NASA Technical Memorandum 111467

Research and Technology 1995 Annual Report

John F. Kennedy Space Center

About the Cover

The cover depicts the transfer of technology from aerospace to private industry.

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NASA Technical Memorandum 111467

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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 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 1995 Annual Report covers the efforts of these contributors to the KSC advanced technology development program, as well as our technology transfer activities.

W.J. Sheehan, 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.

Jay F. Honeycutt
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 John F. Kennedy Space Center (KSC) are NASA's premier factories. The product of these factories is one of the most spectacular products in the world — safe and successful Shuttle launches. The factory is also the traditional domain of the discipline of industrial engineering. Most IE functions, tools, techniques, and technologies evolved from the need to improve shop floor productivity to remain competitive in the marketplace. However, IE technologies are now being successfully applied to virtually every type of process in Government agencies, production industries, service industries, and academia. Decreasing budgets for Shuttle operations and a stable Shuttle flight rate have improved the "market" for IE technologies and capabilities at KSC.

IE research and technology development efforts are frequently different from research efforts in other engineering disciplines because the products of IE research efforts can be new or improved methodologies and processes. The articles in this section demonstrate a variety of new IE methodologies that are sometimes complemented with software development. Advanced IE technologies are generated from applying basic IE principles to new domains and unique problems. KSC has a wide variety of relatively unexplored domains and unique problems for industrial engineers and IE technologies.

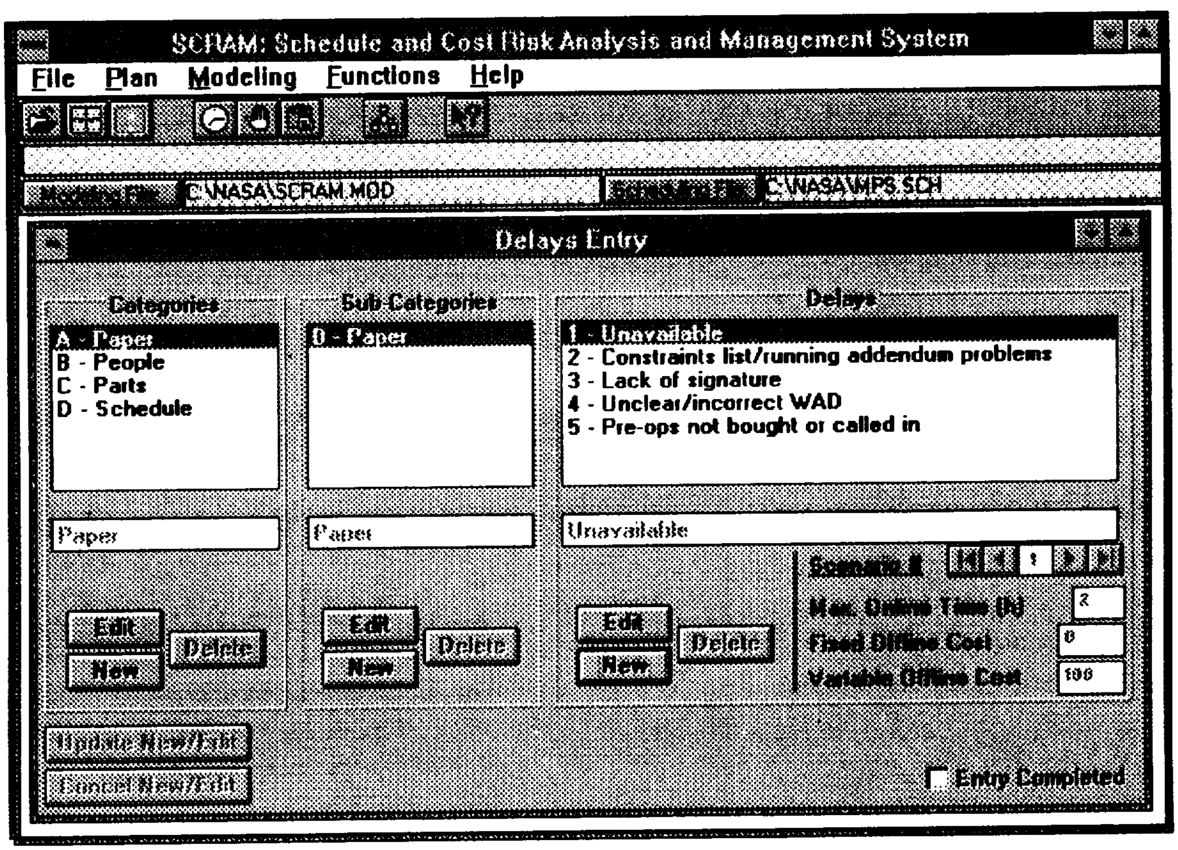
The following IE articles are categorized into four "focus areas" of industrial engineering. These focus areas are: process analysis and modeling, human factors engineering, methods engineering/work measurement, and benchmarking. The development and application of IE technologies in each of these areas is producing tangible benefits for KSC as well as dual-use technology for other organizations.

Process Analysis and Modeling Focus: Schedule and Cost-Risk Analysis Modeling (SCRAM) System

Innovative algorithms and software for schedule and cost-risk analysis of Shuttle ground processing are being developed under a Small Business Innovation Research (SBIR) contract. The major function of the system is to identify 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.

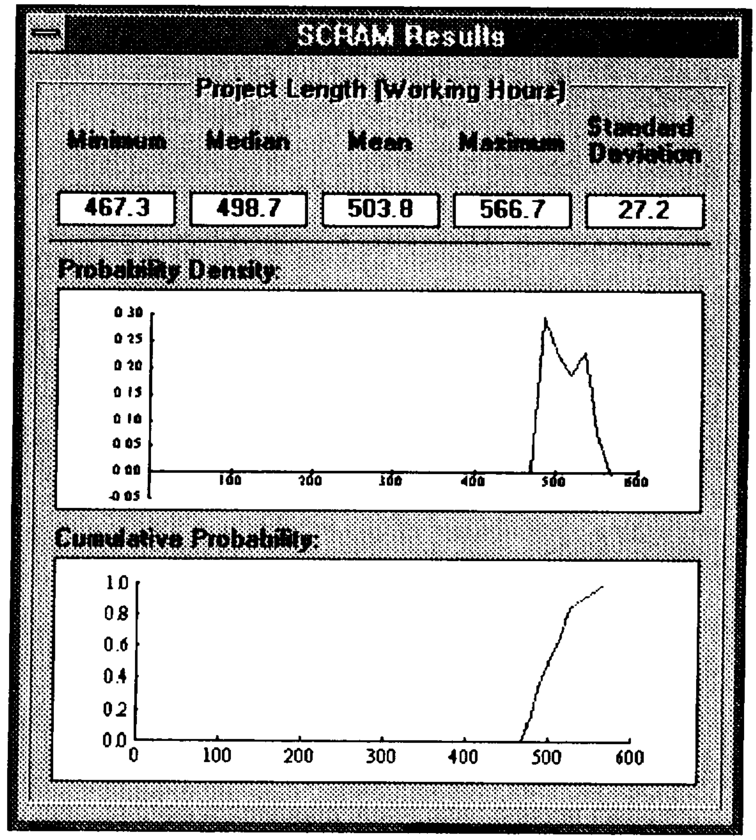
The project is a 2-year Phase II SBIR effort. The main focus of the contract is to design and implement the SCRAM system. The SCRAM system has three components: a risk analysis module, a schedule module, and a system executive. Existing commercial software is being used wherever possible to maximize the efficiency of the development process. The risk analysis module is based on Lumina Decision System's Demos product, and the schedule component is based on the Schedule Publisher product from Advanced Management Solutions. SCRAM is a significant improvement to the state of the art in schedule and cost-risk analysis because it allows realistic models of schedule variables (e.g., task lengths) to be built and analyzed. Existing risk analysis tools provide constrained and limited modeling capabilities. While SCRAM was designed for Shuttle ground processing, it is also applicable to any complex schedule/cost-risk analysis and has substantial commercial potential.

To date, the project focused on developing a PC-based SCRAM system that expands the



Input Screen for Delay Types

Probability Density and Cumulative Probability for Project Length



capabilities of the Macintosh-based system built in 1994. The system provides seamless integration between the three modules of the system and allows the analysis of schedules containing large numbers of activities. The prototype SCRAM software will be 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 SBIR project for software development will finish in April 1996, and KSC industrial engineers will begin using the tool for additional risk analysis applications.

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 (IWES) project plan. Completion of the basic PC-based SCRAM system.

Key milestones:

- 1996: Complete the development of the PC-based SCRAM system. Apply the SCRAM system to additional Shuttle ground processing activities.

Contact: T.S. Barth, TM-TPO-21, (407) 861-5433

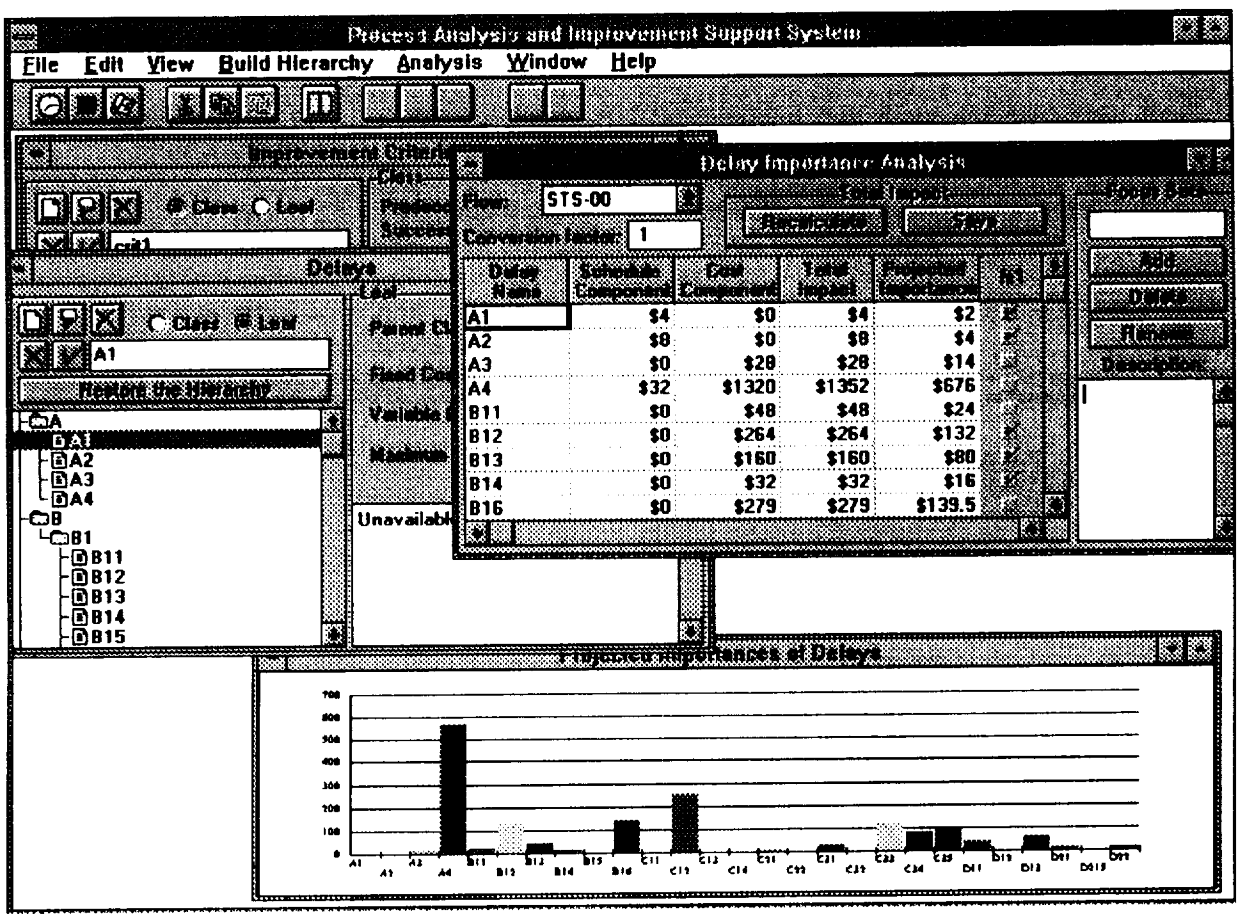
Participating Organization: Lumina Decision Systems (R. Fung and M. Henrion)

Process Analysis and Modeling Focus: Process Analysis Support System (PASS)

A system for analyzing proposed process improvements to Shuttle operations is being developed under a Small Business Innovation Research (SBIR) contract. The function of the system is to support analysts during the critical tasks of identifying particular 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).

Development of this system is part of a 2-year Phase II SBIR effort. PASS was conceived as a spinoff of the Schedule and Cost-Risk Analysis Modeling (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



PASS Prototype Output Screen Showing Hierarchical Organization of Delays, Tasks, and Tabular and Graphical Displays of Delay Importance 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 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. An example output screen from the prototype is shown in the figure. The PASS concept can be applied to a wide variety of process analysis and improvement efforts in Shuttle operations. PASS is anticipated to have significant potential for applications in other industries.

Key accomplishments:

- 1995: PASS concept, design, and successful completion of the initial prototype.

Key milestones:

- 1996: Delivery of a functional prototype and completion of a KSC case study. Generalization of results for advancing root-cause analysis technology.

Contact: T.S. Barth, TM-TPO-21, (407) 861-5433

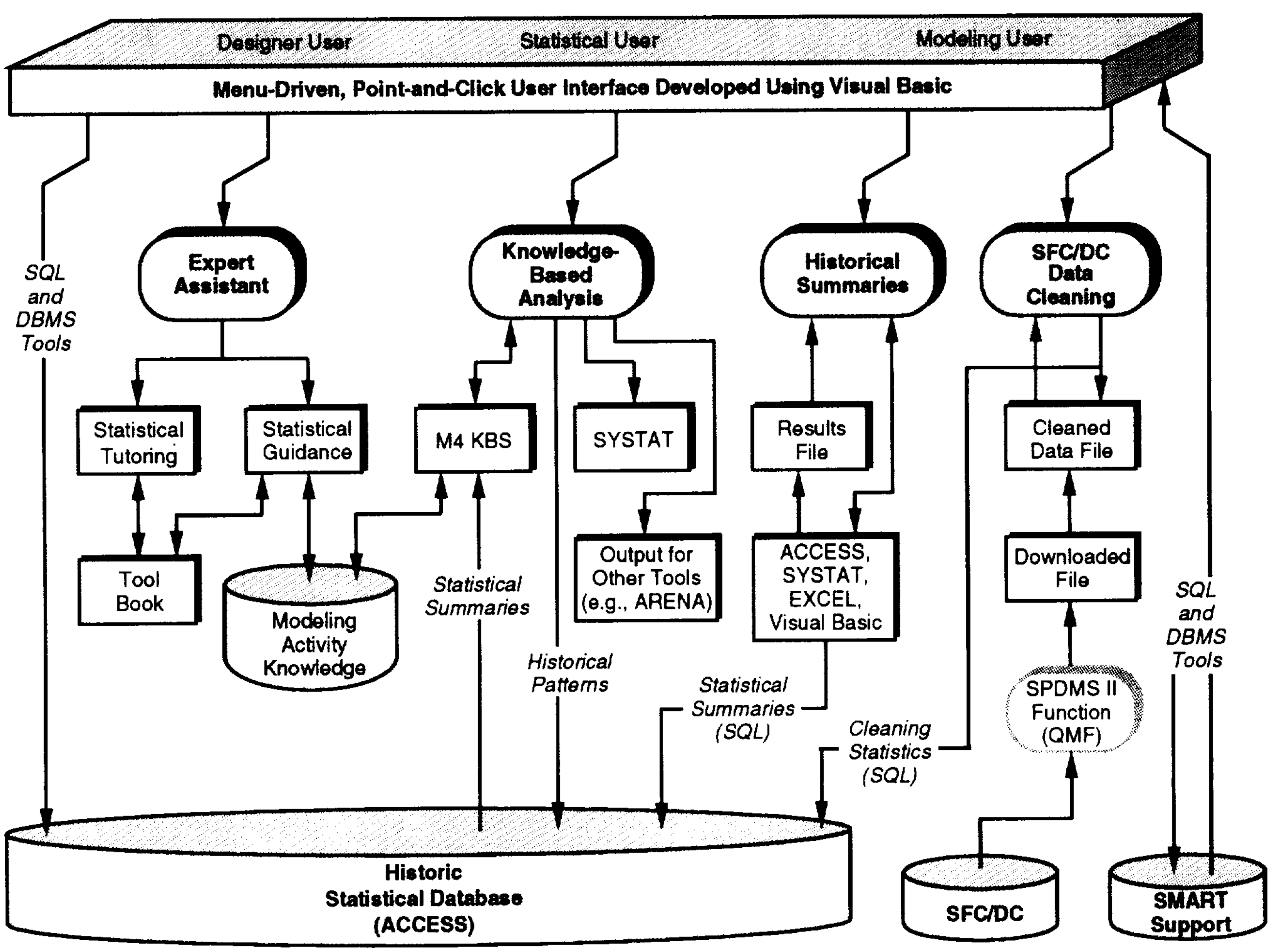
Participating Organization: Lumina Decision Systems (R. Fung)

Process Analysis and Modeling Focus: Shop Floor Modeling, Analysis, and Reporting Tool (SMART)

The KSC Shop Floor Control/Data Collection (SFC/DC) system stores data regarding the begin and end working times of a work authorization document (WAD), start and end times of stoppages experienced by a WAD, and a delay category for the stoppage. This data is entered real time in a majority of the Shuttle processing facilities by the technicians working the WAD. The primary purpose of SFC/DC is to identify processes in need of improvement and to measure the effectiveness once an improvement is implemented. The goals of this project are to develop methods and tools to: (1) effectively access and manipulate the SFC/DC data, (2) analyze the SFC/DC data for immediate decisionmaking, and (3) analyze the SFC/DC data to feed long-term analysis models. The objective of these analysis activities is to reduce or eliminate delays on the shop floor and to gain a better understanding of floor activities.

The effort has been broken into three phases: (1) understanding the actual configuration of the SFC/DC database, (2) know the actual values being stored in the database and prototyping of some of the proposed methods, and

SMART



SMART Framework

(3) further development of the prototypes from phase 2 and full development of new methods and tools for continuous analysis. The deliverable from phase 3 is the full-scale development of a cohesive and integrated environment to support analysis and modeling using the SFC/DC data, called the Shop Floor Modeling, Analysis, and Reporting Tool (SMART).

SMART is designed around a database that would contain statistical information regarding work time, delay duration, and other relevant inferential and descriptive information. This framework was devised under the premises that it must be easy to use and flexible to allow growth of KSC's modeling activities. It is designed to provide guidance to end users, and it integrates off-the-shelf products. SMART is being developed using Visual Basic in conjunction with STATMOST, ACCESS, ExpertFit, ToolBook, and M4. Modules of SMART include an Expert Assistant, a knowledge-based system that will be a tutor and an assistant to KSC engineers regarding statistical analysis techniques, and a knowledge-based analysis system that will generate descriptive statistics, estimate variables of interest, conduct various correlation analyses, conduct various hypotheses testing on the similarity of facilities, compute various joint probability functions for delay duration, enable the collection of historic behavior for future use in other modeling activities, and generate interpreted reports (see the figure "SMART Framework"). Results of various analyses (ANOVA tests, time series, etc.) will form the basis for experiential knowledge, which will answer analysis questions such as: What is the SFC/DC telling us about delays and work times, over time? Is their behavior insensitive to time? Is it insensitive to the orbiter?

In summary, SMART will support three types of users: designer user, statistical user, and modeling user. The designer user will interact with SMART through its application tools to maintain and enhance system functionality. The statistical user will be a student of SMART (to learn about statistics) or an engineer who needs to obtain descriptive statistics and some inferential statistics from the acquired SFC/DC data on a repetitive basis. The modeling user will also be a student of SMART and an engineer who needs to do analysis using SFC/DC data, which is unique to a new modeling activity.

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 Management (SCRAM) system.
- 1995: Enhancements to the initial prototype. This new prototype has a historic database (ACCESS) where descriptive statistics and results of correlation analyses are being stored. Its capabilities have been extended to include the handling of SFC/DC data for purposes other than those set by SMART or SCRAM.

Key milestones:

- 1996: Design and implementation of the expert statistician knowledge base, using the results of an indepth exploration of work data and delay data. Incorporation of additional modeling capabilities into SMART.
- 1997: Initial implementation of SMART at KSC.

Contact: A.M. Mitskevich, TM-TPO-21, (407) 861-5433

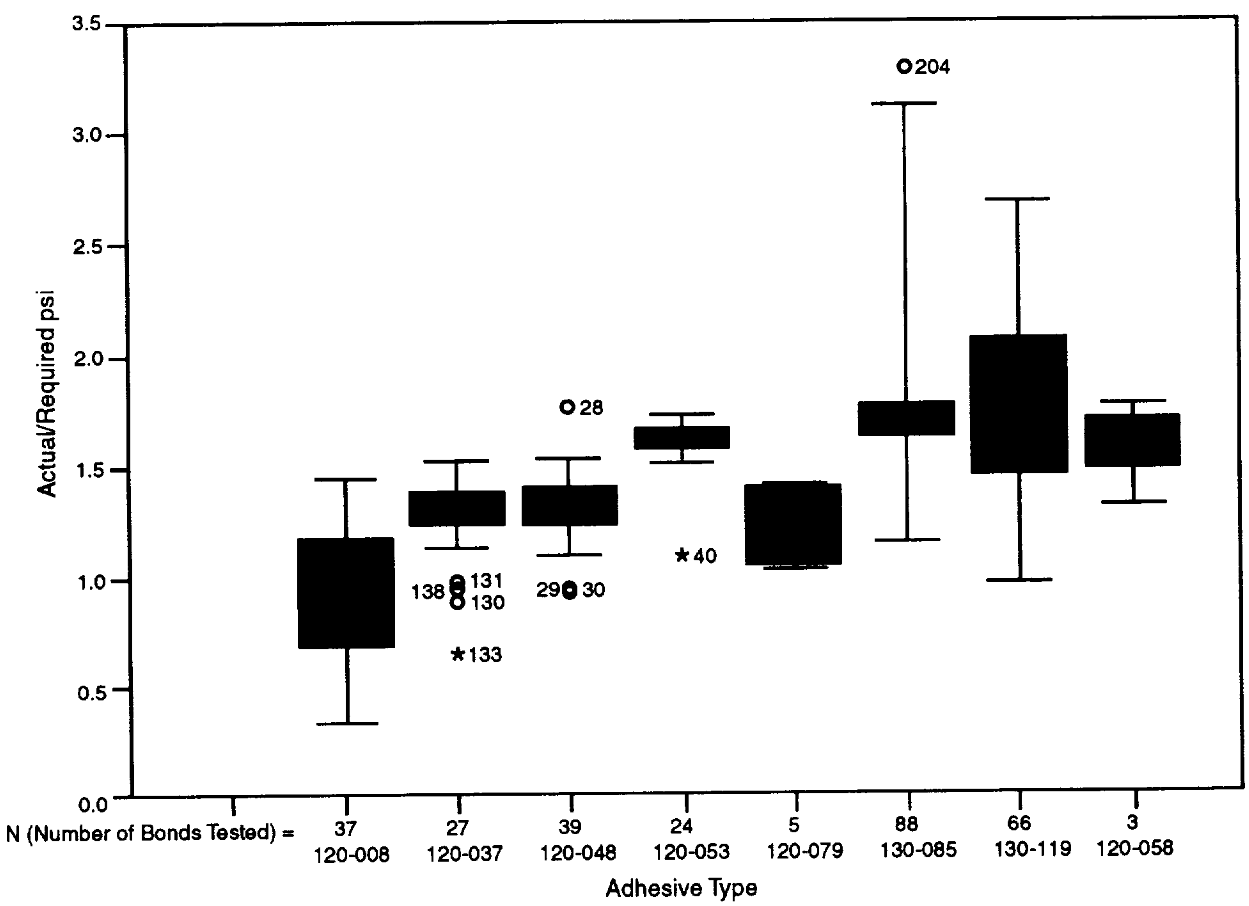
Participating Organization: Florida International University (M. Centeno)

Process Analysis and Modeling Focus: Variable-Form Data Analysis

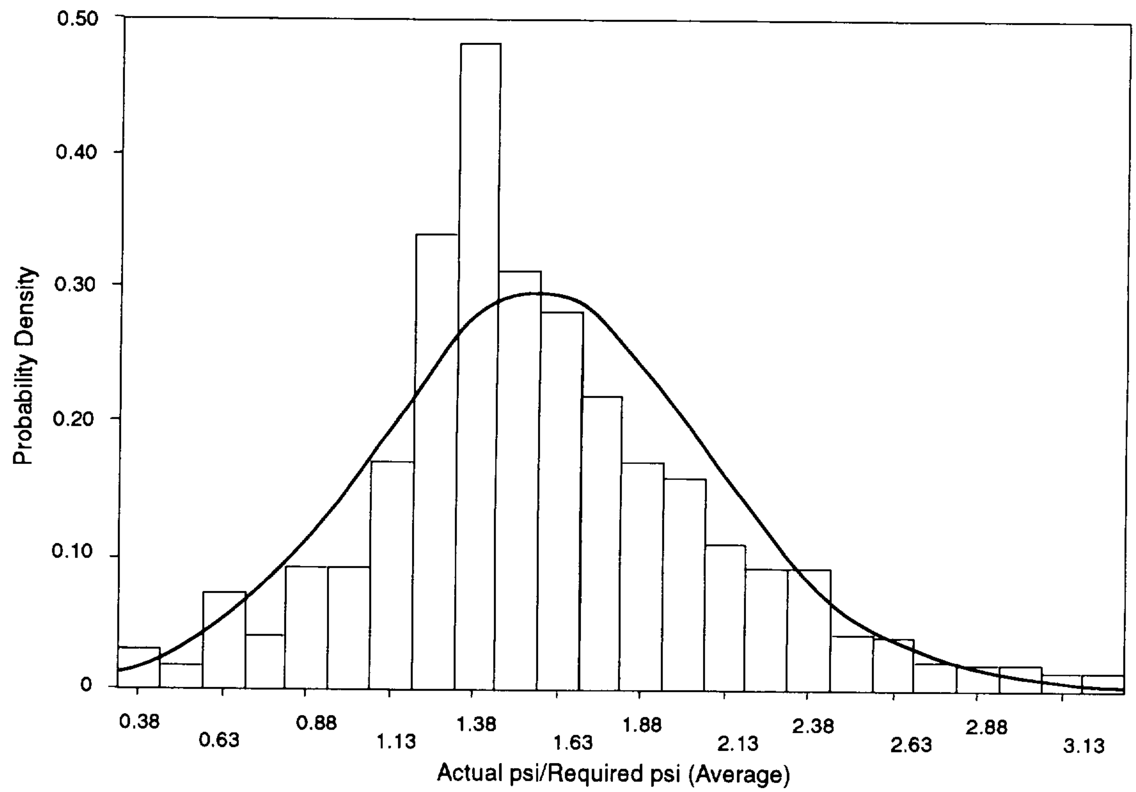
Variable-form data elements collected during the performance of Space Shuttle ground processing operations are used primarily for real-time control and to ensure functional conformance to specifications. These data elements are also useful in statistical analyses related to quality improvement of processing operations. This latter type of analysis requires the use of "Statistical Process Control" procedures. The major objective of this research activity is to specify the procedures appropriate for use in the analysis of variable-form data for Space Shuttle ground processing quality improvement and to demonstrate the use of these procedures on a selected sample of ground processing activities for a variety of engineering systems on the orbiter.

Activity during 1995 was primarily devoted to the identification of ground processing operations that would be amenable to and benefit from statistical process control analysis and to the application of analysis procedures to these operations. An example of one of the tasks identified is in the area of orbiter structural bonding. Shuttle Processing Materials and Processes (M&P) engineers were extensively involved in the investigation of processing tasks where reworks were required due to failure of the bond test strip to meet pull-test strength values.

Project personnel performed a process capability analysis to assist the M&P engineers in gaining insight to the current



Boxplot Showing Capability of Individual Bonding Adhesives



Distribution Describing Overall Capability of Structural Bonding Process

capability of structural bonding processes. Detailed analyses, such as those summarized in the two figures, indicated that the primary reason for structural bonding failures was the lack of process "capability." This lack of capability was primarily associated with a particular two-part epoxy adhesive used in bonds requiring particularly high strength. Project personnel assisted M&P engineers in the design of a 2^7 factorial experiment to determine the variables to be addressed in process improvement activities. When complete, the process improvements have the potential for significant reductions in rework and stronger structural bonds. This translates into improved cost, schedule, and technical performance of the structural bonding processes.

