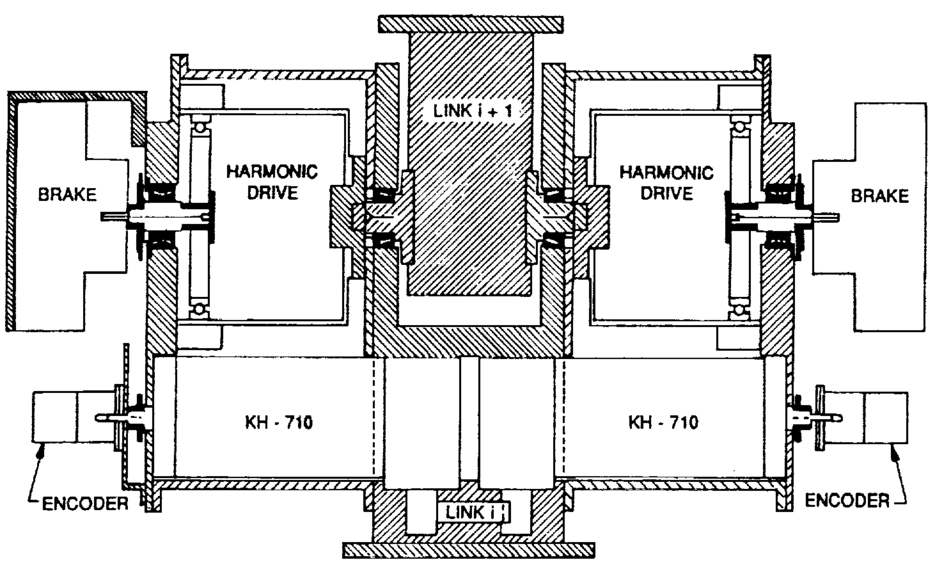
<u>Redundancy Requirements</u>

Since this is the first robot that will be installed next to flight hardware (and especially since it hangs over the radiator doors), the reliability of the robot is extremely important. Recently, several suspended loads at various NASA facilities have had mechanical failures that caused them to drop onto a Spacecraft or flight hardware. If this occurred at the launch pad, not only could an $80 million Spacecraft be damaged, but it would cause an aborted launch. This produces expensive consequences resulting in large amounts of serial-time/money to replace and repair. The existing inspection "buckets" have even collided with the radiator doors and bent them upward. The robot has been designed to not hit any of the radiator panels even in worst-case parking conditions. However, the robot was also designed (for future use) so it could actually touch the entire surface of the radiators. When, and if, the stops and mechanical constraints are removed, the robot control system must be so reliable that there can be no inadvertent moves to cause even "dings" or "scratches" to the sensitive surface. To prevent this from occurring, the ARID has been designed so it contains complete control system component redundancy and additional mechanical constraint redundancy.

Electromechanical design of each joint includes redundant drive shafts, bearings, harmonic drives, brakes, transmission chains, encoders, and motors (see the figure "Redundant Drive Components"). They are sized for the load, torques, and the space available in the stowage position. Electrically, the control system includes redundant motor servocontrollers, redundant indexers, and two separate control computers. Mechanically, redundancy exists by adding a special cable/pulley configuration at two of the joints that would prevent the arm from colliding with the radiators even if both redundant brakes or motor drive chains failed.

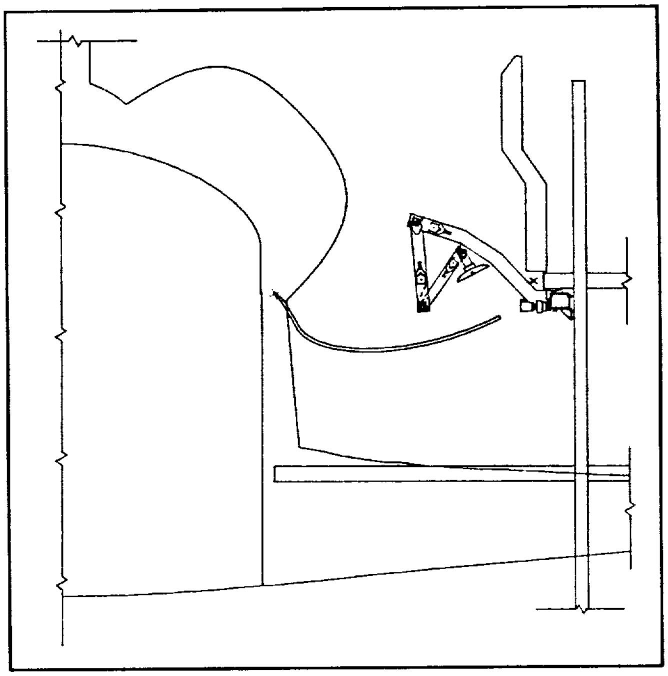
Two motors in parallel could possibly be expected to "fight" each other, but there is a 400-to-1 transmission gear ratio and a small torsional compliance in the harmonic drives and development in the laboratory has resulted in synchronous control of redundant motors. Also, drive components are balanced relative to the load. Therefore, any noticeable motor torque imbalance caused by component failure will be detected and used to shut down the system. The internal motor resolvers are compared against duplicate incremental encoders to provide redundant sensor feedback to enhance troubleshooting by the two computers. Once the fault is identified, the operator can shut down one side of the drive, release its brake, and use the remaining drive to fold the arm back into its tucked position and stow it in its "cubbyhole." In the case of a failure that requires repair of the robot, this will allow the doors to be closed without having to dismantle the robot arm and will enable the operational workflow to continue. A master computer and the slave computer each compare their own calculated kinetic positions, crosscheck positions with each other, and check sensor feedback before allowing parallel-command moves to continue. The redundant system will be used in a "fail-safe" mode. If one computer fails, the other computer is switched in as a lone controller allowing the operation to continue to a safe conclusion.

Simplification is the key to the design. The rotary links perpendicular to the track (prismatic link) of the robot will basically operate in a plane. The arm will be positioned to a location, the joints will be locked, and then the arm will travel lengthwise down a panel (using only the motors in the prismatic axis). Next, the revolute joints will be unlocked and the arm will be lowered to another position that extends outward from the Orbiter. Then the arm will be moved lengthwise again. Photographs will be taken without stopping as the system moves at 4 inches per second. After an automatic scan, the operator may wish to look again at an anomaly or take a "still" photograph. He then can either program that position for an automatic move or manually drive the robot to a point that requires more resolution.



Redundant Drive Components

It is significant to note that the ARID robot involves the application of complete control hardware



Final ARID Configuration

redundancy to enable performance of work above and near expensive critical Shuttle hardware (see the figure "Final ARID Configuration"). There are applications in which a robot would not normally be used because of "reliability" or in situations where an inadvertent move could result in damage to expensive components or even more expensive personnel. In such applications, the consumer marketplace may wish to explore commercialization of these component redundancy techniques.

Contacts:
V. L. Davis, Chau Ba Le, E. Lopez del Castillo, T. A. Graham, and G. Tamasi; 867-4181; DM-MED-12

D. J. Minderman, 867-7584, DM-MED-33

A. P. Smith, 867-9120, DF-FED-21

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Office of Space Flight

High-Speed Flexible Robot Controller

With the advent of high-speed sensor equipment, realtime automated systems have become more feasible. The Robotics Section of NASA's Engineering Development Directorate has undertaken the development of a high-speed robotic controller that compensates for the realtime response deficiencies of commercially available robot controllers. Typical controllers are not designed to respond robustly to streams of realtime sensor data such as vision and force-feedback data used to control a robot manipulator's configuration. This unique control problem prompted the design of a High-Speed Flexible Robot Controller (HSFRC) capable of meeting the demands of realtime, sensor-based control for a generic six-axis industrial manipulator. This system is required for the purpose of fully realizing the benefits of automated mating of umbilicals with flight vehicles. The Robotics Section has already initiated development of this realtime control technology and has established a solid baseline of expertise through relevant analyses, studies, tests, and the production of a working prototype system to demonstrate and evaluate this emerging technology.

The flexibility of this system is found in the software architecture that allows the user to customize the controller to suit any system requirements (see the figure "Run Time Control Software").

The servocontrol is done with an integral term coupled with velocity and acceleration feedback. This feedback increases accuracy and reduces overshoot. The servocontroller also contains a feed-forward gain. This controller takes realtime inputs in world coordi-

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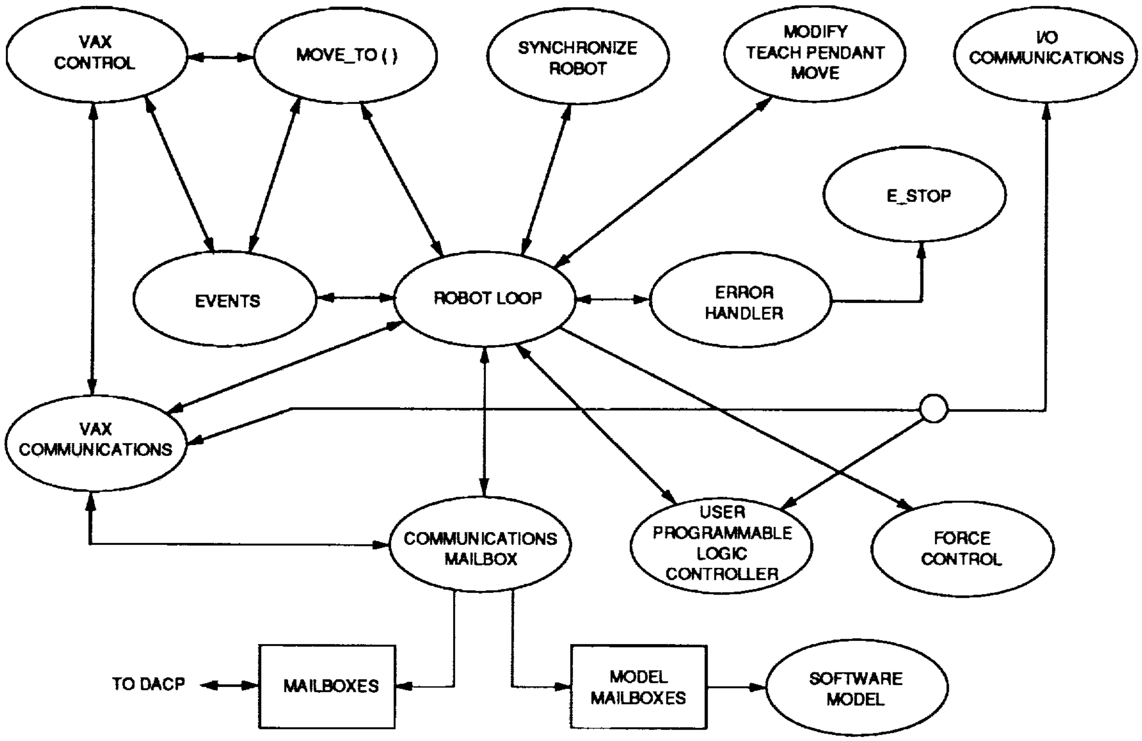
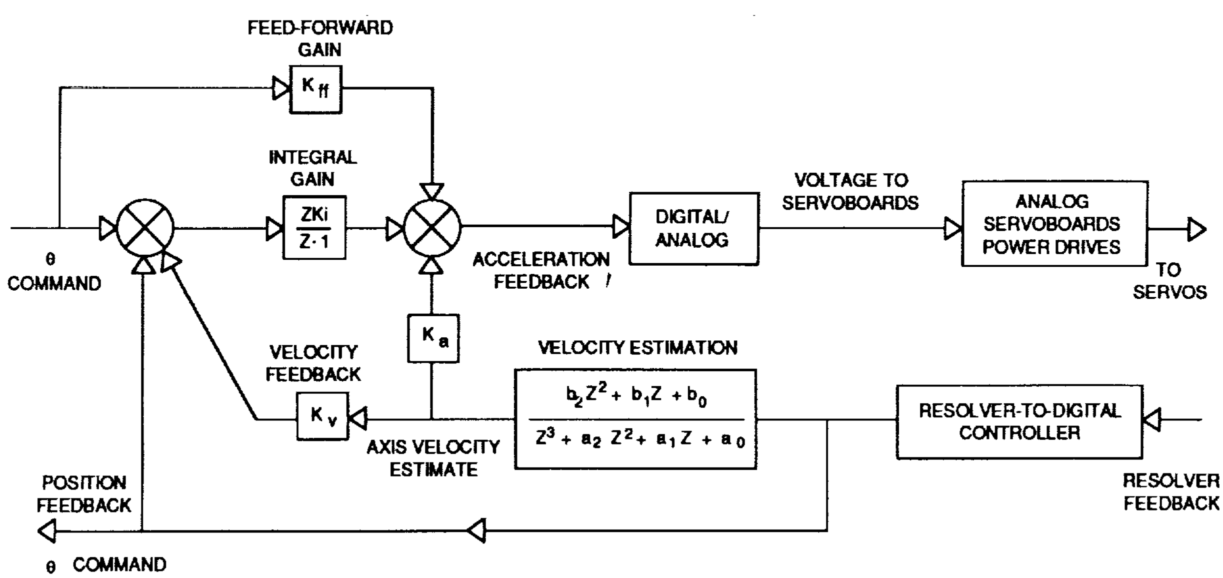
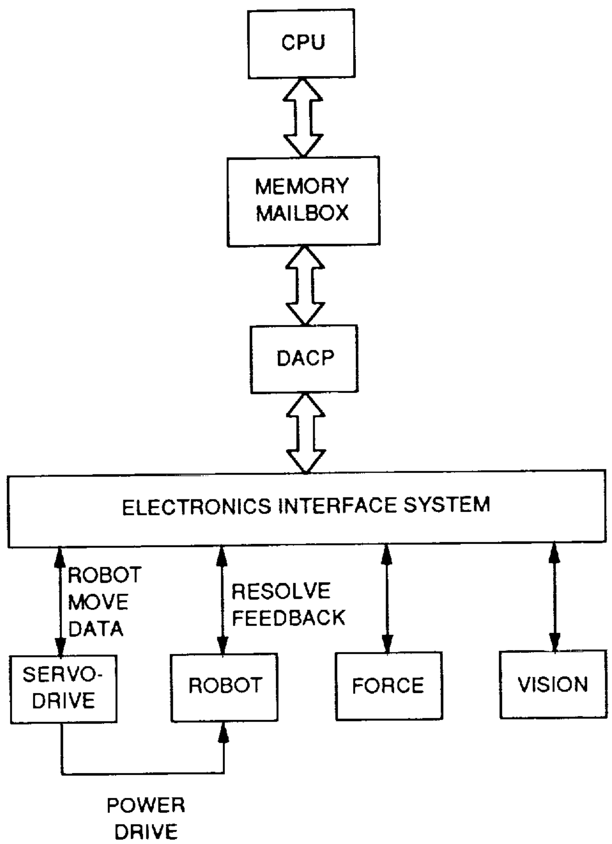


Run Time Control Software

nates and produces a digital servosignal that is sent to the robot's servos through digital-to-analog converters. The actual position of the robot is measured by the resolvers that are installed at each joint of the robot. This information is used to calculate the velocity of the robot and is fed back to the servocontrol loop algorithm as shown in the figure "HSFRC Servocontrol Loop." The velocity is calculated by differentiating the current



HSFRC Servocontrol Loop



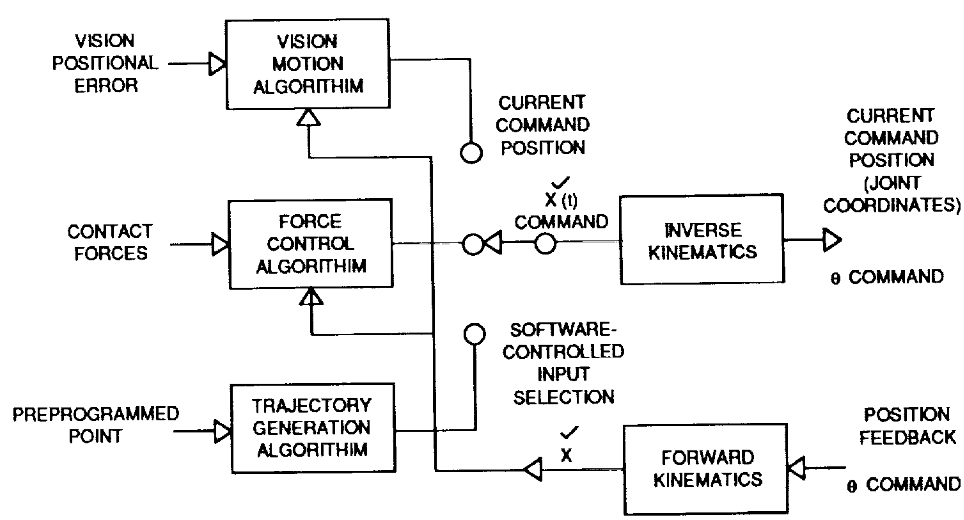
HSFRC Hardware Layout

robot position. This differentiation introduces noise into the calculated velocity; therefore, a low-pass filter is placed inline. This algorithm is used for all joints.

