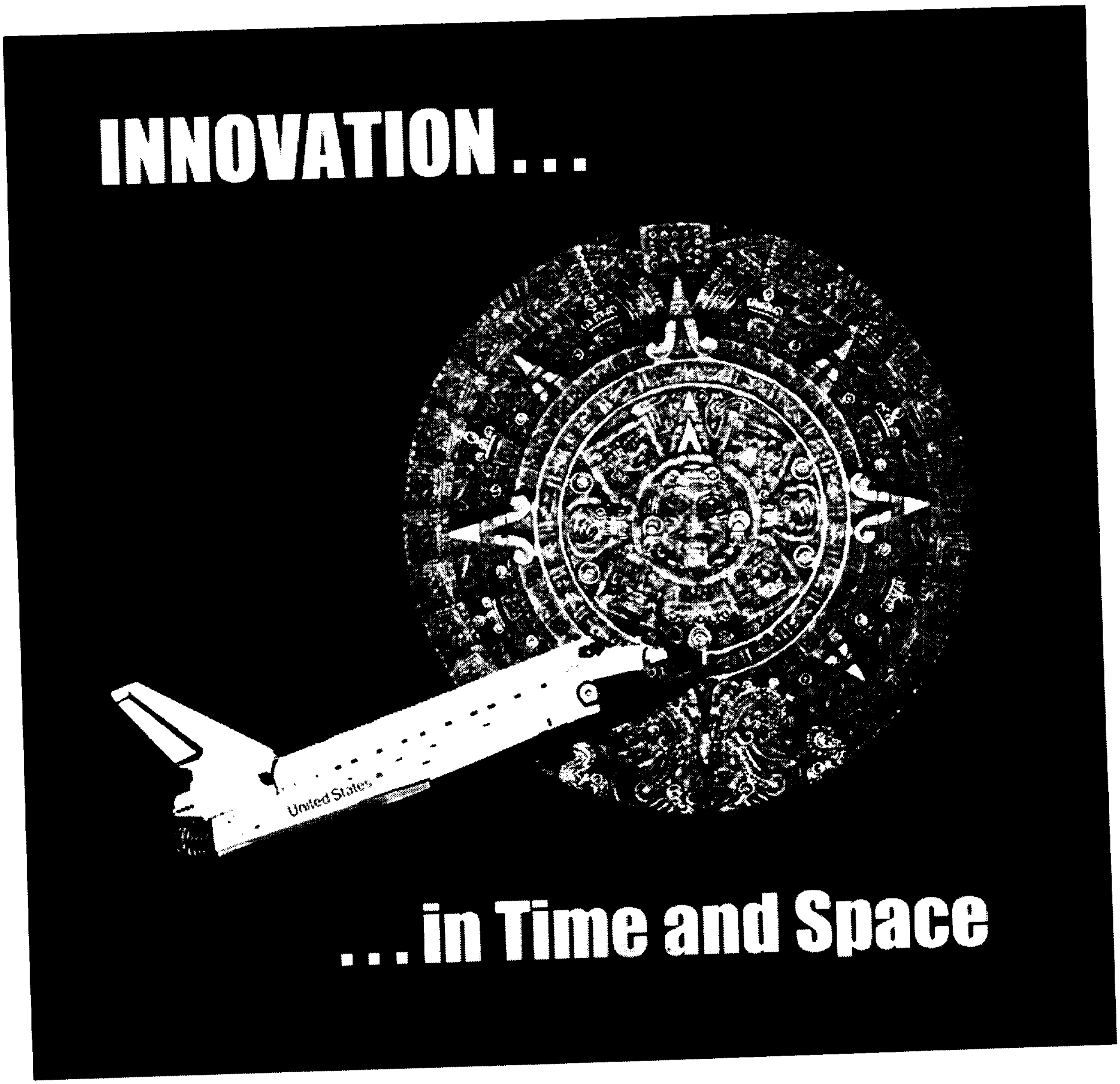
NASA Technical Memorandum 112650

Research and Technology 1996 Annual Report

John F. Kennedy Space Center



About the Cover

A tribute to the diverse workforce at the Kennedy Space Center serving America's diverse needs.

Cover art: by Caroline Zaffery
I-NET, Inc., Engineering Support Contract

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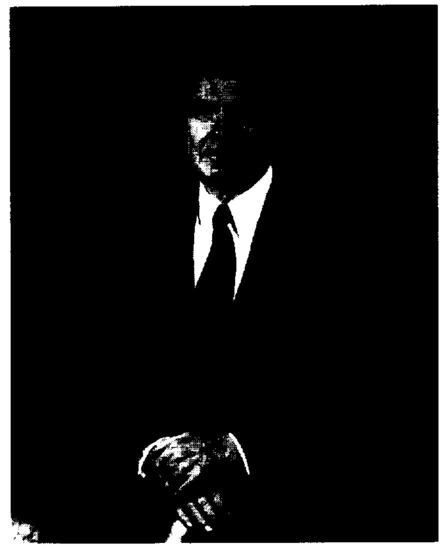
Foreword



As the NASA Center responsible for preparing and launching space missions, the John F. Kennedy Space Center is placing increasing emphasis on its advanced technology development program. This program encompasses the efforts of the entire KSC team, consisting of government and contractor personnel, working in partnership with academic institutions and commercial industry. This edition of the Kennedy Space Center Research and Technology 1996 Annual Report covers the efforts of these contributors to the KSC advanced technology development program, as well as our technology transfer activities.

Gale Allen, Chief, Technology Programs and Commercialization Office (TPO), (407) 867-3017, is responsible for publication of this report and should be contacted for any desired information regarding the advanced technology program.

Roy D. Bridges, Jr.
Director

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Technology Programs and Commercialization

Introduction

John F. Kennedy Space Center (KSC) maintains a vigorous applied research program in support of Shuttle launch activities. Ground support systems, launch and processing facilities, and environmental protection all require continued attention for KSC to remain the nation's premier state-of-the-art spaceport. This issue of the Research and Technology Annual Report highlights many of these applied research activities.

Focusing predominantly on applied research leads KSC to development of new technologies and expertise directly applicable to commercial products and manufacturing needs. The Technology Programs and Commercialization Office aggressively seeks industry participation in KSC's research programs and in the transfer of developed KSC technologies and expertise to industry. Programs and commercialization opportunities available to American industry are described in the Technology Programs and Commercialization Home Page on the World Wide Web at *http://technology.ksc.nasa.gov.*

Industrial Engineering

From an industrial engineering (IE) perspective, the facilities used for flight hardware processing at the John F. Kennedy Space Center (KSC) are NASA's premier factories. The products of these factories are among the most spectacular products in the world — safe and successful Shuttle launches carrying tremendous payloads. The factory is also the traditional domain of the discipline of industrial engineering. IE is different in many ways from other engineering disciplines because it is devoted to process management and improvement, rather than product design.

Industrial engineering is typically used to optimize the operations phase of a project or program. To improve overall performance and quality in most operational programs, it is frequently more cost effective to improve/reengineer the processes for how the work is done rather than to upgrade the hardware. The Space Shuttle is NASA's first major program to have a long-term operational phase; however, all the major current and future human space flight programs (International Space Station, X-33, a lunar base, and human space flight to Mars) are also projected to have lengthy operational phases. Therefore, IE technologies and capabilities are becoming even more strategically important to NASA.

Most IE technologies (methods, tools, techniques, and processes) evolved from the need to improve shop floor productivity in order to remain competitive in the marketplace. However, IE technologies are now being successfully applied to every type of process in Government agencies, production industries, service industries, and academia. The growing need to do things "better, faster, and cheaper" throughout Government and industry has improved the market for IE technologies and capabilities.

The articles in this section demonstrate a variety of new IE methodologies, which are sometimes complemented with computer support systems. The IE articles are categorized into the following four areas: management support systems, human factors engineering, methods engineering/work measurement, and process analysis and modeling. The development and application of IE technologies in each of these areas are producing tangible benefits for NASA and dual-use technologies for other organizations.

Management Support Systems: Kennedy Benchmarking Clearinghouse

Driven by NASA and its KSC contractors' commitment to process improvement and re-engineering in response to the challenges of the current fiscal environment, a pioneering benchmarking consortium was chartered at KSC in January 1994. The Kennedy Benchmarking Clearinghouse (KBC) is a collaborative effort of NASA and all major KSC contractors designed to facilitate effective benchmarking, optimize efficiencies, and leverage quality improvements across the Center.

The KBC developed an original approach to consortium benchmarking that integrates the best features of proven benchmarking models (e.g., Camp, Spendolini, Watson, and Balm). After defining the architecture of the KBC function, the team conducted a "pathfinder" benchmarking study of the Government property management process. Within 2 months from the publication of study findings, three organizations reported a combined cost avoidance of over $41,000; a fourth organization reported a 57-percent reduction in cycle time for processing property loss, damaged, or destroyed (PLDD) reports; and a fifth organization reduced the number of PLDD reports processed by 84 percent. Continued informal benchmarking among process owners also was a synergistic benefit of the consortium benchmarking study.

This cost-effective alternative to conventional benchmarking approaches has provided a foundation for continued benchmarking at KSC through the development of common terminology, tools, and techniques. An example of a useful benchmarking tool is shown in the figure "Total Customer Satisfaction Versus Benchmarking Versus Current Performance." In addition to enhancing benchmarking skills among members, the Clearinghouse is strengthening a KSC culture that values continual improvement and teamwork to achieve excellence.

During 1996, the KBC incorporated the lessons learned from the Government property management study and feedback from several presentations to benchmarking experts in a systematic strategic planning analysis. The strategic planning effort considered customer expectations, KBC capabilities, and the changing business environment. The result is the updated vision illustrated in the figure "KSC Partners and Services." After senior management approval of the revised KBC strategic plan, inputs were solicited on the process of highest overall Center priority for the second major KBC-sponsored benchmarking study. The result was the selection of the hazardous waste management process. The efforts of the KBC team during 1997 will focus on completing the environmental study and continuing to provide additional benchmarking services to customers across KSC.

Key accomplishments:

- 1994: Team charter, formation, strategic planning, and selection of the initial study.
- 1995: Completed a comprehensive practicum or "pathfinder" benchmarking study of Government Property Management. Received a Silver Medal Award (in the applied research category) from the International Benchmarking Clearinghouse.
- 1996: Completed a revised strategic plan. Initiated a hazardous waste management benchmarking study. Recognition of KSC benchmarking as a "best practice" by the Best Manufacturing Practices Center of Excellence.

Key milestones:

- 1997: Completion of the hazardous waste management benchmarking study. Continued refinement of KBC services and strategic plans to reflect NASA's direction for KSC to facilitate Agencywide benchmarking initiatives.

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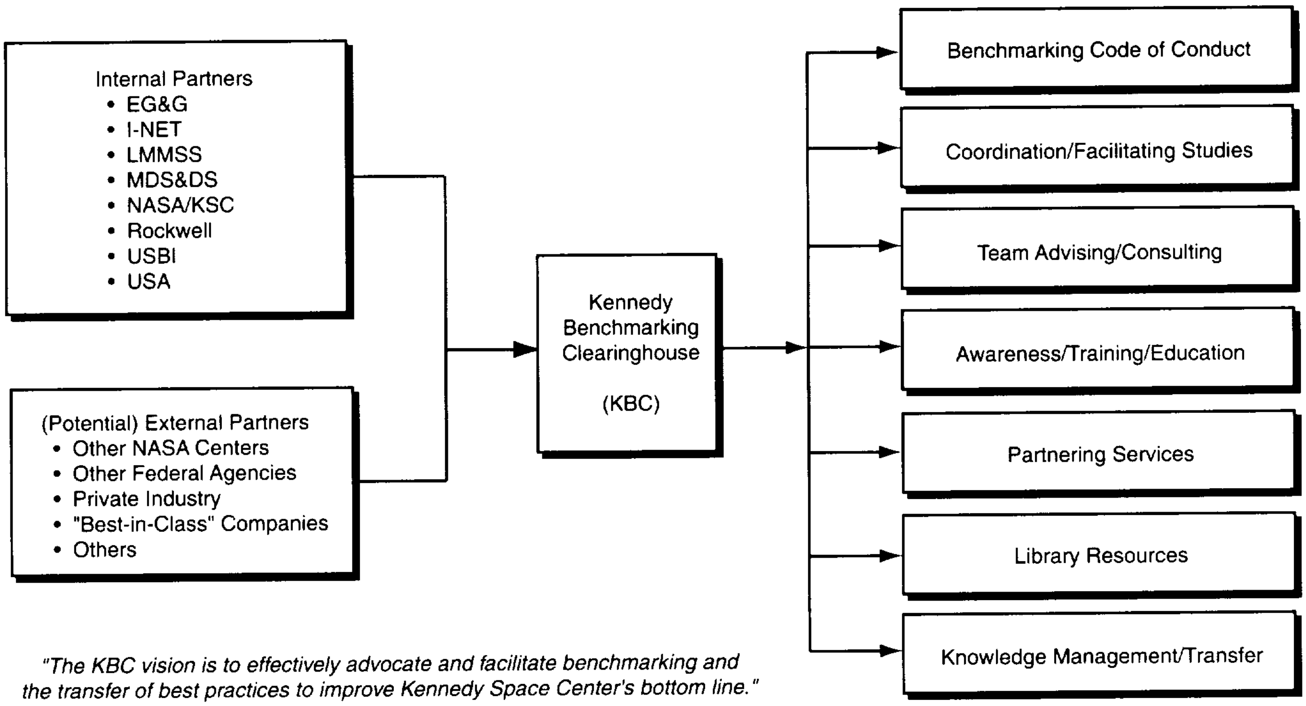
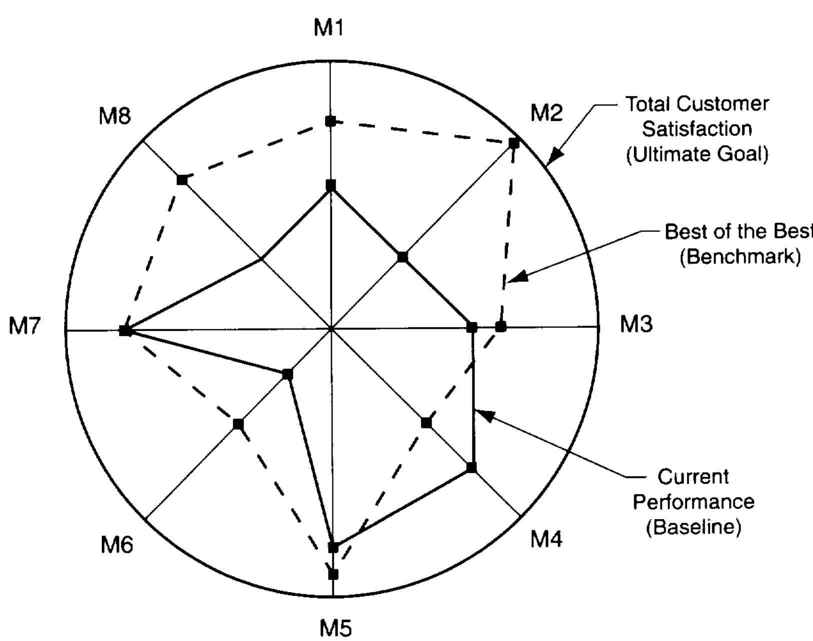
Participating Organizations: McDonnell-Douglas Space and Defense Systems (D.M. DeVito), EG&G Florida, Inc. (J.J. Eads), I-NET, Inc. (G.W. Cain), Lockheed Martin Manned Space Systems (F.A. Lockhart), United Space Alliance (S.C. Morrison), USBI Company (H.L. Novak), and Rockwell Space Systems Division, Florida Operations (K.A. Lieb)



KSC Partners and Services



Total Customer Satisfaction Versus Benchmarking Versus Current Performance

Management Support Systems: Organization- and Process-Level Benchmarking Procedures for Shuttle Processing

Previous work on the project titled "Inter- and Intra-Facility Performance Measurement" conducted in KSC Space Shuttle ground processing involved the development of a prototype benchmarking procedure for use within and across various Shuttle processing facilities. These procedures are primarily applicable to process-level measurements of performance. The application of process-level benchmarking procedures was demonstrated in prototype data collection and comparisons between several KSC processing facilities.

The work performed on the project in 1996 led to development of supplemental procedures for establishing organization-level metrics and measurement procedures. A candidate set of organization-level metrics was developed for the primary functional processes involved in Space Shuttle ground operations. The structure of the candidate measurement matrix is illustrated in the figure "Organizational Performance Candidate Measurement Matrix."

A second component of this project involved an informal benchmarking study to gain insight into the functions of industrial engineering groups in other organizations. Several non-KSC aerospace organizations and additional organizations performing operations requiring processes similar to those found at KSC were surveyed. The major purpose of the survey was to determine the types of functions industrial engineers perform in those organizations. A graph showing the distribution of resources is illustrated in the figure "Comparison of Resource Allocations Between Traditional Industrial Engineering Functions."

Key accomplishments:

- 1994: Review of Shuttle primary process categories and collection of performance measurement information from external organizations.
- 1995: Development of measurement system procedures and selection of candidate organization-level metrics. Completion of process-level data collection and benchmarking comparisons between Shuttle processing facilities.
- 1996: Presentation of candidate organization-level metrics in matrix format and completion of initial industrial engineering functional benchmarking survey.

Key milestones:

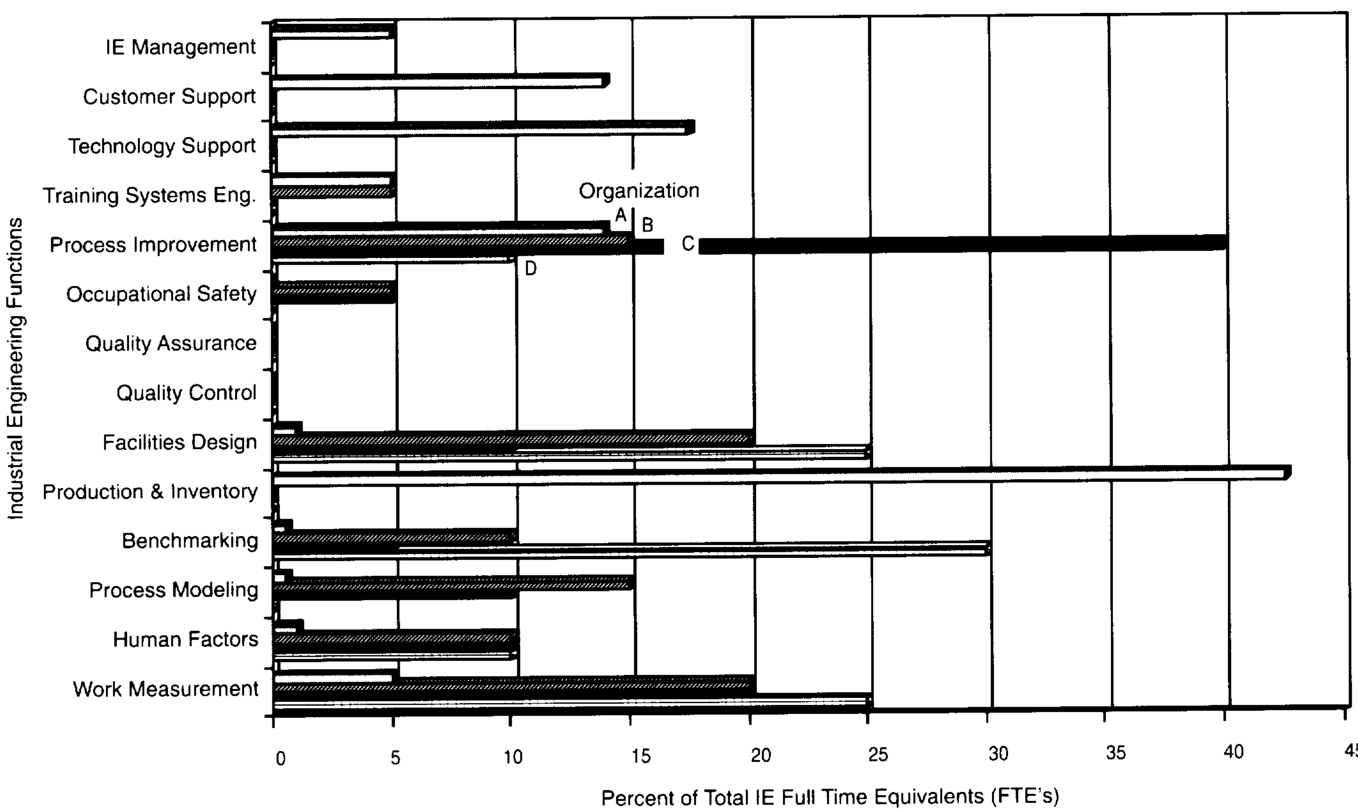
- 1997: Continue review of candidate metrics and develop prototype implementation of the associated measurement system. Continue industrial engineering benchmarking survey as opportunities arise.

Contact: T.S. Barth, PZ-A1, (407) 861-5433

Participating Organizations: University of Central Florida (R. Safford and B. Williams) and Arizona State University (A. Jackson)

PLAN WORK FLOW	PROVIDE WORK INSTRUCTIONS	TRAIN PEOPLE	PROVIDE PARTS, MATERIALS, AND SERVICES	....
Candidate Quantity Ratios				....
	Candidate Performance Ratios			....
		Candidate Quality Ratios		....
			Candidate Inferential Ratios	....

Organizational Performance Candidate Measurement Matrix



Comparison of Resource Allocations Between Traditional Industrial Engineering Functions

Management Support Systems: General Model for Government Transition

Voters today demand a more lean and responsive Government; and politicians, civil servants, and policymakers have taken notice. Concepts like "reinventing Government," which stress efficiency and decisionmaking accountability in the public arena, have set the stage for what people expect of their Government. Voters are looking for reduced Government size, fiscal responsibility through balanced budgets, and privatization where practical and possible.

Privatization is a method used by governments in their efforts to obtain high-quality goods and services at lower costs and on a more timely basis through the transfer of programs and functions to the private sector. NASA is evaluating privatization, where possible and practical, in the strategic plans for the Agency. The transfer of relatively mature functions, such as Space Shuttle operations to the private sector, is consistent with the Federal Government's current direction.

The process of transitioning toward privatization requires a systematic methodology. The table describes a general model, developed under the NASA/ASEE Summer Faculty Fellowship Program, where strategic planning, communication, Center involvement, and a system of incorporating lessons learned are the key concepts. The model is based on extensive research and identification of "best practices" in other Government transition efforts. KSC is the NASA Center most imme diately affected by the transition of Space Shuttle operations to a single prime contractor. This model can be used to provide input to NASA's ongoing assessment of privatizing Space Shuttle operations at KSC.

Step five of the general Agency-level model in the table is to "empower centers to plan and operationalize privatization." The specific actions required to accomplish this include: alignment of Center privatization goals with Agency goals; development of a contract that provides incentives for specific contract measurements; mapping of key processes to contract measures; and development of a system to track, report, and manage those measures. These actions, together with the other steps described in the model, provide an integrated and systematic approach to transitioning toward privatization.

Key accomplishment:

- 1996: Development of a general Agency-level model for privatization and a methodology to operationalize privatization at KSC.

Key milestones:

- 1997: Ongoing refinement and utilization of the model and methodology. Continued implementation of the industrial engineering role in the transition efforts.

General Agency-Level Model for Privatization

1. Define Agency-level goals and objectives with respect to privatization.
   - Define through strategic planning process.
   - Communicate throughout the organization.

2. Identify affected Centers of potential privatized functions.
   - Communicate Agency-level privatization goals and objectives.

3. Evaluate privatization alternatives at Agency and/or Center level.
   - Include NASA Centers in the evaluation.
   - Identify potential functions to privatize.
   - Specify the type of privatization.
   - Perform cost and risk analyses for the entire Agency and individual Centers.
   - Evaluate alignment with, or effect on, the strategic plan.
   - Understand the political implications.

4. If Privatization is chosen, communicate.
   - Ensure communication methods saturate the organization.
   - Relate current and potential plans through communication channels.
   - Relate updates and future communications.

5. Empower Centers to plan and operationalize privatization.
   - Ensure Center-level privatization strategic plans align with Agency strategic plans.

6. Evaluate effectiveness of all privatization efforts at Agency and Center levels.
   - Measure effectiveness against expected goals and objectives over time.
   - Decide to continue present effort, add to, or halt privatization efforts.

7. Document lessons learned at Agency and Center levels.
   - Document inputs, processes, and outputs.
   - Incorporate lessons learned in the process of evaluation and execution.

Contact: J.S. Flowers, PZ-A1, (407) 861-5434

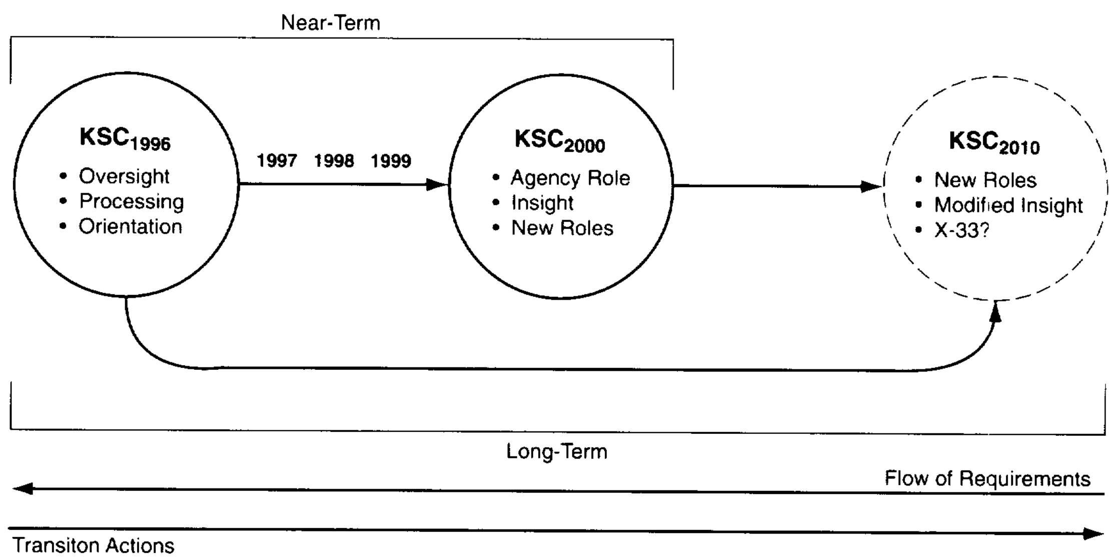
Participating Organization: Kansas State University (J.P. Lavelle and D.W. Krumwiede)

Management Support Systems: Organizational Change Models

KSC, as part of NASA's efforts to perform "better, faster, and cheaper," has begun a large-scale organizational change effort. The KSC effort is similar to other private and public organizations that have attempted downsizing to meet performance requirements. The drivers for KSC's transition include: the reduction in NASA's budget, the award of a Space Flight Operations Contract (SFOC), and a definition of KSC roles based on NASA's strategic plans. These drivers are leading to significantly changing roles for KSC civil servants.

As part of the NASA/ASEE Summer Faculty Fellowship Program, a study was conducted to investigate the best practices in managing organizational change. The study consisted of a literature review on organizational change and interviews with KSC senior management, KSC employees, and heads of major contractors who have previously experienced large-scale organizational changes. A result of these interviews was a set of four models to help understand and manage organizational change.

One of the models, shown in the figure, represents KSC's transition as an "all-term" transition. Two circles were in the original draft of the figure (i.e., year 1996 for the present state and year 2000 for the future state). However, after senior management interviews and focus sessions with KSC employees, a third circle was added to reflect the 2010 time period. The focus groups emphasized the need for KSC to define their future state beyond the near-term timeframe. They felt the year 2000 midterm state was transitory and wanted to define and take action for the long-term state. The word "all-term" was developed by a senior executive at Westinghouse who described his management style as all-term to reflect the need to balance the



KSC "All-Term" Transition Model

organization for both the near and long term. The general implications of this model include:

- Requirements must be met by the transition flow from the definition of the future state.
- The organization must understand the current, near-term, and long-term future states and the relationships among them.
- The transition actions must move the organization from the current to the desired future state.
- Actions must balance survival in the near term with long-term development.
- Long-term actions can be defined in more general terms than the near-term actions.
- Earlier actions should be carefully chosen because they impact choices for longer term actions.
- The strategic direction defines requirements and timeframes from which actions are taken.
- All employees must be planned for.

The senior management interviews, focus groups, and contractor interviews provided the data to support the notion of an all-term transition. The roles of KSC civil servants are changing from oversight (current state) to insight (near-term state) and then to modified insight (long-term future state). KSC must define the actions needed in the current and near term to ensure the long-term state is successfully reached. For example, what actions should KSC take to ensure it has the capability to be the launch and landing site for X-33? KSC management can use this model to balance their actions to ensure current, near-term, and long-term needs are met.

Key accomplishments:

- 1996: Completed interviews with senior management, KSC employees, and heads of contractor organizations. Shared results with the Center Director and Senior Staff. Facilitated senior management planning sessions.

Key milestone:

- 1997: Use of the model by KSC to understand and manage organizational change.

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Participating Organization: University of Central Florida (T. Kotnour)

Management Support Systems: Organizational Learning Process Supporting the NASA Test Director

The purpose of this project is to determine the feasibility and conceptual requirements for development of a system to support the NASA Test Director (NTD) during Space Shuttle launch countdown activities. The system under study uses historical data to improve near real-time decisionmaking while providing better schedule development and implementation methods. An organizational learning perspective is used to guide the development of the system process.

The concept of organizational learning is exhibited in knowledge-sharing efforts aimed at using prior solutions to solve current problems and to avoid repeating past mistakes. Organizational learning is a process of creating, assimilating, and disseminating information and knowledge from one problem-solving experience to another (i.e., one launch to another). The objective of this research effort is to conceptually define the requirements for knowledge creation, assimilation, and dissemination for the NTD.

With over 80 Shuttle launches since 1981, a significant amount of Shuttle launch countdown knowledge exists that can assist future launch planning and execution. This knowledge includes insight into improvement opportunities, effective responses to potential problems, and numerous scheduling characteristics. As shown in the figure, an organizational learning process can support knowledge creation, assimilation, and dissemination between launches (shown as L-1, L-2, L-3, and L-4 in the figure) and enhance the overall learning process of the organization.

Several current processes need to be reengineered to take advantage of technology advances and to meet the challenges of an aging Shuttle fleet. A common example of the current process is the detection of a problem or failure during the conduct of a particular testing procedure. The system engineer performing the test reports the event through a structured test team chain of command to the NTD along with troubleshooting or repair plans and the associated resources required (technicians, equipment, duration, access, etc.) to complete repairs. The NTD, using personal experience combined with input from the test team, picks an appropriate time to insert the particular problem into the schedule. Problems often arise because many additional tasks (platform configurations, safety involvement, special tools or certifications, etc.) are required to accommodate the original task, which may not be immediately obvious to members of the test team. Insight from past problem resolution can provide the test team with valuable knowledge about problem resolution procedures and support/configuration requirements that would save time during critical decisions, streamline operational planning and execution, and ultimately reduce costs. To develop a system to assist the NTD in making quick, accurate assessments and decisions, historical task information must first be collected and evaluated. The historical task information will consist of:

- Plan or activity description
  - Goals to be achieved
  - Conditions under which the activity was evaluated
- Results
  - Actual measurement for cost, schedule, and performance parameters
  - Constraining activities
  - What worked and why
  - What did not work and why
- Recommendations
  - Suggestions for improvement
  - Constraining activities

The knowledge gained from previous launches can be used to support the planning phase of successive launches. This information can be stored in a historical database (shown as the corporate memory in the figure) and used for off-line trend analysis, as a comparison tool in building baseline schedules, and as a resource reference to aid in real-time decisionmaking and scheduling.

Key accomplishments:

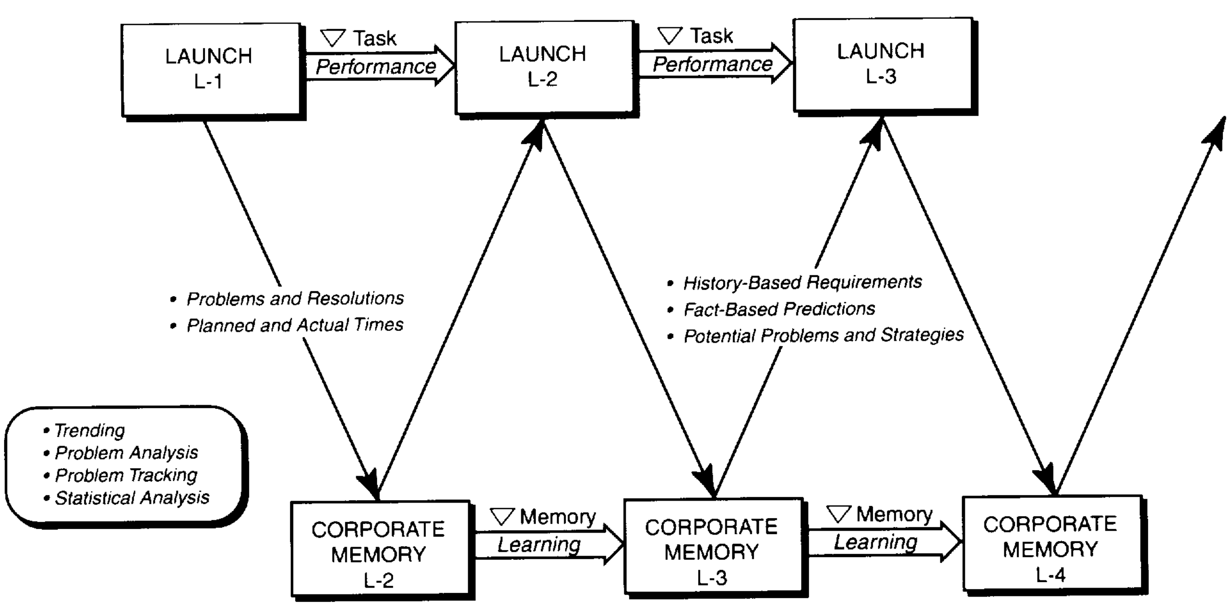
- 1995: Countdown management device initiated.
- 1996: Completion of a management system analysis on the NTD process to understand the current system and the need for a new system. Definition of conceptual requirements for a process and associated tools to support the NTD's.

Key milestones:

- 1997: Definition of potential data collection methods to study the feasibility of an organizational learning process and tool. Identification of operating system software and hardware requirements. Development of system prototype.

Contact: C.M. Orr, PZ-A1, (407) 861-5433

Participating Organizations: NASA/KSC Shuttle Processing (J. Guidi, R. Stevens, J. Spaulding, and J. Leotta) and University of Central Florida (T. Kotnour and A. Quinn)



NTD Organizational Learning Process

Human Factors Engineering: Human Factors Event Evaluation Model

A diagnostic tool for evaluating the contributing causes of accidents in Shuttle ground operations is being developed and used by the KSC Shuttle Processing Human Factors Team. The events evaluated by the Human Factors Team are usually called processing incidents or mishaps. The diagnostic tool is an application of a "team effectiveness leadership model," which was developed during years of research observing a wide variety of high-performance work teams. The studies used to develop and refine the team effectiveness leadership model include observations of KSC teams in Shuttle processing, unmanned launch vehicle processing, and payload processing.

The Shuttle Processing Human Factors Team was established in 1993 to assess human factors issues associated with incidents in ground operations. The team's mission is to embed human factors in all processes required for Shuttle launch and landing operations at KSC. In addition to investigating human errors with its diagnostic tool, the Human Factors Team has developed training courses to raise human factors awareness in the work force, established a Positive Initiative Effort (PIE) for reporting potential work area problems, developed a close-call reporting mechanism, facilitated a morale survey, and published a human factors newsletter.

The Human Factors Team advocates a proactive approach to mitigating the risk of human errors. The diagnostic tool enables development of a database of metrics to accumulate statistics for accidents occurring over a period of time rather than for a single event. The tool was initially tested through application to events recorded in 1995. During 1996, the team's efforts, with respect to the diagnostic tool, were focused on updating the specific causal factors and their definitions based on feedback received through applications of the model to new events. The updated model is illustrated in the figure.

Valuable feedback on the model was received from several presentations within KSC and at external conferences. A process was established within the team to monitor data collected by various team members for accuracy and consistency. Current efforts are focused on developing a user's manual for the diagnostic tool and exploring new ways to analyze and report the accident investigation data to ensure the results of the team's efforts are used in a constructive manner.

Key accomplishments:

- 1991 to 1992: Initial team effectiveness leadership model development efforts at KSC.
- 1993: Formation of the Shuttle Processing Human Factors Team. Refinement of the team model using data from observations of Shuttle processing work teams.
- 1994: First annual report published by the Human Factors Team based on the

initial year of investigations. Continued refinement of the team model in Shuttle processing.

- 1995: Development of the initial diagnostic tool for investigating accidents in Shuttle processing.
- 1996: Validation and refinement of the diagnostic tool. Recognition of a "best practice" by the Best Manufacturing Practices Center of Excellence. Development as a database using causal factors from the model. Initial reports to Shuttle Processing management.

Key milestones:

- 1997: Publish the user's manual for the diagnostic tool. Refine data analysis and reporting techniques. Apply a modified version of the tool to close calls.

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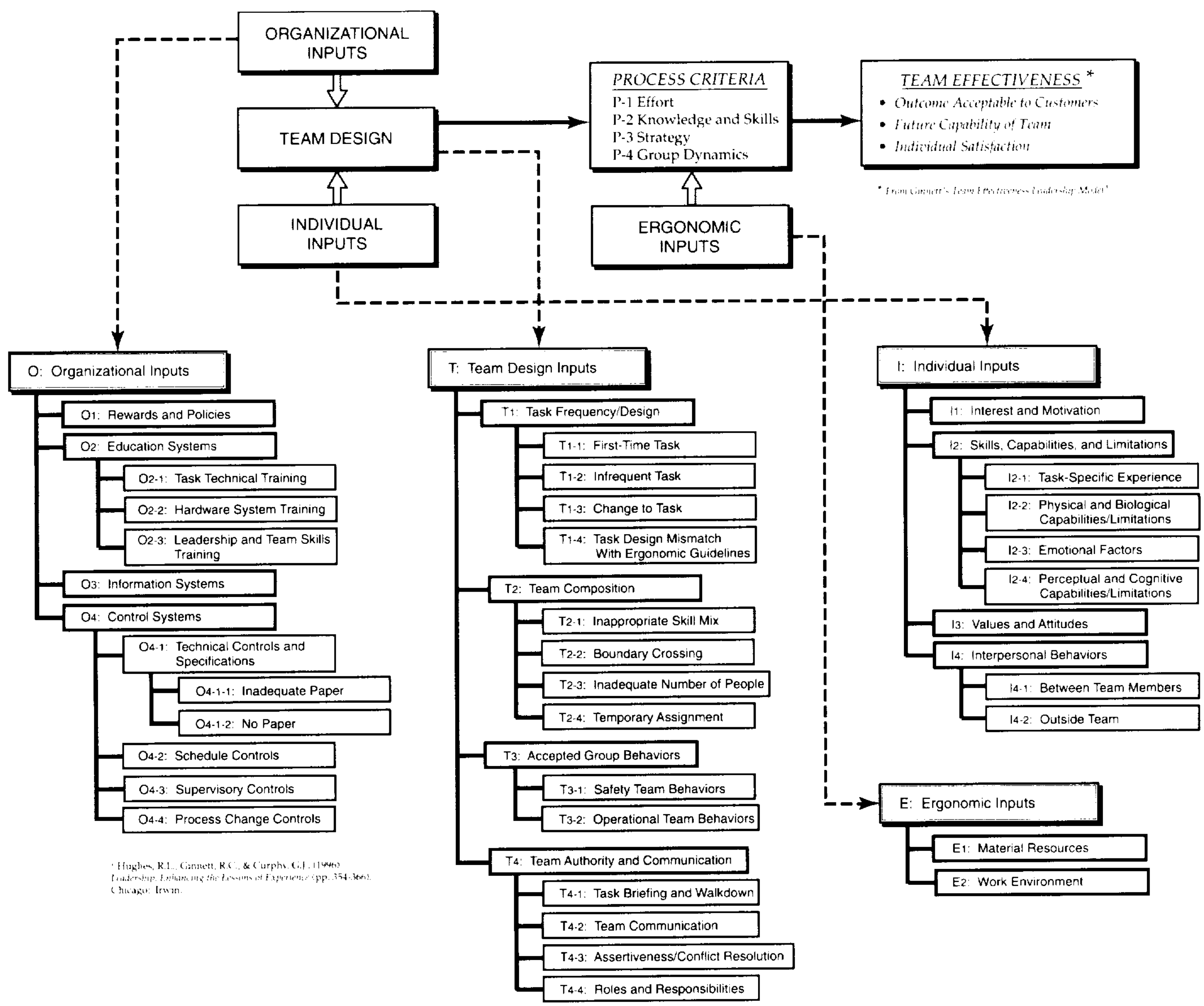
Participating Organizations: United Space Alliance (M. Nappi, D. Blankmann-Alexander, J. Chaput, J. Jamba, M. Parrish, K. Pisula, B. Potteiger, and L. Santana); NASA Shuttle Processing (P. Simpkins, C. Orr, and M. Leinbach); NASA Safety, Reliability, and Quality Assurance (J. Medina and G. Cogan); Ames Research Center (B. Kanki and C. Irwin); Center for Creative Leadership (R. Ginnett); and the U.S. Air Force Academy (J. Austin)



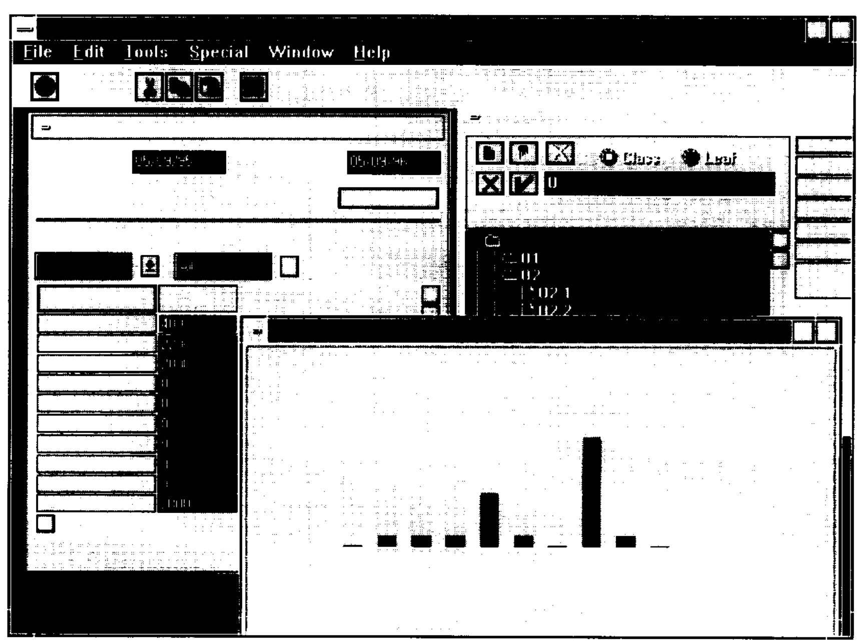
KSC Human Factors Event Evaluation Model

Human Factors Engineering: Human Factors Trend Analysis System

The Human Factors Trend Analysis System (HF-TAS) is being designed to help analysts understand the root causes of process anomalies due to human factors issues at the organizational, team, and individual levels (e.g., incidents that cause personnel injuries, damage facilities, incur additional costs, and/or delay processing). The initial conceptual design and development of software prototypes was performed under a 6-month Phase I Small Business Innovation Research (SBIR) contract.

The development of HF-TAS was motivated by the weaknesses of existing root-cause analysis techniques. Although statistical quality control methods (i.e., methods for assessing whether a process is in control) are quantitatively robust, widely used, and successful, only very simple qualitative methods (e.g., fishbone diagrams) are available for root-cause analysis (understanding why a process is not in control). The result is that industries frequently spend millions of dollars fixing the wrong process problems. The other major motivation for HF-TAS is the importance of human factors in industrial accidents. Research has shown that avoidable human errors are a significant source of process anomalies in many industrial processes (e.g., aircraft manufacturing and maintenance).

HF-TAS has many possible KSC, NASA, and commercial applications. One potential application of HF-TAS at KSC is assisting the Human Factors Team while investigating and analyzing the contributing causes of Shuttle ground processing accidents. (Refer to the article titled "Human Factors Event Evaluation Model.") The major technical innovation of HF-TAS is the anomaly process diagram (APD). The APD is a new, theoretically well-founded methodology for root-cause analysis focused on the repre-



HF-TAS Prototype

sentation of causal, probabilistic relations between process variables.

In the Phase I project, two software prototypes were developed: a working HF-TAS prototype and an anomaly process diagram prototype. Sample screens from these prototypes are illustrated in the figures. The HF-TAS prototype demonstrated the feasibility of the overall concept. The HF-TAS prototype supports the human factors analyst during the tasks of describing investigation results and computing trends in the importance of contributing causes over time. Additional types of analyses (e.g., correlation, sensitivity, and cluster analyses) will be investigated during the Phase II effort to assist human factors analysts in transforming the investigation data into useful information. Methods to effectively communicate the analysis results for management action will also be implemented. The second prototype was the anomaly process diagram technology, which was based on Prevision's Strategist product. Both software prototypes were successfully tested with data from the KSC Human Factors Team.

Key accomplishments:

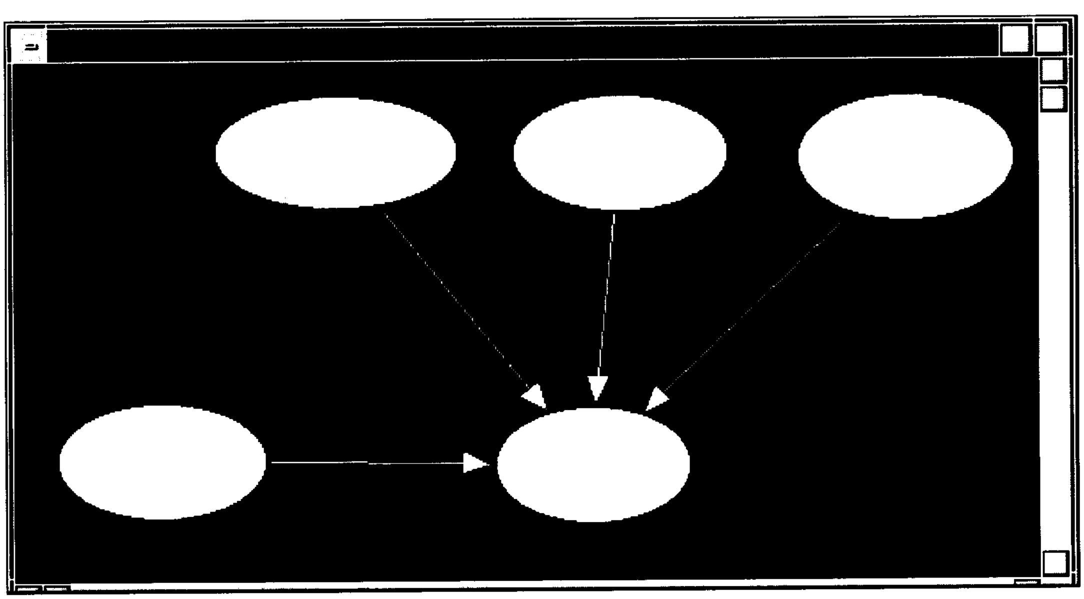
- 1995: Award of the Phase I SBIR contract.
- 1996: Completion of the Phase I feasibility study and software prototypes. Award of the Phase II SBIR contract.

Key milestones:

- 1997: Completion, delivery, and testing of HF-TAS prototypes at KSC.
- 1998: Completion and delivery of the operational HF-TAS system.
- 1999: Commercialization of HF-TAS and anomaly process diagram technologies.

Contact: T.S. Barth, PZ-A1, (407) 861-5433

Participating Organization: Prevision, Inc. (R. Fung and B. D'Ambrosio)



Example Anomaly Process Diagram

Human Factors Engineering: Shuttle and Aircraft Maintenance Human Error Analysis and Interventions

Ground support of both space and aviation operations is a crucial element to safe and effective flight operations. However, time pressures, complexity of the work environment, dynamic changes in schedules, and introduction of new technologies are a few drivers that can lead to human error problems. Maintenance activities are becoming more critical as the nation's Shuttle and aircraft fleets (both commercial and military) continue to age. Past accidents have dramatically demonstrated the potential impact of human error problems in maintenance activities.

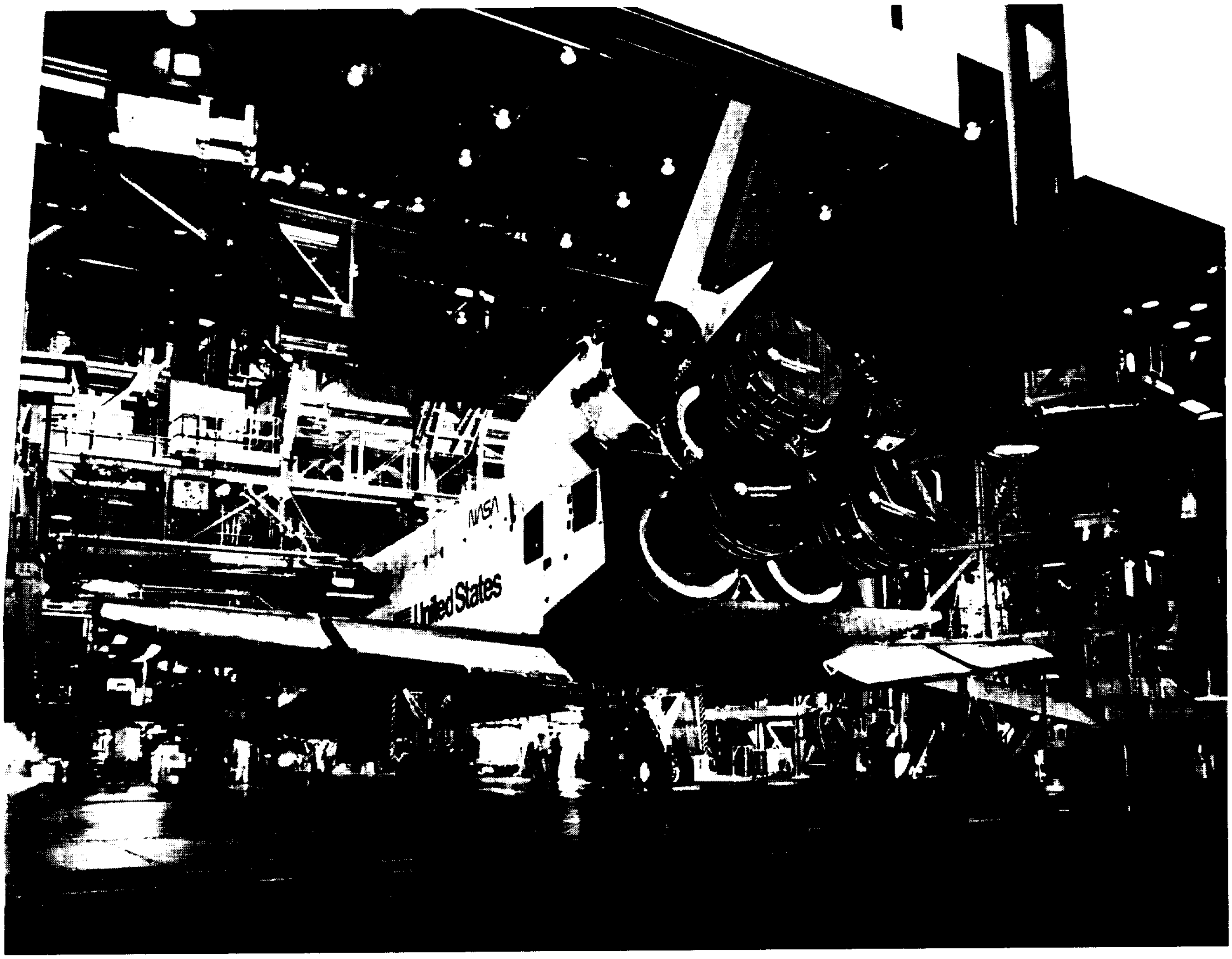
The aviation industry has responded by paying increased attention to human factors issues. For example, innovative developments in flight training technologies, human-centered automation, multimedia information, and decision-aiding systems have been made. However, the adaptation and transference of human factors tools, techniques, and principles to ground operations have been limited. The two primary objectives of this research are: (1) to identify and characterize human factors problems in ground operations and (2) to develop a systematic approach to human factors interventions. Specifically, the goals are to implement training, procedural, and technology solutions directly tied to targeted tasks and processes.

Due to the overlap in human factors issues across Shuttle and aircraft maintenance domains, the potential benefits of technology transfer are great. The photograph shows the primary Shuttle orbiter maintenance facility, which has a work environment and work processes similar to those in depot-level aircraft maintenance centers. Recent efforts have focused on the following two areas:

- Identification of human factors issues in aircraft maintenance: The NASA Aviation Safety Reporting System (ASRS) provides a rich archive of actual operational events related to aircraft maintenance procedures and processing. Because such a database is limited in the aerospace community, the study was undertaken as both a model for Shuttle operations and to obtain substantive results useful in aircraft and aerospace domains. A preliminary report was presented at the annual meeting of the Human Factors and Ergonomics Society in San Diego, California.

- Technology transfer workshops: The overall goal is to identify issues, problems, and "lessons-learned" in common interest areas such as human error and incident analysis, risk analysis techniques, human factors training, and human performance measurement. An initial technology transfer workshop for aerospace, aircraft, and other high-risk operations was held at Ames Research Center (ARC) in September 1996. The workshop focused on human factors aspects of incidents, accidents, mishaps, and close calls in space vehicle and aircraft maintenance.

These efforts demonstrate one area of synergy between NASA's Aeronautics enterprise



Shuttle Orbiter Processing Facility

and the Human Exploration and Development of Space (HEDS) enterprise. The collaboration between ARC and KSC is producing valuable results supporting the goals and objectives of both enterprises.

Key accomplishments:

- 1991 to 1993: Initial application of human factors technologies developed for flight crews to aircraft maintenance crews. Team effectiveness research on Shuttle maintenance crews.
- 1994 to 1995: Initial collaboration with the KSC Shuttle Processing Human Factors Team in the area of human error investigation and analysis.
- 1996: ASRS study completed. Human Factors Workshop hosted by ARC.

Key milestones:

- 1997: Human Factors Workshop focused on training issues hosted by KSC. Continued collaboration between KSC and ARC, including potential new areas such as human-computer interaction.

Contacts: T.S. Barth, KSC, PZ-A1, (407) 861-5433, and B.G. Kanki, ARC, (415) 604-5785

Participating Organizations: NASA Ames Research Center, Battelle Aviation Safety Reporting System, Boeing, Northwest Airlines, United Airlines, Delta Airlines, and Idaho National Engineering Laboratories

Methods Engineering/ Work Measurement: Expert System To Generate Job Standards

KSC industrial engineers are actively engaged in identifying techniques to improve the efficiency and effectiveness of Space Shuttle ground processing. One approach that has demonstrated a high potential for success is the industrial engineering area called work measurement. Although many work measurement techniques and methodologies are best suited for short-duration, highly repetitive activities, there are also approaches to successfully measure the work time associated with long-duration, low-repetition tasks like those inherent in Shuttle ground processing.

A challenge to work measurement practitioners is that there is no guidance on which of several available measurement techniques to use. Practitioners must rely on their own experience, on-the-job training, previous approaches used by their predecessors in the organization, or trial and error. These methods for choosing work measurement techniques can lead to ineffective results and wasted effort. The literature is of little help and there are no references to guide the practitioner. KSC industrial engineers have recognized this deficiency and have begun to research ways to fill the void.

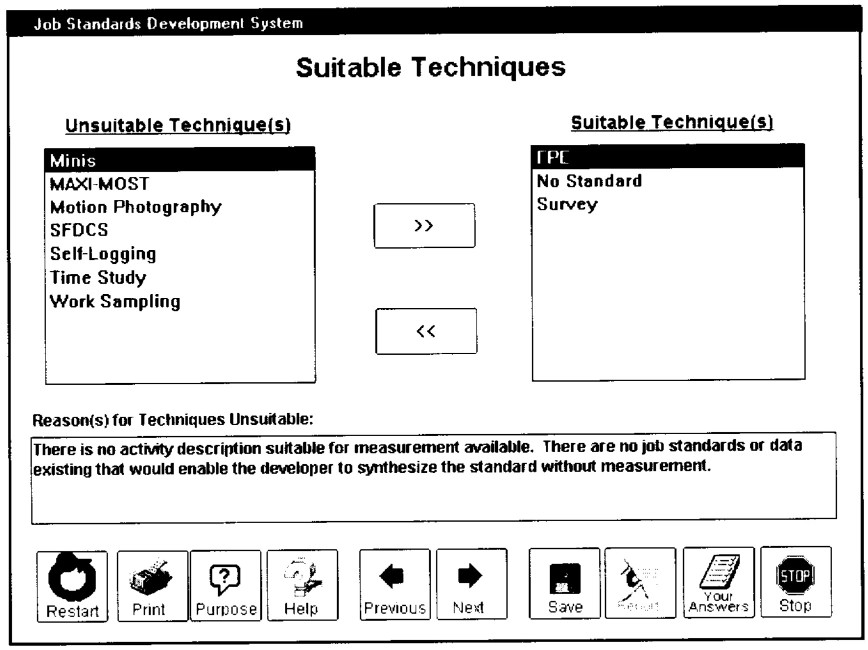
In 1994, KSC industrial engineers and their support contractors began to develop an expert system to help the practitioner make informed decisions about which work measurement technique is best for the situation at hand. The expert system, designed for the PC platform, asks the practitioner a series of questions about issues relevant to technique selection. The expert system uses answers provided by the user to navigate through the relevant issues while helping users select a practical work measurement technique for their application. The system considers many attributes of the problem, including precision requirements of the final result, availability of historical data, estimated task duration, visual accessibility, work force participation considerations, and cost/benefit expectations. Following technique selection, the system helps users through all subsequent steps leading to a reliable estimate of task completion time. Although the system is not yet complete, it can already be seen that inexperienced as well as experienced practitioners will better understand the issues, make better decisions, and better understand the impact of their work measurement technique selection decisions.

Key accomplishments:

- 1994: Successfully demonstrated the prototype expert system to select an appropriate work measurement technique (see the figure).
- 1995: Identified the work measurement techniques to include in the expert system.
- 1996: Coordinated and scheduled field tests of measurement techniques.

Key milestones:

- 1997: Develop, test, and install the Job Standards Development System (JSDS)



Available Techniques Based on User Input

for the KSC environment. The JSDS will include expert systems to select the work measurement technique, guide the work measurement, and compute the job standard.

Contact: A.M. Mitskevich, PZ-A1, (407) 861-5433

Participating Organizations: OMNI Engineering and Technology, Inc. (N. Schmeidler) and OXKO Corporation (S. Oxman)

Methods Engineering/ Work Measurement: Quality Assurance Portable Data Collection System

Work procedures for payload processing and checkout operations at KSC are executed using a paper system. With this system, a procedure is generated using a word processor, printed out, copied, and distributed to members of the test team. The work instructions detailed in the procedure are then executed using a pen to record test data and notes and using quality and technician ink stamps to document the work performed. Changes to the work instructions that occur during the execution of the procedure must be documented on a paper deviation form. Approval signatures must be obtained before the modified instructions can be performed. Once approved, the deviation is then copied and distributed to the test team. Upon completion of the work procedure, the official copy of the procedure, including deviations, is then scanned into a computer and stored in a database.

The objective of the Quality Assurance Portable Data Collection (QAPDC) System project was to automate this process. A Small Business Innovation Research (SBIR) contract was awarded to Sentel Corporation to develop the capability to capture technician and quality stamps and test data electronically, without the need for paper. This project was developed by Sentel and personnel from KSC, lead Center for payload processing.

With the QAPDC System, the procedure is converted from a word processor document to a database. It is then executed using portable computers. Data is entered electronically and distributed to all other terminals. The ink stamp is replaced with an electronic stamp that meets the form, fit, and function of the old ink stamp. A programmable memory chip inside the electronic stamp stores a unique identifier. Each team member has his or her own electronic stamp.

This electronic stamp adds a secure mark to a step, identifying who performed that step and the date and time the step was performed. The electronic stamp is read using a stamp reader that is connected to the serial communication port of the computer. The system provides protection mechanisms to ensure data and stamp integrity. Once the procedure has been worked to completion, it is converted to a portable document format and stored to a database.