Key accomplishments:

- 1994: Completion of variable-form data analyses on two Thermal Protection System (TPS) processes, resulting in potential savings of approximately 200 technician labor hours (plus material and indirect labor costs) per flow.
- 1995: Statistical process control procedures applied to several additional orbiter systems and support processes.

Key milestones:

- 1996: Completion of additional example analyses and a specification of a prototype "general testing philosophy," which incorporates the principles of statistical process control in Shuttle test and checkout activities. Review of a sample of orbiter maintenance requirements and specifications (OMRS's) scrub activities.

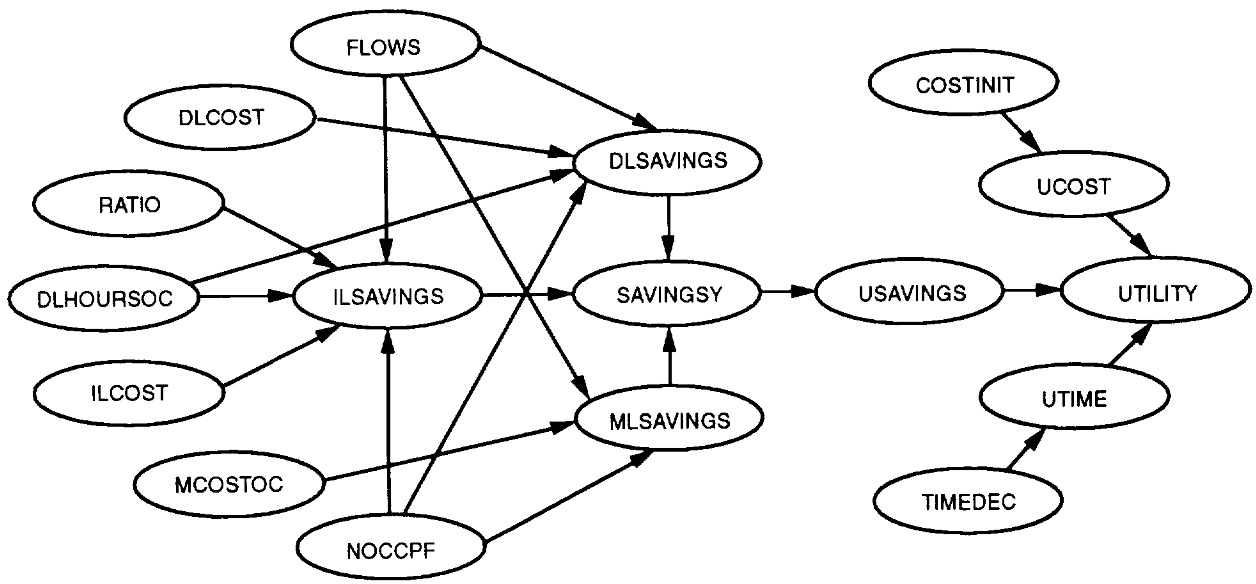
Contact: T.S. Barth, TM-TPO-21, (407) 861-5433

Participating Organization: University of Central Florida (Y. Hosni, R. Safford, and D. Osborne)

Process Analysis and Modeling Focus: Decision Modeling and Analysis

Decision analysis refers to a body of techniques that allows a decision-maker to evaluate uncertainty, risk, and multiple objectives in decision problems. The purpose of this project, as part of the NASA/ASEE Summer Faculty Fellowship Program, was to review various decision analysis (and related) techniques and to apply these techniques to specific problems at KSC. In addition, a commercially available software package for decision analysis was evaluated for use by the industrial engineers in Shuttle Operations.

Problems to which decision analysis techniques were applied included the evaluation and ranking of research proposals submitted to NASA, benefit analysis of a proposed modification to the heater of the orbiter maneuvering system, development of a general procedure for



NOCCPF = the number of occurrences of the change per flow

DLHOURSOC = the increase/decrease in the number of direct labor hours per occurrence

MCOSTOC = the increase/decrease in the material cost per occurrence

FLOWS = the expected number of flows per year

RATIO = the number of indirect hours required per direct hour of labor

DLCOST = the cost per hour for direct labor

ILCOST = the cost per hour for indirect labor

COSTINIT = the initial expected cost associated with the modification

TIMEDEC = the expected decrease in orbiter flow time in days as a result of the modification

DLSAVINGS = the expected yearly savings in dollars from reduction in direct labor hours
= NOCCPF * DLHOURSOC * FLOWS * DLCOST

ILSAVINGS = the expected yearly savings in dollars from reduction in indirect labor hours
= NOCCPF * DLHOURSOC * FLOWS * RATIO * ILCOST

MCSAVINGS = the expected yearly material cost savings in dollars
= MCOSTOC * NOCCPF * FLOWS

Influence Diagram and Variable Definitions for Computing Expected Utility of Proposed Shuttle Processing Improvements the assessment and ranking of proposed improvements to orbiter processing, and analysis of the decision regarding which process to choose (splash or numerical control machining) for the manufacturing of orbiter tiles. Models were developed for the first three applications.

For the third application (development of a general procedure for assessment of proposed improvements), proposed improvements to orbiter processing may be evaluated according to three performance measures: initial cost, yearly savings, and decrease in flow time. For a particular improvement, the values of these performance measures are uncertain. For example, yearly savings are affected by the number of technician man-hours. The actual number of man-hours for a particular activity over a period of 1 year is an uncertain quantity. Hence, the yearly savings for a proposed improvement is also an uncertain quantity.

In decision problems involving multiple performance measures and uncertainty/risk, a process for evaluating tradeoffs among the performance measure values and for considering the uncertainty/risk involved must be employed. One such process involves the use of multi-attribute utility functions. This type of function is a mapping from the outcome space, as defined by a set of performance measures, into a closed interval of the real numbers, usually [0, 1]. Such functions have the property that one probabilistic outcome will be preferred to another if the expected utility for the first outcome is higher than the expected utility for the second.

An influence diagram model was developed for determining the expected utility of proposed Shuttle processing improvements. This model shows the relationships among variables in the decision problem (see the figure).

Key accomplishments:

- 1995: Review of the concepts of problem complexity and problem formulation. Review of management science techniques (especially those related to decision analysis) and development of guidelines for the use of specific techniques. Develop decision analysis models for four applications at KSC. Implement relevant decision models.

Key milestones:

- 1996: Development and implementation of additional decision analysis models supporting complex or uncertain decision problems in Shuttle operations.

Contact: T.S. Barth, TM-TPO-21, (407) 861-5433

Participating Organization: University of Louisville (G.W. Evans)

Process Analysis and Modeling Focus: Optimal Solution to Resource-Constrained Project Schedules With Stochastic Task Durations

A primary responsibility of project managers is task scheduling. Commercial off-the-shelf (COTS) software for project scheduling is available and widely used. However, until recently, these programs only addressed the deterministic problem (where all problem parameters are assumed to be known constants). The stochastic project scheduling problem could only be examined through custom-developed simulation programs (typically very expensive to develop and maintain and having limited input/output capabilities). This situation has now changed, and there are a number of COTS packages that can "solve" stochastic project scheduling problems. Nevertheless, researchers had not previously developed a theoretical basis (model and optimal solution) to this project scheduling problem and, therefore, lacked a reference frame with which to evaluate existing solution methods. This study developed a model and optimal solution to the resource-constrained project scheduling problem with stochastic task durations.

The model developed in this study is a multistage, sequential decision problem composed of M stages, where the start of the project represents the first decision stage and the project is complete when all tasks have completed (see the figure "Multistage Project Scheduling Formulation"). The decision at each stage must be based only on the information known at the time of the decision stage (the state of knowledge at that time). The state of knowledge is dynamic over time and must be determined at each decision stage. The requirement that decisions be based on the state of knowledge is imposed by the presence of an anticipativity constraint. Solutions that violate the anticipativity constraint may provide misleading results since they rely on assumed information (information the project manager may not have known at the time of each decision). Assuming a risk neutral decisionmaker, the optimal solution is a decision policy that minimizes the expected value of project duration over the remaining decision stages while satisfying all system constraints (precedence, resource, and anticipativity constraints). An optimal solution only determines the tasks to start at a given decision stage. The remaining optimal decisions are determined one by one as the stochastic process reveals itself.

The study results and conclusions provide a theoretical basis for the development of heuristic solutions to stochastic resource-constrained project scheduling problems and for the proactive management of project schedule risk.

Key accomplishments:

- 1993: NASA Graduate Student Research Fellowship awarded; literature search and problem formulation.
- 1994: Definition of optimality for both the anticipative and nonanticipative solutions.
- 1995: Completion of the project with the following research findings:

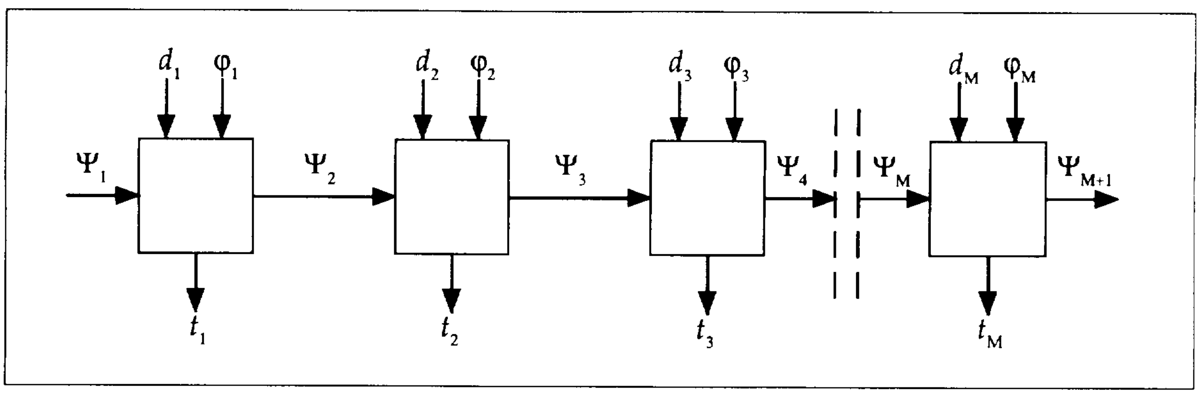
1. Creation of a model, including a mathematical formulation of the decision at each stage.

2. Identification of the anticipativity constraint.

3. Recognition that some of the heuristics used by the COTS project scheduling software (most notably the minimum slack heuristic) violate the anticipativity constraint and may provide misleading results.

4. Demonstration that the resource-constrained project scheduling problem can be modeled as a more general case of other resource-constrained project scheduling problems, including the PERT problem.

5. Proof of the definable stochastic relationships between the respective solution results to three special cases of resource-constrained project scheduling problems.



Multistage Project Scheduling Formulation

The inputs and outputs shown in the figure are:

Ψ_g . the state of knowledge at decision stage g
Ψ_{g+1} the state of knowledge at decision stage (g+1)
d_g the decision made at decision stage g (the set of tasks to start at decision stage g)
φ_g the probability distribution of Ψ_{g+1}, dependent on the decision d_g and the state of knowledge Ψ_g
Ψ_{g+1} the set of possible states of knowledge at decision stage g+1
t_g the time between the g^{th} and $(g+1)^{st}$ decision stages (the return from decision stage g)

The project duration is the sum of the t_g's corresponding to all M decision stages.

Contact: T.S. Barth, TM-TPO-21, (407) 861-5433

Participating Organization: University of Central Florida (A. Fernandez)

Human Factors Engineering Focus: Computer-Based Tutoring

A Shop Floor Control/Data Collection (SFC/DC) System was installed in KSC Shuttle processing facilities to collect data necessary to identify areas of potential improvement and to justify process changes. The original intent of the system was to develop a systematic, proactive approach to enable the work to flow more smoothly on the shop floor, resulting in improved productivity and morale. Shop technicians were tasked to enter data for items such as task assignments and work delays. The customers of the data collected in the SFC/DC System initially emphasized using the shop floor data to support real-time status reporting rather than to initiate longer term process analysis and improvement activities.

After an analysis of the procedures for data entry and reporting, it was determined that inadequate training was a contributing cause for placing only short-term emphasis on the SFC/DC System. The technicians were trained on the mechanics of *how* to use the system but were never formally trained on *why* they should enter good data. Similarly, the owners of processes being measured were not fully aware of the technician's perspective while entering data.

To help focus the SFC/DC System on process analysis and improvement, a computer-based tutorial was developed for Shuttle processing personnel. The tutorial was developed with an off-the-shelf authoring system for delivery over a local area network. The tutorial contains the following features:

1. Flexible user interface. The users are encouraged to select only the portions of the tutorial relevant to their jobs or of special interest.

2. Remediation during exercises. Several exercises are given to train users how to properly use the SFC/DC System. Frequently missed questions contain explanations and remediation for common incorrect responses.

3. Automated tutorial evaluation program. A program was written to analyze user responses and identify areas in the tutorial needing clarification.

Example screens from the tutorial are shown in the figure. Additional benefits of the tutorial include:

1. Serving as a pathfinder for additional just-in-time computer-based training modules for technicians and quality inspectors.

2. Supporting process analysis teams chartered to isolate root causes of processing delays and to make recommendations for process improvements to prevent those delays from recurring. The subject matter collected during the development of the tutorial has been used by these teams.

Key accomplishments:

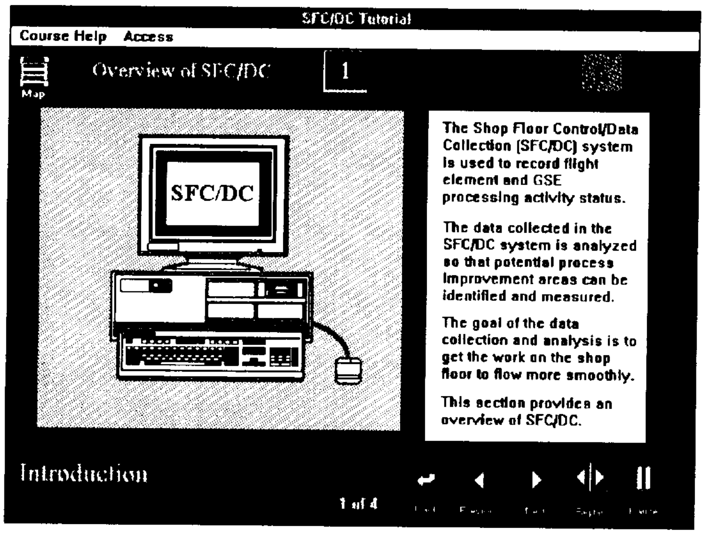
- 1992: Deployment of the SFC/DC System in all Shuttle processing facilities.
- 1993: Initiation of computer-based tutorial software development under a Phase II Small Business Innovation Research contract. Analysis of existing methods for shop floor data collection, reporting, and analysis.
- 1994: User acceptance testing and completion of the final tutorial prototype. Commitment received for implementing a production version.
- 1995: Production version completed and distributed in the Orbiter Processing Facilities. Initiation of a parts process analysis team.

Key milestones:

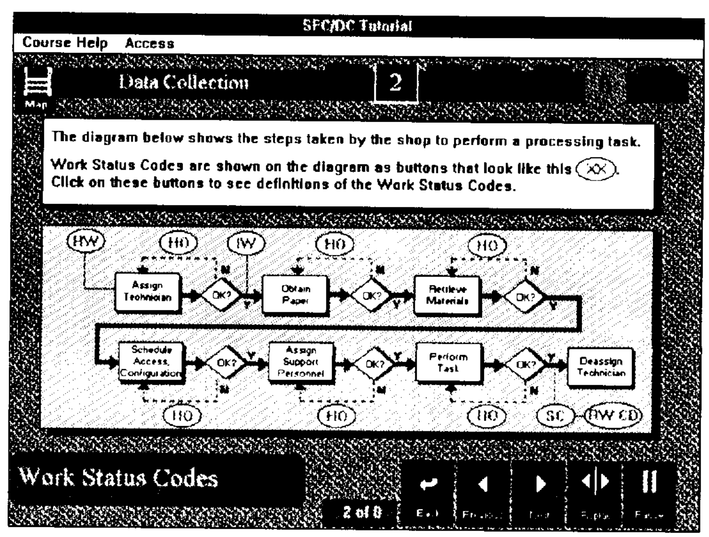
- 1996: Tutorial distribution to additional areas and owners of support processes. Initial use of the automated tutorial evaluation program. Formation of additional process analysis teams.

Contact: T.S. Barth, TM-TPO-21, (407) 861-5433

Participating Organizations: ENSCO (G. Drapé), University of Central Florida (M. Archer), and Lockheed Martin Space Operations



Example Screens From the Shop Floor Control/Data Collection Computer-Based Tutorial



Human Factors Engineering Focus: Diagnostic Tool for Mishap Evaluation

A diagnostic tool for evaluating the causes of mishaps in Shuttle ground processing operations is being developed by the KSC Human Factors Team. At KSC, mishap is a general term that includes both processing incidents and close calls. The diagnostic tool is an application of a "team effectiveness and leadership model," based on several years of studies on a wide variety of high-performance work groups. The studies included observations of KSC teams in Shuttle processing, unmanned launch vehicle processing, and payload processing.

The KSC Human Factors Team was established in 1993 to assess human factor issues associated with Shuttle processing incidents. The team's primary goal is to raise awareness of human factor issues so human factors are embedded in all primary processes required for Shuttle operations at KSC. The team developed human factors training modules and checklists incorporating human factors principles for various segments of the work force. A Positive Initiative Effort (PIE) program was established to encourage technicians to report potential problems in their work areas. The team is attempting to expand its assessment efforts to include all mishaps (both incidents and close calls) so recurring causes of close calls can be identified and corrected before a more serious incident occurs.

A diagnostic tool was required to develop the metrics necessary for this proactive approach to mishap evaluation (see the figure). The tool enables the human factors assessment to focus on relevant areas in the work process. Assessment results will be entered in a database of cause codes that can be analyzed over a period of time.

Key accomplishments:

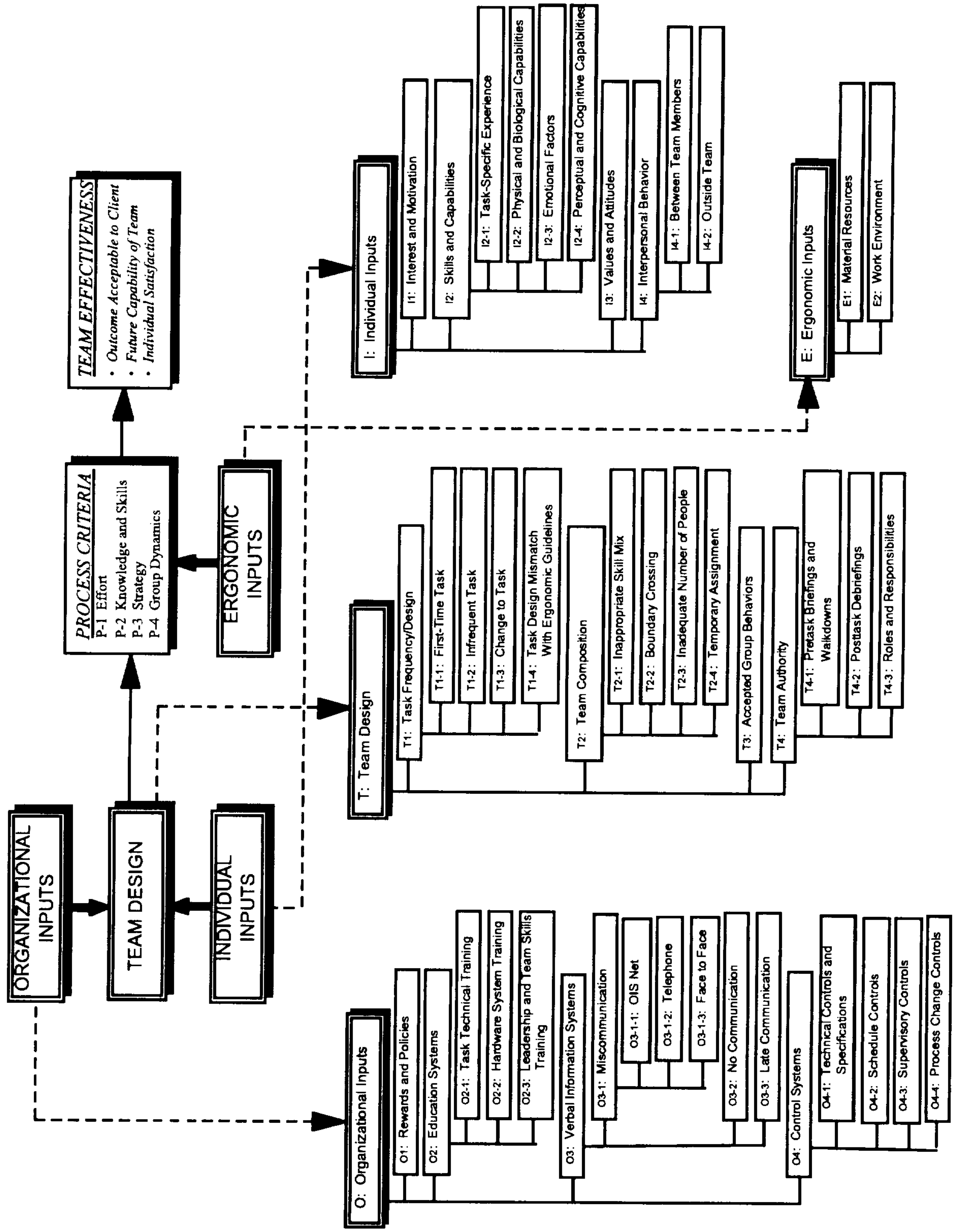
- 1993: Formation of the KSC Human Factors Team. Refinement of the team effectiveness leadership model with data from observation of Shuttle processing teams.
- 1994: Assessment of processing incidents by the Human Factors Team. Initial application of the team model at KSC.
- 1995: Development of the initial diagnostic tool for human factors evaluation of processing mishaps.

Key milestones:

- 1996: Application of the diagnostic tool to past and current processing mishaps. Development of a database to facilitate analyses of the mishap data. Development of an improved close-call reporting system.

Contact: T.S. Barth, TM-TPO-21, (407) 861-5433

Participating Organizations: NASA, KSC Shuttle Operations; NASA, KSC Safety, Reliability, and Quality Assurance; Lockheed Martin Space Operations; Center for Creative Leadership; U.S. Air Force Academy; and NASA, Ames Research Center

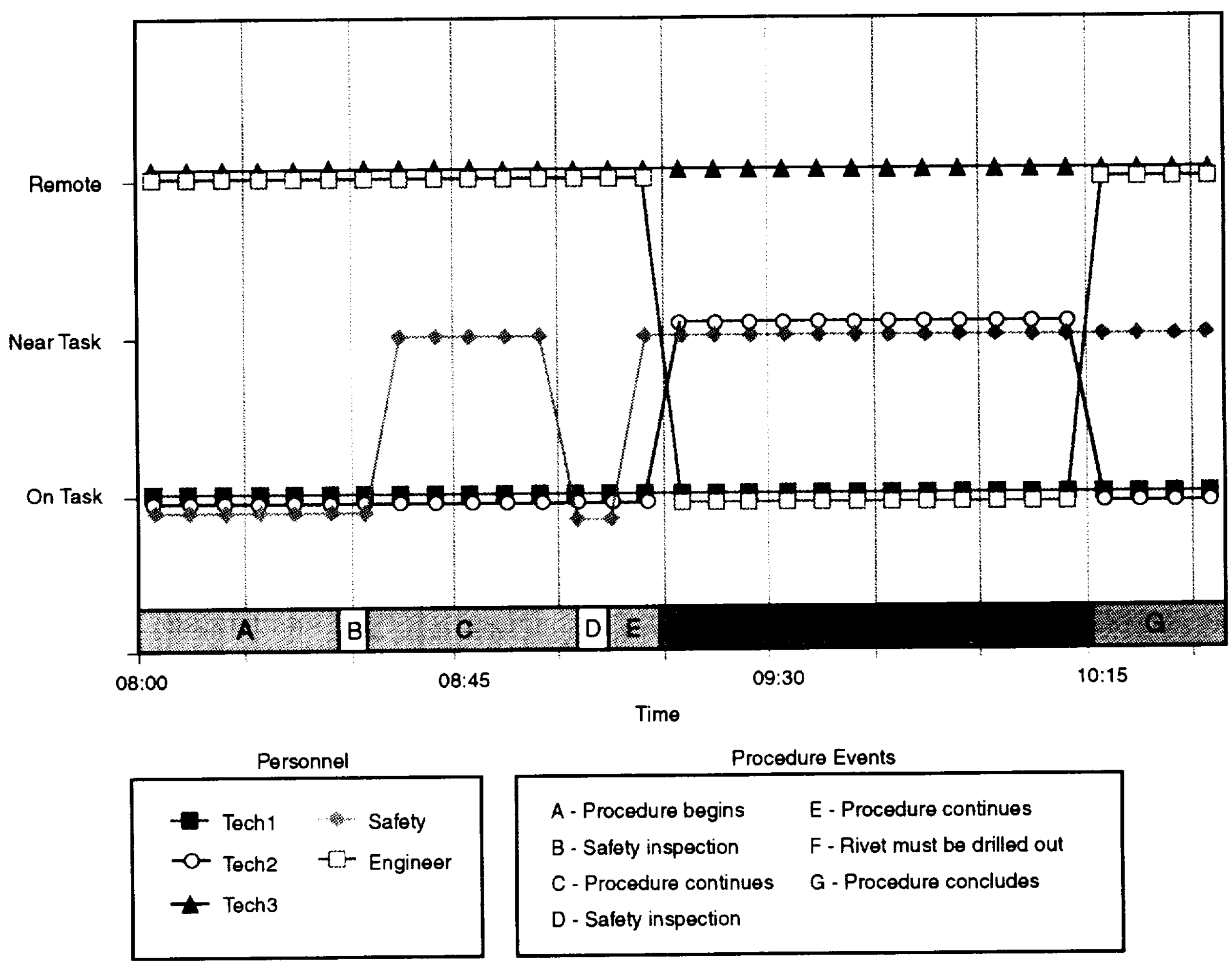


Modified Team Effectiveness Model for Human Factors Evaluation of Mishaps

Human Factors Engineering Focus: Team Effectiveness Research in Shuttle Processing

Most ground processing tasks at KSC are accomplished by teams rather than by individuals. In fact, a common KSC motto is, "Launch work is teamwork!" Task teams frequently consist of technicians, system engineers, quality inspectors, and special support personnel. Therefore, it is necessary to consider team effectiveness when making process improvements to increase productivity and effectiveness of shop floor activities. Team effectiveness is measured by the quality of the team output (task completed without mishaps, on schedule, etc.), the future capability of the team to work together, and the individual satisfaction of each team member. In order to optimize team effectiveness at KSC, it is essential to understand how KSC teams work.

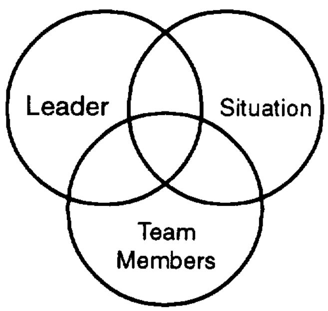
Some of the complexities associated with KSC teams are illustrated in the figure "Timeline of a Shuttle Processing Task," which shows how several team members are located away from the task during different intervals in the task timeline. The Team Effectiveness Leadership Model from the Center for Creative Leadership was applied in order to collect data on how KSC teams work. Data was collected by



Timeline of a Shuttle Processing Task

direct observation of processing tasks during the summers of 1993 and 1994. A questionnaire was used to gather additional data during the observation period in 1994. The project activity during 1995 focused on analyzing the KSC data and extracting meaningful recommendations for several KSC customers.

For example, the questionnaire was adapted for use in a new Shuttle processing initiative called Process Product Integrity Continuous Improvement (PPICI). The PPICI effort is very similar to an industrial engineering work methods analysis and includes a phase for direct observation of processing tasks. The task questionnaire was used to incorporate many human factors and teamwork considerations into the PPICI observer checklist. In addition, observer training and data analysis methods were shared with the PPICI team.



Elements of Leadership Training

The team effectiveness research is also being used by a KSC team developing enhancements to the task team leader (TTL) training program. The basic recommendation is to train the task team leaders to consider the entire team environment, including the other team members and their specific work situations, as shown in the figure "Elements of Leadership Training."