The HSFRC's hardware consists of four major units: (1) the Central Processing Unit (CPU), which executes the servocontrol software, (2) the mailbox system in which all transfers of data to and from the CPU take place, (3) the Data Acquisition Control Processor (DACP), which connects the mailboxes to the interface hardware, and (4) the Electronics Interface System (EIS), which takes data from all sensors and sends data to the robot.

The CPU used for the HSFRC is a Motorolla 68020-based system with a lightning co-processor. This system runs a realtime version of Unix and all servocontrol software is written in "C." The system mailboxes are a chunk of main memory allocated for the purpose of transferring data between the CPU and the DACP. The EIS is the sensor data traffic controller and also decodes the robot's positional data (see the figure "HSFRC Hardware Layout").

The HSFRC takes inputs from realtime sensor systems at rates up to 100 hertz and is capable of sending processed data in world coordinates to the robot at a 100-hertz rate, which increases the control bandwidth from the current 8 hertz to 100 hertz. The world coordinate data is calculated at the servocontrol preprocessor from the robot's current position information fed back from the robot's resolvers (see the figure "HSFRC Servocontrol Preprocessor").



HSFRC Servocontrol Preprocessor

Contact:
Chau Le, 867-4181, DM-MED-12

Participating Organizations:
Iowa State University (Dr. R. Fullmer and K. Bigelow)

Boeing Aerospace Operations, Engineering Support Contract (J. R. Lago)

NASA Headquarters Sponsor:
Office of Space Flight

Knowledge-Based Autonomous Test Engineer (KATE) - A Model-Based Control and Diagnostic Shell

Conventional approaches to developing and maintaining diagnostic and control process software are time consuming and costly. Furthermore, the resulting software may be incomplete and unable to handle situations that were unforeseen when the software was written. Significant advantages are obtained by systematically representing and using knowledge of a system's structure and function. This concept is also known as "model-based reasoning." The Artificial Intelligence Section, Engineering Development Directorate, at the Kennedy Space Center (KSC) is continuing the development of realtime knowledge-based diagnostic and control systems for ground launch operations. The project resulting from these efforts is called KATE. KATE employs concepts of sensor-based and model-driven monitoring and fault location and performs control and redundancy management of process control systems.

KATE is being designed as a generic, model-based expert system shell. The main objective is to provide autonomous control, monitoring, fault recognition, and diagnostics for electrical, mechanical, and fluid system domains. KATE incorporates the engineer's reasoning about control and diagnosis of complex engineering systems in the form of general software algorithms. These algorithms are generic in the sense that they do not contain any domain-specific information. The algorithms are then applied to an exchangeable knowledge base (also referred to as a model base), which describes the structure and function of a specific domain. This knowledge base is essentially a mathematical model of the particular engineering system to which KATE is being applied.

Using this domain-specific model or knowledge base, KATE has the capability of intelligently controlling, monitoring, and diagnosing faults for the particular application. The model produces control operations and expected values for the hardware system's measurements. In addition, it is used to test diagnostic hypotheses generated as explanations for observed failures. The model is automatically updated as the engineering system is manipulated or degrades. The result is increased machine intelligence in reasoning about the system's health and in controlling the state of the hardware system.

KATE is currently implemented in LISP and runs on symbolic processors.

Previous Work

At the Kennedy Space Center, NASA first developed the LOX Expert System (LES) in 1983 to perform fault detection and isolation for the process control system that handles the loading of liquid oxygen into the external tank of the Space Shuttle. In 1985 with the addition of control capability, LES evolved into the more generic and robust model-based system, KATE.

During 1989, KATE was successfully demonstrated against a scale model of the Orbiter Maintenance and Refurbishment Facility's (OMRF's) Environmental Control System (ECS). The OMRF ECS supplies conditioned air to four different compartments of the Orbiter during processing. The hardware model of the OMRF ECS contains a purge unit that supplies chilled air to four ducts that, in turn, supply air to the Orbiter. Each duct consists of a heater for maintaining a constant temperature and a motorized flow control valve for controlling the flow rate. A failure panel has been added to allow for manual failing of various components during testing. An operator can request certain flow and temperature setpoints, and KATE will respond by adjusting the valves and heater output to achieve the setpoints. KATE will also identify and respond to external inputs to the ECS, such as load changes. In addition to control, KATE monitors the system, identifying discrepant measurement values and assigning probable causes. In most cases, control of the system can continue, especially if the discrepancy is due to a measurement failure. KATE's ability to control and diagnose the ECS model is currently available for demonstration.

In February of 1990, the KATE software was implemented as the Generic Control System (GCS) prototype and was successfully integrated into the Generic Checkout System. The Generic Checkout System is composed of a network of Unix-based equipment connected to a physical model of a Shuttle water tanking system, referred to as the Red Wagon. KATE-GCS performs control and diagnosis of chilldown, fastfill, replenish, and other processes related to filling the Red Wagon external tank.

This application of KATE was demonstrated on a Texas Instruments Explorer II. Although KATE is designed to operate the Red Wagon in a stand-alone mode, the Explorer II functions as a display processor within the Generic Checkout System architecture. Communication to the network is accomplished via a Unix co-processor housed in the Explorer II.

Current Activities

The Artificial Intelligence Section is currently focusing on the following two major implementations of KATE: (1) Autonomous Launch Operations (ALO) and (2) Liquid Oxygen (LOX) System.

Autonomous Launch Operations. KATE is being developed under the U.S. Air Force's Advanced Launch System (ALS) Advanced Development Program (ADP) as a project entitled Autonomous Launch Operations. The objective of ALO is to demonstrate an autonomous launch control software system that performs realtime monitoring, fault detection, diagnosis, and control from high-level operations requirements. It is part of an effort to reduce overall launch operation costs by significantly decreasing process control software development and maintenance costs and by greatly reducing launch crew size, human error, and the time required for fault detection, isolation, and recovery.

It is expected that an 80-percent reduction in software development and maintenance costs can be achieved by eliminating application-specific software and automatically generating the required knowledge bases from computer-aided design/computer-aided engineering (CAD/CAE) data base files.

The launch crew size is expected to be reduced to one individual per launch subsystem, a reduction of at least 50 percent from current unmanned launch vehicles, by providing realtime diagnosis and recovery capability. In addition, it is intended that as a result of implementing this research, fewer people will be required to analyze data and make decisions under stress, resulting in a reduction of human errors. Furthermore, the chances of launching on schedule will be improved as a result of this faster analysis of problems and the reduction of human errors.

In order to demonstrate the previously stated goals, two hardware testbeds, a Water (H_2O) Tanking System model and a Liquid Nitrogen (LN_2) Tanking System model, have been constructed.

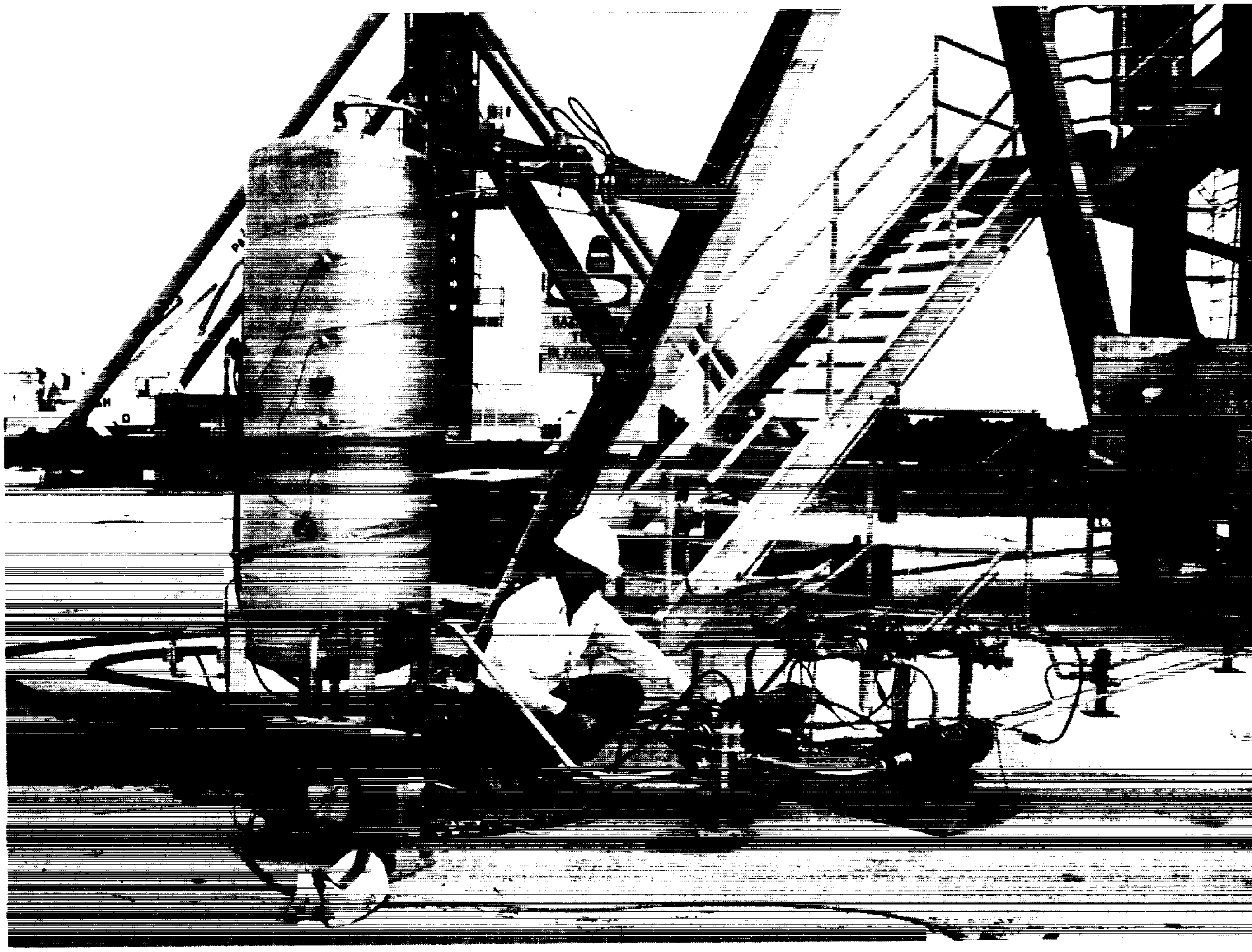
As a first step in demonstrating the KATE software for the ALO project, the H_2O Tanking System model will be used for realtime monitoring, fault detection, diagnosis, and control of fluid tanking systems. As part of the H_2O Tanking System demonstration objectives, KATE will be required to perform the following tanking sequences and operations through its control capabilities: ullage pressurization, transfer line chilldown (simulated), main engine chilldown (simulated), slow fill, fast fill, topping, replenish, fill circuit drain and vehicle pressurization, engine firing (simulated), and drainback. During these H_2O Tanking System operations/sequences, KATE's ability to perform the following tasks will also be demonstrated: dynamic modeling of the physical system, monitoring, anomaly detection and fault diagnosis, explanation of diagnoses through the generation of problem reports, redundancy management, procedure reading, autonomous camera control, single point failure analysis (SPFA), and historical data plotting. Preliminary demonstrations have already begun against the H_2O Tanking System hardware.

In September of 1991, the ALO project plan includes taking another step forward by demonstrating the KATE software against the LN_2 Tanking System model. KATE developers will be greatly challenged by the modeling issues and the required KATE software enhancements surrounding the control and health monitoring of cryogenic fluid systems.

In June of 1992, an integration between the ALO project activities and another Kennedy Space Center ALS ADP (No. 5504) entitled Remote Sensor/Cable Identifier will occur.

In September of 1992, the KATE software will be demonstrated against a multiple-subsystem testbed that will include the existing ECS model hardware, the H_2O Tanking System model, and the LN_2 Tanking System model. This testbed was designed specifically to demonstrate the generic control and diagnostic capabilities in a more launch-realistic environment with KATE software handling a variety of launch support subsystems. A supervisory-level KATE will be tasked to handle the higher level sequencing of the individual KATE-controlled subsystems.

The ALO project plan includes an optional extension for 1993. If the optional year is funded, goals of the project include transferring the KATE software to a conventional



ALO-H_2O Tanking System Storage Tank

hardware and software platform and enhancing the generic software to run against a more robust integrated demonstration testbed, while concentrating on the realtime aspects of monitoring, control, and diagnostics.

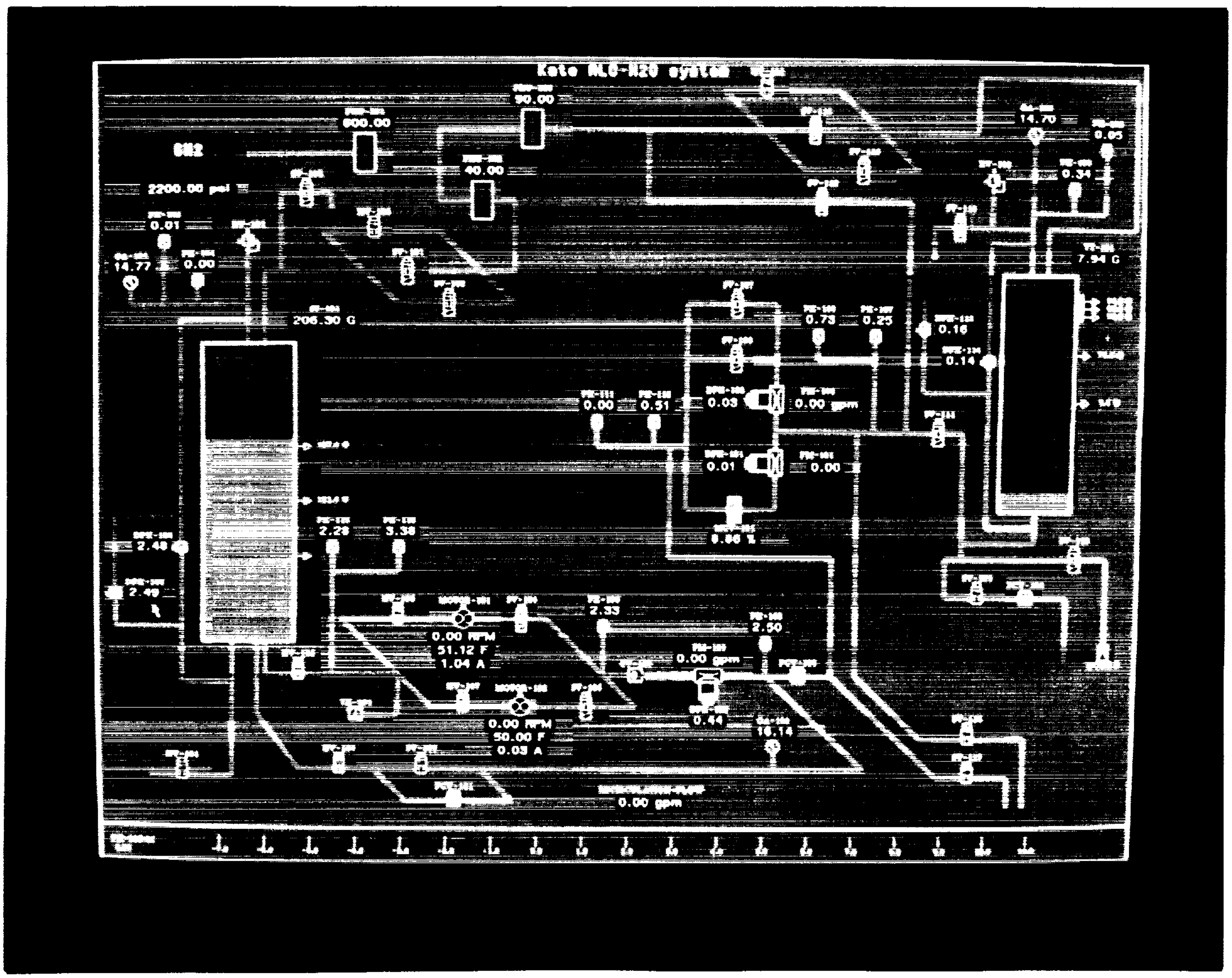
The technology transfer for this program will be accomplished by inviting the ALS prime contractors to attend project reviews and demonstrations and to utilize the software, where applicable, on their advanced projects and/or for unmanned launch complex applications. The KATE developers will act as consultants for the installation and integration into an operational environment.