The main components of the QAPDC System are the central data server (CDS) and the portable data terminals (PDT's). The CDS is the main computer that serves as the network host and database server. PDT's display procedure steps and enable users to collect test data and stamps. The PDT's are standard personal computers (PC's) running Windows 95 or Windows for Workgroups operating systems. Various PC's are used as PDT's, including desktops, laptops, and pen-based tablets. The CDS is a high-end PC running the Win-

Engineer Using Portable Data Terminal in the Microgravity Science Laboratory

dows NT operating system. The following benefits are provided by the QAPDC System:

- The time to process a procedure is decreased.
- The time to gather information for incident investigations and management reporting is decreased.
- Information availability is improved. Test data can be searched and retrieved.
- Everyone on the test team sees changes to the document instantly.
- Accuracy of the procedure is improved as deviations are incorporated directly into the procedure.
- Paper is eliminated.

The system is in the prototype stage and is being developed to support Space Station processing. There are several U.S. and international organizations from both private industry and Government agencies who have expressed an interest in obtaining the QAPDC System for their use.

Key accomplishments:

- 1993: Completed the Phase I study for the SBIR contract.
- 1996: Completed Phase II of the SBIR contract. Demonstrated proof of concept for this system. Patent-pending status obtained by Sentel Corporation for the electronic stamp and stamp reader devices. Received the NASA SBIR Technology of the Year Award in the computer/software category. Completed Phase III by conducting the first pilot study in the Operations and Checkout Building using the Portable Data Collection (PDC) electronic system in parallel with the paper system.

Key milestones:

- 1997: During Phase IV, conduct the second pilot study in the Space Station Processing Facility using the electronic system in parallel with the paper system. Provide information and assistance to other NASA centers, Government agencies, and the private sector who wish to implement the system.
- 1998: For Phase V, provide an operational PDC System for use in Space Station processing.
- 1999: In Phase VI, enhance the operational system. Include an interface to the Payload Data Management System. Provide Internet access to the PDC System. Support all types of work authorization documents.

Contacts: J.D. Lekki, BE-E3, (407) 867-3690; R.B. Hanson, AD, (407) 867-2001; and D.L. Hagist, BR-B1, (407) 867-3523

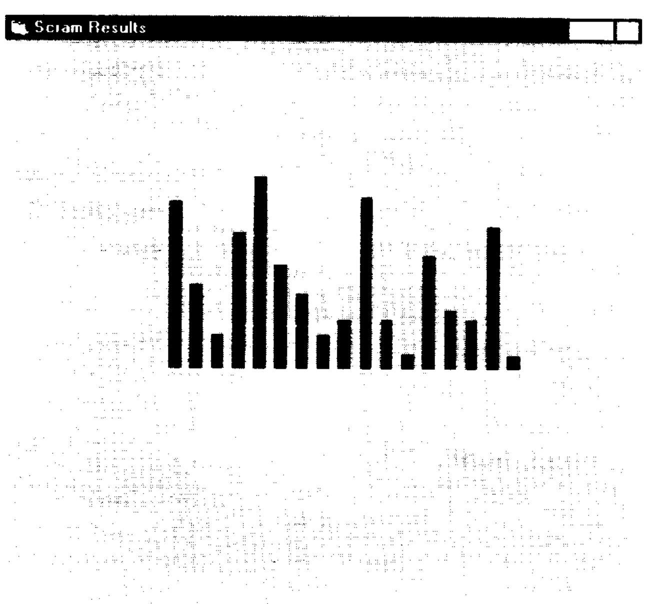
Participating Organizations: Sentel Corporation (J. Neidercorn) and Optimus Corporation (E. Adolphe)

Process Analysis and Modeling: Schedule/Cost Risk Analysis and Management System

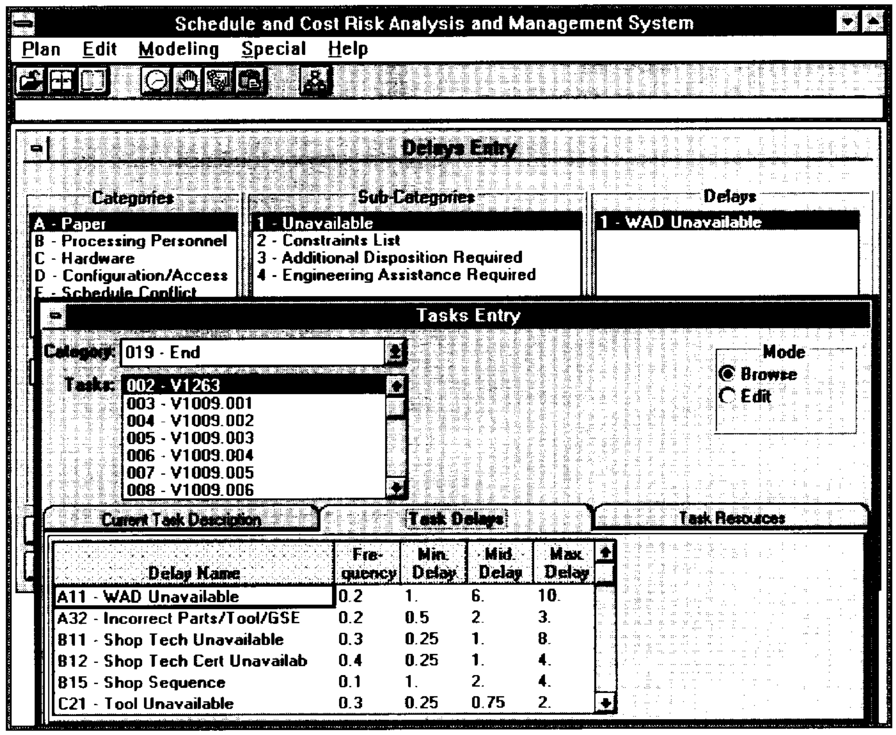
The Schedule/Cost Risk Analysis and Management (SCRAM) system is an innovative system for schedule and cost-risk analysis of Shuttle ground processing. SCRAM was developed under a Small Business Innovation Research (SBIR) contract. The SCRAM system includes a variety of unique features derived from KSC operational needs, including the capability for the analyst to explicitly model and evaluate specific drivers to the uncertainty in an overall project schedule and budget. For Shuttle processing, the major function of the system is to evaluate the types of delays having the most impact on KSC ground processing schedule length and cost, based on actual delay data collected by technicians in a shop floor data collection system.

The SCRAM system has three components: a risk analysis module, a schedule module, and a system executive. Existing commercial software was used wherever possible to maximize the efficiency of the development process. The risk analysis module is based on Lumina Decision Systems' Analytica product, and the schedule module is based on Advanced Management Solutions' Schedule Publisher product. SCRAM is a significant improvement in state-of-the-art schedule and cost-risk analysis tools because it allows realistic models of schedule variables (e.g., task lengths) to be built and analyzed. Existing project risk analysis tools provide only constrained and limited modeling capabilities. Although SCRAM was designed for Shuttle ground processing, it is also applicable to any complex schedule/cost-risk analysis task and has substantial commercial potential.

The second phase of the project focused on developing a PC-based SCRAM system to expand the capabilities of the Macintosh-based system built in 1994. The PC-based system provides seamless integration between the three modules and allows the analysis of schedules containing large numbers of activities. The prototype SCRAM software was applied to a portion of KSC ground processing activities in early 1996. Example input and output screens from the PC-based SCRAM system are shown in the figures. The software development was completed in April 1996, and KSC industrial engineers are evaluating the tool for additional risk analysis applications.



Task Importance Ranking



Task and Delay Data Input Screen

Key accomplishments:

- 1992: Award of the SBIR Phase I contract.
- 1993: Completion of the Phase I feasibility study and SCRAM prototype.
- 1994: Research, design, and implementation of a resource-constrained criticality algorithm. Completion of the Macintosh-based SCRAM system.
- 1995: Successful application of the SCRAM system to a complex scheduling situation, the Integrated Work Control System (IWCS) project plan. Completion of the basic PC-based SCRAM system.
- 1996: Completion and delivery of the PC-based SCRAM system.

Key milestones:

- 1997: Evaluation of the SCRAM system for International Space Station applications. Commercialization of SCRAM capabilities with Advanced Management Solutions.

Contact: T.S. Barth, PZ-A1, (407) 861-5433

Participating Organization: Lumina Decision Systems (R. Fung and M. Henrion)

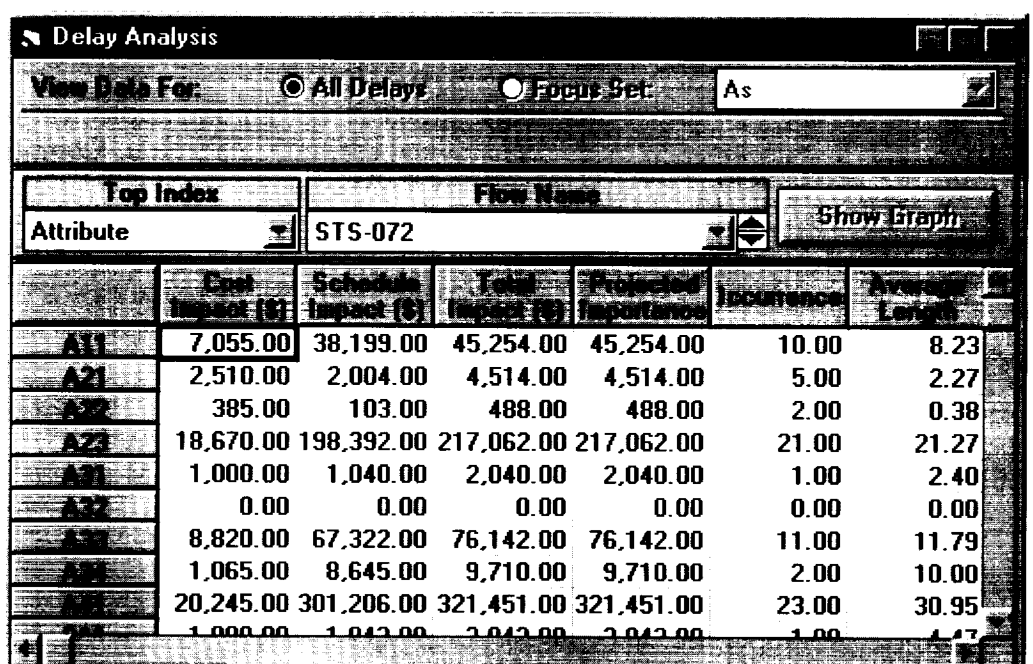
Process Analysis and Modeling: Process Analysis Support System

The Process Analysis Support System (PASS) was developed to analyze proposed process improvements based on needs identified in KSC Shuttle operations. The function of the system is to support analysts during the critical tasks of identifying specific process areas needing improvement and evaluating alternative process improvements (with respect to the identified process areas) against a given set of decision criteria (e.g., reduced cost and reduced frequency or duration of delays).

PASS was developed as one task in a 2-year Phase II Small Business Innovation Research (SBIR) contract. PASS was conceived as a spinoff of the Schedule/Cost Risk Analysis and Management (SCRAM) system described in a separate article in this annual report. The intent of PASS is to provide users with support for process analysis tasks downstream of SCRAM and to approximate several of the key calculations in SCRAM with fewer input data requirements.

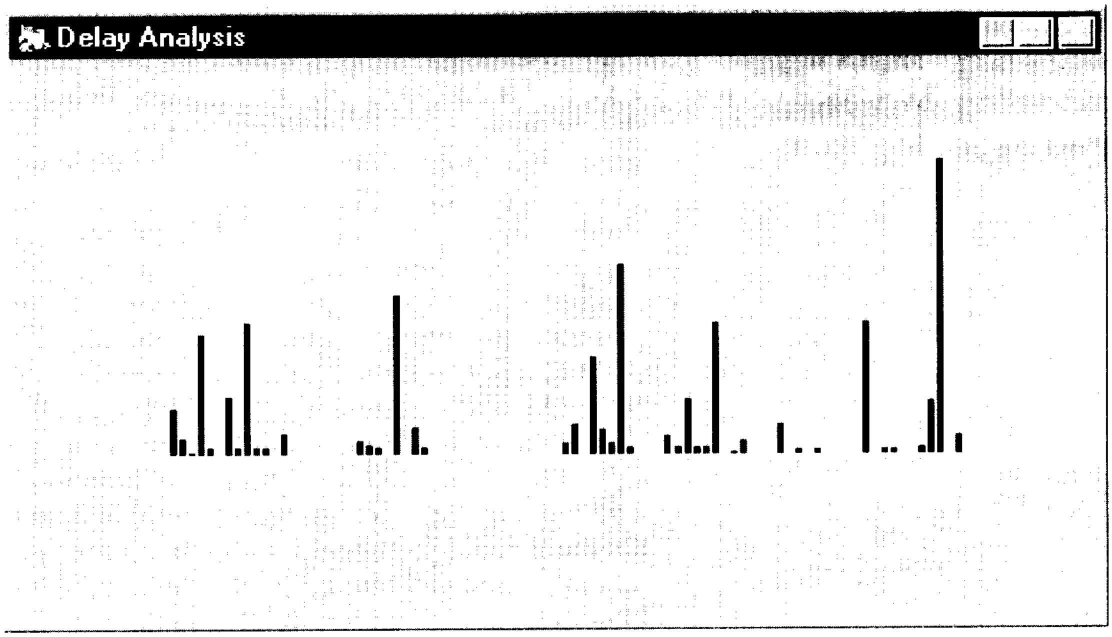
Measuring the importance of delay types to overall project schedule and cost risk is an important first step in the process of conducting a specific type of process analysis in Shuttle operations. Once the delay importances are understood, the major steps required to complete the process analysis are to: (1) understand the root causes of the delays, (2) design alternative process improvements for reducing (or eliminating) the identified root causes, and (3) evaluate the alternative improvements against a set of decision criteria.

PASS is designed to support these steps in a process analysis and improvement effort. Existing methodologies for root cause analysis (e.g., fishbone diagrams) provide extremely



	Cost Impact ($)	Schedule Impact ($)	Total Impact ($)	Projected Importance	Occurrence	Average Length
A11	7,055.00	38,199.00	45,254.00	45,254.00	10.00	8.23
A21	2,510.00	2,004.00	4,514.00	4,514.00	5.00	2.27
A22	385.00	103.00	488.00	488.00	2.00	0.38
A23	18,670.00	198,392.00	217,062.00	217,062.00	21.00	21.27
A31	1,000.00	1,040.00	2,040.00	2,040.00	1.00	2.40
A32	0.00	0.00	0.00	0.00	0.00	0.00
[illegible]	8,820.00	67,322.00	76,142.00	76,142.00	11.00	11.79
[illegible]	1,065.00	8,645.00	9,710.00	9,710.00	2.00	10.00
[illegible]	20,245.00	301,206.00	321,451.00	321,451.00	23.00	30.95

Delay Analysis Table With "Attribute" as Top Index



Delay Analysis Graph

limited support for careful, consistent evaluation of the relative strengths of cause-effect relationships and the tradeoffs between decision criteria. PASS employs recent developments in decision theory to provide these capabilities.

PASS development was initiated in June 1995, and the system design and initial prototype were completed by the end of the same year. Example output screens from the prototype are shown in the figures. The PASS concept can be applied to a wide variety of process analysis and improvement efforts in NASA. PASS is anticipated to have significant potential for applications in other industries and Government agencies.

Key accomplishments:

- 1995: PASS concept, design, and successful completion of the initial prototype.
- 1996: Delivery of a functional prototype and completion of a KSC case study. Generalization of results for advancing root-cause analysis technology.

Key milestones:

- 1997: Application of PASS in Shuttle operations. Investigation of feasibility of incorporating PASS algorithms in the Shop Floor Modeling, Analysis, and Reporting Tool (SMART).

Contact: T.S. Barth, PZ-A1, (407) 861-5433

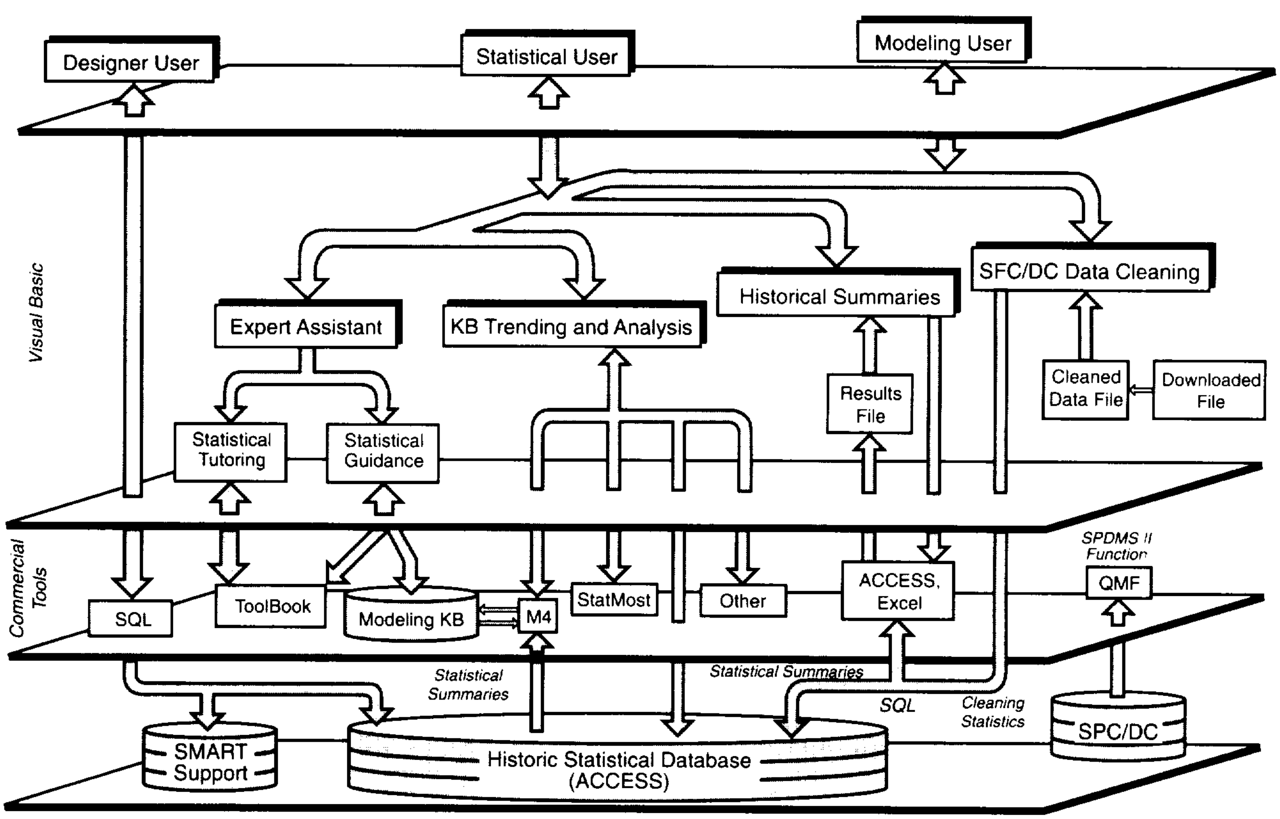
Participating Organization: Lumina Decision Systems (R. Fung)

Process Analysis and Modeling: Shop Floor Modeling, Analysis, and Reporting Tool

This applied research effort uses Shop Floor Control/ Data Collection (SFC/ DC) system data for modeling activities related to Shuttle ground processing. The Shop Floor Modeling, Analysis, and Reporting Tool (SMART) framework relies on knowledge derived from SFC/DC data and other operational procedures. Derived knowledge will become part of a knowledge base managed through an M4 application, whereas operational characteristics are part of a relational database managed through a Microsoft ACCESS application.

The figure "Smart Framework" depicts the various modules of SMART. Numerous commercial tools are being integrated through a customized user interface written in Visual Basic. SMART collects statistical information regarding work time, delay duration, and other relevant historical summaries for future inferential analysis. This information is kept in the historic database per processing cluster (see the figure "SFC/DC Data Clustering Hierarchy"). These clusters are established according to the various stages of the Shuttle processing flow. A knowledge-based trending and analysis module will utilize several data mining techniques to synthesize trends in the historic behavior of certain measures of interest. Such trends will also become part of the knowledge base and/or part of the historic database.

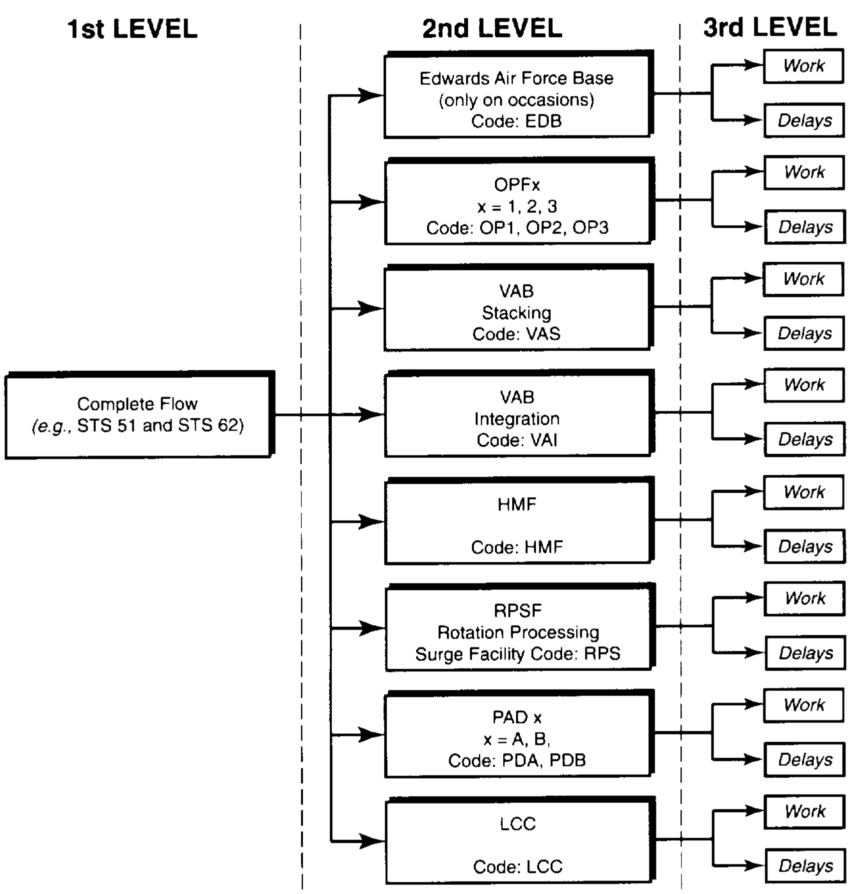
The various capabilities of SMART have been conceived to accommodate the data modeling



SMART Framework

needs of three types of users: (1) a designer user who interacts with SMART through the various commercial tools integrated under it to modify the structure of the support and historical databases and to develop new "canned" reports and new data entry forms, (2) a statistical user who becomes a "student" of SMART (to learn about statistics) or an engineer who needs descriptive and inferential summaries, and (3) a modeling user who uses preset procedures in conjunction with customized ones to support a new modeling activity, such as risk analysis or process simulation.

SMART obtains inputs from the SFC/DC system indirectly. Data from SFC/DC is downloaded from a mainframe using a query language, and the resulting table is moved to a personal computer file so SMART can process it for completeness and usefulness. SMART will enable analyses supporting planning and decision-making. Various studies of SFC/DC data have yielded rules used by the current prototype to ascertain whether a record is complete and statistically useful. If the record is incomplete, the current prototype can repair the record based on the actual number of the work authorization document associated with the record. If the record is complete, SMART checks it to decide whether the record can be used in statistical analysis.



SFC/DC Data Clustering Hierarchy

Key accomplishments:

- 1993: Understanding of the accessibility of the SFC/DC database and its completeness. Specific data extraction protocols were implemented.
- 1994: Prototyping of a data exchange interface to feed spreadsheet templates and the Schedule/Cost Risk Analysis and Management (SCRAM) system.
- 1995: Design and implementation of a SMART prototype using Visual Basic in conjunction with ACCESS. Record assessment capability was enhanced to handle SFC/DC data for purposes other than those set by SMART and SCRAM.
- 1996: Various statistical models were added to SMART and data mining techniques were reviewed. Autonomous statistical interpreter and statistical tutorial were designed.

Key milestones:

- 1997: SMART prototype beta testing at KSC. Implementation of a data mining methodology and autonomous interpreter of statistical analysis. Incorporation of additional modeling capabilities.
- 1998: System delivery to KSC.

Contact: A.M. Mitskevich, PZ-A1, (407) 861-5433

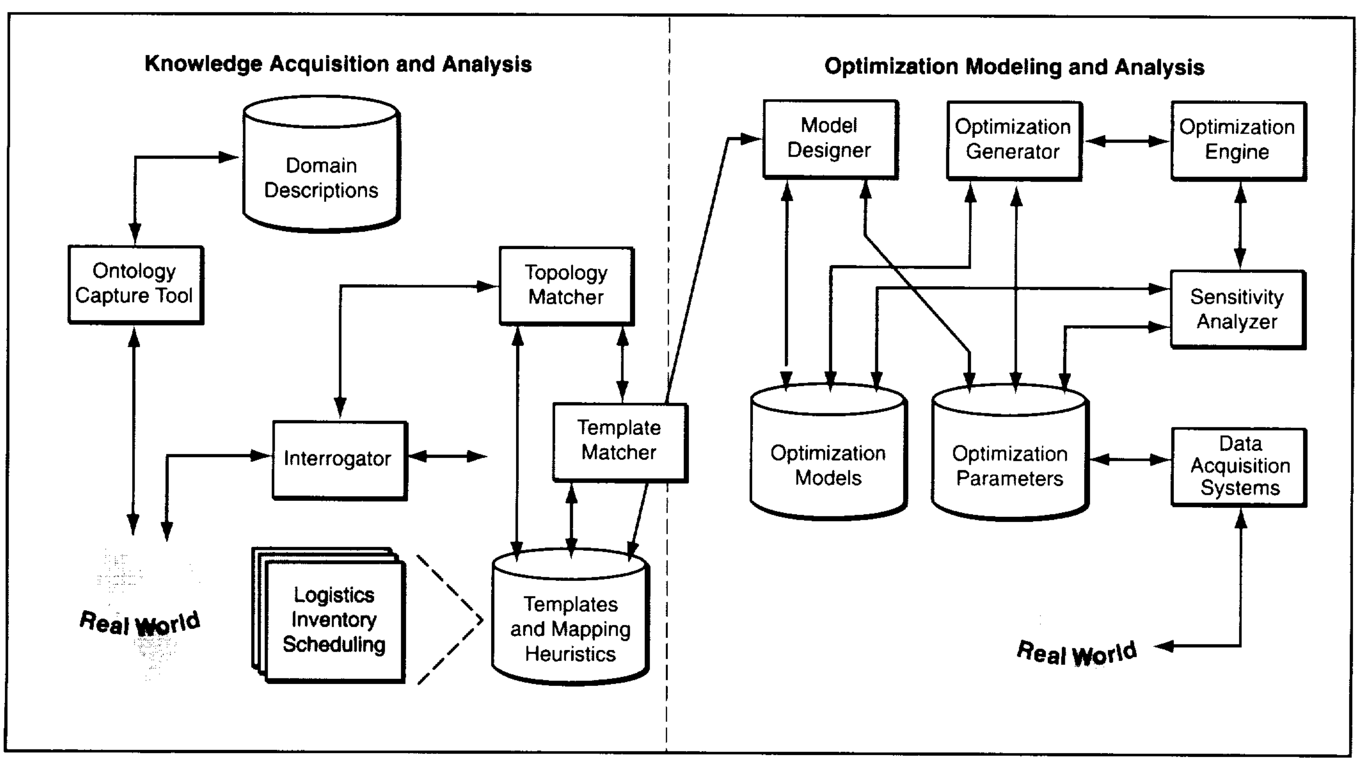
Participating Organization: Florida International University (M. Centeno)

Process Analysis and Modeling: Intelligent Assistant for Optimization Modeling

The versatility of optimization modeling has established it as a popular decisionmaking aid over the last 40 years. Optimization encompasses a suite of powerful decision support paradigms that enable modeling any decisionmaking environment in terms of the objectives, decisions influencing the objectives, and constraints binding the decisions. The potential of these powerful techniques, however, has remained largely unharnessed due to the following inherent difficulties in constructing optimization models:

- Optimization models typically address aspects of the domain often hidden or invisible to casual observers.
- Highly specialized skills are required to design and generate executable models.
- Optimization-based decision support systems typically depend on building custom solutions for different domain situations.
- A shortage of tools exists to leverage the expertise of domain experts.

Preliminary research to alleviate these difficulties was conducted under a Phase I Small Business Innovation Research (SBIR) contract. This effort is a prototype implementation of the Optimization Modeling Assistant (OMA). Several key Phase I objectives were realized during this initial effort. The research team developed a structured method of optimization model development and created a structured, ontology-based method for knowledge acquisition and analysis. Another primary objective was to de-



Conceptual Architecture of OMA

velop a set of heuristics, principles, and rules that encapsulate optimization knowledge and form the knowledge base that assists in optimization model development. Templates were created by researchers that encapsulated the knowledge of optimization modeling paradigms for both application-specific and generic modeling.

A concept of OMA operation and architecture (see the figure), in addition to the prototype implementation, was established during the Phase I research. Follow-on research will consist of activities leading to the full commercialization of the OMA in Government and commercial sectors.

Key accomplishments:

- 1996: Completion of Phase I SBIR contract. Development of the prototype OMA. Selection for Phase II follow-on research.

Key milestones:

- 1997: Refine and extend the OMA templates and refine and harden the intelligent optimization model design knowledge base.
- 1998: Design and build a demonstration version of the OMA and test and validate the OMA with KSC applications.
- 1999: Target commercialization of the OMA in various commercial sectors as well as Government agencies.

Contact: T.L. O'Brien, PZ-A1, (407) 861-5433

Participating Organization: Knowledge Based Systems, Inc. (Dr. P.C. Benjamin)

Processing Analysis and Modeling: Orbiter Ground Processing Workflow Profile Model for Predictive Performance-Based Measurement

In early 1994, KSC industrial engineers initiated a project to identify orbiter processing trends through the analysis of Orbiter Processing Facility (OPF) work processing documentation activity. Analyses focused on assessing the number of planned and unplanned work authorization documents (WAD's) being generated for current orbiter flows and comparing them to available historical data. During the next year, the following observations were made and considered significant:

- The daily count of open OPF planned WAD's during an orbiter flow historically follows a fairly consistent linear profile, indicating relatively routine planned WAD processing.
- The daily count of open OPF unplanned WAD's historically fits the profile of a cubic polynomial curve with an exponential damping factor, characterizing inconsistent but predictable unplanned WAD processing.

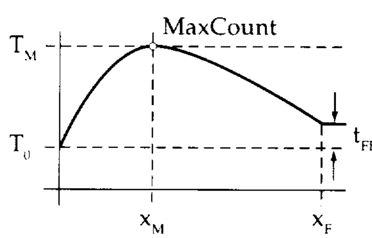
The latter observation proposed the idea that the flow of unplanned orbiter tasks through the OPF could in fact be predictable within a reasonable degree of certainty. Based on these observations, a Hewlett-Packard 48SX scientific calculator was used for initial development and testing of an empirical model for the daily count profile of OPF open unplanned WAD's generated during orbiter processing. The resulting equation for the profile curve was derived through visual inspection and numerical analyses of the WAD count data from previous flows. The equation is shown in the figure "Equation Derived for the OPF Open Unplanned WAD Count Profile Model." The model was subsequently implemented in a spreadsheet and enhanced for operational use.

Several profile curve forecasting approaches were tested using standard polynomial and logarithmic trend lines, recognizing that an accurate forecast of the maximum WAD count day and value would determine the parameters for the equation defining the shape of the profile curve. It was later determined that none of the standard trend lines would adequately forecast the maximum WAD count day and value during the first few weeks of an OPF flow. Consequently, the daily WAD count change rate was evaluated against the empirical first derivative (slope) of the equation for the profile curve. This model-based trend line analysis was successfully added to the forecasting approach to drive a least-squares fit of the model curves against their corresponding data profiles. The analyses were completed by calculating multiple least-squares fit profile curves based on cumulative data for each successive week of the OPF flows. Examples of the spreadsheet interface and a profile curve are shown in the figures "Microsoft Excel 5.0 Interface" and "Example Profile Curve." The resulting profile curves characterized the WAD count data with fit correlations consistently greater than 90 percent.

Key accomplishments:

- 1994: Completed initial data analyses and findings.
- 1995 to 1996: Successfully profiled 16 OPF flows, including STS-65 to STS-68 and STS-71 to STS-82.

Daily Count Function: $T_x = (A \cdot x \cdot (x^2 - x_F^2) - t_F) \cdot e^{-(B \cdot x)} + T_0 + t_F$



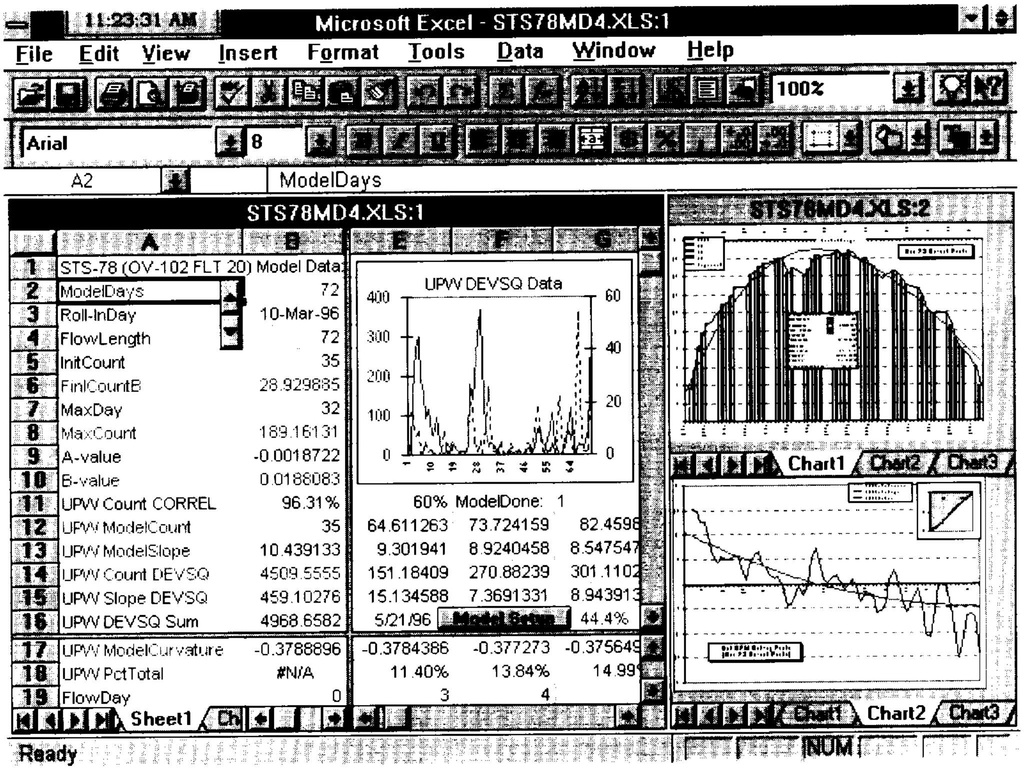
T_x = ModelCount
x = FlowDay
T_0 = InitCount
t_F = FinlCount
x_F = FlowLength

A = MagnitudeFactor
B = DampingFactor

$$B = \frac{A \cdot (3 \cdot x_M^2 - x_F^2)}{A \cdot x_M \cdot (x_M^2 - x_F^2) - t_F}$$

x_M = MaxDay

Equation Derived for the OPF Open Unplanned WAD Count Profile Model



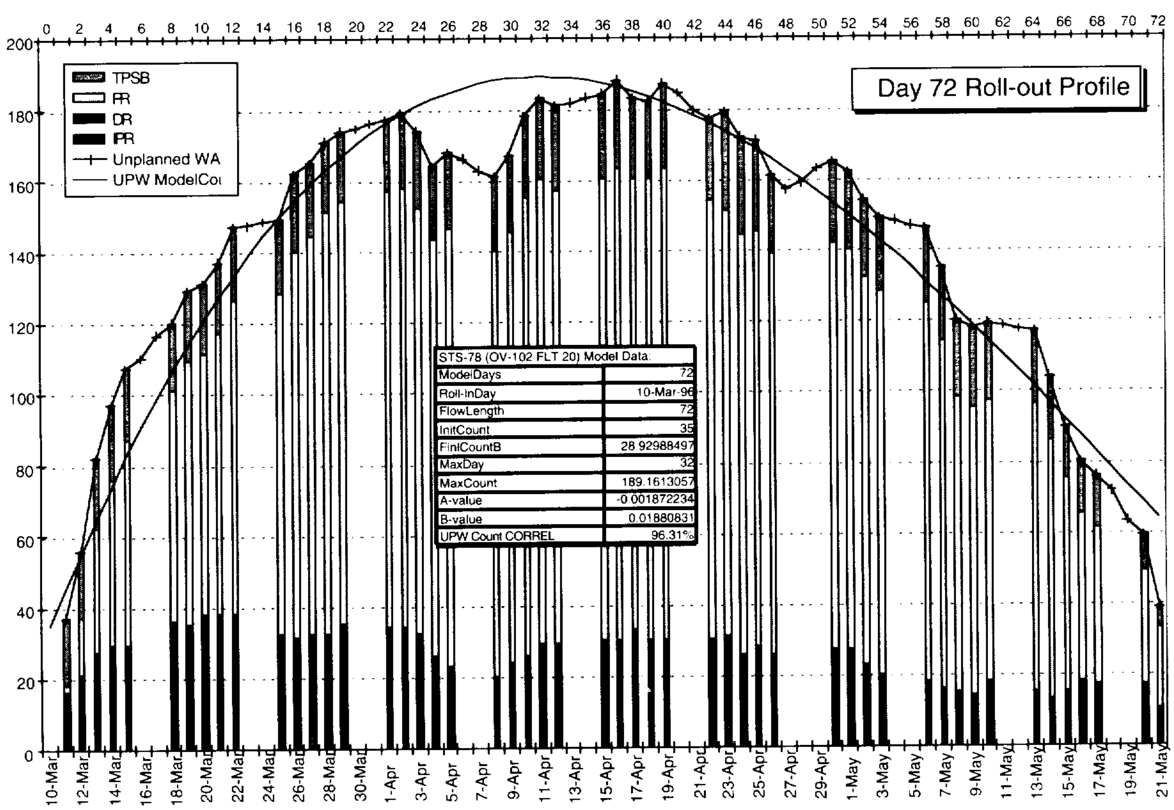
Microsoft Excel 5.0 Interface

Key milestone:

- 1997: Evaluate profile modeling approach for use in developing Shuttle ground operations performance-based measurements.

Contact: T.S. Barth, PZ-A1, (407) 861-5433

Participating Organization: United Space Alliance (S.H. Levels)

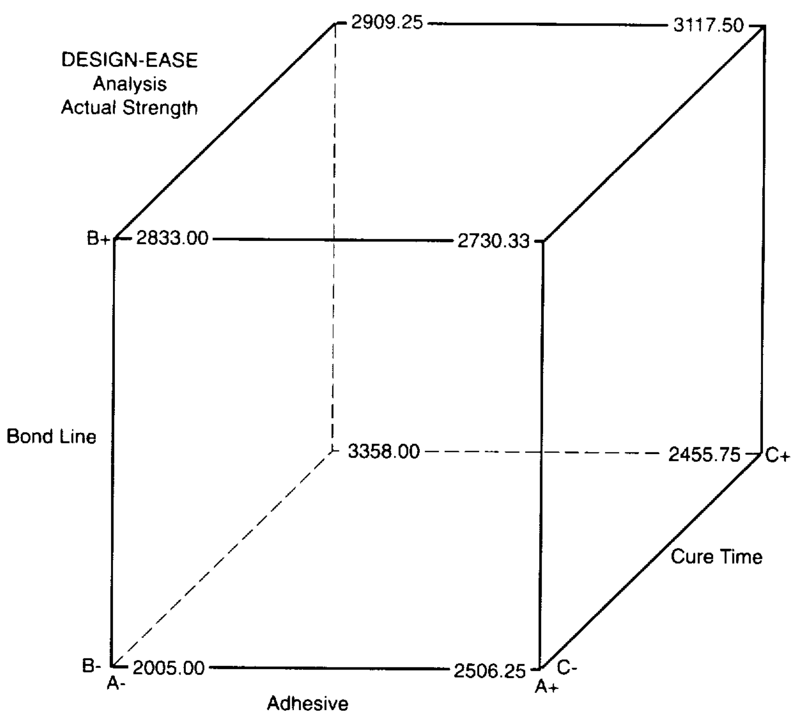


Example Profile Curve

Process Analysis and Modeling: Variable-Form Data Analysis

Variable-form data elements collected during the performance of Space Shuttle ground processing operations are used primarily for real-time control and to ensure functional conformance to specifications. These data elements are also useful in statistical analyses related to quality improvement of processing operations. Process improvement analysis requires the use of statistical process control procedures and enables statistically designed experiments for process changes.

During 1996, one of the project activities focused on the design, conduct, and analysis of sequential multifactor experiments to determine the relationship of factors influencing orbiter structural bond strength. These experimental results are being used to determine potential process changes to reduce the rework associated with bond pull-test failures. The figure "Two-Way Interaction of Structural Bending Process Parameters" shows the improvement in bond strength that can be obtained by changing two of the key process parameters, the bond dwell time and the drying method. The figure "Three-Way Interaction of Additional Structural Bonding Process Parameters" shows the interaction between three additional factors. Based on these experimental results, it appears cost-effective process changes can significantly improve the capability of this specific bonding process (resulting in significant labor and material cost savings).

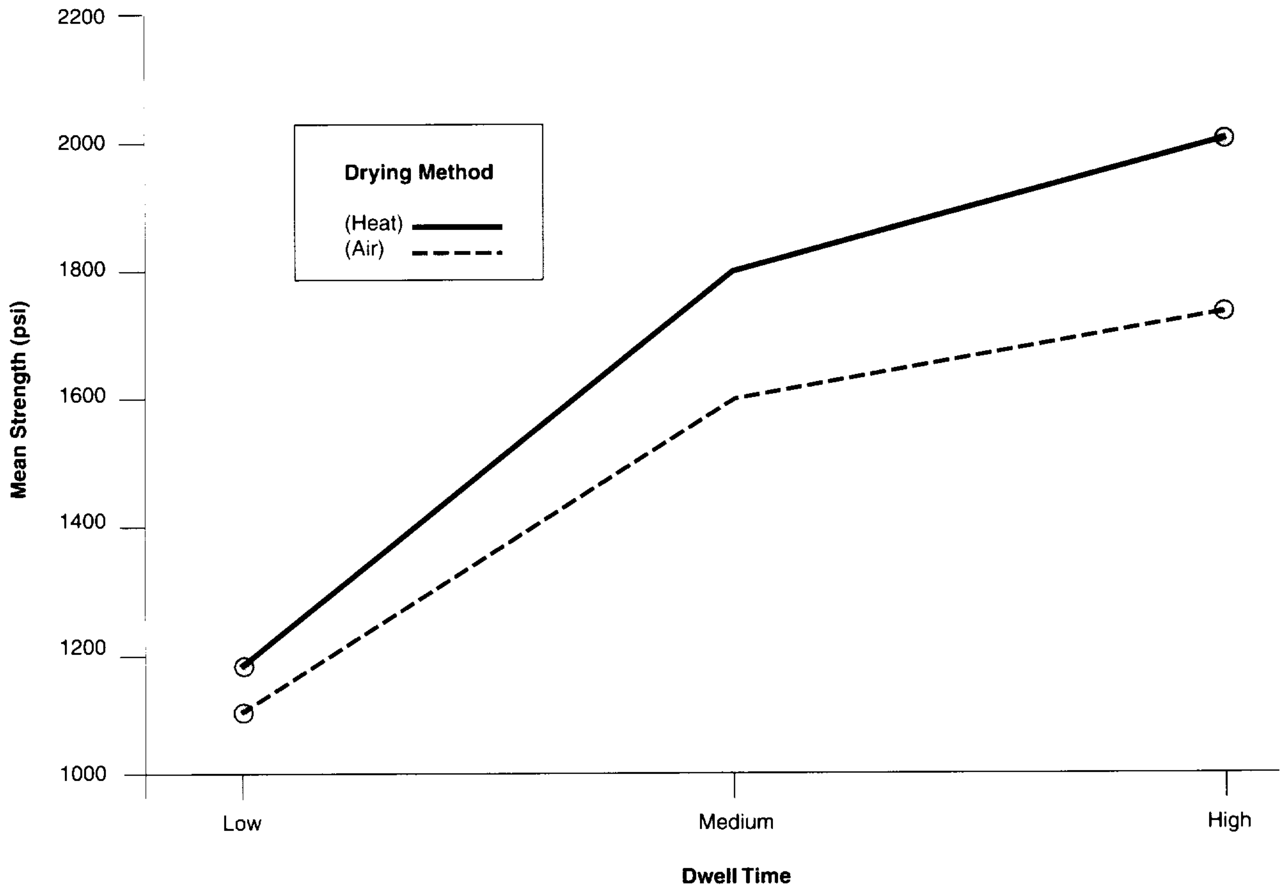


Three-Way Interaction of Additional Structural Bonding Process Parameters

Another major area of project activity involved attending Orbiter Maintenance Requirement Specifications (OMRS) scrub reviews to determine if variable-form data analysis could enhance the process for systematically reviewing and refining Shuttle testing requirements. Data from the scrub reviews was assembled for developing a prototype "general testing philosophy" for systematically incorporating variable-form data collection and analysis in many ground processing activities.

Key accomplishments:

- 1994: Completion of variable-form data collection and analysis on two Thermal Protection System processes. Estimated savings associated with process changes were



Two-Way Interaction of Two Structural Bonding Process Parameters

approximately 200 direct labor hours per processing flow (plus reductions in support labor hours and material costs).

- 1995: Statistical process control procedures were applied to variable-form data from several additional orbiter systems and support processes. Collaboration with USBI for analysis and improvement of solid rocket booster processes resulted in additional savings. The orbiter structural bonding process improvement activity was initiated. Phase I experimental analyses of factors related to bond strength were designed and performed.
- 1996: Phase II of structured experimentation supporting orbiter structural bonding process improvement was completed. A sample of OMRS scrub activities was reviewed to identify additional candidate variables for analysis in quality improvement activities.

Key milestones:

- 1997: Implementation of structural bonding process improvements and measurement of the effectiveness of process changes. Refinement of a prototype "general testing philosophy," which incorporates the principles of statistical process control in Shuttle test and checkout.

Contact: T.S. Barth, PZ-A1, (407) 861-5433

Participating Organizations: University of Central Florida (Y. Hosni and R. Safford), Embry Riddle Aeronautical University (D. Osborne), and United Space Alliance (J. Caratelli and W. Wendorff)

Process Analysis and Modeling: Statistical Process Control for KSC Processing

The use of statistical process control (SPC) at KSC was the focus of this research effort as part of the 1996 NASA/ASEE Summer Faculty Fellowship Program. The research included the following tasks:

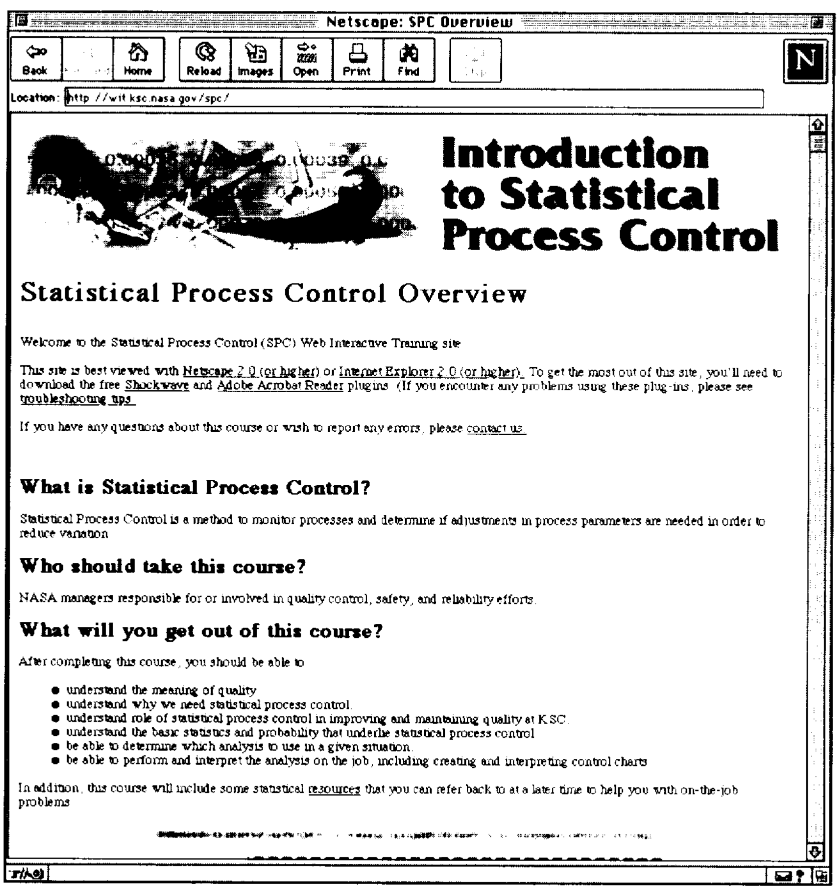
- Developing and teaching a customized KSC Statistical Process Control course for the Safety and Mission Assurance (S&MA) Trend Analysis Group and others

- Developing an Internet version of the SPC course

- Evaluating the application of SPC to present and future Shuttle processing activities

- Evaluating SPC software packages for S&MA use

- Becoming familiar with the people, terminology, and procedures involved in Shuttle processing; and intoducing the types of data gathered in the course of a Shuttle processing flow



The Internet version of the SPC course is entitled "Introduction to Statistical Process Control." The course is accessible at http://kosh/spc. Example SPC analyses are shown in the two graphs, which represent an attribute chart of lost-time case frequency and a variable chart of the performance of solid rocket booster thermal ablative material.

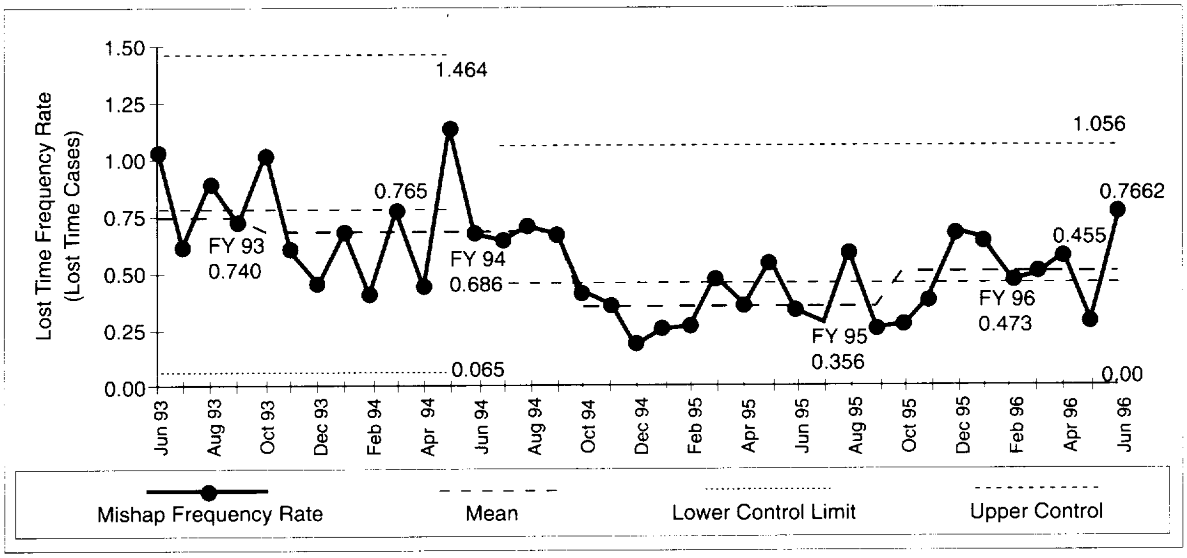
The types of management decisions that can be supported with SPC analysis results are (1) to optimize the use of resources; (2) to eliminate, correct, or reduce inspections (material qualifications, test specimen preparation, correlation with weather data, consistent employee procedures, etc.); (3) to reduce manpower requirements; and (4) to support risk assessments.

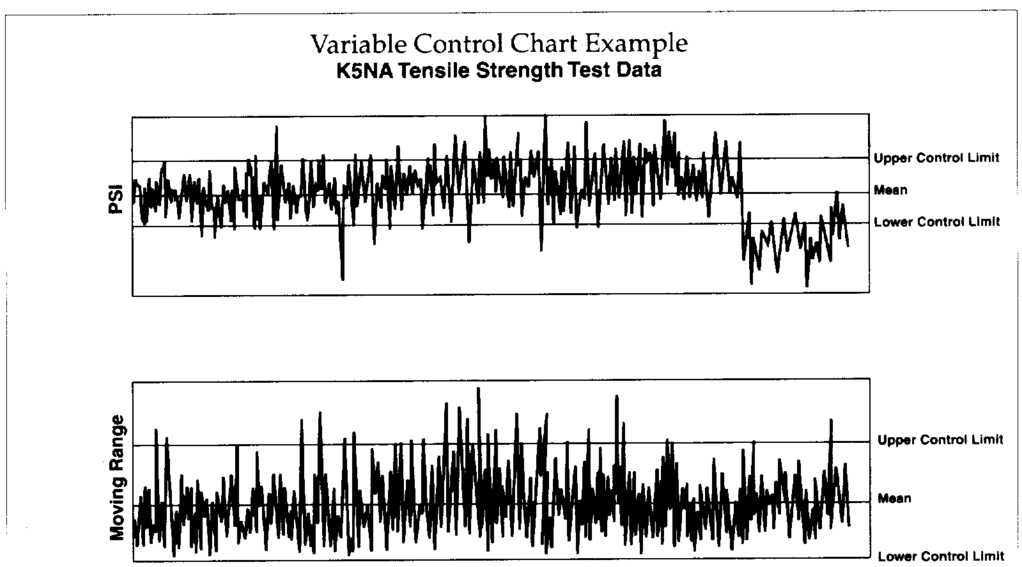
Key accomplishment:

- 1996: Completion of Summer Faculty Fellowship Program.

Key milestone:

- 1997: Continued investigation of SPC applications at KSC.





Contacts: R.W. Tilley, EI-F-C, (407) 867-3480, and H.N. Delgado, EC-E, (407) 867-3473

Participating Organization: Saint Mary's University (R. Ford)

Process Analysis and Modeling: Ground Processing Scheduling System (GPSS)

The GPSS is an artificial intelligence-based scheduling tool developed to support the complexity and dynamics associated with the scheduling of Space Shuttle ground processing at KSC. The GPSS is currently in use as the primary scheduling tool for the Orbiter Processing Facility (OPF). Scheduling in the OPF demands the integration of the processing requirements for the major orbiter systems with (1) a majority of the processing worked in parallel; (2) temporal, configuration, and resource constraints associated with each system's supporting tasks; (3) frequent rescheduling in response to unexpected events; and (4) the need for timely communication of schedule information.

In order to meet the Shuttle processing scheduling challenge, the GPSS development team has successfully used NASA inter-center expertise, dedicated user support, and a rapid development approach. The initial scheduling algorithms were developed by NASA Ames and introduced to KSC where a joint NASA and Lockheed Martin Space Operations Company team expanded and integrated the system with an advanced user interface. The GPSS constraint-based algorithms have been developed to model the temporal, configuration, and resource constraints of each processing activity to be scheduled; to perform schedule conflict resolution; and to respond with schedules containing minimal constraint violations. The user interface has been developed with advanced interactive capabilities that allow the users to manipulate the schedule model and provide the necessary output for decision support.

The GPSS activity supports the NASA research and technology development goals for technology transfer. The development software was licensed to an independent software company that has successfully developed and marketed the first commercial version of the software. KSC looks forward to future licensing arrangements with other commercial parties interested in developing and marketing commercial applications. In order to support other technology exchange programs, the assessment and extension of GPSS functionality was the focus of a NASA/ASEE Summer Faculty Fellowship project this year at KSC.

The re-engineering of the GPSS development code and integration of the GPSS with the Shuttle Operation's Integrated Work Control System (IWCS) is continuing, and expansion of the GPSS to scheduling activities at the Vehicle Assembly Building (VAB) and the launch pads is in work.

Key accomplishments:

- 1989: Initial introduction of the GPSS project to KSC.
- 1990 to 1991: Prototype system and initial OPF knowledge-base development.
- 1992: OPF schedules produced for Space Shuttles Columbia and Endeavour via operational testing.

- 1993: Schedule compression and conflict resolution capabilities incorporated within the test-bed system. Scheduling activity supported for all OPF processing. GPSS team received the Space Act Award. GPSS software licensed for commercial development.
- 1994: Validation, acceptance, and implementation of the development version of the GPSS.
- 1995: Functional application within the IWCS.

Key milestones:

- 1996 to 1997: Complete re-engineering of the GPSS to a C++ version. Establish working interfaces with the scheduling and engineering databases. Implement the GPSS for scheduling at the VAB and launch pads. Initiate GPSS performance enhancements.

Contact: N.M. Passonno, PK-D2, (407) 861-6677

Participating Organization: Lockheed Martin Space Operations (D. Kautz)

Process Analysis and Modeling: Advanced Shuttle Scheduling Technologies — Scheduling System Assessment and GPSS Enhancement

The Ground Processing Scheduling System (GPSS) was the focus of a 1996 NASA/ASEE Summer Faculty Fellowship project. The summer research project consisted of two tasks related to the GPSS: (1) assessment of a commercial product derived from the GPSS and (2) assessment and enhancement of the GPSS algorithms.

The GPSS code was licensed to an independent software company that has successfully developed the first commercial product derived from the GPSS. As the first task of this project, the commercial product was assessed for applicability to the Shuttle ground processing scheduling environment. Results of the assessment showed that the commercial product, while appropriate for the targeted manufacturing customers, does not directly apply to the Shuttle scheduling problem. This assessment also provided further support for the work in progress by the KSC development team to continue re-implementation of the GPSS code from the existing Lisp/C structure to a C++ system.

In support of the KSC development team's effort to re-engineer the GPSS code, an independent evaluation of the GPSS scheduling algorithms and system efficiency was performed. A prototype of an improved deconfliction algorithm was completed and will provide the KSC team with a more efficient starting point for re-engineering this portion of the code. Evaluation of the code also revealed other areas where system efficiency and functionality could be enhanced. The overall results of the project provided additional insight to support the KSC re-engineering activity, as well as ideas for future research and improvement to the overall system.

Key accomplishments:

- 1996: Completed assessment of commercial product. Completed prototype of GPSS deconfliction algorithm and developed ideas for future system enhancement.

Key milestones:

- 1997: Apply for 1997 Summer Faculty Fellowship Program. Integrate deconfliction and system efficiency enhancements.

Contact: N.M. Passonno, PK-D2, (407) 861-6677

Participating Organization: University of Southwestern Louisiana Center for Advanced Computer Studies (Dr. R. Loganantharaj and B. Thomas)

Environmental Technology

The John F. Kennedy Space Center (KSC) is located on the Merritt Island National Wildlife Refuge. Therefore, KSC has always approached its mission with an awareness of the impact on the environment. As a society, Americans have become increasingly concerned about the effect their actions have on the environment. With this awareness, KSC has increased its efforts to develop technologies that are environmentally oriented and proactive.

The projects presented this year cover a wide range of environmental technologies. Engineers are developing effective methods of cleaning without the use of chlorofluorocarbons. Several development efforts are underway that address the safety and disposal of the hazardous fuels used in launch vehicles and satellites.

Another area of interest is the geographical information required to make environmental decisions. A development is continuing to integrate geographical databases that provide easy access to the data used for planning purposes.

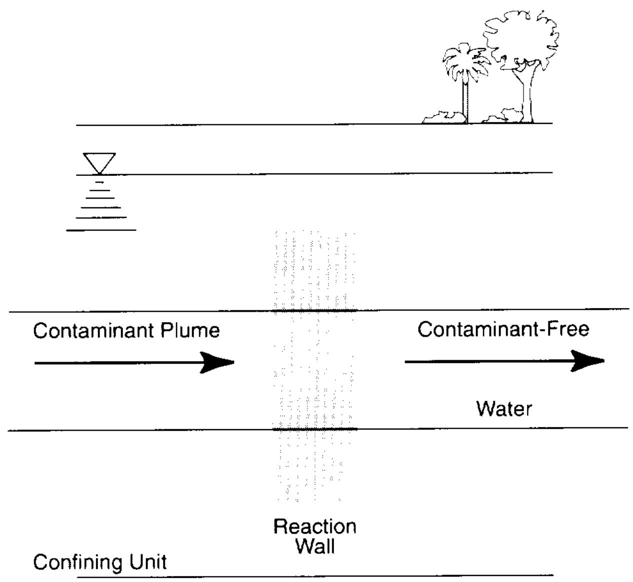
Enhanced In Situ Zero Valent Metal Permeable Treatment Walls

Chlorinated solvents have been widely used by NASA and others in the aerospace industry for over three decades. They have primarily been used as nonflammable degreasers and dryers for electronic parts. Historically, the disposal practices for spent chlorinated solvents have included discharges to surface water and groundwater. It is, therefore, not surprising to find groundwater solvent contamination at 791 of the 1,300 National Priority List sites.