Key accomplishments:

- 1991: Human Factors Engineering memorandum of understanding between KSC and Ames Research Center signed.
- 1993: Basic team effectiveness research in several Shuttle processing facilities.
- 1994: Additional data collection and applied research in the Orbiter Processing Facilities. Recommendations to Shuttle operations management.
- 1995: Additional data analyses and implementation of recommendations.

Key milestone:

- 1996: Additional collaboration with the TTL enhancement and PPICI efforts.

Contact: T.S. Barth, TM-TPO-21, (407) 861-5433

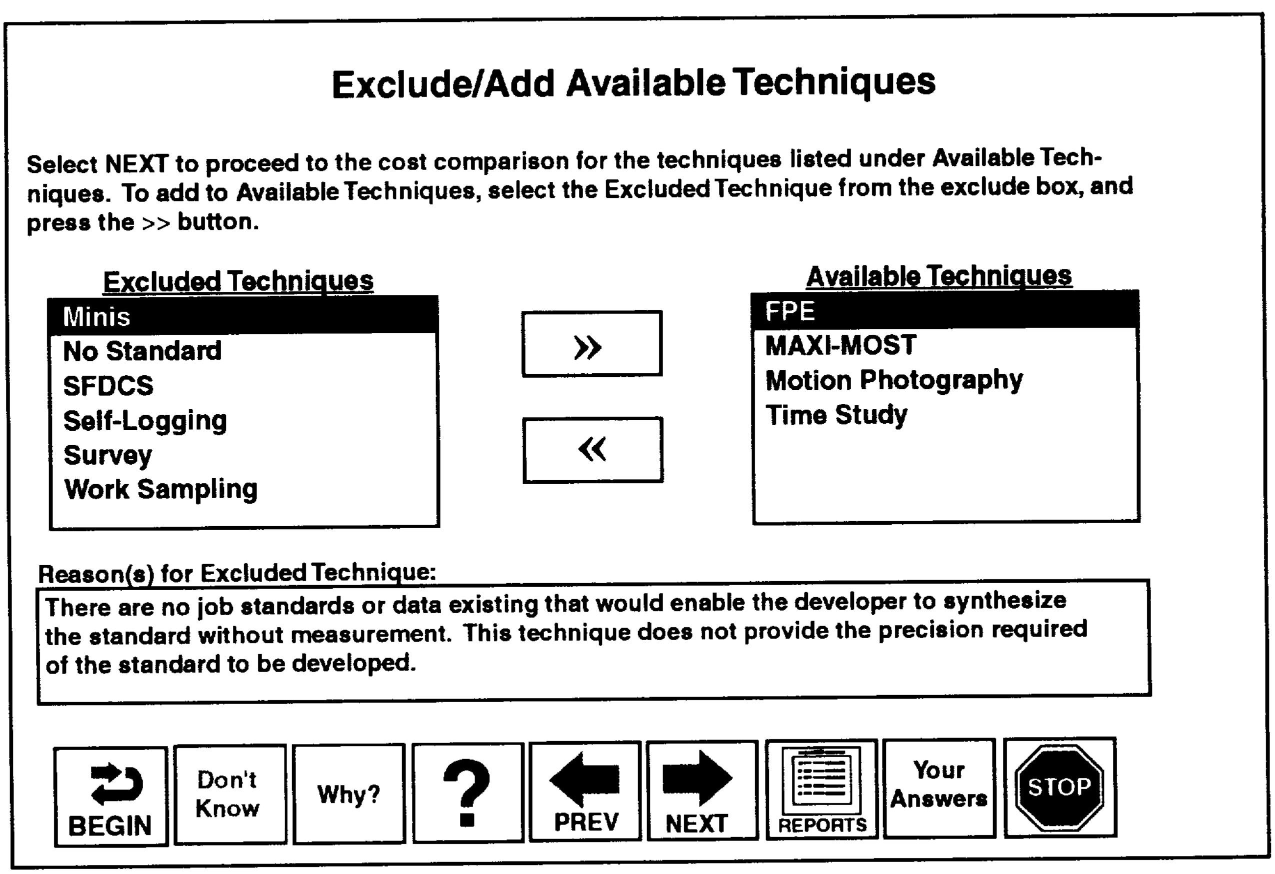
Participating Organizations: Ames Research Center (B. Kanki and C. Irwin), Center for Creative Leadership (R. Ginnett), and the U.S. Air Force Academy (J. Austin)

Methods Engineering/Work Measurement Focus: Expert System To Develop Shuttle Ground Processing Metrics

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 use of work measurement to measure Shuttle ground processing efficiency. Although many work measurement techniques and methodologies are best suited to short-duration, highly repetitive activities, there are 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 the 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. This method of choosing a work measurement technique 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



Available Techniques Based on User Input decisions about which work measurement technique is best for the situation at hand. The expert system, designed for the IBM PC platform, asks the practitioner a series of questions about issues relevant to technique selection. The expert system uses answers provided by users 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, critical path considerations, task duration, visual accessibility, work force participation considerations, and cost and benefit expectations. 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 accomplishment:

- 1994: Successfully demonstrated the prototype expert system to select an appropriate work measurement technique (see the figure "Available Techniques Based on User Input").

Key milestones:

- 1995: Identified, incorporated, and tested enhancements to the work measurement technique selection system.
- 1996: Design, develop, and test a Job Standards Development System (JSDS) 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.
- 1997: Install JSDS at KSC.

Contact: A.M. Mitskevich, TM-TPO-21, (407) 861-5433

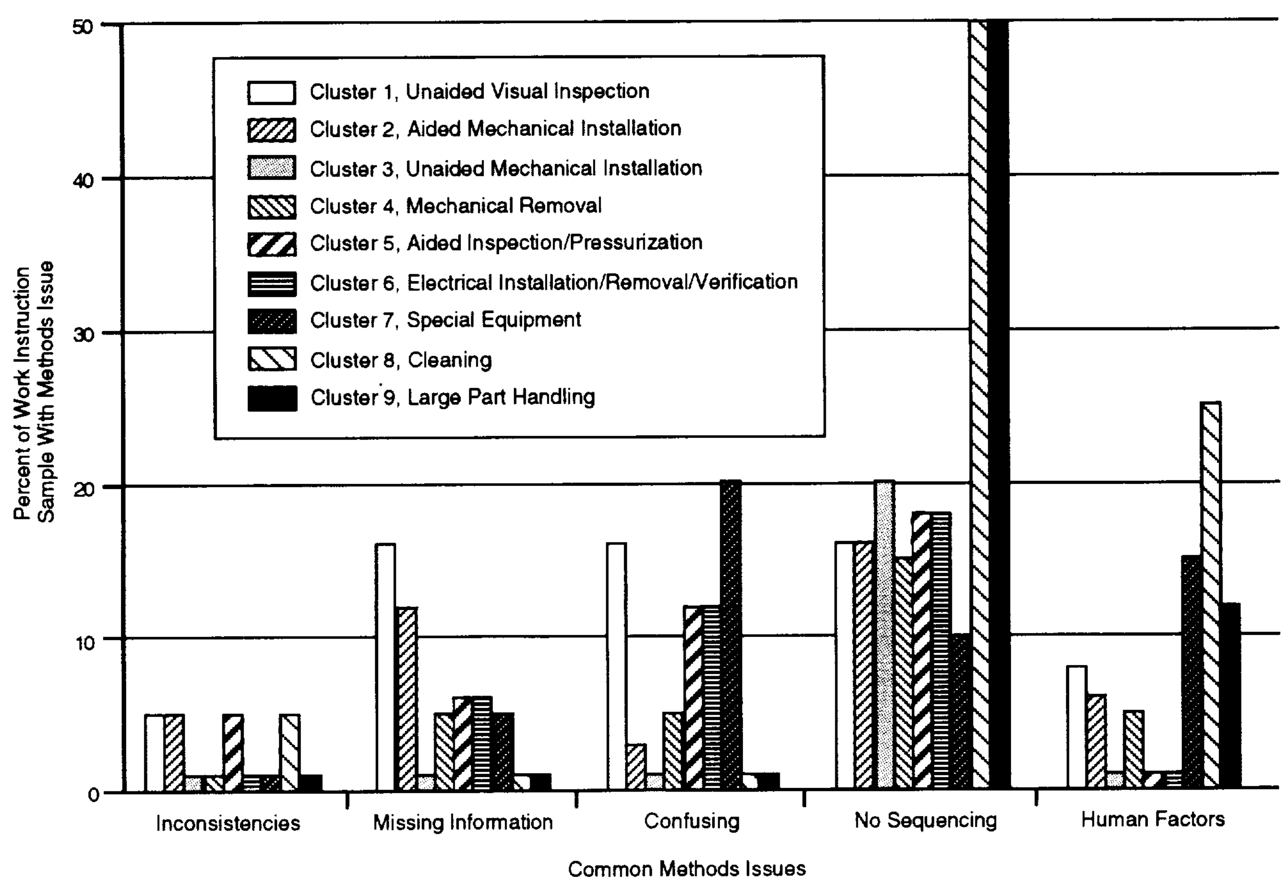
Participating Organizations: OMNI Engineering & Technology, Inc. (N. Schmeidler) and OXKO Corporation (S. Oxman)

Methods Engineering/Work Measurement Focus: Methods Analysis of Orbiter Processing Work Instructions

A primary concern of industrial engineers is performing necessary tasks while minimizing resource utilization. A methods analysis employs several tools and techniques for determining the optimal work methods for a given task. An effort to evaluate the feasibility of employing methods analysis techniques in Shuttle ground processing and to customize those techniques as required was initiated in 1992.

An analysis of work methods examines: (1) how those methods use limited resources (e.g., time, materials, and energy), (2) how methods physically and psychologically affect workers, and (3) the quality of the task results. Improved methods design can increase productivity, reduce the potential of worker strain/injury or other mishaps, and improve the quality of the output. A methods analysis of the work instructions for orbiter processing was initiated to examine how well the work instructions: (1) guide the technicians to perform the goal of the work (e.g., their completeness, correctness, and clarity), (2) take into account the optimal sequencing of work (e.g., in terms of limited resources, common tools, efficiency, and precedence requirements), and (3) take into account the environmental factors, motions and positions of the workers, and facility layout (e.g., in terms of shared resources, human factors, and ergonomics).

A detailed investigation of the planned work for routine Main Propulsion System (MPS)



Methods Analysis Issues Identified by Task Cluster processing in the Orbiter Processing Facility (OPF) indicated several areas for improvement in the work instructions. The MPS was used as a representative OPF system for demonstration purposes. Following the MPS study, a prototype job card incorporating the methods analysis findings was designed and an initial process plan conversion checklist was developed to guide future development of work instructions.

During 1995, methods analysis techniques were applied to a sample of work instructions from other orbiter systems to determine whether similar work instruction issues existed across all orbiter systems and whether these issues were linked to the type of work performed. To perform this analysis, clusters of tasks with similar work content were identified; observations of technicians following the work instructions were performed (the figure "Methods Analysis Data Collection Sheet" illustrates the data collection tool used during task observations); a sample of the work instructions was reviewed; and the results were analyzed (the figure "Methods Analysis Issues Identified by Task Cluster" indicates the percentage of work instructions within each task cluster where work methods issues were identified).

Key accomplishments:

- 1993: Completion of a detailed MPS routine work study. Development of task clusters.
- 1994: Development of a prototype redesigned job card. Recommendations for improving MPS work instructions.
- 1995: Completion of an OPF methods analysis of a sample of work instructions across all orbiter systems. Recommendations supporting process plan conversion.

Key milestones:

- 1996: Integration of analysis results with the Shuttle Processing Contractor's process product integrity continuous improvement (PPICI) effort. Review and update the process plan conversion checklist.

Contact: T.S. Barth, TM-TPO-21, (407) 861-5433

Participating Organization: University of Central Florida (J. Pet-Edwards and K. Stanney)

OMI# **Flow Process Chart** Job Card#__________

Summary	Operation ○	Transport ⇨	Storage ∇	Delay D	Inspect □
Total No.					
Total Dist.					
Total Dur.					

Step	Time	Dur.	Event/Task	Dist.	Event Symbol	Method Recommendation
					○⇨∇D□	
					○⇨∇D□	
					○⇨∇D□	
					○⇨∇D□	
					○⇨∇D□	
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Methods Analysis Data Collection Sheet

Benchmarking Focus: KSC Benchmarking Network

The KSC Benchmarking Network is revising its strategic plan in 1995 with redefined goals and a mission to reflect the changing business environment at KSC. The consortium was chartered in January 1994, driven by a renewed commitment to revolutionary change in response to today's fiscal environment. The group is designed to facilitate effective benchmarking studies, optimize efficiencies, and leverage quality improvements across the Center. Network membership consists of total quality and industrial engineering professionals from ten major NASA and contractor organizations at KSC.

The network developed an original approach to consortium benchmarking that integrated the best features of proven models (e.g., Camp, Spendolini, Watson, and Balm). After defining the architecture of the network (including the two-phase methodology shown in the figure), the team conducted a "pathfinder" benchmarking study of Government Property Management among KSC contractor members. 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.

This cost-effective alternative to conventional benchmarking has provided a foundation for continued benchmarking at KSC through the development of common terminology, tools, and techniques. In addition to enhancing benchmarking skills among members, the network strengthened a KSC culture that values continual improvement and teamwork to achieve excellence. Continued informal benchmarking among process owners also proved to be a synergistic benefit of network benchmarking.

Key lessons learned from the practicum study resulted in the recalibration of not only the subject process but also the architecture of the benchmarking network itself. The improved KSC benchmarking model (see the figure) is transferable to other organizations and industries interested in sharing and creatively adapting best practices in a competitive environment. For these groups, as the aerospace community, the impetus to apply this model derives from the belief that breakthrough improvement is the essence of business survival.

Key accomplishments:

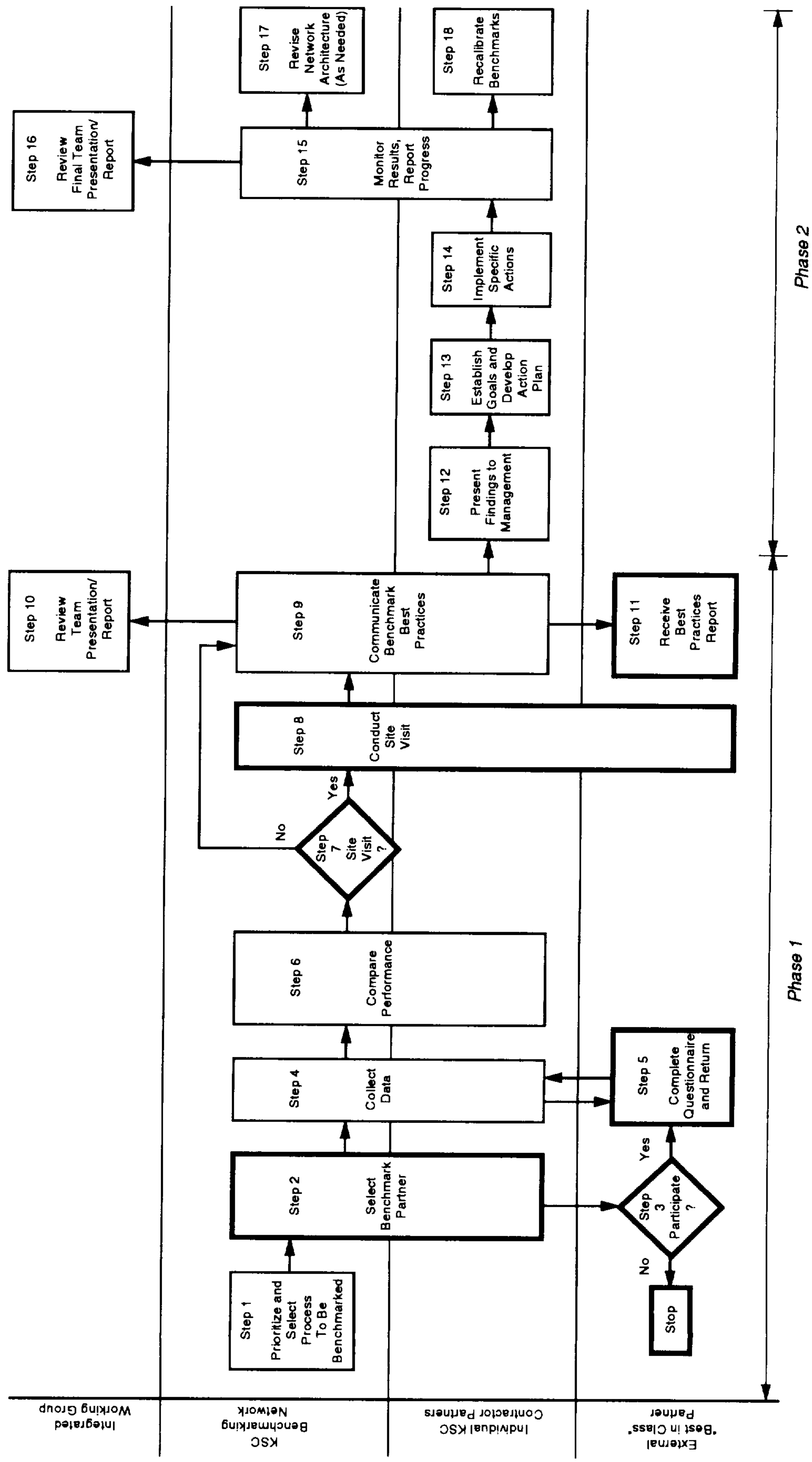
- 1994: Team charter, formation, strategic planning, and selection of initial study.
- 1995: Completion of a comprehensive practicum or "pathfinder" benchmarking study of Government Property Management. Selected by KSC Center Director to represent KSC at the annual NASA Continual Improvement and Reinvention Conference in Washington, DC. Received Silver Award for Benchmarking (in the applied research category) from the International Benchmarking Clearinghouse, a division of the American Productivity and Quality Center.

Key milestone:

- 1996: Completion of a revised strategic plan with redefined goals and mission to reflect the changing business environment. Future benchmark studies will consider candidate processes that support KSC strategic objectives.

Contacts: C. Horton, HM-CIC, (407) 867-2512, and T.S. Barth, TM-TPO-21, (407) 861-5433

Participating Organizations: McDonnell Douglas Space and Defense Systems (D.E. Drew); EG&G Florida, Inc., (J.J. Eads); I-NET, Inc. (J.R. McLamb); Lockheed Martin Manned Space Systems (F.A. Lockhart); Lockheed Martin Space Operations (S. Morrison); Northrop Grumman (J. Beyers); and USBI Company (H. Novak)



Consortium Benchmarking Model

Benchmarking Focus: Internal Benchmarking of Space Shuttle Ground Processing Operations

A major activity of the Inter- and Intra-Facility Performance Measurement project conducted in Space Shuttle ground processing at KSC involved the development of a prototype benchmarking comparison procedure for use within and across Shuttle processing facilities. This procedure was tested in the following three processing areas:

- Hypergolic Maintenance Facility (HMF)
- Rotation, Processing, and Surge Facility (RPSF)
- Orbiter Processing Facility (OPF) high bays

NASA and Shuttle Processing Contractor engineers and technicians from each of these processing areas participated in a number of structured individual and group activities to determine processes and process performance measurements common to all facilities participating in the study. Subsequent activity identified those common processes and process performance measurements for which it would be mutually beneficial to collect and compare data. The project participants decided to collect and share information on measurements related to the following specific operations:

- Astro-arc welding operations
- Leak-check operations

Data collection and analysis procedures were designed by project personnel and implemented by the process stakeholders. The data collected from this study is capable of providing comparison information such as that indicated in the figure "Examples of Benchmarking Comparison Charts."

Key accomplishments:

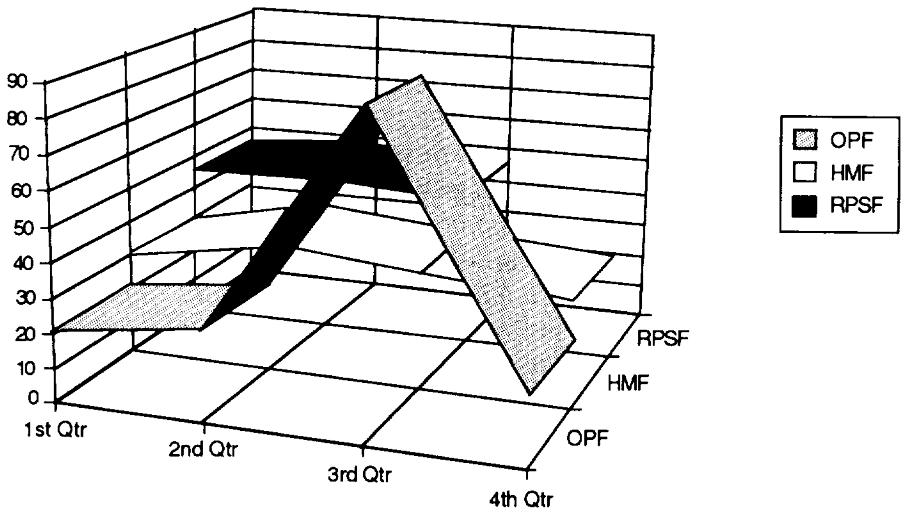
- 1994: Design and implementation of prototype benchmarking comparison procedures in Space Shuttle ground processing.
- 1995: Development of a handbook describing the procedure employed in the prototype application for use by other ground processing facilities initiating benchmarking comparisons.

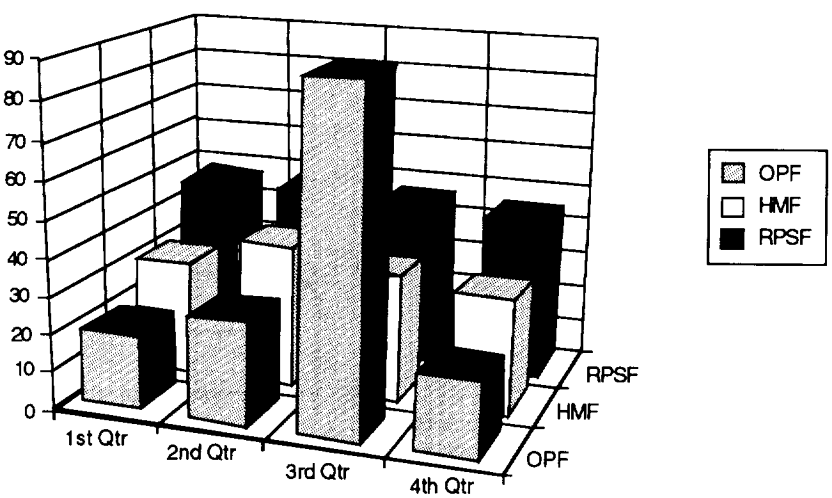
Key milestones:

- 1996: Completion of benchmarking design and implementation.

Contact: T.S. Barth, TM-TPO-21, (407) 861-5433

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



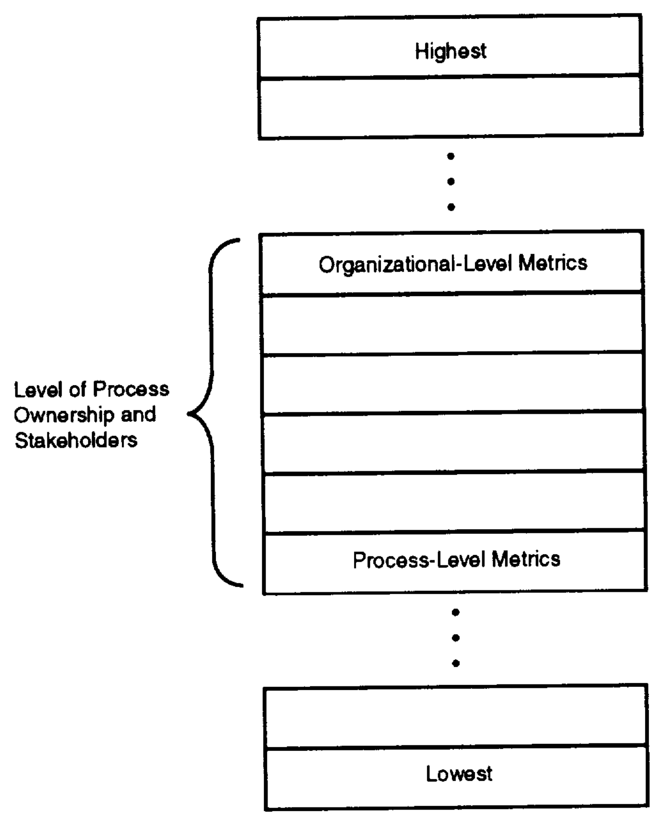


Examples of Benchmarking Comparison Charts

Benchmarking Focus: Organizational-Level Performance Measurement for External Benchmarking

A major component of an inter- and intra-facility performance measurement project conducted in Space Shuttle ground processing at KSC involved the development of a systematic procedure for the measurement of organizational-level performance. This organizational-level performance measurement system was designed to complement the process-level benchmarking performance measurement system previously developed for application in Shuttle ground processing operations. As indicated in the figure "Relative Position of Organizational-Level and Process-Level Performance Metrics," measurements designated as organizational level (as opposed to process level) are relative to the position in the organizational hierarchy at which the measurements will be taken and utilized. Organizational-level performance metrics are relatively high level, oriented toward management needs, and usually related to the bottom-line concerns of the organization.

A benchmarking-oriented review of organizational-level performance measurement systems employed in other organizations indicated a large percentage of these measurement systems fail or are discarded after a relatively short period of time. These failures can generally be attributed to



Relative Position of Organizational-Level and Process-Level Performance Metrics

- Validity
- Accuracy and Precision
- Completeness or Collective Exhaustiveness
- Uniqueness or Mutual Exclusiveness
- Reliability
- Comprehensibility
- Quantifiability
- Controllability/Ownership
- Flexibility
- Cost Effectiveness
- Adaptability
- Maintainability

Necessary Characteristics of Organizational-Level Performance Measurement Systems

the measurement systems' lack of one or more of the characteristics identified as necessary (see the figure "Necessary Characteristics of Organizational-Level Performance Measurement Systems").

For the purpose of organizational-level measurement of Shuttle ground processing, a Multicriteria Productivity/Performance Measurement System was developed. Extensive lists of organizational-level performance metrics used in other organizations were compiled and reviewed. Candidate metrics for the nine major process categories identified by the Shuttle Processing Contractor (SPC) were proposed for use in guiding process stakeholders in the development of measurement sets for specific processes. Finally, an "objectives matrix" approach for displaying the measurement system and for providing a quantified summary of the current levels of the metrics was developed.

Key accomplishments:

- 1994: Review of major SPC process categories and the collection of external organization performance measurement information.
- 1995: Development of measurement system procedures and selection of candidate metrics.