The deliverables will be the resulting generic control, monitor, and diagnostic software system and tools that will provide single-point failure analysis and will permit rapid generation, modification, and verification of knowledge bases for future applications of the software system.

Liquid Oxygen System. Following the integration of KATE into the GCS architecture, Systems Autonomy activities continued with the application to KATE to the Shuttle liquid oxygen loading system. The ongoing objectives of this project are to incorporate technological advances in control, monitoring, and diagnostic techniques as well as lower software development and maintenance cost in the Shuttle ground operations environment.

The KATE-LOX system currently monitors all phases of liquid oxygen loading into the Orbiter's external tank during fueling operations. Discrepancy reporting and a limited amount of diagnosis are also being performed.

Generic utilities provided in the KATE software shell include data plotting (historical and realtime), online schematics, tolerance graphs, and tree displays. Effective monitoring of the subject domain required the addition of application-specific system functions such as fill mode detectors, short-interval sequence timers, and extensions to realtime measurement tracking. Feedback from target users was used extensively to



KATE ALO-H_2O Tanking System Overview

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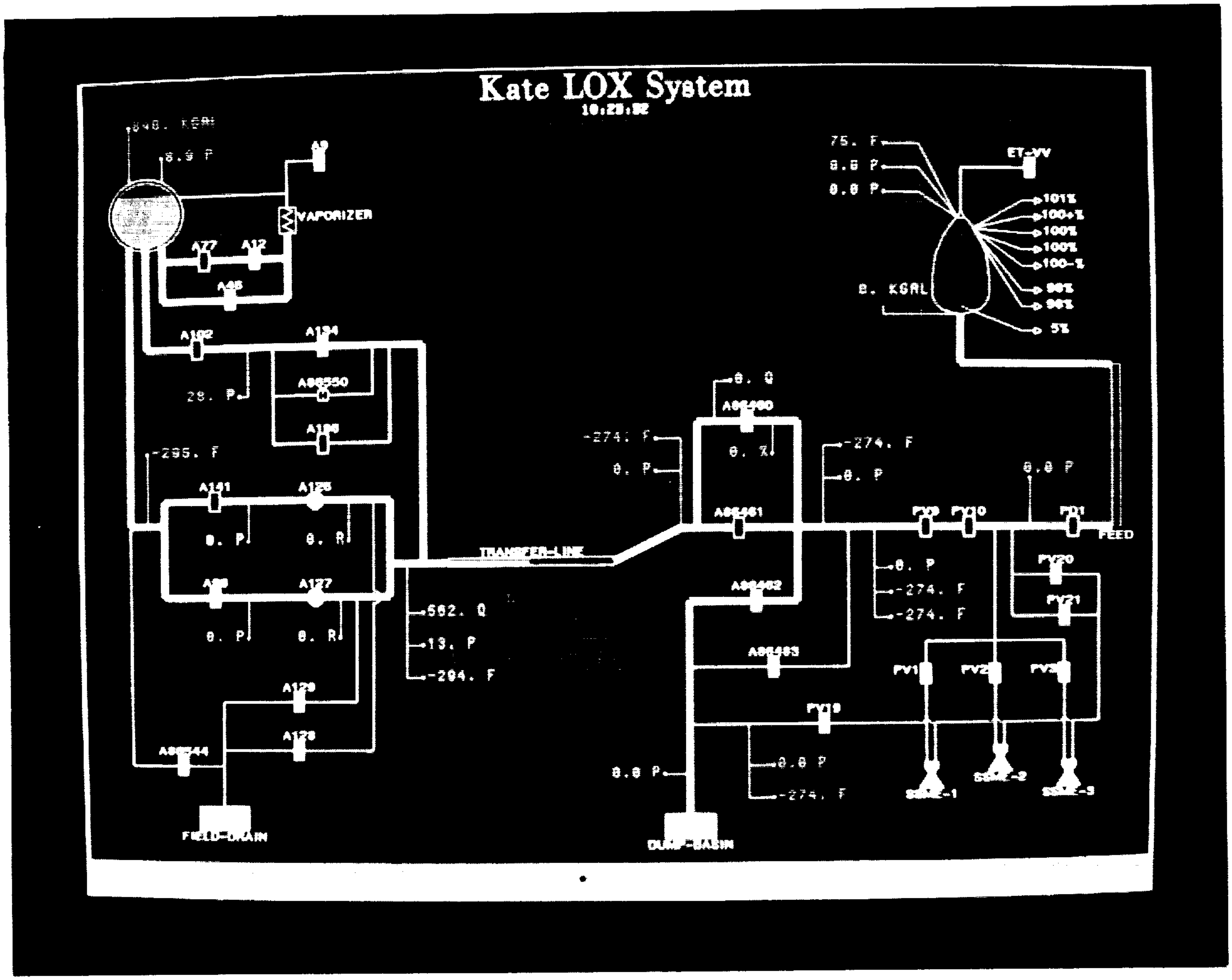

KATE Liquid Oxygen System Overview

design a graphical representation of the LOX system overview that incorporates KSC firing room color-coding convention and icon representations and the animation of the flow of liquid oxygen at critical points in the fill path.

Initial attempts were made to test the KATE-LOX system in the Artificial Intelligence Laboratory using realtime Shuttle playback data from the LOX system. This proved inefficient because playback data is recorded by measurement rather than time, and use of this data required timely resorting. KATE-LOX is installed on a Symbolics XL1200 and now resides in the Vehicle Engineering New Technology Processing Laboratory. Model validation and system testing are being accomplished by exercising the KATE-LOX against the Shuttle Ground Operations Simulator model of the Liquid Oxygen Loading System and online monitoring during live launch countdown loading operations.

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Access to data is performed by an 80486 front-end processor. The 80486 reads LOX-related information being broadcast over the KSC Switched Data Network by a software package known as PCGoal and routes it to a Symbolics workstation. Currently, a combination of 284 vehicle and ground measurements are being processed by KATE-LOX.

Development efforts in 1991 will focus on the completion of the knowledge base, implementation of control advisories, completion of the diagnoser, and design of an explanation facility. End-to-end checkout of the KATE-LOX system in the Vehicle Engineering New Technology Processing Laboratory will be followed by installation in firing room 2 at the Launch Control Center and system validation and verification.

Related Activities

Knowledge Acquisition. Currently, KATE's model bases are built by engineers who have an understanding of KATE's method of knowledge representation and have access to the electrical and mechanical design schematics and design specification documents for the particular application domain. The manual generation of a knowledge base is a time-consuming and tedious task. As a solution, research and development involving the automatic generation of KATE-compatible knowledge bases from CAD/CAE data base files is underway. In addition to in-house development, this research task is being addressed through two outside research projects: the University of Central Florida (UCF) and Prospective Computer Analysts, Inc. (PCA).

A research grant to UCF has sponsored a study to create a tool that can generate knowledge bases from existing CAD/CAE files. Existing data bases associated with most engineering drawings are sparse, usually describing only component names, interconnectivity between components, and minimal functional information. This information is directly translatable, whereas other information required by KATE must be inferred through the use of intelligent tools. UCF has successfully demonstrated the ability to produce an accurate and fairly robust KATE-compatible knowledge base. This 3-year research grant officially terminated in August of 1990; however, some work by UCF continues under a maximum 1-year, no-cost extension. The resulting software tool, referred to as Automated Knowledge Generation (AKG), and associated documentation and user guide, is intended to be analyzed and integrated into existing KATE software utilities by KATE developers.

A Small Business Innovation Research (SBIR) Phase II 2-year contract awarded to PCA is supporting development of a CAD/CAE Knowledge Base Development Tool. Similar to the UCF research grant activities, PCA's project involves the automatic creation of knowledge bases from CAD/CAE data base files but is more encompassing in its objectives. The proposed tool will influence the information input to the CAD/CAE data base by the design engineer. Furthermore, in order to capture the knowledge required by the model base that is not directly transferrable from the CAD/CAE data base, the tool will interface with the system designer during the design phase. The overall objective of the project is to create a tool through which knowledge and information gained throughout the design, development, and operational use of a CAD/CAE-designed system can be retained and utilized to develop and maintain knowledge bases for KATE. Phase II will be complete in July of 1991. At that time, the resulting tool is expected to be demonstrated using the ALO-H_2O Tanking System model as its target application.

Simulation. The KATE software developed for the Generic Control System prototype is currently being enhanced to demonstrate KATE's capability as a simulation tool. This prototype is being implemented on two Symbolics XL1200's and utilizes the knowledge base developed for the Red Wagon. In this two-machine configuration, KATE is installed on both processors. In the first processor, KATE operates in a diagnostic and control mode. KATE also runs on the second processor but simulates actual hardware, or in this case, the Red Wagon.

Possible uses of this tool include simulation of ground support systems and Space Station flight hardware systems for software component checkout and launch team training. Concepts presented by this type of simulation may also be included in a generic simulation prototype currently being developed at KSC in support of "core" software requirements for Checkout Control and Monitoring System II and Test Control and Monitor System.

Space Station Applications. In October of 1989, funding was granted from the Space Station Advanced Development Program to prepare KATE for delivery to the Space Station environment. This project is referred to as the Autonomous Control System (ACS) and its main objective is to implement KATE on a conventional, space-rated hardware platform in both LISP and Ada.

The ACS task suffered a severe funding cut as a direct result of Space Station budget reductions in 1990. Consequently, the decrease in available manpower and lack of development hardware led to a restructuring of the project plan. LISP porting activities to the Compaq 80386 and development of the user interface for the 80386 were delayed in 1990 and completion rescheduled for mid-1991. Implementation and demonstration of KATE in Ada were slipped from 1991 to 1992.

A Functional Requirements Document (FRD) and a Performance Test Plan (PTP) were developed in 1990. The FRD baselines the version of KATE to be implemented on the 80386 in both LISP and Ada. The PTP contains performance criteria and methods for conducting and evaluating system performance tests. Performance testing of the TI Explorer II LISP version of KATE was completed in 1990.

Other milestones for 1991 include producing a detailed design document, which will guide the development of an Ada version of KATE, and gathering system performance data on KATE running in LISP on the 80386.

Summary

The development of KATE and its associated concepts is ongoing. With each new application of KATE, software enhancements are made to enable KATE to become more generic and robust so that it is capable of handling a wider variety of complex engineering systems.

Contacts:
C. L. Belton, B. L. Brown, J. E. Galliher, and P. A. Mullenix; 867-3224; DL-DSD-23

Participating Organizations:
Boeing Aerospace Operations, Engineering Support Contract

McDonnell Douglas Space Systems Company, Payload Ground Operations Contract

University of Central Florida

Prospective Computer Analysts, Inc.

NASA Headquarters Sponsor:
Office of Aeronautics and Space Technology

Remote Umbilical Plate Docking/Insertion

Realtime adaptive control is a necessary tool for tracking a Shuttle vehicle that rocks in the wind while stacked at the launch pad at Kennedy Space Center (KSC). This adaptive control is necessary in order to dock and insert umbilicals (consisting of a ganged connection of electrical and cryogenic/hypergolic fluid lines) without damage to the vehicle and without hazardous leaks. This reduces reconnect times of 17 to 34 hours to less than 15 minutes and eliminates hazards associated with umbilicals that would otherwise have to be connected at launch.

The KSC environment is demanding; the system must withstand heavy acoustical shock and see through fog caused by the dumping of thousands of gallons of water onto the flames of the Shuttle main engines (conditions that exist right after an aborted launch when an umbilical reconnect would take place). These shock and blast conditions rule out sensitive laser tracking. The prototype system being developed at KSC can be upgraded quite easily for this environment. For instance, an infrared filter can be added to the charge-coupled device (CCD) camera and the five dots can be changed to infrared light emitting diodes (LED's) to see through the water vapors without affecting the system architecture or changing the extensive software algorithms.

Speeds at which a target can be blurred are being tracked. The state of the art has been advanced at KSC by developing algorithms and packaging off-the-shelf imaging hardware into process machines that significantly reduce the blurring of moving targets to allow for more precise and smoother tracking.

Adaptive control (trajectory perturbation based on realtime sensory feedback) with heavy inertial loads is being studied. At KSC, engineers are attempting to precisely position 5,000-pound umbilicals (200 pounds initially) with pneumatic counterbalances on future heavier umbilicals. Research in industry has been conducted on compliance-aided insertion of resistors into millimeter-tolerance holes; however, at KSC, heavy umbilicals (oriented perpendicularly with respect to gravity) are being inserted into millimeter-tolerance holes on an object randomly moving with wind-induced perturbations. This induces high torques into servocontrol motors, and stability has been obtained under these extreme conditions.

The Robotics Applications Development Laboratory (RADL) prototype system consists of a vision-based six-degree-of-freedom (6-DOF) tracking system attached to the ASEA robot and a target attached to a separate receptacle plate. Using a passive compliance end-effector, the robot is able to track and insert an umbilical plate mockup (which incorporates fluid, electrical, and data lines) into a receptacle plate mounted on a 3-DOF device that simulates the motion of the Orbiter (see the figure "Remote Umbilical Mating With Dynamic Simulator Target"). The passive compliance device uses nontactile vision tracking and is being augmented by a high-speed flexible robot

Remote Umbilical Mating With Dynamic Simulator Target

controller, which will provide direct access to each joint controller and provide 6-DOF adaptive control capabilities in realtime (30-hertz control updates for vision and 100 hertz for force-torque tracking).

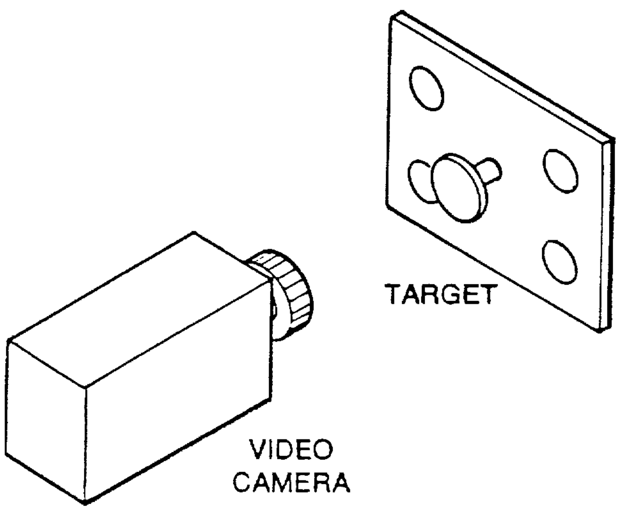
Enhancements include the use of a counterbalance mechanism that removes loads from the robot and enables the robot to disconnect from the umbilical after mating. The robot will be turned off and the umbilical will free float with the counterbalance removing loads from the vehicle. This reduces vehicle design weight and allows more payload to reach space at reduced costs. A floating plate is also incorporated that reduces insertion loads, reduces connect/disconnect surges, and eliminates galling of sensitive cryogenic fluid coupling surfaces. Improvements also have been made in alignment and capture mechanisms to reduce forces, reduce galling, and ensure positive latching.