To date, the most commonly used treatment method for the cleanup of chlorinated solvents has been the pump-and-treat method. With this method, the groundwater is pumped to the surface, and the contaminants are either oxidized or removed with an air stripper. Although the pump-and-treat method was originally thought to be a competent remediation tool, it has shown itself to be most effective in groundwater plume capture and containment. In general, it can be said that the significant operation and maintenance costs associated with pump-and-treat systems eliminate this remediation technique for large-scale cleanups.

Within the last 5 years, a substantial amount of research has focused on the use of zero-valent metals to catalytically enhance the abiotic degradation of chlorinated solvents. Of the zero-valent metals available and tested (iron, cobalt, zinc, and nickel prophyrins), iron is the most attractive due to its low cost and availability. With this technology, iron filings are mixed with sand and placed below the land surface and downgradient of the contaminant source. Natural groundwater gradient transports the contaminated groundwater through the iron/sand permeable treatment wall. As the contaminant comes into contact with the iron filings, catalytic degradation of the chlorinated species begins with what appears to be the simultaneous oxidation of iron by water and the subsequent reductive dechlorination of the contaminant.

Ongoing NASA research is investigating the use of sonicated zero-valent metal permeable treatment walls as a remediation technology to clean groundwater contaminated with chlorinated solvents. As an enhancement technique, ultrasound is used within the permeable treatment wall to restore zero-valent metal activity that has deteriorated with time due to precipitation on the metal surface. Batch studies and column studies have shown that a comparison of half-lives of trichloroethene (TCE) suggests the addition of ultrasound to reactors containing iron increases reaction rates more than twofold over the use of iron alone. Scanning electron microscopy has also shown significant calcification on the surface of iron that has been aged in 200-part-per-million TCE for 30 days as compared to unaged iron, and, when exposed to ultrasound, the calcification decreased significantly in size and coverage on the surface.



Permeable Treatment Wall

Key accomplishments:

- June 1996: Batch studies completed.
- July 1996: Column studies began.

Key milestone:

- Kinetic constants are being determined from laboratory column testing and will be utilized in a field scale design to be implemented at NASA's Launch Complex 34 on Cape Canaveral Air Station's property.

Contact: J.W. Quinn, JJ-D, (407) 867-4265

Participating Organizations: University of Central Florida (Departments of Civil and Environmental Engineering and the Department of Chemistry)

Results of Batch Tests Using Iron and Ultrasound

Conditions	g/L Iron	k, min-1	Half-life, hr*
No ultrasound	5	1.5E-5	0.235
Ultrasound introduced initially	5	3.8E-5	0.112
Ultrasound introduced after 14-day TCE exposure	5	3.2E-5	0.132

* Normalized to 1 m^2/mL

Hazardous Waste Minimization Project

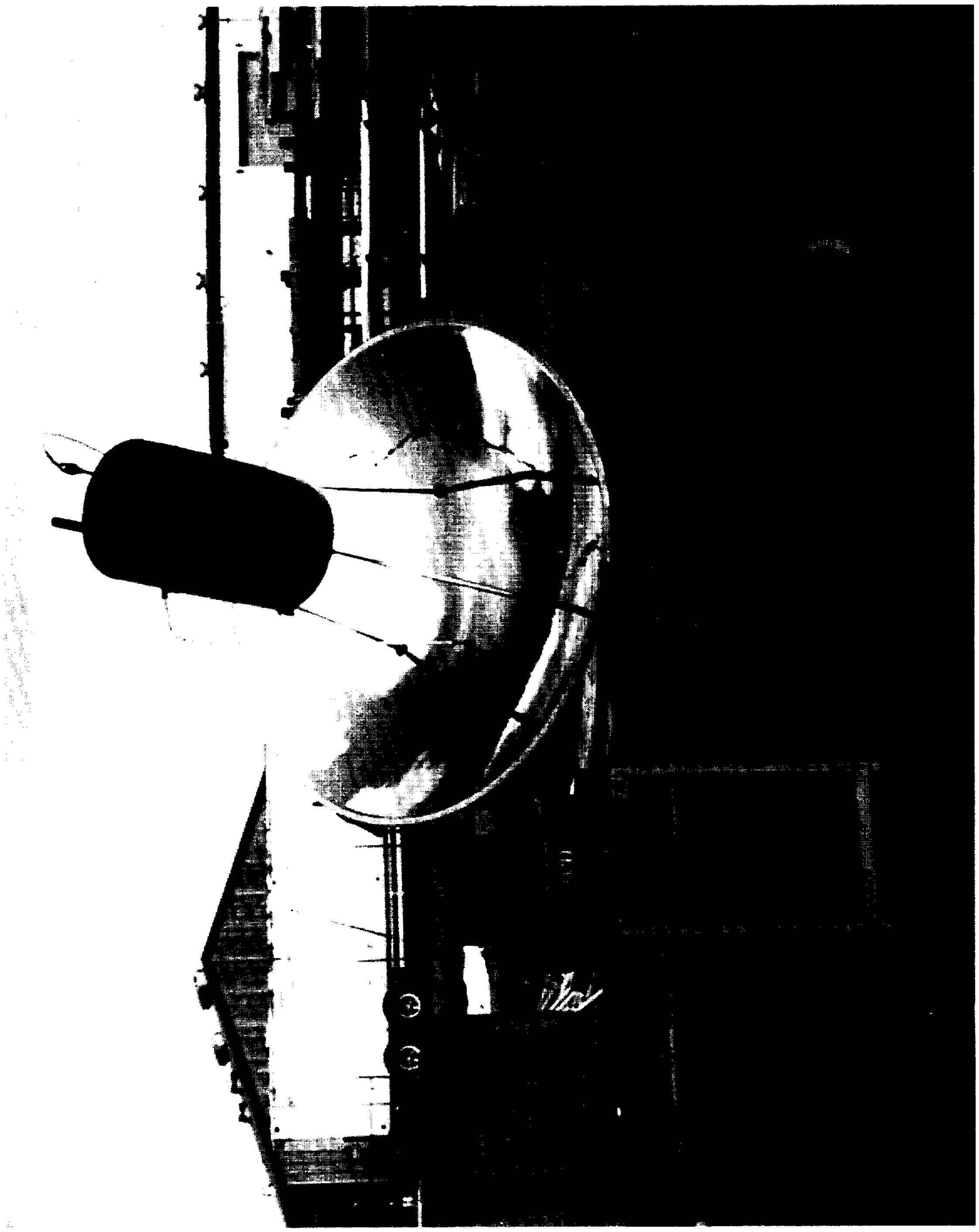
Many hazardous waste streams are generated at KSC by routine operations. They are shipped offsite for treatment and disposal. Reduction in offsite shipment is possible if some onsite evaporation or dewatering system is used to reduce the water content.

To develop such a system, KSC Logistics Operations and KSC Engineering Development Directorates have designed, fabricated, and tested the small system shown in the figure. The system uses a 4.5-foot-diameter paraboloidal reflector and a unique solar evaporator. Preliminary tests with water show that the system can heat the water to its boiling point in about 30 minutes and can boil off 0.33 gallon of water per hour. If solvent CFC-113 is used, the boiloff rate is expected to be about 5 gallons per hour.

A solar tracking unit, supply tank, receiver tank, condenser, and fluid pumping unit will be added to the system. Further tests with water, spent solvent, and oxidizer scrubber liquor will be conducted after this addition is completed.

To develop a field system for the distillation of oxidizer scrubber liquor or recovery of spent solvent (such as alcohol and CFC-113), a 14-foot-diameter paraboloidal reflector has been received. This field system is expected to boil off 2.5 gallons of water per hour or 45 gallons of CFC-113 per hour.

Contacts: F. Lin, LO-MSD, (407) 867-8433; J.F. Poppert, DM-DTL, (407) 867-7287; and C.M. Baker, DM-MGD, (407) 867-7584



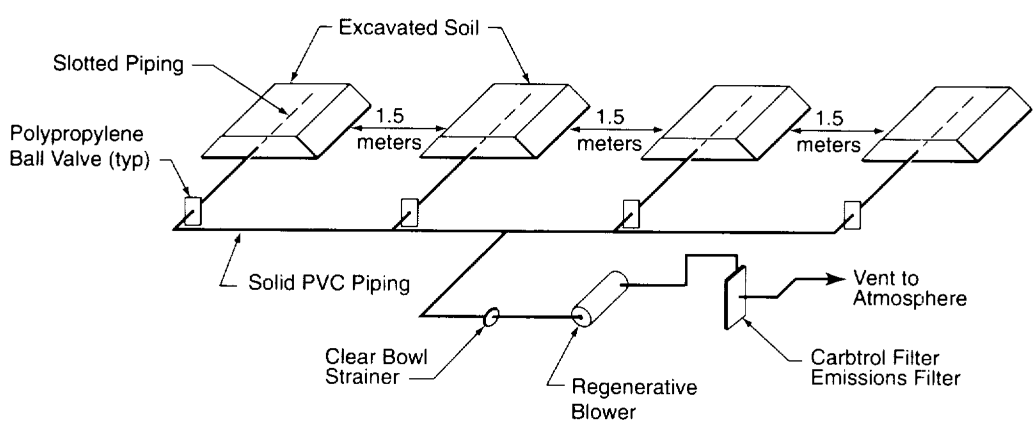
Hazardous Waste Dewatering System

Bioremediation of Diesel-Contaminated Soils Using Biopiles

During construction of a new parking facility at KSC, a construction worker noticed a pungent, diesel-like smell emanating from the soil. The construction site, which was formerly a staging and maintenance area for heavy equipment in the 1960's and 1970's, was determined to have significant soil and groundwater contamination. In an effort to eliminate further leaching of petroleum products (No. 2 diesel fuel) from the soil to the groundwater, the contaminated soils (500 cubic meters) were removed from the site prior to installation of the asphalt surface. Based upon economic considerations, in situ bioremediation through the use of aerated biopiles was the selected remedial action. Alternatives such as thermal treatment were significantly more costly than bioremediation due to high transportation costs.

Biopiles are constructed similarly to windrow composting piles. Long rows of soil, approximately 1.5 to 2 meters in height, are placed on an impermeable barrier and are often covered as well by an impermeable barrier. An irrigation system and ventilation system are typically installed to augment biodegradation and sometimes volatilization. Ventilation systems are installed in a positive or negative pressure mode, depending on air quality requirements for the area. Biopiles are aerated and irrigated with water and nutrients until soils reach clean levels as defined by the regulatory agency (see the figure).

During the course of this remediation study, several parameters were monitored in the laboratory in an effort to prove biotic degradation pathways. Contaminant levels were analyzed weekly, and biological counts of diesel-degrading microbes were performed as well. In addition, biological community patterning, which monitors biological communities via their metabolic responses to a variety of carbon sources, was evaluated as an alternative technique to monitoring biological activity.



Notes:
1. Visqueen and berms not shown in this schematic layout.
2. Minimum 0.3-meter spacing between pile and berm.

Biopile System

Time To Achieve Clean Soil Standards

Pile Number	Time (Weeks)	Initial TRPH Concentration (mg/kg)
1	4	261
2	4 to 5	123
3	12 to 13	3,000
4	12 to 13	1,293

The importance of proving biotic degradation pathways stems from regulatory requirements. At the time of this remedial effort (1994), bioremediation was still considered an innovative technology and was often reluctantly approved by regulators as a remedial technique. For this reason, proving that biotic, as opposed to abiotic degradation mechanisms, were dominant became paramount to the perceived success of the remediation.

In this study, bioremediation using biopiles was determined to be an effective remediation technique. Laboratory testing confirmed that biological degradation was the mechanism responsible for the contaminant reduction. Enumeration counts were up to 20 times greater in the biopiles than in a noncontaminated background soil sample. Biological community patterning was also found to be an effective tool for correlating transitions in the biological community to contaminant degradation. The entire remedial process achieved clean soil [less than 10 milligrams/kilograms total recoverable petroleum hydrocarbons (TRPH)] within 12 weeks at a cost of $50 per cubic meter.

Key accomplishment:

- Achieved clean soil levels within 12 weeks of system activation.

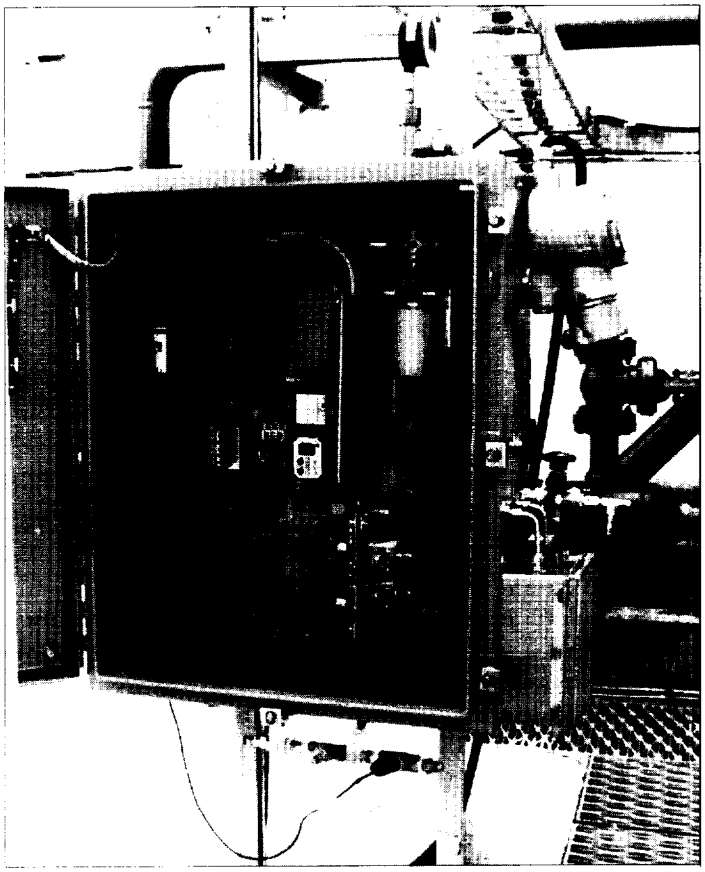
Contact: J.W. Quinn, JJ-D, (407) 867-4265

New Process and Equipment for Waste Minimization: Conversion of Nitrogen Oxide Scrubber Liquor to Fertilizer

This is Phase III of a five-phase project to develop a new scrubber liquor and control system to eliminate the oxidizer scrubber liquor waste stream, improve the efficiency of the current oxidizer scrubbers and lower the nitrogen oxide (NO_x) emissions, and lower the scrubber operating costs. The waste stream will be eliminated by using the oxidizer (nitrogen tetroxide) to produce potassium nitrate, a commercial fertilizer, while lowering the oxidizer emissions. This new scrubber liquor and control system has value to KSC and other users of NO_x scrubbers and will replace the current 25-weight-percent sodium hydroxide scrubber liquor, which is the second largest waste stream at KSC. This project is based on experience gained on the Engineering Support Contract in the development of a new method for monitoring emissions for KSC hypergolic scrubbers and on previous experience that developed uses for pyrotechnic byproducts as fertilizers. This effort conforms to the requirements stated in Executive Order No. 12856 (Federal Compliance With Right-To-Know Laws and Pollution Prevention Requirements, dated August 6, 1993) and Executive Order No. 12873 (Federal Acquisition, Recycling, and Waste Prevention, dated October 20, 1993).

Phase I, the laboratory proof-of-concept study, found that a scrubber liquor based on 1-percent hydrogen peroxide controlled to a pH of 7 with potassium hydroxide would produce the desired product (potassium nitrate) and lower the scrubber emissions. Phase II of this project was conducted at the oxidizer storage farm of Launch Pad 39A. This test demonstrated that the process control system would operate to control the pH and hydrogen peroxide concentration on a full-scale oxidizer scrubber. The test produced 525 gallons of a 4-percent solution of potassium nitrate (which had a pH of 7.9), hydrogen peroxide concentration of 1 percent, and no potassium nitrite.

Phase III redesigned the process control system and housed it in a purged enclosure, which is shown in the figure. The objectives of the field test at the Hypergol Maintenance Facility were to produce potassium nitrate from the scrubbing process, measure the scrubber efficiency, and test the ability of the control system to control the pH of scrubber liquor and the hydrogen peroxide concentration. Samples of the oxidizer scrubber liquor were collected during the test, and the analysis is now in progress. Approximately 800 gallons of potassium nitrate scrubber liquor were prepared during the test. The pH of the scrubber liquor produced during the test was 6.7; however, three drums removed from the scrubber tank near the start of the tests had a pH of 13.3. The efficiency of the scrubber without the aspirators averaged 99.7 percent and ranged from 99 to 99.9 percent; however, with the aspirators, the efficiency dropped to as low as 83.4 percent, but the overall average was greater than 90 percent.



Hydrogen Peroxide Concentration and pH Control System

Two problems were encountered during the test that affected the performance of the control system. First, a large amount of sediment, initially in the scrubber liquor tank, blocked the flow in the scrubber-liquor sampling loop, which caused loss of the pH and hydrogen peroxide control. This sediment appeared to be a mixture of old clay packing used previously in the scrubber towers and sodium carbonate produced when the aspirators push air through the 25-weight-percent sodium hydroxide solution. Once the lack of flow was discovered and the blockage eliminated, the pH controller adjusted the pH back to 7. Second, the metering pumps used in the hydrogen peroxide control system did not operate properly due to the pressure on the suction side. This problem may have been due to the pump design and/or the solids in the sampling loop.

Redesign of the process control system has started with the objective of eliminating the components that caused problems during the field test. Specifically, solutions included the selection of a different pH controller, metering pumps for the hydrogen peroxide system, a filter system in the sample line, and the addition of a flow indicator in the scrubber-liquor sample loop.

Key accomplishments:

- A method to eliminate the second largest waste stream at KSC (oxidizer scrubber liquor waste).
- A new scrubber liquor that improves the efficiency of the oxidizer scrubbers.
- Simplified operation at the oxidizer scrubber that eliminates preparation of the scrubber liquor (since the system starts with water in the scrubber liquor tank and then prepares the liquor as needed).
- Production of potassium nitrate, a fertilizer currently purchased by KSC for use on lawns and citrus groves.
- Demonstration that the process control system worked on full-scale scrubbers.
- The target concentration of potassium nitrate is 10 weight-percent; however, the capacity is only limited by saturation (approximately 24 weight-percent).

Key milestones:

- Phase IV will be an instrumentation development project to produce a fieldable control system to be qualified for use on all oxidizer scrubbers at KSC.
- Phase V will produce and deploy the control system on all oxidizer scrubbers at KSC.

Contacts: R.C. Young, IM-ENV, (407) 867-8295, and D.E. Lueck, DL-ICD, (407) 867-4439

Participating Organization: I-NET, Inc. (C.F. Parrish and R.G. Barile)

Automated Test System for Toxic Vapor Detectors

The NASA Toxic Vapor Detection Laboratory (TVDL) at KSC has been using the Process Control and Data Acquisition System (PCDAS) for about 9 years. This system is used to generate vapors of known concentrations at controlled conditions of temperature and humidity. The PCDAS logs the test conditions and the test article responses in data files for analysis by standard spreadsheets or custom programs.

The PCDAS was originally developed to perform standardized qualification tests and acceptance tests for a commercial off-the-shelf (COTS) toxic vapor detector to replace the hydrazine detectors for the Space Shuttle launch pad. It has since become standard test equipment for the TVDL and is indispensable in producing calibration standard vapor for the new hydrazine vapor monitors at 10-part-per-billion (ppb) concentrations. Recently there have been several requests for information about the PCDAS by other Government laboratories with similar needs, both on and off KSC.

The PCDAS at the TVDL uses COTS vapor standard generators, which have been modified at the TVDL for computer control. In addition, the controllers for dilution flow, temperature, and humidity (FTH) were modified to extend the control range downward to 10-percent relative humidity (RH) and to allow the use of dry dilution air. The modification to extend the RH range involved adding two valves and relays to operate the valves and to disable humidity control when dry air is required. Because the output from the FTH controller is mixed with the toxic vapor standard, the temperature and humidity control loop is closed after the two gas streams are combined in a mixing vessel. The temperature and humidity in the mixing vessel are fed back to a control computer where the control loop is closed. In order to extend the range of environmental conditions available to test, the FTH controllers, sample vessels, and instruments under test (IUT) can be placed into an environmental chamber. This allows tests at temperatures from 0 to 50 degrees Celsius (°C) and RH from 0 to 90 percent, simulating the extremes of conditions likely to be encountered in the environment of the many NASA locations that potentially would use these instruments (Florida, New Mexico, Virginia, California, etc.)

The standard TVDL PCDAS can control two toxic vapor standard generators with three channels each, two FTH controllers, and six toxic vapor IUT's. It can deliver flows from 5 to 50 liters per minute at temperatures from near 0 to 50 °C using an environmental chamber to maintain the sample temperature. The concentration range for toxic vapors depends on the permeation source installed in the generator. Typical vapor concentrations range from 50 parts per million to 5 ppb. The PCDAS can provide closed-loop control of temperature and RH delivered to two sample vessels, typically one for zero gas and one for toxic vapor standard gas.

Two sample vessels, one for zero air and one for toxic vapor sample, are required at very low concentrations to minimize the time required to passivate the sample vessel and tubing that carry the toxic vapor standard.

The PC used to control the PCDAS is a DOS-based 80x86 platform with at least two ISA bus slots available for input and output cards. An analog-to-digital (A/D) input card reads temperatures, humidities, flows, and instrument responses. A digital-to-analog (D/A) output card controls voltage commands to the FTH controller. The D/A card also has digital outputs that control relays to select the on/off state of valves that control gas flow. The PCDAS is programmed in source code so all manipulations of the data can be verified and documented for validation and future reference.

A personal computer was chosen because it is simple and inexpensive, can be procured competitively from many sources, and is supported by a wide range of compiler choices. The Pascal language was chosen for the PCDAS because it is structured, modular, easy to use, easy to maintain, and readable by nonprogrammers. There are very good compilers and software tools available. The program is presently run in a Windows environment. The system user manual is being prepared in Hypertext Markup Language (HTML) with links from the table of contents, table of figures (linked to digital pictures), and index and will reside on the PCDAS computer. Program development, testing, and maintenance are done entirely by TVDL personnel.

Program modules were written and tested separately over a period of time as they were needed for specific project requirements and integrated into a single program. These modules control the toxic vapor generators and the FTH controllers, time the sequence of events, write data to disk files, and evaluate response and recovery times for the IUT as requested by the test engineer. Data from the measured test conditions and instrument responses is logged in readable text files that serve as an electronic strip chart, and instrument responses are recorded on a paper strip-chart recorder as well for setup. All system commands and controls can be recorded to text files if needed to identify causes of unexpected conditions.

The TVDL has four PCDAS's used for standard tests of toxic vapor monitor instruments. A fifth system is being built for Wiltech, the calibration contractor for Shuttle operations, that will be used to calibrate sensors for measurement of hydrazine vapors at concentrations of 10 ppb. The PCDAS's at the TVDL run almost continuously during a project requiring tests and produce data 24 hours a day, leaving the scientists free to do the data analysis and reports. At least two other Government laboratories have expressed an interest in using the automated test capability of the PCDAS's, and one laboratory has requested that NASA build eight similar systems to perform a large qualification test program.

Key accomplishments:

- Performed automated tests of monomethylhydrazine (MMH) and nitrogen dioxide (NO_2) instruments for HVDS II.
- Performed automated tests of portable ammonia instruments for the Space Station Processing Facility.
- Performed automated tests of instruments for PFVD-10 at 10-ppb hydrazine.
- Performed tests/calibration of an ion mobility spectrometer at 10-ppb hydrazine.
- Performed tests of DMES offgassing from Shuttle Thermal Protection System tiles.
- Performed calibration of Interscan instruments for 10-ppb MMH.

Key milestone:

- Construction started on the PCDAS for the Wiltech calibration laboratory.

Contacts: D.E. Lueck, DL-ICD-A, (407) 867-4439, and P.A. Mogan, DL-ICD-A, (407) 867-9167

Participating Organization: I-NET, Inc. (C.B. Mattson, T. A. Hammond, and C.J. Schwindt)

Advanced Software

The goal of the Advanced Software program at the John F. Kennedy Space Center (KSC) is to investigate and apply emerging computer technologies to meet current mission requirements and to ensure requisite technologies will be available to fulfill future vehicle, payload, and launch requirements.

To meet the challenge of becoming more effective in all aspects of KSC work, reliability and safety must be maintained as processing time and cost are reduced. Products must be extracted from the expanding technological base, and these products must be utilized to solve KSC 's needs.

This year's Advanced Software program employs a broad range of disciplines and technologies. Monitoring and diagnostic systems are being developed that utilize both model- and rule-based technologies. The Propulsion Advisory Tool utilizes a rule-base to perform diagnostics on the Shuttle's main propulsion system. The Intelligent Component Expert (ICE) utilizes model-based reasoning, and a prototype has been developed for liquid oxygen loading of the Shuttle's main propulsion system. ICE has also been applied to several other systems in past years (e.g., active thermal control system for the environmental control and life support system of the Shuttle). The Ground Processing Scheduling System provides an artificial-intelligence-based tool to aid engineers in scheduling Shuttle time- and safety-critical tasks. The Orbital Maneuvering Subsystem (OMS) Integrated Vehicle Health Management (IVHM) testbed incorporates a rule-base to automatically execute test procedures. Applications are also being developed that utilize advanced software technologies. These applications include the Nitrogen Gas Alternative Support Predictor, which is a spreadsheet-based application to aid in the calculation of the gaseous nitrogen supply during launch. In addition, the OMS IVHM testbed incorporates a portable on-line test procedures system and the transmission of near real-time test procedure results over the Internet.

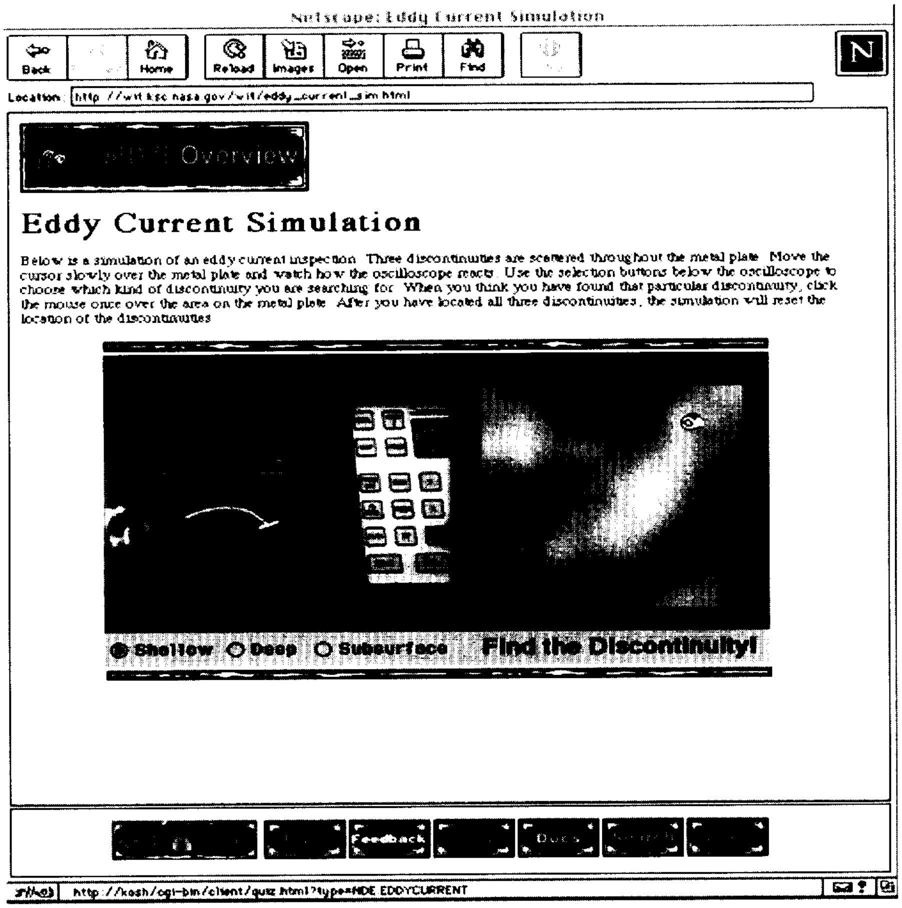
Web Interactive Training Simulations

The I-NET Multimedia Laboratory developed a series of World Wide Web based simulations of nondestructive evaluation techniques. These simulations are an integral part of the Web Interactive Training (WIT) Nondestructive Evaluation (NDE) Overview course. The purpose of the course is to familiarize NASA personnel with the NDE techniques in use at KSC. NDE physically tests the material integrity of a part, component, or system without damaging it. The NDE Overview presents each of the methods in use with a video overview of the technique in action, text and graphics explaining theory and application, an interactive simulation of the technique, and tests randomly generated from a database of questions.

The Multimedia Laboratory developed simulations for the following NDE methods: visual inspection, liquid penetrant testing, magnetic particle testing, eddy current testing, leak testing, ultrasonic testing, and radiographic testing. The purpose of these simulations is not to certify personnel to perform the techniques but rather to familiarize them with the respective methods.

Each of the simulations is designed to imitate a real-world process in a simple manner while minimizing the learner's download time. (Each simulation is approximately 30 kilobytes in size.) These simulations incorporate repetition, learning by example, and positive feedback. Each simulation follows the same general model: using the technique under study, the student searches for discontinuities randomly scattered throughout a test object. For example, the radiographic testing simulation enables the student to simulate a computed tomography scan of a simple cylinder. The student moves the scanner head along the cylinder and observes the scan on the simulated computer screen. When the student identifies a possible discontinuity, he or she clicks on it and is immediately provided feedback. If the student is correct, the simulation resets and again randomly scatters the discontinuity. This enables the student to repeat the simulation as many times as needed.

These simulations were designed and developed using Macromedia Director and its native programming language, Lingo. Macromedia Director is a well-established multimedia authoring package used for delivering content through CD ROM, kiosks, and now the Web. Lingo is a high-level object-oriented language structured around controlling media attributes and human interface considerations. A Director extension, Afterburner, compresses and optimizes the data for network delivery. This compression protects the programming code from being downloaded and repurposed by users. Students need the free Macromedia Shockwave for Director plug-in for their Web browser in order to run the simulation.



Key accomplishments:

- 1996: Completed simulations for the following NDE methods:

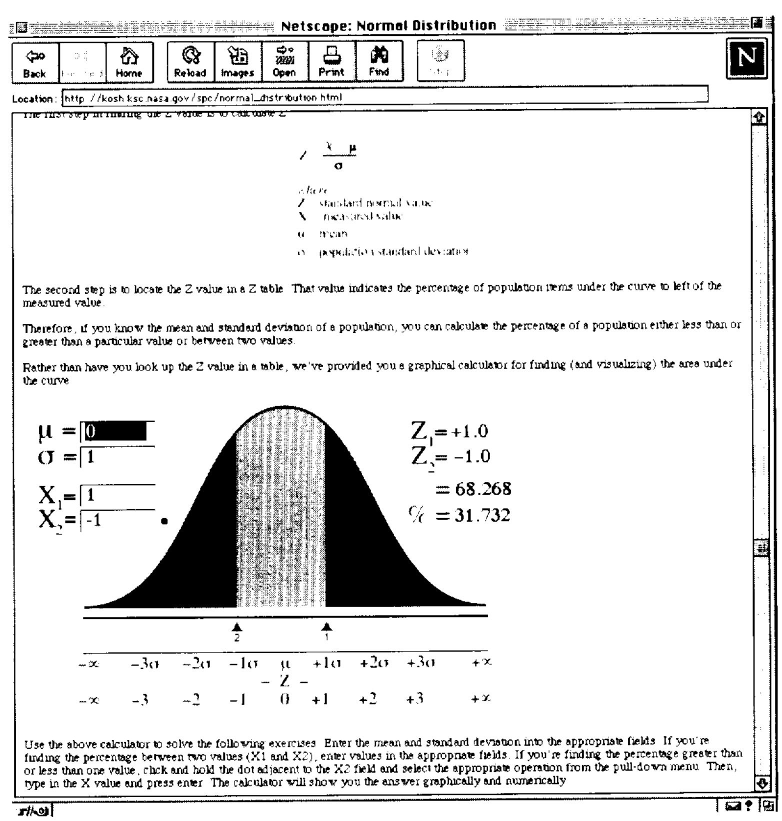
  - Visual inspection
  - Liquid penetrant testing
  - Magnetic particle testing
  - Eddy current testing
  - Leak testing
  - Ultrasonic testing
  - Radiographic testing

Key milestone:

- 1997: Completion of simulations for an advanced NDE training module focusing on radiography.

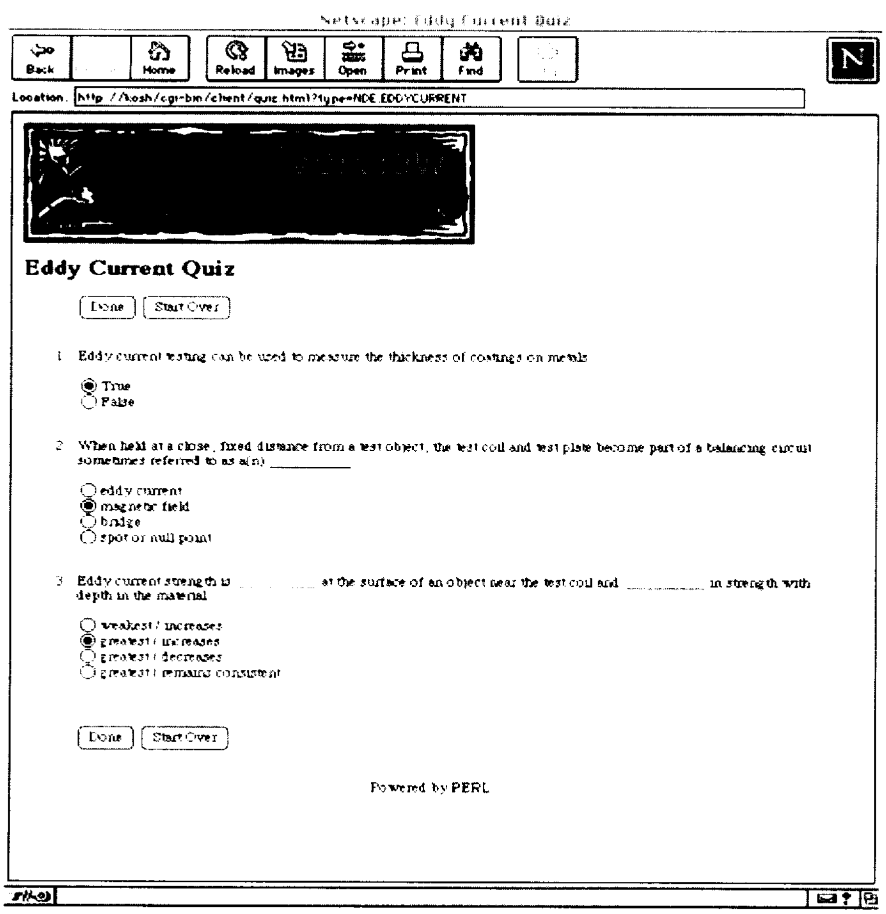
Contacts: J.D. Collins, DL-ICD-A, (407) 867-4438, and R.W. Tilley, EI-F, (407) 867-3199

Participating Organization: I-NET, Inc. (R.B. Wright)



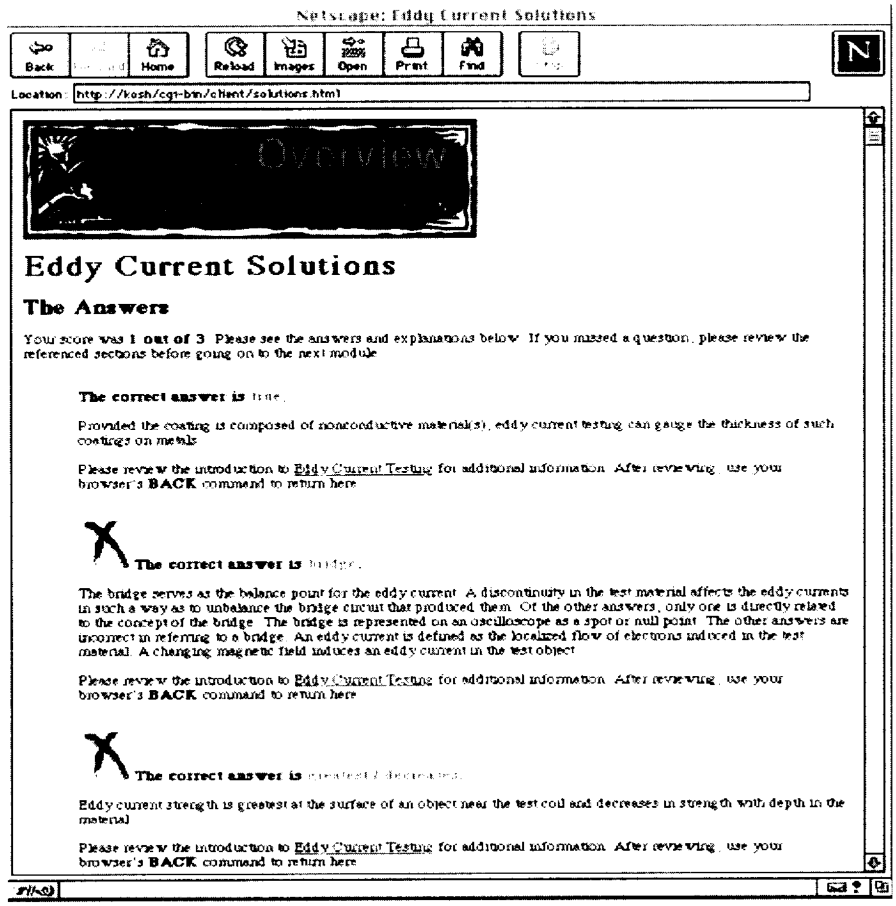
Web Interactive Training Testing Database

As part of the Web Interactive Training (WIT) project, the I-NET Multimedia Laboratory designed and developed a World Wide Web based testing program that randomly generates quizzes from a database of questions. This testing is an integral part of the Nondestructive Evaluation (NDE) Overview course. The purpose of the course is to familiarize NASA personnel with the NDE techniques in use at KSC. NDE physically tests the material integrity of a part, component, or system without damaging it. The NDE Overview presents each of the methods in use with a video overview of the technique in action, text and graphics explaining theory and application, an interactive simulation of the technique, and tests randomly generated from a database of questions.



At the end of each module within the NDE Overview, students have an opportunity to test and reinforce what they have just learned. They are presented with a short multiple-choice quiz, not longer than three questions. This quiz is randomly generated from a database of questions and is different every time the student attempts to take the quiz. After submitting answers, students are immediately presented with a score, a brief explanation of the answers, and a link to the place in the course where that topic was covered. Feedback and remediation are immediate and the student cannot cheat. The program prevents them from returning to the same quiz and retaking it. In the future, the Multimedia Laboratory plans to implement student tracking and grading.

The testing interface is Hypertext Markup Language (HTML) form-based and compatible with 99 percent of the Web browsers in use. The testing database was written in Perl and partially converted to Java. Eventually, the program will be entirely converted to Java for ease of future expandability and possible cross-platform deployment. The question database was first developed in a standard, off-the-shelf database program and exported as a tab-delimited file. This file contains questions, answers, explanations, and hyperlinks to review points throughout the course.



The WIT testing follows a client-server model where a special server handles testing requests. The server spawns a new version for each student so each is essentially dealing with his or her own testing server. This enables more people to access the testing database without a perceptible delay in performance. The database stores the raw HTML that will be handled by the browser. Each testing request generates a custom-built HTML page on demand. A high-level hypertext protocol directive prevents the students from being able to retake the same quiz.

The testing database is open ended and extensible; that is, other classes of questions can be added with little or no changing of the code. In 1997, the Multimedia Laboratory will develop an advanced NDE module focusing on radiography. The current testing database can be easily adapted to serve this advanced course.

Key accomplishment:

- 1996: Completed testing of the database for the NDE Overview course.

Key milestones:

- 1997: Complete the conversion of the code from Perl to Java. Add new classes of questions to serve the advanced NDE module.

Contacts: J.D. Collins, DL-ICD-A, (407) 867-4438, and R.W. Tilley, EI-F, (407) 867-3199

Participating Organization: I-NET, Inc. (R.B. Wright and T.A. Bierman)

Internet Display of PC GOAL Real-Time Data Using Java (JGOAL)

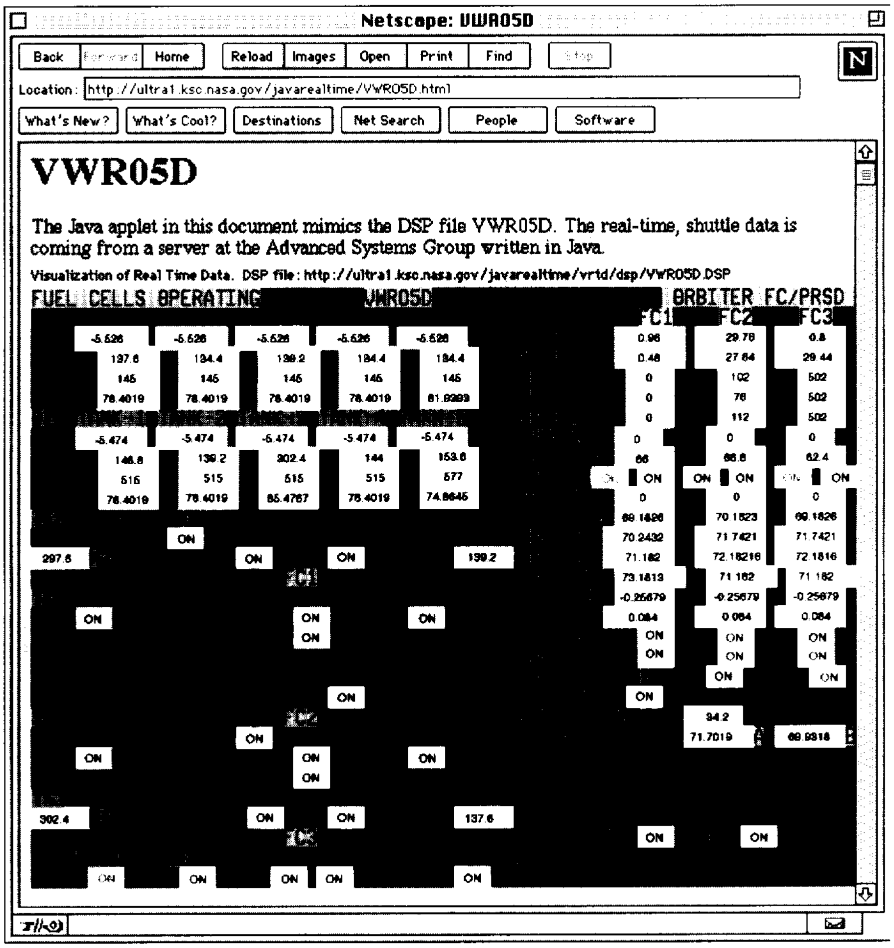
The rapid growth of Internet (World Wide Web or Web) access to information during 1995 and 1996 resulted in a significant paradigm shift in how information is accessed and the resulting expectations of users concerning information availability and ease of access. During the past 2 years, however, the type of information accessed on the Web has primarily been static in nature. The recent availability of Java has enabled a new class of applications containing dynamic content and real-time data sources over the Internet. Already, some early adopters of Java are experiencing an 80-percent reduction in development/deployment costs for client/server applications. The use of Java for real-time PC GOAL data display demonstrates how existing applications at KSC could be implemented using the Internet paradigm.

Currently, the display of PC GOAL real-time data involves a centralized server receiving data from the common data buffer and sending it to PC clients for display on predefined screens. The PC clients use MS-DOS and character cell graphics, with close ties to the hardware, operating system, and network interface. This implementation has limited security or ability to work globally, and the PC must be dedicated to displaying the data. The use of Java, a programming and runtime environment designed to work with the Internet, presents an ideal solution, eliminating much of the effort in establishing a client/server connection across a local or wide area network. Java supports implementation for both applications and "applets" (small programs designed to run in a Web browser such as Netscape Navigator or Internet Explorer). An applet is used for the client display of JGOAL screens (see the figure "Java PC GOAL Application"). A Java-based solution provides the following advantages:

- Geographic independence: Java applets (client) and Java applications (server) work locally or over the Internet, providing the flexibility to display information globally as required.
- Shorter development and training: Utilizing a commercial off-the-shelf (COTS) Web browser client (display) shortens the software development process and minimizes implementation time and costs.
- Write once, run anywhere: Applications are written once to run anywhere, ensuring portability and architectural independence rather than obsolescence. The clients and servers may be run on almost any hardware or operating system from PC's to mainframes.
- Security: Policies for access and safe execution of Java applets are easily established.
- Easy administration: Administration and distribution of application updates are easy to manage, since the latest applets are downloaded as needed from the server.
- Multiple PC GOAL displays: Use of existing PC GOAL displays (DSP files), made possible by a Java translation application, enables rapid availability and efficient use of legacy code for supporting multiple PC GOAL displays on one or many desktop computers.

The Phase 1 goal for the project demonstrated the feasibility of using Java and a COTS Web browser to display real-time Space Shuttle data of PC GOAL (see Java PC GOAL real-time display). This has been successfully demonstrated by the Automated and Intelligent Systems Laboratory, using multiple computer configurations as follows: (1) hardware: Intel X86, Sun SPARC, Motorola POWER PC; (2) operating system: Solaris, SunOS, WindowsNT, Windows95, and Macintosh Finder; and (3) Web browser: Netscape Navigator (2.02 and 3.0) and Internet Explorer (3.0).

Phase 2 involves taking the proof-of-concept work completed in Phase 1 and applying the technology to solve actual monitoring requirements at KSC and other NASA centers. To accomplish this, further system design and testing will be needed in the areas of: (1) tuning the applet (client) and application (server) for maximum performance; (2) establishment of robust extensible class libraries of reusable software components for present and



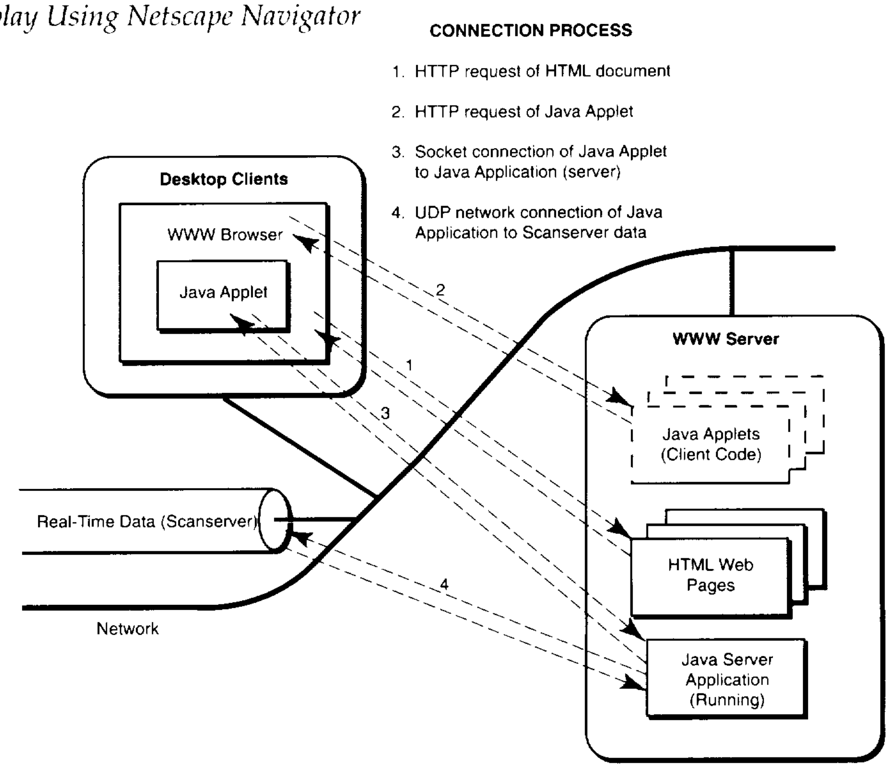
Java PC GOAL Real-Time Display Using Netscape Navigator

future projects; (3) analysis of network bandwidth utilization; (4) connecting to data sources, both real time and historical; (5) development of graphical user interfaces to increase display options; (6) development of enhanced display objects such as strip charts, graphs, overlays, etc.; and (7) extensive system level testing and certification.

The viability of utilizing Java, a new language/runtime environment, in conjunction with a COTS Web browser to rapidly develop and deploy process monitoring and control applications has been demonstrated. This new technology has the potential to significantly reduce the time and cost of developing and maintaining applications, given the flexibility to write the application once and run it anywhere. This type of solution has potential applicability at KSC and other NASA centers and as an industry technology transfer in the areas of training (live or simulated data sources), real-time monitoring (live Space Shuttle data or other data source), expert/advisory systems (for predictive analysis), and historical review (postmission data analysis and review).

Contact: W.C. Jones, DM-ASD, (407) 867-4181

Participating Organizations: I-NET, Inc. (J.M. Dockendorf and C.H. Goodrich), Florida Institute of Technology (Dr. R. Stansifer), and Princeton University (K. Gillett)



Java PC GOAL Application

Nitrogen Gas Alternative Support Predictor

NASA and the U.S. Air Force use gaseous nitrogen extensively in the processing of launch vehicles and during launch countdowns. The nitrogen is generated at the Air Liquide plant on Merritt Island and distributed via pipelines throughout KSC and Cape Canaveral Air Station (CCAS). A supply failure during a Shuttle countdown at the plant could result in a launch scrub. The large volume of high-pressure gaseous nitrogen in the pipelines, however, can provide hours of continued supply and allow the countdown to proceed if contingency actions are taken and sufficiently accurate predictions are made as to the amount of support time remaining.

Nitrogen Gas Alternative Support Predictor (NGASP) software is being developed to predict the amount of support time remaining as a function of existing conditions and optional contingency actions such as a reduction of nonessential usage and the addition of rechargers to the pipelines.

The contingency support time remaining is essentially the volume of gaseous nitrogen available divided by the predicted usage (flow rate). Predictions were previously made using worksheets and hand calculations repeatedly performed for changing pressure and usage conditions and for alternative contingency actions under consideration. An ideal way to automate the predictions seemed to be the development of a standard spreadsheet application; Microsoft Excel was selected.

The NGASP software will be used at the Converter Compressor Facility (CCF), located between the Launch Control Center and the two launch pads. The flow of nitrogen and helium to the launch pads and other facilities is controlled at the CCF.

The spreadsheet calculations use pressure and flow rate values from Launch Processing System (LPS) telemetry and telemetry from the Air Liquide plant. Use of the spreadsheets provides instant and accurate predictions for a variety of input scenarios involving reduced usage and incremental flow rates that can be added to high-pressure or low-pressure lines via available rechargers.

The project was officially funded beginning October 1, 1995. An initial version of the software was developed and delivered to the CCF along with a notebook computer for use as a temporary stand-alone platform. That version was used during several Shuttle countdowns for reference, familiarization, and assistance in establishing requirements. A final operational version was delivered to the user.

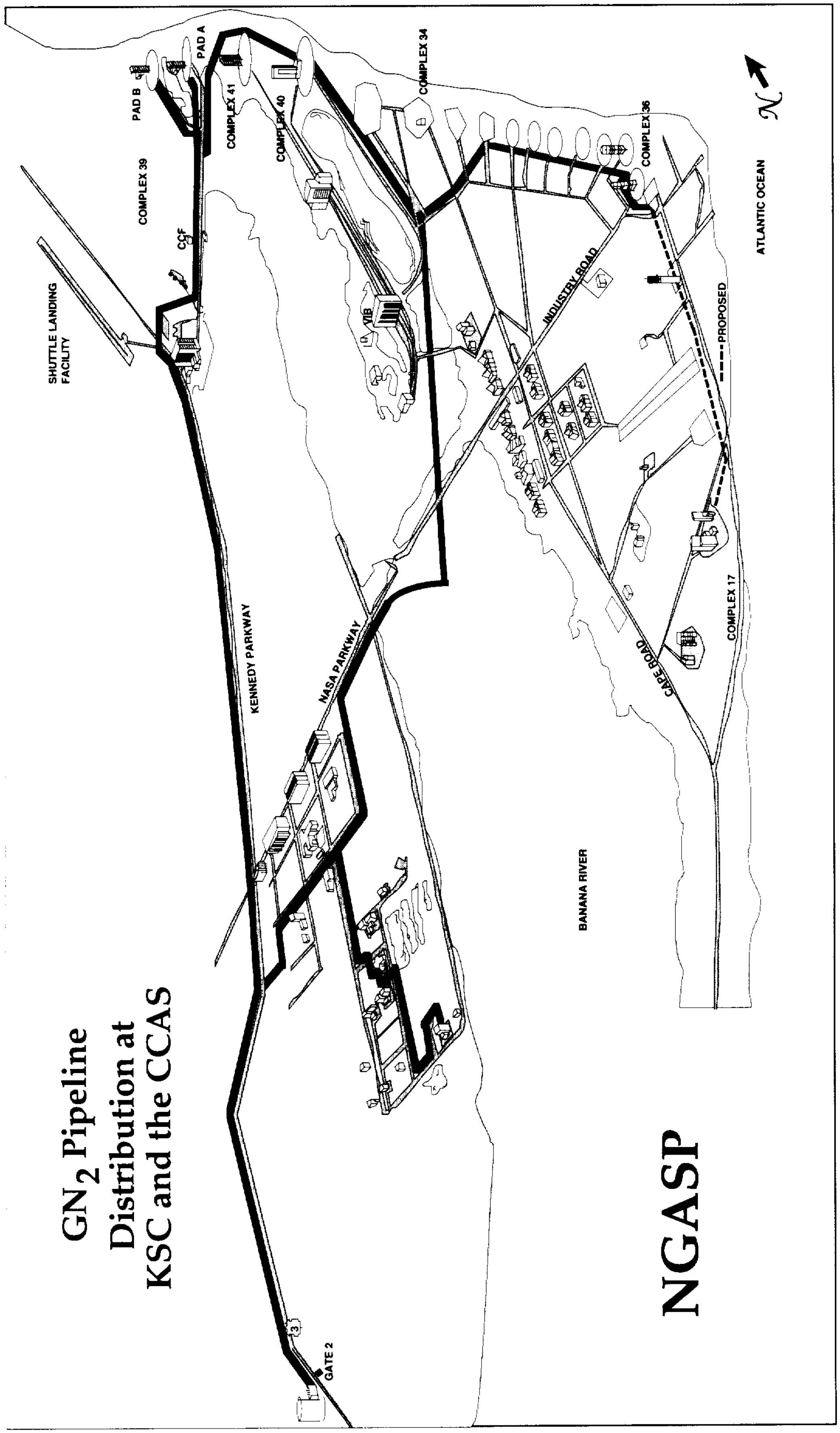
Functionality includes linking of the spreadsheets to Air Liquide and LPS telemetry for continuous real-time spreadsheet updating as pressures and flow rates change. Support time predictions for additional failure and contingency action scenarios will be added to the present version.

Key accomplishments:

- 1995: Initial prototype version developed and delivered for familiarization and establishment of requirements. Definition of hardware and software requirements initiated.
- 1996: Establishment of detailed requirements. Direct link of the software to telemetry. Development, testing, documentation, and delivery of the system. Identification of additional needed improvements.

Contact: W.C. Jones, DM-ASD, (407) 867-4181

Participating Organization: I-NET, Inc. (C.H. Goodrich and D.W. Chenault)


GN2 Pipeline
Distribution at
KSC and the CCAS
NGASP
SHUTTLE LANDING FACILITY
COMPLEX 39
PAD B
PAD A
CCF
VAB
COMPLEX 41
COMPLEX 40
COMPLEX 34
COMPLEX 36
COMPLEX 17
INDUSTRY ROAD
CAPE ROAD
KENNEDY PARKWAY
NASA PARKWAY
BANANA RIVER
ATLANTIC OCEAN
PROPOSED
GATE 2
3
N

Web-Based Electronic Documentation

One role of the Advanced Systems and Analysis Division is to investigate, understand, and disseminate new and alternative software and computer technologies that may be of use within the KSC community. The World Wide Web (WWW) has become the communication medium of choice for millions of individuals around the globe due to its extensive capabilities, low cost, and simple and platform-independent interface.

Because of this wide acceptance of the WWW, Web server applications were developed in the Advanced Systems and Analysis Division's laboratory to provide a paperless "engineer's notebook," a document review/commenting system, and a near real-time equipment test monitoring facility. These prototype systems are currently under evaluation for application to current Shuttle operations and/or next-generation launch vehicle processing and testing.

Test Engineer Uses Pen-Based System To Record Test Results

Reducing the paperwork associated with prelaunch activities has been the goal of other projects, but using the WWW as the foundation of a paperless system gives this system unique benefits. For example, there are no implementation costs for users who already "have access to the Internet." In addition, platform-specific requirements or geographical limitations are unnecessary as Web browsers are now available for nearly any type of computer in almost any location.

Traditionally, the manual operational testing method occurs as follows:

1. A procedure is written.
2. Copies of the procedure are circulated (or mailed out) for review.
3. Reviewer comments or redlines are sent back to the document owner, and new copies of the procedure are periodically distributed so reviewers can comment on the effects of other reviewer inputs.
4. After several iterations, the procedure is approved and a test date is scheduled and announced.
5. The test date is adjusted until all parties who need to monitor the test can schedule their visit (or arrange their flights).
6. The test is run according to the procedure, manually

recording times and measurements on the printed procedure.

7. The completed test document is archived after copies have been made for attendees.

With the Web-based approach, the process would be streamlined as follows:

1. A procedure is posed as a Web page.

2. Reviewers are notified (E-mail) of the Web location of the procedure to be reviewed.

3. Reviewers use their Web browser to view the procedure, submit their comments, and view the comments of other reviewers. Reviewers are notified when new releases of the procedure are posted.

4. After all reviewers have posted electronic signatures to the last release of the procedure, a test date is scheduled and announced.

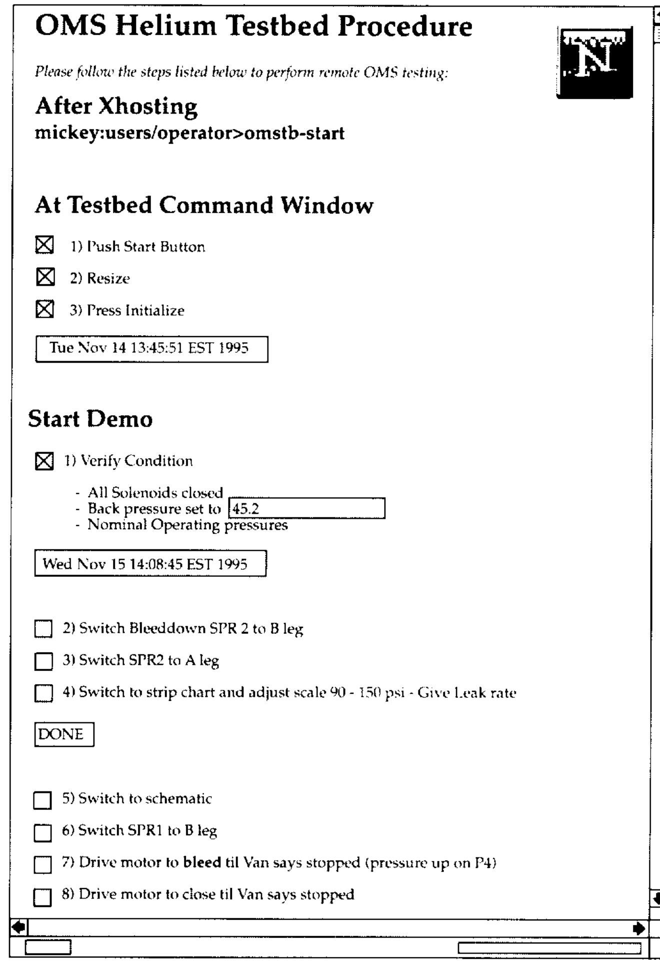
5. The test date is unlikely to need adjustment since most offsite individuals will remotely "view" the test as it occurs (via their Web browser).

6. The test is run according to the procedure displayed on a portable pen-based system running a Web browser and networked to a local server. Steps are checked as they are completed and are electronically timestamped. Measurements may be entered manually or electronically sampled and averaged on command. As procedure steps are completed, Web browsers around the country that are monitoring the test are updated.