Key milestones:

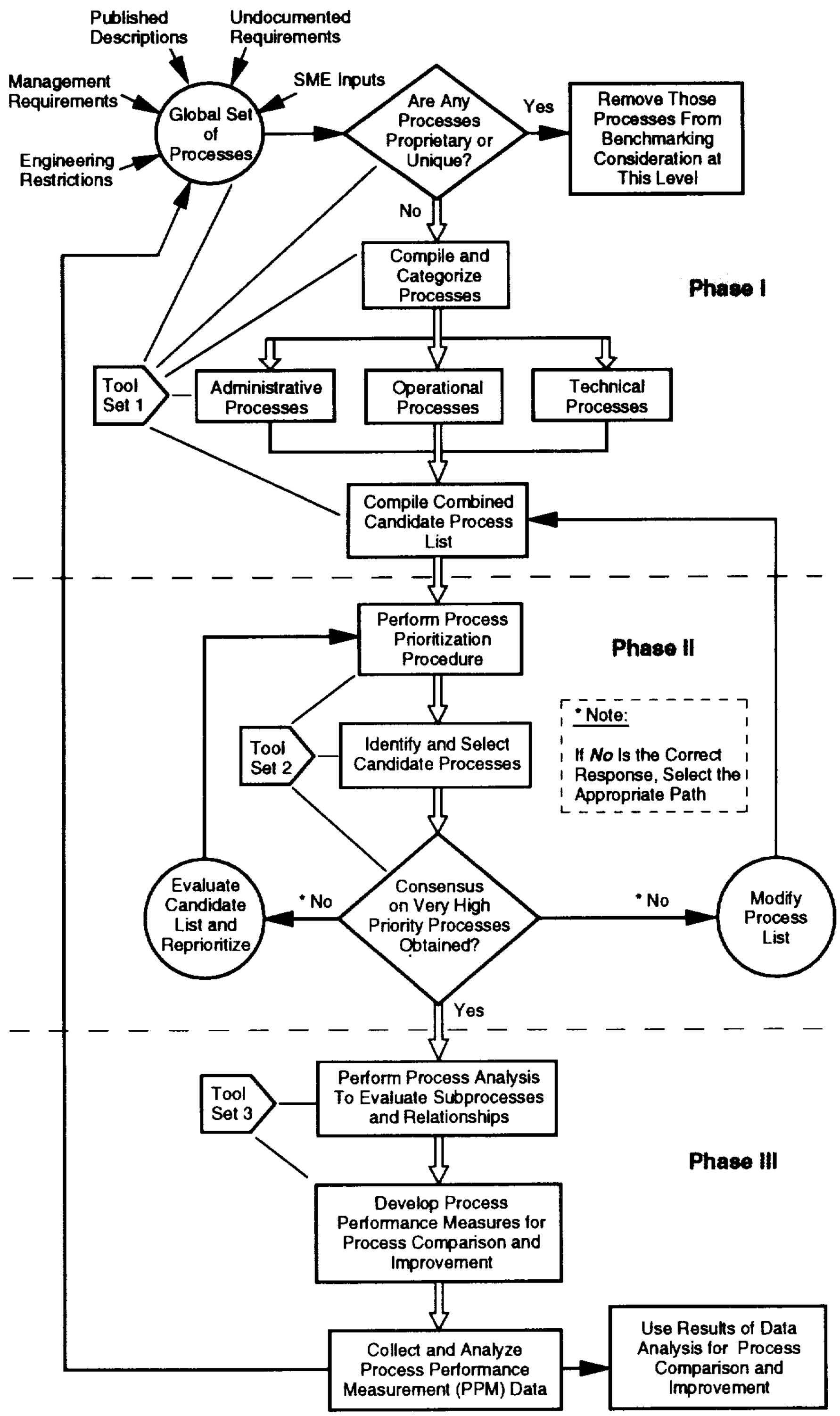
- 1996: Prototype measurement system development.

Contact: T.S. Barth, TM-TPO-21, (407) 861-5433

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

Benchmarking Focus: Process Disaggregation Procedure (PDP)

Benchmarking is a process improvement tool that integrates well into various organizational Continuous Improvement of Processes (CIP) activities. Benchmarking permits groups of process owners and stakeholders to evaluate their individual functions while comparing those functions to other groups performing similar processes. The interfacility comparison research activity at KSC is based loosely on work performed by the Oregon Productivity Center, entitled Productivity Interfirm Comparison (PIC), which is centered around a structured process identification and measurement activity to support required competitive benchmarking and comparative analyses. Process comparisons developed during this research activity have provided useful information for improvement activities across several Shuttle processing facilities at KSC.



Three-Phase Process Disaggregation Procedure Model

Project activities centered around the development and testing of a systematic procedure for identifying and analyzing processes for benchmarking comparison. Three participating facilities across Shuttle operations were selected, and stakeholders within the facilities were identified. The PDP model (see the figure) was developed to facilitate the identification and collection of comparative process performance measures (PPM's). The basic structure supporting the PDP methodology is similar to the manufacturing environment wherein an aggregate business plan is broken into lower level system and subsystem requirements, eventually resulting in a bill of materials for each product in the business plan. Similarly, the PDP looks at the entire set of processing activities within a department, division, company, or corporation before breaking these high-level process descriptions into smaller, more generic subprocesses for comparison at the process level across multiple organizations.

Phase I of the disaggregation procedure permits the Process Improvement Team (PIT) to identify, screen, and categorize one or more processes from a Global Process Set (GPS) for improvement analysis and comparison. The processes that define a specified level in the organization are the ones identified for each PDP activity cycle.

The PDP Phase II activities are focused on process prioritization and analyses. The GPS data generated and screened during Phase I is now evaluated for relative prioritization in the context of the entire organizational-level process set. Each process is given equal consideration using a prioritization technique to establish multiple levels of process priorities before selecting the top-ranked processes for further analysis and benchmarking. Appropriate sets of tools and techniques are then utilized to satisfy the goal of process prioritization under the PDP.

Phase III of the PDP model is designed to provide a structure for data collection and analysis centered on those very high-priority processes defined during Phase I and II activities. Phase III of the PDP phase is analogous to a total quality endeavor where PPM's are identified for control charting. The data should be used to baseline the existing processes and to help determine if changes made to processes are effective. Information gained from self-directed, internal analysis and from external benchmarking studies can be used to improve the performance of the overall system.

Key accomplishments:

- 1993: Integration of the systematic PDP. Comparison of processes using top-ranked/common processes selected during Phase I.
- 1994: Comparative analyses for process-level activities. Integration of the PPM's into selected facilities to support comparative analyses.
- 1995: Completion of data collection requirements. Compilation of data results using organizational-level measures for selected processes at KSC. Report to Shuttle processing management on results of comparison activities.

Contact: T.S. Barth, TM-TPO-21, (407) 861-5433

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

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.

Hypergolic Oxidizer and Fuel Scrubber Emissions

Hypergolic fuels and oxidizer are emitted to the environment during fueling and deservicing of the Shuttle and other spacecraft. Such emissions are difficult to measure due to the intermittent purge flow and the presence of suspended scrubber liquor. A new method for emissions monitoring was introduced in the Research and Technology 1994 Annual Report. This article is a summary of the results of a 1-year study of scrubbers at the Shuttle launch pads and Orbiter Processing Facilities (OPF's). The study proved emissions can be determined from field scrubbers without direct measurement of vent flow rate and hypergol concentration in the vent gas.

This new approach is based on the scrubber efficiency, which was measured during normal operations, and on the accumulated weight of hypergol captured in the scrubber liquor, which is part of the routine monitoring data of scrubber liquors. To validate this concept, three qualification tests were performed, logs were prepared for each of the 16 hypergol scrubbers at KSC, and the efficiencies of KSC scrubbers were measured during normal operations. Also, an estimate of the annual emissions was made based on the scrubber efficiencies and the propellant buildup in the scrubber liquor.

The key concept demonstrated by this study is that scrubber emissions can be calculated by a one-time measurement of scrubber efficiency and then by periodically measuring the buildup of fuel or oxidizer in the scrubber liquor reservoir. The equation for this calculation is:

$$\textit{Emissions (wt.)} = [(1/EFF)-1] \times \Delta\,(\textit{wt. of hypergol}) \tag{1}$$

where the *emissions* is the calculated amount of fuel or oxidizer released during the period between the scrubber liquor samples and the *EFF* is a weighted average of typical operations.

Data from the proof-of-concept (POC) tests are used to calculate the emissions two ways. First, flows and outlet concentrations are measured over a representative range of operational conditions. Such a test conforms to National Institute of Occupational Safety and Health (NIOSH) method 3503 for measuring stack emissions. Using these data, the emission value is simply the flow rate times the outlet concentration times the operation time:

$$\textit{EPA Emissions (wt.)} = \textit{Flow Rate} \times \textit{Outlet Conc.} \times \textit{Time} \tag{2}$$

The *EFF* requires an inlet hypergol concentration measurement:

$$EFF = (\textit{Inlet Conc.} - \textit{Outlet Conc.})/\textit{Inlet Conc.} \tag{3}$$

The second or new emissions method requires both a knowledge of EFF and samples of scrubber liquor to determine fuel or oxidizer buildup in the liquor. Equation 1 is then used to calculate the second emission value, and this is compared with the NIOSH method using equation 2 for a given time period. The comparison provides a basis for validation of the new emissions method.

Since the gas flow rates through the scrubber, the concentration of the outlet vapor, and the duration of the flow conditions were known for POC tests, it was then possible to calculate the emissions. The results of the emissions estimated by the NIOSH method compared with the results calculated from the efficiency and weight change are:

- Two-tower fuel scrubber: 12.3 g for NIOSH versus 15.9 g for the new method

- Four-tower fuel scrubber: 4.7 g for NIOSH versus 5.9 g for the new method

- Four-tower oxidizer scrubber: 5,600 g for NIOSH versus 3,500 g for the new method

These results confirm that the emissions from the KSC scrubbers can be monitored by measuring the buildup of hypergol propellant in the liquor and then using the appropriate efficiency to calculate the emissions. The efficiencies of 12 KSC scrubbers, measured under actual servicing operations and special test conditions, were assumed to be valid for all subsequent operations until a significant change in hardware occurred. Based on these concepts, scrubber liquor log data were collected and used to estimate the total emissions from 16 scrubbers for 3 years. The results showed that 0.3 kilogram per year of fuel and 234 kilograms per year of oxidizer were emitted.

The efficiency data provided in the table represents the inlet-concentration-weighted average efficiencies for each scrubber measured during normal operations. The inlet-weighted average adjusts the efficiency for those operations that contribute high concentrations of hypergol to the scrubber. The efficiency values provided in the table are recommended efficiencies that should be used with the scrubber waste logs to calculate the emissions.

Key accomplishments:

- A method to calculate the efficiency of a scrubber without measuring the stack flow rate.
- A reduction in the effort required to calculate the scrubber emissions by analyzing data already available from waste disposal logs (concentration and amount of waste scrubber liquor).
- Simplified sampling operation that eliminates errors observed with current methods of monitoring scrubber emissions.

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)

Efficiencies of KSC Scrubbers for Calculation of Emissions by the New Method

Scrubber	Efficiency (Percent)
Pad 39A fuel farm	99.816
Pad 39A oxidizer farm	99.925
Pad 39A Fixed Service Structure (FSS) fuel scrubber	99.922
Pad 39A FSS oxidizer scrubber	99.765
Pad 39B fuel farm	99.966
Pad 39B oxidizer farm	99.585
Pad 39B FSS fuel scrubber	99.966
Pad 39B FSS oxidizer scrubber	99.585
OPF Bays 1 and 2 fuel scrubber	99.924
OPF Bays 1 and 2 oxidizer scrubber	83.810
OPF Bay 3 fuel scrubber	99.926
OPF Bay 3 oxidizer scrubber	87.319
Hypergolic Maintenance Facility (HMF) Building 961 fuel scrubber*	99.925
HMF Building 961 oxidizer scrubber*	85.565
HMF Building 1212 fuel scrubber*	99.925
HMF Building 1212 oxidizer scrubber*	85.565

*Values shown were not measured but were calculated as the average efficiency of the OPF's.

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

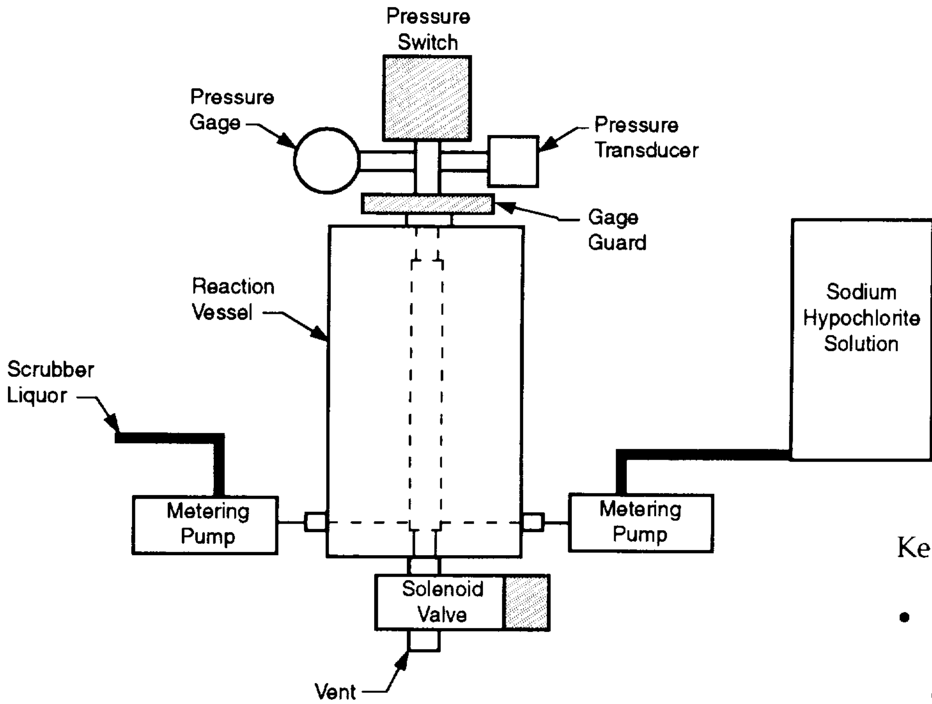
A new emissions control system has been developed for the oxidizer scrubbers that eliminates the current oxidizer liquor waste and lowers the NOx emissions. Implementation of this new system would eliminate the second largest waste stream (approximately 250,000 pounds per year) at KSC, which currently costs approximately $0.20 per pound or $50,000 per year. This effort is in accord with 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). The new scrubber liquor starts with 1-percent hydrogen peroxide at a pH of 7. A new process control system adds hydrogen peroxide and potassium hydroxide to the scrubber liquor to maintain those initial conditions. The result is the formation of a solution of potassium nitrate, which can be sold as a fertilizer.

A laboratory scrubber was equipped to measure the efficiencies of different scrubber liquors under conditions similar to field operations. The newly formulated scrubber liquor required control of pH and hydrogen peroxide concentrations. Therefore, to maintain the hydrogen peroxide concentration in the scrubber liquor, a portion of the liquor is sampled off-line in an automated peroxide reaction chamber (private communications, The Foxboro Co., M. Frant, 1983). The output of this device automatically controls the rate of addition of hydrogen peroxide to the circulating scrubber liquor. The hydrogen peroxide concentration was controlled by monitoring the pressure generated when sodium hypochlorite (bleach) was added to a sample of the scrubber solution (see the figure). The reaction of hydrogen peroxide with sodium hypochlorite is:

$$H_2O_2 + NaOCl \rightarrow H_2O + NaCl + O_2$$

The volume of the reaction chamber is approximately 10 milliliters. The pressure switch, pressure transducer, and gage are isolated from the reaction chamber with a gage guard that has a Teflon diaphragm. A solenoid valve is attached to the bottom of the reaction vessel. Two metering pumps supply the scrubber liquor sample and sodium hypochlorite solution. The pH of the scrubber liquor is controlled with a Cole-Parmer model H-56025-40 proportioning pH controller with adjustable flow rates (0 to 5.2 gallons per hour).

The effect of pH on the efficiency appears to pass through a maximum at approximately a pH of 7 and then drops on either side for the single pass and liquor recycle laboratory tests. When the pH was extended in the recycle runs, the efficiency appeared to increase below 5 and above 9 pH. Increase in peroxide reactivity was observed for acidic and alkaline solutions and was attributed to the increased instability of hydrogen peroxide. Also, there was a significant drop in the pH of the



Hydrogen Peroxide Concentration Control System

scrubber liquor from the top to the bottom of the scrubber. For example, when water was used as the scrubber liquor (initial pH of 7), the pH dropped to 2 when the nitrogen dioxide concentration was 100 parts per million.

Hydrogen peroxide concentrations from 0.1 to 2 percent increased the efficiency from around 76 percent for the existing liquor, 25-weight-percent sodium hydroxide, and 73 percent for water to 82 to 96 percent for L/G's (liquid-to-gas mass flow ratios) from 7.5 to 12.6. Analysis of the scrubber liquors for the presence of nitrite ions indicated the oxidation with hydrogen peroxide has oxidized all the nitrite ions to nitrate ions, which was one of the objectives for the addition of hydrogen peroxide to the scrubber. Without the presence of hydrogen peroxide, the concentration of nitrite and nitrate ions is almost equal. Since nitrite ions disproportionate to form nitric oxide and nitrate ions, oxidation of the nitrite ions is desirable to lower the emissions of nitric oxide.

The primary objectives of this study were achieved. A new scrubber liquor was developed that was less expensive to use than the current 25-weight-percent sodium hydroxide when all factors were considered, including waste disposal, preparation of the scrubber liquor, and handling a hazardous waste (the spent oxidizer scrubber liquor). Improvement in the scrubber efficiencies is the second most important accomplishment of this study, and these changes are significant.

Key accomplishments:

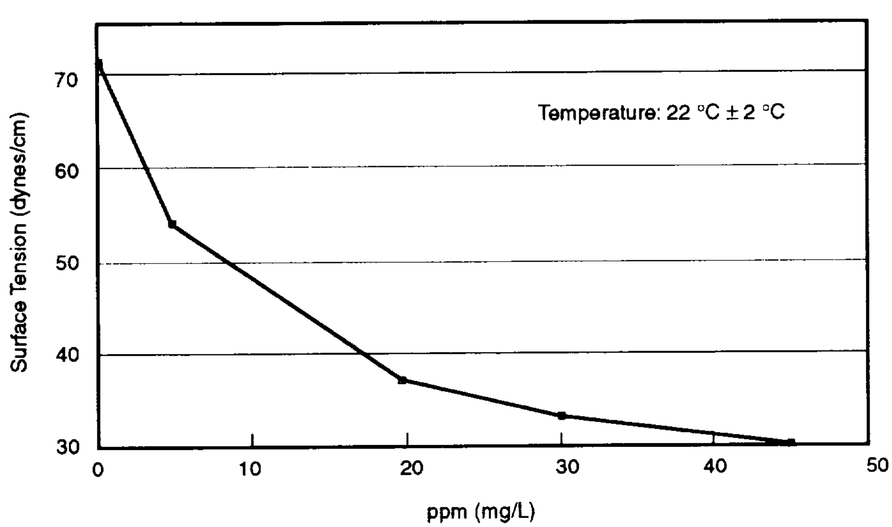
- A method to eliminate the second largest waste stream at KSC (oxidizer scrubber liquor waste).
- A new scrubber liquor that improves the efficiency of the oxidizer scrubbers.
- Simplified operation at the oxidizer scrubber that eliminates preparation of the scrubber liquor, since the system starts with water in the scrubber liquor tank and then prepares the liquor as needed.
- The fertilizer company will remove the scrubber liquor from the storage tank, thus eliminating the handling problems.
- The target concentration of potassium nitrate is 10 weight-percent; however, the capacity is only limited by saturation (approximately 24 weight-percent).

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)

Replacement of Freon With Zonyl® FSN-100 Treated Water in Particulate Verification Tests

Recent field tests concerned with determining the extent of particulate contamination on parts by using a water rinse demonstrated that the rinse water did not penetrate into areas where very narrow passages were located. It was postulated that the reason for this behavior was due to the high surface tension of water. Because the water was not contacting all surfaces of the test part, particulate counts were often lower than those determined by using a Freon rinse. It was reasoned that if the surface tension of water could be lowered to that approaching Freon, its performance for this application should be equal to that of Freon. Thus, a program was conducted to evaluate a series of surfactants to determine the most effective for this application. The candidate surfactants had to be effective at very low concentrations and could not leave a residue on the part. After conducting a number of tests, it was determined that DuPont's Zonyl® FSN-100, a fluorinated nonionic surfactant, gave the best performance. Field tests have been conducted with this surfactant and have been in agreement with laboratory studies which show that the Zonyl is very effective for this application.



Surface Tension of Dupont Zonyl® FSN-100

When deionized water with a surface tension of 72.8 dynes•cm^{-1} is treated with Zonyl at 25 parts per million (ppm), the surface tension is reduced to a range of 35 to 37 dynes•cm^{-1}. This surface tension has proven to give good agreement with particulate test data that was generated by using a CFC 113 wash. Test data also show very little surfactant drag-out is observed with the Zonyl. For example, a 500-milliliter test solution of 25-ppm Zonyl experienced a loss of less than 1 ppm of Zonyl after contacting five batches of small stainless steel parts. Each batch represented 1 square foot of surface area. Field tests have demonstrated that the filtered Zonyl wash solution can be used for periods of up to 3 weeks. The Zonyl wash solutions are nontoxic and nonhazardous and can be disposed of through typical biological wastewater treatment facilities.

Key accomplishments:

- CFC 113 was replaced in the particulate verification test with a nonpolluting, nontoxic, inexpensive wash solution.
- Test data show the Zonyl wash solutions produce particulate contamination verification data that is as reliable as that obtained with CFC 113.

Contact: G.J. Allen, LO-MSD-1, (407) 867-3911

Participating Organization: University of Central Florida, Department of Chemistry (C.A. Clausen, J. Wild, and V. Prasaad)

Chemistry Associated With Waterproofing Silica Tiles

Tiles and blankets used in the Space Shuttle have silica fibers as their major component. The silica surface adsorbs water because of residual surface hydroxyl groups that can form hydrogen bonds with water molecules. This property, combined with the extremely open structure of the tiles and blankets (approximately 90-percent free space), necessitates waterproofing of the silica with hydrophobic silicon agents. Dimethylethoxysilane (DMES) is used as the waterproofing agent. Because reentry burns off these agents, rewaterproofing with DMES is performed between each flight. This process is expensive and labor intensive and generates toxic vapors. Although the DMES rewaterproofing process has proven to be very successful for the present Shuttle program, the more cost-effective reusable future space vehicles will have to employ a simpler and less expensive waterproofing process. An understanding of the chemistry associated with waterproofing has intrinsic value in itself and could suggest alternative strategies.

Key accomplishments:

- A mechanism for the reaction of DMES with silica and an explanation of how monofunctional silicating agents like DMES work to produce a waterproofed silica surface were proposed.
- Several experiments using x-ray photoelectron spectroscopy (XPS) were designed. XPS is a surface analysis technique.

Key milestones:

- Elemental concentration depth profiles were obtained for orbiter tiles after rewaterproofing and reentry.
- Silicon carbide formation was detected on a tile after reentry. Silicon carbide is thermally stable and is commonly observed when silicones are decomposed in a reducing environment.

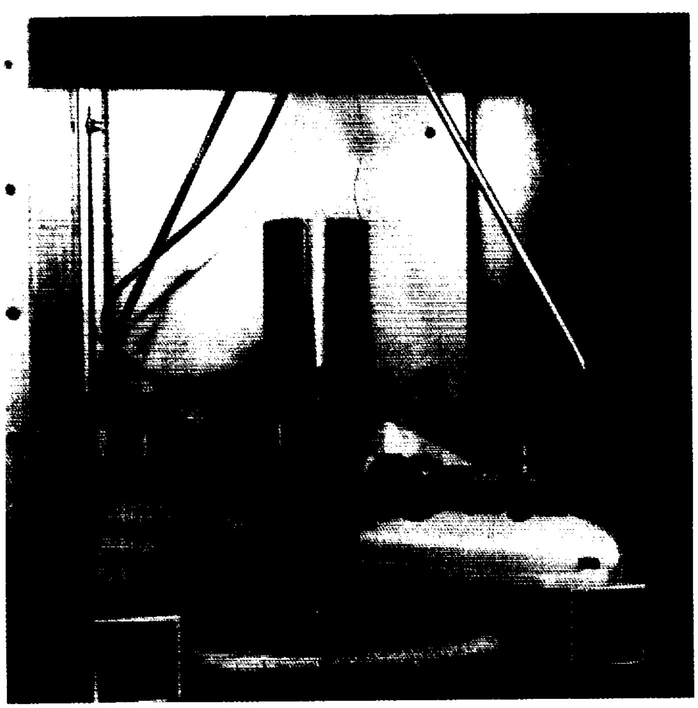
Contacts: O. Melendez and T.A. Schehl, LO-MSD-1C, (407) 867-3910

Participating Organization: LeTourneau University (D.I. Ford)

Environmental Testing of Components for Use in Hypergolic Propellant Systems

Most of KSC's ground support equipment (GSE) dates back to the beginning of the Space Shuttle program in the late 1970's, or even earlier to the 1960's Apollo program. In many cases, spare parts are no longer available to maintain the GSE components; therefore, new components are being qualified to replace the obsolete hardware in the KSC GSE. In addition to the normal environmental and functional tests of components such as valves, regulators, and transducers, some hardware requires additional nonstandard testing.

The hypergolic propellant GSE is one of these areas with additional unique testing requirements. The hypergolic propellant oxidizer, nitrogen tetroxide (N_2O_4), and the fuels, hydrazine (N_2H_4) and monomethylhydrazine (MMH), are extremely reactive and toxic materials. Previous experience with introducing new polymeric materials and unique hardware designs into the hypergolic propellant GSE has dictated the need for special test requirements.



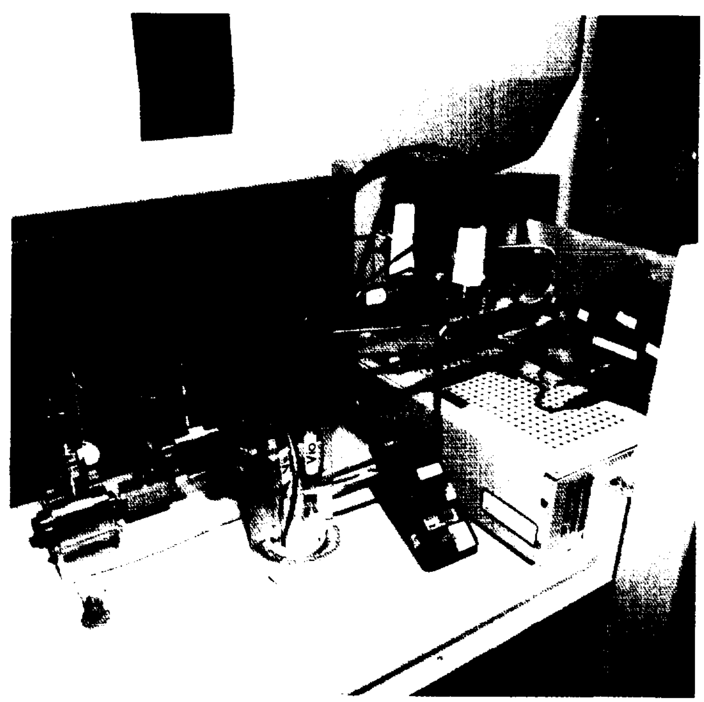
A hypergolic propellant component (solenoid valve) is installed in the Environmental Test Chamber for testing with the internal fluid surfaces wetted with N_2O_4.

Several new components selected for use in the hypergolic propellant GSE were identified as requiring additional testing. The testing required exposing the internal wetted surfaces of the components to an N_2O_4 environment while performing a series of functional tests over the temperature range of -3.9 °C (25 °F) to 43.3 °C (110 °F) and a pressure range of 3.45 kPa (0.5 psig) to as high as 5.17 MPa (750 psig).

This testing was successfully performed by the Materials Science Division in a facility designed to handle small quantities of hypergolic propellants. The testing was conducted in a small environmental chamber with an operating temperature range of -53.9 °C (-65 °F) to 100 °C (212 °F), which was specially configured to perform these required tests. This work was supported by the NASA Development Testing Laboratory.

Contact: P.J. Welch, LO-MSD-2T, (407) 867-1403

The Environmental Test Chamber configured for testing hypergolic propellant component is located in the laboratory facility designed for the handling of small quantities of hypergolic propellants.



An elaborate control system was installed on the top of the Environmental Test Chamber to perform the functional tests of the hypergolic propellant component.

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: Orbiter tile rewaterproofing and inspection, payload inspection and handling and facility maintenance and inspections.

Cable and Line Inspection Mechanism (CLIM)

The objective of this project is to design and develop a system to remotely inspect the 3/4-inch-diameter emergency egress cables (i.e., slide wires) and the 1/2-inch-diameter lightning protection cables at Launch Complex 39 (LC-39) launch pads.

The 3/4-inch emergency egress cables are currently inspected yearly or after a significant lightning strike. Inspectors ride in the slide wire personnel carrier and perform visual inspections of the cable. The inspectors look for broken strands, reduction of cable diameter, and corrosion. The lightning protection cables are currently not inspected because no capability exists to inspect them.

A system is under development that will perform these cable inspections. With the new system, the inspectors will be able to remotely view the cable via a radio frequency (RF) video link and measure the magnetic area of the cable with an electromagnetic sensor. This will

View From LC-39 Launch Pad of the Emergency Egress Cables eliminate the hazardous job of inspecting the cables from the emergency egress personnel carriers. This system will also be able to inspect all the lightning protection cables (i.e., new capability).