6-DOF Tracking

A major innovation is a robotic vision subsystem that measures the relative position and orientation of a specially designed target and provides realtime control to a large robotic mechanism. The subsystem uses standard image processing algorithms implemented directly in circuitry instead of computer programs that consume more time. This feature makes it possible to extract complete sets of target tracking data from successive image frames at the rate of more than 30 frames per second.

A solid-state video camera views the target, which consists of five bright or reflective circles, four located at the corners of a square and the fifth located at the center of the square but offset from the plane of the square (see the figure "Tracking Camera/Target"). The raw image data is sent to image processing circuitry that performs a convolution difference-of-Gaussian edge-analysis filtering operation to clarify the picture elements representing the edges of the circles. On the Shuttle, the fifth circle could be implemented simply as a styrofoam thread-spool glued in the center of four painted circles.

The image is then processed further to obtain the centroids of the five circles. The locations of these centroids relative to each other and to the overall image frame are processed to obtain three Cartesian coordinates of the target relative to those of the camera. Triangulation calculations based on the vector relationships among the locations of the five circles and the central axis of the target yield the roll, pitch, and yaw angles that describe the orientation of the target relative to the line of sight and the field of view of the camera (see the figure "6-DOF Target Discrimination in the RADL"). Thus, the relative position and orientation of the target are determined in all six degrees of freedom (see the figure "6-DOF Robot Target Tracking"). The offset of the central circle from the plane of the other four circles can be increased or decreased to increase or decrease the sensitivity of the subsystem to the pitch and yaw of the target and to provide more accurate distance-to-the-target information.



Note:
The five bright circles of the target are positioned in such a way that the video images of them can be processed into data on the position and orientation of the target relative to the camera.

Tracking Camera / Target

6-DOF Target Discrimination in the RADL

The output data may have to be transformed into spherical or other coordinates

6-DOF Robot Target Tracking

used by any other robot. However, this transformation can be performed easily in software. If the robot is changed, it is necessary only to change this software.

Contact:
E. Lopez del Castillo and V. L. Davis, 867-4181, DM-MED-12

Participating Organizations:
Boeing Aerospace Operations, Engineering Support Contract (J. R. Bledsoe, R. P. Bennett, J. R. Lago, A. C. Hiebert, and A. H. Ladd)

Adaptive Automation, Inc. (Dr. P. Walsh)

NASA Headquarters Sponsor:
Office of Aeronautics and Space Technology

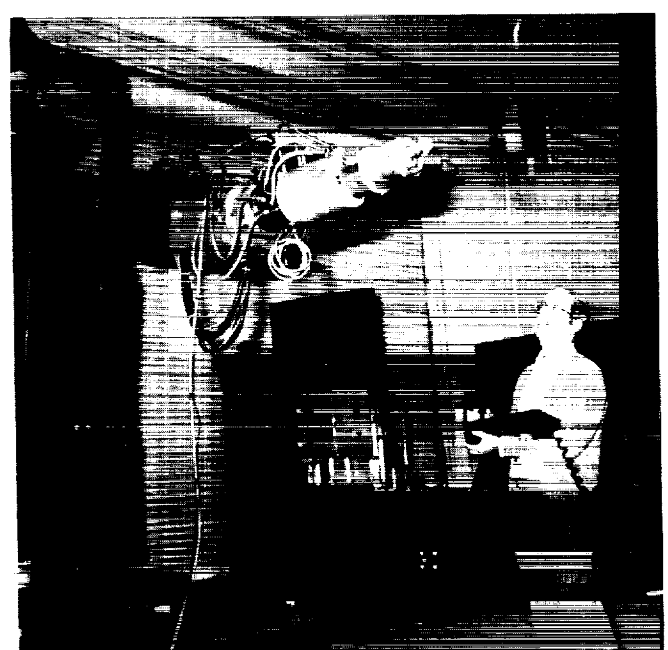
Torque Sensing End-Effector (TSEE)

The TSEE was produced from a Small Business Innovation Research (SBIR) project to develop an "intelligent" tool/gripper to open or close valves during hazardous maintenance or emergency work. The TSEE features servocontrol of jaw-opening dimensions, nontactile/tactile sensors, and torque feedback to determine and maintain optimum seat pressure settings. This feedback provides reflective force feedback to an operator and to automatic computer-controlled operations enabling determination of valve position and preventing damage to valve seals. A Phase I SBIR produced a small working model and a Phase II SBIR (see the figure "Large Phase II TSEE") produced a hardened mechanism with a user-friendly data base capable of operating in hazardous NEC Class I, Division I, Group B, hypergolic/cryogenic environments.

The TSEE's interchangeable gripper can locate a valve position and rotate continuously to open or close valves ranging from either 0.5 to 4.0 inches or 3.5 to 6.0 inches in size. Valves can be opened that have a torque range of 10 to 150 inch-pounds. The TSEE has a unique nontactile torque sensor utilizing magnetoelastic phenomena.

The end-effector is used in conjunction with a computer controller that can interpret commands from an operator at a computer keyboard, from a parallel digital interface on the robot carrying the end-effector, or from a serial communications link to another computer. This lets the system open and close valves and determine if the valve is turning as expected from any of these operating modes.

The computer that controls the end-effector stores information about a range of valves whose positions need to be adjusted. Valves are identified to the system by labels that may be descriptive or numeric. Information in the valve data base is used to



Large Phase II TSEE

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identify valves and to provide information on turning ranges, gripping forces, valve handle sizes, and current status or position of the valves. Once valve configuration information has been put into the system, operations of the valve will automatically update the data base.

A TSEE can be incorporated with the six-degree-of-freedom target tracking system to allow a remote operator [Space Station astronaut, Flight Telerobotic Servicer (FTS) remote controller, nuclear cleanup engineer, or fire fighter] to: (1) position or teleoperate the robot in front of a panel where it can see the target, (2) let the target tracker autonomously orient the robot at the correct angle and distance from the panel, and (3) activate a stored program to perform pretaught routines. The TSEE locates valves (which may be in the wrong position with stems in or out) through simple sensors and then performs pretaught operational sequences to "safe" an operation in a hazardous environment. This can be done with existing technology rather than waiting for telerobots to incorporate artificial intelligence to perform "smart" autonomous operations. This product can also enhance robotic applications in NASA and industry without redesigning existing valve panel facilities for robotics. It will provide safer and less serial-time operations in hazardous environments.

Contact:
Chau Ba Le, 867-4156, DM-MED-12

Participating Organizations:
Automated Dynamics Corporation (E. Hauber)

Boeing Aerospace Operations Engineering Support Contract (J. C. Windham)

NASA Headquarters Sponsor:
Office of Space Flight

Intelligent Launch Decision Support System (ILDSS)

The overall objective of the ILDSS Project is to develop prototypes of tools for the launch team that support decisionmaking during Shuttle launch countdowns. The specific objectives of ILDSS were determined in a feasibility study performed in the summer of 1988 by Arthur D. Little, Inc. The objectives identified were time management, anomaly management, and verbal capture.

Time management by the NASA Test Director (NTD) during terminal count was the first objective chosen for prototyping. The first phase of the time management project focused on a Time Management Integrated Display (TMID). The TMID provides a substrate for all the successive phases. A conceptual prototype was developed in 1989 and a realtime field prototype was developed in 1990.

The realtime field prototype has been field tested against Shuttle countdown simulations, terminal countdown demonstration tests, and launch countdowns. The follow-on phases (of situation annunciation, interactive "what-if," and advisory capabilities in terms of situation action and reactive planning) that were planned in 1990 were deferred until 1991 in order to develop the unplanned realtime field prototype. The decision to develop the realtime field prototype was made when realtime Launch Processing System data became available external to the launch environment. Technology transfer of the realtime TMID field prototype into the launch environment and into the Checkout, Control, and Monitor System II portion of the Common Operational Research Equipment (CORE) Project is planned in 1991.

Operational use of Launch Commit Criteria (LCC), a subset of anomaly management, was the second objective chosen for prototyping. This project will begin in 1991. No work is currently planned for verbal capture.

TMID

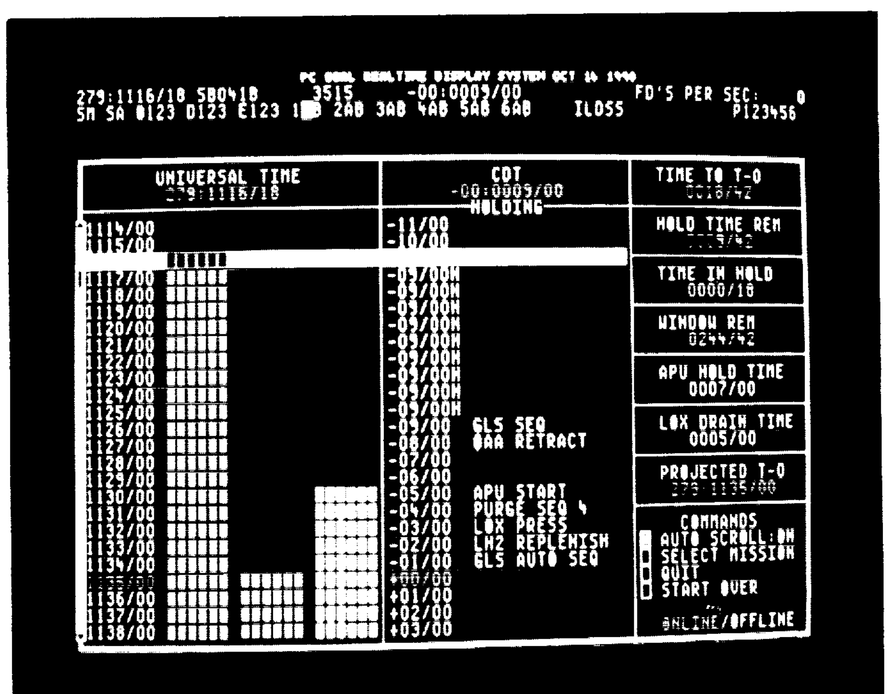
Time management by the NTD simplistically consists of those decisions required by the extension of the T-9 minute hold or invocation of an unplanned hold at one of the remaining hold points. This requires maintaining mental models of the dynamic state of the countdown and managing the process that determines when to resume the count. The TMID integrates information currently available on firing room clocks and hard-copy timelines and correlates the information graphically in realtime.

The figure "Prototype Overview of the ILDSS" is a black and white print of a color screen from the realtime TMID field prototype. It depicts the end of the STS-41 countdown just after entering the 10-minute hold at T-9 minutes.

The TMID screen consists of vertical timelines, a horizontal "now" bar, clocks, and commands. The timelines are Universal Time (UT) and Countdown Time (CDT). The "now" bar at the top correlates the timelines. The clocks are UT, CDT, Time to T-0, Hold Time Remaining, Time in Hold, Window Remaining, APU Hold Time, LOX Drain Time, and Projected T-0. The commands are toggle automatic scrolling for the "now" bar, select a mission profile, quit, and start over.

Each row of the UT timeline represents 1 minute of UT and is labeled in UT with the starting time for that minute. There are three windows that are not labeled. From left to right, the windows are the resume window, the launch window, and the auxiliary power unit (APU) runtime window.

The resume window uses green, yellow, and red. It is displayed in UT but is dependent on CDT, the launch window, collision avoidances (COLA's), and APU run time. This window is enabled after T-20 minutes and counting and is active when there is a hold pending and when there is a hold. It is not active when CDT is counting and there are no holds pending. The colors are used in traffic-light fashion to indicate the situation if the count were resumed at that point in the timeline. Green (go) indicates that if the count were resumed at that point in the



Prototype Overview of the ILDSS

timeline, then projected T-0 would fall within the launch window, would not fall within a COLA, and full APU contingency run time would be available. Yellow (caution) indicates that if the count were resumed at that point in the timeline, then projected T-0 would fall within the launch window, would not fall within a COLA, but full APU contingency run time would not be available. Red (stop) indicates that if the count were resumed at that point in the timeline, then projected T-0 would either fall past the end of the launch window or within a COLA.

The launch window uses blue. It is defined directly in UT without any dependencies. COLA's appear within the launch window in red and are also defined directly in UT without any dependencies. This window is always enabled and active.

The APU runtime window uses cyan, green, and yellow. It is displayed in UT but is not anchored in UT until the APU's are started. It depends on CDT until that point and will slip accordingly when holds are extended or unplanned holds are invoked prior to APU start after T-5 minutes. The window changes from cyan to green and yellow after APU start. Green indicates the nominal time to T-0 and yellow indicates the APU contingency run time. This window is always enabled and active.

Each row of the CDT timeline represents 1 minute of UT. Each row is labeled in CDT with the starting time for that minute. Labels for holds are in yellow and have an H suffix. There are no windows. Ground Launch Sequencer milestone events are shown as text in the minute in which they are planned. Events are shown in white initially and then switched to cyan to indicate that they have occurred based upon the appropriate function designator status.

When a hold is extended or an unplanned hold is invoked, it is possible for a row in the timeline to represent more than 1 but less than 2 minutes of UT. It will always be in the past so that each row in the future will always represent 1 minute of UT.

In order to represent "now" on the timelines, a "now" bar is drawn horizontally across both timelines for correlation of the two. The "now" bar is equal to 1 minute of UT. The idea is to position the bar so the current UT is within its boundary. When enough time has passed so that the current UT is no longer within the "now" bar, it is moved down the timelines to the next minute.

The clocks are numeric displays of three types: (1) time-of-day, (2) contingency, and (3) countdown. Clocks with firing room analogies act similarly to their firing room counterparts and are marked parenthetically with FR. Time-of-day clocks display Julian day and 24-hour time. Time-of-day clocks are UT (FR) and Projected T-0. Contingency clocks display unsigned time as 24-hour time. They count down and then count up when they reach zero. Counting is enabled and disabled depending upon events. The amount of time displayed on a particular clock varies from hours to minutes. Contingency clocks are Hold Time Remaining (FR), Time in Hold, Window Remaining (FR), APU Hold Time (FR), and LOX Drain Time. Countdown clocks display signed time as daytime and 24-hour time. They also count down and then count up when they reach zero. Counting is enabled and disabled depending upon events. Countdown clocks are Time to T-0 (FR) and CDT (FR).

Development

The conceptual prototype development has been done on Symbolics 36XX LISP machines with high-resolution monochrome monitors in Common LISP and Flavors under Genera 7.2. The field prototype development has been done on 286 and 486 personal computers (PC's) with EGA mode color monitors in Microsoft Quick C 2.5 under DOS and uses the same hardware and software development environment as PC GOAL. The field prototype resides within a customized version of PC GOAL software. PC GOAL is a project that provides a facility for developing GOAL-like data-driven displays that can be run in realtime against LPS data with a GOAL-like user interface.