7. The completed test document becomes part of an electronic archive that may be browsed at any future date.

Key accomplishments:

- 1995: Demonstration of a paperless "engineer's notebook," a document review commenting system, and a near real-time equipment test monitoring facility.



- 1996: Enhance document review/commenting system to support features such as routing and electronic signatures. Generalize these applications for use both inside and outside NASA. Develop a "smart" test procedure that can recognize invalid data and dangerous situations. Investigate using automated measurement reading and test step verification to minimize operator input.

Key milestones:

- 1997: Continue development of online editing capabilities. Expand functionality to include the near real-time transmission of PC GOAL data over the WWW to Java-enabled browsers.

Contact: W.C. Jones, DM-ASD, (407) 867-4181

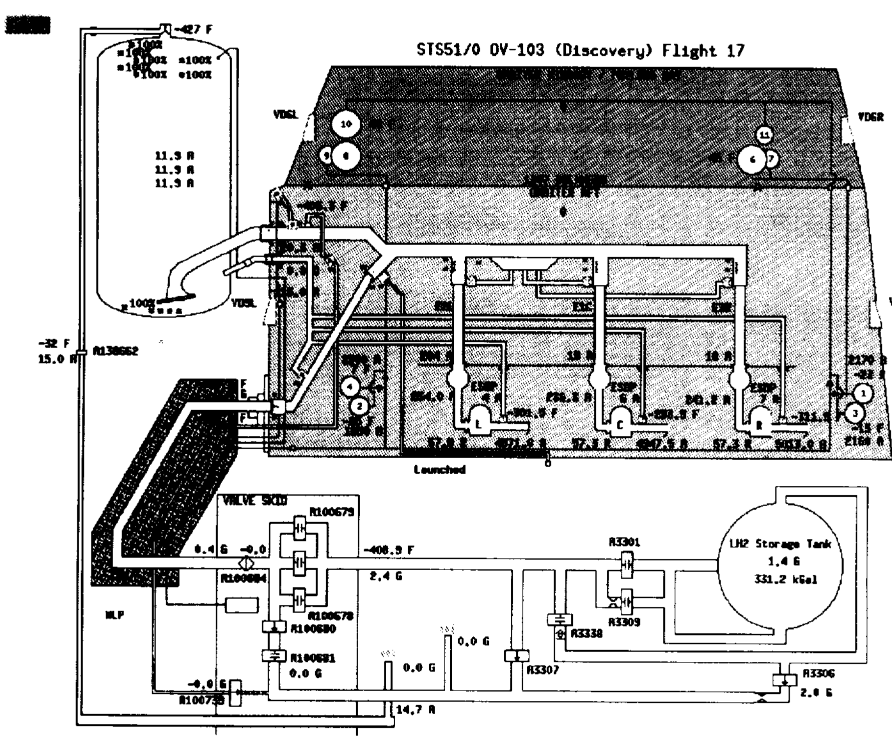
Participating Organizations: I-NET, Inc. (S.R. Beltz), Rockwell International Corporation (J.M. Engle), and Lockheed Martin Space Operations

Propulsion Advisory Tool

The idea for the Propulsion Advisory Tool (PAT) was born out of the frustration and delays incurred by the KSC launch team in the summer of 1990. During the hydrogen leak investigations, the team had a difficult time assembling the data for evaluation. The system used to track the Main Propulsion System (MPS) during launch lacked robustness and speed due to strict configuration controls and the dated equipment. The only way the team could compare data was to tape it to walls and do a manual comparison. In addition, the MPS is a major contributor to on-pad scrubs and troubleshooting efforts. It is a driver behind vehicle processing and, like other subsystems, is rapidly losing expertise due to ebbing design center and vendor support. As a result, these pools of knowledge are being lost forever. Hence, the need exists for an advisory computer system to track the MPS that is a knowledge-based system with user-friendly storage and retrieval of the data and data plotting.

PAT is a joint development project among NASA/KSC, United Space Alliance, a Lockheed Martin Company, and Rockwell International Space Systems Division (KSC and Downey). PAT is an expert system that focuses on launch day operations to monitor MPS health by following the transfer of liquid hydrogen and oxygen through the ground systems and orbiter into the external tank. To accomplish this, PAT relies on data from analog pressure/temperature sensors and discrete valve position indicators as well as data for the aft background purge effluent for liquid hydrogen, liquid oxygen, and helium leakage.

PAT uses incoming data for two parallel operations. One path is used to display the MPS liquid oxygen and liquid hydrogen propellant loading system. The user can display plots of any applicable MPS measurements, in any combination. Historical data can also be plotted with "live" data. The other path feeds the PAT knowledge base. This expert system software uses a rule/model base of knowledge captured from MPS engineering experts to predict and detect anomalies or trends. The user is warned of potentially hazardous conditions in addition to suggesting a corrective action. The groundwork has been laid for use of neural nets in the PAT knowledge base.



Liquid Hydrogen Screen

The system software has been operational since the spring of 1992. In 1993, additional hardware and the liquid oxygen software were delivered. In 1994, debugging of the system software was completed, and the team received the NASA Group Achievement Award for accomplishments to date on the project. The accomplishments for 1995 were the delivery of the liquid oxygen anti-geyser expert system software and the system software for the Space Shuttle main engines. 1996 marked the final development phase for the project and the start of the certification process to qualify the system for use in Firing Room 1.

Key accomplishments:

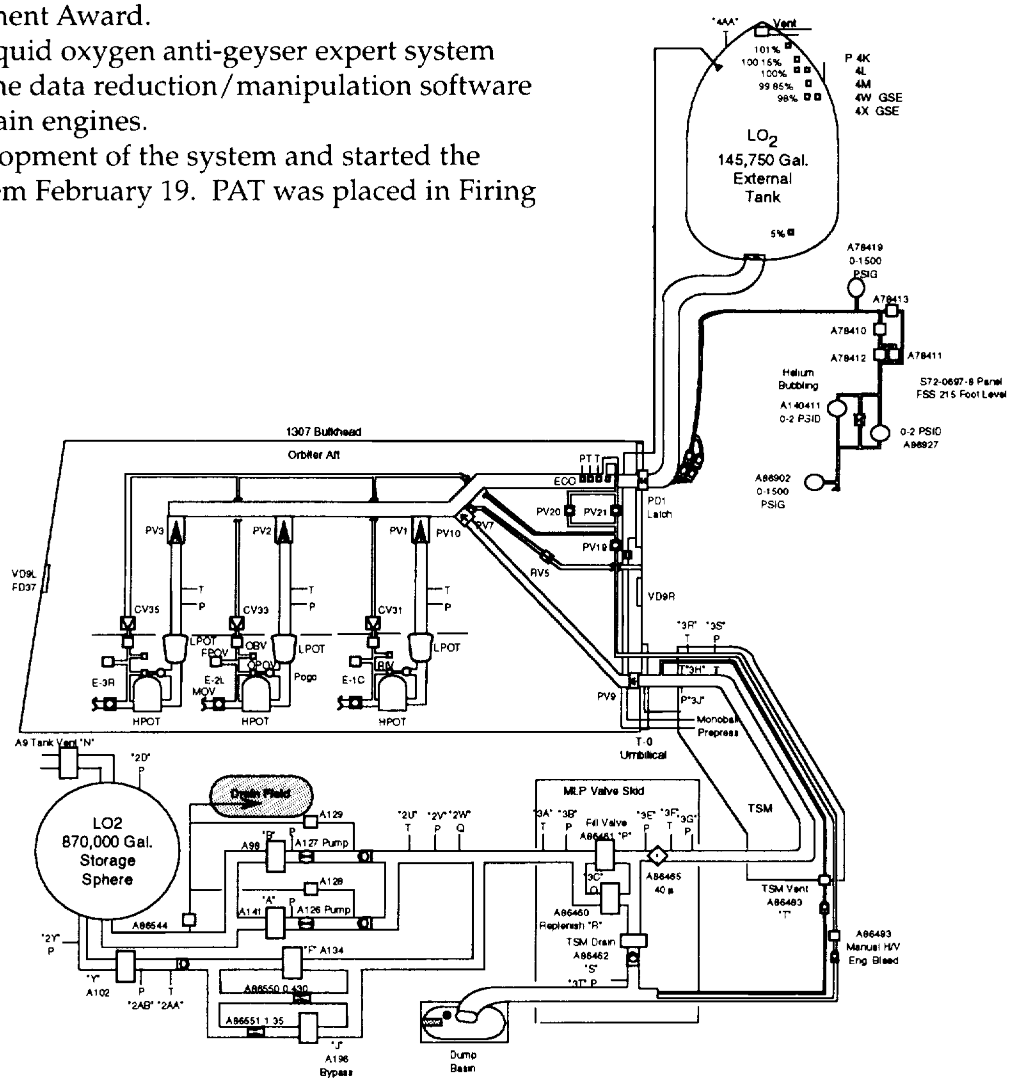
- 1992: Initial demonstration of the software technology and delivery of the hardware. Implementation of the initial liquid hydrogen data reduction/manipulation prototype.
- 1993: Delivery of the liquid oxygen data reduction/manipulation software and hardware.
- 1994: Debugging of the system software. Team received the NASA Group Achievement Award.
- 1995: Delivery of the liquid oxygen anti-geyser expert system software. Delivery of the data reduction/manipulation software for the Space Shuttle main engines.
- 1996: Completed development of the system and started the certification of the system February 19. PAT was placed in Firing Room 2.

Key milestones:

- 1997: Complete the certification of the system and place the Propulsion Advisory Tool in the prime firing room.

Contact: R.J. Beil, PK-G3, (407) 861-3944

Participating Organizations: United Space Alliance (L.T. Bird); Sanders, Lockheed Martin Space Operations (R. Costantino); and Boeing North American (L.H. Fineberg)



Liquid Oxygen Screen

Intelligent Component Expert (ICE)

ICE is a model-based monitoring and control system used to support Shuttle launch operations. ICE uses a mathematical model of a system to predict the values of measurements. When a discrepancy between predicted values and actual measurement values occurs, ICE determines and reports possible failed components that would explain the discrepancy. ICE then supplies the operator with recommendations on how to proceed under these circumstances.

The model of a system is represented as a knowledge base (KB), which is loaded into the ICE shell at run time. In this manner, each application differs only by the KB that has been loaded. Basically, a KB consists of descriptions of individual hardware components, equations that map each component's input values to its output values, and connections between the components.

ICE, originally developed in LISP, was successfully converted to C++ and Open Software Foundation (OSF) Motif. During the reimplementation, object-oriented design methodologies were used to maximize code modularity, reuse, and maintainability. A significant effort was also made to simplify the process of integrating ICE with custom user displays, specialized diagnostic algorithms, and new data sources. For example, the user interface was decoupled from the rest of the ICE shell to simplify ICE's future migration to other operational platforms and systems. In addition, generic widget handlers and interface services were provided to allow users to construct their own process overview panes and specialized dialog managers. Other features provided by ICE are:

1. The diagnostic engine of ICE was implemented as a tool box, allowing the incorporation of highly divergent diagnostic algorithms into a common environment.

2. The real-time data interface was standardized so all data providers are interchangeable.

3. ICE's monitoring and simulation tasks were implemented as completely separate steps in the ICE reasoning process, and their interaction among themselves and other reasoning tasks can now be managed directly from the user interface.

4. ICE's fault detection process was extended to allow for future inclusion of advanced monitoring techniques such as trend perception and statistical process analysis.

Since the low-level KB structure was changed significantly to simplify its integration with ICE, ICE's KB editor was also implemented in C++. This editor, while still in its prototype stage, provides a graphical interface to a template-based, context-sensitive text editor. With it, objects can be selected from a standard component library, named, specialized, and inserted into the application KB.

Tree displays are provided to allow the user to visualize the connection between objects.

The most recent application of ICE was a proof-of-concept demonstration of ICE for one subsystem of the Shuttle Vehicle Health Monitoring System (VHMS). The subsystem selected was the Active Thermal Control System (ATCS) for the Environmental Control and Life Support System (ECLSS) of the VHMS. Additional work has been done to apply ICE to the monitoring of the Shuttle's liquid oxygen (LOX) loading process. Prototype modeling for LOX loading of the Shuttle's main propulsion system (MPS) was done jointly with the help of the Florida Institute of Technology.

Key accomplishments:

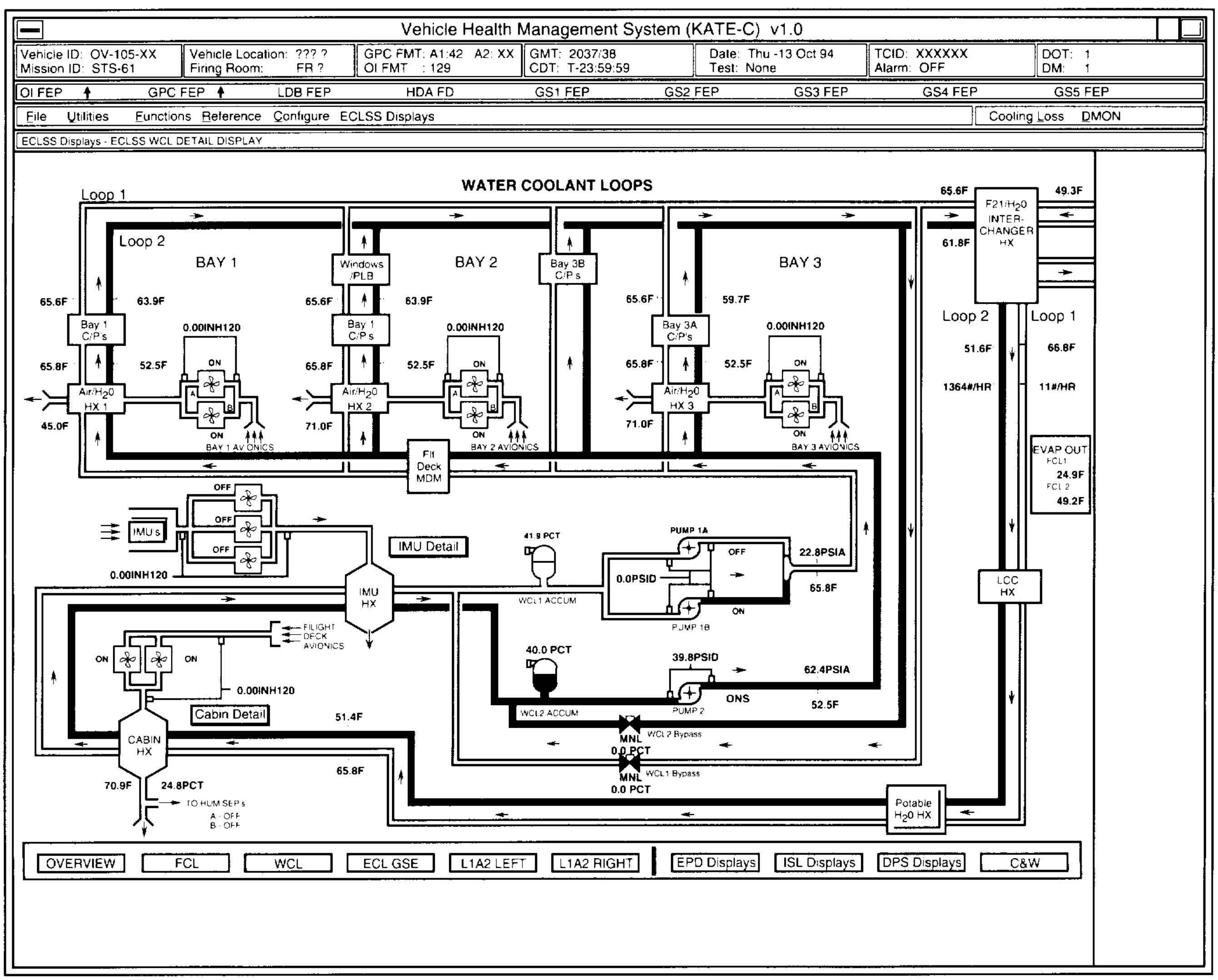
- Reimplementation of ICE core functionality in C++.
- Successful proof-of-concept demonstration of ICE for the ATCS subsystem of the VHMS.
- Development of a prototype model for LOX loading for the Shuttle's MPS.

Key milestones:

- Apply ICE to other operational processes.
- Extend MPS LOX loading model.

Contact: W.C. Jones, DM-ASD, (407) 867-4181

Participating Organizations: I-NET, Inc. (C.H. Goodrich) and Florida Institute of Technology (Dr. J. Whitlow)



ICE Application — Orbiter Environmental Control and Life Support System

Nondestructive Evaluation

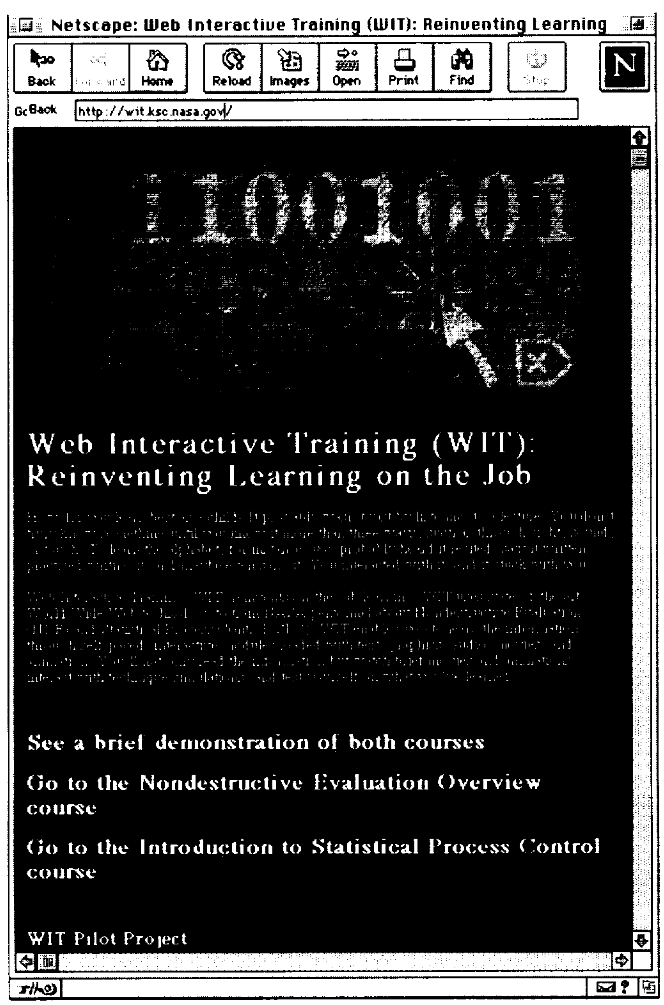
The Nondestructive Evaluation (NDE) Technology program at the John F. Kennedy Space Center (KSC) includes the development of inspection and verification instruments and techniques that can provide information (external or internal) to hardware and component structures in a nonintrusive manner. The technology includes, but is not limited to, laser, infrared, microwave, acoustic, structured light, other sensing techniques, and computer and software systems needed to support the inspection tools and methods.

The present effort in this discipline is being directed toward reducing Shuttle processing costs using these technologies. The long-term effort of the program is to develop cost-effective NDE techniques for inspecting and verifying space vehicles and their components during manufacture and to continue validating those items during assembly/launch and on-orbit or during space flight.

Web Interactive Training

New technologies have made training at the desktop more cost effective than traditional training methods. Desktop training enables the student to learn according to his or her own pace, schedule, and learning style, and it provides on-the-job performance support after completion of the course. Desktop training could augment or supplant existing training methods; it uses time and resources more efficiently than do many current methods.

The Web Interactive Training (WIT) project uses multiplatform interactive media to deliver training to NASA. The primary delivery technology is the TCP/IP-based World Wide Web. A feasibility prototype and two full courses have been completed to verify and validate the design technologies incorporated and developed. The full courses include the Nondestructive Evaluation (NDE) Overview and the Introduction to Statistical Process Control course. The next phase of this project is the conversion of two advanced courses. One course will be Nondestructive Evaluation—Radiography, and the other will be Advanced Statistical Process Control. The project incorporates state-of-the-art multimedia technologies to meet the defined objectives.



There are many technical considerations and approaches to this project. The majority of the effort will involve advanced Hypertext Markup Language (HTML) scripting, hardware and software setup, and design. This effort also includes instructional system design, digital photography, scanning, media conversion, audio and video recording, compression, animation, formatting, scripting, programming, and beta testing. The process includes research and implementation of late-breaking technologies like digital video streaming for introductions, CGI interfaces for forms and testing feedback, shockwave simulation modules, Java, and other advanced client/server features.

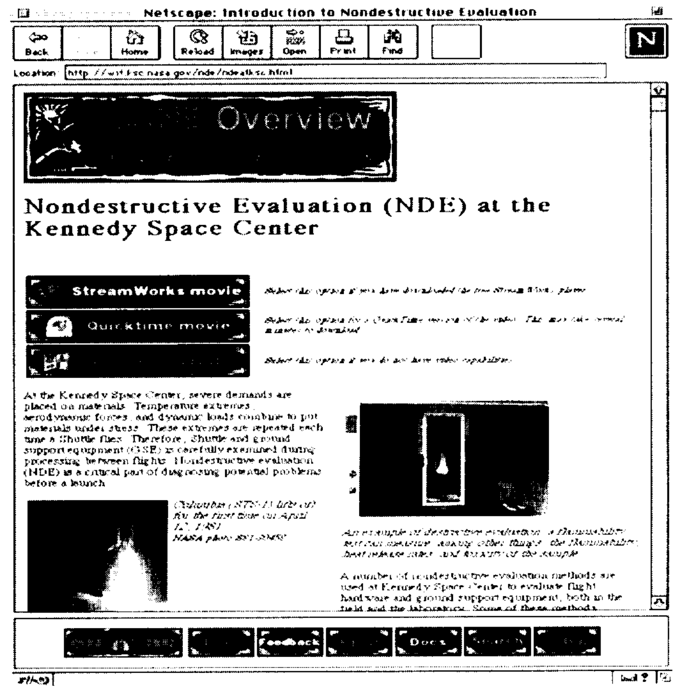
Future efforts involve advanced security functions, student tracking capabilities, performance support functions, adaptive learning, integration into centralized NASA training activities, and research in Just-in-Time training using mobile communication technology.

Key accomplishments:

- 1995: Completion of the feasibility prototype.
- 1996: Incorporation of hypertext, graphics, streaming audio, video, animation, and reporting. Designed a state-of-the-art Web server capable of serving NASA online training. Completion of two training modules (NDE and Statistical Process Control). Inclusion of a random test generator with testing database and interactive feedback.

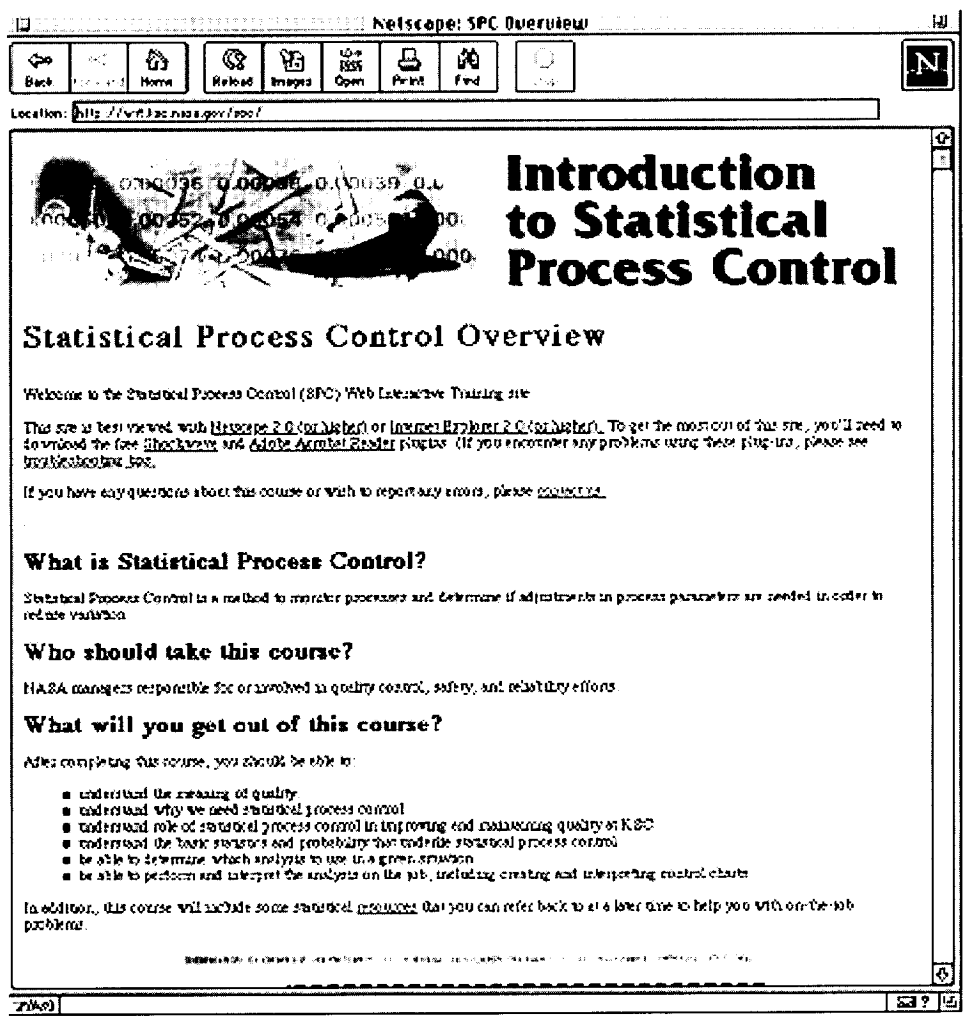
Key milestones:

- 1997: Completion of two advanced training modules (NDE—Radiography and Advanced Statistical Process Control). Research in new delivery technologies and techniques and Just-in-Place training.



Contacts: J.D. Collins, DL-ICD-A, (407) 867-4438, and R.W. Tilley, EI-F, (407) 867-3199

Participating Organization: I-NET, Inc. (D.S. Metcalf)



Analysis of Nonstationary Signals Using Wavelets for Extracting Resonances

To determine the frequency composition of a signal for mechanical analysis, signal processing tools such as the Fast Fourier Transform (FFT) and the Short Time Fourier Transform (STFT) are used. However, the use of Fourier analysis for frequency component extraction is restricted to band-limited stationary signals. Thus, small transients may not be detected due to a smoothing effect of the FFT, or the FFT spectrum may be smeared due to frequency ramping or discontinuities in the signal. Space Shuttle launch-induced acoustic and vibration signals can be classified as nonstationary random and exhibit features of a very short duration transient. Various techniques have been employed to overcome the limitations of the FFT for nonstationary data. These techniques include windowed Fourier Transform (Gabor or STFT), synchronous sampling to remove revolutions-per-minute-ramp effects, Wigner-Ville analysis, and wavelet analysis.

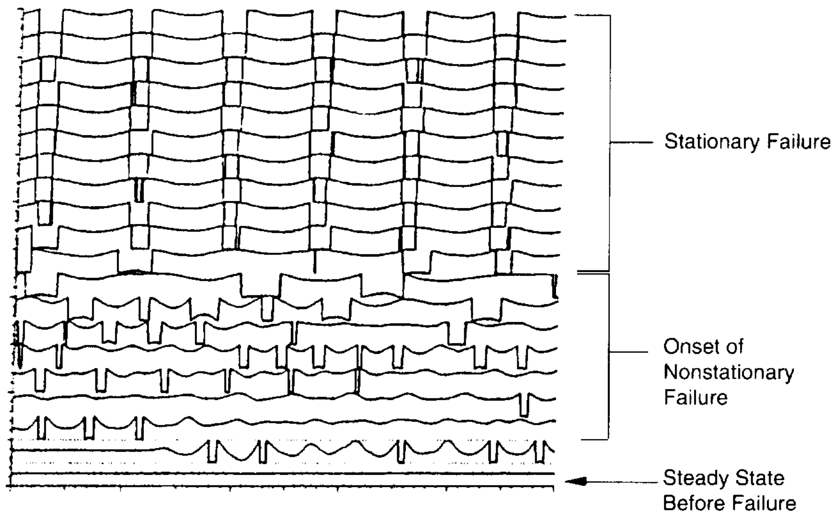
Wavelet analysis is based on a fundamentally different approach in which the signal is decomposed on a series of special-basis functions called wavelets, which are localized in time and have an integral value of zero. Wavelet analysis can pinpoint local phenomena in nonstationary signals and provide the capability to compress or de-noise a signal without appreciable degradation, while preserving both high-frequency and low-frequency components. Wavelet techniques can be extended to detect and analyze impending bearing failure in rotating machinery (see the graphs).

Key milestones:

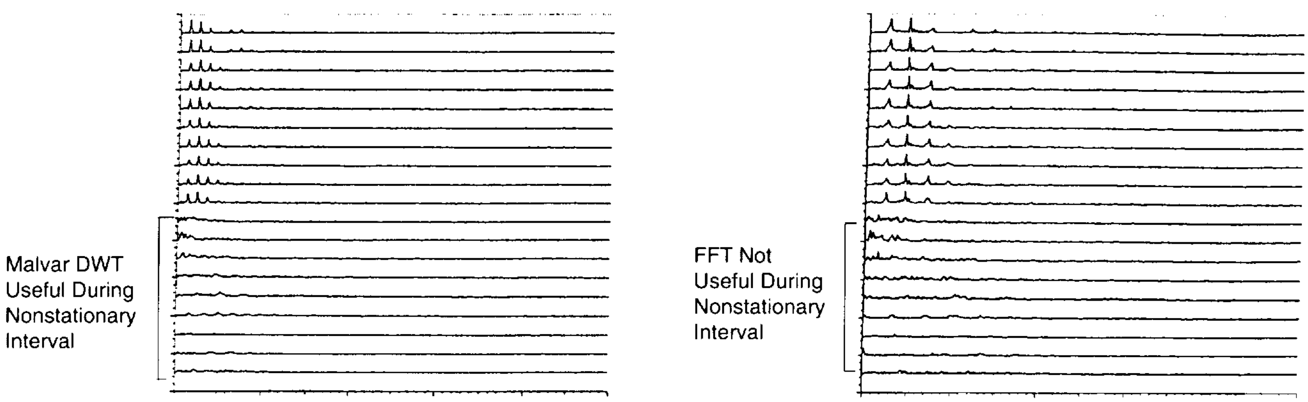
- 1997: The wavelet analysis methods will be applied to Space Shuttle launch-induced acoustic and vibration signals to highlight key low-frequency components affecting structural resonance. The wavelet analysis methods will be applied to liquid oxygen pump rotating machinery analysis for condition monitoring, machine diagnostics, and bearing fault detection and prediction.

Contact: R.J. Werlink, DM-ASD, (407) 867-3748

Participating Organizations: I-NET, Inc. (R.N. Margasahayam) and EG&G Florida, Inc. (O.J. Varosi)



Time Domain Signal for Impending Bearing Failure



Comparison of DWT and FFT

Sound Technology for Availability, Reliability, and Safety

During 1996, significant progress was made towards assessment and implementation of newer technologies to support Space Shuttle operations. Performance and condition monitoring of Space Shuttle components and related ground support equipment in support of various missions has created an opportunity to lower operational costs, improve safety, and enhance reliability and maintainability. This opportunity stemmed from the development and utilization of acoustic emission (AE), ultrasonic, and sound pressure measurement techniques in evaluating behavior of materials, nondestructive testing, continuous machinery monitoring, nonintrusive flow measurements, leak detection, and acoustic loading on structures.

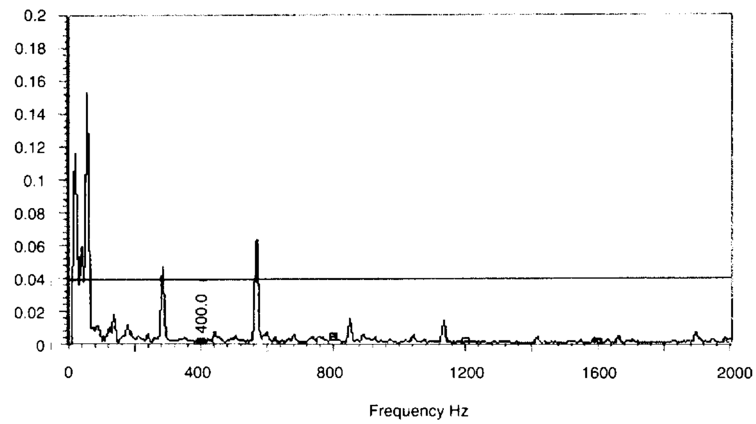
AE testing is a powerful method for examining the behavior of materials deforming under stress. Acoustic emission may be defined as a transient elastic wave generated by the rapid release of energy within a material. Materials "talk" when they are in trouble; with testing equipment, one can "listen" to the sounds of cracks growing, fibers breaking, and many other modes of active damage in stressed material. The small-scale or subsurface damage is detectable long before the actual failure, so the AE technique can be used as a nondestructive, nonintrusive method for finding defects during structural proof tests and plant operations. AE testing also offers unique capabilities for materials research, quality control testing, weld monitoring, and leak detection. Moreover, increasing regulatory requirements, coupled with stringent demands for proactive maintenance, reliability, safety, improved productivity, and environmental compliance in various process industries, have led to intensified efforts for the practical use of AE technology. AE technology usage now facilitates structural integrity monitoring of aging infrastructures, plant life extension, and addressing areas of environmental safety.

Key milestones:

- 1997: Evaluate AE-technology-related hardware and software from various vendors. Conduct tests to assess applicability of AE technology to identify bearing faults, gas leaks, concrete spalling problems, and structural integrity of holddown posts.

Contact: R.J. Werlink, DM-ASD, (407) 867-3748

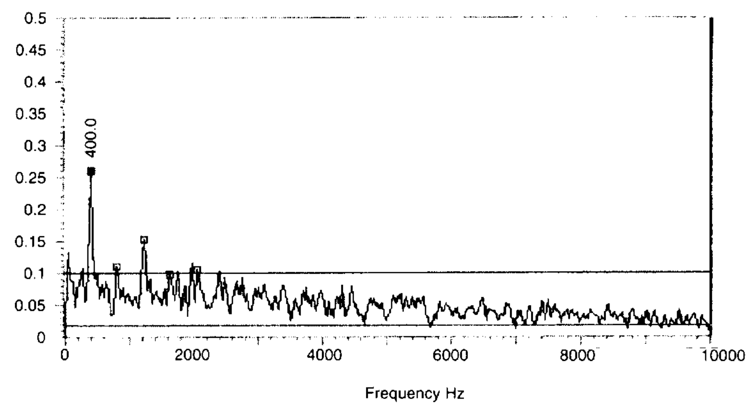
Participating Organization: I-NET, Inc. (R.N. Margasahayam)



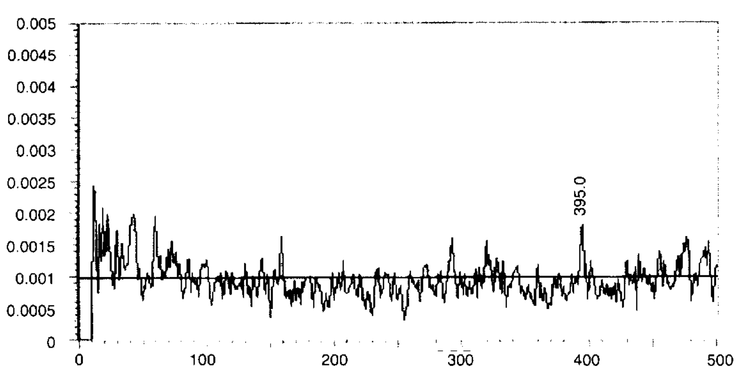
Velocity

Ball passing frequency outer (BPFO) race at 400 hertz not clearly identified with velocity measurement

Acceleration enveloping helps to detect the defect (qualitative assessment)



Acceleration Enveloping



SEE Technology

AE technique helps quantify the defect; low amplitudes of AE indicate onset of problem and impending failure

Early Identification of Bearing Damage Using AE (Enabling Proactive Corrective Action)

Verification Test Article Project

During a Shuttle launch, ground support equipment and structures in the proximity of the launch pad are subjected to intense vibration due to acoustic pressure generated by rocket exhausts. Continuous monitoring of launch-critical loads (acoustics) and simultaneous structural response (vibration and strain) is vital for design of new and proactive maintenance of existing structures. By the end of 1996, the collection of acoustic, vibration, and strain data from seven launches from Launch Pad 39A was completed on a cantilever beam, called the Verification Test Article (VETA). Analyzed data from these launches was crucial for validating a random vibration response model based on the deterministic approach developed at KSC. A detailed report outlining the validation methodology was released in 1996.

VETA measurements proved extremely valuable in characterizing two separate zones of acoustic loading on the ground support equipment. Tests showed the liftoff peak acoustics (between T+2 to T+7 seconds) are often overshadowed by a significant secondary peak (between T+10 and T+17 seconds). This second peak, the "plume impingement" peak, is directly attributable to the Shuttle roll maneuver. The liftoff peak is composed primarily of high-frequency components above 50 hertz. The secondary plume impingement effect contributes significantly to the structural resonances because of its low-frequency composition. Limited launches and failed sensors restricted analysis efforts to evaluate effects of launch trajectory, multimodal contribution, and effects of higher modes on the overall response and prediction confidence intervals.

Key accomplishment:

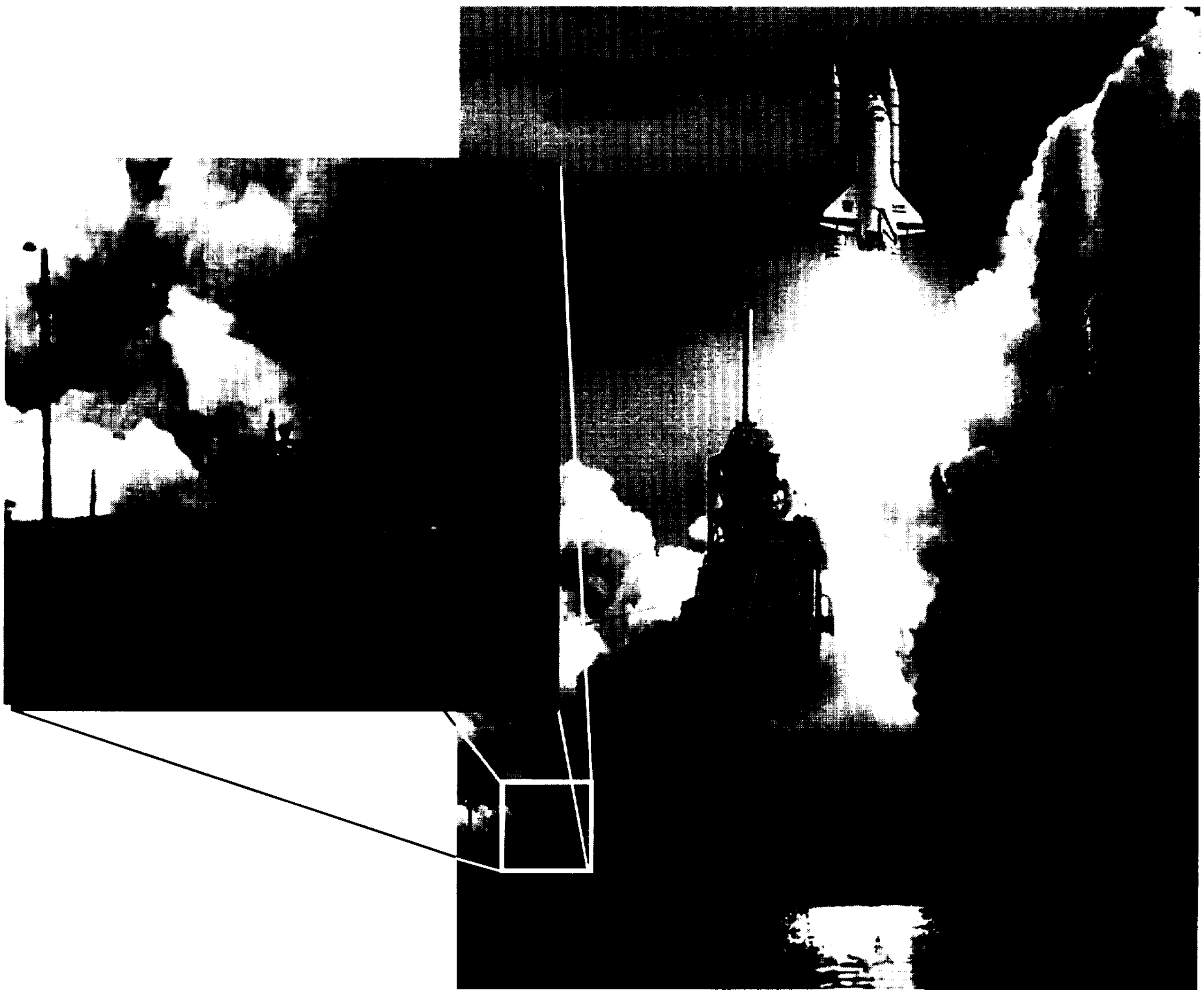
- 1996: Completion of KSC-DM-4291 documenting test analysis and results.

Key milestone:

- 1997: Collect data from five launches from Launch Pad 39A.

Contact: R.E. Caimi, DM-ASD, (407) 867-3748

Participating Organizations: I-NET, Inc. (R.N. Margasahayam), United Space Alliance (F. Walker), and EG&G Florida, Inc. (R. Neely and L. Albright)



Mechanical Engineering

The Mechanical Engineering program at the John F. Kennedy Space Center (KSC) supports the development of technology with analysis, design, and operation of launch and ground support equipment for space flight vehicles. Technology is advanced by a broad variety of analysis including structural deflection, dynamic response, stress, dynamic data requirements, reduction, and processing. Also included are single and multiphase flow, cryogenic fluid flow and storage, thermal insulation development, and fracture mechanics. Launch-induced environments are predicted and evaluated with test spectra, modal testing, portable dynamic data acquisition, and analysis. Mechanical Engineering also covers system and mechanism troubleshooting, component testing, and development of tools, devices, and systems for fabricating systems and obtaining required cleanliness.

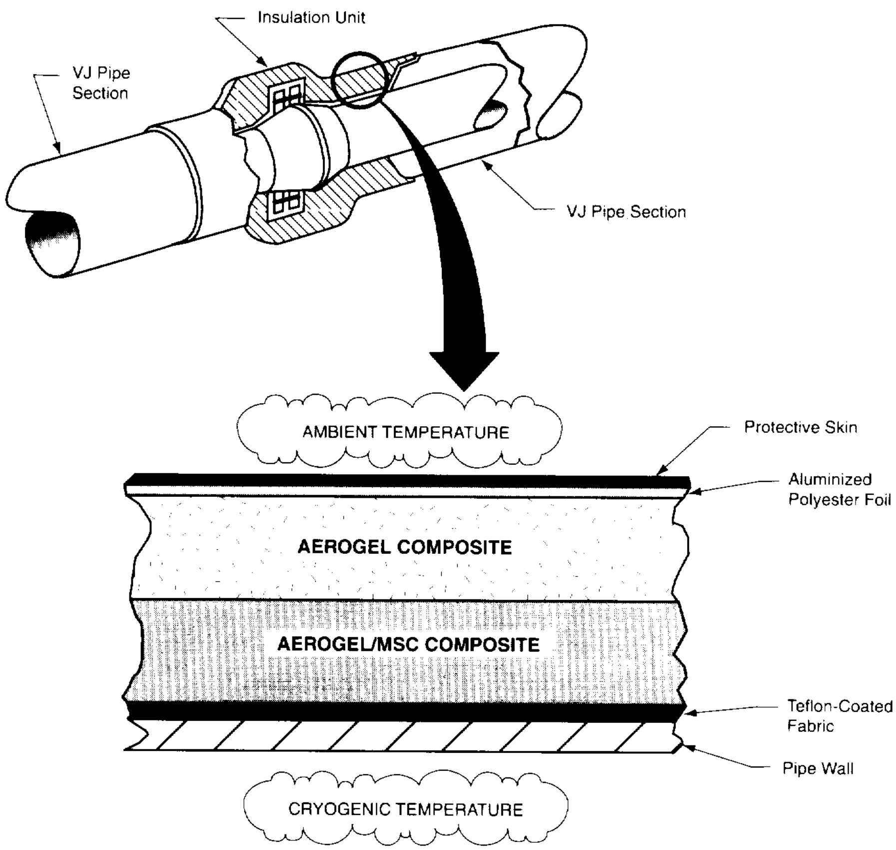
Aerogel-Based Superinsulation

The Aerogel-Based Superinsulation was developed by Aspen Systems, Inc., of Marlborough, Massachusetts. This technology was developed under a NASA Small Business Innovation Research (SBIR) contract for KSC. This superinsulation is an innovative, flexible cryogenic insulation with extremely low thermal conductivity. The design of this product takes advantage of the low thermal conductivity of the ultralow-density aerogels (ULDA's) and incorporates a flexible, durable matrix to maximize applicability. The core of the superinsulation technology is aerogels formed at the fiber-fiber contacts, forcing solid heat transfer to occur through the aerogels. This configuration both improves the ease of handling aerogels and reduces the heat transfer rate through the fiber materials. The close-packed structure of aerogels also eliminates the open structures in the fiber matrix and, thereby, minimizes convection heat transfer. Therefore, improved thermal resistance can be achieved for both evacuated and nonevacuated systems while maintaining good flexibility. In addition, by producing the aerogels in an opacified fiber matrix, the structure also significantly inhibits radiation heat transfer in the infrared range.

Aerogel Composite Superinsulation Products

This technology can be easily adapted to a broad range of commercial applications. Potential commercial uses include (1) cryogenic applications in the transportation, storage, and transfer of cryogens; (2) near-room temperature applications such as refrigerator insulation; and (3) elevated temperature applications such as insulation for high-temperature industrial processes and furnaces. The new insulation may be designed for cryogenic or elevated temperature applications. Some benefits of the aerogel-based superinsulation are: (1) high-performance CFC-free insulation, (2) flexible and easy-to-use configuration (ideal insulation for objects with irregular shapes), (3) lightweight and durable, and (4) available in blanket or clamshell (molded) product forms.

The basic form of the superinsulation system is a blanket composed of aerogel-based radiation shield layers and low thermal conductivity aerogel/fiber matrix composites. The final product can be a blanket, sheet, sleeve, or clamshell unit, depending on the application (see the photograph). The



Example Clam-Shell Application

blanket alone can be employed as an alternative to multilayer insulation or perlite powder in vacuum-jacketed systems. The configurations of the sheet and sleeve units are similar to the blanket but add outer skin and backing material. The outer skin provides (1) a weather barrier to prevent condensation of moisture or air, (2) safety and strength during handling and installation, and (3) durability for protection from harsh environments. The configuration of the clamshell unit is similar to that of the sheet or sleeve but is custom-sized to piping, pipe flange, or piping components (see the drawing). In this case, the superinsulation can be relatively rigid (not brittle) for insulating simple objects such as piping or can be flexible for insulating complex-shaped objects.

The thermal performance of the aerogel-based superinsulation has been measured by both transient heat flux and liquid nitrogen boiloff methods. The apparent thermal conductivity of the plain blanket superinsulation is lower than 1 milliwatt per meter-kelvin (R-value per inch greater than 140) at high vacuum (below 10E-5 torr) with cold and warm boundary temperatures of 77 and 280 kelvin. Most importantly, the thermal conductivity has been shown to be insensitive to residual gas pressure up to a vacuum level of 10E-1 torr. The thermal conductivity in ambient pressure nitrogen is below 10 milliwatts per meter-kelvin (R-value per inch greater than 14).

Currently, Aspen Systems is producing aerogel thermal insulation products for a variety of customers. Prototype superinsulation systems are being field tested at KSC.

Contact: J.E. Fesmire, DM-MGD, (407) 867-7969

Participating Organization: Aspen Systems, Inc. (S. Rouanet)

Liquid Nitrogen Boiloff Calorimeter

A liquid nitrogen boiloff calorimeter was fabricated at KSC for testing cryogenic insulation materials. The unit was previously used at Aspen Systems, Inc., of Marlborough, Massachusetts, for measuring the thermal performance of new aerogel-based superinsulations. The evaluation of commercially available cryogenic insulation as well as further testing of the aerogel composites is scheduled. The calorimeter features a 24-inch-long, 6-inch-diameter test chamber (volume is approximately 10 liters), which is oriented vertically with a thermal guard chamber on each end. The test chamber is enclosed by a 14-inch-diameter by 48-inch-long vacuum can. An overall view of the system is shown in the photograph and the schematic diagram.

The insulation test article is installed around the stack of chambers in the desired thickness (up to 2 inches). Temperature sensors are installed on the surface of each chamber and on the outer surface of the insulation. In operation, all three chambers are filled to capacity and maintained full until a steady-state thermal equilibrium is obtained (heavy-wall stainless steel construction provides added thermal stability). The test chamber is then isolated while replenish flows of liquid nitrogen are continuously supplied to the two guard chambers. The upper chamber is maintained at a slightly higher pressure [approximately 0.5 pound per square inch gage (psig)] to prevent the test chamber's boiloff gas from liquefying. The boiloff gas is routed to a flowmeter where it can be measured and monitored as required. This flow of nitrogen gas is directly proportional to the radial conduction of heat through the insulation. The basic relation is as follows:

$$\dot{Q} = h_{fg} \bullet \dot{m} = \frac{2\pi k L\left(T_o - T_i\right)}{\ln\left(D_o/D_i\right)}$$

where,

h_{fg} = heat of vaporization (joule per gram)

$\dot{m}$ = boiloff rate (gram per second)

L = length of chamber (meter)

k = thermal conductivity (water per meter-kelvin)

T_o = insulation surface temperature (kelvin)

T_i = chamber surface temperature (kelvin)

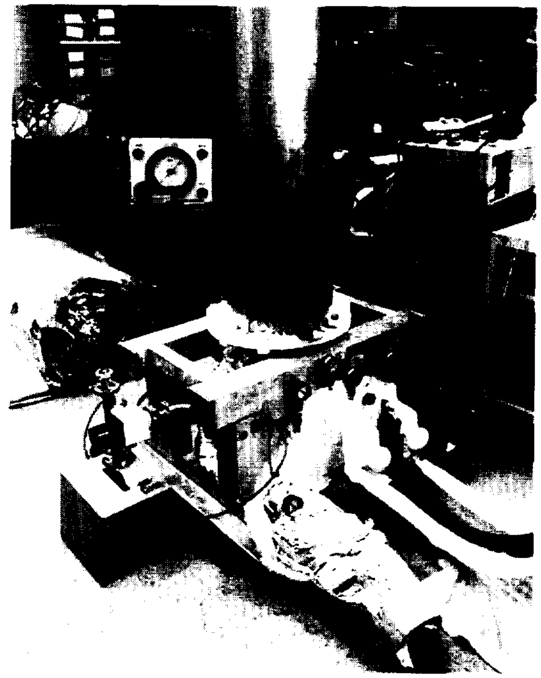
D_o = insulation outer diameter (meter)

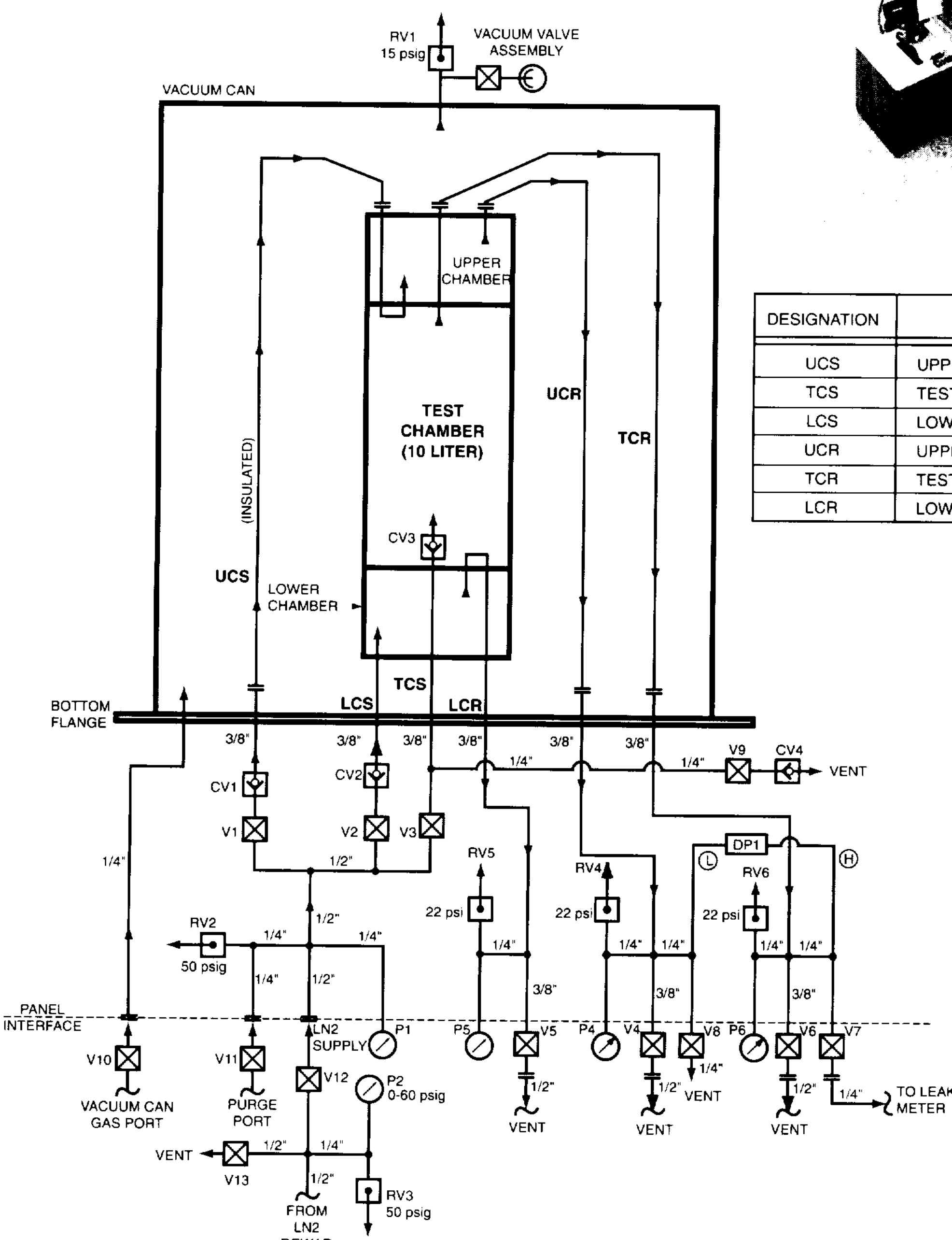
D_i = chamber outer diameter (meter)

Thus, the apparent thermal conductivity of the insulation can be computed by knowing the boiloff rate, the geometry of the chamber, and the temperature difference across the insulation thickness.

The boiloff calorimeter is designed to operate at a test pressure of below 10^{-3} torr up to 15 psig. The liquid nitrogen supply is provided through a 0.5-inch line at approximately 20 psig. Monitoring and data acquisition are accomplished using a LabView computer interface. The system design incorporates a removable vacuum enclosure that allows quick reconfiguration of the insulation test article.

Contact: J.E. Fesmire, DM-MGD, (407) 867-7969





DESIGNATION	DESCRIPTION
UCS	UPPER CHAMBER SUPPLY
TCS	TEST CHAMBER SUPPLY
LCS	LOWER CHAMBER SUPPLY
UCR	UPPER CHAMBER RETURN
TCR	TEST CHAMBER RETURN
LCR	LOWER CHAMBER RETURN

Liquid Nitrogen Boiloff Calorimeter Schematic

Cryogenic Shutoff Valve Testing

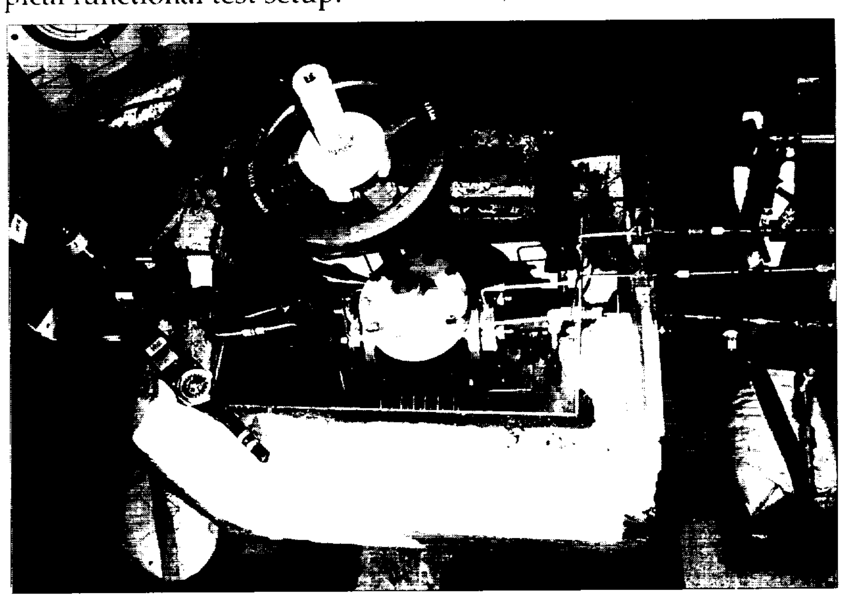
Prior qualification test projects for hardware used in propellant loading systems have led to the development of a standardized test procedure for the performance evaluation of cryogenic shutoff valves. This standardized test procedure, which is detailed in KSC-DM-3886, was used to qualify cryogenic gate valves for liquid oxygen service in the Space Shuttle propellant loading systems. The testing was conducted under the authority of KSC's Safety and Obsolescence (S&O) program at the NASA Development Testing Laboratory.

The standardized procedure includes functional tests, thermal shock tests, life cycle tests, and flow tests in an ordered sequence. The functional test is composed of a series of ambient and cryogenic temperature leak checks, internal and external, conducted in designated increments of inlet pressure and valve actuation cycles. The photograph gives a view of the typical functional test setup. The cryogenic temperature is -321 degrees Fahrenheit (liquid nitrogen) and the leak check fluid is helium gas at pressures up to 250 pounds per square inch gage. Over 20,000 actuation cycles were performed on a total of six gate valves for the S&O qualification testing program. The results are summarized in KSC-DM-4143.

Numerous engineering evaluation tests of cryogenic valves have also been conducted. Engineering evaluation tests typically include a prescribed sequence of functional and life cycle tests. Cryogenic butterfly, gate, globe, and ball valves from over a dozen different manufacturers (sizes from 1/4-inch to 12-inch diameter, Class 150 or 300) have been tested and evaluated for a variety of applications.

Contact: J.E. Fesmire, DM-MGD, (407) 867-7969

Participating Organizations: United Space Alliance (M. Pringle) and I-NET, Inc. (R.E. Koss)



Cryogenic Gate Valve Qualification, Functional Test Setup

Cryogenic Test Bed

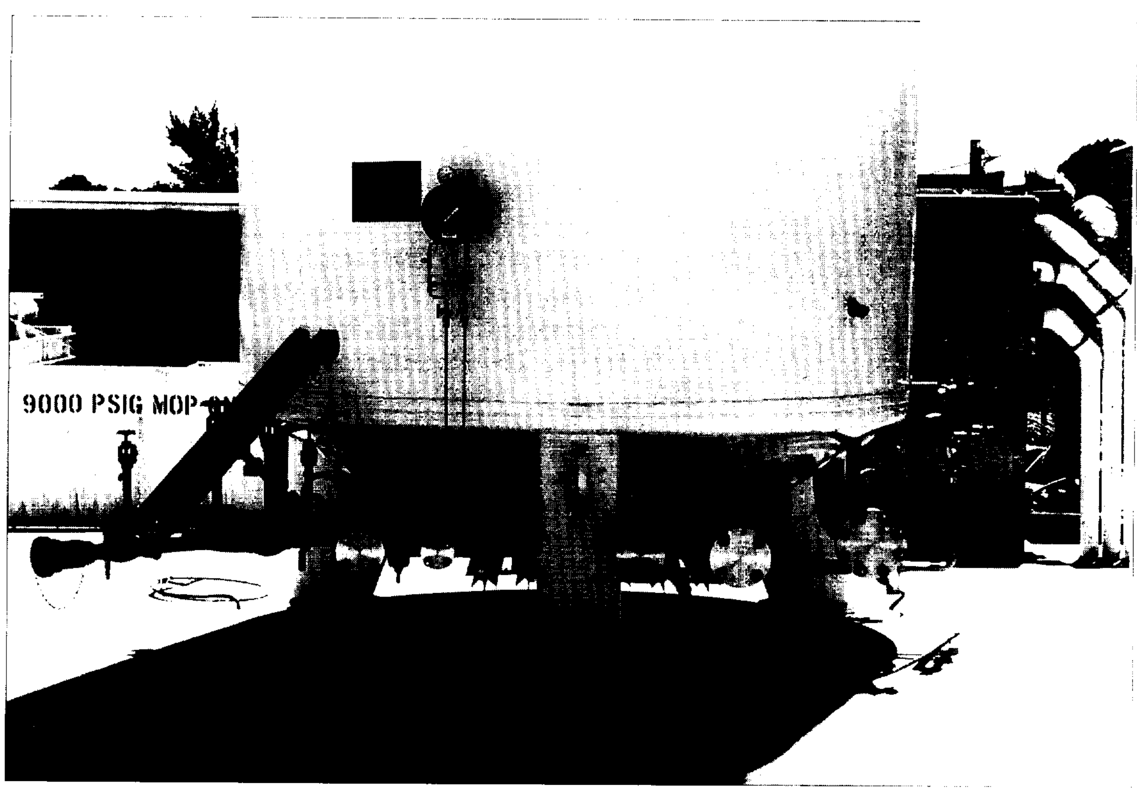
Phase I of the KSC Cryogenic Test Bed has been constructed at the NASA Development Testing Laboratory. The core of the test bed is a 6,000-gallon liquid nitrogen dewar manufactured by MVE, Inc., and was activated in January 1996. The vertical dewar has a maximum allowable working pressure of 250 pounds per square inch gage and features a liquid withdrawal capacity of over 1,000 gallons per minute. Liquid withdrawal nozzles from 2 to 4 inches in diameter are provided as shown in the photograph.