A prototype system has been designed and is currently undergoing engineering development testing. The prototype is self-contained and has all the resources necessary to perform its tasks (i.e., power, control, sensing). The prototype is propelled by a brushed direct-current motor and uses a commercial off-the-shelf (COTS) camcorder with digital image stabilization to ensure a stable video image for inspections. The inspection image has three unique views of the cable to ensure the entire circumference of the cable is seen. The audio channel on the camcorder records the sensor readings from sensors that measure the physical diameter and magnetic area of the cable. A COTS RF system (i.e., receiver and transmitter) is integrated into the system that allows remote control and viewing of the cable inspection process. The camcorder records the entire inspection process (i.e., video and audio channels) for off-line viewing and detailed analysis in an office environment. The prototype system size is 24 by 10 by 10 inches and weighs approximately 30 pounds.

The prototype system has been fabricated, assembled, and tested in NASA's Advanced System Development Laboratory. A piece of 3/4-inch, 75-foot-long cable has been installed in the laboratory for testing purposes. The drive, RF, and video systems have been tested. Laboratory testing of the sensors that measure the physical diameter and magnetic area of the cable will begin at the end of calendar year 1995. Field testing of the prototype will begin in March 1996. Upon completion of the field testing, a production unit will be developed, tested, and placed in field operations. The production unit design will be based on lessons learned from the prototype.

Key accomplishments and milestones:

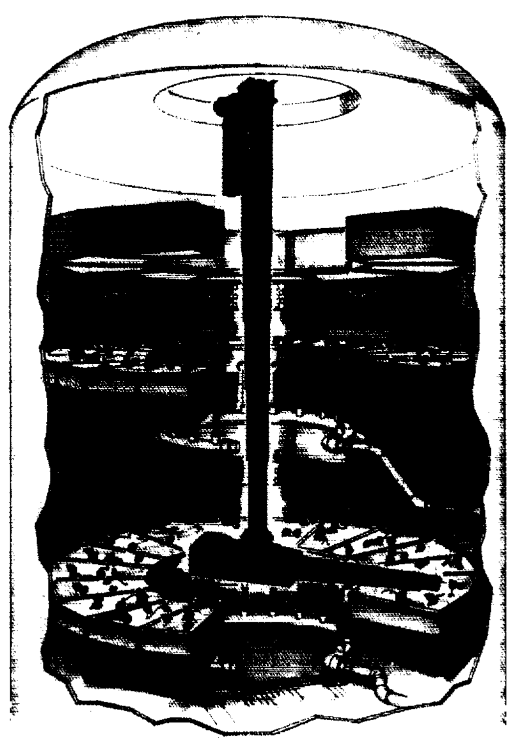
- April 1995: CLIM system concept and design initiated.
- September 1995: Demonstrated functionality of the drive, RF, and video systems of the prototype system on the laboratory test fixture. Received approval for use of the RF system at KSC.
- First Quarter 1996: Test prototype system on emergency egress cables at Launch Pad A.
- Third Quarter 1996: Development of the production system complete.
- Fourth Quarter 1996: Acquire baseline data for Launch Pad A and Pad B cables.

Contacts: T.A. Graham and T.J. Ross, DM-ASD, (407) 867-4156; K.M. Nowak, TE-FAC, (407) 861-3087; and G.A. Hall, DL-ICD-T, (407) 867-3185

Participating Organization: Lockheed Martin Space Operations (A.P. Grant)

Advanced Life Support Automated Remote Manipulator (ALSARM)

The objective of the ALSARM project is to develop a prototype system to take environmental measurements inside the Biomass Production Chamber (BPC) breadboard project (also known as the Controlled Ecological Life Support System or CELSS) at KSC. This project is being performed in conjunction with the University of Central Florida (UCF). A two-semester design course at UCF resulted in several concepts for the ALSARM. KSC and UCF decided on a final concept that would meet all the system and BPC requirements. The project is approximately 90 percent complete and will conclude in early 1996 with a demonstration of the prototype ALSARM in the BPC.



ALSARM in the BPC

The BPC consists of two separate levels that are used to grow crops in an almost totally enclosed environment. The BPC will help NASA understand how to grow crops in space for lunar or Mars bases. During the course of study, technicians have to enter the chamber to measure environmental parameters such as air temperature, infrared (IR) temperature, relative humidity, air velocity, and light intensity. Entry of personnel into the BPC disturbs the environment in several ways. The opening of the chamber door accounts for about half of the chambers' daily leak rate. The technicians contaminate the environment by their respiration, which expels carbon dioxide (CO_2) and organic products. The mere presence of the technicians can modify the airflow patterns in the BPC. The environmental measurements, which take about an hour, are performed serially. Also, it is difficult for people to take measurements at exactly the same points from one type of measurement to another or from one test to another. The ALSARM will be an automated method of taking these measurements, which will eliminate the personnel entry, reduce the chamber leak rate, and allow more consistent measurements.

The ALSARM will integrate state-of-the-art systems in control, mobility, 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 manipulator to take plant samples and eventually perform other functions such as planting and harvesting. This end-effector is being developed during phase II of the ALSARM project, which started in late November 1995.

Key design features of the ALSARM include: (1) automated control via a tether cable, (2) a 3-degree-of-freedom robot manipulator, (3) a multiple sensor array, (4) interfaces to existing NASA databases, and (5) development of an end-effector for plant sampling.

The accomplishments for 1995/early 1996 include the final design details on the 3-degree-of-freedom manipulator, development of a test mockup of the BPC in the Advanced Systems Development Laboratory (ASDL), testing of the assembled ALSARM in the mockup, and a design start on the end-effector.

Completing the ALSARM fabrication and assembly was a major effort for 1995/early 1996. Integration and testing of the ALSARM subsystems (vertical column for Z-translation, rotation fixture for rotation about the vertical column, electrical system, sensor array, and data acquisition system) should be completed by late February, and installation into the BPC should occur no later than mid-March 1996.

Key accomplishments and milestones:

- August 1993: Project initiated and concept designs evaluated.
- June 1994: Final report and design concept completed.
- October 1994: Systems Requirements Review completed.
- December 1994: Final design review held.
- September 1995: Fabrication of ALSARM components initiated.
- March 1996: Fabrication of the ALSARM complete.
- April 1996: Testing of the ALSARM complete.
- March to May 1996: Activation and validation of the ALSARM.
- June 1996: Installation of the ALSARM into the BPC.
- Mid-1996: Initiate development of the ALSARM end-effector.

Contacts: M.D. Hogue, DM-ASD, (407) 867-1720; T.A. Graham, DM-ASD, (407) 867-4156; and J.C. Sager, MD-RES, (407) 853-5142

Participating Organizations: NASA, Advanced Systems and Analysis Division; NASA, Biomedical Operations and Research Office, Biological Programs; and University of Central Florida (Dr. R. Johnson and Dr. Z. Qu)

Automated Window Inspection Device (AWID)

The goal of the AWID project is to develop an inspection tool for use during launch operations Shuttle flow processing. The AWID will reduce the likelihood of human operators failing to identify orbiter window defects by aiding them in the performance of their duties. The approach this project has taken is to develop a precision, lightweight frame that can carry optical inspection instruments across the surface of each window in a predictable and repeatable manner, while the window remains installed on the orbiter. The inspection records will be archived and fields will include the location, size, depth, and date of each identified defect. This will allow comparisons of window damage from flight to flight.

Inspection of the orbiter windows is a task that must be performed during each Shuttle flow in the high bays of the Orbiter Processing Facility. Three types of damage to the glass are identified. First, impacts with particles in space cause hypervelocity damage sites on the orbiter thermal window panes. Second, inevitable handling mishaps leave scratches or dings on the windows that must be identified. Finally, subsurface damage or bruises are believed to be the result of low-velocity impact during flight or on the ground.

Each of these types of damage must be identified and verified that they are not hazardous to the next flight of that orbiter. This inspection is currently performed manually by technicians using a magnifying glass and a high-intensity light source in an effort to find and document all the visible defects on or below the window surface. The presence of surface scratches and various other defects are also noted. Each defect found is marked on a full-scale sheet of clear acetate film as an overlay map of the window. This manual record of size and flight is developed and maintained as a history of each window.

After the defects have been identified and located, the depth of each defect is determined by measuring dimensions on a mold impression of that defect. This information is sent to the responsible design center engineer (or representative) where a stress analysis is completed to determine if the windows are safe for use on the next flight. The inspections are tedious and difficult to perform, and, on at least one occasion, a defect was not found until the vehicle was rolled out to the pad. Operating this close to a schedule margin has the possibility of impacting flight schedules.

The AWID uses an X-Y positioning frame to precisely move a scanner housing that contains optical detection and measurement instrumentation over the entire surface of the window being inspected. The scanner housing is driven by two stepper motors in the X and Y directions with dial-cord-type cable linkage, all under computer control. The components are supported in the frame by bogeys, contained within each frame rail, riding on dual-track ball-bearing rollers. Two commercial off-the-shelf desktop computers are used for control, analysis, and operator interface. Dedicated image processing circuit boards off-load much of the analysis effort from the system central processing unit.

A previous prototype version of the AWID used an optical hand scanner, mounted in a scanner housing with a line array element as the sensor for surface defects. The instruments used in the current configuration are a polarized light microscope (PLM) for locating both surface and subsurface defects and a refocus microscope (RM) to measure the depth of the selected defects. A manual positioning feature is included to allow an operator to reach the entire window surface with the PLM video camera or to jog in small steps with the RM.

During scanning operations, a pneumatic dust-removing scheme is employed to remove surface dust (which will be interpreted by the sensors as defects) from the image data. Pressurized, filtered breathing air is passed through an ionizer assembly powered by polonium 210, then forced through an air jet nozzle to push debris away from the camera field of view. The ionizer creates both positive- and negative-charged ions in order to discharge static electrical charges generated by air flow friction contact with the surface of the window glass. The air jet nozzle intensifies the flow and directs it to the target area.

The PLM will detect both surface and subsurface defects. Subsurface defects are not sensed directly. In operation, image variations occur when viewing internal strain in the glass as opposed to viewing glass that has no internal strain. These strains are caused by subsurface cracks, which are believed to be artifacts of low-velocity collisions. The optical effect is present when the area of the window is illuminated with polarized white light. This light is reflected from the rear surface of the glass to a miniature color video camera. For glass that has no strain, the image is nulled out by a crossed polarization filter positioned in front of the camera. For glass that has been strained, variations in the strain inside the glass cause polarization rotation of light that passes through the volume of glass. This rotation causes a color image of the variations to appear through the nulled-out surface overlay image in the camera field of view.

The PLM consists of a folded imaging system in order to fit the dimensions available in the scanner housing. Illumination is performed by a 5-volt incandescent lamp, which generates a white light beam that passes through a polarizing filter and focuses beneath the surface of the window. Approximately 4 percent of the incident light reflects off the front surface of the glass, and the balance passes into the window. At the rear surface, 4 percent is again reflected back toward the source, and the balance passes out of the glass through the rear surface. The two 4-percent return beams contain all the image data that is analyzed for the identification and location of window defects.

In both surface and subsurface modes, an image of the defect region is separated from the reflected light path by a beam-splitting mirror, which directs the image to a miniature color video camera. Light reaching the camera passes through two filters. The first filter is a liquid crystal beam retarder that causes the polarization to be rotated roughly 90 degrees, so light reflected from the surface is allowed through the camera polarizing filter and on to the camera for imaging surface defects. The second is a standard polarizing filter, which, for the subsurface mode, is at crossed polarization from the illumination in order to cancel light from areas of the glass surface reflections that contain no stress fields.

Contacts: J.D. Collins and F.W. Adams, DL-ICD-A, (407) 867-4438; H.N. Delgado, RM-INT, (407) 867-3163; and C.G. Stevenson, TV-MSD-1, (407) 861-3603

Participating Organizations: I-NET, Inc. (Dr. S.M. Gleman, S.W. Thayer, C.G. Hallberg, C.M. Lampkin, and J.E. Thompson); Lockheed Martin Space Operations (G. Jensen); and Rockwell International Corporation (S.E. Holmes)

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 utilize 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 utilizes 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.

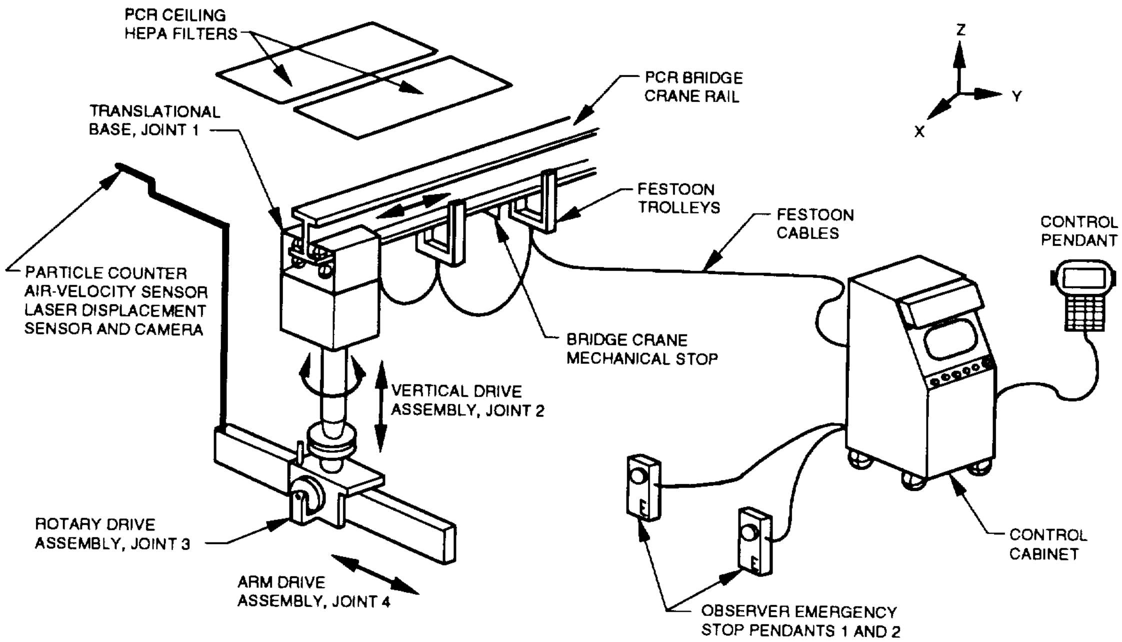
The HFIS is an operational system in use at both of the Launch Complex 39 (LC-39) launch pads. The system was turned over to operations (i.e., Lockheed Martin Space Operations) in the beginning of calendar year 1995 and is being used to perform inspections.

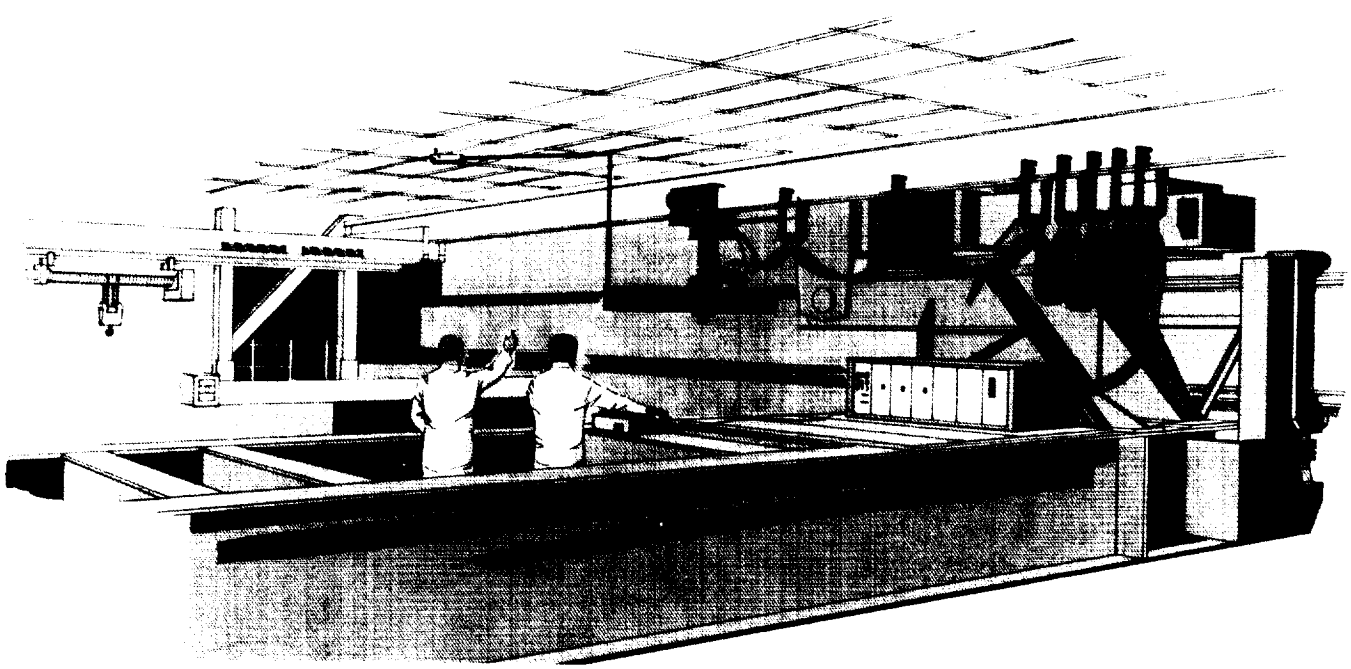
Key milestones and accomplishments:

- 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 Vehicle Engineering (TV) and Lockheed Martin Space Operations.

Contacts: T.C. Lippitt, DM-ASD, (407) 867-3266; T.A. Graham, DM-ASD, (407) 867-4156; and M.R. Murazzi, TV-MSD-6, (407) 861-3629

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



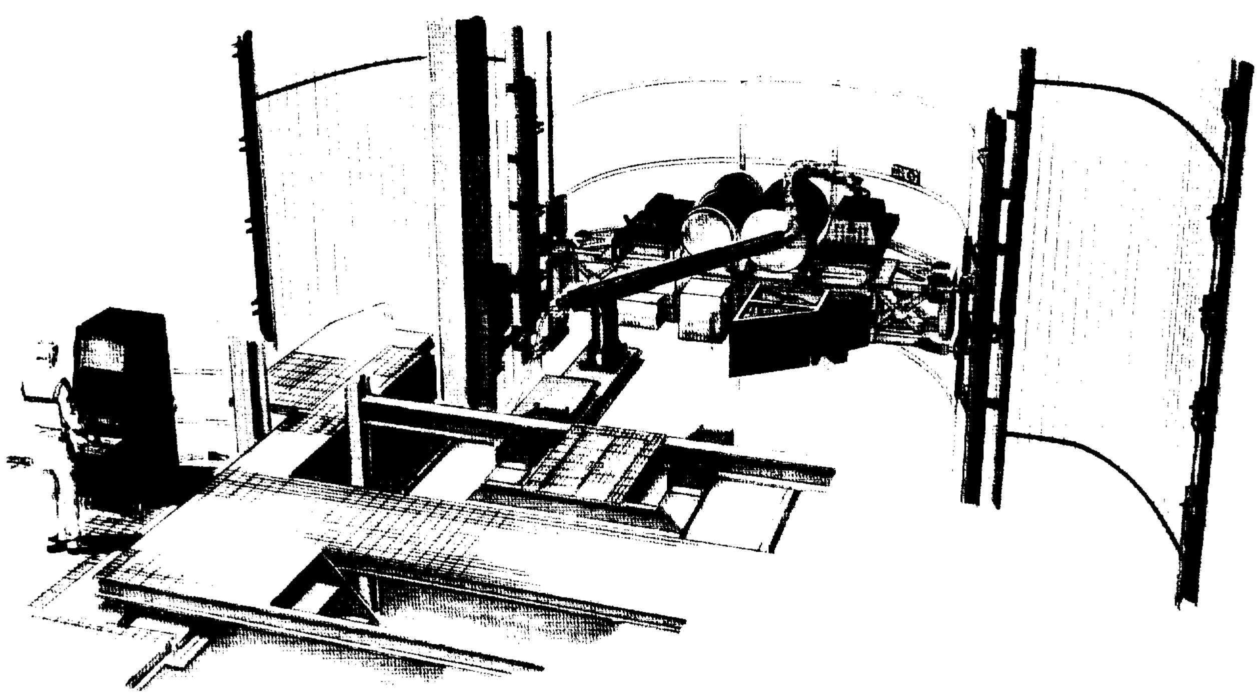


HEPA Filter Inspection System (HFIS)

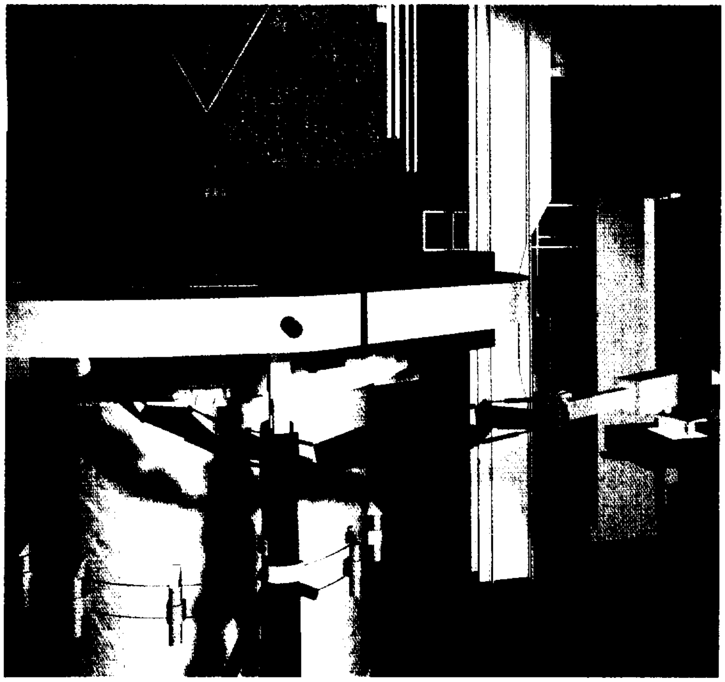
Payload Inspection and Processing System (PIPS)

A project is being initiated to design and develop a robotic system for Space Shuttle payload bay and payload processing operations in the Launch Complex 39 launch pad 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 times 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-



Payload Inspection and Processing System



Payload Inspection and Processing Robot

freedom (3-DOF) base (three 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:

- 1995: Developed a PIPS conceptual design. Completed development of a prototype user interface. Initiated development of software control algorithms for coordinated movement and path planning.
- 1996: 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 T.A. Graham, DM-ASD, (407) 867-4156

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

Automated Tile Processing System (ATPS) Development

The objective of this project is to design and develop a prototype mobile robotic system to process the lower surface orbiter tiles. The project is approximately 90 percent complete. The system will perform partial preflight and postflight visual inspection and rewaterproofing of 85 percent of the lower surface tiles. This development effort will conclude with a demonstration of the prototype mobile robotic system in the third quarter of 1996. Certification will be initiated upon completion of a successful demonstration of the system to operations personnel.

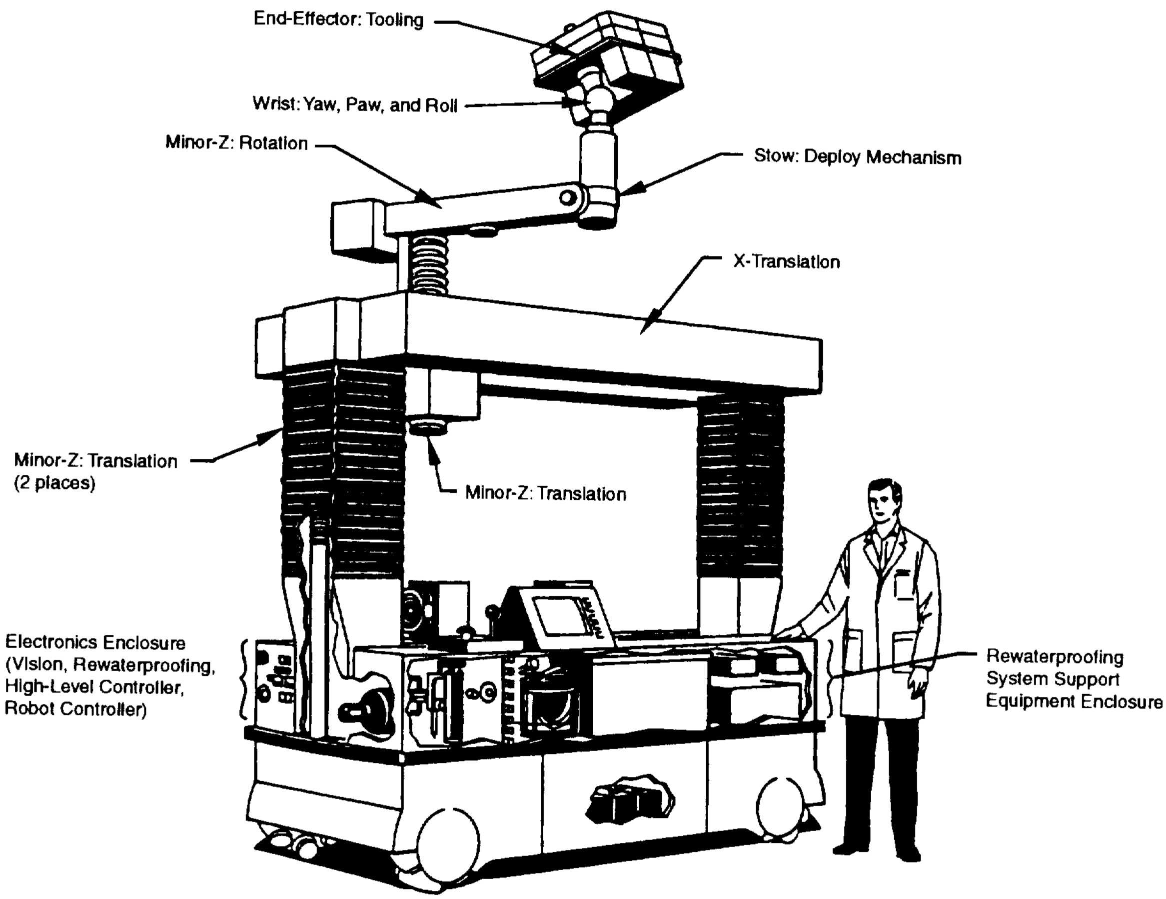
Maintenance and repair of the orbiter Thermal Protection System (TPS) tiles involve many labor-intensive tasks. As a result of a detailed orbiter TPS automation study, orbiter lower surface tile rewaterproofing and visual inspection were selected for initial implementation. Both of these tasks are performed on more than 20,000 tiles for each orbiter refurbishment flow. Automation of these processes will save TPS flowtime and man-hours. Cost savings are estimated to have a return on implementation costs in less than 2 years. Enhancements to initial inspection capabilities will result in additional man-hour savings. These savings will be realized through paperwork reduction (i.e., documentation processing) for each of the tasks automated because the robot information system will be integrated with existing data management and information processing systems. Quality and reliability will be improved by providing accurate inspections and rewaterproofing. Increased personnel safety will result because human exposure to the rewaterproofing chemical will be significantly reduced for the lower surface tile rewaterproofing process. Long term, the ATPS has been designed to support automation of other labor-intensive TPS processes that could result in more than 2,500 man-hour savings per orbiter flow.

The robotic system will integrate state-of-the-art systems in navigation, control, mobility, manipulation, information management, and sensor technologies to inspect and rewaterproof the lower surface orbiter tiles in the Orbiter Processing Facility at KSC.

Key design features of the system include: (1) a self-contained operation (i.e., no tether required), (2) redundant sensors used in critical applications to ensure safe operation, (3) a 7-degree-of-freedom manipulator with a 3-degree-of-freedom mobile base, (4) an intuitive graphical user interface, (5) an off-board information system for preparing and viewing orbiter TPS inspection and rewaterproofing processes, and (6) interfaces to existing NASA orbiter processing databases.

Significant progress was made during fiscal year 1995 toward completion of the development of the mobile robot; this included the electrical, electronic, mechanical, and software areas. In the electrical and electronic areas, accomplishments included: (1) redesign of the entire electrical system to conform to KSC and industrial practices; (2) design, fabrication, and testing of four multiple-layer printed circuit boards for the safety system; (3) design, fabrication, and testing of four additional printed circuit boards; (4) initiation of the rewiring of the entire mobile robot; and (5) repackaging of all electronic components in manipulator and electronic enclosures. The following accomplishments were made in the software area: (1) redesign, implementation, and testing of the motion control for the mobile base; (2) redesign and partial implementation of the motion control for the manipulator; (3) definition, prototyping, design finalization, and nearly completed implementation of the robot user interface; (4) design and nearly completed implementation of the high-level controller; and (5) initiation of testing and modification to the vision system code to correct deficiencies and to improve its readability and maintainability. Several accomplishments were made in the mechanical area including: (1) redesign of the minor-Z rotate actuation, (2) redesign of the entire wrist drive system, (3) redesign of all (i.e., three) electronic enclosures, and (4) other miscellaneous modifications. Finally, a functional demonstration was given to operations personnel in the KSC Advanced Systems Development Laboratory.