Contacts:
A. E. Beller, 867-3224, DL-DSD-23
F. J. Merlino, 867-4735, TP-VPD-1
J. Simon, Jr., 861-2910, TV-PEO-2

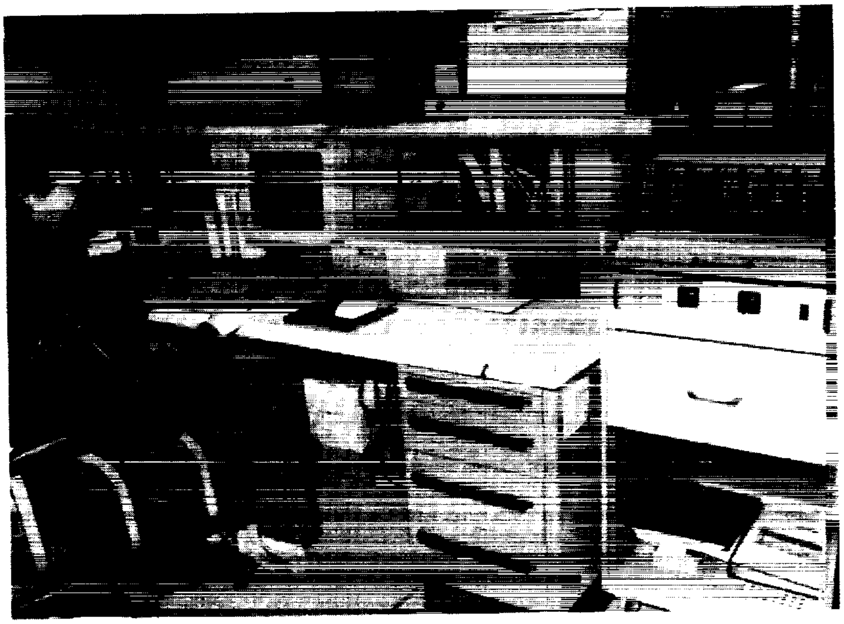
Participating Organization:
Boeing Aerospace Operations, Engineering Support Contract (H. G. Hadaller and M. J. Ricci)

NASA Headquarters Sponsor:
Office of Space Flight

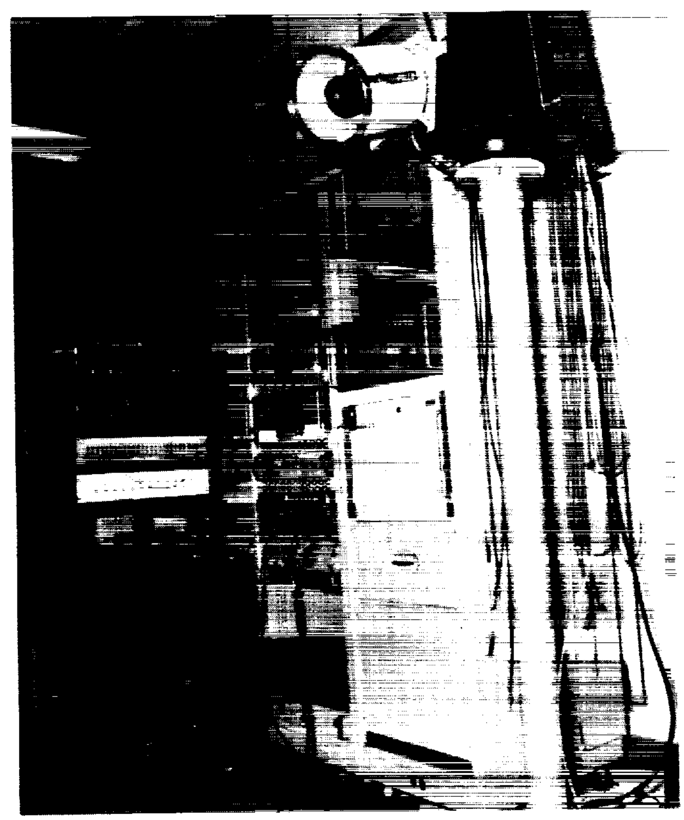
Fiber Optics, Communications, and Networks Laboratory

The Fiber Optics, Communications, and Networks Laboratory has been expanded during the last year to include a Networks Development group. The Fiber Optics and Communications group provides engineering support for the John F. Kennedy Space Center (KSC) copper and optical fiber cables. The major share of its human and material resources is assigned to the evaluation and application of state-of-the-art fiber optics communication technology. This includes fibers, connectors, splicing techniques, electro-optical receivers and transmitters, and multiplexing. Three other significant laboratory tasks are: (1) maximizing the utilization of the existing fiber optic and copper cable plant; (2) providing the technical expertise and hardware for the video and photo-optical systems used in support of KSC technical operations; and (3) defining and furnishing test equipment necessary for the maintenance of communications, video, and photo-optical systems.

The networks section of the Fiber Optics, Communications, and Networks Laboratory is dedicated to a wide range of computer-network-related activities. This area serves as the primary operations hub and network control center of the KSC data network. The majority of all network monitoring, troubleshooting, and support is performed from this location. This laboratory is also responsible for the evaluation and application of advanced network systems technologies. These technologies are intended to provide the most efficient utilization of the cable plant and the maximum possible support to the network users at KSC.



Prototype Fiber Optic TV Camera Project Control Terminal



Camera / Pan-Tilt Units Connected by 17 Kilometers of Single-Mode Fiber With Successful Operation

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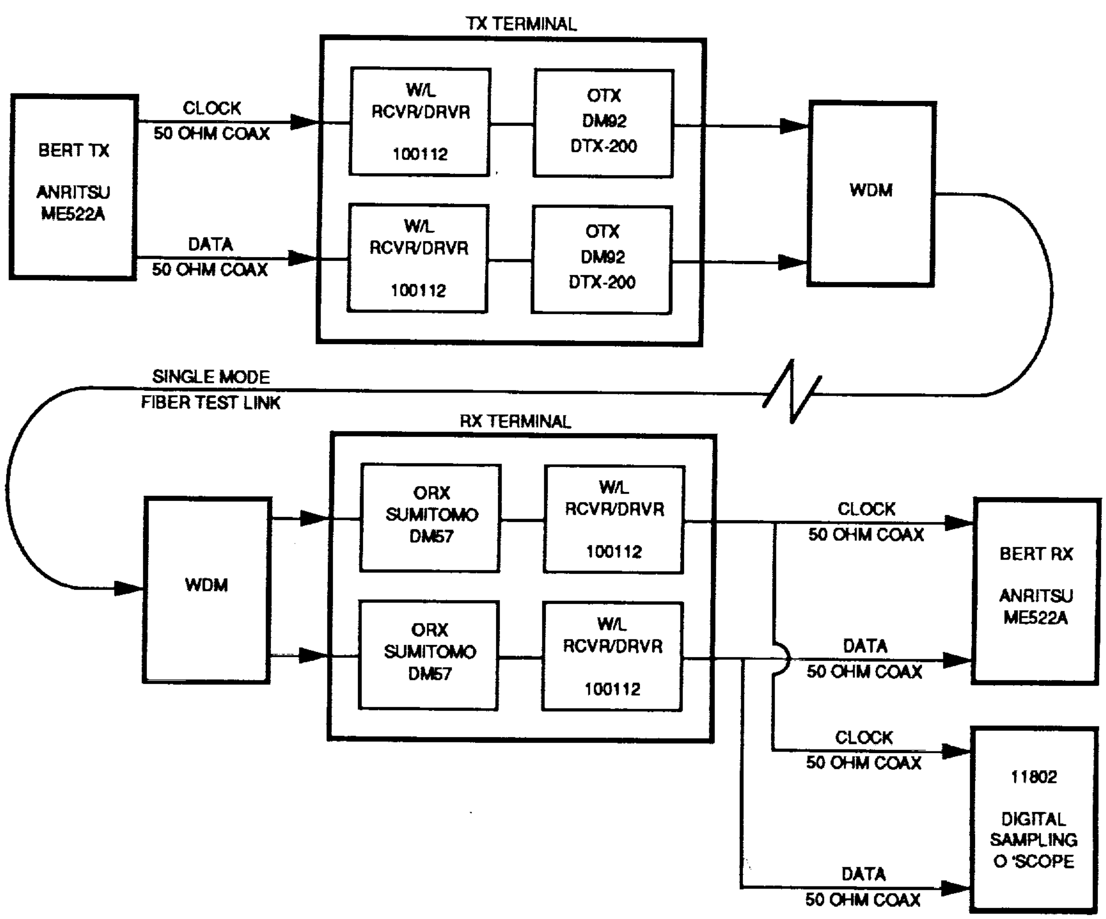
Fiber Optics, Communications, and Networks Laboratory

General

The Fiber Optics, Communications, and Networks Laboratory provides engineering support for the optimization of copper and optical fiber communication links at the Kennedy Space Center (KSC). During the last year, the capability of supporting networks has been added to what used to be known as the Fiber Optics and Communications Laboratory. The major share of its human and material resources is assigned to the evaluation and application of state-of-the-art fiber optics communication technology. This laboratory defines and furnishes test equipment necessary for the development and evaluation of communications, video, and photo-optical systems. Acceptance testing of new technologies to be used in support of KSC technical operations, including individual fiber optic components, is a task accomplished by the Fiber Optics, Communications, and Networks Laboratory. This laboratory has been involved with the development of the next generation of variable-rate, high-speed data links.

Variable High-Data-Rate Fiber Optic Link Development

The need for variable high-data-rate fiber



DC to 150-Mb/s Single-Mode Fiber Optic Test Link optic links at KSC has been increasing over the past few years to support the Space Station Processing Facility (SSPF) requirements. The Fiber Optics, Communications, and Networks Laboratory has designed and fabricated a fiber optic data link that will operate at any data rate between 0 and 150 megabits per second. The system consists of two rack-mountable units with two independent channels to accommodate data and clock. To provide such a wide variability of data rates, the clocking information must be sent along with the data. The system was designed to operate on single-mode fiber due to modal noise and jitter considerations.

One of the major design goals of high-data-rate systems at KSC is to keep the jitter under 5 percent. Such a low jitter was accomplished using optimized 100K series emitter-coupled-logic (ECL) circuits. The electronic portion of this system will transfer data at up to 585 megabits per second. The laser drivers, PINFET receivers, and dispersion characteristics of the fibers are the limiting factors. The units were field tested with fiber distances of 8.8 and 15 kilometers. The jitter remained under the desired 5 percent when the optical energy on the receiver remained above minimum sensitivity levels. Two different optical sources were tested successfully. No errors were detected during the field test at data rates of up to 200 megabits per second. This system provides the user with a transparent link so that whatever goes in will come out the other side, which will allow an end user complete flexibility utilizing any protocol.

In order to consider configurations where only one optical fiber would be needed, wavelength division multiplexing (WDM) was tested. A system was designed to put two wavelengths (1300 and 1550 nanometers) on one fiber and separate them at the receiver side. The results are preliminary at this point; however, there are some situations where the WDM approach would prove an adequate solution. The longer wavelength (1550 nanometers) does exhibit some undesirable jitter characteristics on fiber that has the zero dispersion point designed to be at 1310 nanometers. This jitter can be within the desired goal if the fiber length is limited.

This prototype system is in the process of being repackaged into a chassis with redundant power switching units and vertical mounting of the communication channels. Due to the unusually high data rates involved, the development of a mother board is critical and has slowed the work. Next year, however, it is expected that the repackaged vertical mount chassis will be complete.

The Fiber Optics, Communications, and Networks Laboratory is also developing a variable high-data-rate fiber optic link that will operate at 0 to 1.2 gigabits per second for distances of 330 meters. This system would be used to link computer systems in the same building such as the SSPF. Concept studies, analysis, and circuit design have been completed. The parts are being procured and will be available for prototype fabrication during the upcoming year.

Contact:
P. T. Huang, 867-4548, DL-ESS-12

Participating Organization:
Boeing Aerospace Operations, Engineering Support Contract (F. H. Galloway and R. W. Swindle)

NASA Headquarters Sponsor:
Office of Space Flight

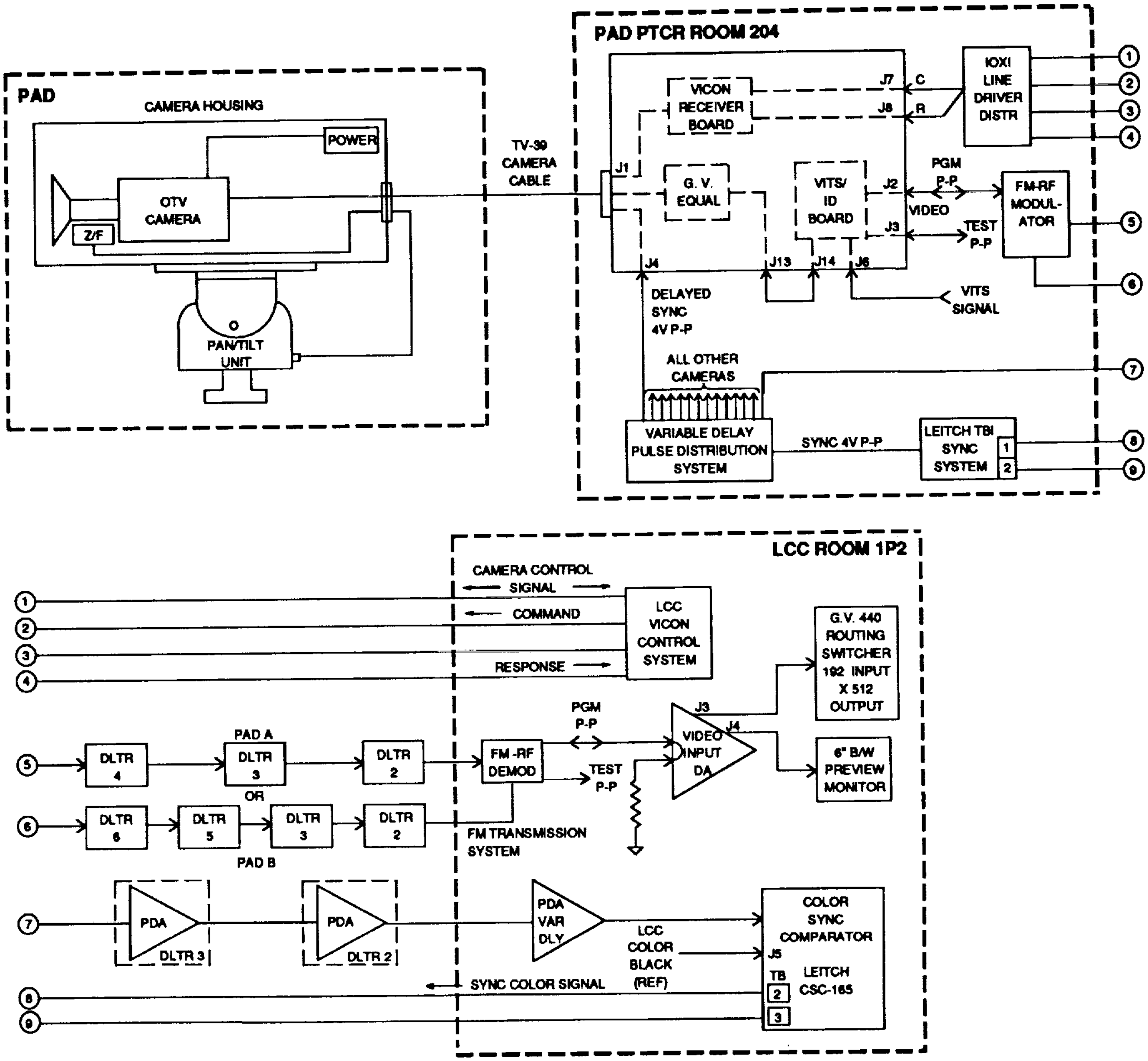
Direct Fiber to Operational Television Camera System

The Fiber Optics, Communications, and Networks Laboratory is participating in the development of a television camera system that will be the prototype for the next generation of an operational television (OTV) system camera for use on the launch pad. The OTV system at the Kennedy Space Center (KSC) provides realtime and recorded visual information necessary to conduct and document hazardous and nonhazardous activities during daylight and nighttime operations involving buildup, integration, launch, and landing of the Space Transportation System. This engineering and safety information must be of the highest achievable quality. This quality must be sustained without material degradation and during duplication, development of training aids and materials, engineering evaluation, and analysis for the detection, investigation, and correction of anomalies. To that end, each element of the system must meet the maximal performance criteria to ensure optimum overall picture quality and resolution.