The vessel is vacuum jacketed and insulated with a fiberglass/MLI composite. The dewar system also includes a capacitance liquid-level control system with a computer output capability for measuring flow. The system is used in the testing of a wide range of cryogenic equipment and in development of new cryogenic technologies. Recent test activities include two-phase flowmeter development, superinsulation testing, and cryogenic valve qualification.

Phase II of the Cryogenic Test Bed has been designed and will include fixed piping for 3- and 6-inch-diameter runs (or adaptable from a 1/2-inch up to a 10-inch size) approximately 40 feet in length.

Contacts: E.W. Ernst and J.E. Fesmire, DM-MGD, (407) 867-7969

Participating Organization: I-NET, Inc. (J.L. Rigney)



Cryogenic Test Bed, Liquid Nitrogen Dewar

Two-Phase Quality/Flowmeters

The goal of the project was to measure the flow rate and composition of two-phase mixtures to control and monitor fluid transfer. The current flow technology cannot measure flow rates in multi-phase mixtures with a practical device. Some examples include the following: (1) filling of the Space Shuttle cryogenic propellants (liquid hydrogen and liquid oxygen), (2) controlling the quality of steam in power plants, (3) transferring liquid oxygen for industrial use, and (4) providing process control for the food industry (solid/liquid solutions). Details of application examples include:

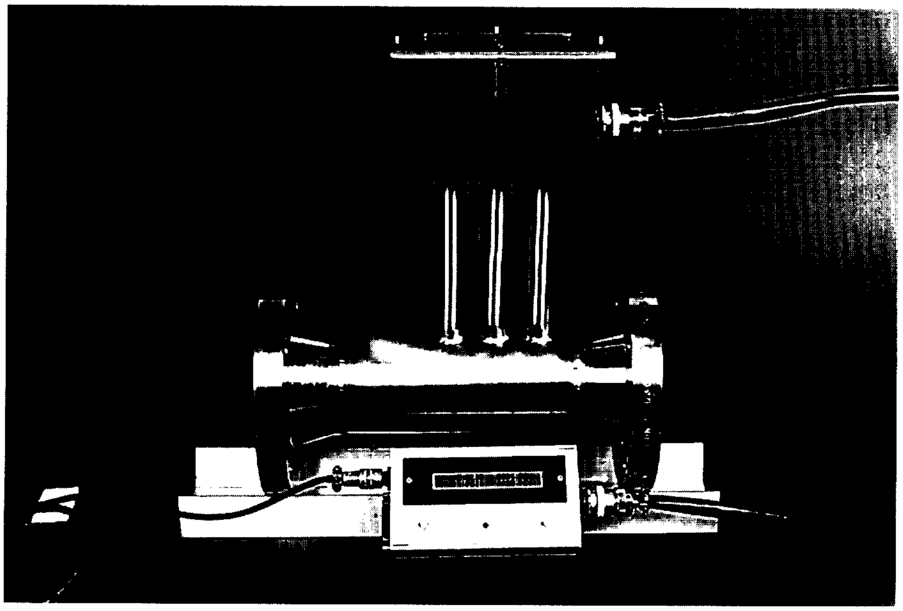
1. Bidirectional flow rate and quality near real-time with no moving parts or flow obstructions useful for steam plants where maintenance of high-quality vapor is important.

2. Food processing where the maximum velocity of a solid/water mixture is required to determine optimum sterilization times.

3. Level indicator for use in modular cryogenic tanks (for example, that of the Space Station Cryo Carrier). The fill level or overfill condition can be monitored electronically using a simple compact quality meter. This is the configuration developed by I-NET, Inc.

The fill rate (velocity) and efficiency (quality) for existing Shuttle propellants would provide cryogenic propellant savings and time savings by determination of when 100-percent liquid is present during chilldown. This is especially important in determining maximum recovery times after a revert of the fill flow caused by equipment problems. The meter can be used for diagnosis of increased heat leaks (insulation/vacuum piping failures). Advanced Shuttle replacement vehicles using slush hydrogen (solid-liquid phases) require density, phase, and flow monitoring, which can be provided by the meter.

Possible use as a humidity indicator in Shuttle and future vehicle fueling and continuous determination of the dew point prior to the introduction of cryogenic propellants precedes the costly current method of dew point determination using sampling and off-line laboratory analysis. The quality flowmeter is based on measurement of the dielectric constant variation between the phases of a two-phase mixture. As the ratio of the two phases changes, the overall capacitance changes. The capacitive flow/quality meter consists of an insulated pipe section with an inner solid probe held in place by standoffs. The probe is electrically isolated from the inside of the pipe and has a wire attached to both ends, which are also electrically isolated from each other. The wires pass through the pipe wall to a connector. An innovative capacitance measuring circuit measures capacitance with very high sensitivity. Two circuits are used, and each measures the average capacitance of the mixture around each end of the probe. A personal computer is used to store and analyze the



Cryogenic Flowmeter

readings to get the delta time of a moving two-phase mixture. This delta time equates to velocity and flow rate. The meter has an increase in the inner diameter around the probe to keep the flow cross section constant and has a vacuum jacket to minimize heat losses. It was designed to be used on cryogenic flows, such as liquid nitrogen, oxygen, and hydrogen. Pressure and temperature of the mixture are also measured on the meter. With these parameters, density can be calculated.

Another configuration uses three parallel plates held in the center of the flow stream by Teflon insulators. The electronics measure capacitance of the center plate to the side plates as the mixture passes through. Quality, pressure, and temperature sensors provide real-time values on the liquid crystal display at a relatively slow rate. This unit is simple and ruggedly designed for field use where velocity is not required.

Monitoring capacitance changes to measure a physical phenomenon is not a new concept. Indeed, a range of sensors has been developed that utilizes capacitance measurements. The present system is not significantly more sensitive than those available off the shelf but demonstrates a significantly higher dynamic range and a quicker response.

Key accomplishments:

- 1993: Designed/fabricated the flow/quality meter prototype. Designed/fabricated the quality meter with a real-time display. Displayed the quality meter at Technology 2003.
- 1994: Tested meters in series using a liquid nitrogen tanker. Presented a technical paper at the Technology 2004 conference. Submitted a Technology Brief.
- 1995: Submitted the patent to the Patent Office. Initiated a technology transfer program.
- 1996: Chose an industrial partner and began joint NASA/industrial development of a commercial sensor. Fabricated improved electronics and hardware.

Key milestones:

- 1996: Applied for the patent. Began development of the commercial version of the sensor.
- 1997: Explore a broader range of uses for the meter including steam monitoring and waste water monitoring. Distribute and test prototypes at NASA centers.

Contact: R.J. Werlink, DM-ASD, (407) 867-3748

Participating Organization: I-NET, Inc. (Dr. R.C. Youngquist)

Analysis of Geysering in Vertical Liquid Oxygen Fill Lines in No-Flow Conditions

Geysering has been a problem during loading of launch vehicle liquid oxygen tanks. Geysering of cryogenics normally requires a vented tank partially filled with cryogen with a vertical pipe extending from the bottom of the tank holding cryogen in a no-flow condition. Heat transfer through the walls of the vertical pipe causes boiling of the cryogen and formation of vapor bubbles on the pipe inside wall. The bubbles are initially held to the pipe wall by surface tension. As the bubbles increase in size from additional heat transfer and vaporization, the buoyant forces on the bubbles increase, overcoming the surface tension forces. The bubbles break away from the pipe wall and rise up the pipe. Some of the bubbles may meet forming a larger bubble. The static head pressure at the bottom of the larger bubble is reduced by the diameter of the bubble minus the smaller rise of fluid in the tank, which has a much greater diameter than the pipe. This reduction of pressure at the base of the larger bubble caused by the bubble formation and the rising of the bubble in the pipe causes spontaneous boiling. Liquid and vapor are rapidly forced out of the pipe. The evaporation subcools the liquid, causing vapor to collapse as the liquid falls back into the pipe. This may result in water hammer pressure and damage in the pipe and launch vehicle.

Dr. D.W. Murphy developed a geysering correlation published in Advances in Cryogenic Engineering, Volume 10, Plennum Press, New York (1965). The dimensions related to geysering in the vertical pipe at the bottom of the flight vehicle tank are shown in the sketch. D equals the inside diameter of the pipe in inches. L is the length of the pipe from its connection to the bottom of the tank to the shutoff valve in inches. The Murphy geysering plot has a Y axis relative to these dimensions, which is defined by the following equation:

$$Y = \frac{\frac{L}{D}}{D^{0.68}}$$

The X axis is defined by the following terms:

$$X = \frac{\frac{Q}{A} L}{12\alpha \, (P_r)^{1/3}}$$

where:

Q/A = heat flux at the pipe wall, British thermal units per square foot hour

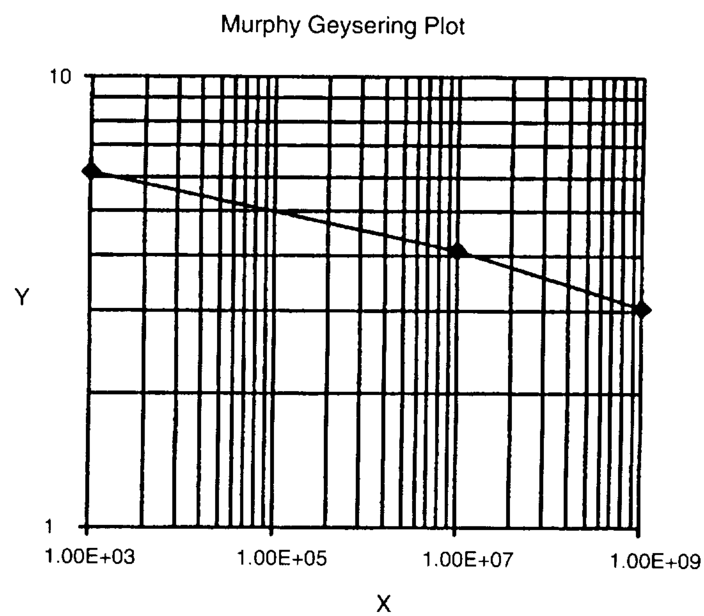
α = thermal diffusivity of the cryogen, square foot per hour

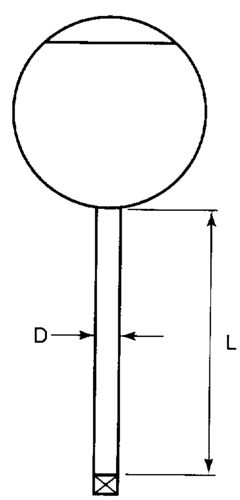
P_r = Prandtl number of the cryogen

Murphy set up many tests and plotted X and Y. A line was formed where points above the line geysered. Points below the line did not geyser (this line is shown in the plot).

A Microsoft Excel program was written that uses a least mean squares curve fit of the geyser correlation line, calculates the X and Y values, and sees if the condition is in the geysering area. The thickness of thermal insulation is also entered. The program calculates a number of line dimensions and uses logic statements to identify which are in the geysering area. This program is useful for predicting geysering in vertical cryogenic pipe lines when the flow stops because of a system revert.

Contact: F.S. Howard, DM-ASD, (407) 867-3748





Tank and Pipe Drawing Showing Dimensions for Calculating X and Y

Selecting Optimum Sizes for Cryogenic Vacuum-Jacketed Lines Based on Minimum Heat Input

When designing new cryogenic transfer systems using vacuum-jacketed piping, it is desirable to size the piping to provide the minimum heat input for the required fluid transfer rate. Cryogenic transfer systems for space launch vehicles are usually liquid hydrogen and liquid oxygen. Normally, vacuum-jacketed pipe is used for the transfer systems to minimize heat input on both liquid oxygen and liquid hydrogen.

Vacuum-jacketed piping is expensive in comparison with bare-wall pipe. Heat enters the cryogen being transferred in the vacuum-jacketed pipe from the air around the pipe. Heat is also generated by the friction of fluid as it moves against the pipe walls as it is transferred through the pipe.

Heat transfer from the air through the walls of the pipe increases linearly with the pipe diameter because the heat transfer area is directly proportional to the diameter. Heat transfer from friction is high for small pipes and decreases rapidly as the pipe diameter increases. The total heat input is the sum of these two heat inputs. When these values are plotted as shown in the graph, the total has a minimum heat input value for a 6-inch pipe.

A Microsoft Excel program was written to determine the pipe size with the minimum heat input for the desired flow rate for liquid hydrogen, liquid oxygen, liquid nitrogen, and liquid helium vacuum-jacketed transfer piping. The graph is a plot of the results of liquid oxygen being transferred through a 1,500-foot-long vacuum-jacketed transfer line at 150 gallons per minute. The program calculates the heat input for all sizes from 2-1/2-inch to 12-inch nominal pipe sizes for schedule 10 piping. Goal Seek is used to rapidly solve for the friction factor (f) using the Colebrook equation for each size calculation:

$$\frac{1}{\sqrt{f}} = -2 \log_{10}\left[\frac{\varepsilon/D}{3.7} + \frac{2.51}{R\sqrt{f}}\right]$$

where:

ε/D = relative roughness

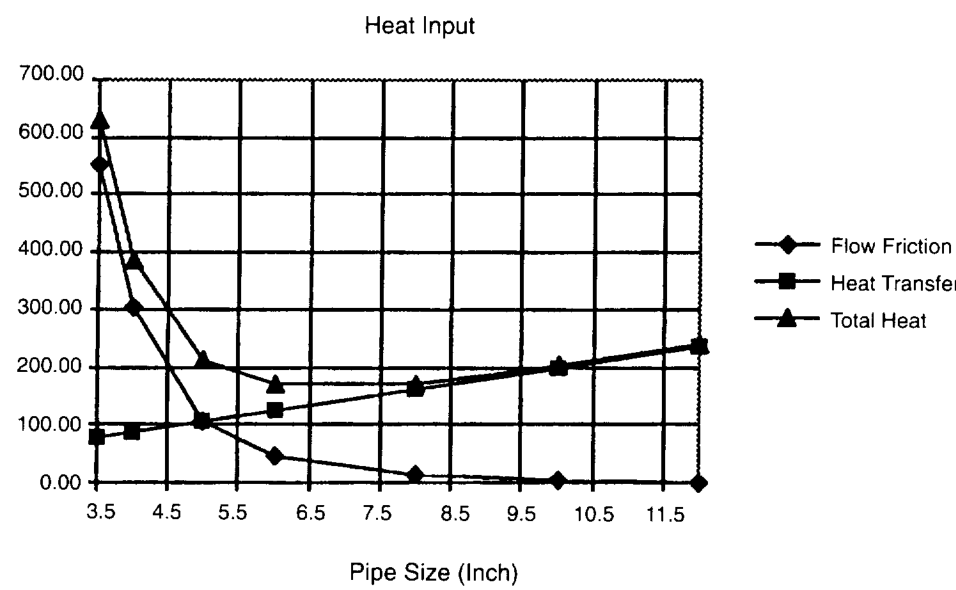
R = Reynolds number

Macros are used to automatically step through the calculations. The program will also make bare-wall pipe calculations for liquid oxygen and liquid nitrogen.

The program operator selects the cryogen being transferred, and a macro loads the thermophysical properties. The programmer then inputs the desired flow rate and the length of pipe line being used for the transfer and selects the calculate button. A series of macros leads the program though calculations for each size pipe, lists all the heat inputs, plots the results, and selects the optimum pipe size.

This type of analysis and use of this program saves on the initial system costs and the continued costs of cryogenic logistics throughout the years the system is being used. It is particularly valuable when the densification of the cryogen is required by subcooling.

Contact: F.S. Howard, DM-ASD, (407) 867-3748



Reusable Solid Rocket Motor Enhancement Tool

The Advanced Systems Division (DM-ASD) of the Mechanical Engineering Directorate is currently working with United Space Alliance Systems Engineering to design and fabricate a new data acquisition instrumentation panel for use during solid rocket motor assembly operations in the Vehicle Assembly Building (VAB).

The Reusable Solid Rocket Motor Stacking Enhancement Tool (SSET) project will replace three existing segment-processing data acquisition panels with a single panel providing updated processors, an intuitive "smart" graphical user interface, and the capability of recording all data.

At the present time, segment shaping, alignment, and segment mating are accomplished and verified using several different measuring systems. Three of these data acquisition systems used during segment assembly operations will be updated with enhanced capabilities during the SSET project. These systems are the Temposonics Panel, which displays the distance to mate and the segment rate of engagement during motor assembly; the Sine Bar Panel, which calculates the segment shape; and the segment Lifting Beam Load Panel, which displays the loads in the segment lifting beam drop links and leveling links.

The current lifting beam load panel does not have the capability to record segment lifting beam loading, which is highly desirable. Also, the current data acquisition systems do not provide a single display for the operator. The data displays are extremely limited in the information they provide and are difficult to read.

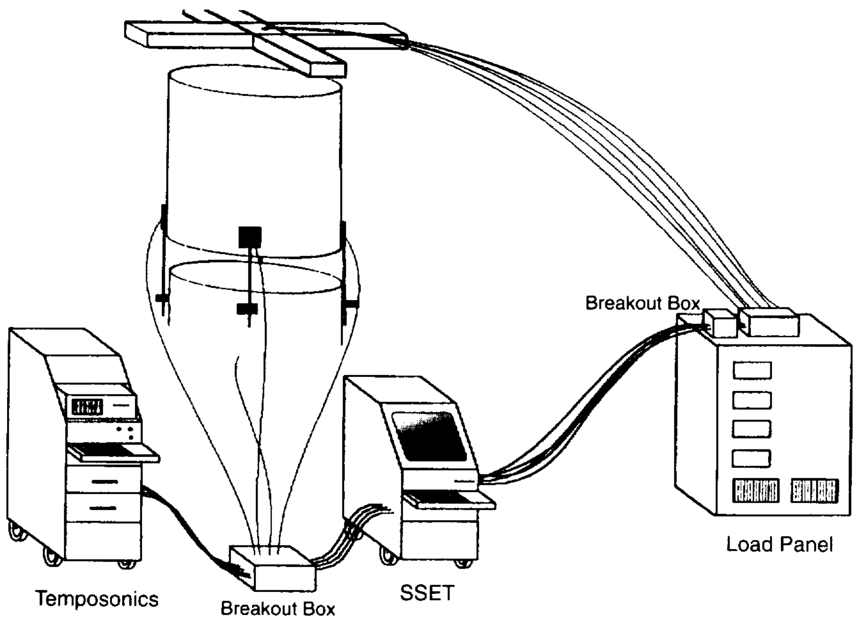
Phase One of the SSET project was to build a proof-of-concept panel, which combined the functions of the Temposonics and Lifting Beam Load Panels. The proof-of-concept panel was fabricated and tested in NASA's Advanced Systems and Development Laboratory. Upon completion of the laboratory testing and checkout, the SSET panel was further tested during inert segment operations in the VAB. The next phase of testing was a demonstration of the proof-of-concept panel's capability by "shadowing" flight hardware operations. During testing in the flight operations area, personnel from all disciplines who will be involved in using the SSET panels, and the data supplied by it, were able to review and critique the SSET proof-of-concept panel. Subsequently, at the end user's request, the SSET panel was used to graphically display and gather engineering data for evaluation during STS-79 RSRM destacking operations.

Phase Two of the SSET project, design fabrication and testing of four SSET panels, commenced October 1996. Activities planned for 1997 include establishing SSET panel design requirements; development of the hardware, electrical, and software designs; and initiation of panel fabrication. The Phase Two SSET production panels will be turned over to United Space Alliance to replace their present systems. These panels will be combining the functions of the Temposonics panel, Lifting Beam Load panel, Sine Bar Panel, and RSRM segment shaping prediction program into one console while providing an intuitive graphical user interface and the capability of recording all data.

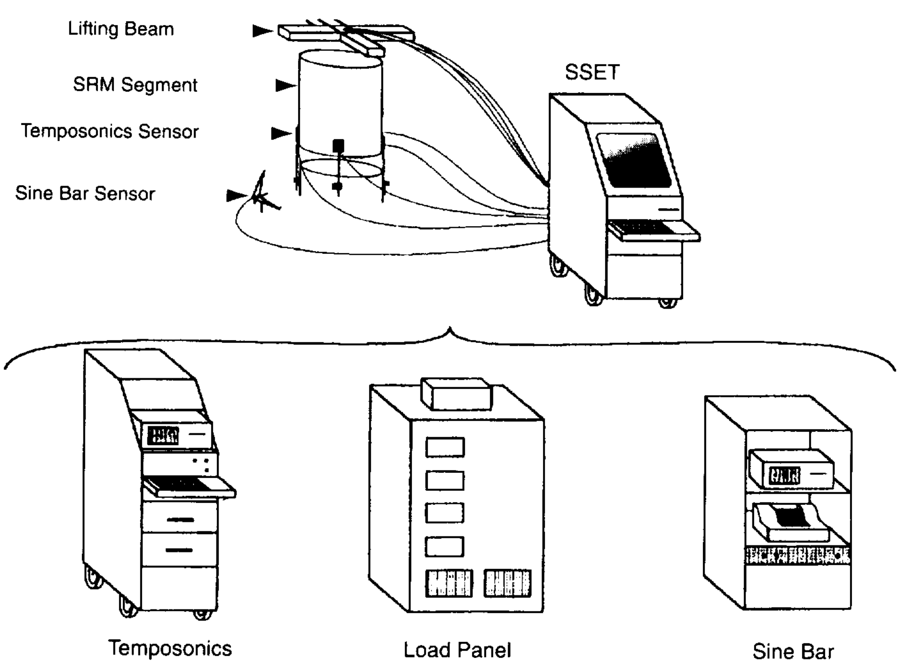
The last phase of the project will examine replacing the current Temposonics sensors with a three-dimensional position sensor.

Key accomplishments:

- January 1996: DM-ASD requested by Space Shuttle Vehicle Engineering to investigate improvements to the RSRM segment assembly data acquisition systems.
- February 1996: Phase One design and development of SSET proof-of-concept panel initiated.
- June 1996: Laboratory testing and evaluation of SSET proof-of-concept panel.
- July 1996: Demonstration of SSET proof-of-concept panel by "shadowing" inert segment handling operations and assembly of flight hardware.



Phase One Proof-of-Concept "Shadowing" Configuration



Present/Future System Configuration

- August 1996: At user's request, "shadowed" the destack of STS-79 RSRM's to gather data for engineering evaluation. Phase One completed.
- October 1996: Funding approved for design and fabrication of four production SSET panels.

Key milestones:

- 1997: Generate SSET design requirements. Development of SSET panel hardware, electrical, and software designs. Begin fabrication and assembly of first SSET production panel.

Contacts: P.G. Henderson and A.J. Bradley, DM-ASD, (407) 867-4181

Participating Organizations: I-NET, Inc., and NASA/United Space Alliance Vehicle Engineering

Analysis of Transfer Piping During Cryogenic Pipe Line Chill Down

Equations used in the Space Shuttle Cryogenic Propellant Systems software are now available in a Microsoft Excel program for engineers to solve two-phase flow liquid oxygen transfer problems. The two-phase flow condition exists during system chilldown when heat is being removed from the piping and piping system components. Once the chilldown is complete, single-phase liquid flow should be maintained.

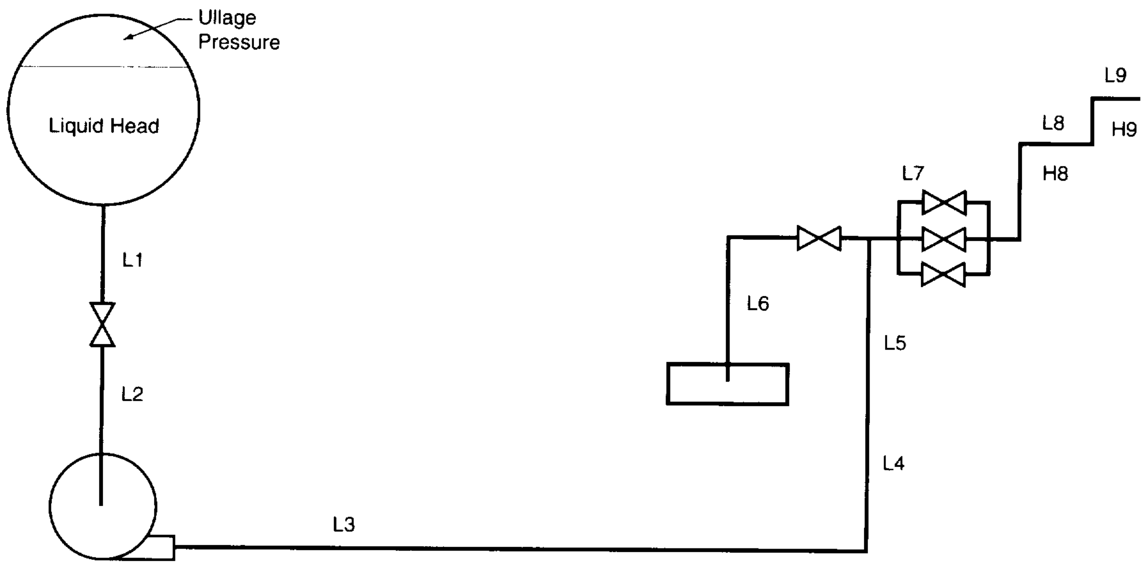
The equations are based on a computer program written in 1974 by R.O. Voth, W.G. Steward, and W.J. Hall in a "Study of Cryogenic Propellant Systems for Loading the Space Shuttle," to analyze two-phase flow for design of cryogenic transfer piping.

The schematic shows the typical arrangement of piping for a liquid oxygen transfer system. The program user inputs the length and diameter of piping runs.

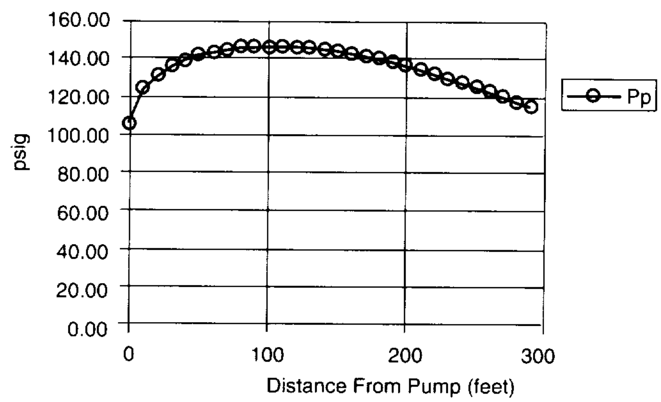
Calculations consider the pressure and flow at the interface of the wall of moving liquid and the vapor downstream. Pressure drops are calculated from the liquid flow and the gas flow downstream. The program calculates the maximum pressure generated at a given distance down the pipe as shown in the graph "Peak Pressure." As liquid oxygen is vaporized and expands, the velocity of the vapor produced leaving the pipe is limited to the velocity of sound in the pipe at that pressure and temperature. This causes the pressure in the pipe to build to a value larger than that produced by single-phase liquid flow. When the pipe diameter is reduced, the maximum pressure rises significantly.

The program calculates the chilldown time (see the respective graph). This data is useful in determining the system operating timing. The program can also be used to calculate the water hammer generated by the time required to close shutoff valves against liquid oxygen flow. The curve shown in the graph "Water Hammer" demonstrates the importance of taking plenty of time to close the system valves. The program runs on Microsoft Excel, version 5.0.

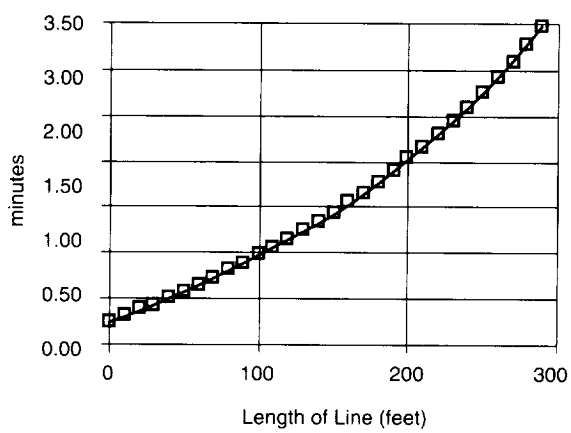
Contact: F. S. Howard, DM-ASD, (407) 867-3748



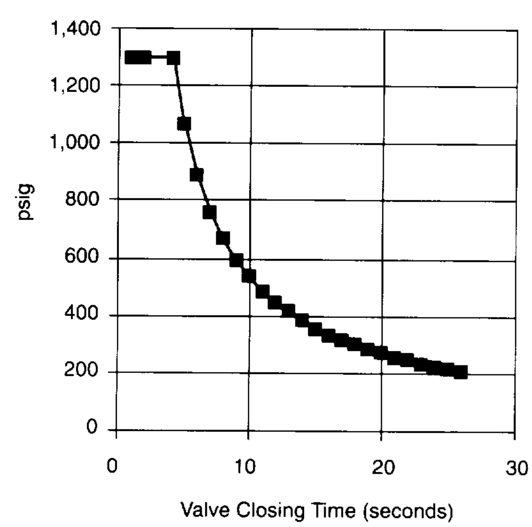
Piping for a Liquid Oxygen Transfer System



Peak Pressure



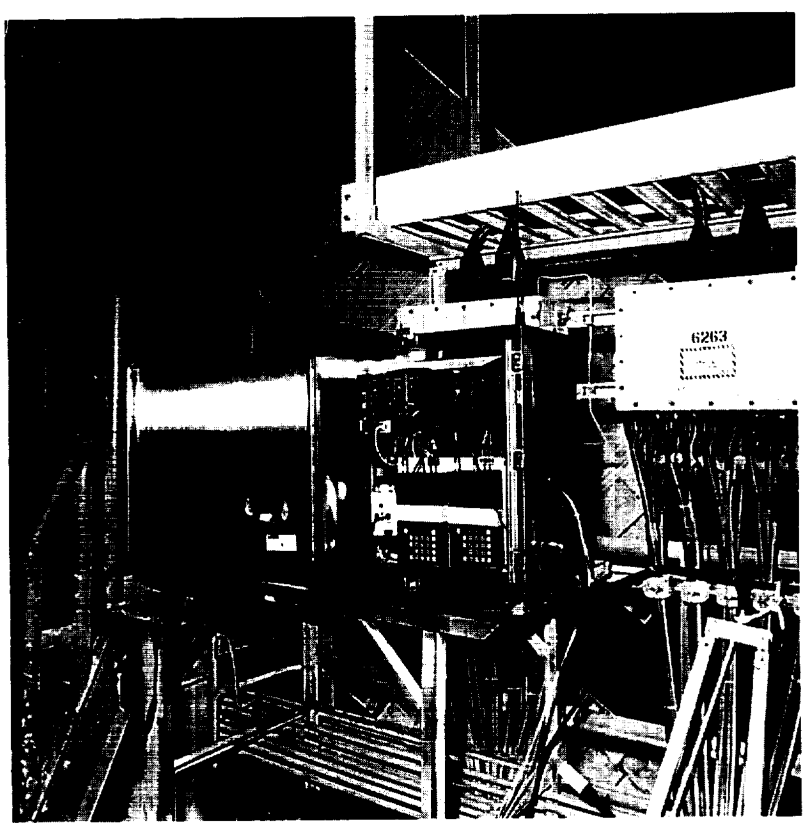
Chilldown Time



Water Hammer

Nonintrusive Flow Measurement System (NFMS)

During 1996, extensive research and development were focused toward application on nonintrusive techniques to support Space Shuttle operations prior to launch. An important aspect was the use of ultrasonic flowmeters to accurately measure loading of fuel monomethylhydrazine (MMH) and oxidizer (nitrogen tetroxide) into the Orbital Maneuvering System and the Reaction Control System tanks. In this application, ultrasonic technology proved to be flexible, cost effective, reliable, hazardfree, productive, and streamlined. Moreover, use of SCAPE suits could be eliminated. Several catastrophic failures associated with the conventional turbinemeters used in hypergol loading clearly attest to the need for adaptation of nonintrusive technology both in terms of cost savings and improving operational safety.



Nonintrusive Hypergol Flow Rate Measurements in Launch Pad 39B

When Space Shuttle Discovery experienced a buckled cooling plate due to the freezing of water through its cooling system, ultrasonic technology again proved valuable. Measurement of extremely low flow rates (0.1 to 0.3 feet per second) through small-diameter (1/4-inch) pipes inside the orbiter cargo bay dictated the use of nonintrusive technology. Using ultrasonic flowmeters manufactured by Panametrics, in situ measurements were made on 1/4-inch pipes on the oribters Discovery and Atlantis, and the results were corroborated with those from flow models developed by Rockwell.

Key accomplishments:

- 1996: Successfully demonstrated the use of ultrasonic technology to monitor and measure hypergol loads. Demonstrated the feasibility of ultrasonic technology to measure extremely low flow rates on the orbiter water cooling system.

Key milestone:

- 1997: Extension of ultrasonic technology to other areas and seamless adaptation into Shuttle operations.

Contact: R.J. Werlink, DM-ASD, (407) 867-3748

Participating Organization: I-NET, Inc. (R.N. Margasahayam) and EG&G Florida, Inc. (O.J. Varosi, R. Neely, and L. Albright)

1/4-Inch Cooling Plate Tube Ultrasonic Flowmeter Test on Discovery

Condition Monitoring and Fault Identification in Rotating Machinery (CONFIRM)

Loading of the Space Shuttle external tank with liquid oxygen is accomplished via a pump/motor/bearing assembly located at the northwest corner of Launch Complex 39. Since the assemblage is vital to the success of any mission, it is continuously monitored to detect, identify, and assess its condition and take appropriate actions to minimize the impact on launch. Condition or health monitoring technologies that are being considered for use fall into two major categories: Mechanical Vibration Signature Analysis (MVSA) and Motor Current Signature Analysis (MCSA). Also, the Acoustic Emission (AE) technique and a Lube-Oil Analysis (LOA) will be used as early warning tools for predicting impending failures. Mechanical, electrical, and flow-induced problems will be addressed in this multi-year research program.

The present effort is directed toward the installation of a pump/motor/bearing assemblage at the Launch Equipment Test Facility (LETF) to simulate Launch Complex 39. This setup will provide a test bed for research and development, testing of variable frequency drives, and hands-on training for launch pad personnel. The assemblage will serve as a platform for the evaluation of newer online condition/health monitoring technologies. Such online machinery monitoring will lead to improvements in operational efficiency, eliminate shutdowns, reduce maintenance costs, and prevent catastrophic failures. Early detection and correction of impending failures will significantly improve reliability while enhancing safety.

Key accomplishments:

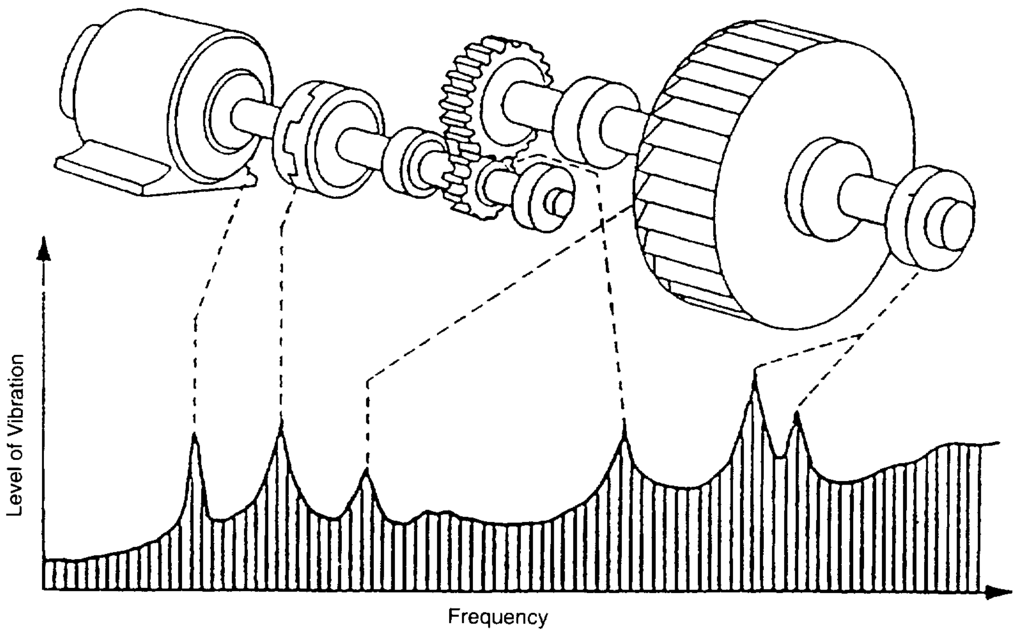
- 1996: Implementation of the liquid oxygen pump assemblage at the LETF. Procured and validated SKF condition monitoring hardware and software on the 75-horsepower pump assemblage.

Key milestone:

- 1997: Assess condition monitoring technologies and variable frequency drives on the 300-horsepower pump assemblage.

Contacts: A.F. Rodriguez, DM-MGD, (407) 867-7969, and R.J. Werlink, DM-ASD, (407) 867-3748

Participating Organizations: I-NET, Inc. (R.N. Margasahayam and M.J. Ynclan) and EG&G Florida, Inc. (R. Neely and O. Varosi)



Low Frequency Range
- Unbalance
- Misalignment

Speed or Displacement Mode

10 hertz to 1 kilohertz

Intermediate Frequency Range
- Vibration due to gear meshing
- Trouble due to resonance

Acceleration (LOW) Mode

1 to 10 kilohertz

High Frequency Range
- Vibration of rolling bearing
- Fluid vibration

Acceleration (HIGH) Mode

7 to 40 kilohertz

Frequency Distribution of Abnormal Vibration in a Rotating Machine and Measurement Mode

Electronics and Instrumentation

The Electronics and Instrumentation Technology program at the John F. Kennedy Space Center (KSC) supports the development of advanced electronic technologies that decrease launch vehicle and payload ground processing time and cost, improve process automation, and enhance quality and safety. The program includes the application of electrical and electronic engineering disciplines, particularly in the areas of data acquisition and transmission, advanced audio systems, digital computer-controlled video, environmental monitoring and gas detection instrumentation, and circuit monitoring instrumentation. The near-term program focuses on Shuttle ground processing enhancement by developing instruments that improve ground support equipment used in monitoring, testing, and vehicle processing. The long-term program will develop technology for support of future space vehicles, payloads, and launch systems by advancing the state of the art in launch vehicle and payload processing electronics and instrumentation to reduce costs and improve safety.

Laser-Based Alignment Tools

Over the previous 4 years, a variety of laser-based alignment tools has been developed for use at KSC. A few of these tools are general purpose in nature, but most have been designed and fabricated to solve specific problems related to Shuttle processing. Specific application systems for which substantial development was done to meet the requirements of the end users are:

1. External Tank Positioning-Forward End

   a. Problem: Find a way to facilitate the alignment of the external tank (ET) when it is hanging from a crane and needs to be lowered onto alignment pins attached to the solid rocket boosters (SRB's).

   b. Solution: Hardware was designed and fabricated to allow lasers and batteries to be located inside the SRB alignment pins. The resultant laser beams shoot straight up to hit targets that are temporarily attached to the ET. The ET can then be moved laterally until the laser spots hit the center of the targets; at which position, the ET can be lowered directly onto the SRB alignment pins. (Note that these alignment pins are not part of the flight hardware.)

2. ET Centering and Alignment-Aft End

   a. Problem: After the forward end of the ET is hung from the SRB's, the aft end is still free to move. It is necessary to locate the ET precisely in between the SRB's and then lock it into position.

   b. Solution: Hardware was fabricated and converted to full ground support hardware that uses both ultrasonic ranging and laser crosshairs to allow the accurate location of the ET in between the SRB's. This hardware is composed of magnetically attached transducers that are placed onto the SRB's and project both a laser crosshair pattern and ultrasonic pulses at the ET. The ET can then be moved until the laser crosshair is centered on a prelocated spot on the ET. A battery-operated control module in communication with the transducer modules displays the distance between the ET and each SRB and allows the ET to be shifted left and right until it is centered.

3. Vent Hood Positioning

   a. Problem: A vent hood is placed over the top of the ET to remove cryogenic fuels and oxiders that have boiled out of the tanks. Positioning of the vent hood relative to the ET is cumbersome and inaccurate due to access restrictions.

   b. Solution: A laser/ultrasonic tool was constructed that sits on top of the ET and projects both a laser spot and ultrasonic pulses directly upward onto the vent hood. The vent hood can then be laterally moved until the laser spot is centered. A remote module, attached via a cable to the tool, displays the distance from the ET to the vent hood using the ultrasonic pulse time delays. This information allows the vent hood to be lifted and lowered until it is at the correct distance from the ET.

4. Laser Plumb Bobs

   a. Problem: When horizontal payloads are positioned 30 feet in the air over the payload compartment, it is difficult to locate them so that when they are lowered they mate correctly with the orbiter latches.

   b. Solution: Hardware was constructed to hold both the batteries and lasers so a laser beam is projected directly downward from the payload. Consequently, the laser spots show the users where the payload would be if it were lowered. This allows the users to easily locate the horizontal payload over the orbiter payload compartment even though it is 30 feet in the air.

5. Payload Relative Height Monitor

   a. Problem: When vertical payloads are readied for insertion into the payload compartment, it is important to determine the height at which they will end up in the orbiter. This would help to ensure such items as protective shrouds placed over previously installed payloads are not affected by the insertion of a new payload.

   b. Solution: A laser was installed onto a rotatable platform that can be accurately leveled. This platform is then held on a rack and pinion system that allows the platform to be raised and lowered. In practice, the system is magnetically attached to an I-beam within the payload changeout room and the laser platform is leveled. The laser can then be aimed at a point on the payload by rotating the platform and raising/lowering the platform. The laser can then be aimed into the orbiter by rotating the platform to see where that point on the payload will be when it is laterally moved into the orbiter. The platform can be raised or lowered until the laser spot hits other hardware to determine the final clearance.

Contact: J.D. Collins, DL-ICD-A, (407) 867-1603

Participating Organization: I-NET, Inc.

Ultrasonic Leak Detector

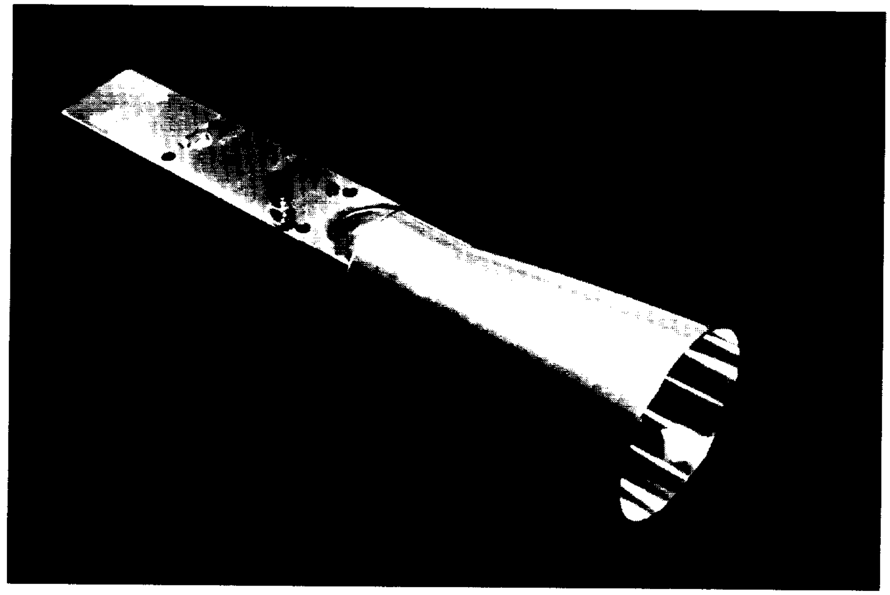
On three separate occasions during the period from the fall of 1990 to the spring of 1992, engineers on the Engineering Support Contract provided quick-response, prototype, ultrasonic detection hardware to help find leaks. In each case, a leak source was found, but the long-term use performance of the units was questionable. Background noise and inadequate sensitivity made locating the leaks tedious and difficult. In two of the cases, users with good hearing spent several hours walking around solid rocket booster segments before marking potential leak sites. Yet, in all three cases, an argument could be made that the ultrasonic detection hardware was able to locate the leak sources successfully, even if the performance was borderline. Off-the-shelf ultrasonic leak detection hardware exists and has been used by several operations groups; but it has not been successfully used in many cases due to poor sensitivity, difficulty of use, and a complicated operator interface. Consequently, both the Advanced Operations Office and the Safety Office felt that development of quality, user-friendly, ultrasonic leak detectors was a worthwhile endeavor.

Jet-type leaks (i.e., leaks that are not laminar) create turbulent pressure variations that can be detected with an ultrasonic transducer. By developing very sensitive ultrasonic detection equipment, small leaks can be located quickly from a remote location. The following areas warranted study for potential design improvements over off-the-shelf instruments: choice of transducers, preamp design, processing circuit design, air-coupled-system collector design, and contact-system transducer design.

A newly developed ultrasonic transducer, the 40R16A from American Piezo Ceramics, had slightly higher sensitivity and almost half the noise of the standard Panasonic unit. Consequently, use of this new transducer, coupled with a new preamp design, doubled the earlier performance. An innovative processing module was constructed to downconvert the ultrasonic signal to the audio frequency range so a user can listen to the ultrasonic signals with a pair of headphones.

Another significant improvement over off-the-shelf systems was achieved by the use of collecting horns, which collect and focus the ultrasonic signals in the air onto the transducer, significantly improving the system performance.

In some cases, operations personnel need to locate ultrasonic leaks at close range (e.g., along a seam). For these cases, an ultrasonic pencil, which is essentially the same as the transducer geometry previously described but with the horn removed, allows the transducer to be moved closer to the potential leak source. The proximity of the transducer to the seam more than makes up for the removal of the collecting horn and allows for sensitive leak detection.



Key accomplishments and milestones:

- Development of high-performance ultrasonic leak detector systems using innovative circuitry, improved transducers, collecting horns, operator-friendly design, near-field configurations, and contact sensors.

- After receiving input from field testing, implemented a new design, enhancing the ease of use of the unit and making it more rugged. Ten of these new systems were fabricated. Three were delivered to KSC operations and are being used to search for leaks on flight hardware and to locate leaks in ground support equipment. Two systems were delivered to Johnson Space Center where documentation and testing led to NASA approval for the use of this hardware on Shuttle missions. One unit is with Boeing in Huntsville, Alabama, where interest has been shown in using it on the Space Station; one is with Rocketdyne for use in testing the Shuttle main engines; and one is with the U.S. Air Force for use in fuel tank leak tests.

- Patent currently pending with the U.S. Patent Office covering the electronics innovations and the collecting horn design.

- Exclusive-use license signed with UE Systems, Inc., which plans to commercialize aspects of the new design. One of the existing units with this company aids them in converting aspects of the design to the commercial arena.

Contacts: C.A. Barrett, DL-ICD-A, (407) 867-4449; J.D. Collins, DL-ICD-A, (407) 867-4438; and C.G. Stevenson, TV-MSD, (407) 861-3603

Participating Organizations: I-NET, Inc. (R.C. Youngquist) and Rocketdyne

Radio Propagation Mapping Using the Global Positioning System

The objective of a radio communications system is to cover a specific geographical area and produce reliable communications within that area. There are certain factors that contribute to radio communications being unreliable or unpredictable in a given geographical area.

Radio waves ideally propagate outward in a uniform pattern losing energy as the wave spreads out. Whether manmade or natural, there are obstacles that scatter the radio waves and make the prediction of reliable communications difficult. When the wave is scattered in this fashion, it is called fading, a difficult phenomena to predict for a given geographical area.

Predicting the signal strength at a location is complicated. In a radio system when the attenuation of the signal becomes large due to fading, communications cannot be relied upon. A radio system can be installed and working properly but, over time, buildings may be built and the surrounding vegetation will grow. This all contributes to loss of communications.

A location in the area of coverage that does not have good communications is called a "dead spot." A radio system operator only finds out about these problems when users complain. In most cases, the user cannot define the exact location of the problem. A means to determine these dead spots is needed that is relatively fast and accurate and has the ability to track changes as the system environment changes over time. A global positioning system (GPS) can be teamed with a radio receiver to find and map these dead spots. These maps give the radio system operator insight into the reasons for poor system performance so changes can be made in the radio system. The map also provides an ideal method for evaluating changes in the system over time.

There are four main components to this system: (1) the GPS receiver (gives the current position), (2) a differential receiver (makes corrections to the GPS receiver and produces a more accurate position), (3) a radio receiver (measures the signal strength of the radio frequencies), and (4) a laptop computer (controls all the receivers, writes the information to a file, and generates a map). All four components are mounted in a mobile van, and the data is collected by driving the mobile van to the areas of interest and recording the information about signal strength and position. An example output to the laptop is shown in the table.

Date	Time	Position	Frequency	Signal Strength
8/10/96	9:00:01	40:22:40 latitude 120:45:34 longitude	173.001 Mhz	-70 dBm

The mobile van is driven through an area of interest. The laptop computer has a background map on its video display. If the measurement needs to be recorded, the operator presses "return" on the computer; and the information of frequency, signal strength, and position is recorded to a file.

A map is produced from the measurements and provides a visual representation of the radio system performance over a given geographical area of interest. The operator can see a large area that the transmitter covers and make informed decisions from this information. Data are accurately and quickly gathered in an efficient manner. This method also produces a history of the radio system that can trace causes and effects.

Combining these three technologies in a unique way leads to understanding of an important natural resource, radio communications. This unique approach ensures the natural resource of radio frequencies will be used to its fullest extent.

Key accomplishment:

- 1996: Successfully demonstrated the use of GPS to make radio propagation maps.

Key milestones:

- 1995: Identified the need for a better way to analyze radio propagation and equipment needs. Identified various vendors as suppliers.
- 1996: Procured necessary equipment and software. Integrated vendor-supplied software and GPS hardware. Received radio equipment.
- 1997: Install hardware into a mobile van. Write custom software to integrate the GPS with the radio receiver. Software will output radio signal strength and GPS coordinates into a database file for postprocessing the vendor-supplied Geographical Information System (GIS) software.

Contact: F.M. McKenzie, DL-CMD-R, (407) 867-1391

Participating Organization: I-NET, Inc. (R.B. Birr)

Self-Contained Magnetic Field Sensor

The goal of this project is to design a self-contained sensor capable of measuring magnetic fields generated by lightning strikes. This sensor will record the peak amplitudes of all three orthogonal components of both the magnetic field and its derivative. The sensor will be installed in the Payload Changeout Room (PCR) on each launch pad. Information provided by the sensor will be used to assess the magnitude of the voltages induced into cables attached to instrumentation or electronic equipment inside the PCR.

Lightning strikes, which usually carry currents in the order of tens of thousand amperes with risetimes in the order of a few microseconds, generate large magnetic fields. The rapidly changing magnetic field causes an electromagnetic force to be induced into electric conductors exposed to it. Depending on the area covered by these conductors, the induced voltage can reach several kilovolts even inside the PCR.

The sensor has been designed to operate unattended for up to 2 weeks on fully charged batteries. It consists of the following modules:

- Antenna loops (used to generate a small signal when exposed to a varying magnetic field)
- Input amplifiers and integrators (amplifies and integrates the voltages induced into the sensing loops)
- Data converters (converts the analog waveforms into digital form)
- Data processing and storage (checks if the waveforms exceed the threshold levels and stores the waveforms for later retrieval)
- Real-time clock (used to time stamp every waveform to allow correlation with other sensing devices)
- Data input/output (used to interface with a personal computer to retrieve data and to reset the sensor)

Key accomplishments:

- Designed, built, and installed the self-contained magnetic field sensor.
- Developed the software for data retrieval and analysis.

Key milestones:

- Continue to monitor the magnetic fields induced inside the PCR.
- Prepare a final report of the results of the testing at the PCR.

Contacts: W.E. Larson, DL-ICD-T, (407) 867-3185, and G.L. Thomas, EI-C-A, (407) 861-4117

Participating Organization: I-NET, Inc. (P.J. Medelius, H.J. Simpson, J.D. Taylor, and J.J. Henderson)

Nonintrusive Cable Tester

The objective of this project is to design and build a nonintrusive electrical cable tester for checkout of the Space Shuttle. The Space Shuttle uses dedicated signal conditioners (DSC's) for the purpose of conditioning transducer outputs and other signals to make them compatible with orbiter telemetry, displays, and data processing systems. The DSC's are located throughout the orbiter, often in difficult-to-access locations in the vehicle fuselage. When troubleshooting a potential instrumentation problem, cables frequently have to be demated to verify the cable is not the source of the problem. Once a cable is demated, all systems that have a wire passing through the connectors have to be retested when the cable is reconnected. This results in many hours of revalidation testing on systems that were unrelated to the original problem. The nonintrusive cable tester will save many hours of testing during every Shuttle flow.

A cable can be nonintrusively tested by applying a signal to one end of the cable and using a magnetic pickup coil to monitor the presence of that signal along the length of the wire. A short or open circuit along the cable would cause the receiver to lose the signal past that point thus indicating the location of the problem. Existing commercial cable-testing equipment injects a signal in the several hundreds of kilohertz range. The use of such commercial equipment is not feasible when the DSC's are on line, since the DSC's frequency response is limited to a few tens of hertz, and a several hundred kilohertz signal would be severely attenuated by them. The presence of the DSC's makes the use of a low-frequency injection signal imperative. This results in two major challenges:

1. The amount of energy radiated by a shielded cable is greatly reduced at lower frequencies since the shielding of the cable becomes almost 100 percent efficient.

2. The voltage at the output of a pickup coil, when subjected to a varying magnetic field, is directly proportional to the frequency of the signal being picked up. A 100-kilohertz signal would result in an output voltage 10,000 times larger than the output voltage from a 10-kilohertz signal.

These two challenges were overcome by using a very narrow bandpass filter followed by a high-gain amplifier stage and a quadrature demodulator This high-gain amplifier is required to amplify the small voltage at the output of the pickup coil. An injection frequency of 10 hertz was selected in order to ensure the signal applied to one end of the cable could pass through the DSC's. Since the amount of noise that is applied to the amplifier's input is directly proportional to its bandwidth, a 16th order bandpass filter with a 0.1-hertz bandwidth at a 10-hertz center frequency was used to eliminate signals outside the band of interest. The amplifier/filter combination was designed to have a gain of about 100 decibels. The design of the quadrature detector allows for the accurate detection of the presence of an injected signal even when the signal-to-noise ratio is much smaller than unity.

Key accomplishments:

- Designed and prototyped the high-gain amplifier, narrowband filter, and the quadrature demodulator.
- Performed laboratory testing of the system.

Key milestones:

- Continue laboratory testing of the nonintrusive tester.
- Conduct tests through the DSC's.

Contact: W.E. Larson, DL-ICD-T, (407) 867-3185

Participating Organization: I-NET, Inc. (P.J. Medelius and H.J. Simpson)

Pad Personnel Locator

The objective of the Pad Personnel Locator project is to design and develop a radio frequency (RF) transponder-based system using RF identification tags. There is a requirement to monitor the location of personnel within the launch pad perimeter after cryotanking begins during Shuttle countdown for launch. These personnel include the astronauts, closeout crew, ice team, and, if necessary, rescue personnel. Monitoring these personnel is currently performed using a combination of television camera monitoring and radio link verbal communication. In the event of an emergency at the launch pad, location of injured personnel could be difficult since smoke and deluge water could obscure the view of the television cameras. The ability to accurately determine the location of injured personnel would allow rescue crews to immediately reach the desired location, minimizing their own exposure to the hazardous conditions present at the launch pad.

The approach selected to track and locate personnel as they move through the launch pads is based on the use of radio-frequency-activated identification (RF-ID) tags. These RF-ID tags do not require any external power source for operation, thus making their installation easy and inexpensive. Each RF-ID tag will contain information that will uniquely determine its position at the launch pad. Personnel working at the launch pad will be equipped with a transponder unit that will perform the following functions:

1. Emit an ultra-low power UHF signal that is received by nearby RF-ID tags.

2. Receive the response signal sent back by nearby RF-ID tags.

3. When polled, retransmit to a control station the information received from the RF-ID tags, along with their relative signal intensity as received by the transponder.

The RF-ID tags are designed to respond to a specific code. The tags will be placed along the launch pad structure in such a way that no two tags with the same code will be within the range of the interrogating unit. The interrogating unit will sequentially transmit all different codes (three or more) providing for enough time for a potential response for the correct tag within its range.

Key accomplishments:

- Designed and prototyped the RF-ID tags and the transponder/interrogator device.
- Developed the test software for the transponder and the control station.

Key milestones:

- Continue laboratory testing of the performance of the RF-ID tags and the interrogator.
- Conduct field trials of the system in the laboratory and on the launch pad.
- Evaluate the performance of the system in field tests.

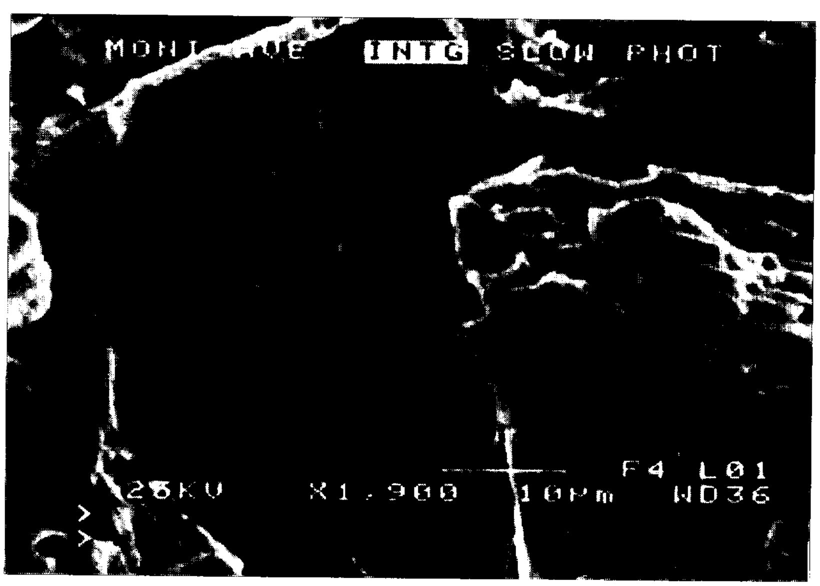
Contact: W.E. Larson, DL-ICD-T, (407) 867-3185

Participating Organization: I-NET, Inc. (P.J. Medelius, H.J. Simpson, J.D. Taylor, and S.J. Romine)

Development of an Expert System To Assist Fractographical Analysis

Failure analysis of flight hardware and ground support equipment frequently requires the examination of a fracture surface, characteristics of which vary with material, environment, and loading condition. As there are almost an unlimited number of combinations of these three parameters, fractographical analysis often requires a literature search and discussion with peers. The need to expedite these time-taking components of fractographical analysis is high, especially for flight-critical failures.

Although the fractographical information associated with the primary features of common materials is readily available in atlas-type publications, the information that is system specific or associated with secondary features is difficult to locate in the open literature. An expert system is desired so these individual pieces of information can be stored as they are found and grow in expertise. As most engineering materials are common to NASA and private industry, the tool can be easily commercialized.



Scanning Electron Micrograph of the Fracture Surface (Magnification: 1,900X)

This effort has two distinctively different components, software engineering and materials science. The former is done inhouse headed by NASA Advanced Systems and Analysis Division, and the latter is done by NASA Logistics Operations, Materials Science Division. As the tool has to serve as a peer to users, outside experts need to be invited to input their expertise.