The effort for fiscal year 1996 will focus on completing the development, integration, and testing of all subsystems into a functional robotic system. A demonstration of the fully functional system is expected in the April-to-June timeframe of 1996. The certification process can be initiated after the system demonstration. It is expected the system certification will require approximately 9 to 12 months to complete.



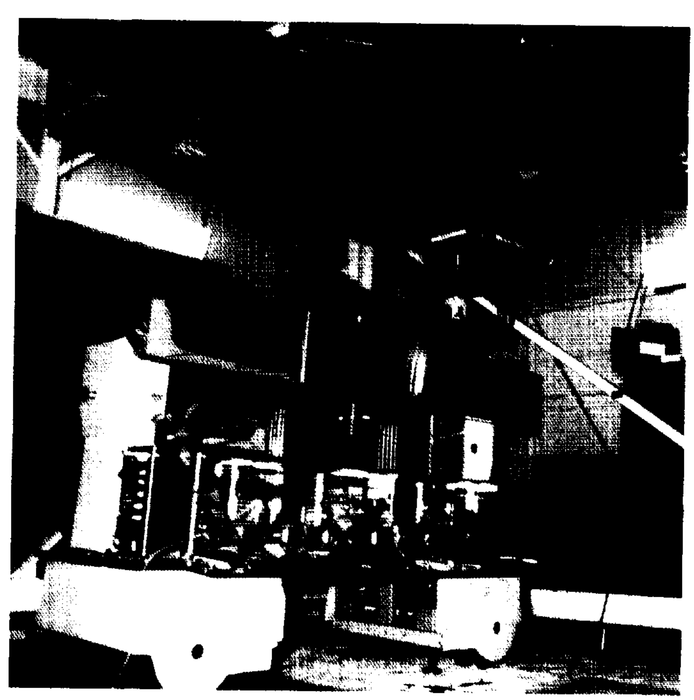
KSC Tile Robot Configuration

Key accomplishments and milestones:

- 1991: Project and subsystem designs initiated.
- 1992: Technology demonstrations of mobile base, vision, and rewaterproofing subsystems.
- 1993: System and subsystem prototype designs complete and subsystem integrations initiated.
- 1994: Proof-of-concept mobile robot delivered to KSC from Carnegie Mellon University.
- 1995: Made design changes necessary to convert the proof-of-concept mobile robot to a functioning prototype. Functional demonstration given to KSC operations personnel.

Contacts: T.A. Graham, DM-ASD, (407) 867-4156, and T.J. Ross, DM-ASD, (407) 867-1720

Participating Organizations: NASA, Advanced Systems and Analysis Division; NASA, Orbiter Thermal Protection Systems Branch; I-NET, Inc.; Rockwell Space Systems Division; and Lockheed Martin Space Operations



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. KATE utilizes model-based reasoning, and a prototype has been developed for liquid oxygen loading of the Shuttle's main propulsion system. KATE 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.

Automated Database Design

The goal of this project is to design and implement a system that will build a database design from natural language descriptions of a problem, entered by users with no knowledge of databases or programming.

The system has two major components: (1) a natural language understanding (NLU) component that parses and understands the sentences typed by the user and (2) a problem-solver (PS) component that identifies the entities, attributes, and relations from the output of the NLU. A brief description of these components can be found in the KSC Research and Technology 1994 Annual Report, and a detailed description can be found in the paper "Automated Database Design From Natural Input," published in the 1995 Goddard Conference, pages 29 to 44.

A prototype has been in operation since December 1994. A major effort in 1995 was made to enhance the system by bringing the user into the loop. This is being accomplished by: (1) asking the user for clarification in those cases in which the system fails to parse or interpret difficult sentences and (2) asking the user to help the problem-solver in those cases in which it cannot determine if it must create a new relation, entity, or attribute from the user's sentence.

Another effort was the design and implementation of a knowledge acquisition interface by means of which end-users can provide the system with some minimum background knowledge needed by the system to construct a database model for the user's application. This is needed because the method used is based on semantic interpretation, and the system needs to know at least the ontological categories for each word.

In this regard, an intensive study of the WordNet was made (see the WordNet home page, *http://www.cogsci.princeton.edu/~wn*), which is an on-line, public domain tool. WordNet organized lexical knowledge in terms of word senses, which are captured in a reduced set of ontological primitives organized into an inheritance hierarchy, similar to the ones developed by this system. There are striking similarities between some of the ontological categories in WordNet and the ones that have been used in this system for approximately 8 years; however, there are also important differences stemming from the different criteria used in designing the ontology. There are also some problems with using WordNet for understanding in its present form (for example, the underspecification of some of its concepts, no ontological categories for adjectives and adverbs, and others). But, in general, WordNet is impressive, and WordNet ontological categories are being mapped into the system. A version of WordNet implemented in Common LISP is already working within the system. It is intended that a somewhat modified WordNet lexical knowledge base will become the lexicon of the system.

The progress made includes continuous enhancements to the NLU system and the design and implementation of the PS. A prototype has been finished that is able to construct entity-relationship diagrams for different kinds of problems. The system has also been tested in the acquisition of knowledge from encyclopedic texts ("Acquiring Knowledge From Encyclopedic Texts"; F. Gomez, R. Hull, and C. Segami; 1994 ACL Conference on Applications of Natural Language Processing; Stuttgart, Germany; pages 84 to 90). Also, four journal papers describing aspects of the system were published or are in the process of being published. The system, written in Common LISP, runs on SPARC workstations.

Key accomplishments:

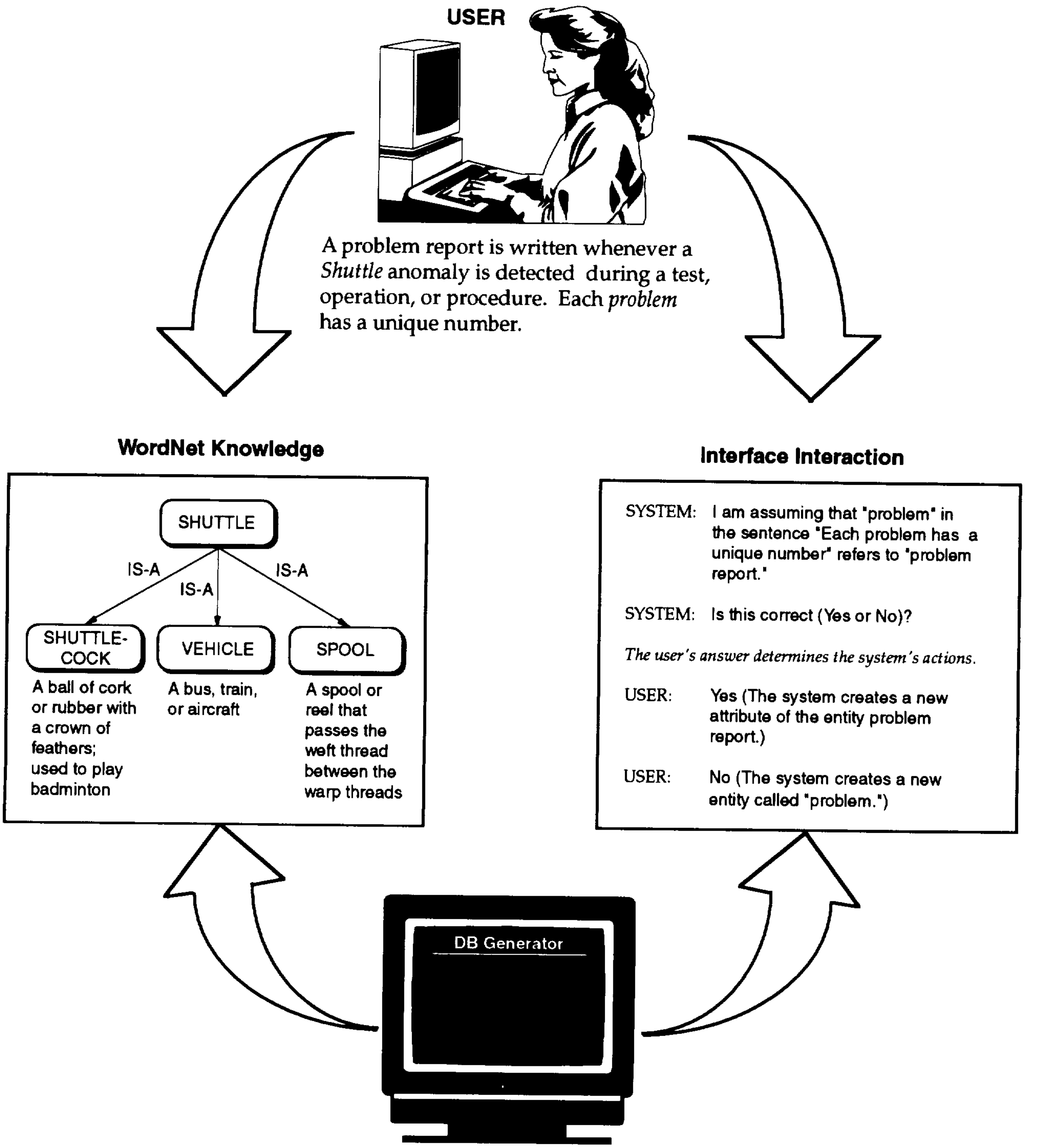
- 1993: Began the project, conducted a literature survey, and completed the initial design of the system.
- 1994: Prototype completed and running.
- 1995: Enhanced the interface to the system.

Key milestones:

- 1996: Complete the interface and the integration of WordNet into the system.

Contact: Dr. C. I. Delaune, CG-ISO-1, (407) 867-8656

Participating Organization: University of Central Florida (Dr. F. Gomez)



Interface Components

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. 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 is to 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 standalone platform. That version was used during several Shuttle countdowns for reference, familiarization, and assistance in establishing requirements.

Plans include 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. Features such as diagnostics and user-friendly input schemes, embedded or linked schematics, drawings and user documentation, and report generation capabilities will be included among the improvements to be implemented over the next year. Trade studies will be performed to determine the usefulness of further improvements in accuracy (e.g., effects of variations in parameters, such as temperature). The desirability of additional enhancements, such as natural language query capability and expert-system-based operator advisors, will be examined.

Key accomplishments:

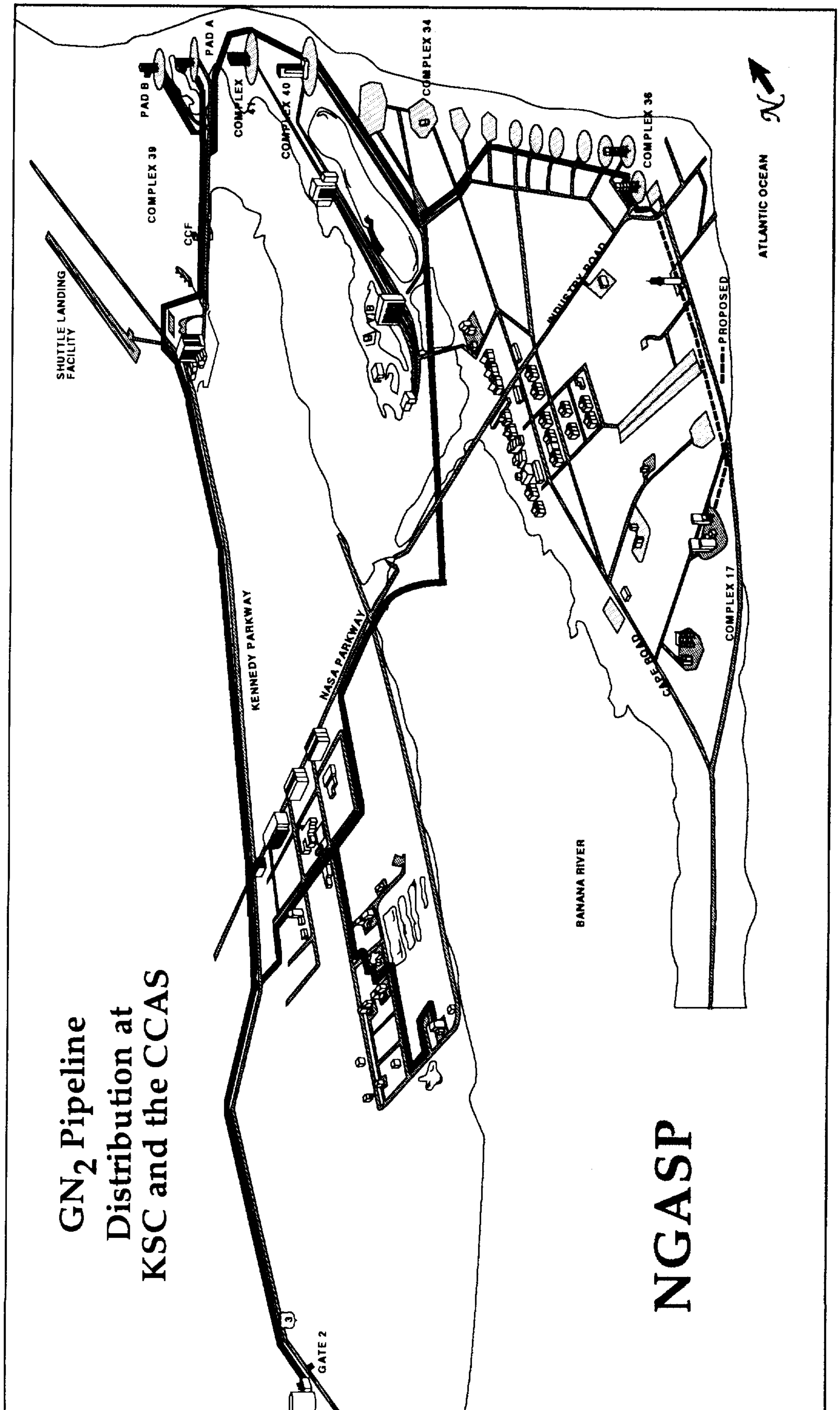
- 1995: Initial prototype version developed and delivered for familiarization and establishment of requirements. Definition of hardware and software requirements initiated.

Key milestones:

- 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.

Contacts: P.A. Engrand, DM-ASD, (407) 867-3770, and T.A. Graham, DM-ASD, (407) 867-4156

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



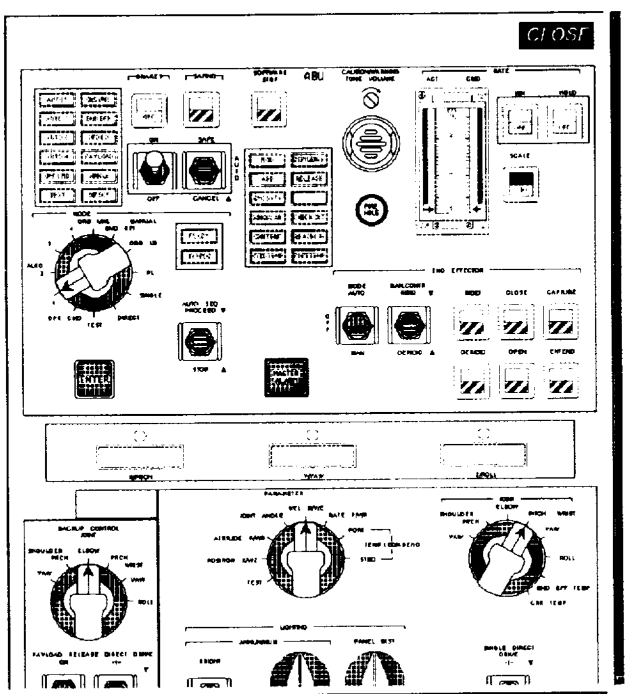
GN2 Pipeline Distribution at KSC and the CCAS
NGASP
SHUTTLE LANDING FACILITY
COMPLEX 39
PAD B
PAD A
CCF
COMPLEX 41
COMPLEX 40
COMPLEX 34
COMPLEX 36
VIB
INDUSTRY ROAD
KENNEDY PARKWAY
NASA PARKWAY
CAPE ROAD
PROPOSED
COMPLEX 17
BANANA RIVER
ATLANTIC OCEAN
GATE 2
3
N

Expert Learning for Vehicle Instruction by Simulation (ELVIS)

Shuttle hardware engineers are responsible for supporting a number of vehicle subsystem tests. The normal division of labor requires an engineer to take primary responsibility for certain operations and maintenance procedural documents. Successful testing and processing of the orbiter depends on the hardware engineer's ability to determine nominal or anomalous performance of Shuttle subsystems. This requires the engineer to be familiar with the system and associated operations procedures. Unfamiliarity with an operations procedure can compromise Shuttle safety and reliability.

One solution to this problem is to provide a training tool available in the office that can adequately simulate the test environment and allow an engineer to gain familiarization with an operations procedure. This familiarization can lead to a savings in testing time and processing time of unnecessary problem reports.

The ELVIS training system has been developed to provide a high-fidelity interactive training tool modeling the orbiter systems and ground support equipment and to provide operations procedural training for Shuttle system engineers. The system provides the user with interfaces as close as possible to those normally encountered in processing operations. Additionally, the system is accomplished by a monitoring system indicating procedural errors.



ELVIS Orbiter Panel Interface

The objectives for development of the prototype training system were to provide:

1. Adequate modeling of the system that the procedure was designed to test.

2. Sufficient modeling of the Launch Processing System (LPS) environment where the operations procedure is executed.

3. Ability to execute multiple Ground Operations Aerospace Language (GOAL) monitoring and control application programs utilized in the performance of an operations procedure.

4. Incorporation of a procedural monitoring system used to ensure procedural integrity and provide operator feedback.

5. Orbiter panel and switch monitoring and control.

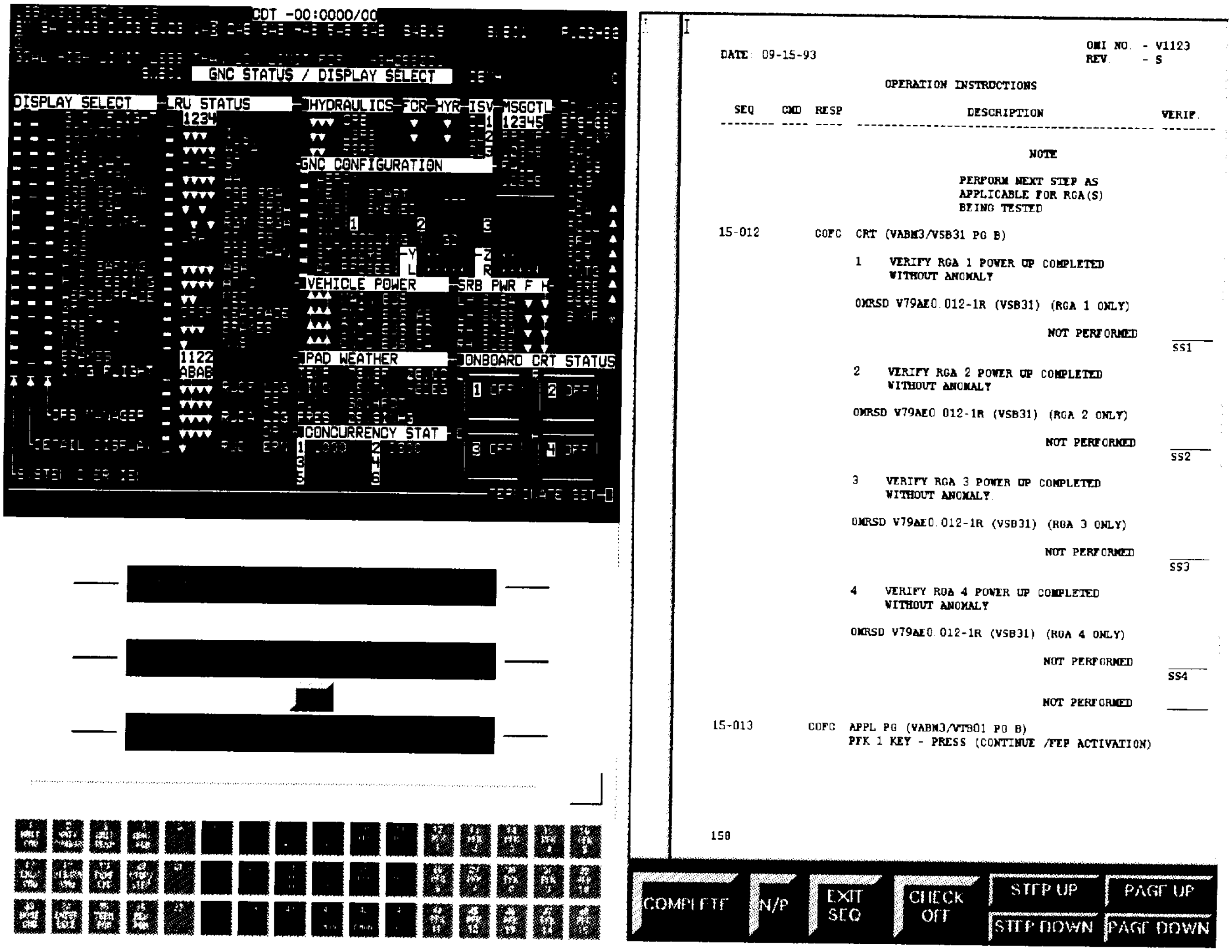
6. Ability to utilize the system in an office environment.

The ELVIS software development has been in the form of a phased iterative approach to product development. During phase 1 of the life cycle, the ELVIS software was engineered as a prototype in order to establish a proof of concept, demonstrate the feasibility of the ELVIS software product, and determine user acceptance. The prototype was demonstrated to users to allow the user interface to be examined for accuracy, clarity, and simplicity. Phase 2 involved the review, utilization, and refinement of the initial prototype system into a production training system. Phase 3 of the ELVIS life cycle includes implementation of the training system across multiple orbiter subsystems and sustaining engineering of the ELVIS software product.

Key accomplishments:

<u>Phase 1</u>

- September 1993: Interactive procedure trainer for vehicle engineering concept.



ELVIS User Interface

- August 1994: ELVIS prototype complete.
- September 1994: Presentation of ELVIS prototype training system to Vehicle Engineering and Shuttle Management and Operations. Approval to bring ELVIS prototype to a production training system.

<u>Phase 2</u>

- April 1995: ELVIS software beta release (0.1).
- June 1995: Spinoff utilization of ELVIS for GOAL application software debug.

<u>Phase 3</u>

- August 1995: ELVIS software release (1.0).

Key milestones:

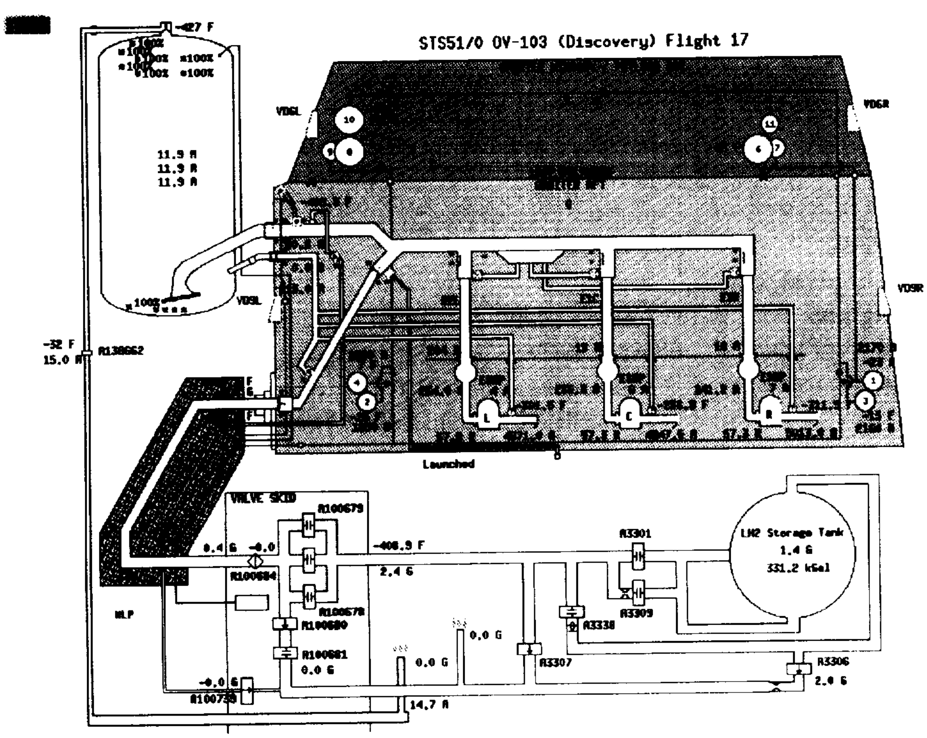
- March 1996: ELVIS software release (2.0).
- April 1996: Complete integration of ELVIS with the EXpert Systems for Operations Distributed USers (EXODUS) UNIX Checkout and Monitoring System (UCMS) for utilization of playback and live operations test data.
- September 1996: ELVIS software release (3.0).

Contacts: G.S. Estes, T.E. Beever, B.P. Bryant, M.D. Dalton, J. Fluhr, G.M. Stahl, and S.B. Wilson, TV-GDS, (407) 861-3783

Propulsion Advisory Tool (PAT)

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; Lockheed Martin Space Operations; Sanders, 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 delivery of the liquid oxygen anti-geyser expert system software and the system software for the Space Shuttle main engines.

Key accomplishments:

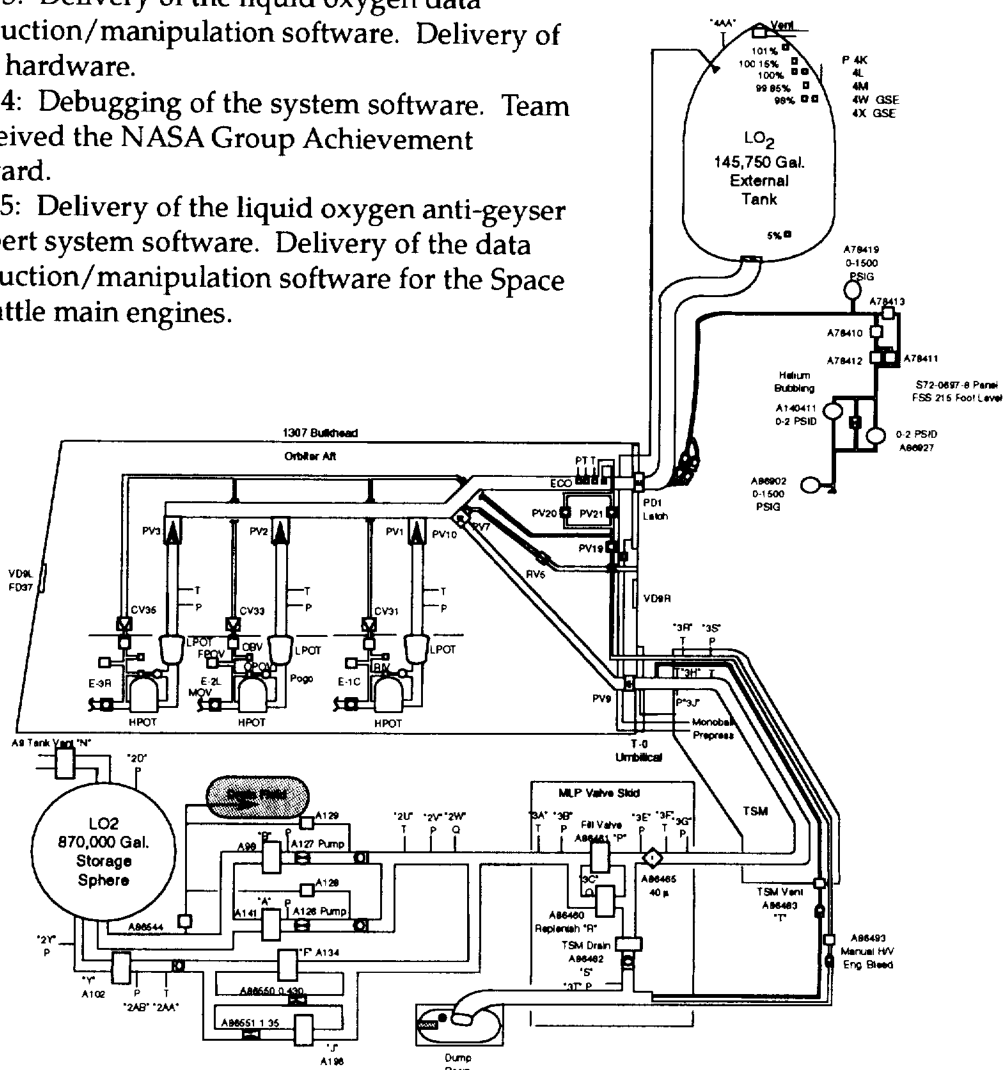
- 1992: Initial demonstration of the software technology. Implementation of the initial liquid hydrogen data reduction/manipulation prototype. Delivery of the hardware.
- 1993: Delivery of the liquid oxygen data reduction/manipulation software. Delivery of the hardware.
- 1994: Debugging of the system 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.