The existing OTV system (refer to the figure "Existing OTV System") consists of a mixture of color, monochrome, and infrared television cameras. Television cameras with a scan rate approved by National Television Systems Committee (NTSC) are presently used to monitor launch operations. At the launch pad, these cameras are connected to camera control units in the Pad Terminal Connection Room (PTCR) via TV-39 multicore camera cable. The camera control units contain built-in video equalizers to compensate for loss in transmission on this cable. The video output from the camera control units is connected to a frequency modulation radio frequency (FM-RF) modulator; the radio frequency outputs of these modulators are combined onto coaxial trunk cables. The trunk cables proceed through numerous repeater stations to the Launch Control Center (LCC). In the LCC, the radio frequency signal from these trunks passes through a splitter to individual demodulators. The demodulated video signal is then fed to a video routing switcher for distribution to the end users, to recorders for documentation of launch operations, and to the NASA Select channel for use at other NASA centers.

The prototype OTV camera system (refer to the figure "Prototype OTV System") consists of a color television camera at the launch pad connected to the camera control unit in the LCC via a single fiber optic cable, which is utilized for bidirectional transmission of video, synchronization, control, and status signals. This prototype eliminates the necessity of equipment for camera control and synchronization at the launch pad and eliminates the requirement for repeaters between the launch pad and the LCC. The camera control unit and the camera head each contain a fiber optic transmitter and receiver connected to the optical fiber via a wavelength division multiplexer. Signals for synchronization and control of the camera and control of the pan-and-tilt head are transmitted from the camera control unit to the camera head on one optical wavelength (1330 nanometers), while the camera's video output and status information are returned on the same fiber utilizing a different wavelength (1550 nanometers).

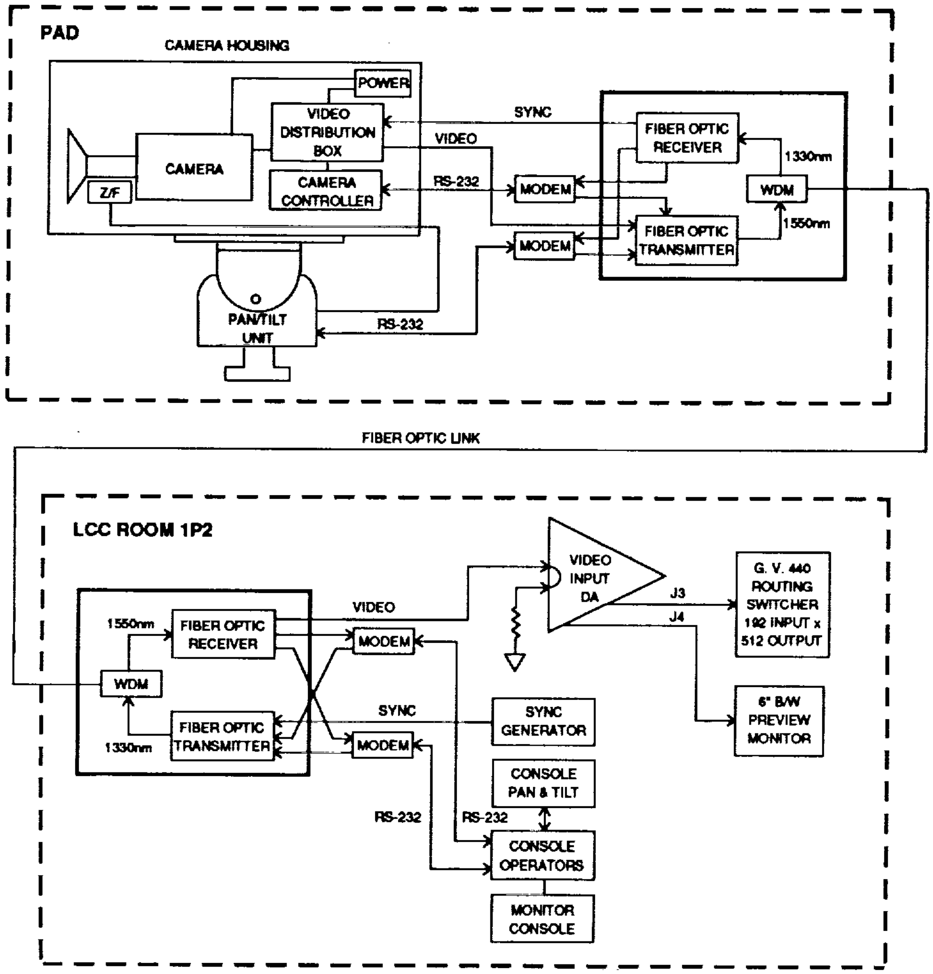
The prototype system is being used to study analog transmission of component video versus analog transmission of composite video from the camera. Future tests will



Existing OTV System

concentrate on digital transmission of video over fiber.

A series of tests of the existing and prototype television transmission systems were conducted to evaluate the potential benefits of fiber optic transmission for OTV signals used in monitoring and documenting launch processing operations at KSC. These tests supplied both subjective and objective data on the benefits of improvements in this transmission media to the monitoring of launch processing operations. Some of the measured improvements attributed to fiber optic transmission include: (1) an increase in the resolution of the camera signals from approximately 400 lines to in excess of 800 lines, (2) a decrease of distortion attributable



Prototype OTV System

to a differential phase from 2 degrees to 0.5 degree, (3) a differential gain from 2 percent to 1.5 percent, and (4) an improvement in the signal-to-noise ratio from 56 decibels to 69 decibels.

The project is also using the prototype to study the potential of and the requirements for a new camera control system utilizing a host central processor and local area network to provide control, monitoring, and fault reporting for the OTV system. While microprocessor-based systems for camera control are used in the existing OTV system, the camera interfaces are primarily hardware based. This situation results in system limitations on the type, number, and compatibility of control functions that can be interfaced. The prototype system uses serial data communication with a microprocessor-based camera to maximize the ability to address and control camera functions. The prototype system software has been written in C language. The software provides the user access to and status reporting of the camera system functions, including control of the camera, lens, pan-and-tilt mechanism, and lighting system and remote monitoring of the pressure in the camera housing, pan-and-tilt housing, and light assemblies.

Contact:
J. E. Kassak, 867-4548, DL-ESS-12

Participating Organizations:
Boeing Aerospace Operations, Engineering Support Contract (F. H. Galloway and J. E. Brogdon)

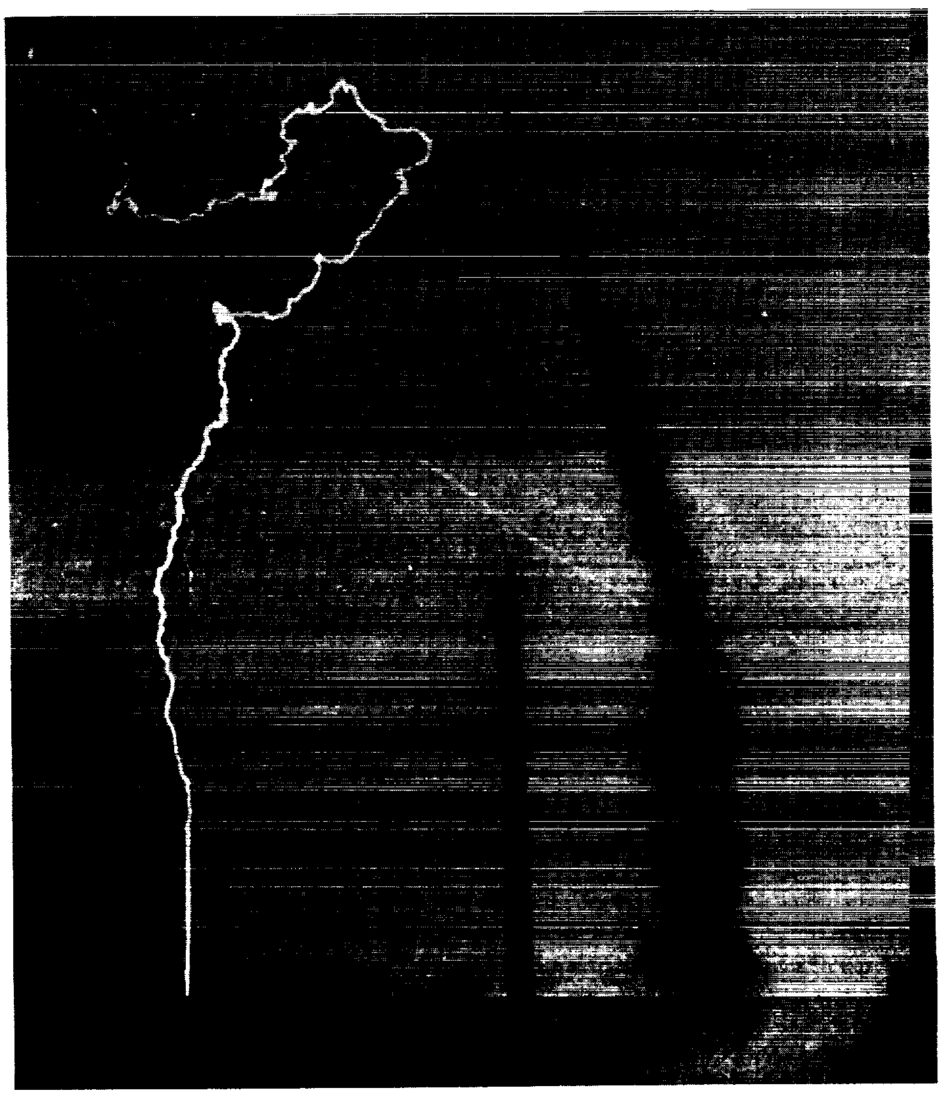
Lockheed Space Operations Company, Shuttle Processing Contract (C. D. Smith and R. E. Niedermeier)

NASA Headquarters Sponsor:
Office of Space Flight

Meteorology

Atmospheric Science Field Laboratory

The Atmospheric Science Field Laboratory was established at the John F. Kennedy Space Center (KSC) to provide a focal point for thunderstorm and lightning studies. The laboratory has the tools and expertise to delve into all aspects of lightning phenomena, including measurement of electric and magnetic fields, space charges, and lightning current densities. Data produced by the laboratory's research efforts are used to improve forecasting accuracies, design lightning detection equipment, and optimize lightning protection facilities, equipment, and personnel through the use of physical and mathematical models. The latest research programs supported by the laboratory utilize both a 6-million-volt lightning simulator and rocket-triggered lightning.



Rocket-Triggered Lightning

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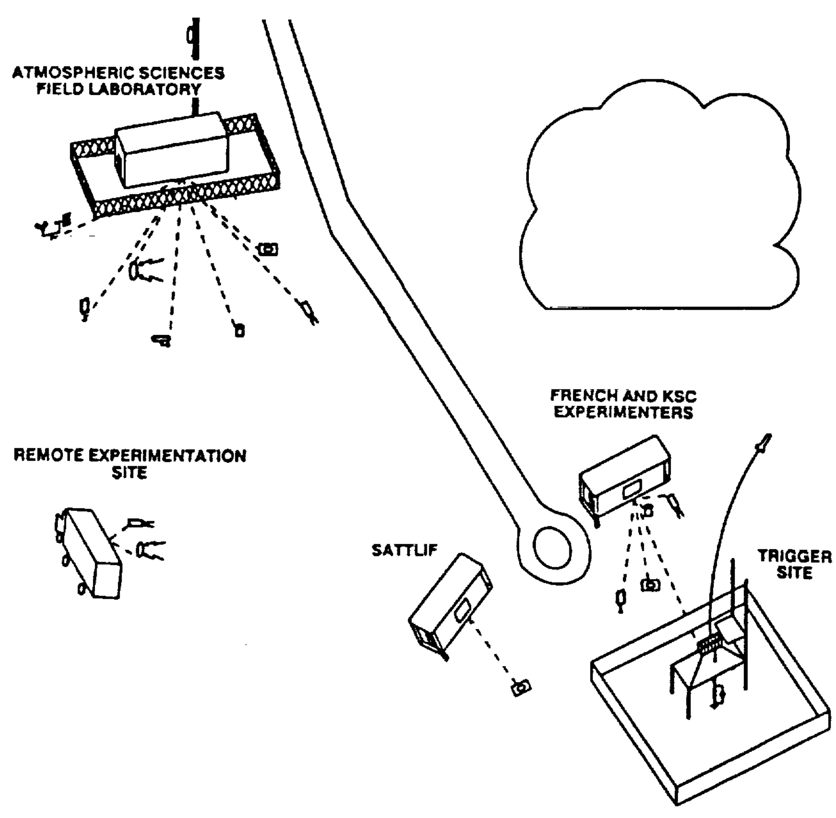
Field Testing of the Sandia Transportable Triggered-Lightning Instrumentation Facility (SATTLIF)

In 1988, the Lightning Environment Working Group (LEWG) was established by the Department of the Army to investigate the effects of lightning environments on the safety and reliability of nuclear weapons inside storage structures. In support of the LEWG, a computer model has been developed by Electromagnetic Applications, Inc. (EMA), for predicting environments inside maintenance buildings and storage structures.

Under proper thunderstorm conditions, lightning can be initiated artificially using a procedure that is now generally considered to be technically routine. In this technique, a small anti-hail rocket is sent aloft during appropriate conditions dispensing a thin wire behind it that is grounded at the launcher end. At a typical height of 100 to 500 meters, upward-going streamers develop from the top end of the wire, which then lead to the initiation of lightning to the ground. The ensuing flash generally follows the ionized channel left when the wire vaporizes under the streamer current. In this way, the flash is directed to the desired terminus point, where it can be used for testing purposes.

In 1990, the SATTLIF was developed and field tested during July and August at the Kennedy Space Center's (KSC's) triggered-lightning test site in Florida. The test site is configured as shown in the figure "KSC Rocket-Triggered Lightning Test Site Layout." The SATTLIF operations shelter is a 20-foot, all-steel transportainer that has been converted into an instrumentation van. The objectives of this preliminary field trial were to check out all the SATTLIF systems, gain experience with the triggering rockets and their handling, and acquire damage data produced by measured lightning on a variety of metallic specimens. Each of these objectives was met, and the SATTLIF was demonstrated to perform very reliably. Its initial major application will be the testing of an ordnance storage bunker (igloo) to direct-strike lightning. This testing will take place during the 1991 summer lightning season on a specially fitted igloo located at Fort McClellan, Alabama.

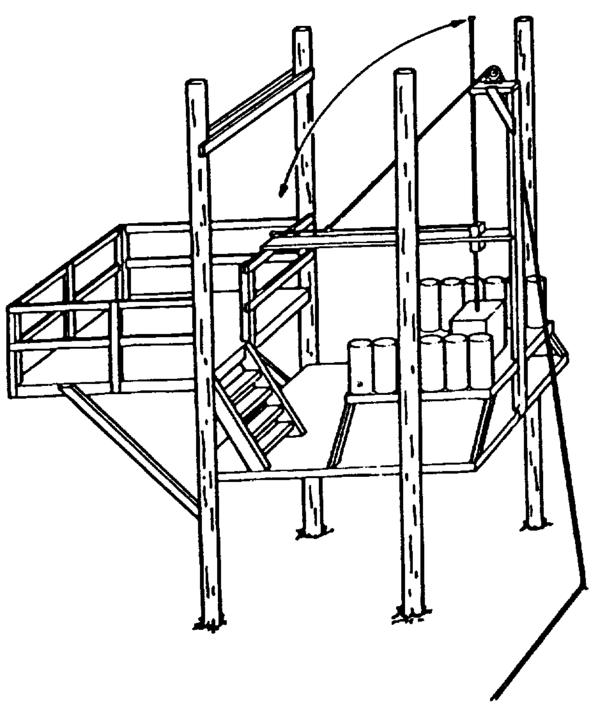


KSC Rocket-Triggered Lightning Test Site Layout

The figure "Rocket-Triggered Lightning Experiment Platform at KSC" shows the setup used for triggered-lightning tests of 2-1/2-inch-diameter metallic disks of various alloys and thicknesses. Each disk was placed in a cup at the end of a pole that was raised to a vertical position in order to expose the disk to triggered lightning. Results showed that a 10 to 20 coulomb continuing current stroke could melt through an 0.08-inch-thick disk of aluminum alloy. This result confirmed simulated lightning tests showing that the Shuttle external tank's 0.088-inch-thick aluminum skin could be perforated by a continuing current stroke as low as 20 coulombs.