Key accomplishments:

- Engineering support was acquired from software experts for 1 man-year.
- Those who are interested in or have attempted the development of a fractographical expert system were identified via the network.
- An outside expert from Southern University was secured for input.
- A prototype fractographic reports database was developed.

Key milestone:

- A preliminary logic tree for steel will be established.

Contact: R.U. Lee, LO-MSD-2T, (407) 867-8749

Participating Organizations: NASA (P.A. Engrand), I-NET, Inc. (N. Tuttle), and Southern University (Dr. R. Diwan)

Ultraviolet/Infrared Hydrogen Fire Detector

The objective of this project was to develop a reliable hydrogen flame detector that can detect the presence of a small hydrogen flame, even when reflections from the large flare stack are received. Hundreds of commercially available detectors are used on Launch Pads A and B to monitor the hydrogen fuel systems for fires. These detectors are prone to troublesome false alarms from reflections of the large flare stack flame that is continuously lit during fueling of the external tank. Alternative commercially available flame detectors combine an ultraviolet (UV) detection system with an infrared (IR) detection system to avoid false alarms by requiring high irradiance and flame flicker in both UV and IR bands. Hydrogen fires emit radiation in both bands, but the IR detection circuit in most commercial detectors measures in the irradiance band from carbon dioxide, a byproduct of hydrocarbon flames.

Another problem with commercial units is the flicker detection circuit. The flicker detection circuit, a feature intended to avoid false alarms from hot objects or solar reflection, can cause false alarms due to reflections from the flare stack or changing shadows from personnel or animal movements nearby. An advantage of combined UV and IR detection is the reduction of false alarms due to nonflame sources that emit only UV radiation such as lightning or welding arcs.

Measurements of UV and IR radiation were taken using small hydrogen flames and a large flare stack in the background. Results of the measurements conducted with small flames and with the large flare stack allowed certain important characteristics of the flames to be identified, which was used as part of the detection algorithm. Two parameters were selected to implement the algorithm:

1. When the radiation detected by the IR and UV detectors originated from the same source and were received directly by the detectors and not from a reflection, the time-domain cross-correlation of the UV and IR radiation showed waveforms with a high degree of similarity. When the detectors were not pointing to the hydrogen flame but were receiving reflections from possibly more than one source (e.g., UV from the hydrogen flame, IR from the sun), the cross-correlation showed vastly different waveforms.

2. The flickering of the small flame was found to be much faster than that of the flare stack. Frequency analysis of the IR waveforms showed that the flickering of the flare stack is concentrated under 5 hertz, while the small flame extends into tens of hertz.

   a. The output of the UV detector, which is originally a series of pulses, is electronically integrated in order to convert it into a continuous signal.

b. One UV and two IR signals are converted to digital form by the analog-to-digital converter.

c. The digital signal processor (DSP) computes the frequency spectrum of the flickering of the IR signal. The DSP also computes the cross-correlation of the UV and the IR signals.

d. If the cross-correlation is larger than a preset threshold (0.5 to 0.6, where a value of 1.0 means identical waveforms) and the analysis of the flickering indicates that the source of the radiation is a small flame and not the flare stack, an alarm condition is asserted. The cross-correlations are performed on the UV and IR radiation received in the last 2 seconds, and its value is continuously updated. When this value drops below a preset threshold (0.3 to 0.4), the alarm condition is removed. This operation is continuously repeated, and alarm conditions are updated every 2 seconds.

This detector permits the accurate detection of small hydrogen flames while minimizing the occurrence of false alarms caused by other sources of radiation such as the large flare stack. The technique is not limited to the detection of hydrogen fires. A similar technique could be used to improve the performance of other fire detectors and be used with different fire sources. The detector unit has been designed to incorporate in a single enclosure all the components needed for the fire detection, such as the UV and IR detectors, lenses, amplifiers, converters, and the digital signal processing unit. The capabilities include interfacing with a computer to allow changes of the cross-correlation thresholds.

Key accomplishments:

- Designed, built, and tested the UV-IR hydrogen fire sensor.
- Developed the software for data retrieval and analysis.

Key milestone:

- Conduct additional field testing.

Contact: G.A. Hall, DL-ICD-T, (407) 867-3185

Participating Organization: I-NET, Inc. (P.J. Medelius and H.J. Simpson)

Adaptive Noise Suppression Using Digital Signal Processing

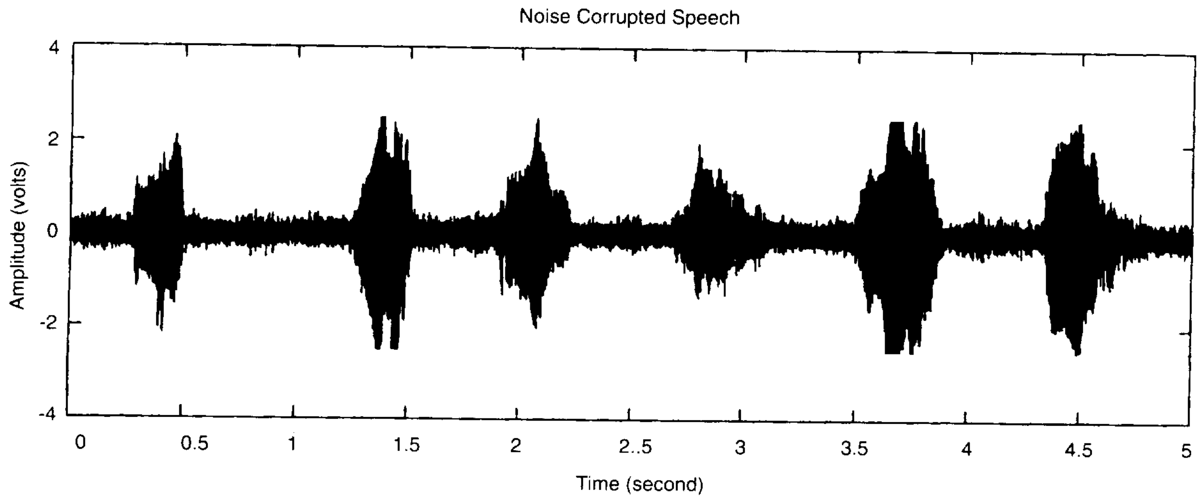
During Shuttle processing at KSC, several instances have been encountered in which voice communications among test team members were significantly impaired due to one or more of the test participants being required to communicate from locations with high ambient noise levels. Ear protection for the personnel involved is commercially available and is used. However, commercially available noise-canceling microphones are not adequate to produce the required noise reduction for outbound communications links.

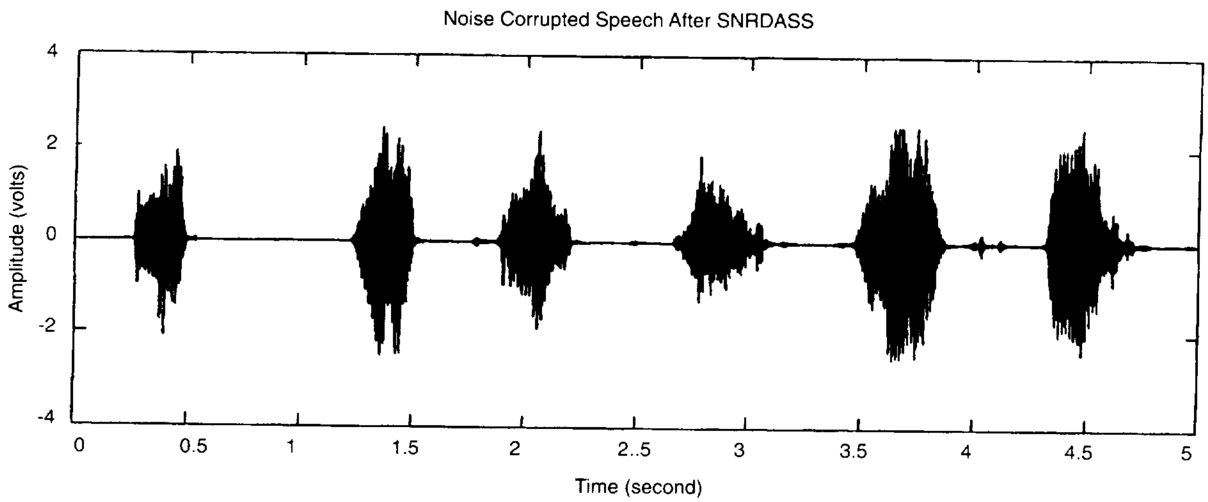
This technology involves application of digital signal processor (DSP) technology in conjunction with speech recognition and spectral manipulation techniques in order to achieve a high-level reduction of microphone-induced noise transmission.

A signal-to-noise ratio-dependent adaptive spectral subtraction (SNRDASS) algorithm is developed to eliminate noise from noise-corrupted speech signals. The algorithm determines the signal-to-noise ratio and adjusts the spectral subtraction proportion appropriately. After spectral subtraction, low amplitude signals are squelched. A single microphone is used to obtain both the noise-corrupted speech and the average noise estimate. This is done by determining if the frame of data being sampled is a voiced or unvoiced frame. During unvoiced frames, an estimate of the noise is obtained. A running average of the noise is used to approximate the expected value of the noise.

Noise or noise-corrupted speech enters the microphone. A high-gain amplifier is used to bring the voiced signal up to the ±2.5-volt range used by the analog-to-digital (A/D) converter. Before entering the A/D converter, the signal passes through an anti-aliasing low-pass filter with 3-decibel attenuation at 3 kilohertz and 30-decibel attenuation at 5.9 kilohertz. It is then sampled by the A/D converter using 12-bit resolution and a 14.925-kilohertz sampling rate. At this point the DSP performs noise suppression using signal-to-noise ratio-dependent adaptive spectral subtraction. Next, the digital signal is converted back to an analog signal at a rate of 14.925 kilohertz using the digital-to-analog (D/A) converter. It is then sent through a smoothing filter, which for the data obtained in the testing was a low-pass Bessel filter with a 3-decibel frequency of 3 kilohertz. This can be replaced with a voice band filter, which is a bandpass filter with low and high 3-decibel passband frequencies of 3 and 300 kilohertz, respectively. If the voice band filter does not have good damping characteristics, the smoothing filter is necessary or transients will be produced from the step discontinuities resulting from the D/A conversion. After the voice band filter, the signal is modulated and transmitted by the communication device.

The words "test, one, two, three, four, five" were spoken into the microphone. The original sampled signal and the signal after spectral subtraction





are shown in the graphs. Spectral subtraction provided approximately 20 decibels of improvement in the signal-to-noise ratio. The listening test verified that the noise was virtually eliminated with little or no distortion due to musical noise.

Key accomplishments:

- 1996: Successfully demonstrated the use of DSP algorithms for the elimination of noise from noise-corrupted speech signals. As part of the NASA / ASEE Summer Faculty Fellowship Program, published "Adaptive Noise Suppression Using Digital Signal Processing" by Dr. D. Kozel of Purdue University.

Key milestones:

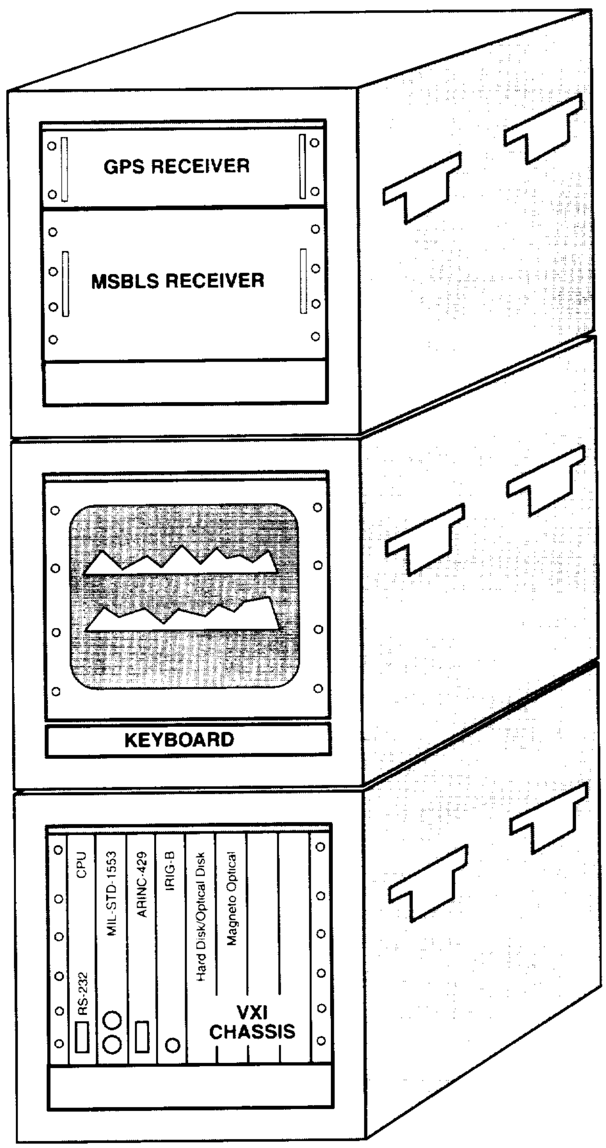
- 1996: Procured necessary equipment and software. Set up a DSP laboratory for development of DSP software and hardware. Wrote algorithms for noise suppression on voice communication channels.
- 1997: Develop hardware implementation of algorithms on DSP hardware. Participate with a commercial partner for commercialization. This device will be a lightweight portable unit to insert between the communications microphone and the communications device itself.

Contacts: J.A. Devault, PZ-C1, (407) 867-3521, and F.M. McKenzie, DL-CMD-R, (407) 867-1391

Participating Organizations: Purdue University (Dr. D. Kozel) and I-NET, Inc. (R.B. Birr)

VXI-Based Miniaturized MSBLS Flight Inspection System

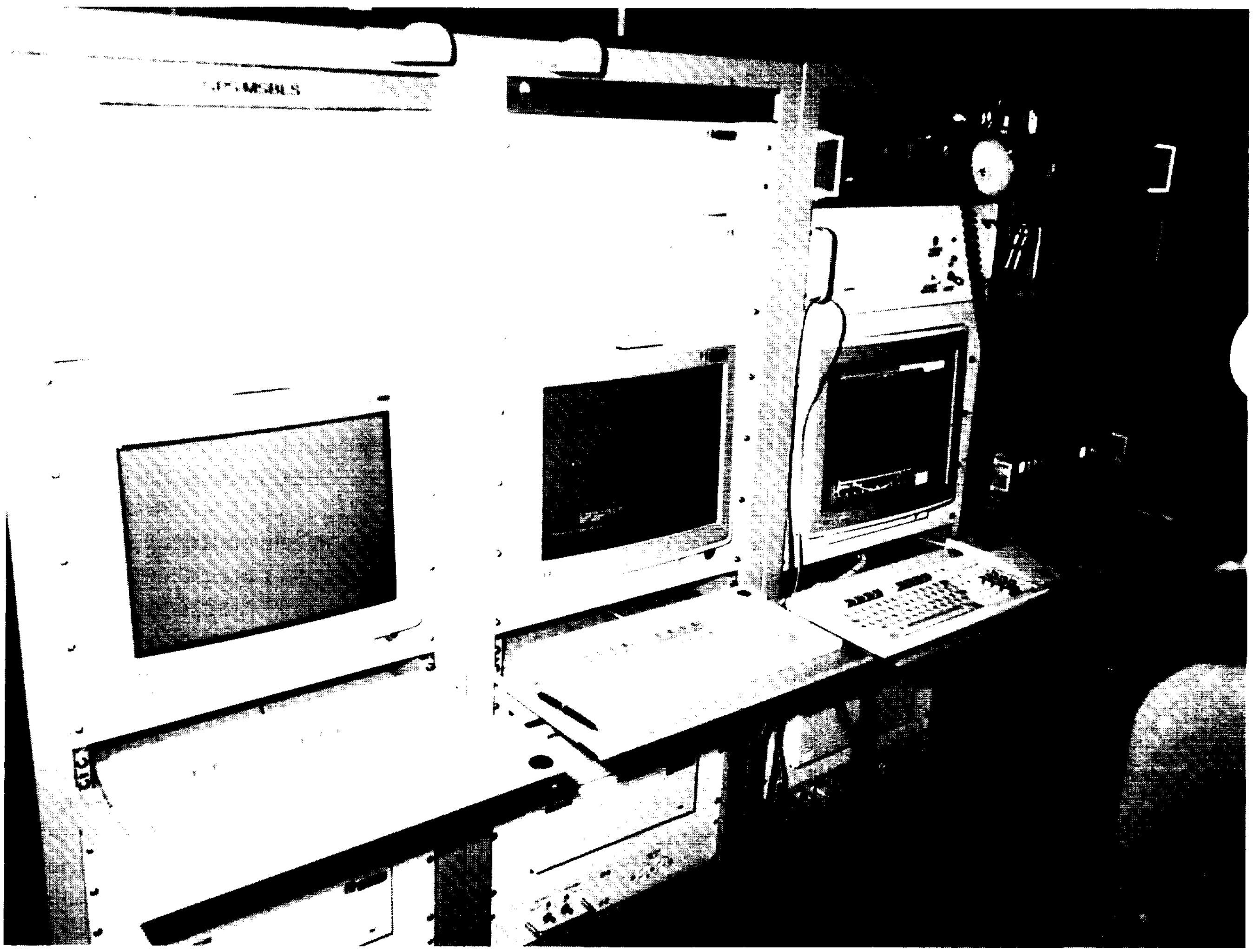
During the past year, the Landing Aids Laboratory personnel have completed the development of a VXI bus-based miniaturized next-generation Microwave Scanning Beam Landing System (MSBLS) Flight Inspection and Certification System. The Space Shuttle uses the MSBLS and the Tactical Air Command and Navigation System (TACAN) to provide precision guidance during the last stages of Shuttle missions prior to landing. These systems, located at each designated Shuttle landing site must be flight tested, certified, and adjusted at periodic intervals of 1 and 2 years for primary and emergency landing sites, respectively. Existing flight test systems consist of rack-mounted electronic instrumentation mounted on two bulky cargo pallets that fit into a C-130 aircraft used to simulate the Shuttle's landing approach.



MSBLS Miniaturized Flight Inspection System

The VXI system that will be used to flight test and certify MSBLS-equipped Shuttle landing sites is physically a much smaller system than the existing pallet-mounted equipment. The system uses an industry standard rack-mountable commercial off-the-shelf (COTS) chassis that allows high-speed device-to-computer communication between peripheral and storage devices. Inhouse-developed X-Windows graphics-based software controls and acquires navigation data from the Global Positioning System (GPS), MSBLS, and TACAN receivers.

Real-time analysis and comparison of navigation data streams against precision GPS position information are used to determine if adjustments to MSBLS and TACAN systems are required. The VXI system's processor communicates with the receivers through three serial busses: MIL-STD-1553, ARINC-429, and RS-232. The VXI system also contains an IRIG-B Time Code Generator used to time stamp the data received from the MSBLS receiver. Use of



Existing Flight Inspection System

the VXI-based miniaturized flight inspection system will reduce time, effort, and money required to perform annual inspection of the MSBLS systems. The reduced size of the flight inspection system will enable flight inspections to be performed in conjunction with astronaut training using the Shuttle Training Aircraft. This will result in performing two Shuttle program requirements simultaneously, therefore saving a significant amount of time and money.

Contact: S.W. Boyd, DL-ICD-T, (407) 867-6929

Participating Organization: I-NET, Inc. (T. Erdogan and R.L. Reyes)

Calibration of Space Shuttle Landing Aids Using the Global Positioning System

NASA flight rules require that all designated Shuttle landing sites be inspected and certified every other year by actual flight testing using Shuttle receivers mounted in a test aircraft. There are landing sites located at KSC in Florida, Edwards Air Force Base in California, White Sands Missile Range in New Mexico, Zaragoza and Moron in Spain, Ben Guerir in Morocco, and Banjul in The Gambia.

The original flight inspection system was the Precision Laser Tracking System (PLTS), which used a high-powered laser to optically track the test aircraft from a truck semi-trailer next to the runway. The data taken onboard the test aircraft was synchronized with PLTS data after each test to determine the accuracy of the existing landing aids. The PLTS was expensive to move and operate and did not provide real-time data, and foreign countries were reluctant to grant permission to operate a powerful laser at their facilities. After evaluating several alternatives, NASA chose the Global Positioning System (GPS) to be the PLTS replacement and developed a working system 6 years ago.

The Space Shuttle uses the Tactical Air Command and Navigation System (TACAN) and the Microwave Scanning Beam Landing System (MSBLS) to provide reentry and precision auto-land guidance at the end of each space mission. This system provides for flight testing using the GPS, MSBLS, and TACAN receivers on a test aircraft. The data is compared in real time so system changes can be made if system adjustments are required or a particular flight run is bad, thus saving considerable flight and personnel time.

The MSBLS Flight Inspection and Certification System is a comprehensive electronic system consisting of computers, navigation receivers, and interface units between different data sources. Electronic components are rack-mounted on two separate cargo pallets placed in a C-130 aircraft forward cargo bay. The pallets contain navigation receivers, data processing computer equipment, many interface adapters, uninterruptable power supplies, distribution circuitry, remote display of real-time test data, and a display for the pilots that gives aircraft position relative to the required flight path. The data control and processing units consist of high-performance work stations that control and acquire navigation data from MSBLS, GPS, and TACAN receivers. Computers receive position data from respective receivers and convert and compare the current GPS aircraft position to MSBLS and TACAN-provided position information. A graphical presentation of differences between the GPS-versus-MSBLS and GPS-versus-TACAN data is displayed and recorded for data reduction purposes. The real-time processing GPS and MSBLS position data allow any required adjustment and alignment of the MSBLS to be performed during flight checks.

The TACAN is a worldwide air traffic navigation system operated by the Department of

Defense (DOD) and used by civilian and military aircraft. TACAN ground installations, known as beacons, provide an L-band (1 gigahertz) signal that indicates the range and magnetic bearing angle from the TACAN antenna to the user. Each orbiter has three independent, redundant TACAN sets, each with two antennas.

The MSBLS is a Ku-band precision approach and landing radio navigation aid that provides slant range, azimuth, and elevation data to the orbiter from approximately an 18,000-foot altitude, 15-nautical-mile range, through touchdown. Each runway has two MSBLS shelters, one for elevation and one for azimuth and distance. The azimuth and elevation data are broadcast by a rapidly oscillating antenna.

The GPS consists of 24 DOD-operated satellites that allow suitably equipped users to determine their location and the accurate time. At almost all locations on the Earth, at least four satellites are visible above the radio horizon. Each satellite broadcasts a spread spectrum signal containing a time code and supplementary information including the location of the satellite (the ephemeris). The receiver identifies and locks onto the spread spectrum signals from the visible satellites and derives the satellite coordinates and the difference between the satellite clock reading and the receiver clock reading. This time difference multiplied by the speed of light is the pseudorange, which includes the actual range, the receiver clock error, and several other error terms due to atmospheric and other effects. The receiver makes various corrections to the raw pseudorange and, through a process called quadralateration, derives an estimate of the user coordinates and the correct time.

In order to do a composite analysis of MSBLS far-field signal performance, a series of radials, arcs, and glide slopes are flown by the test aircraft. Radials are flown at a constant altitude of 8,000 feet at 0, ±3, ±6, and ±9 degrees from the runway centerline in azimuth to check the accuracy of the MSBLS signal coverage regions out to its maximum range of 22 nautical miles. Glide slopes are flown at 4, 3, 2, and 1.5 degrees in elevation to check the position accuracy as the aircraft altitude decays. Arc flights are flown in a semicircle fashion at an 8- and 15-nautical-mile radius from the MSBLS shelters to check for possible tilt of the beam due to the scanner platform being out of alignment. Flight runs at 200 and 400 feet of altitude are sometimes required to check for low-angle multipath effects. TACAN beacon stations are checked by flying 10-nautical-mile orbits and radials at an 8,000-foot altitude to determine system and position performance at all quadrants.

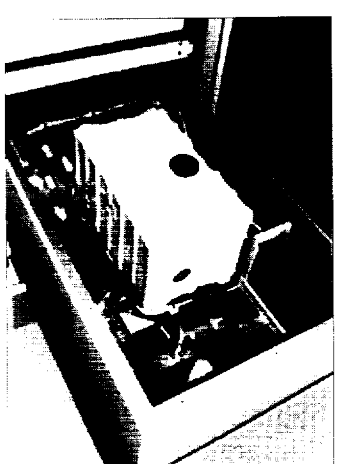
Data is plotted as a GPS-measured variable versus a MSBLS- or TACAN-measured variable. This requires transforming the GPS location coordinates into the proper comparison format, such as a MSBLS elevation angle. These plots are examined for excessive noise, multipath, or bias errors and, if necessary, corrective action is taken. Bias error is generally taken to require an adjustment of the antenna position. If all the test paths exhibit acceptable ranges of error, then the system is certified.

The GPS receivers have been replaced with units that provide ambiguity resolution on-the-fly and should provide real-time accuracies on the order of 10 centimeters. This will enable certification flying completely through the envelope required for autoland capability. Software is being upgraded to incorporate a Kalman filter algorithm to smooth MSBLS data using a barometric altitude and a means of providing refraction correction using temperature and pressure profiles captured during the test flights.

Contact: S.W. Boyd, DL-ICD-T, (407) 867-6741

Participating Organization: I-NET, Inc. (T. Erdogan, S.O. Starr, and R.L. Reyes)

Fourier Transform Infrared Spectrometer (FTIR) Based Portable Ammonia Monitoring System for Space Station Processing



Interior of FTIR

Processing of hardware for the International Space Station Alpha (ISSA) will be performed in the Space Station Processing Facility (SSPF) at KSC. The current ISSA design will use ammonia as a refrigerant. Monitoring of ammonia vapor concentrations during loading and storage is required because of its toxic and flammable properties. The NASA Contamination Monitoring Laboratory (CML) at KSC has designed, fabricated, and delivered a prototype Portable Ammonia Monitoring System, also referred to as the Ammonia Detection Cart. This prototype has been used during validation testing of the Ammonia Servicer, which contains and controls the ammonia loaded into the ISSA elements. The final versions of the Ammonia Detection Cart will be used for environmental area monitoring during the processing of ISSA elements that require liquid ammonia.

The requirements for an ammonia detection instrument were impossible to meet with traditional electrochemical or catalytic combustion sensors. In this application, ammonia vapors had to be monitored in both the part-per-million (toxicity) and percent (flammability) ranges. Another complicating factor was that many other chemical compounds may be present in the area while ammonia is being monitored. These compounds include cleaners, solvents, and vapors produced by the curing of materials used to pot electrical connections. For these reasons, FTIR technology was selected. A commercial off-the-shelf (COTS) industrial FTIR with 0.5-wave number resolution was selected and a compact Intel™ 80486 PC was embedded in the FTIR to perform data acquisition and computation of vapor concentrations. Custom software for the embedded computer was developed for discrimination and quantification of compounds from their absorbence spectra. Two of these FTIR units are integrated into each Ammonia Detection Cart to provide analysis of two physically separate sampling points.

Since ammonia is potentially flammable at high concentrations, the cleanroom area where the Ammonia Detection Carts will be used is classified as Class 1, Division 2, Group D, per Article 500 of National Fire Protection Association (NFPA) 70. For this reason, the Ammonia Detection Carts were designed and built to meet the requirements of NFPA 496, Standard for Purged and Pressurized Enclosures for Electrical Equipment. Dry nitrogen will be used as the purge gas and is provided within the SSPF facility. For the final Ammonia Detection Carts, electromagnetic interference/radio frequency interference (EMI/RFI) shielding is required to eliminate emissions that may harm sensitive spacecraft components. Portability was also a requirement since it will be necessary to move the Ammonia Detection Carts to monitor several locations within the processing area.

The prototype Ammonia Detection Cart was constructed from a COTS Electrical Industries Association 19-inch rack enclosure with a NEMA 12 environmental seal. This enclosure was mounted on a dolly assembly with casters suitable for cleanroom use. The two FTIR units were integrated into the enclosure along with an uninterruptible power supply (UPS), a gas sample delivery subsystem, an alternating current power control panel, enclosure heat exchanger, alarm horn, alarm beacon, and an overall system control computer with a display. All external electrical components had to qualify for use in a Class 1, Division 2, hazardous area. The system controller monitors status and ammonia concentrations reported by the FTIR's. It also monitors the UPS for power failure and low battery conditions and the gas sample delivery subsystem for low flow indications. All status conditions and ammonia concentrations are displayed by the system controller on a flat-panel display viewable through a window in the enclosure door. The system controller will sound the alarm horn and light the flashing alarm beacon when ammonia concentrations are detected at 25 parts per million (threshold limit valve) or 4 percent (1/4 of the lower explosive limit) by either of the two FTIR's. A different sound is emitted by the horn for each concentration level. A low-level audible alert will sound when a low-flow gas delivery condition is detected or cabinet purge pressure falls below safety limits. The system controller can also communicate status and alarm conditions to an external system.

Currently, three production Ammonia Detection Carts are being built for delivery to the SSPF. The final Ammonia Detection Carts will use a slightly smaller enclosure, have EMI gasketing added, and have an upgraded PC-based system controller with an active matrix display and touchscreen.

Key accomplishments:

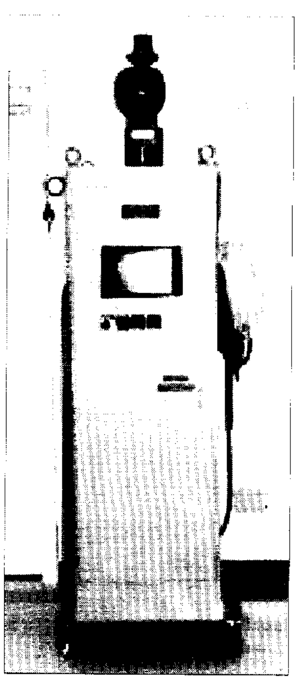
- Prototype Portable Ammonia Monitor Cart fielded.
- Final design completed and approved.
- Fabrication and installation drawings for final cart design released.
- Procurement of all hardware for final carts completed.
- Prototype Ammonia Detection Cart supported validation testing of the Ammonia Servicer in the SSPF.

Key milestones:

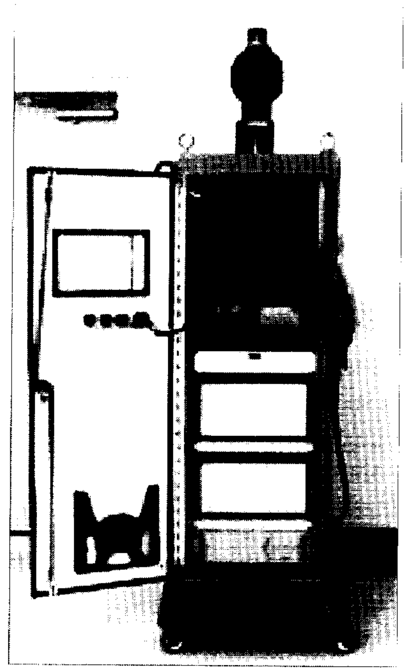
- Build, test, and deliver three final Portable Ammonia Monitor Carts to the SSPF.

Contact: P.A. Mogan, DL-ICD-A, (407) 867-9167

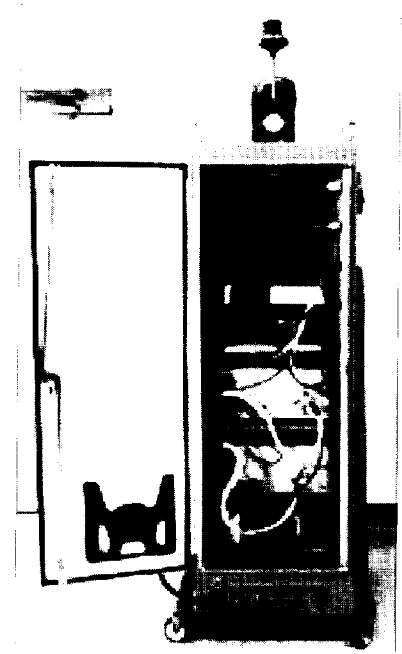
Participating Organization: I-NET, Inc. (G.J. Bedette and C.J. Schwindt)



Ammonia Cart Front



Front View Internal



Rear View Internal

Packet Data Analyzer

KSC is developing the International Space Station (ISS) Communications and Tracking Checkout System (C&TCS) for support of ISS U.S. International Standard Payload Rack interface verification. The C&TCS is a high-fidelity simulation of ISS Communication and Tracking Subsystem (C&TS) Ku-Band Return Link and the Marshall Space Flight Center Payload Data Services System (PDSS). The C&TCS will permit the ISS principal investigators to test and verify their systems and experiments with ISS Flight Equivalent Unit (FEU) interfaces and process data, as if in actual orbit operations during launch preparation at KSC.

The payload data to be sent to the PDSS can be of several formats from the ISS payload racks which are: MIL-STD-1553, Institute of Electrical and Electronic Engineers (IEEE) 802.3, bit stream, pulse frequency modulated (PFM) television camera signals, and Consultative Committee for Space Data Systems (CCSDS) packets. The PFM, MIL-STD-1553, and IEEE 802.3 data are converted to CCSDS packet formats and routed to the C&TS high rate frame multiplexer (HRFM) FEU. The HRFM multiplexes a combination of eight-bit stream and packet data channels and four TV camera packet channels into a CCSDS Physical Channel Access Protocol Data Unit (CCSDS_PCA PDU). This CCSDS_PCA PDU is a 25- to 150-megabit-per-second data stream that has encapsulated data structure and error correction information for processing on the ground.

To verify these payload data formats, KSC and Goddard Space Flight Center (GSFC) have developed a Payload Data Analyzer (PDA). The PDA verifies data streams from Space Station experiments, HRFM Payload Ethernet HUB Gateway (PEHG) and Payload Multiplexer/Demultiplexer (P/L MDM). In addition to performing the standard CCSDS return-link data processing function (i.e., Reed Soleman error detection and correction), the PDA is capable of verifying the header format of directly inputted CCSDS packets. It is also able to perform data field comparison of the processed CCSDS data stream against either a fixed pattern or a live instrument input. By combining the header format and data pattern verification, the PDA is capable of performing a bit error rate (BER) calculation. The BER test is not possible for experiments because the PDA only has access to the experiment rack output.

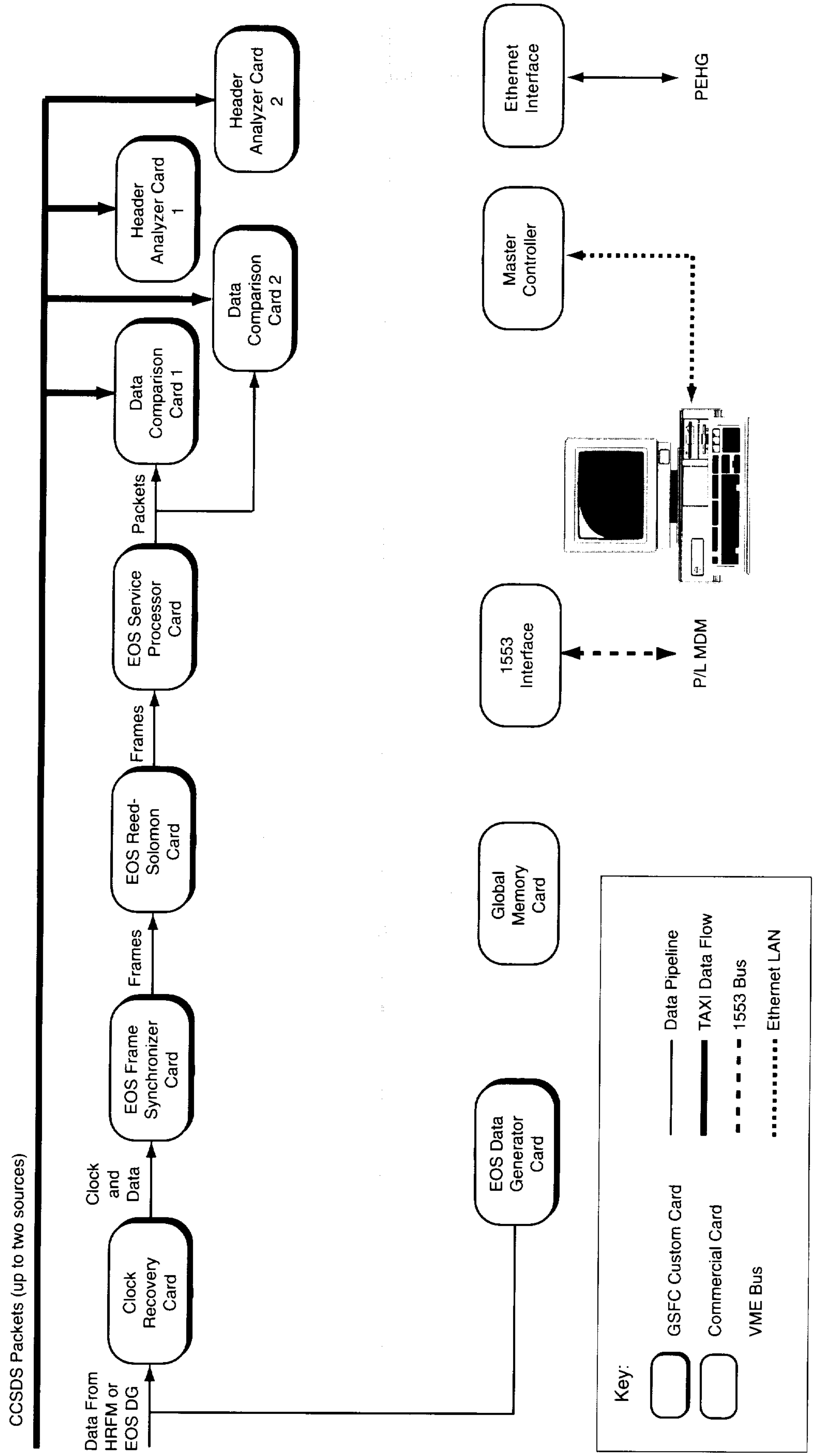
The PDA system performs six types of data checking or modes of operation:

1. Checks that experiments are correctly forming CCSDS packets and bit stream headers and verifies proper packet gap timing and bandwidth allocation.
2. Performs BER testing of the Space Station HRFM.
3. Verifies that the Space Station HRFM is not introducing errors into the CCSDS packet, bit stream headers, or data field.
4. Checks that the SGS Test Set Digital Processing Element [SGSTS (DPE)] is correctly forming CCSDS bit stream and packet data units.
5. Verifies that the PEHG is not introducing errors into the CCSDS packet (IEEE 802.3 to CCSDS packet conversion).
6. Verifies that the P/L MDM is not introducing errors into the CCSDS packet (MIL-STD-1553B to CCSDS packet conversion).

The PDA is a combination of commercial-off-the-shelf (COTS) and custom hardware and software. COTS VME embedded controller, memory and interface cards, and a Sun Microsystems, Inc., Sparc 5 provide the hardware platform for the PDA. The functionality of the PDA is provided by custom VME cards developed by GSFC for Advanced Orbiting Systems Front End Processing and the PDA itself. Sun UNIX (Solaris) and Wind Rivers VxWorks operating systems are the bases for the application software, Telemetry Processing Control Environment (TPCE) and Modular Environment of Data Systems (MEDS), developed by GSFC.

Contact: M.M. Scott, Jr., DL-CMD-R, (407) 867-1391

Participating Organization: McDonnell Douglas Aerospace Space and Defense Systems (M. Olenick and J. Gatlin)



PDA Subcomponent Flow Diagram

Low Differential Pressure Generator

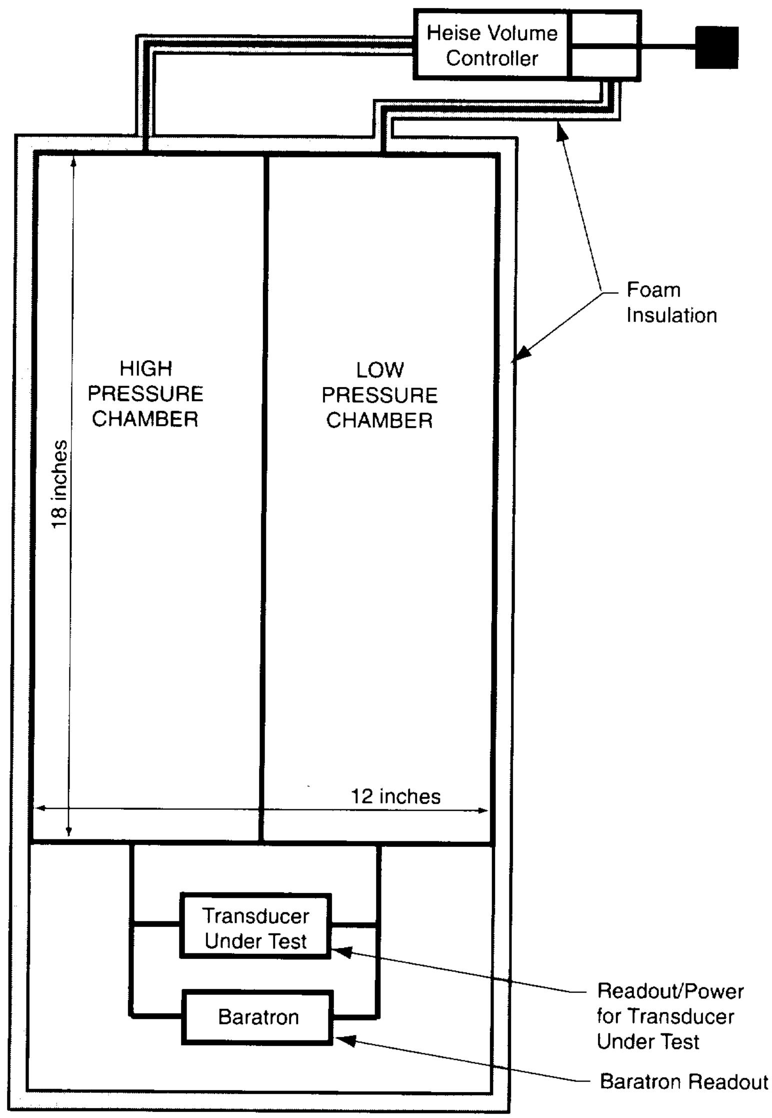
Low differential pressure transducers are the accepted method to monitor the room pressure for KSC cleanrooms. The goal of this project was to develop a technique and the test equipment to perform qualification testing on new low differential pressure transducers in a cost-effective manner and without requiring an environmentally controlled room.

Due to funding, an inexpensive method of qualification testing for the Setra Model C264 (range = 0.0- to 0.1-inch H_2O column) differential pressure transducer will be used in KSC cleanrooms. The previous method used for evaluation in the region of 0.001- to 0.1-inch H_2O was to send the transducer to the KSC Standards Laboratory and perform a cross-floated, dead-weight test using very expensive equipment. The cost of this test equipment prohibited its use in other labs. The charter for the Standards Laboratory is to perform calibrations, not full qualification testing. For qualification testing of the Setra, a less expensive piece of test equipment that could control the differential pressure to a high degree of resolution and transfer the accuracy of the Standards Laboratory into the qualification testing was needed.

It was decided that to generate the low differential pressure setpoints needed for qualification testing very small gas volume changes could be made against the test article and, according to Boyle's Law (assuming isothermal contraction/expansion), a corresponding pressure change would be detected by a pressure standard. This is the basis for the low differential pressure generator.

A prototype was developed using a pair of PVC tanks, a Volumetrics volume controller, and a Mensor 1-pound-per-square-inch pressure standard. This work showed that the technique had promise; however, a transfer standard quality differential pressure manometer in the range of 0.1-inch H_2O and a better control on the gas temperature would be needed to minimize thermally induced drift.

To provide the necessary calibration transfer, an MKS Baratron 1-torr (0.575-inch H_2O) differential pressure capacitance diaphragm manometer was purchased and calibrated by the KSC Standards Laboratory. This device gave the qualification testing the needed 4-to-1 turndown ratio when compared to the Setra's 1-percent, full-scale accuracy. The next step was to control the gas temperature fluctuations due to room temperature variations. The design and fabrication of a thermally isolated tank for a volume controller to generate the small pressure changes into were committed. This steel tank is 18 inches in length and 12 inches in diameter and has a dividing steel wall partitioning the tank into two equal volumes that are in thermal contact. The outside of the tank is wrapped in foam insulation, and the two tank volumes are connected to the two ports of a Heise volume controller. The Baratron's



differential ports are connected to the test ports on the other end of the tank, as well as the transducer under test. (See the figure for the system schematic.)

The mode of operation is to generate a small volume change in the Heise volume controller, thus generating an even smaller volume change in the two-chamber tank. Since the Heise controller is plumbed differentially to the tank, a volume increase in one tank chamber also generates an identical volume decrease in the other tank chamber.

The volume changes cause a pressure difference that is measured by both the Baratron and the test transducer. By using very small changes to the Heise volume controller, an operator can set differential pressures from 0.0- to 0.5-inch H_2O with a minimal amount of effort.

This technique and equipment are controllable to within 0.00025-inch H_2O and can give repeatable measurements to within 0.3-percent full scale. Since the design is simple and the transfer standard is laboratory quality, this system can be made into a portable unit for use in cleanroom testing.

Key accomplishments:

- 1993: Prototype unit was constructed and evaluated.
- 1995: Prototype unit was perfected into the present unit. Low differential pressure generator was used for evaluation of the Setra low differential pressure transducer. NASA Tech Brief was written on the low differential pressure generator.
- 1995/1996: Effort was started by NASA Technology Programs and Commercialization Office to patent the idea and disseminate feelers to industry for a joint development of a portable version.

Key milestone:

- 1996/1997: Complete the patent process and work with an industrial partner on a portable version.

Contact: G.A. Hall, DL-ICD-T, (407) 867-6788

Participating Organization: I-NET, Inc. (S.J. Stout and R.T. Deyoe)

Automated Window Inspection Device (AWID)

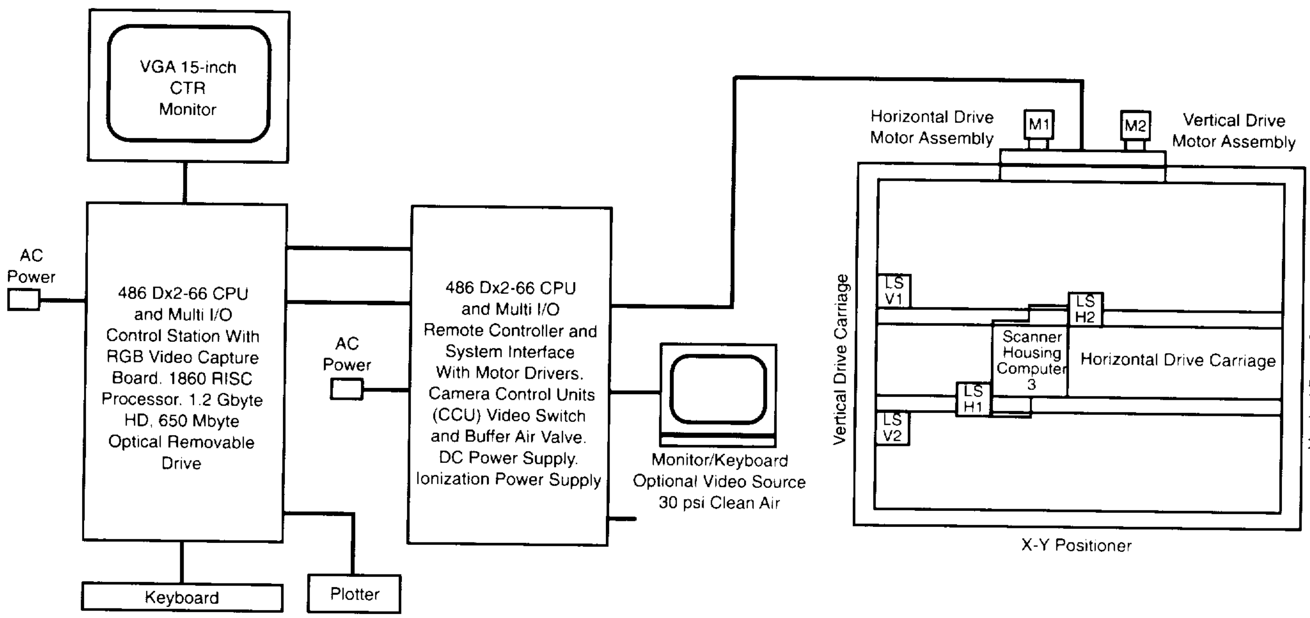
The goal of the AWID project is to develop a window inspection tool for use during orbiter processing in the Orbiter Processing Facility (OPF). The AWID will have the capability to enhance the probability of human operators to identify orbiter window defects by aiding them in the performance of their inspection duties. The technical approach is to provide a precision, lightweight frame that can safely carry optical inspection instruments above the surface of each of the six forward windows in a predictable and repeatable manner. AWID inspection records will be archived with data fields including the location, size, depth, and date of each defect identified, permitting comparisons of window damage from flight to flight.

The following types of damage to the glass are identified: (1) impacts with particles in space causing hypervelocity damage sites on the orbiter's forward thermal window panes, (2) inevitable handling mishaps that leave scratches or dings on the windows, and (3) subsurface damage or bruises believed to be the result of low-velocity impacts during flight or on the ground.

The AWID's X-Y positioning frame moves an optical scanner housing containing detection and measurement instrumentation over the entire surface of each window being inspected. The scanner housing is driven by two stepper motors in the X and Y directions with a dial-cord-type cable linkage under computer control. Two commercial off-the-shelf computers are used for control, analysis, and user interface. Dedicated image processing circuit boards perform the analyses using specific detection algorithms.

A polariscope with a miniature video camera is used for locating both surface and subsurface defects. A refocus microscope with a video camera is used to measure the depth of selected surface defects. Dust particles are removed from the windows by providing filtered air passed through an ionizer to nozzles aimed at a camera's field of view.

The normal operational sequence, after the initial alignment of the scanner housing to the window, is to begin an optical scan of the window. At that point, the scanner housing stops and waits for mechanical settling of the image and records the image of the surface and then the subsurface image. This takes about 100 milliseconds, after which the scanner housing moves to the next video frame on the window when the imaging processing and video analysis for that pair of frames are complete. The AWID software initiates a program that evaluates the video return and performs calculations on the data from the surface defects. The result of this analysis creates elliptical shapes around the defects and provides dimensions and angle of rotation information of their major and minor axes. The analysis of subsurface defect identification and the algorithms is similar. The amount of data stored for the record of each defect is less than 100 bytes.



Block Diagram of the AWID

Work in progress:

- Software testing, debugging, and final coding.
- Preparation of operation and maintenance documentation.
- Preparation of the acceptance test procedure.
- AWID testing in the Special Purpose Instrumentation Laboratory.
- Fit test on the orbiter and Orbiter Processing Facility platforms.
- AWID testing on the orbiter in the Orbiter Processing Facility.
- Certification of AWID.

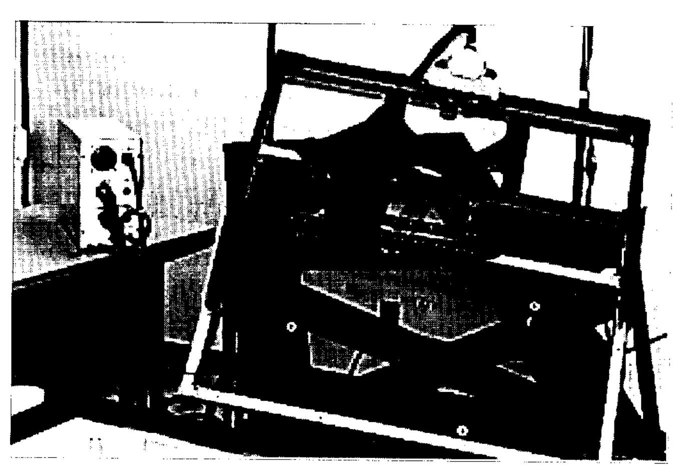
Key accomplishments:

- 1995: Redesign, new development, and test of a polariscope and a refocus miscroscope. Detail design of the spider adapters, X-Y positioner, and scanner housing. Preparation of the requirements document, certification plan, and system description.

- 1996: Redesign of spider adapters and the X-Y positioner. Fabrication of the spider adapters, X-Y positioner, scanner housing, cabling, motor control-computer-to-scanner interface housing, and transport cart. Improvement of the refocus microscope. Acquisition of optical calibration standards. Software definition and coding for the motor control computer, data computer, and scanner microprocessor. Formal design documentation.

Contacts: F.W. Adams, DL-ICD-A, (407) 867-4449; R.K. Summers and B.M. Braden, PK-H4, (407) 861-0933; and R.W. Tilley, EI-F-C, (407) 867-3480

Participating Organization: I-NET, Inc. (T.D. Greenfield, C.M. Lampkin, J.E. Kachnic, C.G. Hallberg, S.W. Thayer, P. Thayer, S.J. Klinko, and G.J. Bedette)



Component Refurbishment and Chemical Analysis (CRCA) Facility Oxygen Deficiency Monitoring System (ODMS)

The new ODMS will be installed in the CRCA facility for the purpose of monitoring atmospheric concentrations of oxygen and providing alarms to warn personnel about areas where an oxygen-deficient atmosphere exists. There are 56 ODMS's at KSC, 55 of which are patterned after a NASA Engineering Development design that was developed in the mid-1980's. These systems use one oxygen analyzer that is sequentially fed four to six location air samples by a sample system, which consists of a manifold of solenoid valves and a pump controlled by a multiplexer. These systems employ a complex, cumbersome, and expensive set of supervisory relays and circuits to monitor the health and status of system components and subsystems. This is required to meet stringent KSC policies for personnel life protection systems and equipment and for facilities and equipment that are involved in launch support File VI requirements. The 56th system located in the Space Station Processing Facility (SSPF) has oxygen sensors located at each point where nitrogen or helium might leak. While having an analyzer dedicated to each monitoring location is highly reliable, it is expensive and does not make use of allowable exposure times.

The operational heart of the CRCA facility is a large cleanroom area where instrumentation and pneumatic equipment of all types are serviced. There are six high-pressure and flow test cells in the cleanroom where oxygen monitors must be used. The test cells have a number of gaseous nitrogen (GN_2) and gaseous helium (GHe) panels where both high pressure [10,000 pounds per square inch (psi)] and regulated pressure (100 or 300 psi) lines are in use. There are four other rooms where substantial quantities of GN_2 are used and, even though it is at low pressure, it presents a potential hazard due to oxygen deficiency. Nine of these 10 rooms are located within the cleanroom area, and the 10th room is a nonconditioned air equipment annex.

Instrumentation for monitoring low oxygen content is located in an interior air-conditioned corridor. Instrumentation is excluded from the cleanroom because instrumentation servicing might introduce contaminants and is excluded from the annex because the nonconditioned atmosphere would be detrimental to instrumentation. In order to develop a new and better design approach, the following requirements for the CRCA ODMS differ from those of other systems:

- Must satisfy File VI requirements and eliminate supervisory circuits.
- Must monitor each sample location a minimum of once every 90 seconds.
- Be capable of measuring oxygen content in the sample to 90 percent of full scale within 10 seconds.
- Use commercial off-the-shelf (COTS) hardware and hardware currently in the Federal Stock System or USA Logis-

tics Stock System to the greatest extent possible.

- Be designed to be readily maintainable.
- Initiate a visible alarm both inside and outside the room whenever the oxygen content drops to 19.5-percent oxygen.
- Initiate an audible alarm whenever oxygen content drops to 19.5 percent oxygen.
- Provide a 4- to 20-milliampere signal to the Complex Control System (CCS).
- Provide an annunciator signal in the CRCA corridor indicating a low oxygen condition in all monitored rooms.
- Dehumidify sample lines to prevent condensation in the lines.

The File VI and supervisory requirements are eliminated by using 100 percent, on-line redundancy. This results in a primary and a backup system. The two systems are operated in an out-of-phase mode; that is, they do not check the same sample point at the same time. This means that each point is sampled twice as often as required, so that if one system fails, the requirement is still met. The use of one sensor per sample line was rejected as sensor intensive since an analyzer can measure a sample in 10 seconds, enabling it to monitor up to six samples a minute.

A new sample delivery system similar to, but far superior in performance to, the mid-1980's style has been developed. Transport pumps are used to maintain a continuous flow through sample lines. A sample pump and valves located near the transport pumps draw off a small portion of the sample and route it to the analyzer. This new sampling system is controlled by a programmable logic controller (PLC). Prime and backup systems are linked together in the PLC software; this is where sequencing and lead-lag functions are controlled.

The system is divided into three subsystems. Two of these subsystems monitor sample lines from three test cells each. The third subsystem sample lines originate from the other four rooms. Since a leak in a small test cell with high pressures is likely to rapidly displace breathable air, the six test cells are monitored every 60 seconds, while the larger rooms with larger volumes and lower pressure gas are monitored every 80 seconds. Since each room has two sample lines, one of these lines is monitored by both the prime or backup system each 30 or 40 seconds, respectively. This means that each room is checked every 15 or 20 seconds by one system or the other. This is four times the sampling frequency required.

The system contains a comprehensive set of self-health checks. These health checks are part of the System Failure Subsystem, which provides 4- to 20-milliampere signals to the CCS, which uses continuous automatic monitoring. If a failure occurs, CCS personnel dispatch troubleshooting crews to the CRCA facility. A local annunciator panel alerts arriving systems engineers and safety personnel to the problem location.

The sample dehumidification requirement is met with a COTS thermoelectric sample gas chiller. This device uses the Peltier effect and solid-state construction. Equipment cost is relatively high, but low maintenance costs on the continuously operating system coupled with very high reliability offset it. A substantial design effort was expended developing a new system using COTS components. Virtually all the hardware items are stocked in either the United Space Alliance Logistics or the Federal Stock Systems. Many components are used in other ODMS's. Beyond logistical considerations, this gives operators and maintenance personnel familiarity with the new design. The maintainability requirement has been satisfied by NASA and contractor users, who as members of the project design team have provided requirements that are incorporated into the system design.

In summary, KSC has widespread and greatly diversified ODMS applications. Existing system designs are complicated and expensive. The new CRCA ODMS design simplifies the approach, increases reliability, and significantly reduces costs per sample by utilizing redundancy, improved sample collection, and the latest in system controls.

Contact: P.A. Mogan, DL-ICD-A, (407) 867-9167

Portable Aft Mass Spectrometer (PAMS)

The PAMS is a portable self-contained helium leak detector system, which is accurate to better than 1/10 part per million of helium in air. It meets all requirements for Shuttle ground support equipment. It is fully documented and qualified by an acceptance test procedure.

The PAMS is a multi-use device capable of analyzing gas in sample lines, sniffing ambient helium levels, or pumping down a test article and measuring internal leak rates. The system is housed on a roll-around cart that is 23 inches wide, 45 inches high, and 30 inches deep. It is sized to fit through the airlock of the Mobile Launcher Platform (MLP) and through most bulkheads and stairways in the MLP. The PAMS is a modular design having 3 sections of 70 to 168 pounds each and can be disassembled for ease of transport. Its total weight is 346 pounds. It contains all the necessary calibration gases on the cart and is computer controlled by menu options. The PAMS has the capability to self-calibrate, self-leak test after a bottle hookup or sample line change, monitor and display long-term leak test trend data, monitor and display a pressure decay self-test of its sample system, and record 10 columns of data (including Greenwich Mean Time, elapsed time, helium raw sensor volts, helium parts per million, inlet pressure sample system flow rate, events markers valve number, and sample system pressure).

File storage is on hard disk in ASCII comma delimited format, and all data and valve commands and several procedures are automated for minimum operator effort. Computer control menus are grouped as pages or screens including a setup page (test type, calibration gas types, and the range desired), leak check page, auto-calibration page, drift check page, V1202 test specific page, engine shop page specific to V1294, and new pages on demand.

PAMS was originally designed to support the V1202 aft helium signature leak test at the launch pad. This test involves flowing air through the aft section of the orbiter while the propulsion system is pressurized with helium. Any leaks show up as increased helium concentrations above the 5.22-part-per-million normal background concentration. This test was originally done using the Prime Hazardous Gas Detection System, but system maintenance considerations required another system be used. PAMS is that system. A proof-of-concept system was designed and built for tests in 1992. It successfully proved it could support the V1202 test. A preproduction prototype was built and delivered in 1993. The first three production units were delivered in 1994 and 1995.

Subsequently, the Main Engine Shop in the Vehicle Assembly Building requested several systems with the added capability to pump down a test article. (The original PAMS operated in sniffer mode only.) Three second-generation production systems have been made and delivered. Two more are to be built for a total of eight systems.

PAMS can read helium levels in air to an accuracy of better than 1/10 part per million with excellent stability and low drift. Helium calibration gases accurate down to 2 parts per billion are obtained from the Bureau of Mines as the National Institute of Standards and Technology cannot supply the required accuracy. PAMS uses a commercial leak detector that is plumbed into an extensive sample delivery system. The leak detector has dual Faraday detectors offering simultaneous high- and low-range signal data. This is important as it eliminates range changing with its attendant calibration errors.