Key milestones:

- 1996: Certification of the system. Propulsion Advisory Tool placed in the firing room.

Contact: R.J. Beil, TV-FSD-3, (407) 861-3944

Participating Organizations: Lockheed Martin Space Operations (L.T. Bird); Sanders, a Lockheed Martin Company (R. Costantino); and Rockwell International Space Systems (L.H. Fineberg)



Liquid Oxygen Screen

OMS Integrated Vehicle Health Management (IVHM) Testbed

Certification of the Shuttle Orbital Maneuvering Subsystem (OMS) helium system for flight is an intrusive, labor-intensive test procedure. KSC history has typically shown that at least 50 percent of the time spent performing an actual test is spent setting up and tearing down the test equipment, as well as resolving anomalies encountered during testing. Most anomalies encountered during testing are determined to be problems with the test equipment, not with the flight hardware. The intrusiveness of the test setup itself invokes other test requirements and sometimes creates anomalies that would not have occurred if the test setup had not been performed (that is, a leak in a flight air-half coupling) resulting from poppet actuation during testing.

The use of single-stage-to-orbit (SSTO) technologies to reduce the operational costs for the X-33/RLV programs provides the opportunity to reduce the recurring production and refurbishment costs associated with the external tank and solid rocket boosters currently used by the Shuttle. However, the adoption of the SSTO philosophy will drastically increase fluid-system complexity, which already represents one of the largest operational cost drivers on the Shuttle orbiter. While several system-level technologies, such as common commodities and electromechanical actuators, have been recommended to help reduce these operational costs, the helium pressurization systems (and the costs associated with their maintenance and certification for flight, as well as the invasiveness of the testing itself) will remain largely unchanged from that of the Shuttle orbiter.

This project will attempt to reduce the recurring operational costs associated with the checkout and certification of flight helium systems, using the OMS helium system as a model of a generic helium pressurization system. IVHM technologies and techniques will be applied to a mockup of the OMS helium system with the objective of proving that the every-flight test requirements, levied by the operations and maintenance requirements and specifications document (OMRSD), can be verified using onboard test equipment. This project is funded through the Marshall Space Flight Center (MSFC) Long-Term, High Pay-Off Program in Code X. This is a joint-effort project where Rockwell International is providing the basic OMS testbed components; NASA KSC is providing facilities, commodities, and design engineering support; and NASA KSC Shuttle Engineering is providing expertise in the OMS system and IVHM testing.

The approach to this project is to use a combination of software, instrumentation, and component changes to perform a checkout of the OMS helium system without the use of external ground support equipment. The premise is that helium system component data can be gathered during the postflight helium system blowdown from approximately

2,000 to 300 pounds per square inch. The components to be tested are series/parallel redundant regulators, series/parallel redundant check valves, and the burst disk/relief valve assembly. The IVHM system must be able to capture functional performance and leakage data from the regulators and check valves and leakage for the burst disk. Two nonintrusive technologies currently under investigation for this application are acoustic emissions for flow verification and ultrasonics for leakage quantification. An onboard bias and vent control unit, composed of a motor-driven, back-pressure regulator (which will soon be replaced by an electronic back-pressure regulator) and two three-port solenoid valves (which will soon be replaced by a four-way, motor-driven, L-turn ball valve) will be used to bias open the primary-stage regulators and to induce a reverse pressure differential across the check valves. Several high-fidelity pressure transducers will be used to obtain performance and leakage data.

A SUN workstation (SUN IPX with two 68040 processors in a VME chassis) performs all control and data acquisition for the testbed. However, due to the high-frequency output from the acoustic emission sensors, the data acquisition and control system is currently being upgraded to a SUN 20 with MIPS Laguna boards, coupled with local digital signal processing. This will allow sample rates in excess of 100,000 samples per second. This high-rate data acquisition system, coupled with the acoustic emissions and ultrasonic sensors, will be able to identify, quantify, and isolate internal and external helium system leakage.

After all OMS OMRSD helium system requirements can be successfully satisfied in the testbed using this ground-based data acquisition and control system, the successful IVHM technologies and data acquisition system will migrate to a flight package for an inflight demonstration.

Key accomplishments:

- Activated the OMS IVHM test site.
- Demonstrated a technique for series/parallel redundant regulator functional and series/parallel redundant check valves using an IVHM system.
- Demonstrated flow verification through individual check valve poppets using acoustic emission sensors.

Key milestones:

- 1996: Successfully develop nonintrusive approach for leak detection, quantification, and isolation. Perform automated demonstration of end-to-end checkout of OMS helium pressurization system. Migrate to onboard data acquisition and evaluation.
- 1997: Fleet lead test of nonintrusive technologies at White Sands Test Facility. In-flight demonstration of nonintrustive technologies. Development of reliability data and calibration techniques. Begin the cryogenic component development.

Contact: R.M. Davis, DE-TPO, (407) 867-2780

Participating Organizations: NASA (C.W. Pierce and W.T. Powers) and Rockwell International (J.M. Engle)

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.

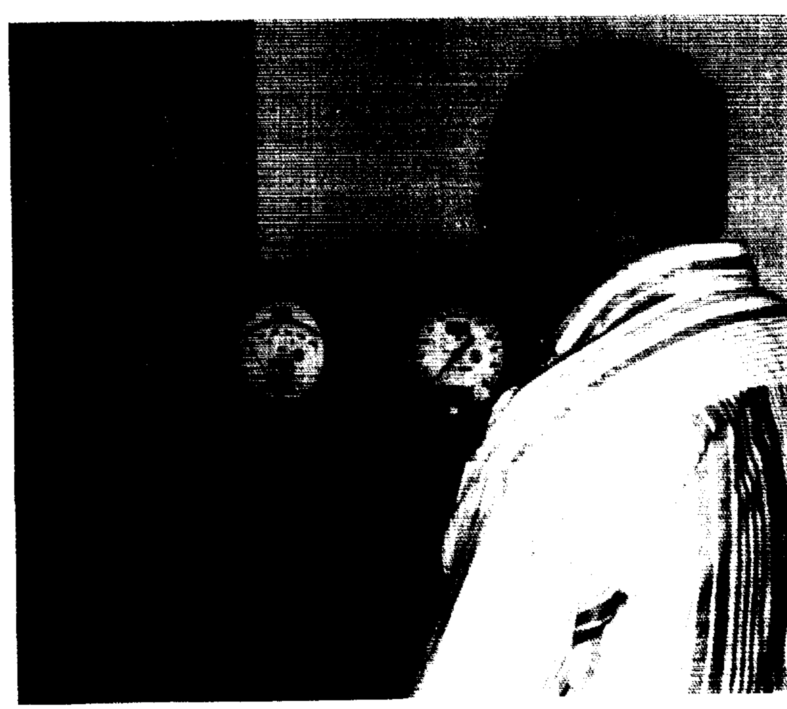
Reducing the paperwork associated with prelaunch activities has been the goal of other projects, but using the WWW as the foundation of a paperless system gives this system unique benefits. For example, there are no implementation costs for users who already "have access to the Internet " In addition, 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 data is scheduled and announced.
5. The test data 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 (via 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.



Test Engineer Uses Pen-Based System To Record Test Results 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.

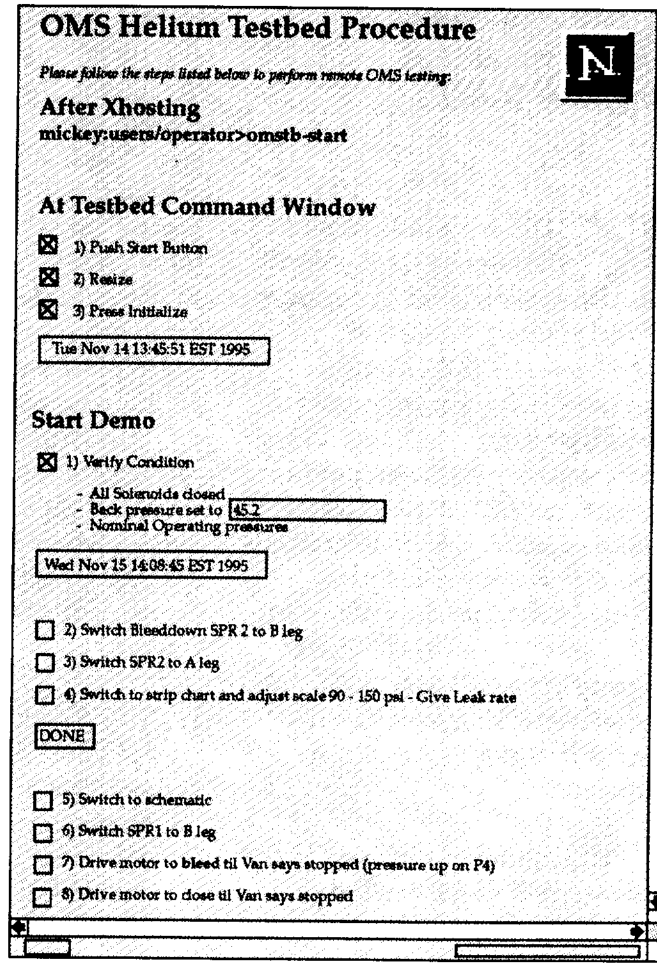
5. The test date is unlikely to need adjustment since most offsite individuals will remotely "view" the test as it occurs (via their Web browser).

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.



Key milestones:

- 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.

Contacts: P.A. Engrand, DM-ASD, (407) 867-3770, and T.A. Graham, DM-ASD, (407) 867-4156

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

Knowledge-Based Autonomous Test Engineer (KATE)

KATE is a model-based monitoring and control system used to support Shuttle launch operations. KATE uses a mathematical model of a system to predict the values of measurements. When a discrepancy between predicted values and actual measurement values occurs, KATE determines and reports possible failed components that would explain the discrepancy. KATE 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 KATE 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.

KATE, originally developed in LISP, was successfully converted into C++ and Open Software Foundation (OSF) Motif. The new version (called KATE-C) was necessary to make KATE compatible with the operational platforms being used at KSC. 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 KATE-C with custom user displays, specialized diagnostic algorithms, and new data sources. For example, the user interface was decoupled from the rest of the KATE-C shell to simplify KATE-C'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 improvements provided by KATE-C were:

1. The diagnostic engine of KATE-C 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. KATE-C's monitoring and simulation tasks were implemented as completely separate steps in the KATE-C reasoning process, and their interaction among themselves and other reasoning tasks can now be managed directly from the user interface.

4. KATE-C'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 KATE-C, KATE's KB editor was also reimplemented 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 KATE was a proof-of-concept demonstration of KATE-C 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 KATE 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:

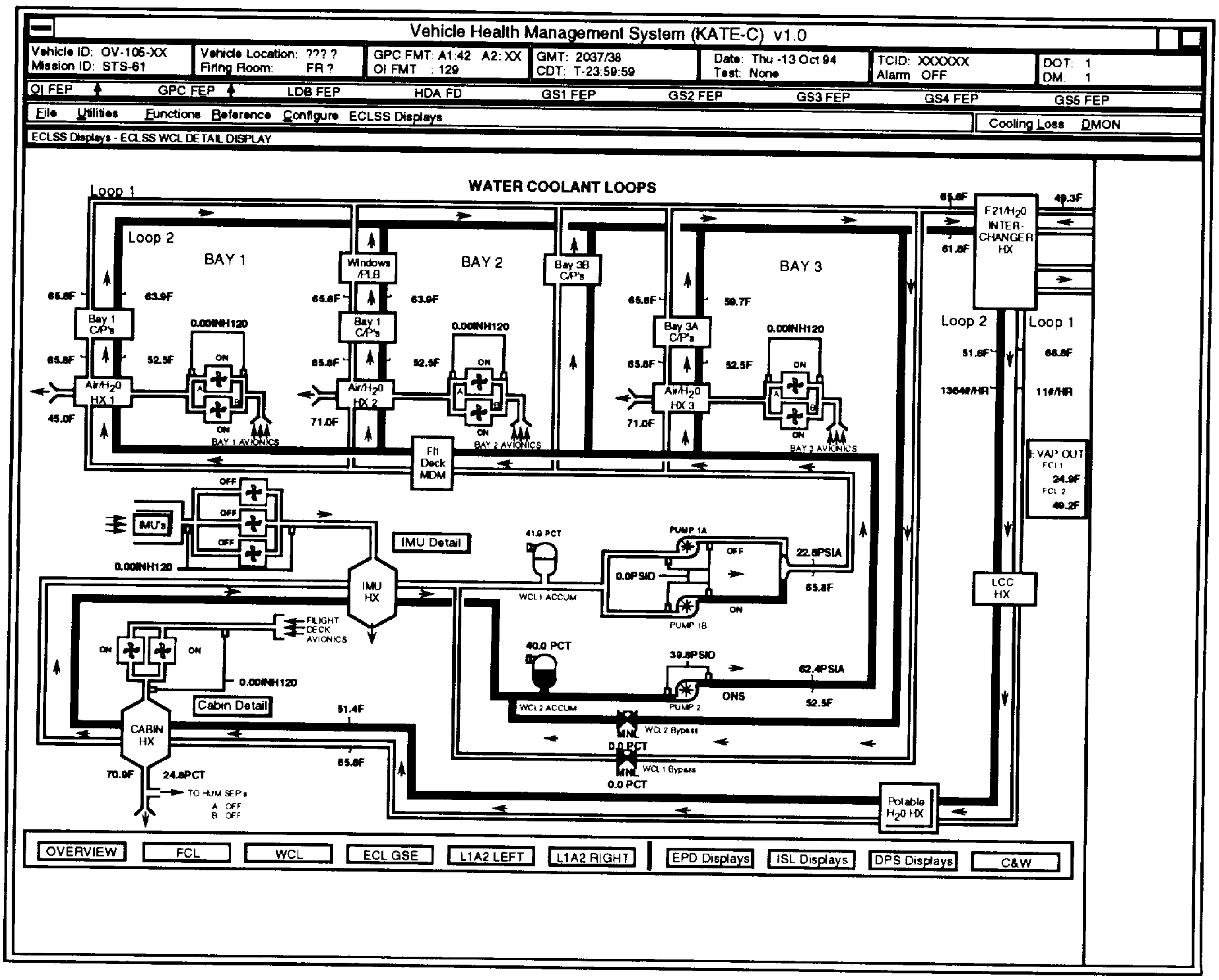
- Reimplementation of KATE core functionality in C++.
- Successful proof-of-concept demonstration of KATE-C for the ATCS subsystem of the VHMS.
- Development of a prototype model for LOX loading for the Shuttle's MPS.

Key milestones:

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

Contacts: P.A. Engrand and T.A. Graham, DM-ASD, (407) 867-3770

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



KATE Application - Orbiter Environmental Control and Life Support System

Mass Measurement Assurance Program

Standards laboratories generally obtain traceability to national standards by sending an artifact to the National Institute of Standards and Technology (NIST) for comparison. Measurement Assurance Programs (MAP's) are used by groups of cooperating laboratories to reduce the NIST expense associated with sending their own artifact to NIST. A MAP involves a pivot laboratory that sends a transfer artifact, specifically procured for the purpose, to NIST. Then all participating laboratories measure the artifact prior to returning it to NIST. The pivot laboratory is responsible for procedures, data reduction, analysis, and reporting. The resulting data not only verifies each laboratory's artifact with respect to national standards, it provides information regarding the measurement process, the reliability and stability of the transfer artifact, and the laboratory's measurement competence compared to other laboratories. The only problem is getting volunteers to accept the cost and responsibility of being a pivot laboratory.

There are several MAP's in work between NASA centers. The most recent one is a Mass MAP that utilizes a standardized procedure and a data reduction program. The idea is to reduce the time and expense of being a pivot laboratory while validating the mass measurement process at participating NASA field installations. The data reduction, analysis, and reporting software are included in a single package that can be utilized by any pivot laboratory interested in establishing a Mass MAP. When the artifacts are returned from NIST, they will be sent to each participating laboratory.

Key milestones:

- A list of participating laboratories was established.
- Mass artifacts were purchased.
- Mass artifacts were sent to NIST for certification.
- A procedure and the software were completed.

Contact: R.R. Kotowski, LO-SOD-3C, (407) 867-4737

Advanced Shuttle Scheduling Technologies — Ground Processing Scheduling System (GPSS)

The GPSS is an artificial-intelligence-based scheduling tool being developed to support the complexity and dynamics associated with the scheduling of Space Shuttle ground processing at KSC. The GPSS is currently in use in its development state as the primary scheduling tool for the Orbiter Processing Facility (OPF). Scheduling in the OPF demands the integration of the processing requirements for 24 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. The development associated with integrating the GPSS with the Shuttle Operation's Integrated Work Control System (IWCS) is continuing, and plans are in place to extend the use of the GPSS to scheduling activities at the Vehicle Assembly Building (VAB) and the launch pads.

In order to meet the Shuttle processing scheduling challenge, the GPSS development team has successfully utilized NASA intercenter expertise and a rapid development approach with dedicated user support. The initial scheduling algorithms were developed by NASA Ames and introduced to KSC, where they were expanded and integrated with an advanced user interface. The work at KSC has been performed jointly by NASA and Lockheed Martin Space Operations. The GPSS constraint-based algorithms have been developed to: (1) model the temporal, configuration, and resource constraints of each processing activity to be scheduled; (2) perform schedule conflict resolution; and (3) respond with schedules containing minimal constraint violations. The user interface has been developed with advanced interactive capabilities that allow users to effectively and efficiently 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 on a 2-year exclusive basis to an independent software company that is developing and marketing the first commercial version of the software. The licensing rights are now nonexclusive, and KSC looks forward to future licensing arrangements with other commercial parties interested in developing and marketing commercial applications. At KSC, the development software is being reengineered into a sustainable software product that will be operationally deployed and integrated within the IWCS.

Key accomplishments:

- 1989: Initial introduction of the GPSS project to KSC.
- 1990: Prototype system ready to support testing in the OPF.
- 1991: Initial OPF knowledge base established via field testing.
- 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.

Key milestones:

- 1995: Complete integration of the GPSS development software within the IWCS.
- 1996: Complete reengineering 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 pads.

Contact: N.M. Passonno, TM-TPO-22, (407) 861-6677

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

Web Interactive Training (WIT)

New technologies have made training at the desktop cost effective. Desktop training could augment or replace existing training methods. Interactive, learner control enhances training and facilitates just-in-time learning and reference. WIT uses time and resources more efficiently than many current training methods in use.

WIT uses multiplatform interactive media to more effectively and efficiently deliver training to NASA. The primary delivery technology is the TCP/IP-based World Wide Web. A feasibility prototype has been completed to verify and validate the design technologies incorporated and developed into the project. The next phase of this project is the conversion of two existing classroom-based courses on nondestructive evaluation (NDE). Two levels of training will be delivered. One is an informational level called Awareness+ to teach a broad audience and to serve as a just-in-time reference. The second level is a performance support system called Basic Knowledge and Practice. This level will meet many of the same functional requirements as the classroom instruction segment of the existing training. 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 and hardware and software setup and design. This effort also includes digital photography, scanning, media conversion, audio and video recording, compression, animation, formatting, scripting, programming, CD-ROM creation, and beta testing. The process includes research and implementation of late-breaking technologies like digital audio streaming for narration, common gateway interfaces (CGI's) for forms and testing feedback, Java, and other advanced client/server features.

Key accomplishments:

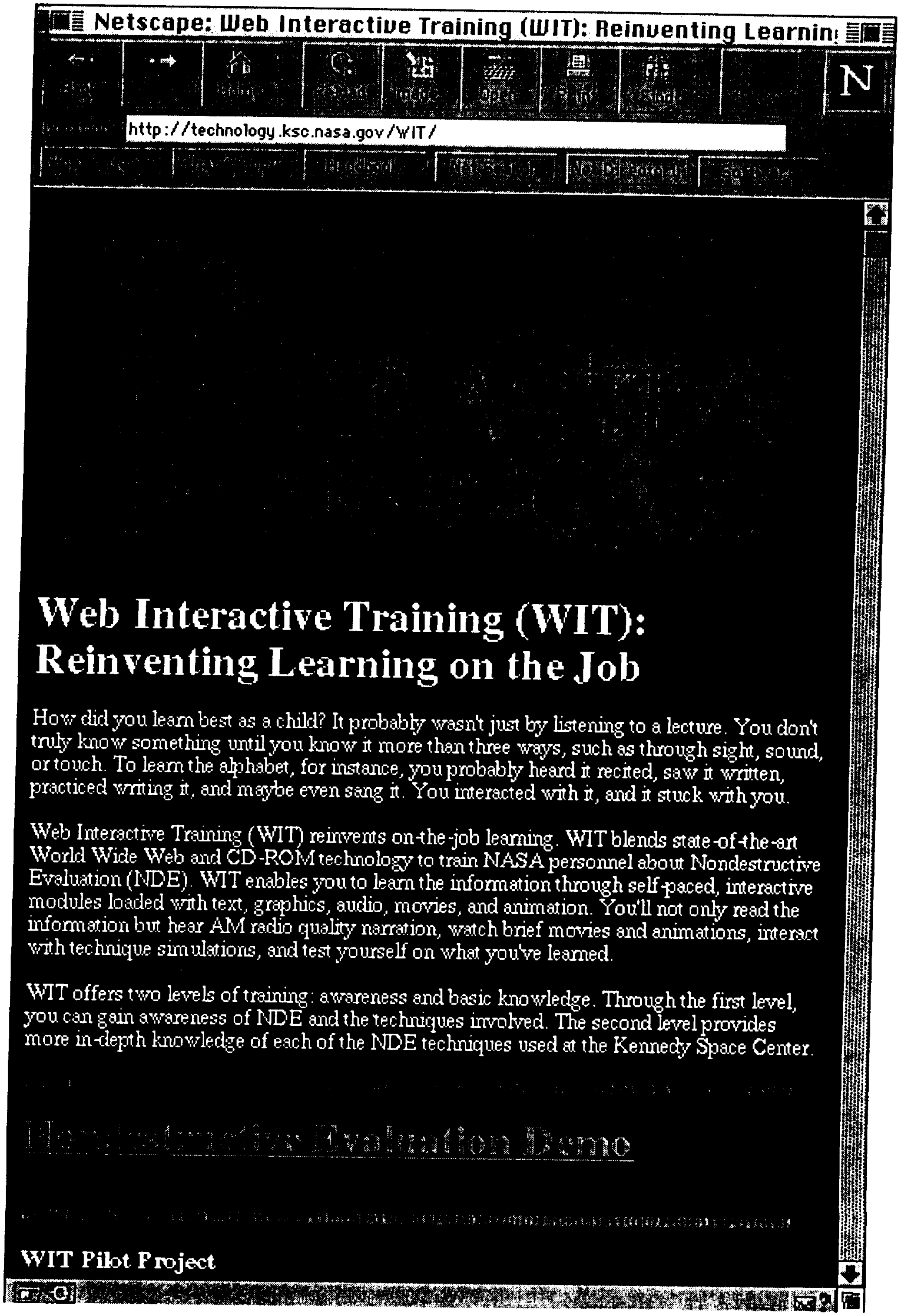
- Completion of feasibility prototype.
- Incorporation of hypertext, graphics, streaming audio, video, animation, and reporting.

Key milestones:

- Design a state-of-the art Web server capable of serving all available NASA on-line training in FY 96.
- Complete two modules in NDE training by the end of FY 96.
- Inclusion of a random test generator with a testing database and interactive feedback in FY 96.

Contacts: J.D. Collins, DL-ICD-A, (407) 867-2634, and R.W. Tilley, RM-SAO, (407) 867-7590

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



Netscape: Web Interactive Training (WIT): Reinventing Learnin

http://technology.ksc.nasa.gov/WIT/

Web Interactive Training (WIT): Reinventing Learning on the Job

How did you learn best as a child? It probably wasn't just by listening to a lecture. You don't truly know something until you know it more than three ways, such as through sight, sound, or touch. To learn the alphabet, for instance, you probably heard it recited, saw it written, practiced writing it, and maybe even sang it. You interacted with it, and it stuck with you.

Web Interactive Training (WIT) reinvents on-the-job learning. WIT blends state-of-the-art World Wide Web and CD-ROM technology to train NASA personnel about Nondestructive Evaluation (NDE). WIT enables you to learn the information through self-paced, interactive modules loaded with text, graphics, audio, movies, and animation. You'll not only read the information but hear AM radio quality narration, watch brief movies and animations, interact with technique simulations, and test yourself on what you've learned.

WIT offers two levels of training: awareness and basic knowledge. Through the first level, you can gain awareness of NDE and the techniques involved. The second level provides more in-depth knowledge of each of the NDE techniques used at the Kennedy Space Center.

Nondestructive Evaluation Demo

WIT Pilot Project

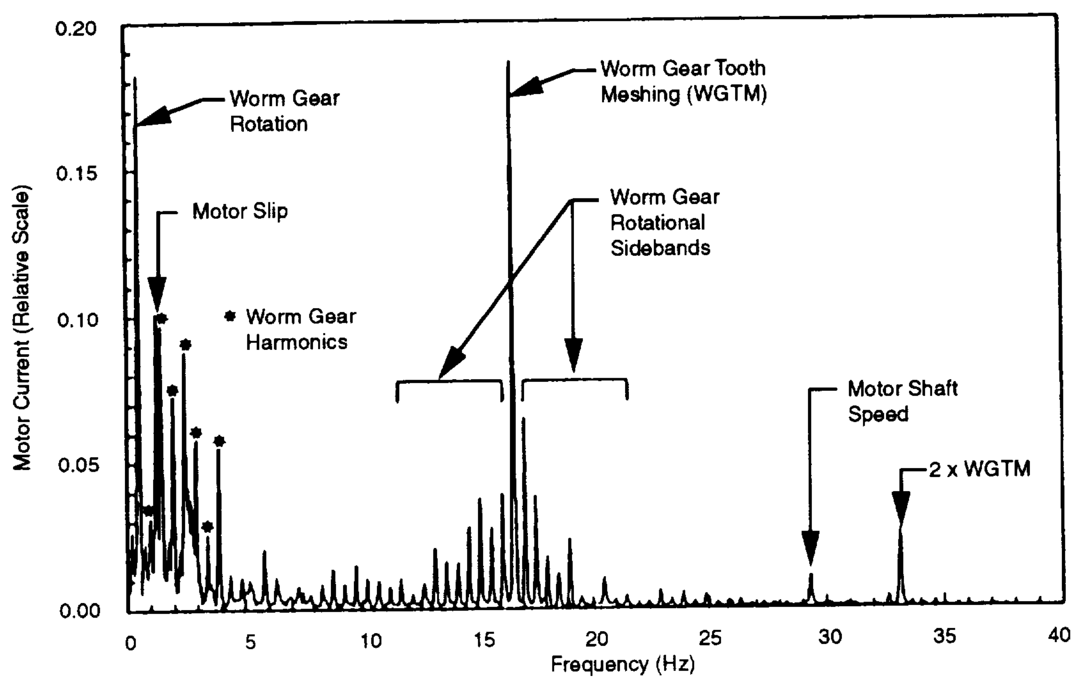
Electronics and Instrumentation

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.