Contact:
W. Jafferis, 867-3404, DL-ESS-23

Participating Organization:
Boeing Aerospace Operations, Engineering Support Contract (J. R. Stahmann)



Rocket-Triggered Lightning Experiment Platform at KSC

NASA Headquarters Sponsor:
Office of Space Flight

Meteorological Monitoring System (MMS), Phase I

Objective

The primary purpose of the NASA Phase I Small Business Innovation Research (SBIR) project for the Meteorological Monitoring System (MMS) was to research state-of-the-art computer techniques for artificial intelligence, man-machine interfaces, and information display applications, and to apply these techniques to the design of a system for the automated realtime monitoring of critical weather elements at Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS). The objectives for this research were that the MMS should:

1. Continuously monitor data from weather sensors at KSC and CCAFS

2. Disseminate weather forecasts and warning information to system users

3. Review the ingested data in light of established criteria either set by the system as a default or changed by the user

4. Sound an alarm when a threshold value is exceeded

Background

Weather impacts most NASA operations at KSC. Severe weather can result in injury to people, loss of equipment, and even destruction of a space vehicle. The MMS will reduce the risk of damage and personal injury by providing managers with timely data on the threat and occurrence of severe weather and on the trends in the current weather that may impact operations in the near term. By monitoring the wind tower network, the lightning sensors, the radar, and local observations, in conjunction with knowledge about KSC operations, the MMS will be of valuable assistance to managers in the decisionmaking process.

Approach

To develop the MMS design, ENSCO, Inc., completed the following tasks:

1. Reviewed weather warning and advisory criteria, launch constraints, and flight rules

2. Reviewed meteorological data to be ingested by the system

3. Reviewed user interface requirements

4. Selected the system hardware, system software, and design of the applications software

Results

The accomplishments of Phase I of the MMS project are:

1. The hardware and software design for the operational Phase II system

2. The development of the prototype displays for the MMS

3. The development of a prototype Weather Information Network Display Systems (WINDS)

4. The development of the proposal for Phase II of the MMS. The proposal was submitted to NASA in August 1990 and is under evaluation at this time. The proposal describes the hardware requirements to ingest and analyze the data from the different sources.

Contact:
J. A. Caraballo, 867-4888, RT-SAF-3

Participating Organization:
ENSCO, Inc. (G. E. Taylor, Ph.D.)

NASA Headquarters Sponsor:
Office of Space Flight

Technology Utilization

Congress has charged NASA with the task of stimulating the widest possible use of technology resulting from the space program. Thousands of these applications, known as spinoffs, have been transferred to the public and private sectors of the U.S. economy. This transfer of technology includes spinoffs in medicine, electronics, computer systems, design, and management.

This section of the R&T report describes four such developments of technology at the John F. Kennedy Space Center (KSC): (1) a digital hearing aid, (2) a radon removal device, (3) a portable air conditioner using heat pipe technology, and (4) magnetic resonance imaging. The technology from these projects has come from the space program and the application has been transferred to industry.

Magnetic Resonance Imaging Technology

Background

In November 1989, the American Cancer Society, Florida Division, Inc., and NASA Kennedy Space Center signed a Memorandum of Understanding establishing a means by which space technology could be formally transferred to the medical profession. The agreement broke new ground in the transfer of technology developed for the space program to lifesaving cancer-control applications on earth. The partnership represents the first systematic approach to matching a list of medical needs with space technology. The Magnetic Resonance Imaging (MRI) project at the University of South Florida is one of the projects undertaken by the partnership. The project involves the development of computer software that can analyze MRI data sets, mathematically identifying different tissue types in the body and generating color-coded images. The new technology will allow for the generation of a single composite magnetic resonance image in which each tissue type is represented by a different color. The color intensity of the tissue reflects the probability of correct tissue classification as well as the boundary definition between tissues.

Approach

MRI uses magnetic fields and radio waves to form images of soft tissues in the body, allowing for the detection of certain soft tissue tumors with greater sensitivity than any other imaging modality, including x-ray.

When a patient enters the magnetic field created by the MRI, a radio signal is beamed through the body. When the beam is turned off, the body tissue releases energy that is picked up by a scanner and converted to computer data. The data can then be used to create three-dimensional images of body tissues.

MRI has the unique capability to generate a number of image data sets with varying levels of soft-tissue contrast. Mathematical analysis of several images allows for subtle differences in image contrast or features to be enhanced providing better boundary definition of a tumor site. The MRI project is concerned with monitoring tumor response for patients who have head and neck tumors

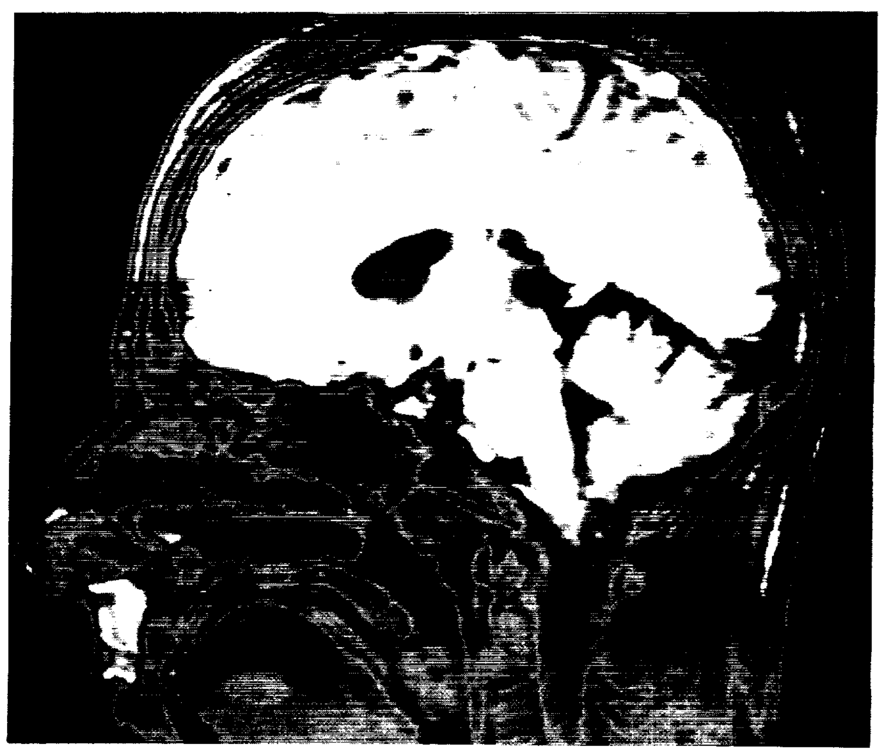


Image Enhancement of the Brain

or ovarian cancer and are undergoing radiation therapy treatments.

Application

The MRI technology gained from the project will make tumor diagnosis more specific and sensitive. In addition, improvements in the ability to identify tumor location and boundaries will make the planning and treatment of patients undergoing externally directed radiation more accurate and precise.

Contact:
R. L. Butterfield, 867-3017, PT-PMO-A

Participating Organizations:
American Cancer Society
Artificial Cognition Systems, Inc.
University of South Florida

NASA Headquarters Sponsor:
Office of Commercial Programs

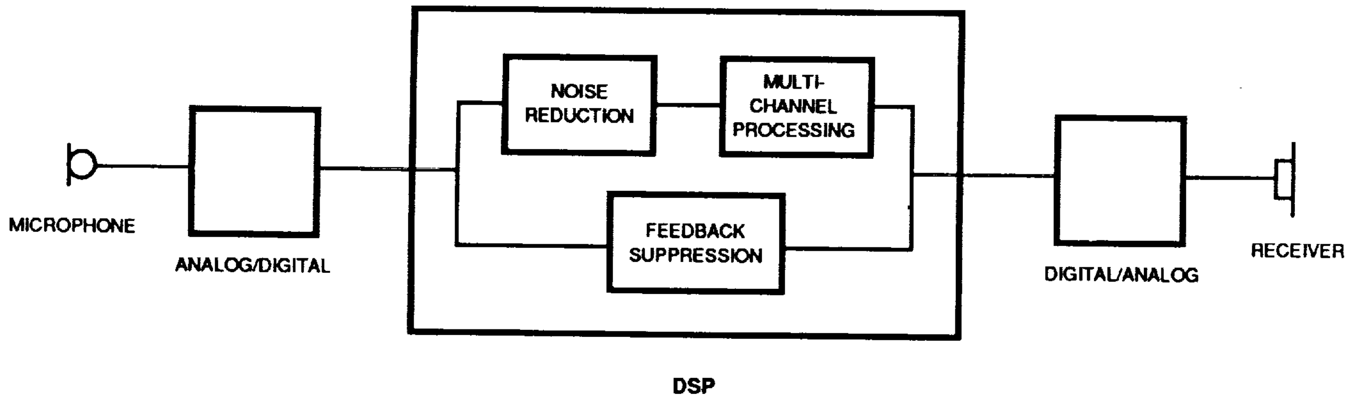
Development of a Digital Hearing Aid

The purpose of this project is to develop a digital hearing aid that will lead to improved performance of acoustic amplification for the hearing impaired. Digital hearing aid technology can provide the flexibility of adjustment and control of auditory signal processing required to better compensate for the patient's hearing impairment than is possible with conventional analog technology or even hybrid technology in which analog amplifiers and filters can be adjusted with digital logic.

Five digital hearing aid prototypes using custom very large scale integration (VLSI) circuitry for all digital signal processing functions have been completed. A block diagram of the digital hearing aid is shown in the figure "Functional Block Diagram of the Digital Hearing Aid." These prototypes are benchtop systems employing nine custom VLSI circuits to provide multichannel compression, noise reduction, and feedback suppression processing. This combination of circuits is capable of implementing over 11 million multiply-accumulate operations [finite impulse response (FIR) digital filter taps] per second. The hearing aid digital filter tap values, gain coefficients, compression parameters, and related information are downloaded by a host computer system that includes an acoustic measurement system for quantifying the acoustic coupling of the hearing aid to the user's ear canal.

In a clinical application, the audiologist provides information regarding the hearing loss and hearing aid prescription to the host computer. Typically, this consists of the desired amount of amplification and maximum power output over the auditory frequency range. The host computer combines this prescribed hearing aid fitting with the measured acoustic characteristics of the patient's ear canal and the hearing-aid/ear-canal coupling to derive the data downloaded to the hearing aid. The acoustic measurement system is then used to verify the performance of the hearing aid. The measured mean-square-error (MSE) associated with achieving the desired amplification curve from 250 to 6000 hertz is less than 3.5 decibels. The prescribed fitting is then refined using subjective and objective test procedures controlled by the host computer. These tests include the presentation of audio-visual information stored on video laser disks.

The incorporation of digital signal processing into a hearing aid opens the door to

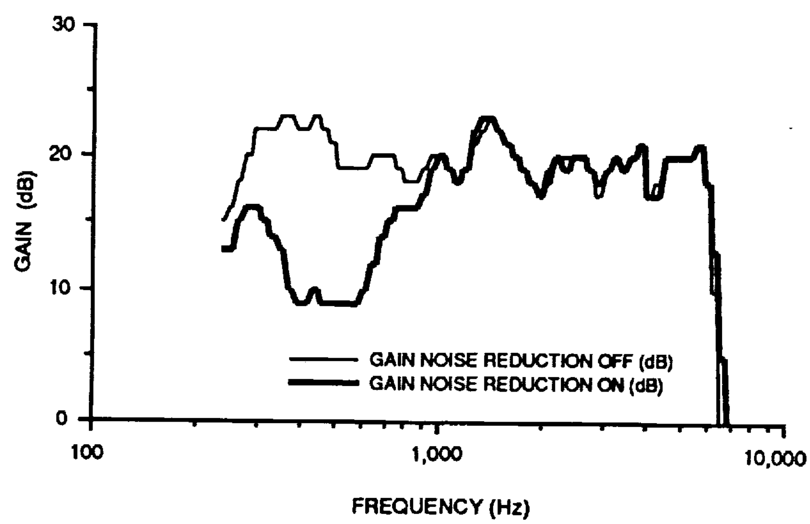


Functional Block Diagram of the Digital Hearing Aid

powerful signal processing techniques such as adaptive filtering. These adaptive filtering capabilities have been used to create unique processing methods for noise reduction and feedback suppression. Current hearing aids do not adequately address the problems most hearing aid users encounter when trying to listen to speech in environments with competing noise. No current hearing aid incorporates active methods to prevent the occurrence of oscillatory feedback.

The noise reduction processing uses an adaptive filter to generate a linear predictive coding (LPC) estimate of the noise component of each incoming sample. In practice this will allow the noise reduction to be "fit" to an individual's hearing loss and subjective preferences. Current analog noise reduction methods can only choose from a limited set of frequency/gain responses in contrast to the enormous range of responses resulting from the use of the adaptive digital filter. Hearing impaired subjects rated the subjective clarity of speech in noise higher with the noise reduction processing on than with the noise reduction off. Objective testing of speech intelligibility also showed improvements with the noise reduction active. The response of the noise reduction processing to a narrowband noise is shown in the figure "Hearing Aid Gain."

The feedback oscillation that occurs in hearing aids is analogous to the feedback problem that occurs in public address systems. Similarly, the solutions currently



Note:
Hearing Aid Gain in the Presence of 500 Hertz One-Third Octave Band of Noise With and Without Noise Reduction Active

Hearing Aid Gain

used in such systems are to either reduce the system gain (turn down the volume) or provide better isolation for the input microphone. In the case of in-the-ear hearing aids, the isolation of the microphone is for all practical purposes fixed and the only solution is to reduce the gain. This reduces the effectiveness of the hearing aid in that low-level sounds and quiet speech may not be amplified sufficiently to be understood by the user. The feedback suppression method used in the digital hearing aid employs an adaptive filter to model the acoustic feedback path. This feedback path is determined by the physical placement and coupling of the hearing aid input (microphone) and output (receiver) transducers to the user's ear canal. Using this method, greater than 15-decibel increases in stable hearing aid gain have been achieved.

Two new custom VLSI circuits have been designed this year that will be used with a previously completed multichannel digital signal processing (DSP) circuit to implement the body-worn version of the digital hearing aid previously described. The adaptive signal processor (ASP) circuit is a digital signal processor that combines the noise reduction and feedback suppression systems previously distributed over eight chips onto a single circuit. The ASP contains two adaptive FIR filters, five fixed FIR filters, two tapped delay lines, a noise generator, and a memory controller used to bootstrap the body-worn prototype. The transistor count for this circuit exceeds 83,000 field effect transistors (FET's). The second new circuit, the analog interface processor (AIP), is an integrated analog/digital and digital/analog system that includes various programmable gain and filtering stages. This chip combined with the two DSP circuits forms the complete processing path of the digital hearing aid. Body-worn prototypes will be constructed with these three circuits for use in 1991.

Contact:
R. M. Davis, 867-2780, PT-AST

Participating Organizations:
Central Institute for the Deaf, St. Louis, Missouri (A. M. Engebretson, D.Sc.)

Washington University, St. Louis, Missouri (R. E. Morley, Jr., D.Sc.)