Future activities include extending the design to other facilities such as orbiter maneuvering subsystem pod maintenance. Hydrogen detection can also be incorporated into PAMS if needed. Temperature compensation is being retrofitted to decrease warmup time and drift.

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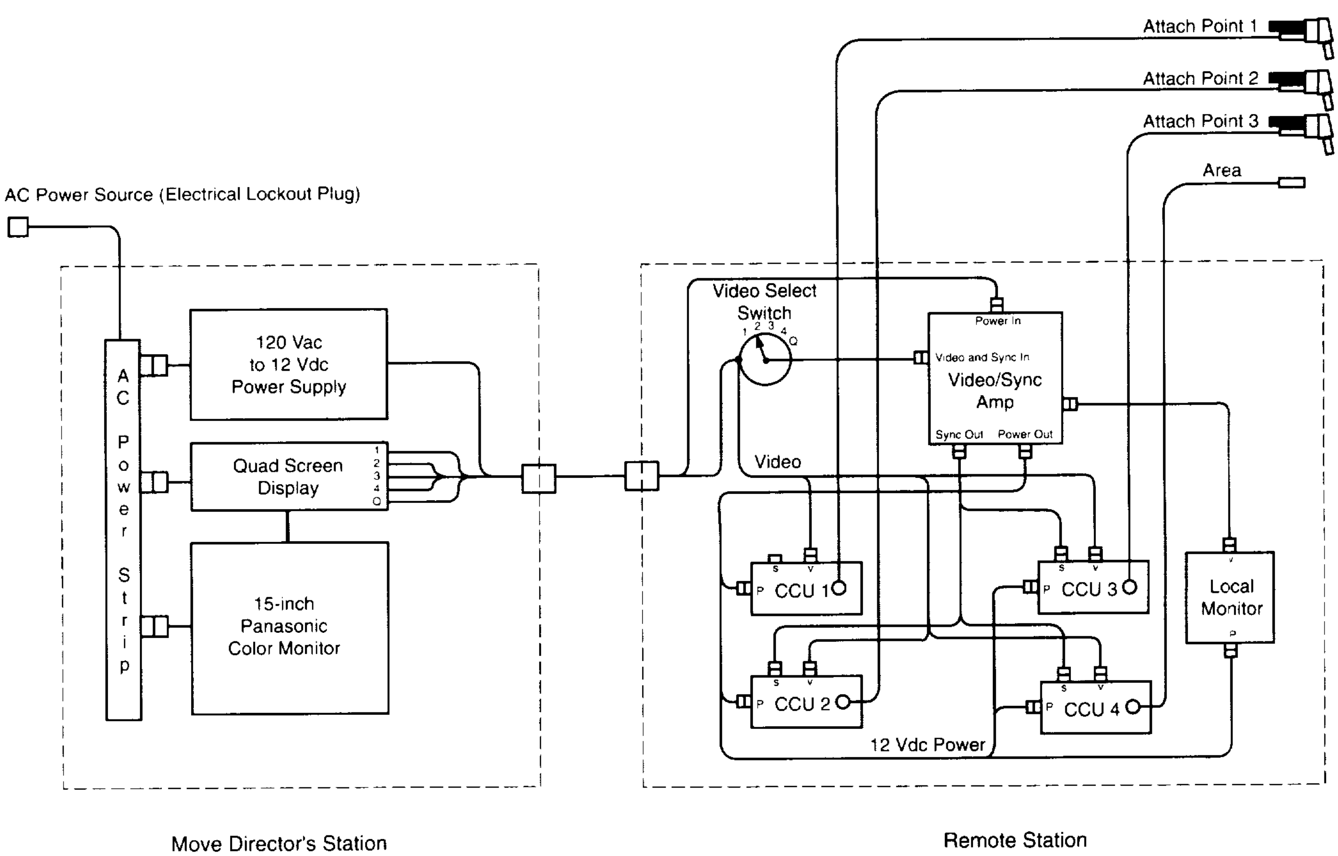
Participating Organization: I-NET, Inc. (S.L. Lingvay, R.J. Hritz, G.R. Naylor, C.M. Lampkin, D.C. Young, W.E. Rutherford, and F. Lorenzo-Luaces)

Orbiter Maneuvering System Pod Video Alignment Tool

Installing the Orbital Maneuvering System (OMS) pods onto the orbiter structure in the Orbiter Processing Facility (OPF) is a time-consuming operation. A method to align the main attach point bolt holes was needed to aid in visualizing the relative positions of the large, heavy structures in order to install the attach point bolts. Access to the attach points is difficult due to interfering structure elements and recessed locations. There is no line-of-sight view of these areas so technicians can see and advise the "move director" what adjustments are required to provide precise alignment of the OMS pod to the orbiter structure such that the bolts will drop in. Present methods for final alignment usually required the technician to gauge the alignment by reaching into the bolt hole with a finger and feeling the offset of the bolt holes. Directions to center the bolt holes are then used to guide the OMS pod for final alignment and installation.

A concept was developed that used a small "lipstick" size video camera housed in a clear polycarbonate tube, replicating the size of the actual bolts, a 1/2-inch and two 7/8-inch bolts. Illumination was to be provided by four miniature lamps installed at the top of the clear tube. A prototype was developed and tested during actual move operations. Although the video approach proved satisfactory by showing the positions of the two bolt circles, the level of illumination was marginal having to travel down the

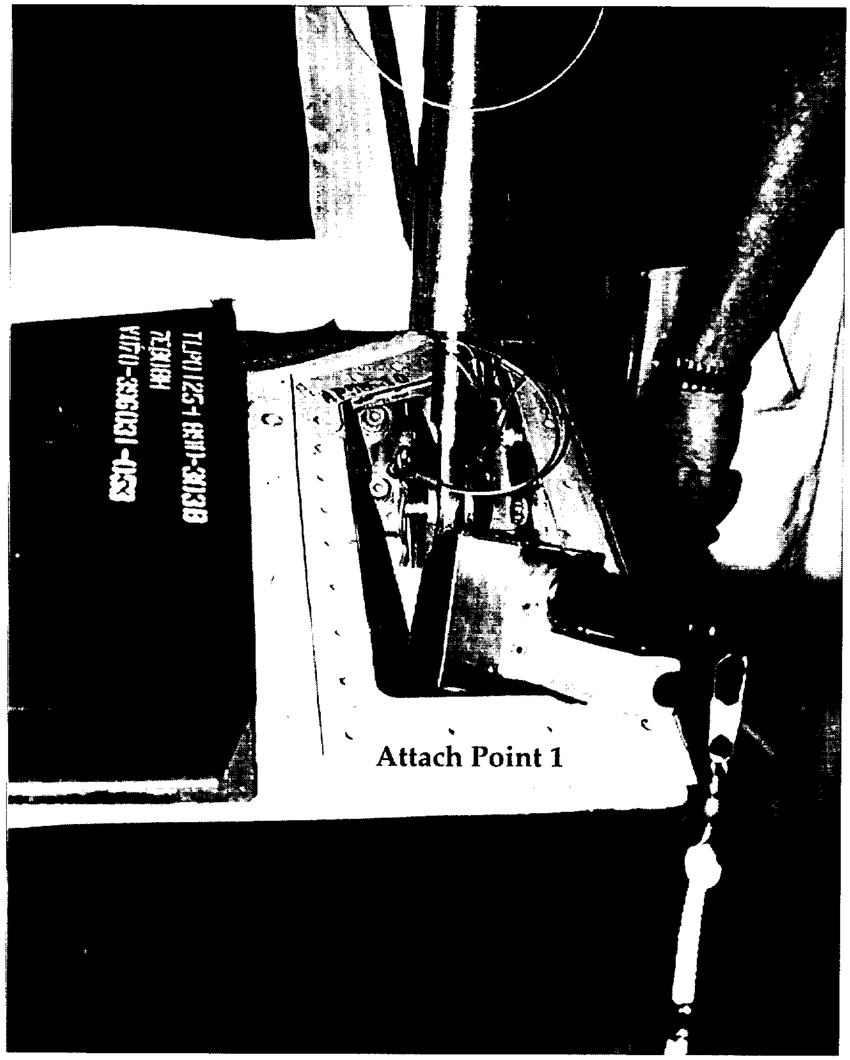


OMS Pod Video Alignment Shop Aid

polycarbonate tube. A new design was investigated that used a Mini Maglite® to provide the light source through a beam splitter directly to the target area. The returning image was reflected by the beam splitter to the video camera. This assembly was constructed in three parts: a main body that housed the flashlight and video camera with its prism, an optical body that contained the beam splitter and mirror, and the polycarbonate tube that adapted the assembly to the particular bolt size. Because of difficult access to the attach point bolt holes and the desire to have only one style unit with adapters to service the particular attach point, the preferred right angle design had to be altered to 98 degrees to clear all interfering structures. A major challenge during the development process was that an OMS pod with no bolts in the attach points had severely limited access (since bolts are required while the OMS pods are in the Hypergolic Maintenance Facility, on the ground support equipment transporter, and on the orbiter). Thus, measurements and estimates were relied upon for the final design and fabrication. The final packaging provided two transport cases for housing the equipment. The large transport case contains the Move Director's Display, the quad screen generator, and the power supply for the cameras and remote monitor. The smaller transport case contains the interconnect cables, the camera control units, a miniature local monitor for camera set up, and the three cameras used for viewing attach points 1, 2, and 3.

Key accomplishments:

- 1995: First proof-of-concept item was built and tested during installation of the OMS pod.



OMS Pod Optical Probe in Attach Point 1

- 1996: Kickoff meeting to document firm requirements and discuss the design approach. First prototype unit built and tested. Second unit with upgrades built and packaged for portability use in the OPF. Unit modified to accommodate difficult access. Final test during orbiter/OMS pod installation.

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Participating Organization: I-NET, Inc. (T. D. Greenfield, C.G. Hallberg, J.E. Kachnic, C.M. Lampkin, and R.B. Cox)

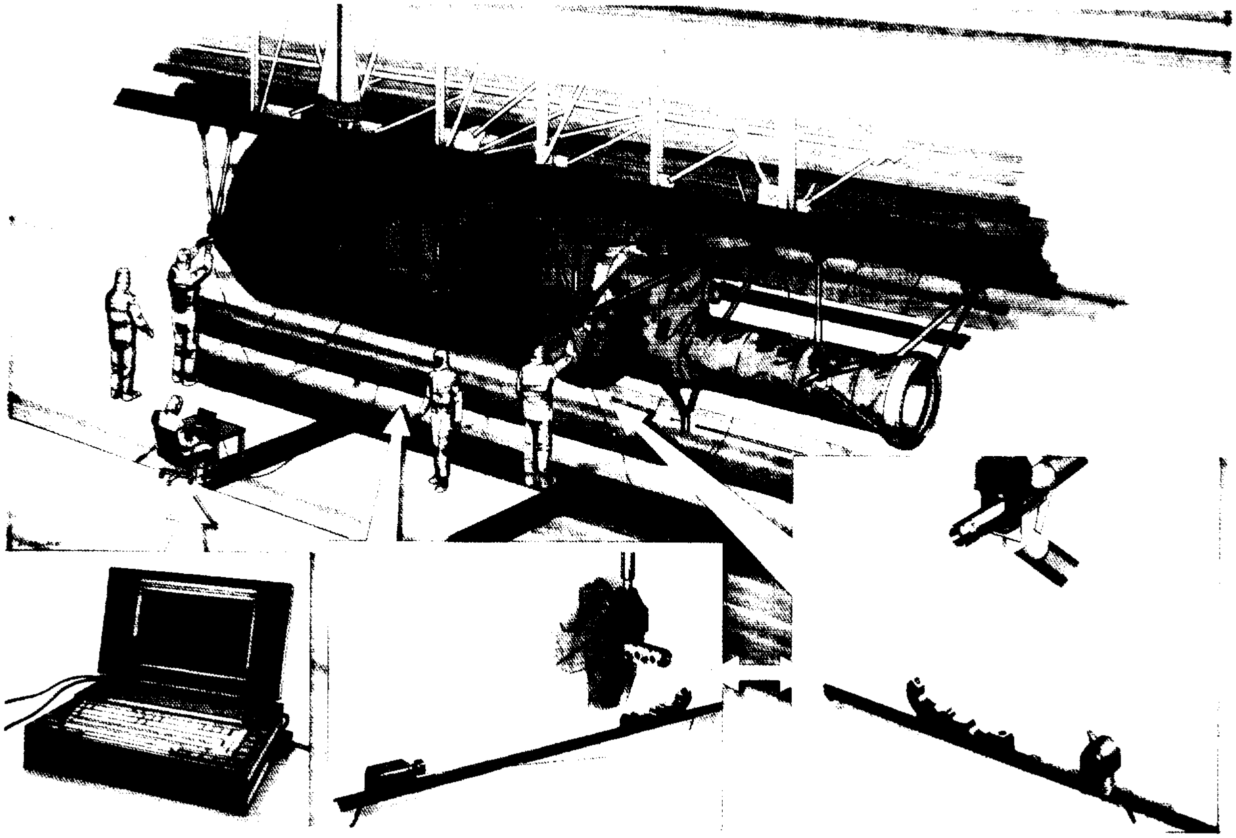
Advanced Payload Transfer Measurement System

The objective of this project is to develop a simple, low-cost, robust, centrally operated, and portable system to automatically measure the three-dimensional offsets between the payload trunnions and their supports during payload transfer operations in the Vertical Processing Facility (VPF), the Operations and Checkout (O&C) Building, the Space Station Processing Facility (SSPF), and the Payload Changeout Room (PCR).

Trunnions are standard structural components used to secure payloads to the Space Shuttle cargo bay and to the payload processing facilities. When loading multiple payloads, 6 to 12 of them must be moved in a coordinated manner to carefully secure payloads on their support latch or hooks. Currently, a technician is required at each trunnion location to measure the three-dimensional offsets using tethered rulers. The move conductor uses an intercom system to get the offsets from each trunnion technician and maneuvers the payloads by sending verbal commands to a crane operator.

The system under development will consist of a network of coordinate measurement transducers attached to each trunnion. Data from each transducer will be displayed to the move conductor on a computer screen in an intuitive manner. Studies of 1993 cost data for operations at the OPF and PCR indicate a potential cost savings of $110K per year. Similar numbers are expected for operations in the O&C, SSPF, and VPF. Time savings of 1 to 4 hours per payload transfer operation are anticipated. This system will increase measurement accuracy and reliability, reduce error opportunities, increase payload and technician safety, and provide an avenue for payload transfer automation in the PCR and VPF. Future expansion capabilities include calculations of the next move command and closed-loop control for greater time savings. The coordinate measurement transducer also has commercial potential in the areas of crane operations, construction, assembly, manufacturing, automotive, and aerospace.

The project was initiated in January 1995. The system has been designed, and the prototype hardware has been fabricated and tested in the Advanced Systems Development Laboratory. This hardware includes a coordinate measurement unit with an embedded microcontroller, a network for multiple coordinate measurement units, and a user interface for the display of the coordinate measurement unit data. The effort in the upcoming year will focus on developing the production system based on the prototype hardware developed during 1995.



Payload Lift From Cargo Bay, OPF High Bay 1

Key milestones and accomplishments:

- January 1995: Project initiated.
- August 1995: Network and graphical user interface software developed and tested.
- September 1995: System requirements formalized.
- October 1995: Prototype hardware fabricated, assembled, and tested.
- Second quarter 1996: Developed the production coordinate measurement unit.
- Third quarter 1996: Developed and performed the test plan on the production system.
- Fourth quarter 1996: Redesigned and reworked as necessary to improve system performance.
- 1997: Complete fabrication, testing, and demonstration.

Contacts: E. Lopez del Castillo, DM-ASD, (407) 867-4156, and W.C. Jones, DM-ASD, (407) 867-4181

Participating Organizations: NASA, Orbiter Mechanisms and Payload Handling Systems Branch; NASA, Flight Crew and Processing Support Branch; I-NET, Inc.; Rockwell Space Systems Division; McDonnell Douglas Space and Defense Systems; and Lockheed Martin Space Operations

Universal Signal Conditioning Amplifier Certification Station

The new state-of-the-art Universal Signal Conditioning Amplifier (USCA), designed and developed at KSC, will replace the old amplifiers used in the Permanent Measurement System (PMS). The new amplifier will be used in conjunction with temperature, flow, pressure, displacement, and strain gage measurements used in ground support equipment. Due to the large number of amplifiers that have to be certified, an automated certification station needs to be developed to support testing of several USCA's at a time. The main purpose of the certification station is to test the functionality of a USCA before installation at the Mobile Launcher Platforms and the launch pads.

The USCA certification station consists of a high-density switch system, direct current calibrator, digital multimeter, frequency counter, two special RS-485 to RS-232 converters, a controller, external memory sources (EMS's), and power supplies. The certification station is required to support automatic testing of up to 20 USCA's. To accomplish this, a high-density switch system is required to connect the input and output of each USCA to the different test equipment (see the figure). The communication line between the USCA and the controller is accomplished through two separate RS-485 to RS-232 converters. The first converter is used to transmit and receive commands to the USCA from the controller. This interface was necessary to control and monitor the different configurations of a USCA. The second converter receives the digital output from the USCA to the controller. This converter is designed to store up to 8 kilobits of digital output data and to transmit the data to the controller.

The controller is an IBM-compatible personal computer with a 486 processor. Required computer hardware includes a multifunction input/output board, GPIB card, and two RS-232 ports. The multifunction input/output board is used to remotely control the power supply output voltage. The control and monitoring of all test equipment are accomplished using Institute of Electrical and Electronic Engineers (IEEE) 488.

The certification software was developed using National Instrument LabView 4.0. The certification software consists of several test sequences. The sequences will verify the following: the accuracy of the amplifier analog and digital outputs at different gains, the effect of the power supply deviation on the functionality of the amplifier, the different excitation types, the communication circuits, and the excitation sense signal. Statistical processing is accomplished on the test data to provide the best information. If a test returns an error or an out-of-range measurement, the software develops a report that will assist the repair technician in fixing the problem. All test data is stored in data error files that archive each unit's history.

The main technical obstacle that made the certification station a challenge was the problem of electrical noise. The amplifiers are tested at a very high gain (2,000) with normal input voltage range of ±5 millivolts direct current. Noise in the microvolt range can affect the accuracy of the amplifier output at this high gain. It was determined that equipment in the certification station created noise in excess of this specification. Several hardware and signal-switching configurations were investigated in an attempt to minimize the electrical noise.

Key accomplishments:

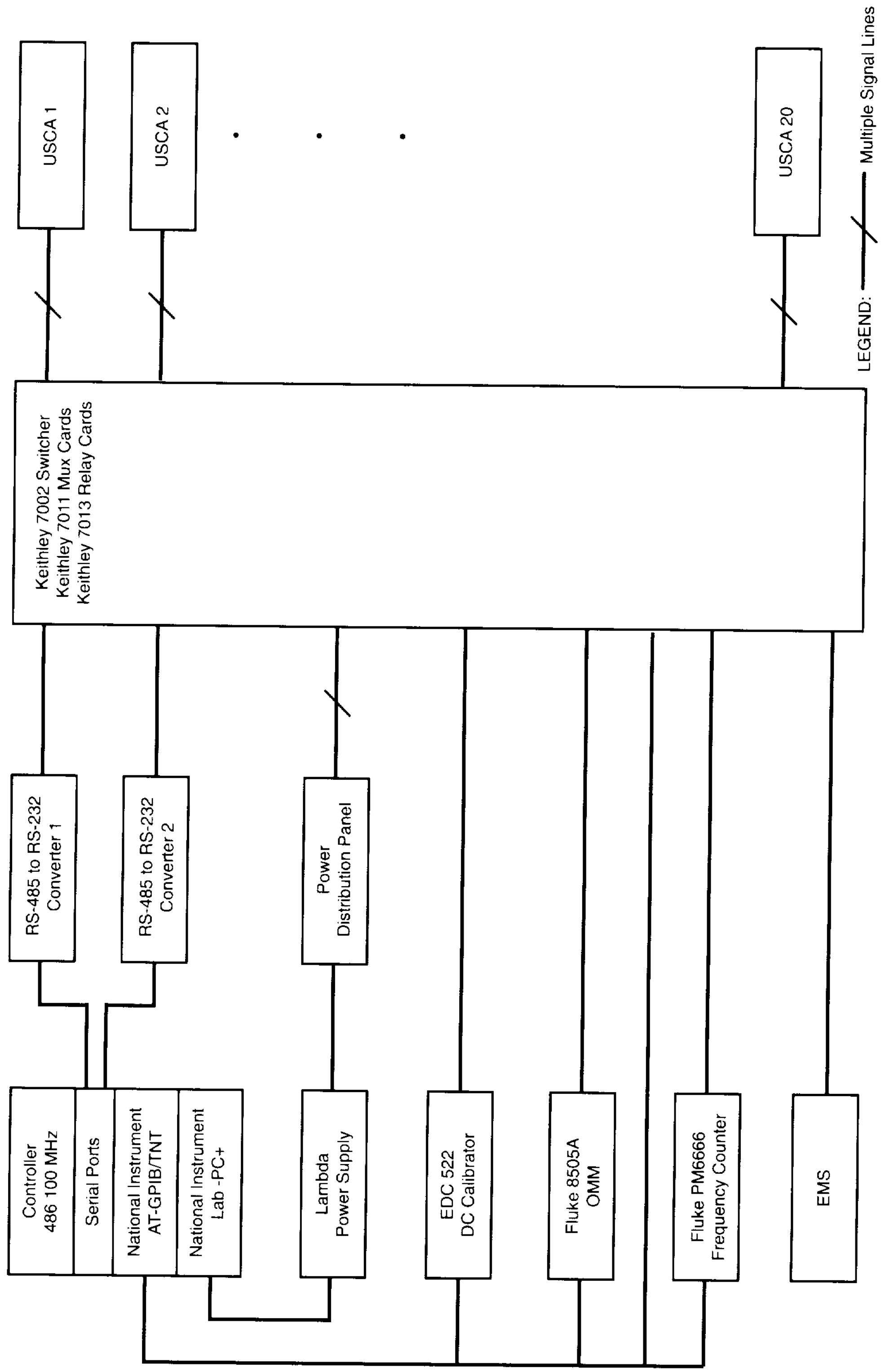
- 1996: Develop USCA test requirements and specification test equipment. Integrate the USCA certification station rack and develop the LabView software interface.

Key milestones:

- 1997: Test the initial order of 100 USCA's and train operations personnel on maintenance and operation. Develop a diagnostic matrix to help repair technicians locate and fix problems with USCA's. Deliver the USCA certification station to Operations for use.

Contacts: A.R. Lucena, Jr., DL-ICD-C, (407) 867-2597, and W.E. Larson, DL-ICD-T, (407) 867-6745

Participating Organization: I-NET, Inc. (L.J. Robinson)


USCA 1
USCA 2
USCA 20
LEGEND:
Multiple Signal Lines
Keithley 7002 Switcher
Keithley 7011 Mux Cards
Keithley 7013 Relay Cards
RS-485 to RS-232 Converter 1
RS-485 to RS-232 Converter 2
Power Distribution Panel
Controller 486 100 MHz
Serial Ports
National Instrument AT-GPIB/TNT
National Instrument Lab -PC+
Lambda Power Supply
EDC 522 DC Calibrator
Fluke 8505A OMM
Fluke PM6666 Frequency Counter
EMS

Data Acquisition System Laboratory's Quick Response Test Support of the Naval Ordnance Test Unit's Railcar "Hump" Test

The Data Acquisition System (DAS) Laboratory at KSC has several means of supporting testing activities. The main focus of concern is in quick-response testing or test support requiring a minimum amount of setup time. For small-scale tests, the DAS Laboratory can be ready to support data acquisition in as little as 2 hours. These tests can be supported in the Launch Equipment Test Facility (LETF) or at any remote site as long as the facility or generator power (110 volts alternating current, 60 amps) is readily available. Assets include: a control room at the LETF capable of acquiring data from 128 measurements (80 of which can require signal conditioning), two roll-around portable data acquisition systems (PDAS's) capable of supporting 32 measurements (10 of which can require signal conditioning), and a Fast Response Instrumentation Van (FRIV) capable of acquiring signals from 50 measurements (20 of which can require signal conditioning). All of these systems are based on National Instrument LabView data acquisition software. The customer can receive plots of data immediately upon completion of testing.

The Naval Ordnance Test Unit (NOTU) Railcar "Hump" Test was a prime example of the DAS Laboratory's capabilities. The customer required data from accelerometers in several different locations on two separate test articles. These test articles were located in two separate railcars that were coupled together. These railcars were scheduled to be dynamically coupled or "humped" to a line of stationary railcars. The purpose of the testing was to determine if "humping" of the railcars would violate the shock limits for items shipped by railcar. There were three obvious hurdles to overcome: (1) How is the data acquired? (2) Is there power for the systems? (3) Will the shock of the railcars coupling interfere with the data acquisition? The maximum expected shock was 10 g's for three locations and 5 g's for the remaining locations with a frequency of interest less than 100 hertz.

Due to the constraints of this test, a stand-alone DAS was custom built. The system consisted of a power supply box, a signal conditioning box, and a 16-channel TEAC Digital Audio Tape (DAT) recorder. The power supply box consisted of two separate circuits, one for the signal conditioning box and one for the transducer excitation. The signal conditioner's supply consisted of two 12-volt-direct-current (V dc) batteries connected in series. The transducer excitation supply consisted of two 12-V dc batteries connected in parallel to a precision 10-V dc voltage divider. The signal conditioner box consisted of a 20-channel Burr Brown Instrumentation Amplifier Board that was modified to provide a balance circuit for bridge-type transducers, single pole (RC type) 100-hertz low pass filters, and switchable shunt calibration capability for each channel. Sixteen of the 20 inputs were wired to a standard KSC bulkhead 10-pin female connector.

The corresponding outputs were wired to female BNC connectors (to facilitate connection to the DAT recorder). The TEAC DAT recorder was not modified in any way for test support. It was set up to record at 10 kilohertz, 5 V dc. A specially designed power pack, supplied by TEAC, was mounted external to the DAT recorder. Standard KSC instrumentation cabling was utilized between all transducers and the signal conditioner box.

Before testing, a total of 18 accelerometers was calibrated end to end, through the DAS at the Precision Fabrication and Cleaning (PFC) calibration laboratories. PFC standards are traceable to the National Institute of Standards and Technology (NIST).

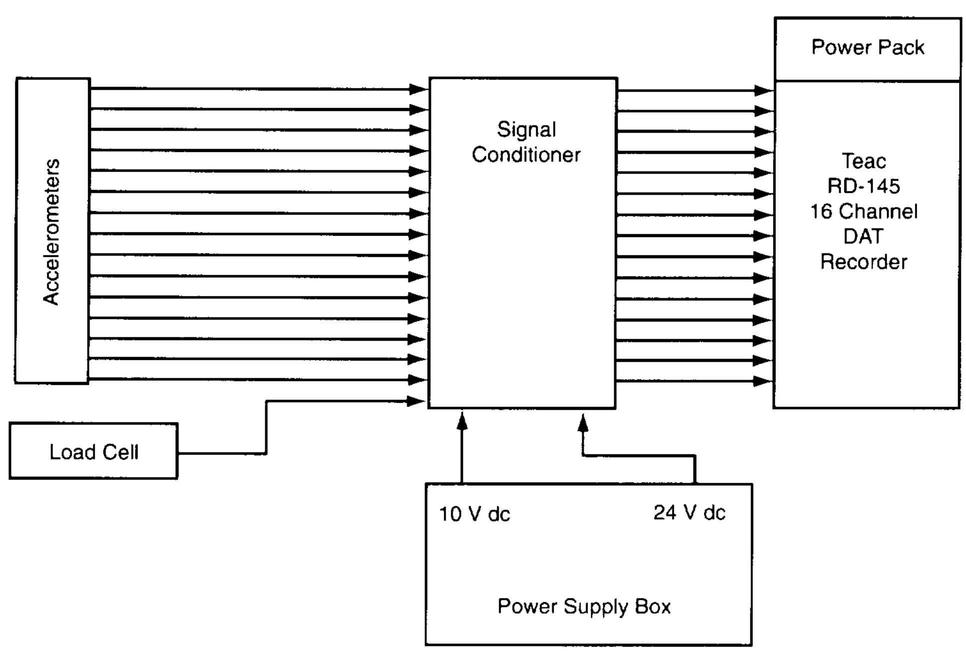
For test support, the FRIV was relocated to the test site. The DAS was mounted, in a manner to reduce as much shock as possible, between the two coupled railcars, and the measurements were cabled to the signal conditioner box accordingly. Before each run, each measurement's excitation voltage was checked, and its shunt calibration voltage was verified. A typical run was conducted. First, the DAT recorder was started. Second, a locomotive pushed the two coupled cars up to a set speed (e.g., 10 miles per hour) and released them. Next, the two coupled railcars ran into (humped) a stationary line of box cars. Once the area was deemed safe, the tape was removed from the DAT recorder. The tape was brought to the FRIV and installed into a second DAT recorder. Finally, the impact data was played back through the FRIV's LabView-based DAS. Plots were then generated and provided to the requester. This process took approximately 10 to 15 minutes from start to finish.

Key accomplishments:

- Prepared instrumentation to support testing.
- Supported all testing activities, including reducing and delivering all data.

Contact: W.E. Larson, DL-ICD-T (867-6745)

Participating Organizations: I-NET, Inc. (J.B. Crisafulli) and United Space Alliance (H. Yamada)



NOTU Hump DAS

Development of a 10-Part-Per-Billion Hydrazine Portable Analyzer

Both NASA and the United States Air Force (USAF) use hydrazine (HZ) in their spacecraft as a hypergolic fuel, either in the form of HZ, monomethylhydrazine (MMH), or unsymmetrical dimethylhydrazine (UDMH). These substances are highly toxic and are known or suspected carcinogens. Although the threshold limit values (TLV's) established by the American Conference of Governmental Industrial Hygienists for personal exposure had been set for many years at 100, 200, and 500 parts per billion (ppb) (for HZ, MMH, and UDMH, respectively), the values have recently been changed to 10 ppb for all three compounds. NASA, in conjunction with the USAF initiated a project at the NASA/KSC Toxic Vapor Detection Laboratory (TVDL) to develop a portable fuel vapor detector (PFVD) able to detect 10 ppb (PFVD-10). The PFVD-10 project was conceived as a two-phase effort: Phase I consisted of laboratory tests of potential technologies to identify those that could provide reliable detection at the 10-ppb level, and Phase II was more extensive laboratory tests on a production prototype based on the most promising technologies selected from Phase I. Three different technologies from three separate instrument manufacturers were evaluated in Phase I: (1) an electrochemical cell from Interscan (the manufacturer of the current portable hydrazine detectors used at KSC), (2) a colorimetric paper-tape detector from GMD Corporation, and (3) an ion mobility spectrometer (IMS) supplied by Graseby Ionics Corporation.

The Interscan electrochemical analyzer was the only instrument able to meet the basic performance criteria shown in the table. The GMD detectors were eliminated because, even though they could detect HZ and MMH from the 10-ppb threshold to above 400 ppb, their response times were slow and, even more importantly, they showed a major change in response due to relative humidity (very low readings at low humidity and very high readings at high humidity). The IMS was also eliminated because it could not detect MMH or HZ below 25 ppb and because it experienced so many component failures and other problems during testing that its evaluation was terminated early before a characterization was completed.

Based on the results of Phase I testing, the Interscan electrochemical cell analyzer was selected for continuation into Phase II, and four production prototypes were procured from Interscan for a detailed evaluation at the TVDL. During Phase II testing, the production prototypes were tested. Although the Interscan instruments did not meet every specification for all three hydrazines during the

Acceptance Test Criteria

Test	Criteria
Precision	±10-percent maximum deviation from the mean value
Linearity/accuracy	±1 ppb or ±15 percent of actual, whichever is greater
Zero drift	±2 ppb for 4 hours
Span drift	±15 percent of span value for 4 hours
Response	50 percent of span in 2 minutes at 10 ppb

Phase II tests, they performed well enough to be identified as the instrument of choice to provide a monitoring capability for hydrazine at the reduced TLV level of 10 ppb.

Key accomplishments:

- Evaluation of several technologies as potential candidates for monitoring at the newly established HZ TLV of 10 ppb.
- Selected the Interscan electrochemical analyzer as the instrument of choice for monitoring HZ at the 10-ppb level based on performance criteria.

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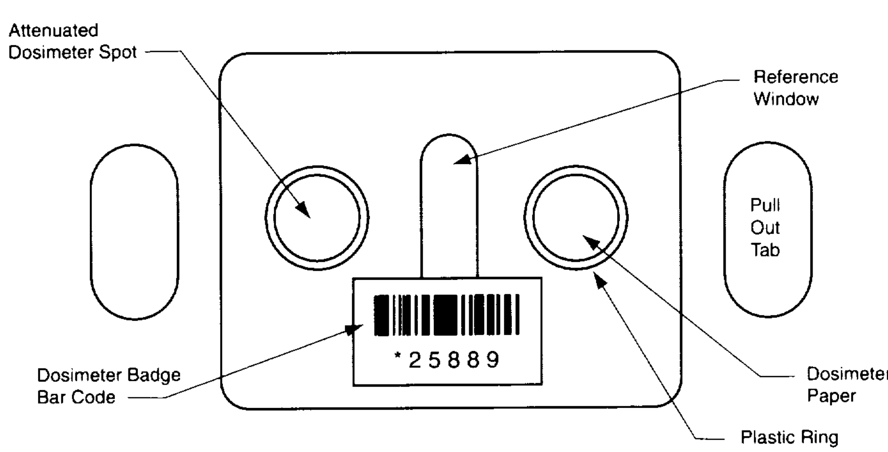
Participating Organization: I-NET, Inc. (N.A. Leavitt, D. Curran, B.J. Meneghelli, and T.A. Hammond)

Personnel Dosimeter for Dimethylethoxysilane

The outer surface of the Shuttle orbiter that is subject to high thermal stress during reentry is covered with a Thermal Protection System (TPS) made up of tiles and blankets. These tiles tend to absorb water that would damage or displace the tiles in space, so a waterproofing agent, dimethylethoxysilane (DMES), is injected into the TPS as part of the prelaunch processing in the Orbiter Processing Facility (OPF) prior to each Shuttle flight. Because DMES is toxic, the OPF high bay cannot be opened for normal work after a waterproofing operation until the DMES concentration is verified by measurement to be below the threshold limit value (TLV) of 0.5 part per million (ppm). A DMES personnel dosimeter badge that can be worn by individual workers both during and after waterproofing operations has been developed and field tested at the OPF.

During laboratory testing, several commercially available paper tape dosimeters were evaluated for linearity, repeatability, response to sunlight, artificial light, DMES, tetramethyldisiloxane (TMDS), ethanol (EtOH), and other potential interferences that might be present during the waterproofing operation. Based on test results, the GMD (Bacharach) two-spot dosimeter badge was chosen and used during all field testing. The testing for responses to TMDS and EtOH was particularly important since both these compounds are produced as byproducts during the hydrolysis reaction of DMES and water. A badge holder, which had been previously developed for use with similar two-spot badges, was needed to shield the dosimeter badges from the darkening effects of both sunlight and artificial light. All the DMES and TMDS vapor standards used during the test program were generated under controlled conditions of temperature (25 degrees Celsius) and relative humidity (45 percent) using a Kin-Tek Span Pac (Model 361), a precision standard toxic vapor generator. A Midac Model G1001 Fourier Transform Infrared (FTIR) and laptop computer were used to display and log the concentrations of DMES and TMDS vapors generated by the Kin-Tek Span Pac.

Upon exposure to DMES/TMDS vapors, the dosimeter badge undergoes a chemical reaction, which produces a color change on the surface of the badge. This color change is monitored using a Minolta Chroma Meter. The Minolta Chroma Meter is a compact tristimulus color analyzer that



DMES Dosimeter Badge

measures the reflective colors of various surfaces. In order to allow for ease of use during dosimeter testing, a badge reader/holder was fabricated. Several badge holder drawers were also fabricated to accommodate further testing on several physically unique badge configurations.

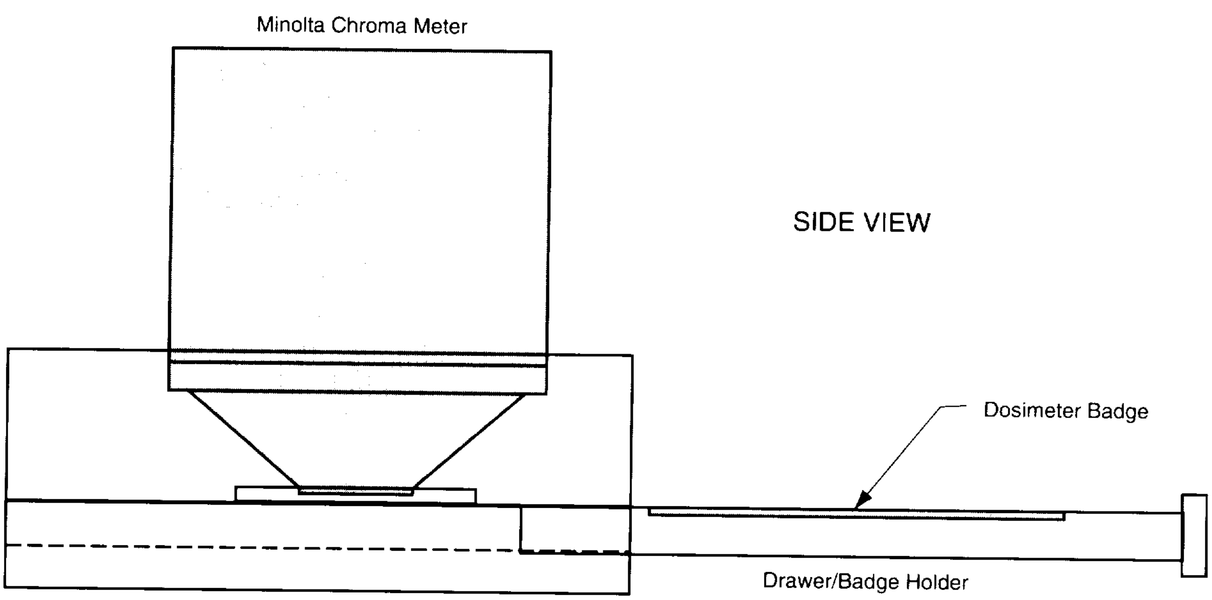
Using LabView, an automated program was developed to control the Minolta in the reading and downloading of dosimeter information to an external microprocessor via an RS232 link. A handheld scanner was used to obtain unique bar-coded information on each dosimeter and badge user. This information was stored along with a date stamp, response data, and calculated dose for each badge. Field tests of the DMES dosimeter and badge reader system were completed during two Shuttle waterproofing operations in OPF's 1 and 3. During the field trials of the DMES dosimeter, badges were placed near the five fixed Shuttle points used by an FTIR-based system to compare dosimeter responses with FTIR-based data. The data collected from the DMES dosimeter badges compared favorably with the FTIR data during the waterproofing operations as well as after the completion of the operation prior to the reopening of the OPF.

Key accomplishments:

- A DMES personnel dosimeter badge was developed for use in the OPF during waterproofing operations.
- A badge holder/reader system was developed that allows for automatic recording of dosimeter badge response data and can easily be adapted to a variety of dosimeter configurations.

Contact: D.E. Lueck, DL-ICD-A, (407) 867-4439

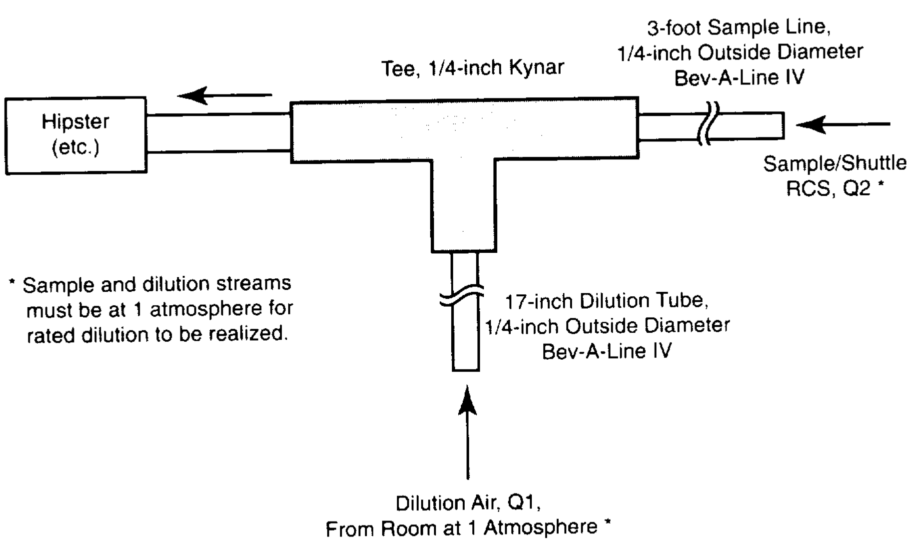
Participating Organization: I-NET, Inc. (B.J. Meneghelli, L.J. Robinson, T.R. Hodge, J.J. Curran, and C.K. Cantrell)



DMES Dosimeter Badge Holder

Extending the Range of Hypergol Propellant Detectors With a Sample Dilution System

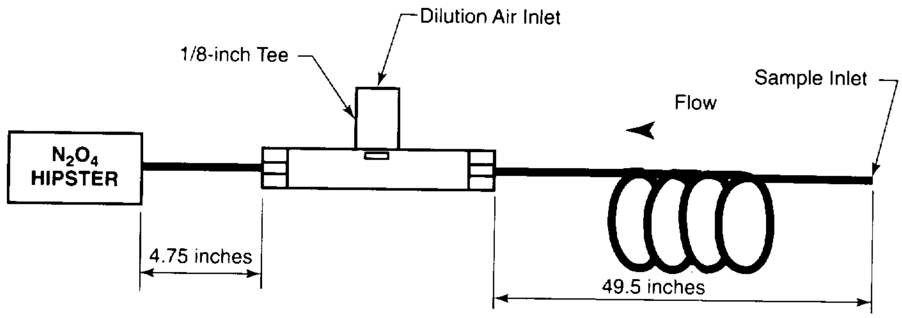
The hypergolic propellants monomethylhydrazine (MMH) and nitrogen tetroxide (N_2O_4) are reacted together in the Space Shuttle Reaction Control System (RCS) to maneuver on orbit and, in the Orbital Maneuvering System (OMS), to deorbit. Propellant vapor detectors are used to ensure personnel and mission safety in areas where vapors could leak into the environment. Substantial volumes of hypergols remain in propellant tanks and tubing after landing; thus, servicing the thrusters and engines is a hazardous operation requiring personal protection equipment and hypergol monitors. The sample diluter arose from a request by Lockheed Martin to measure the propellant level being purged from an RCS propellant manifold to the Orbiter Processing Facility (OPF) vent system. The class of personal protection gear depends on the propellant concentration. Up to this point, Energetics Science Incorporated (ESI) detectors that measure in the range of 0 to 200 parts per million (ppm) have been used. At the start of a servicing operation as the propellant is purged from the manifold, its concentration is far above the instrument range. The requirements to initiate a thruster service operation are that the MMH concentration must be no higher than several hundred parts per million and the N_2O_4 must be below about 5,000 ppm.



MMH Dilution Device

New sample diluters were developed to dilute concentrated hypergolic propellant vapors into the range of detectors in current use. The maximum range of "hipsters" (i.e., 6000 series ESI's) is 200 ppm for MMH and 500 ppm for N_2O_4. The request to the Toxic Vapor Detection Laboratory (TVDL) was made for a quick fix to prevent work stoppage associated with servicing Shuttle thrusters. The resulting hardware developed by the TVDL is a simple tee with sample and dilution tubes designed to dilute the propellant vapor into the range of the ESI 6000 detectors. These designs meet the goals of a 3:1 dilution for MMH and a 30:1 dilution for N_2O_4. Earlier designs were made with dilutions up to 100:1 and with the capability of selecting the dilution ratio in the field.

A Kynar tee was used for MMH dilution. Kynar is a plastic material and is 1/4-inch outside diameter (OD). Sample tubing was 3 feet (straight run), 1/4-inch OD Bev-A-Line IV; the side leg was the same tubing, 17 inches long. A brief test was performed to prove the dilution ratio at an appropriately high concentration of MMH, close to



Hookup and Use of the Dilution System

that anticipated in the application. An ESI 7000 MMH detector was used instead. The latter had a range of 0- to 200-ppm MMH. To verify the dilution ratio, a 4.7-liter Teflon sample bag was filled with 3 liters of gaseous nitrogen (GN_2) and various amounts of liquid MMH. A nominal MMH concentration in the bag was calculated from the GN_2 volume, and the liquid MMH was injected with a syringe. With the dilution device connected to the ESI, readings of a diluted sample and an undiluted sample were recorded. Also, a 5-milliliter (mL) sample of the bag was captured in 5 milliliters of 0.1 molar sulfuric acid solution and assayed per the standard TVDL procedure for fuel scrubs employing a coulometer.

The fuel diluter is roughly 3:1 as desired. It will give the desired dilution if all the precautions are followed: (1) the sample is at atmospheric pressure, (2) the sample and dilution tubes are not contaminated with particulates that substantially block the gas flow, (3) the dilution tube is at atmospheric pressure and is not drawing fuel-contaminated air, (4) the sample and dilution tubes are neither lengthened nor shortened and are not fitted with other elements or fittings that would alter the flow resistances, and (5) both sample and dilution streams are drawn under suction by the hipster or other detector.

The N_2O_4 diluter consisted of the following pieces: (1) 4.7 inches of 1/8-inch OD 316 stainless steel (SS) used as the connection between the dilution system and the hipster inlet system, (2) a 316 SS run tee, and (3) 49.5 inches of coiled 1/8-inch OD 316 SS used as the sampling end of the dilution system.

Measurements were taken of the flows at both the dilution air and sample inlets using an SKC Inc. ACCUFLOW digital calibrator. The measured flow ratio for the dilution system was 27. For a concentration check of the system, the dilution apparatus was attached to the hipster and set up to pull in a sample of N_2O_4 in air. The N_2O_4/air mixture was obtained from Air Products as a certified gas mixture whose concentration was listed as 6,480 ppm. The following data shows the observed hipster output value for a series of sampling tests: test 1 was 230 ppm, test was 240 ppm, test 3 was 228 ppm, test 4 was 235 ppm, and the average was 233 ppm.

The calculated dilution ratio based on the input value of 6,480 ppm and the average output value of 233 is 28. The N_2O_4 dilution device is roughly the 30:1 requested. As with the MMH dilution system, it will give an accurate dilution if all the precautions are followed.

Key accomplishments:

- Fuel and oxidizer sample diluters were fabricated using standard fittings and tubing.
- Verification of the diluter performances showed they will meet requirements and facilitate thruster servicing while eliminating work stoppage and scheduling uncertainty.

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Participating Organization: I-NET, Inc. (R.G. Barile, T.R. Hodge, and B.J. Meneghelli)

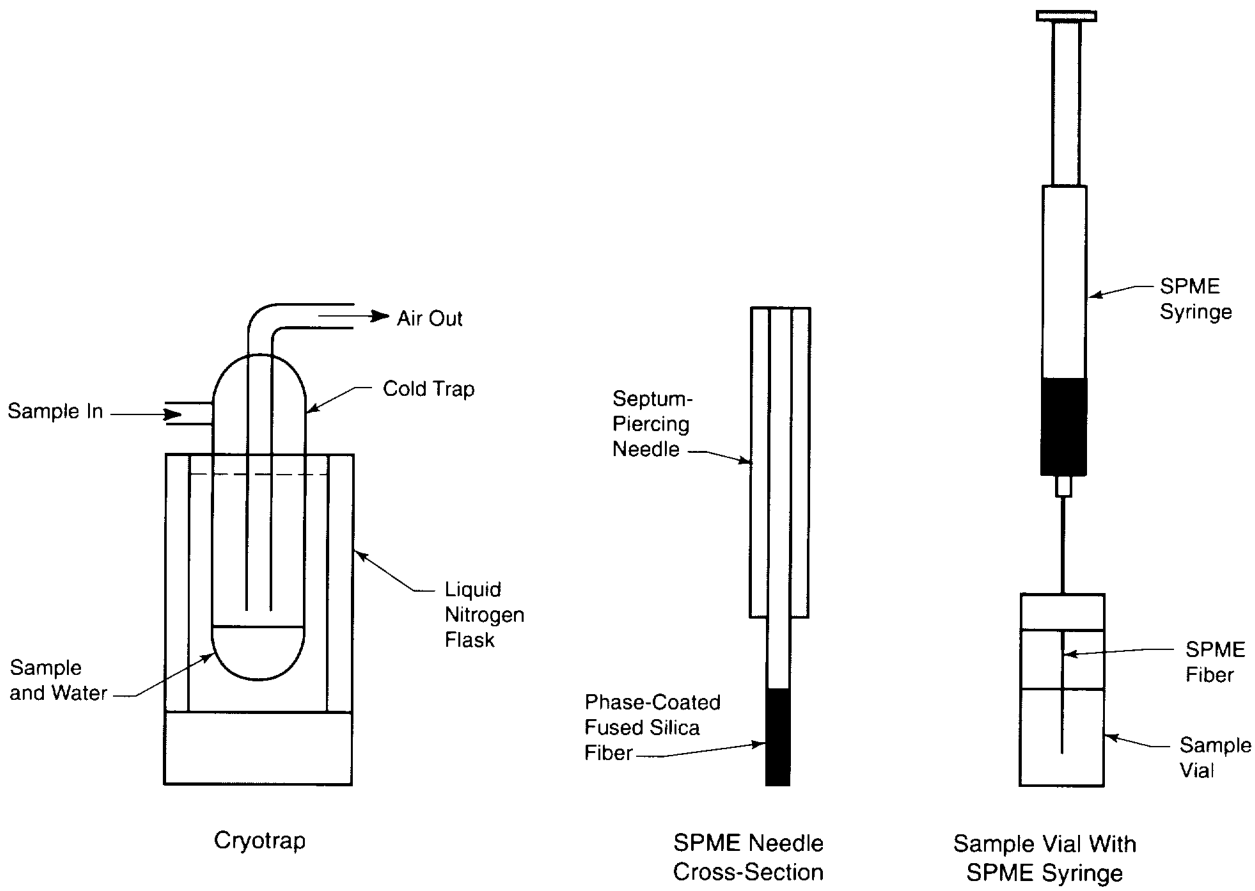
New Analysis System Cryogenic Trapping and SPME Sampling

As part of an effort to develop analytical procedures to measure 10-part-per-trillion (ppt) levels of volatile and semivolatile organic compounds in air, it was found that the combination of cryotrapping followed by solid phase microextraction (SPME) was very effective. Standard Environmental Protection Agency collection methods (adsorbent traps, liquid impingers, and cryogenic traps) require time-consuming solvent extraction methods or thermal desorption methods. Thermal desorption methods, however, can result in degradation of sensitive materials. Solvent extraction methods, including super critical fluids, add uncertainty due to sample loss and the inability to inject most of the captured sample into the analytical instrument. Traditionally, cryotrapping has suffered as a sampling method due to the presence of water, which has required that the sample be extracted from water, transferred to a solvent, concentrated, and injected into the gas chromatograph. Typically, only a small portion of the sample is actually injected into the instrument for analysis, which decreases the overall sensitivity of the sampling method. This new method combines cryotrapping with SPME analysis to simplify the sampling procedure and increase the sensitivity of the method by injecting most of the sample into the gas chromatograph (GC).

The SPME device consists of a silica fiber coated with different adsorbent materials that vary in type and coating thickness depending on the application. The fiber is attached to a stainless-steel plunger in a protective holder. The thin layer of coating on the SPME fiber allows for far shorter residence times during thermal desorption as compared to traditional adsorbents with thermal desorption units. Therefore, analytes can be captured in water, then absorbed from the sample, and thermally desorbed onto a column at a controlled temperature that minimizes sample degradation.

The experimental setup for the cryotrap and SPME injector is shown in the figure. The cold trap has a removable outer tube, which is used to capture the sample. Liquid nitrogen or dry ice is used to freeze the organic sample along with the water vapor as the sample vapor is drawn through the cryotrap. The organic compounds are condensed on the walls along with the water vapor from the atmosphere.

After the sample has been collected and the condensed air is allowed to evaporate, the contents of the cryotrap are quantitatively transferred to a sample bottle and used directly or diluted to a known volume. If the sample volume is adjusted, an aliquot of this sample is then taken to be analyzed by gas chromatograph/mass spectrometer (GC/MS). An SPME fiber is placed in the aliquot, the analyte is adsorbed to the fiber, the fiber is removed and placed in the injection port of the GC/MS, and the analyte is then thermally desorbed from the fiber to a cool column.



Cryotrap With SPME Sampler

The process uses the normally problematic capture of water in the cryotrap system to its advantage and results in a solvent-free injection with a minimum of sample preparation. The method is fast and efficient in the use of the captured sample. Typically, 10 to 40 percent of the sample can be transferred to a GC column, which is a significant improvement over other methods. Therefore, much larger volumes of air can be sampled without concern about the presence of water.

Key accomplishments:

- The sampling and extraction processes are not labor intensive like many of the other techniques.
- Data has shown the extraction process to have nominally a 10- to 40-percent capture and release efficiency compared to less than 1 percent for some of the other techniques.
- The technique uses atmospheric water to its advantage and eliminates it as a problem in the analysis.
- By using the SPME fiber, the sample injected into the GC/MS is free from solvent effects. This makes the sample inherently cleaner and less susceptible to interferences.

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Participating Organization: I-NET, Inc. (C.F. Parrish and P.H. Gamble)

Life Sciences

The Life Sciences Technology program at the John F. Kennedy Space Center (KSC) primarily supports the development of advanced technologies for application in long-term human habitation in space. The near-term focus of the Advanced Life Support (ALS) Breadboard Project is biomass production improvement, resource recovery development, and system engineering. Plant Space Biology is investigating lighting and nutrient-delivery hardware systems, the effects of environmental conditions (i.e., carbon dioxide and temperature) on plants growing in flight-type chambers, and microgravity effects on plant growth and development. These efforts are directed toward evaluating and integrating components of bioregenerative life support systems and investigating the effects the space environment has on photosynthesis and carbon metabolism in higher plants.

Supercritical Self-Contained Breathing Apparatus

Many of the propellants used aboard U.S. launch vehicles are toxic to humans. Hydrazine, monomethylhydrazine, and nitrogen tetroxide are a few that exhibit threshold limit values at less than 1 part per million. Protective measures must be provided to personnel handling these agents and those who must respond to spills or other emergency situations. The use of a self-contained breathing apparatus is critical for the protection of the human respiratory system. Conventional apparatus store the breathing medium, generally air, as a compressed gas. However, this old technology relies upon heavy, high-pressure cylinders that must be carried by the user or firefighter. In the mid-1980's, a liquid air breathing apparatus was developed and implemented at KSC to support extended duration work, while maintaining similar or lower backpack weights. This article describes a further evolution of this technology, which involves the use of supercritical air.

A supercritical air self-contained breathing apparatus has been developed under a Small Business Innovation Research (SBIR) contract with the Aerospace Design and Development Company. It has been tested extensively by the NASA Biomedical Laboratory at KSC. This system stores 7.2 pounds of air in the supercritical form (-300 degrees Fahrenheit, 750 pounds per square inch) in a specially fabricated titanium dewar. This quantity of high-density air (53 pounds per cubic foot) provides a sufficient capacity for a vigorously exercising rescueman for at least 1 hour. Low levels of work can be supported for 3 hours on a system that weighs little more than a conventional compressed air apparatus. The supercritical air pack is housed in a low-profile backpack, making it usable for astronaut rescue through the small orbiter overhead access hatch. A recent addition to the system was the integration of a liquid-cooled suit. This liquid-cooled garment acts as a heat exchanger for the pack while providing cooling to the user. This modification removes nearly 5 pounds of weight from the pack with no loss in capacity.

This technology is considered a significant advancement in the state of the art in self-contained breathing apparatus. It is especially suited for teams involved in hazardous material cleanup, fighting tall building fires, and performing subway rescue where positive pressure breathing apparatus are required for long time periods.

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Participating Organization: Aerospace Design and Development Company (H.L. Gier, Ph.D.)


06
SCAMP

Advanced Life Support and Space Biology (ALSSB) Engineering

The ALSSB Engineering group provides three primary functions for the Life Sciences Support Facility (LSSF) contract at KSC. The cornerstone of the group's work is the continued operation and development of the KSC Advanced Life Support Breadboard Project. The breadboard is a large-scale test bed for conducting integrated studies of biological life support components (plant growth, waste processing, resource recovery, etc.). Existing breadboard hardware and software systems are maintained and modified. In addition, new systems and components are designed, developed, and implemented as required.

ALSSB Engineering research focuses on two key areas: system and component process optimization. Biological processes are quantified in engineering terms (reliability, mass, volume, energy, automation, maintainability, etc.). This data is used to develop system-level models that define the operational envelope of biological life support systems. The data is also used to develop improved life support hardware and processes. These efforts are documented in numerous reports and publications. The ALSSB Engineering group also supports other LSSF activities. Calibration and maintenance of 15 controlled environment chambers and related support hardware is essential for ensuring the integrity of the scientific research conducted at KSC. Other areas of support include the Inorganic and Organic Chemistry Laboratories, Payload Development, and Mission Management.

Key accomplishments:

- 1988: First atmospherically closed operation of the Biomass Production Chamber (BPC).
- 1990: Metal halide lamps tested as a BPC lighting source.
- 1991: Atmospherically separated the two levels of the BPC. Installed the pressure compensation system in the upper BPC.
- 1992: New environmental monitoring system computer installed. Completed the condensate recovery system. Installed the pressure compensation on the lower level of the BPC. Installed the oxygen scrubbers for long-term atmospheric closure of the BPC.
- 1993: Redesigned and installed the new environmental control system computer software and hardware for the BPC.
- 1994: Integrated and operated the Breadboard-Scale Aerobic Bioreactor (B-SAB) with the BPC for continuous recycling of plant nutrients. Completed the redesign and implementation of breadboard alarms. Started the 14-month continuous operation of the breadboard.
- 1995: Installation of stand-alone, mechanical backup controllers. Development of a portable nutrient delivery system monitor for commercial growth chamber experi-

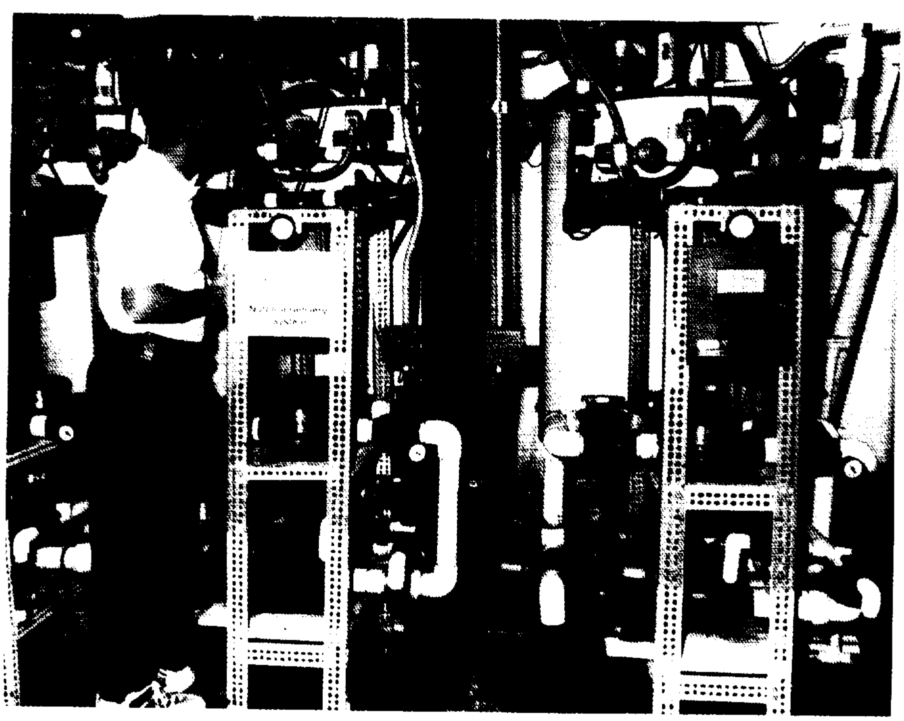
Atmospheric Gas Monitoring and Control Equipment Used for the Breadboard

ments. Completed the 14-month continuous operation of the breadboard.

- 1996: Began a 3-year continuous operation of the breadboard. Continuous production of mixed crop growth tests using wheat and potato. Added in situ atmospheric temperature and relative humidity control system sensors inside the BPC. Installed the Breadboard Resource Recovery Integration Laboratory. Fabricated MEMICS, a small sealed plant growth chamber for plant and engineering experiments. Implemented a reliability and maintainability database for the breadboard.