NASA Headquarters Sponsor:
Office of Commercial Programs

Mobile Heat Pipe Air Conditioner

An experimental air conditioner was developed using heat pipe technology for the purposes of heat dissipation, dehumidification, and energy saving. The machine was designed and built for NASA by Dinh Company, Inc., of Alachua, Florida. It is used to provide fresh air within narrowly specified limits regarding cubic feet per minute, pressure, humidity, and temperature.

The machine was delivered to NASA in August of 1990 and has brilliantly demonstrated that heat pipes, a spinoff technology from NASA, could be used to prodigious advantages. The machine is performing as designed and meets all the required specifications. It uses a turboblower to compress 1000 to 1400 cubic feet per minute of fresh air to 4 pounds per square inch gage. The air overheated by compression passes through a bank of heat pipes that dissipate the heat to the outside. The removal of this huge amount of heat would normally require a large conventional refrigeration system, which in this case has been eliminated. The compressed and now cooled-down air passes through the precooled section of another set of wraparound heat pipes, which further lowers the temperature of the air. Therefore, by the time the air arrives at the evaporator, its temperature is brought down to the desired level necessary for maximum removal of moisture. The compressed air, now considerably cooled down and dry, then passes through the reheat section of the wraparound heat pipes that brings its temperature up to the specified level. The air provided meets the specifications required by NASA for the interior of the Shuttles when they are on the ground.

The innovative use of heat pipes in different configurations and for different purposes allows the Dinh system to provide the same performances as a conventional air conditioning system with three times the capacity and size. In addition to its capability of maintaining the supply air at the specifications required, this heat pipe air conditioning system permits energy savings of a 65- to 70-percent range over conventional air conditioning systems.

Contact:
R. A. Turner, 867-3688, DF-FED-33

Participating Organization:
Dinh Company, Inc.

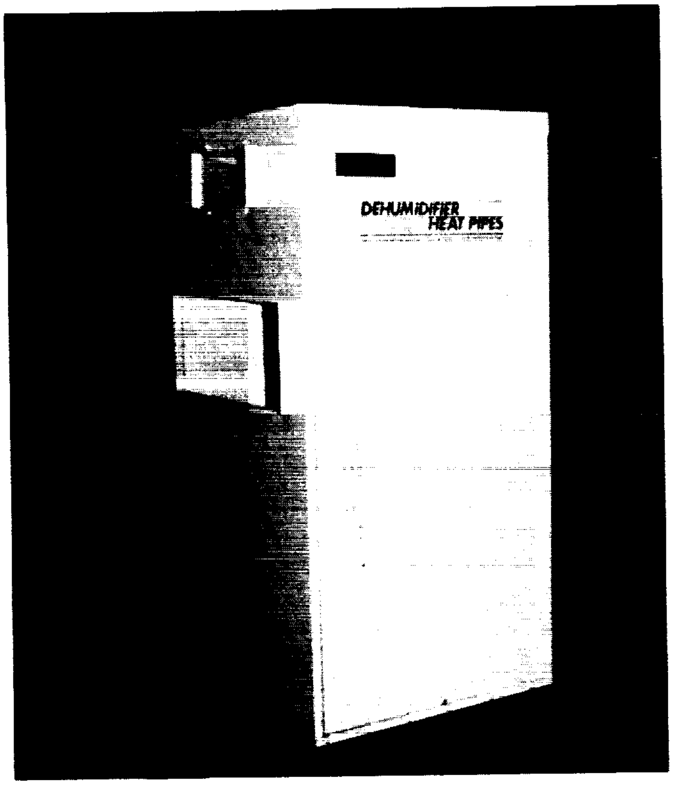
NASA Headquarters Sponsor:
Office of Commercial Programs

Heat Pipe in Radon Mitigation (Dinh Radon Fighter)

One of the most direct ways of mitigating radon is to open all the windows, but such a solution would require enormous amounts of energy to compensate for the loss of inside heated or cooled air. Radon is a natural gas produced by the decay of radioactive materials in the soil and has been found to cause cancer. A level of 30 picocuries per liter inside the house could be as harmful as smoking two packs of cigarettes a day.

Mobile Heat Pipe Air Conditioner

The solution provided by the Dinh radon machine is to pump fresh air to the inside of the house, which creates a slight positive pressure that will chase out radon and with



Dinh Radon Machine

it other pollutants and bad odors. This positive inside pressure also prevents radon from filtering up from the ground.

The machine is a small, high-efficiency, fresh-air heat pump that pumps 250 cubic feet per minute of air into the house while pulling out 200 cubic feet per minute, leaving behind 50 cubic feet per minute to create the positive pressure. It dehumidifies the pumped-in air and, depending on the season, cools or heats the air to the level of the inside temperature. Thus, the introduction of fresh air has little or no effect on the existing air conditioning or heating system.

A specially designed configuration of a heat pipe is used to increase dehumidification of the incoming air and to exchange heat between the incoming and outgoing airstreams. This reduces the loss of heat or cooled air to a minimum. Other features are also incorporated to maximize efficiency, one of which is the use of the cold condensate to cool the heat pipes.

In January 1990, a prototype installed at a house in Gainesville with an annual radon level averaging 22.2 picocuries per liter has brought that level down to 4.2 picocuries per liter (4 picocuries per liter is considered safe by the Environmental Protection Agency). The machine tested is reported to have used approximately $18 worth of electricity in a month.

Compared to other methods of radon mitigation, the fresh-air method has the advantage not only of mitigating radon but also of flushing the house of other indoor contaminants such as formaldehyde, carpet insecticides, cooking odors, vapors, and smoke. This machine is also a low-energy-cost solution for the addition of fresh air now being required for some public buildings.

Contact:
R. A. Turner, 867-3688, DF-FED-33

Participating Organization:
Dinh Company, Inc.

NASA Headquarters Sponsor:
Office of Commercial Programs

Mechanics, Structures, and Cryogenics

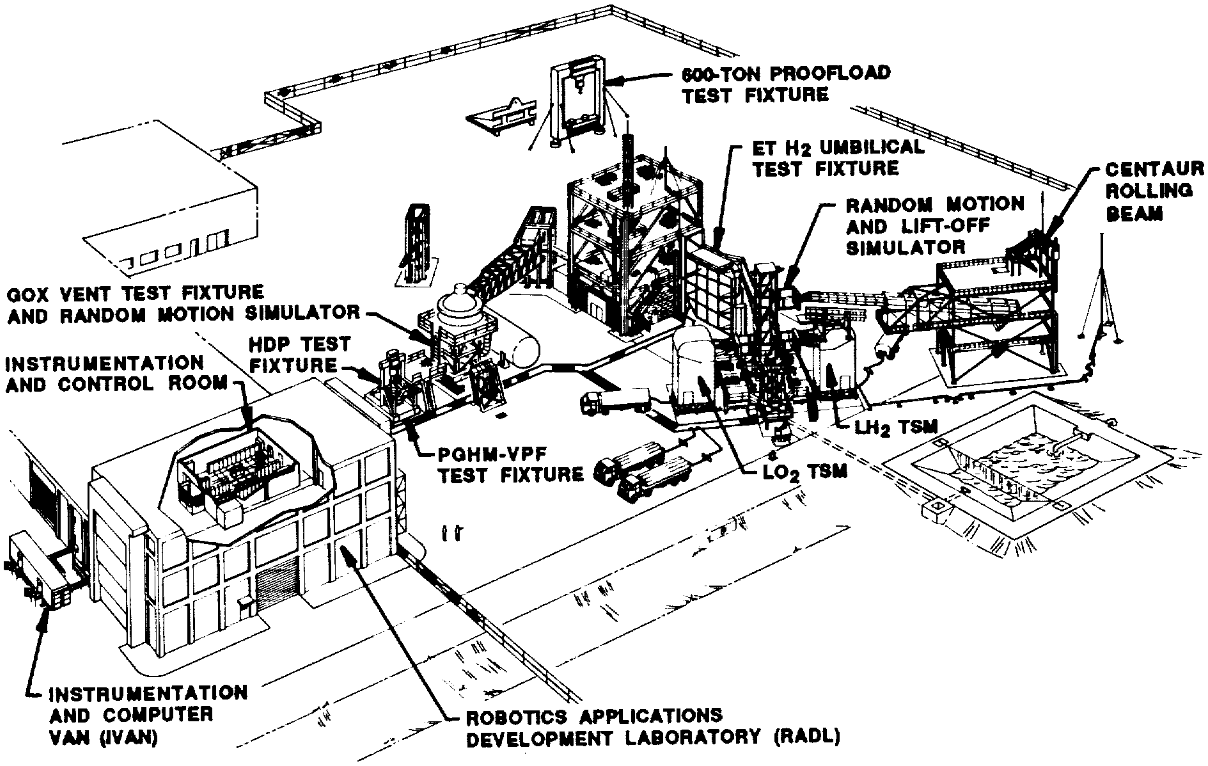
The sheer magnitude of the mechanical systems and attendant structures at the John F. Kennedy Space Center (KSC) requires unique facilities and equipment to solve design and operations problems or to advance the state of the art in mechanical and civil engineering. Four major areas that support the mechanics, structures, and cryogenic design and research effort are: (1) the Launch Equipment Test Facility, which is the primary testbed for full-scale, proof-of-concept testing of the umbilicals, service arms, holddown posts, and other ground-to-vehicle electrical and fluid connections used at the launch sites; (2) the computer-aided design and computer-aided engineering facilities, where modeling is accomplished via an extensive design software library; (3) the Prototype Laboratory, which provides the services and tools to rapidly convert the engineering designs to hardware; and (4) the academic community in which conceptual design and theoretical analyses are performed.

Launch Equipment Test Facility

The Launch Equipment Test Facility is a unique engineering complex dedicated to the development and qualification testing of virtually all the NASA launch equipment mechanisms. The facility's test fixtures and supporting electrical/electronic systems have the capability to simulate launch-site conditions such as cryogenic loading and flow, pyrotechnic operation, random motion, abort motion, lift-off motion, and other phenomena associated with launch operations. An extensive measurement system is available to obtain, record, display, and analyze the data associated with the testing. The facility also supports development and qualification testing of fluid system valves and other components, free-fall restraints, load-bearing fixtures and lifting slings, and robotic applications development.

Prototype Laboratory

The Prototype Laboratory provides KSC with a civil-service-staffed facility that has the capability to develop, fabricate, modify, model, breadboard, and/or test all manner of electrical and mechanical passive or active components, subsystems, and systems on a nonproduction or limited-production basis. The technical staff has the versatility to work from rough sketches as well as from formal engineering drawings. The laboratory is composed of a mechanical department (including metal working, sheet metal forming, welding, and a high-pressure fluid test cell), a woodworking and model-making department, an electrical/electronic department, an instrumentation department, and a personal computer board fabrication department capable of fabricating single- or doubled-sided printed circuit boards from customer-supplied positives or negatives.



Launch Equipment Test Facility

Prototype Laboratory

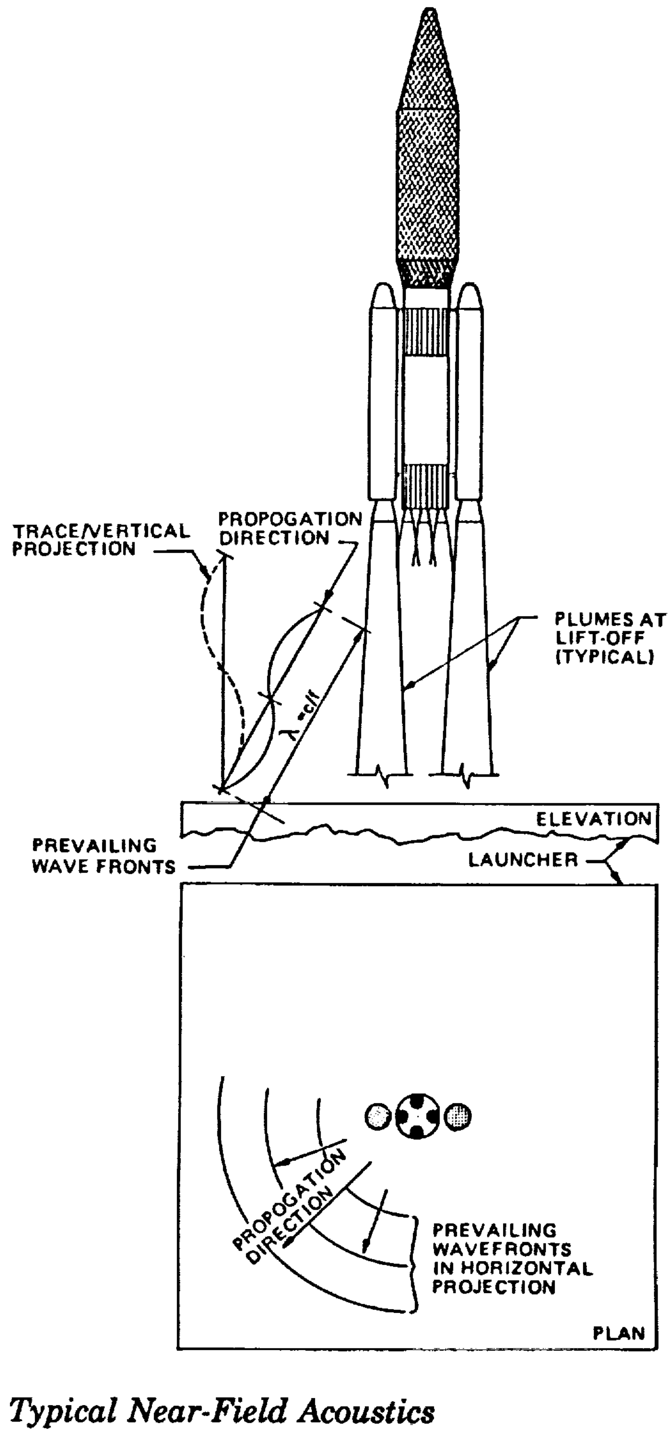
Response of Structures to Random Acoustic Excitation

Structures near a launch pad must be designed to withstand intense acoustic loadings generated by rocket exhausts. The factors influencing the acoustic excitation process and the resulting structural response are numerous and cannot be predicted precisely. Rather, they can be modeled as stochastic (random) processes in time and space and can be specified in terms of statistical properties (such as the correlation and cross-correlation functions in the time domain, or the spectral and cross-spectral densities in the frequency domain). Ongoing research at Kennedy Space Center attempts to use available spectral measurements from past launches to gain physical insight to accurately define launch-induced acoustics. Additionally, theoretical reasoning is also being exercised to construct and verify noise excitation models so as to develop a more general solution. Implementation of structural response to acoustic input via matrix formulation is being worked on. Lastly, environmental testing will be sought to verify analytically predicted response behavior of structures subjected to such random acoustic excitations.

Contact:
R. E. Caimi, 867-4181, DM-MED-11

Participating Organization:
Boeing Aerospace Operations, Engineering Support Contract (R. Margasahayam and V. Sepcenko)

NASA Headquarters Sponsor:
Office of Space Sciences and Applications



Typical Near-Field Acoustics

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15. Supplementary Notes

16. Abstract

As the NASA Center responsible for assembly, checkout, servicing, launch, recovery, and operational support of Space Transportation System elements and payloads, Kennedy Space Center is placing increasing emphasis on the Center's research and technology program. In addition to strengthening those areas of engineering and operations technology that contribute to safer, more efficient, and more economical execution of our current mission, we are developing the technological tools needed to execute the Center's mission relative to future programs. The Engineering Development Directorate encompasses most of the laboratories and other Center resources that are key elements of research and technology program implementation and is responsible for implementation of the majority of the projects in this Kennedy Space Center 1990 Annual Report.

For further technical information about the projects, contact David A. Springer, Projects Management Office, DE-PMO-5, (407)867-3035. Thomas M. Hammond, Technology Utilization Officer, PT-PMO-A, (407)867-3017, is responsible for publication of this report and should be contacted for any desired information regarding the Center-wide research and technology program.

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