Key milestones:

- Late 1996: Installed the breadboard gray water (shower, wash, and clothes-washer) production and collection system. Initiated processing of gray water through the biomass production system.
- 1997: Install the breadboard solid-state fermentor for biological processing of CELSS solid waste (nutrient recovery and carbon dioxide production). Combination of wheat and potato nutrient solution (50-percent reduction in nutrient water volume). Installation of a robotic arm for remote BPC operations. Increased automation of the breadboard processes. Development of a remote manipulator end effector for the robotic arm in the BPC.
- 1998: Incorporate processing of human metabolic waste in the breadboard resource recovery system.
- 1999: Complete a 3-year continuous operation of the breadboard.



Portion of the Nutrient Delivery System Used With the Breadboard

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Participating Organization: Dynamac Corporation (B.W. Finger, M.S.)

Advanced Life Support (ALS) Biomass Production Chamber

A primary objective of ALS Biomass Production Chamber (BPC) tests is to obtain baseline performance information for bioregenerative life support systems (productivity, gas exchange, nutrient use, and transpiration) under realistic ALS environments. One major test was completed, and a second test was initiated during 1996.

A study was conducted to determine the effect of atmospheric filtering on tomato production. A seedless selection of "cherry" tomato (Reinmann Phillip 79/57) was used for this study. Ethylene is a gas produced by plants that results in shorter plants and promotes fruit ripening but is detrimental to plant growth at high concentrations. Ethylene filters allowed direct comparison of tomatoes grown in an ethylene-enriched and a normal atmosphere.

The use of ethylene filters delayed the ripening of tomatoes and resulted in taller plants but did not appear to have affected yields. Yields of fresh tomato were four times greater than any other variety evaluated by NASA (approximately 25 kilograms per square meter), which equates to over 50 pounds per square meter. Tomatoes are being evaluated for their nutritional value and versatility in food processing.

Continuous Production of Different Aged Potato (Cultivar Norland) Plants on Hydroponic Solutions Containing Minerals Recycled From Inedible Biomass

An ambitious, multi-year study using bioregenerative life support technologies was also initiated in 1996. A primary objective is to establish whether different crops can share a common atmosphere and nutrient solution from waste recycling systems without impacting the crop's capacity for air revitalization, water purification, or food production. Integration of the different biological waste processing technologies into the plant production system will occur over the next 36 months. This approach will allow evaluation and comparison of different technologies in a "steady-state" bioregenerative system.

Initial results have been very informative. Yields of wheat (cultivar Apogee) have been the highest obtained to date in the BPC. It was found by mixing light/dark cycles in the BPC that low-level light pollution inhibited tuber formation in potato (cultivar Norland). It was observed that the effect of a biologically active compound promotes tuber formation and reduces plant size in staggered planting of different aged potato plants on a common solution. Research is being directed toward identifying and managing environmental and biological influences on crop performance. Modifications of the photoperiod, air temperature, and nutrient temperature are being incorporated into the experimental protocols. This experiment promises to be the most realistic evaluation of bioregenerative life support technologies conducted by NASA to date. The baseline data obtained will be used in the design and construction of the BIOPLEX facility at Johnson Space Center, Texas.

Potato (Cultivar Norland) Production During Continuous Production in Hydroponic Solution Where Nutrients Are Recovered From Inedible Biomass

Key accomplishments:

- 1992: Determined the effect of the photoperiod on potato growth.
- 1993: Evaluated the effect of atmospheric filtering on the growth of wheat and potato. Grew lettuce on recycled nutrients.
- 1994: Grew wheat on recycled nutrients and initiated a long-term evaluation of batch versus continuous production with potato.
- 1995: Demonstrated the feasibility of long-term continuous operation of a bioregenerative life support system using recycled nutrients. Completed one soybean and one tomato test.
- 1996: Initiated breadboard-scale testing of wheat and potato sharing a common atmosphere.

Key milestones:

- 1997: Initiate breadboard-scale testing of wheat and potato sharing a common nutrient solution.
- 1998: Initiate breadboard-scale testing of wheat and potato with the integration of biological processing of gray water and other human waste streams.

Contact: J.C. Sager, Ph.D., JJ-G, (407) 853-5142

Participating Organization: Dynamac Corporation (G.W. Stutte, Ph.D., and C.L. Mackowiak)

Advanced Life Support (ALS) Biomass Production Research

In support of KSC's ALS Breadboard Project, ancillary plant studies provide input to the development of plant production procedures for the Biomass Production Chamber (BPC) [see the article "Advanced Life Support (ALS) Biomass Production Chamber"]. Much of the development work supports the Johnson Space Center BIOPLEX facility, where the integration of human and bioregenerative components of a human habitat will be tested.

Nutrient recycling will be important to any ALS, and sodium budgets between plants and humans will need to be determined. Sodium is a major component of urine and soap and continual addition of sodium to the plant system through human waste streams may reach excessive levels and reduce plant productivity. If sodium accumulates in the edible portions of the plant, humans will get sodium from the plants (food) and dietary salt supplements could be reduced. Salt partitioning in lettuce and radish has been tested, and spinach is being tested to determine salt budgets for ALS. Table beet will also be tested. Both spinach and table beet have high affinities for sodium, where it primarily accumulates in the edible leaves.

The potential number of fruit crops fitting ALS requirements is quite small. Strawberry is one of the best candidates since it is high in nutrients and sugar and it fits the production requirements. Large yields (5.7 kg m^{-2}) were produced but many of the fruit were misshapen. Manual/mechanical pollination is being tested to promote large, well-developed fruit. Manual pollination may improve yields and, since strawberry will be grown in small quantities, total labor requirements would be minimal.

Research continues on the plant growth regulator effect observed when potato plants are continuously cultured in a recirculating hydroponic system. The effects include reduced vegetative biomass and hastened tuberization, which may be beneficial to an ALS. The same effects have been observed for plants grown under both environmentally inductive and noninductive conditions. To help characterize active compounds, separations are being tested on in vitro potato plantlets. These bioassays require much less space than a hydroponic plant system while providing similar information.

Key accomplishments:

- 1992: "Supraoptimal Carbon Dioxide Effects on Soybean Growth and Development in Controlled Environments" was published in the Journal of Plant Physiology.
- 1993: Wheat was grown on minerals recycled from inedible soybean and wheat biomass.
- 1994: "Comparison of Aerobically Treated and Untreated Crop Residue as a Source of Recycled Nutrients in a Recirculating Hydroponic System" was published in Advances in Space Research.
- 1995: "Vegetative Growth of Potato Under High-Pressure

Potato Bioassay Study Using Foam Supports and Gas Permeable Covers

Sodium, High-Pressure Sodium SON-Agro, and Metal Halide Lamps" was published in HortScience.

- 1996: "Growth and Stomatal Behavior of Hydroponically Cultured Potato at Elevated and Super-Elevated CO_2" was published in the Journal of Plant Physiology.

Key milestones:

- 1997: Test hydroponic crop production systems for processing gray water.
- 1998: Test bioprocessed urine for use in crop production.
- 1999: Test bioprocessed human solid waste in crop production.

Contact: J.C. Sager, Ph.D., JJ-G, (407) 853-5142

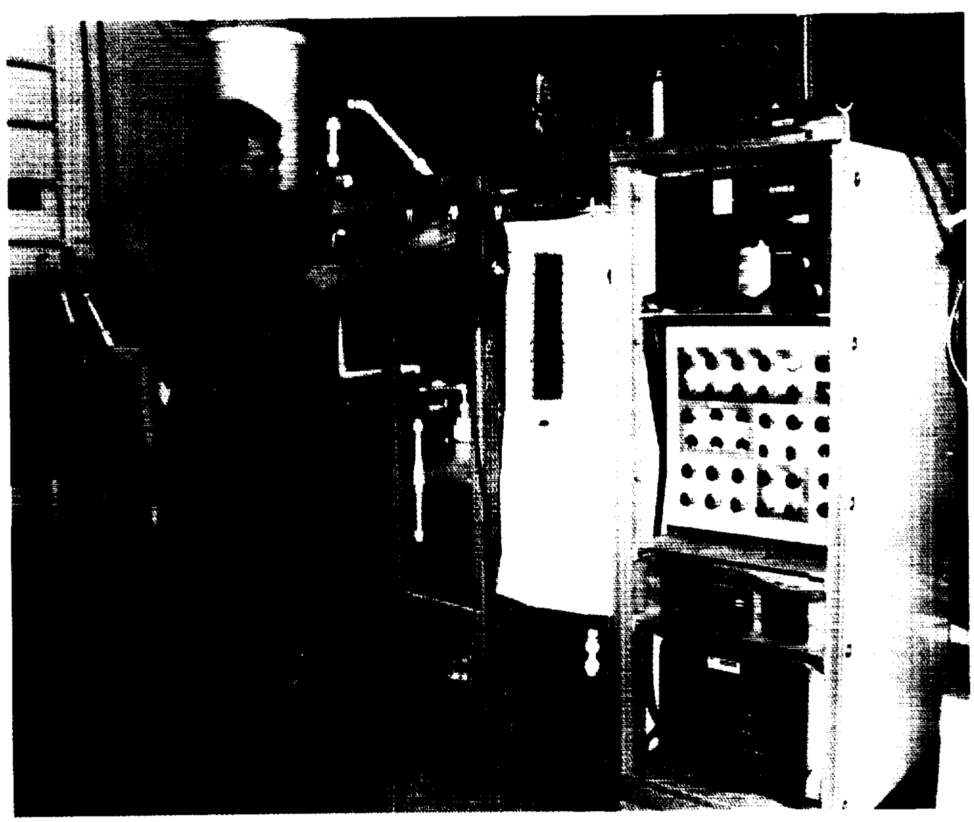
Participating Organization: Dynamac Corporation (C.L. Mackowiak and G.W. Stutte)

Advanced Life Support (ALS) Resource Recovery and Biomass Processing Research

Resource recovery and biomass processing are major components of a functional Controlled Ecological Life Support System along with biomass production, crew, and system integration. The challenge has been to recycle inedible material into carbon dioxide and mineral forms that can be used by crops and to convert these inedibles into food, thus more efficiently using ALS energy, volume, weight, and crew time.

The ultimate goal has been to design, fabricate, test, and operate, at a breadboard scale, ALS biomass processing and resource-recovery components. Candidate processes are identified and studied with small, laboratory-scale (0.1- to 2-liter size) systems to identify key environmental and process control parameters. Intermediate-scale systems (i.e., 8- to 10-liter size) are then used to optimize these key process parameters and to gain operational experience with the potential hardware, software, process control and monitoring, and biological subsystems. Then, the full-scale components are designed, fabricated/procured, set up and tested, operated, and integrated with the other systems within the ALS breadboard. ALS Resource Recovery research focused on three areas this year:

- Intermediate-scale research continued to concentrate on process optimization with the completion of a study begun last year on the effects of bioreactor retention time. This study concluded with an intermediate-scale integration study comparing the best



Breadboard-Scale Aerobic Bioreactor

rapid retention time (1 day) with one run at a conventional retention time (8 days) with the effluents used for testing in the replenishment of nutrients in a hydroponic crop growth solution.

- The potential role and costs/benefits of aerobic composting of inedible crop residues were initiated at the intermediate scale.

- The use of biological resource recovery components to biodegrade soaps in gray water (i.e., crew wash water, laundry water, and dishwater) was also initiated at the intermediate scale.

Next year, resource recovery will continue to focus on aerobic composting of inedible crop residues with process optimization studies and integration studies at the intermediate-scale leading to incorporation of composting at the breadboard scale by mid-year. Biological processing of gray water will also continue at the intermediate scale, and plans for processing of urine and human solid wastes will be developed.

Key accomplishments:

- 1986 to 1988: Initial cellulose conversion research.
- 1989: Cellulose conversion process optimization studies.
- 1990: Flask-scale studies of cellulose conversion.
- 1991: Completed biomass processing studies on cellulose conversion with five breadboard-scale runs.
- 1992: Initiated flask-scale studies of microbial aerobic decomposition of crop residues.
- 1993: Design, fabrication, and operation of intermediate-scale aerobic bioreactors. Design and fabrication of the Breadboard-Scale Aerobic Bioreactor (B-SAB).
- 1994: Integration and first operation of the B-SAB, recycling nutrients to the Biomass Production Chamber. Process optimization.
- 1995: Integration of the B-SAB with other crops (white potato). Completion of integration studies encompassing anaerobic biological processing of crop residues with downstream processing components.
- 1996: Completion of intermediate-scale tests of the effects of bioreactor retention times on aerobic biological processing of crop residues. Initial studies of aerobic composting for mineral recovery and carbon mineralization.

Key milestones:

- 1997: Integration of gray water processing into breadboard-level resource recovery. Integration of composting of crop residue solid wastes into breadboard-level resource recovery. Intermediate-scale studies of biological processing of urine and human solid wastes.
- 1998: Integration of biological processing of urine into breadboard-level resource recovery. Intermediate-scale studies of biological processing of human solid wastes.
- 1999: Integration of biological processing of urine and human solid wastes into breadboard-level resource recovery.

Contact: J.C. Sager, Ph.D., JJ-G, (407) 853-5142

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

Automation and Robotics

The automation and robotics program at the John F. Kennedy Space Center (KSC) is focused on providing solutions to current and future launch vehicle and payload processing operational issues and problems. The program also provides a forum for NASA research centers to demonstrate advanced robotic technologies for problems that must be addressed and solved for future space missions. In this role, KSC provides an excellent opportunity to take technologies out of the laboratory and make them work reliably in the field. This field testing is focused by selecting space mission technologies that are also applicable to ground processing applications and problem areas. Field testing is critical to the successful insertion of robotic technologies for both NASA and commercial applications.

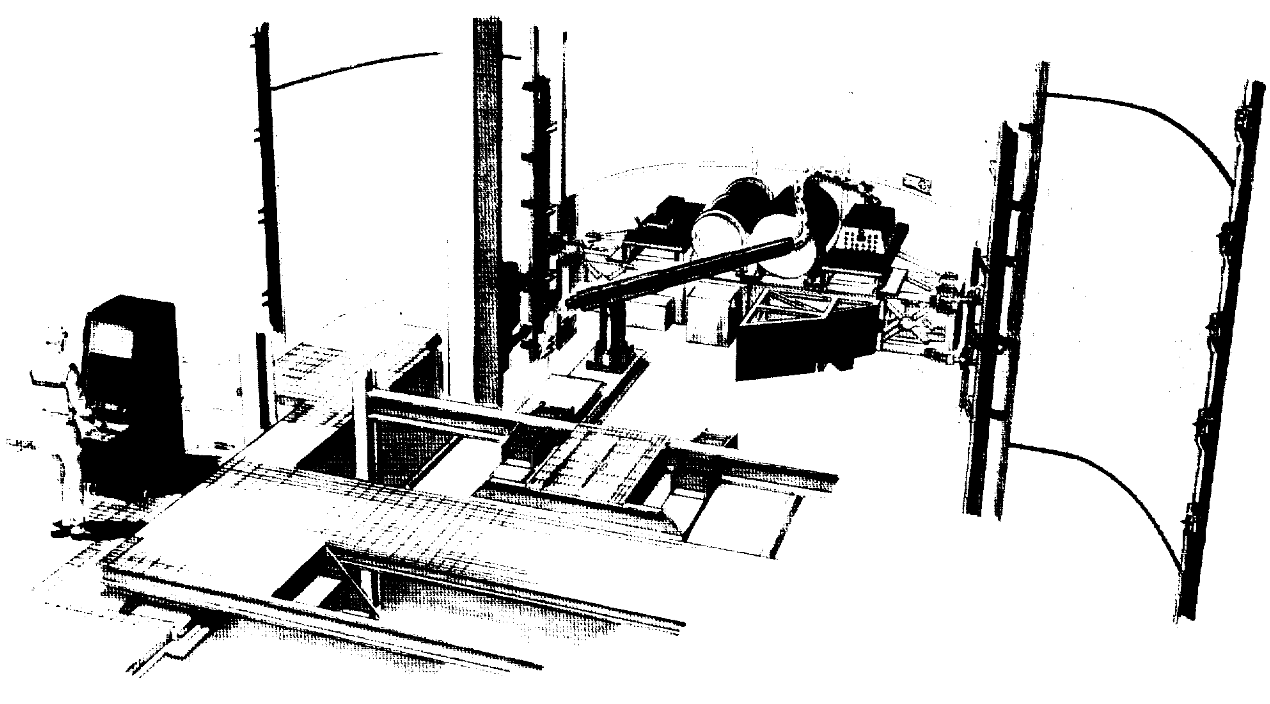
Technology areas that KSC is working with other NASA centers to develop and apply include: integration of real-time controls with advanced information systems, obstacle-avoidance sensors and systems, multidegree-of-freedom robotic devices and systems, intelligent control systems, imbedded and distributed controls, inspection sensors and systems, integration of advanced software technologies in control and sensor interpretation, and model- and rule-based systems for health monitoring and diagnosis. All of these technologies can be applied to automating ground processing tasks.

Application areas that are currently being addressed during this year's program include the Solid Rocket Motor Stacking Enhancement Tool, the Advanced Payload Transfer Measurement System, and the Cable Line Inspection Mechanism.

Payload Inspection and Processing System (PIPS)

A project is being initiated to design and develop a robotic system for Space Shuttle payload bay and payload processing operations in the Payload Changeout Room (PCR). A study and conceptual design was completed to identify and evaluate processing tasks that would benefit from the use of a robotic system to perform inspections and light manipulation in difficult access areas around payloads. Due to space and reach constraints, payload access in these facilities can be difficult. Some processing tasks are as simple as inspecting the proper mating of connectors or the removal of camera lens caps. Even though these are simple tasks, they often require expensive custom-designed access platforms and pik-boards to reach the area. The PIPS will be designed to reach these areas and perform these processing tasks, thereby eliminating considerable expense and hazards associated with the present operations. Operations at the PCR were the prime focus of the effort; however, other facilities such as the Orbiter Processing Facility (OPF) were also considered.

The PIPS will be flexible enough to "thread" into the highly constrained payload areas and perform visual inspections, payload closeout photography, contingency inspections and verifications, spot cleaning, foreign object debris removal, cover installation and removal, and line connections. The conceptual system is made up of a unique long-reach (3-meter) serpentine manipulator covered by an obstacle detection proximity SensorSkin, inspection cameras, end-effector grippers and cleaning tools, a 3-degree-of-freedom (3-DOF) base (three



Payload Inspection and Processing System

Payload Inspection and Processing Robot

translations), a mobile control station, and a graphical user interface. The key design features include portable components that break down into two-person-carrying subassemblies, a wheeled control station cabinet, a facility interface to existing platform mounting locations, teleoperated control, and redundant safety systems. The design emphasizes a quick setup, minimal facility modifications, use in multiple facilities, clean room operation, and ease of use by trained technicians. This concept will be analyzed in detail in the design process and may be subject to changes as the design develops.

Work is currently underway to demonstrate several of the key technologies required for the PIPS; these include a serpentine manipulator (i.e., 18 DOF's), a whole arm obstacle proximity sensing system (i.e., SensorSkin), and a graphical user interface for teleoperation control. An integrated demonstration is being developed to illustrate how these technologies can be combined into an operational system. The demonstration will take place in the Advanced Systems Development Laboratory using the serpentine manipulator, SensorSkin, graphical user interface, and a mockup of the next Hubble Telescope servicing mission payload. Payload processing tasks will be simulated for the demonstration.

Key accomplishments:

- Performed a system study and need analysis.
- Completed the conceptual design and computer graphic model of the conceptual robot design.
- Received a prototype serpentine arm (8 DOF's) built by Foster Miller, Inc., through a Phase II Small Business Innovation Research (SBIR) project. This arm has been upgraded from 8 DOF's to 18 DOF's and incorporates a distributed control system.
- Received the prototype SensorSkin developed by Merritt Systems, Inc., through a Phase II SBIR project. The SensorSkin has been installed on the prototype serpentine arm.
- Completed the design requirements document.

Key milestones:

- 1996: Developed a PIPS conceptual design. Completed development of a prototype user interface. Initiated development of software control algorithms for coordinated movement and path planning.
- 1997: Demonstrate the prototype serpentine manipulator arm, SensorSkin, and prototype user interface in a laboratory mockup.

Contacts: T.C. Lippitt, DM-ASD, (407) 867-3266, and W.C. Jones, DM-ASD, (407) 867-4181

Participating Organizations: NASA, Payload Processing Division; McDonnell Douglas Space Systems; and Ohio State University

Launch Complex 39 Payload Changeout Room HEPA Filter Inspection System (HFIS)

A robotic system has been developed at KSC to automate a dangerous, critical, and time-consuming task of High-Efficiency Particulate Accumulator (HEPA) filter inspection in the launch pad Payload Changeout Room (PCR). The HEPA filters are critical to maintaining the clean room atmosphere in the PCR to protect Shuttle payloads.

Previously, filter inspection was performed manually and took approximately 120 man-hours to complete. This inspection task required technicians to use ladders and special access platforms deployed on top of a six-story, movable structure inside the PCR. This massive structure, known as the Payload Ground Handling Mechanism (PGHM), is used to move satellites and other payloads in and out of the Shuttle orbiter's cargo bay.

The HFIS is a portable 4-degree-of-freedom (DOF) robot that uses the existing 5-ton bridge crane rails in the PCR ceiling to implement one of its degrees of freedom. The HFIS mechanism has a custom integrated end-effector consisting of the following: a particulate counter and air flow velocity sensor, a laser distance sensor, and a CCD video camera. The HFIS is controlled through a user-friendly graphical interface via a supervisory computer consisting of an input/output processor, motion controller, and host computer. System users can manually or automatically perform HEPA filter inspections with the systems. During these inspections, real-time filter test status is provided to the operator by the graphical user interface, and detailed test data is recorded on a tape drive for detailed analysis and reporting.

The HFIS is an operational system in use at both of the Launch Complex 39 (LC-39) launch pads. The system was turned over to operations (i.e., Lockheed Martin Space Operations) in the beginning of calendar year 1995 and is being used to perform inspections.

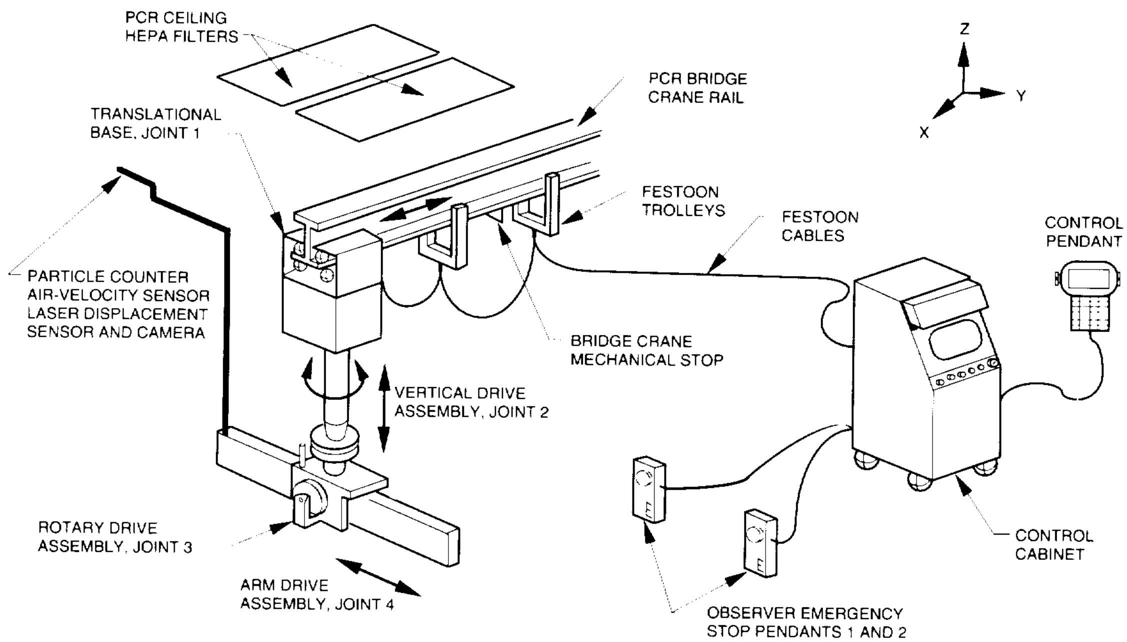
Modifications are underway for an improved sensor using graphite composite and an improved user interface to program the location of filter inspection sequences.

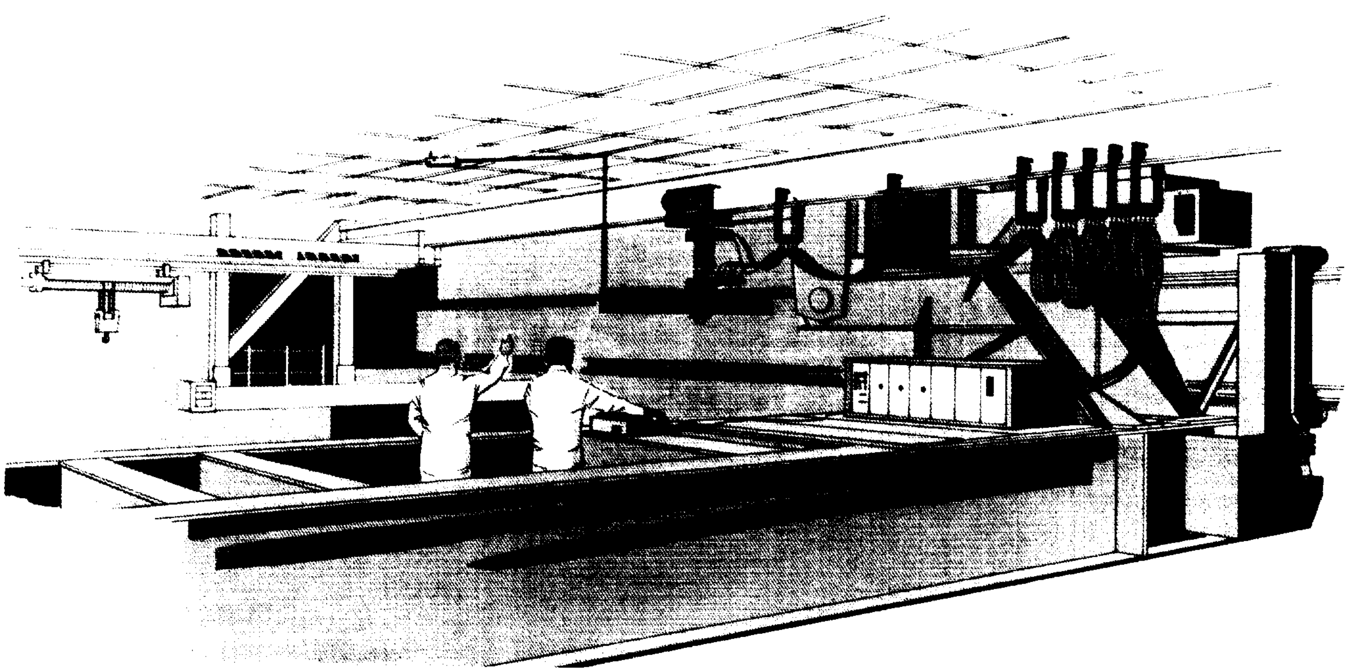
Key milestones and accomplishments:

- June 1994: HFIS integrated and ready for operations at LC-39, Pad A.
- February 1995: HFIS integrated and ready for operations at LC-39, Pad B.
- March 1995: HFIS operation turned over to NASA Vehicle Engineering and Lockheed Martin Space Operations.

Contacts: T.C. Lippitt, DM-ASD, (407) 867-3266; W.C. Jones, DM-ASD, (407) 867-4181; and F. DelaPascua, PK-H6, (407) 861-3631

Participating Organizations: I-NET, Inc.; NASA, ESC/PVD Pyrotechnic and Launch Accessories; and Lockheed Martin Space Operations





HEPA Filter Inspection System (HFIS)

Advanced Life Support Automated Remote Manipulator (ALSARM)

The objective of the ALSARM project is to develop a robotic system to take environmental measurements in the Controlled Ecological Life Support System (CELSS) Breadboard Project Biomass Production Chamber (BPC) at KSC. This robotics project is a cooperative effort between NASA and the University of Central Florida (UCF) Department of Mechanical and Aerospace Engineering. A senior-level design course at UCF has resulted in a robotic arm design that will meet all BPC engineering and scientific requirements. The project is nearing completion and will conclude in mid-1997 with the installation of ALSARM in the BPC.

The BPC is a 7-meter-tall by 3-meter-diameter chamber that consists of two separate levels used to grow crops in an almost totally enclosed environment. The BPC is helping NASA understand how to grow crops in space for future offworld missions. During the course of plant growth experiments, engineers and scientists enter the chamber to measure environmental parameters such as air temperature, infrared radiation, relative humidity, air velocity, and light intensity. Entry of personnel into the BPC disturbs the environment in several ways. Opening the chamber door accounts for a significant percentage of the chamber daily leak rate. Personnel contaminate the environment by their respiration, expelling carbon dioxide and organic products into an otherwise closely monitored and controlled environment. Another challenge is one of taking accurate, consistent measurements. It is difficult for experimenters to take measurements by hand at exactly the same points from one data gathering session to another. The ALSARM will be an automated method for taking these measurements, which will significantly reduce contaminant introduction resulting from personnel entry, minimize the chamber leak rate, and allow more consistent measurements.

ALSARM in the BPC

The ALSARM will integrate state-of-the-art systems in control, manipulation, information management, and sensor technologies to perform the BPC environmental measurements. The system will be expanded to include an end-effector (or tool) on the horizontal arm to take plant samples. This end-effector is being developed during phase II of the ALSARM project, which started in September 1996.

Key design features of the ALSARM include (1) automated control via computer communications links, (2) a 3-degree-of-freedom robot arm, (3) multiple sensor array, and (4) development of an end-effector for plant sampling.

The accomplishments for 1996 and early 1997 include the final design details of the arm, testing of the assembled ALSARM in a BPC mockup, and design completion of the end-effector.

Completing the ALSARM design was a major effort for late 1995 through 1996. Integration and testing of the ALSARM subsystems (vertical arm for Z-translation, rotation fixture for rotation about the vertical arm, horizontal arm for X-Y translation, electrical power system, sensor array, and control and monitor system) should be completed by late March 1997, and installation into the BPC should occur no later than mid-May 1997.

Key accomplishments and milestones:

- September 1995: Fabrication of ALSARM components initiated.
- September 1996: Redesign of the Horizontal Telescoping Assembly (HTA) initiated.
- November 1996: Redesign of the HTA completed.
- February 1997: Fabrication of the ALSARM complete.
- April 1997: Validation testing of the ALSARM complete.
- May 1997: Installation of the ALSARM into the BPC.
- Mid-1997: Refine development of the ALSARM end-effector.

Contacts: M.D. Hogue, DM-ASD, (407) 867-1720; and W.L. Little and J.C. Sager, JJ-G, (407) 853-5142

Participating Organization: University of Central Florida (Dr. R. Johnson and Dr. Z. Qu)

Materials Science

The Materials Science Technology program at the John F. Kennedy Space Center (KSC) supports advanced technologies directed toward improving launch site safety, operability, and maintainability. The program includes application materials engineering, materials testing, chemistry, and other science disciplines. The near-term program focuses on Shuttle ground processing improvement by providing materials and coatings that afford better corrosion control, materials with better hazardous systems compatibility, and improved testing methods and instrumentation. The long-term program will investigate materials technology that can be used to develop new launch and processing facilities for future vehicles and payloads, will reduce the cost of maintenance, will provide higher safety and reliability, and will provide more environmentally friendly systems.

Efforts To Prevent Rebar Corrosion

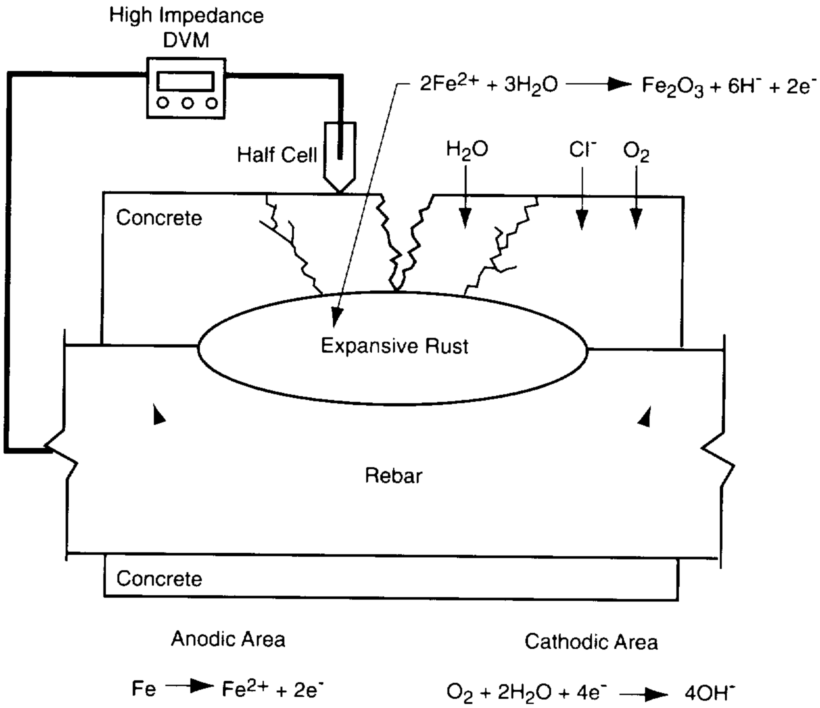
Steel-reinforced concrete is one of the best engineered composite materials. Steel and concrete are not only complementary, but steel is also compatible with concrete in most environments. However, in a marine environment, salt contaminates the concrete; and when the chloride ions reach the steel, corrosion is initiated. After corrosion starts, the bond at the concrete-steel interface is compromised, resulting in a separation of concrete from the steel.

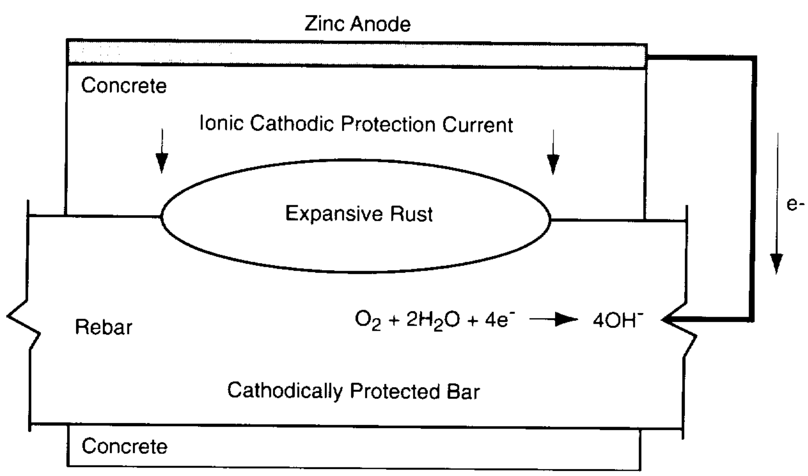
Steel-reinforced concrete is costly to repair. These costs can be avoided by installing corrosion protection on new construction to prevent cracking and the spalling of the concrete. Also, for existing structures, the structure life can be extended by retrofitting corrosion protection.

Savings in new construction can be measured by extension of design life (tens of years) of the reinforced concrete structures (buildings, bridges, piers, cooling towers, etc.). For existing structures (Vehicle Assembly Building roof deck, bridges, etc.), the remaining life cycle can be extended, saving the cost of new replacement construction and/or repair.

There are a number of promising techniques that have potential to stop or impede the corrosion process. These techniques that arrest corrosion are being investigated. These investigations include:

- Improve performance qualities of zinc hydrogel corrosion protection: Evaluate the performance of the zinc alloy hydrogel sheeting in the Florida marine environment by conducting depolarization measurements.
- Zinc coatings evaluated by electrochemical impedance spectroscopy: Measure the barrier at the steel/concrete interface to determine the effect at this location (joint effort with Florida Atlantic University).
- Electromigration of the chemical corrosion inhibitor: Measure corrosion current and corrosion potential of reinforcing steel after treatment with electrically driven corrosion inhibitors (joint effort with the University of Central Florida).
- Migration of corrosion inhibitors: Measure corrosion current and corrosion potential of reinforcing steel after treatment with migrating corrosion inhibitors.
- Thermally sprayed zinc coating to mitigate concrete rebar corrosion: Measure corrosion current and corrosion potential at an existing sprayed zinc site after treatment with flame-sprayed zinc.
- Edge effect of thermally sprayed zinc: Compare corrosion current and corrosion potential for different configurations of thermally sprayed zinc.
- Corrosion inhibitor testing by electrochemical cell method: Measure corrosion current





and corrosion potential of reinforcing steel in an electrochemical cell to compare different inhibitors.

Key accomplishments:

- Data collection system was installed on the NASA Causeway bridge for measuring corrosion protection of flame-sprayed zinc.
- Three industry partners are involved with NASA in a joint effort to solve rebar corrosion problems.
- Corrosion test blocks were fabricated to evaluate migrating corrosion inhibitors.

Key milestones:

- Develop procedures to test a zinc hydrogel product.
- Continue to monitor corrosion protective measures over the long term and to evaluate new products as required.

Contacts: T. Yang, IM-FFO-A, (407) 867-4454, and R.U. Lee, LO-MSD-2T, (407) 867-1403

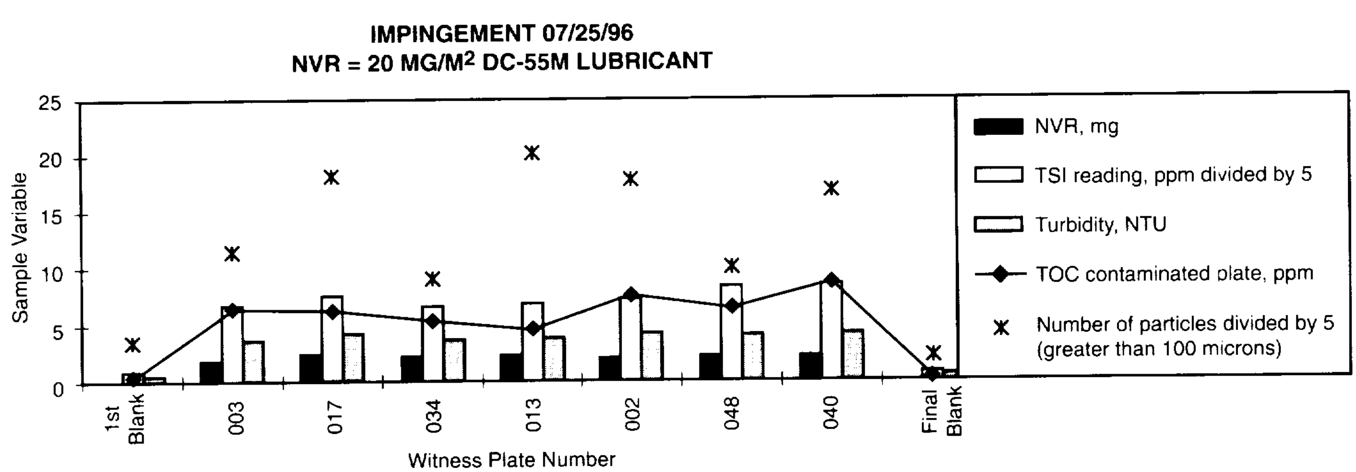
Participating Organizations: I-NET, Inc. (R.G. Barile, J.J. Curran, D.E. Counts, C.K. Cantrell, and C.H. Fogarty); University of Central Florida (V. Desai and R. MacDonald); and Florida Atlantic University (B. Hart and S.K. Lee)

Progress in Precision Cleaning at KSC

New environmentally sound precision cleaning and verification techniques have been developed for critical systems and components used at KSC. This technology was required to replace former methods traditionally employing chlorofluorocarbon (CFC) 113. The new patent-pending technique of precision-cleaning verification is for large components of cryogenic fluid systems. These are stainless steel, sand-cast valve bodies with internal surface areas ranging from 0.2 to 0.7 square meter (m^2). Extrapolation of this technique to components of even larger sizes (by orders of magnitude) is planned. In the new technique, a high-velocity water stream impacts the part to be verified. This process is referred to as air/water impingement and forms the basis for the Impingement Verification System (IVS). The system is unique in that a gas stream is used to accelerate the water droplets to high speeds. Water is injected into the gas stream in a small, continuous stream. The air/water mixture is then passed through a converging/diverging nozzle where the gas is accelerated to supersonic velocities. These droplets impart sufficient energy to the precision-cleaned surface to place nonvolatile residue (NVR) contaminants into suspension in the water.

The sample water is collected, and its NVR level is determined by total organic carbon (TOC) analysis at 880 degrees Celsius. The TOC, in part-per-million carbon, is used to establish the NVR level. A correlation between the former gravimetric CFC 113 NVR and the new IVS NVR was found from experimental sensitivity factors measured for various contaminants. The successful correlation of NVR with TOC was published in the precision-cleaning literature, including 1995 JANNAF proceedings.

More recent work was focused on the particulate contamination of critical parts. When precision cleaning is done, not only NVR but also particulate contamination is of concern. For example, level 100 requires that a 0.1 m^2 (1 square foot) area of surface cleaned or verified (sampled) by impingement must have 0 particles



greater than 100 microns, a maximum of 11 greater than 50 microns to 100 microns, etc. The particles in an impingement sample are quantified by filtering the sample (e.g., 50 milliliters, with an 0.8-micron filter and counting particles under a microscope). A study of particulates associated with KSC's impingement system was recently initiated. Particulates were found in the impingement water and the breathing air. These were easily eliminated by prefiltering. Impingement-panel air and water filters were cleaned, and acetone (wash solvent) was filtered. Testing with witness plates continues. A concern of the impingement stream creating particulates by shearing metal parts was settled by observing that metal particles were negligible in impingement samples of witness plates.

While studying particulates, known amounts of NVR correlated well with turbidity measurements. This new finding will make impingement verification more applicable to contaminant NVR materials, which have little or no organic carbon such as Krytox. Also, an NVR meter (formerly made by TSI) made by American Fluid Corporation correlated well with known NVR on precontaminated witness plates.

In a related project, new environmentally benign solvents will be used to clean certain surfaces instead of impingement for parts that are not compatible with water. Compatibility testing of solvents and ground support equipment (GSE) gaskets and other materials was completed for Genesolv 2000 (HCFC 141b), Castrol Super Clean, WP Power Cleaner 310L, Allied AK225, and Dupont Zonyl. Most new solvents tested so far were found to be compatible with typical GSE surfaces such as elastomers and metals.

Key accomplishments:

- Impingement samples were analyzed for particulate contamination, typical sources of particles were identified, and procedures were established to eliminate them.
- Concern for metal particles created by the impingement jet was settled.
- Two more methods were identified, turbidity and NVR meter, that strengthen the case for impingement verification of NVR.
- Nonaqueous solvents were systematically evaluated for compatibility with GSE materials.

Contacts: G.S. Melton, LO-MSD-2M, (407) 867-7048, and G.J. Allen, LO-MSD-1C, (407) 867-3910

Participating Organization: I-NET, Inc. (R.G. Barile, C.H. Fogarty, C.K. Cantrell, and D.E. Counts)

Photochemically and Thermally Cross-Linkable Polyconjugated Systems

The goal of this project involves the conversion of organic polyconjugated systems that are soluble in nonpolar solvents into water-soluble systems that are either photochemically or thermally cross-linkable. The polyconjugated systems may be applied to selected substrates, such as fabrics, in aqueous solutions and subsequently cross-linked to produce durable coatings on the fabrics. The systems selected will have the capability of providing electromagnetic shielding and antistatic properties to the substrate fabrics.

The University of Arkansas at Little Rock is conducting this project based on electrically conducting polymers such as polyaniline, polypyrrole, and polythiophene that have been modified to enhance solubility during processing. Subsequent to processing, the modified polymers will then be converted to insoluble materials via thermal or photochemical cross-linking. A key innovation in this program has been the development of techniques to effect polymerization in sulfonated lignin to yield doped water-borne conducting systems. This effectively accomplished the first milestone of the program in the first year, and the development of this technique will be continued. Work will now focus on the characterization of these polymers and, subsequently, the addition of functional groups to the polymers to permit thermal or photochemical cross-link ability. Finally, fabrics typically used in cleanroom garments will be coated with these polymers and evaluated against the acceptance criteria for use at KSC.

Contact: C.J. Bryan, LO-MSD-2, (407) 867-4614

Participating Organization: University of Arkansas at Little Rock (T. Viswanathan)

Effects of Chemical Aging of Polymers on Performance Properties

The project seeks to measure the changes in performance properties of polymeric materials resulting from environmental exposure, to determine the mechanisms of chemical aging, and to develop life-prediction models. Specifically, changes in chemical and morphological structure caused by aging processes will be measured and correlated with performance-related properties. Life-prediction models will enable the consumer to select and use materials with increased confidence.

A major limitation of the life of polymeric-based components (elastomers, thermoplastics, adhesives, and composites) is deterioration in performance properties in service or natural environments. Pyrolysis, hot oxidative (air) aging, and hydrolysis are the most common life-limiting factors. Attack by other chemical species or by ultraviolet radiation can accelerate aging. Polymer antidegradants can retard some effects, but sometimes the effect is temporary. Skin effects are frequently not considered but can often prolong resin life considerably.

The 3-year project will require numerous tasks. The first task involves aging samples in controlled environments for specified time periods. Penetration of challenge chemicals will be characterized in terms of diffusion and solubility. Chemical changes will be measured by various analytical techniques. Morphological changes will be measured by thermal analysis and microscopy. Elastic modulus, ultimate strength, fatigue crack growth resistance, and stress relaxation will be determined of virgin samples and specimens from the above tasks. The data will be studied to identify correlations. Improvements in aging models should result.

Key accomplishments:

- A survey of relevant literature was performed. Areas studied were chemical structure, morphology, and properties of materials of interest.
- Test procedures for the effect of chemical aging on physical performance properties of fluorinated thermoplastics were specified and performed.
- Chemical analysis tests to characterize chemical aging of fluorinated thermoplastics were started.

Key milestone:

- An improved accelerated aging test plan will be developed.

Contact: P.D. Faughnan, LO-MSD-1M, (407) 867-3400

Participating Organizations: Huston-Tillotson College (L.J. Baye, Ph.D.); Texas Research Institute/Austin; and Materials Engineering Research Laboratory (MERL), United Kingdom

Evaluation of the Compatibility of Materials Used in Breathing Air Devices

NASA facilities are encouraged to use standard, off-the-shelf breathing air devices whenever possible. These devices serve many purposes: fire fighting, air and oxygen-enriched emergency medical response, self-contained totally encapsulating suites, area emergency egress, area-restricted entry, etc. NHB 8060.1 (Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments That Support Combustion) requires that materials used in breathing gas systems must be evaluated for flammability, impact sensitivity, odor, and offgassing.

Unfortunately, many commercially available devices contain materials that will not meet the requirements of NHB 8060.1. Analysis of the limited data available on the flammability and reactivity of materials under near-ambient conditions raises serious concerns about the risks to NASA and contractor personnel using these devices, especially in emergency situations. With the advent of higher operating pressures, the material compatibility issue becomes even more important.

It is desirable that a program to evaluate the compatibility of materials in breathing air and oxygen-enriched gases be initiated to identify materials that meet the requirements of NHB 8060.1. The test data could then be used to develop material selection lists for breathing air and oxygen-enriched gas systems. These lists could then be provided to aid the National Institute of Occupational Safety and Health (NIOSH) in the evaluation of the designs used in these devices when the devices are submitted for certification.

Materials typically used in compressed air and oxygen-enriched systems have been identified. Some examples of the materials to be identified include: ethylene-propylene dienemonomer (EPDM) rubber, nitrile rubber, nylon 6/6, Neoprene, Tefzel, Teflon, Viton, Kel F, Halar, butyl rubber, polyacetal, silicone rubber, and polyethylene.

Test atmospheres of interest include breathing air up to 5,000 pounds per square inch (psi), enriched breathing air containing 25-, 50-, and 75-percent oxygen at ambient and elevated pressure, and oxygen. To evaluate the flammability of materials in these atmospheres, NHB 8060.1, Test 1, is being used for tests up to 50 psi and NHB 8060.1, Test 17, is being used above 50 psi.

The mechanical impact sensitivity of materials is being determined in these gaseous atmospheres in accordance with ASTM G-86. Threshold energy levels are being determined at each pressure, and threshold pressure levels will be determined at the maximum impact energy level. ASTM D-2512 is being followed to determine the mechanical impact sensitivity in liquid air containing 23.5- and 27.5-percent oxygen.

The autoignition temperature of materials is being determined in accordance with

ASTM G-72. The heat of combustion of materials will be determined in accordance with ASTM D-2382. This data can be used in models being developed to aid in assessing the probability of metal system component ignition from a burning polymer.

NIOSH is very interested in this program and has indicated that the results may be used in the future in the evaluation of emergency breathing air devices.

Key accomplishments:

- The majority of tests were completed on Teflon and Viton in 1995.
- Kel F and nitrile rubber tests were about 50 percent completed.
- Silicone rubber, Neoprene, and EPDM tests were begun.
- During 1996, tests were completed on Teflon and Viton.
- Kel F, nylon, silicone rubber, Neoprene, EPDM rubber, and nitrile rubber tests were about 75 percent completed.

Key milestones:

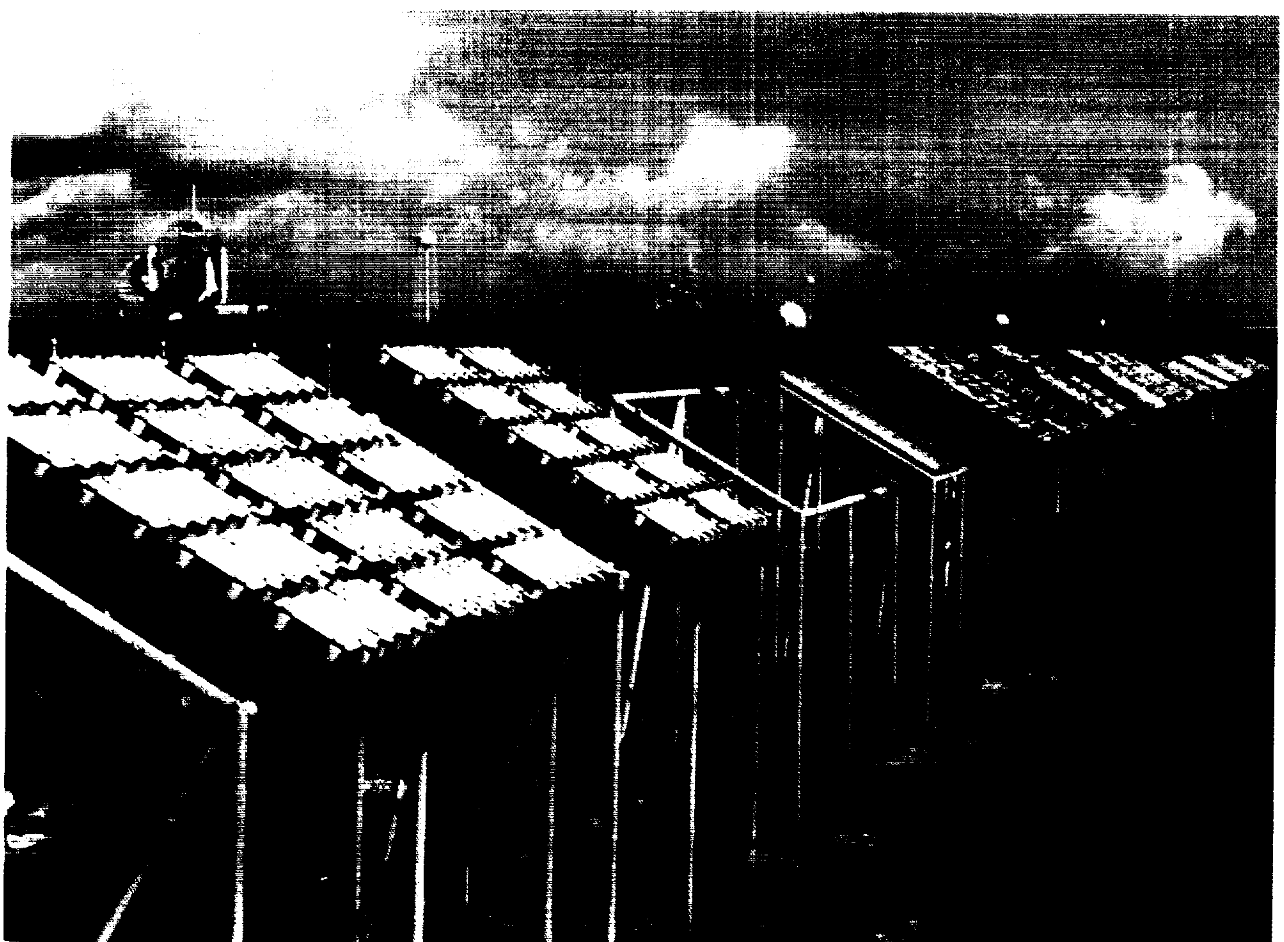
- 1997: Complete the Kel F, nylon, silicone rubber, Neoprene, EPDM rubber, and nitrile rubber tests. Begin testing on the following materials: Halar, polyethylene, Tefzel, Buna S rubber, polymide (Vespel SP-21), polyacetal (Delrin), butyl rubber, and polyphenylene oxide (Noryl).

Contact: C.J. Bryan, LO-MSD-2, (407) 867-4614

Environmentally Compliant Coating Systems for the Shuttle Launch Sites

In recent years, environmental regulations have sought to restrict the use of paints and coatings with high concentrations of solvent. The use of the solvent-based, inorganic, zinc-rich primers currently tested and approved could be prohibited at KSC in the near future due to their volatile organic content (VOC) levels. These materials all have VOC levels of 450 grams per liter (3.75 pounds per gallon), whereas the maximum levels allowed in some areas (such as California, certain counties of Florida, and many other urban areas of the United States) are 420 grams per liter (3.5 pounds per gallon) or lower. Legislation has dictated that this level be reduced to 350 grams per liter (2.8 pounds per gallon). Therefore, it is a real possibility that the inorganic, zinc-rich primers and topcoat systems presently approved at KSC will be prohibited and unavailable for use.

In response to this circumstance, the current study has been expanded to search for inorganic, zinc-rich coatings and topcoat 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 produces environ-



Test Panels at the Beach Corrosion Test Site mentally compliant, inorganic zinc coatings such as high-volume solids and water-based systems. New topcoat systems are being developed to conform to the anticipated strengthening of environmental air quality standards.

The application of these environmentally compliant coating systems was completed in April 1991, and the test panels were exposed in May 1991 to atmospheric contaminants at the KSC beach corrosion test site with concurrent applications of an acid slurry to simulate the conditions experienced at the launch site. The results of the 18-month exposure and laboratory data have been compiled in a report available under document number FAM-93-2004. The results of this testing have identified many environmentally compliant coating systems to be used on KSC launch structures and ground support equipment. The successful coating materials have been included on the Approved Products List contained in KSC-STD-C-0001. The panels have completed the 60-month exposure cycle, and the report documenting the results is being prepared.

Key accomplishments:

- Successfully applied the environmentally compliant coating systems to over 300 test panels and exposed them at the KSC beach corrosion test site for 60 months.
- Conducted laboratory tests on the zinc primers to determine the heat resistance and adhesion to carbon steel.
- Evaluated the coating systems at the 18-month point and prepared a report detailing the beach exposure and laboratory data.

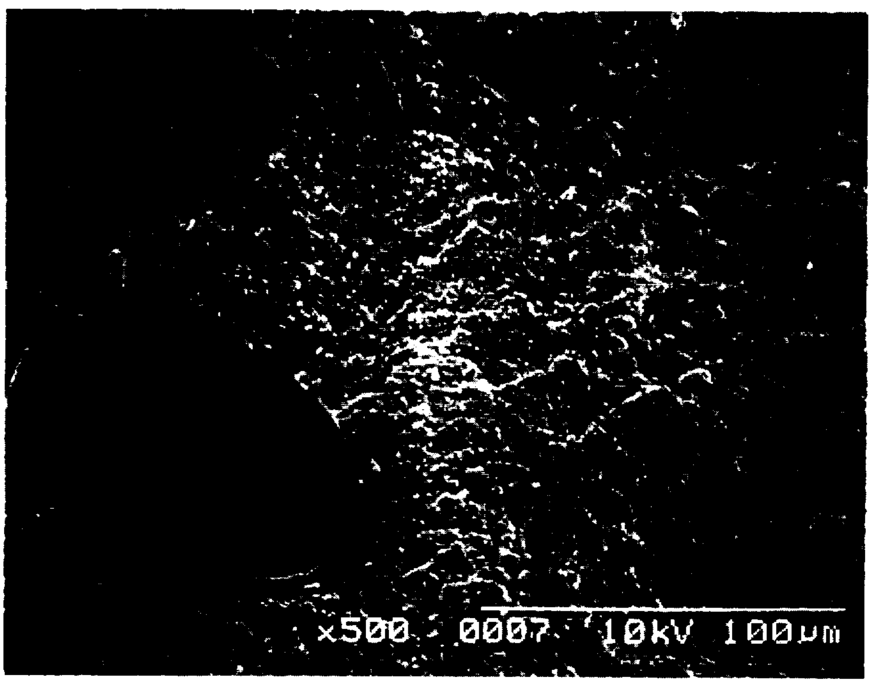
Key milestones:

- Produce a final report for the 60-month exposure period to document the performance of the coating systems.
- Continue to monitor the state-of-the-art environmentally compliant coating technology and evaluate new products as required.

Contact: L.G. MacDowell, LO-MSD-1M, (407) 867-3400

Fracture Morphology of Selective Polymer Systems Under Monotonic and Fatigue Loading

Failure analysis of nonmetallic components is an important activity at KSC. Features seen on failed components are compared with features published in literature on similar test specimens broken under controlled conditions. Analysis of fracture surfaces of failed polymeric components yields information such as fracture origin location, stress characteristics, and service environment. Polymer systems in use at KSC are not fully represented in the literature, making analysis difficult.



Micrograph Showing a Higher Magnification (500X) of the Redial Marks Emanating From the Macrovoid

The project seeks to characterize the fracture surfaces of polymers under overloading and fatigue conditions. Twelve polymer systems of interest to KSC have been selected. Geometrically identical specimens will be overloaded, and the resulting fracture surfaces will be examined by optical and scanning electron microscopy to establish their general mechanical behavior. Specimens will also be subjected to tension-tension cyclic loading. Crack tip growth will be observed with a traveling optical microscope. The fracture surfaces will be examined as described earlier. An atlas of damage and fracture surface features will be prepared and delivered to KSC.

Key accomplishments:

- Fluoroelastomers, polyimides, and silicone rubber were evaluated.
- An atlas was prepared and articles were submitted for publication.

Key milestone:

- Three polymer systems will be fully evaluated each year.

Contact: P.D. Faughnan, LO-MSD-1M, (407) 867-3400

Participating Organization: Tuskegee University (H.A. Aglan, Ph.D., P.E.)

Research and Development of Materials and Components for Protective Clothing for Personnel Handling Rocket Fuels

Personnel involved in fueling operations wear fully encapsulating ensembles to prevent exposure to corrosive and toxic chemicals. The fuels, hydrazine and monomethylhydrazine, are flammable and possible carcinogens. The oxidizer, nitrogen tetroxide, is corrosive since it reacts with water to form nitric acid. Exposure to the oxidizer would cause immediate chemical burns. The current generation propellant handler's ensemble (PHE) is based on 1970-era technology.

Prototype PHE

Under an earlier grant, materials and components were procured and evaluated for physical properties and chemical resistance. The project seeks to develop and deliver to KSC a fully functional prototype PHE based on materials and components recently introduced to the market. The most promising material, glove, and boot were selected for the prototype construction. The suit design and component integration is complete resulting in the first prototype. The first prototype will be evaluated and improvements will be incorporated in a second prototype.

Key milestones:

- Suit design.
- Integration of suit and components such as boots, gloves, closure, and visor.
- Evaluation of prototype.

Contact: P.D. Faughnan, LO-MSD-1M, (407) 867-3400

Participating Organization: Tuskegee University (N. Vahdat, Ph.D.)

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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 advanced technology development program. This program encompasses the efforts of the Engineering Development Directorate laboratories, most of the KSC operations contractors, academia, and selected commercial industries – all working in a team effort within their own areas of expertise. This edition of the Kennedy Space Center Research and Technology 1996 Annual Report covers efforts of all these contributors to the KSC advanced technology development program, as well as our technology transfer activities.

Gale Allen, Chief, Technology Programs and Commercialization Office (DE-TPO), (407) 867-3017, is responsible for publication of this report and should be contacted for any desired information regarding the advanced technology program.

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