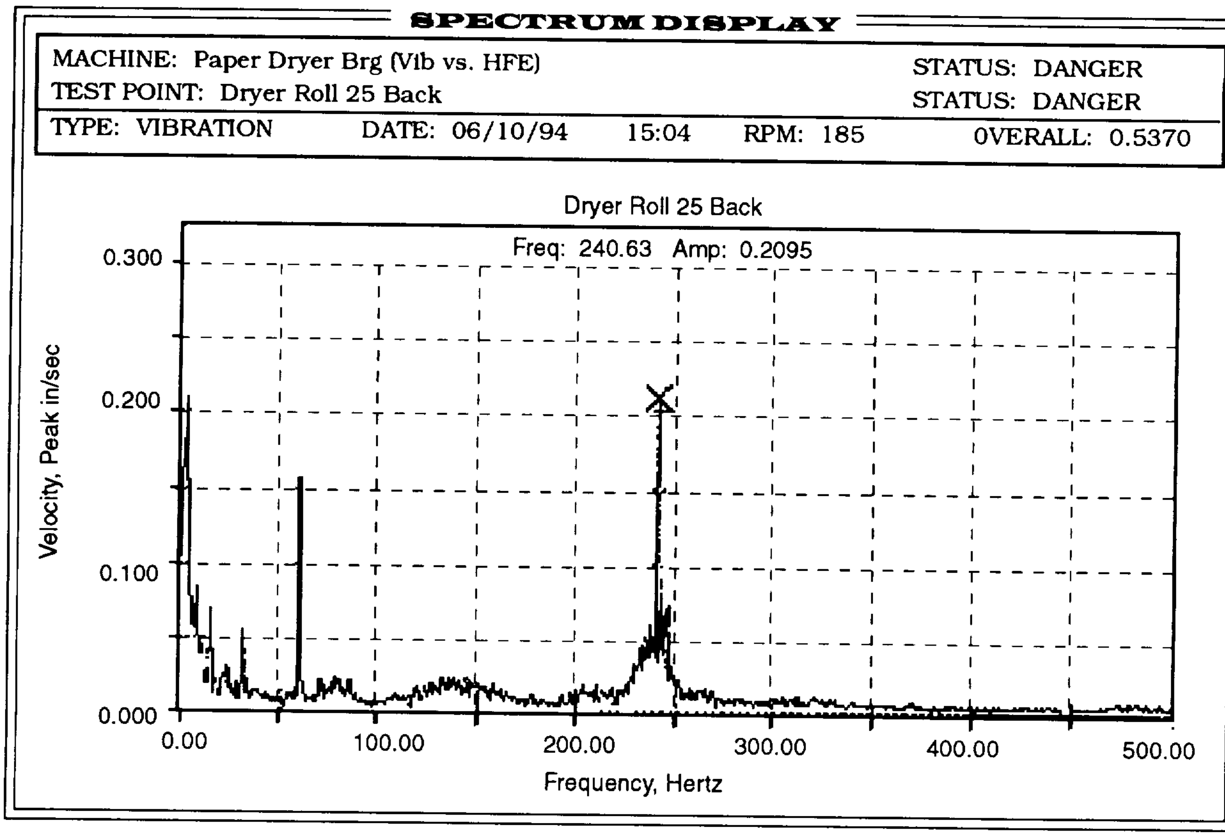
Liquid Oxygen Pump Assembly Motor Current/ Mechanical Signature Analysis

Loading of the Space Shuttle external tank with liquid oxygen (LOX) is accomplished via a pump/ motor/bearing assembly located at the northwest corner of Launch Complex 39. Since the LOX pump assembly is vital to the success of any mission, ensuring its safety and reliability necessitates that the assemblage be monitored continuously. The analysis tool must be able to instantaneously detect, identify, and assess the machine condition in order to take appropriate actions that will minimize launch impact.

LOX pump assemblage parameters requiring evaluation may either be dynamic (vibration) in nature or process related (temperature, pressure, and flows). Presently, two separate technologies are being considered to provide both qualitative and quantitative assessment: (1) motor current signature analysis (MCSA) and (2) traditional mechanical vibration signature analysis (MVSA). MCSA gives only qualitative information on mechanical loads at the present; any quantification efforts would entail correlation of motor current data with mechanical loads. However, measurements from both technologies can be analyzed using modern digital signal analysis techniques. Since each defect produces a unique set of vibration patterns (or signatures), abnormal features of the LOX pump assemblage, such as imbalance, misalignment, bearing and gear wear, electrical problems, cavitation, and structural resonances, can be detected. Lastly, on-line machinery condition or health monitoring can lead to improvements in operational efficiency, eliminate shutdowns, reduce maintenance costs, and prevent catastrophic failures.



Example of Motor Current Signature Analysis (MCSA)



Typical Mechanical Vibration Signature Analysis (MVSA)

Key accomplishments:

- 1995: Procured the equipment to duplicate the LOX pump assemblage at the Launch Equipment Test Facility (LETF). Researched MCSA and MVSA analysis tools.

Key milestones:

- 1996: Set up the LOX pump assemblage and establish the LETF as a test bed for testing, training, and analysis.

Contacts: A.F. Rodriguez, DM-MGD, (407) 867-7969, and R.J. Werlink, DM-ASD, (407) 867-4181

Participating Organization: I-NET, Inc. (R.N. Margasahayam and M.J. Ynclan)

KSC Radio Traffic Monitoring

KSC makes extensive use of mobile radio communications in performance of its daily operations. The existing Radio Frequency Communications System consists of over 2,000 mobile radios, mobile radio subsystems, communications centers, and interconnecting cable plant. These subsystems are used for administrative and operational support for the Space Shuttle and other KSC operations. The goal of this project is to collect data on the amount of radio traffic at KSC and analyze how this traffic is distributed across the different users. This project will identify congested radio channels and areas that have no radio coverage at KSC.

In analyzing a radio system, a key characteristic to consider is the amount of radio traffic during the busy hours (analyze for peak load). Due to the large geographical area of KSC and the shadowing effect caused by large buildings, a single receiver/antenna pair cannot

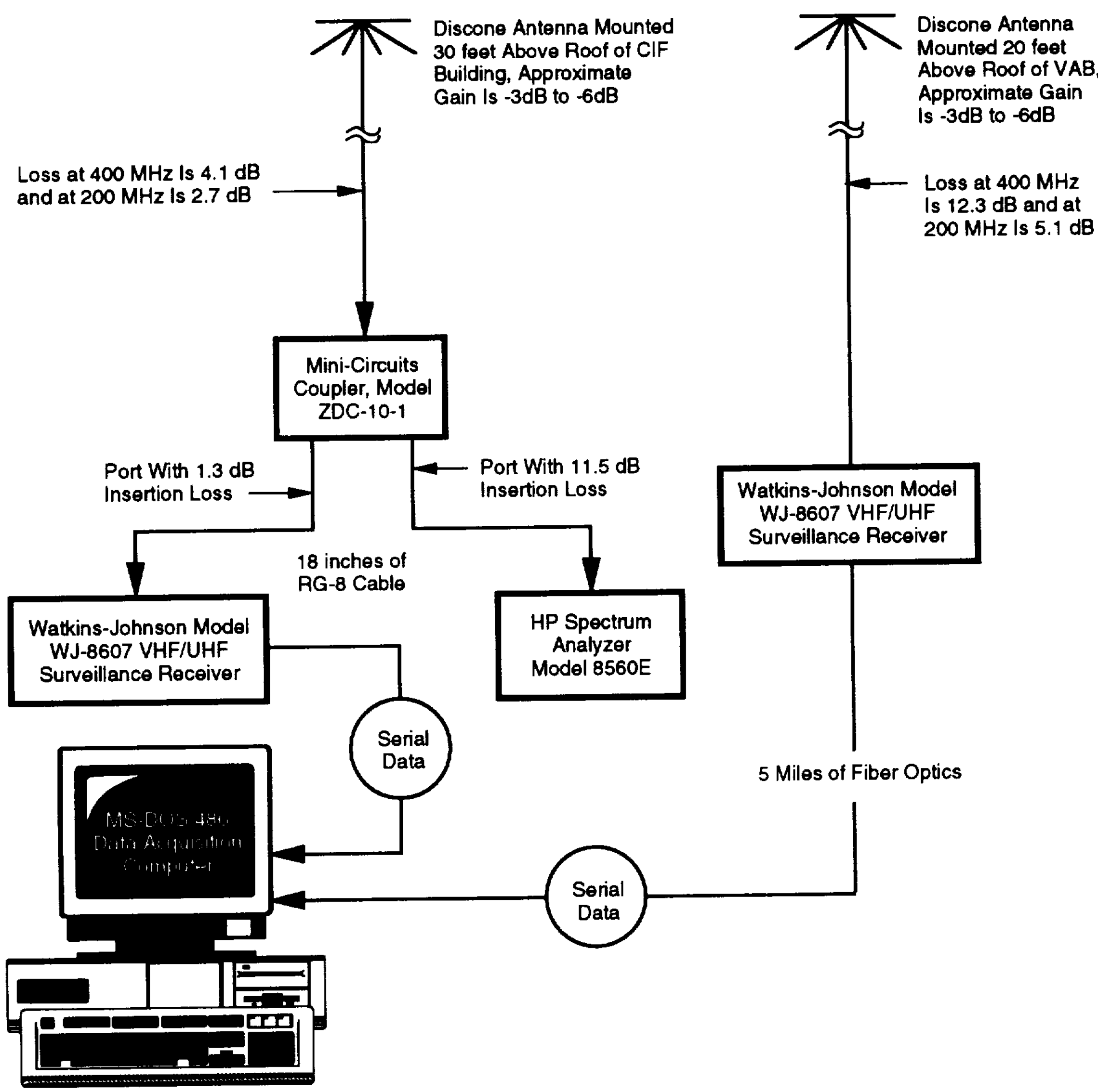


Diagram of Equipment Used To Record Channel Activity cover the whole KSC area. As shown in the diagram, two omnidirectional discone antennas have been installed, one on top of the Central Instrumentation Facility in the Industrial Area at 60 feet and the other on top of the Vehicle Assemble Building in the Launch Complex 39 area at 520 feet. Each antenna is connected to its own radio receiver (Watkins Johnson 8607). Each receiver is capable of scanning up to 100 radio channels per second to detect radio transmissions of interest at KSC. The system is presently scanning 63 KSC frequencies every second.

The output of the radio receiver is signal strength for each scanned channel. This data is outputted through the serial port of each receiver. The receivers are wired to the computer in the Radio Frequency Laboratory via serial data links. The information is then written to the hard drive of a computer (486-33 megahertz) and backed up on external optical disks. There have been over 7 gigabytes of data collected in the last 19 months.

Special software was written to control and synchronize each radio receiver as well as to analyze the large amount of data. A request for information is sent from the computer to the radio receivers, the information is sent back from both radio receivers to the computer, and the signal strength for each channel is written to the hard drive of the computer with a date and time stamp for each sweep of the 63 channels. The request is sent again, repeating as long as the program is running. The data coming back to the computer from the receivers is synchronized in such a way that the computer can choose the strongest signal. Since both radio receivers may "see" the same transmission, only the strongest signal is recorded. This all takes place in 1 second for all 63 channels of interest.

After the data is collected, extensive statistical analysis is conducted. The analysis yields the overall amount of radio traffic at KSC at any given time. Of particular interest is the peak amount of traffic over any given hour. This information can also be broken down per channel, yielding information on radio channels and usage. This in turn, yields the probability of calls being blocked due to other users. This information can be used to identify radio channels that are congested and radio channels that are not being used efficiently. Decisions can then be made on how to make the radio system more efficient by moving users to other channels or providing a basis for the implementation of a modern radio system.

The analysis of the radio system at KSC will expand this year, with the integration of a radio receiver with a Global Positioning System (GPS) receiver in a mobile van, for KSC-wide coverage. Combining these two technologies will map information about the radio environment at KSC including areas with little or no coverage from the transmitter sites, multipath problems, interference problems, and signal strength of the transmitters throughout the Center. In parallel, software will be developed to provide a real-time graphical display of radio system activity.

Key accomplishments:

- Procured and installed hardware for data collection of KSC radio traffic.
- Developed software to control the radio receivers and analyze the collected data.
- Processed data and provided statistical analysis.

Key milestones:

- 1994: Hardware selection and setup, as well as validation of the software.
- 1995: Algorithms for statistically analyzing data.
- 1996: Interface GPS with a surveillance receiver; develop a real-time graphical display.
- 1997: Install into a mobile van.

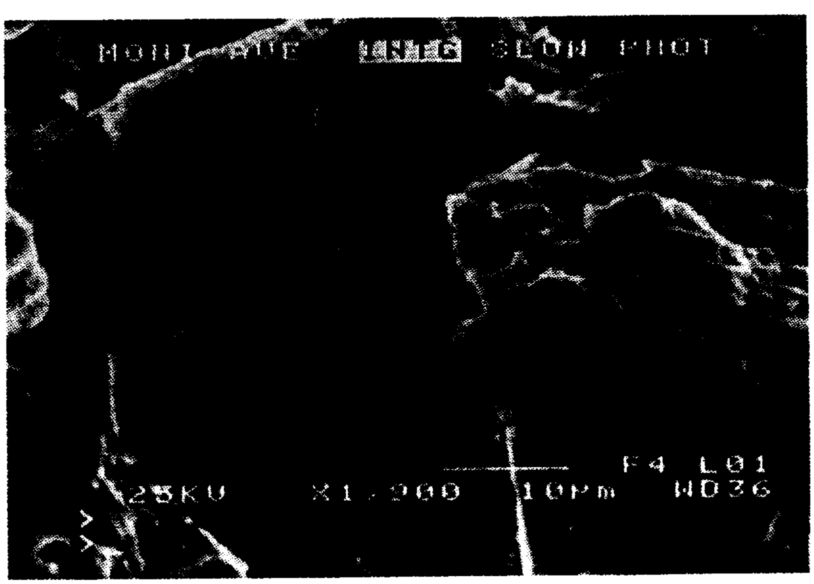
Contact: F.M. McKenzie, DL-CMD-R, (407) 867-1391

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

Development of an Expert System To Assist Fractographical Analysis

Failure analysis of flight hardware and ground support equipment frequently requires the examination of the 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 (DM-ASD), and the latter is done by NASA Logistics Operations, Materials Science Division (LO-MSD). 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.

Key milestones:

- An outside expert will be located and secured for input.
- A preliminary logic tree for steel will be established.

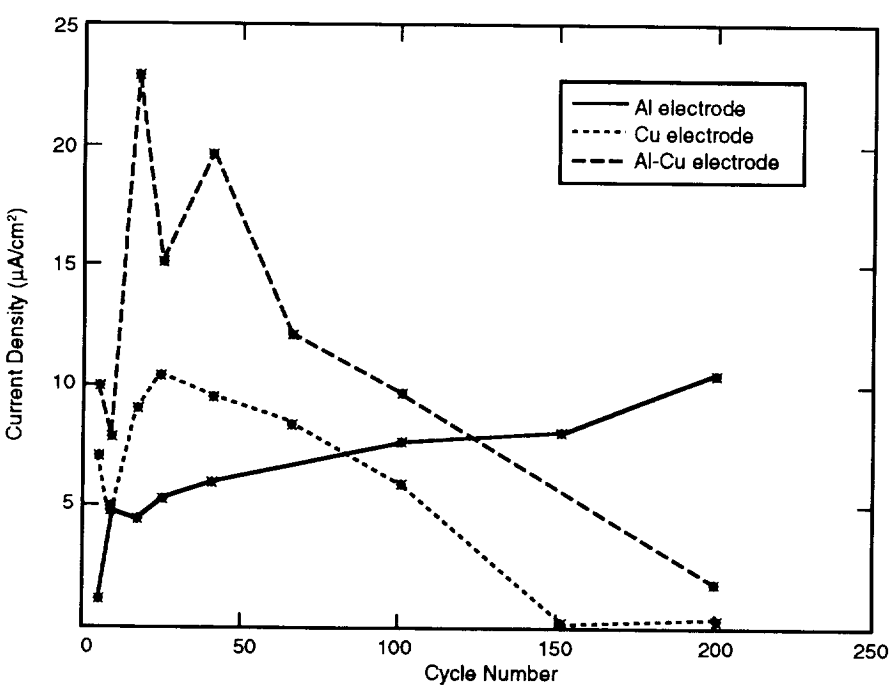
Contact: R.U. Lee, LO-MSD, (407) 867-3400

Participating Organizations: NASA, DM-ASD (P.A. Engrand) and I-NET, Inc. (R.J. Merchant)

Development of Atmospheric Corrosion Sensor Technology

The subtropical marine atmosphere of KSC is very corrosive to metals. KSC's corrosion control program has continuously applied new corrosion control measures to maintain the integrity of flight hardware and ground support equipment. Unfortunately, the area of atmospheric corrosion control, especially in predictive capability, has not benefited much from recent advances in corrosion science. The main difficulty has been that the amount of electrolyte condensed on a metal surface is too limited for reliable measurement of electrochemical parameters.

In general, as the volume of electrolyte decreases, the size of a test coupon should decrease proportionately. Modern vacuum deposition technology makes the fabrication of microsensors practical. The goal of this research is to combine the predictive capability of modern corrosion science and microfabrication technology so predictive capability can be improved.



Average Corrosion Current Density (Tafel Extrapolated) Versus Number of Fog Cycles in the Fog Test With 3.5-Percent NaCl Solution

The microsensors developed by the U.S. Navy will form the base for sensor development. The design will be appropriately modified. This approach is especially attractive as the development cost can be reduced and a bidirectional technology transfer can be achieved. The final product will be a technology that can be utilized for multipurpose corrosion testing, including corrosivity of a given environment, corrosion rate of a metal, and effectiveness of a protective paint coating. Data reduction software will also be developed to interpret measured electrochemical signals.

Key accomplishments:

- The U.S. Navy agreed to provide their sensors and fabricate new sensors to KSC's design.
- Various sensor layouts are under test.

Key milestone:

- Sensor design will be completed in 1996.

Contact: R.U. Lee, LO-MSD, (407) 867-3400

Participating Organization: Southern University (R. Diwan)

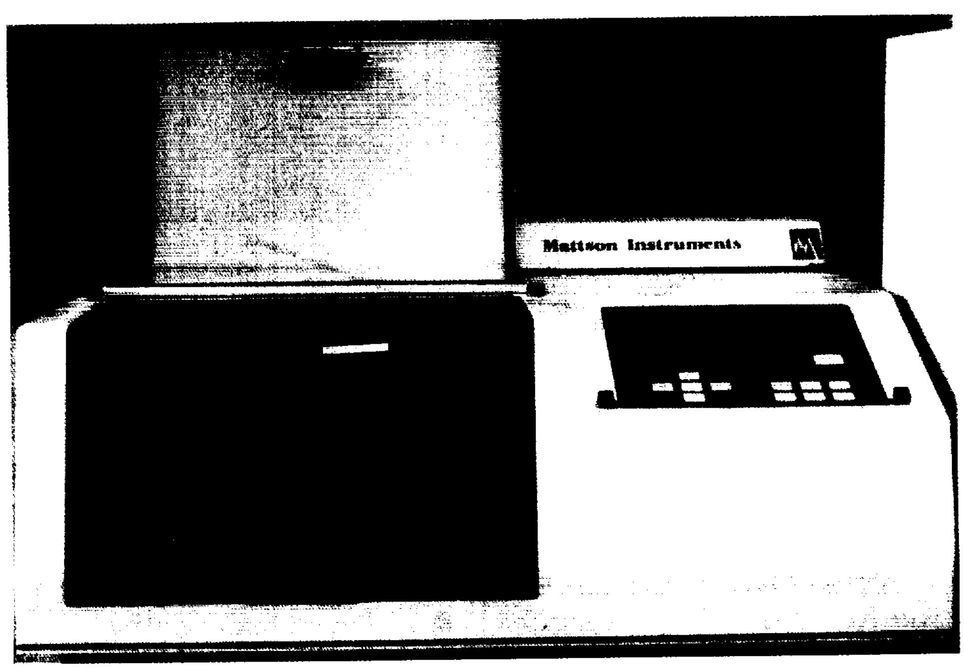
Fourier Transform Infrared (FTIR) Quantification of Industrial Hydraulic Fluids in Perchloroethylene

Chlorofluorocarbon 113, (CFC 113) commonly known as Freon™ 113, is the primary test solvent used for validating precision-cleaned hardware at KSC. It is also used as a general laboratory solvent for analytical work in a variety of sample matrices. A 1993 preliminary report published by the Environmental Protection Agency (EPA) suggested the feasibility of replacing the CFC 113 with tetrachloroethylene, more commonly referred to as perchloroethylene (PCE), in their standard infrared (IR) method for the determination of oil and grease content.

KSC precision cleans approximately 260,000 components annually at the Component Refurbishment and Cleaning Facility. CFC 113 has typically been used to degrease and validate the cleanliness of these components. Using the suggestions by the EPA, KSC decided to investigate the feasibility of using PCE as a validation solvent in selected areas, particularly because of the high degree of solvation compatibility with organics and the nonflammable nature of the solvent.

Methods of analyses using dispersive infrared spectrophotometry have been performed extensively for qualitative identification and for quantification at high concentrations ranging from high parts per million (ppm) and percent levels. Introduction of FTIR spectroscopy has provided a means for utilizing infrared techniques for quantification at low-ppm concentrations. Experimental data was collected to assess the feasibility of utilizing PCE and FTIR for the detection of low levels of industrial hydraulic fluids in PCE.

Calibration curves were prepared for a series of standard



FTIR Spectrometer

dilutions of hydraulic fluids in PCE. The infrared absorbance spectra were recorded with an FTIR instrument operated from a computer-based data collection and spectral analysis system and using fixed and variable path length potassium bromide sample cells.

The results indicate it is possible to detect about 20 ppm of the hydraulic fluid in PCE using selected absorbance spectral peaks of the analyte. By optimizing certain variables that may affect interpretability of the results obtained, the method may equally be applicable to the detection of hydraulic fluids below 20 ppm.

Key accomplishments:

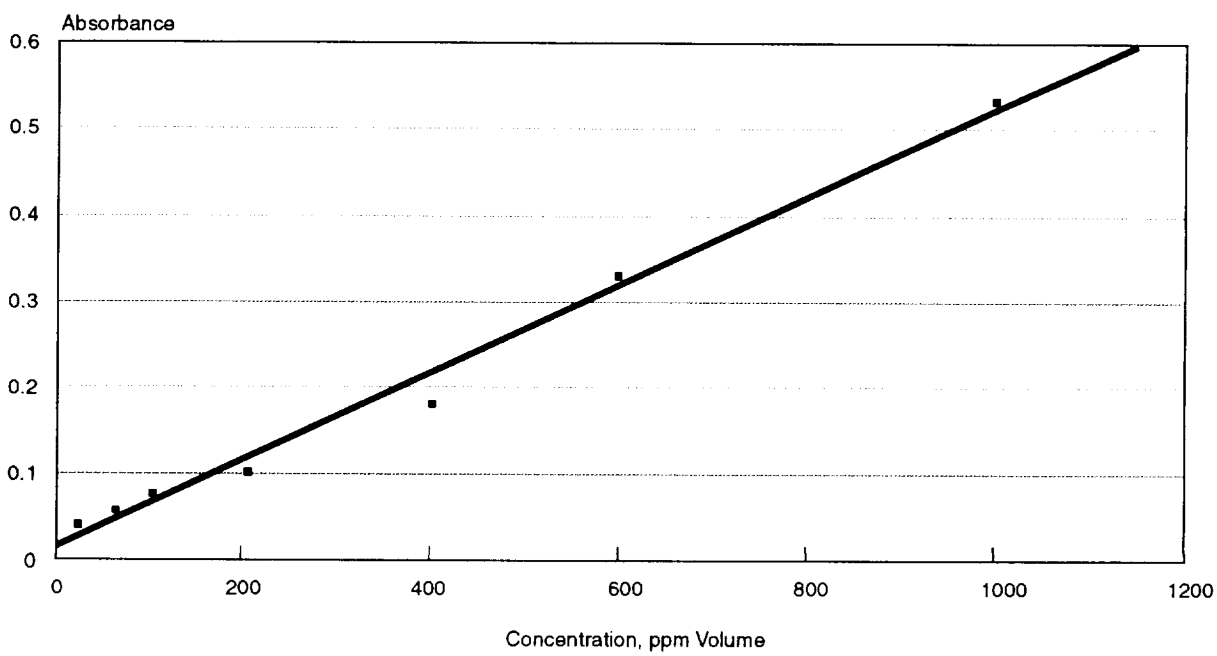
- The feasibility of using PCE and FTIR for verification of cleanliness has been demonstrated.
- Calibration curves above 20-ppm concentration have been developed.

Key milestones:

- Use a more sensitive IR detector to evaluate detection of lower levels of hydraulic fluid concentrations.
- Establish a single calibration curve for the various hydraulic fluids and oils identified as possible contaminants.

Contact: G.J. Allen, LO-MSD-1, (407) 867-3910

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



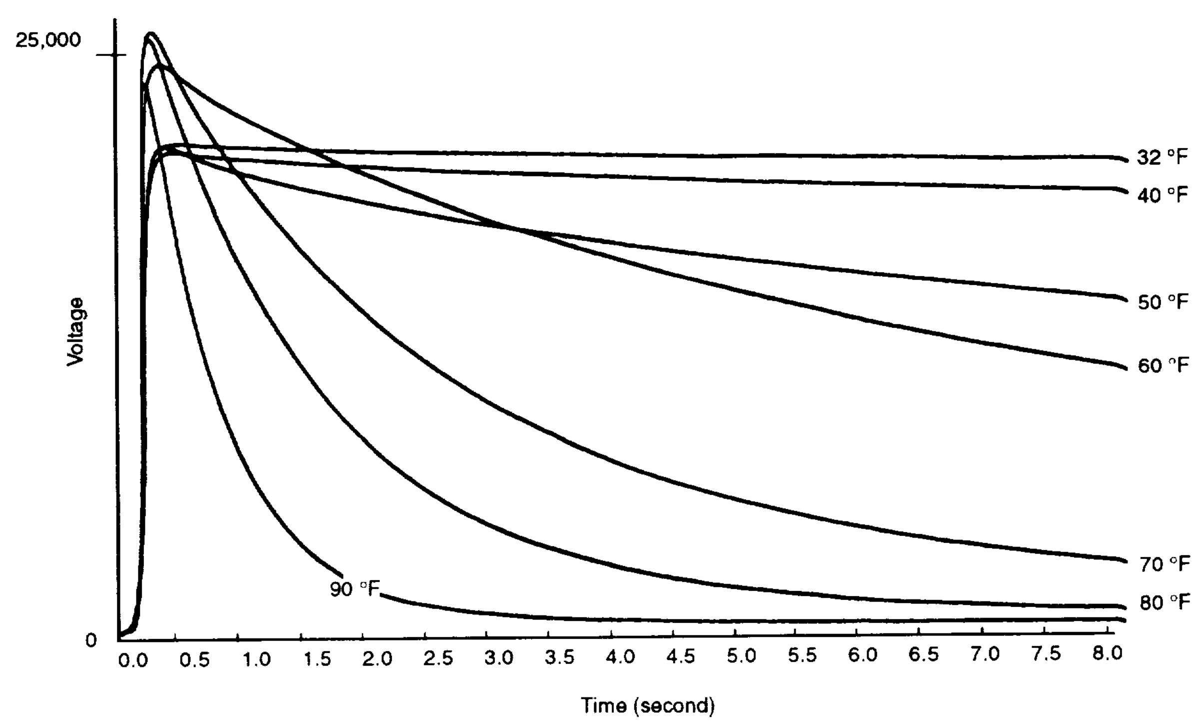
FTIR Calibration Curve, Red Mil-H-5606 Fluid in PCE (KBr Cell 1.5 mm R2 = 0.99)

Electrostatic Laboratory Developments

Electrostatic testing of thin films and clothing materials has been routinely performed in the Materials Science Laboratory (MSL) since the need was first identified in the 1960's. It was at this time that the Triboelectric Test Device was developed. This device is at present the only device that has been successful in the determination of the electrostatic properties of charge generation and decay rates. The MSL has evaluated the electrostatic properties of thousands of materials. The American Society for Testing and Materials is currently in the process of adopting this test as one of its standards. The National Fire Protection Association already has adopted it as a standard test.

Recently, the robotic version of the Triboelectric Test Device was used to investigate the effect that temperature has on the triboelectric properties of materials (see the graph). This was the pioneering investigation into temperature effects and revealed valuable information not previously known. Some of this data was presented at the 19th Mr. Clean Conference held in Cocoa Beach, Florida. At this time, the robotic version of the Triboelectric Test Device is being modified by the MSL to perform the first electrostatic tests on materials in a vacuum.

The MSL Triboelectric Laboratory is recognized around the world as a leader in this



RCAS 2400, 45-Percent Relative Humidity field. The laboratory routinely provides help to Government agencies or aerospace contractors in the selection and safe use of electrostatic materials. The MSL has helped universities, friendly foreign governments, private industry, and the U.S. Army, Air Force, and Navy to resolve electrostatic problems and test techniques.

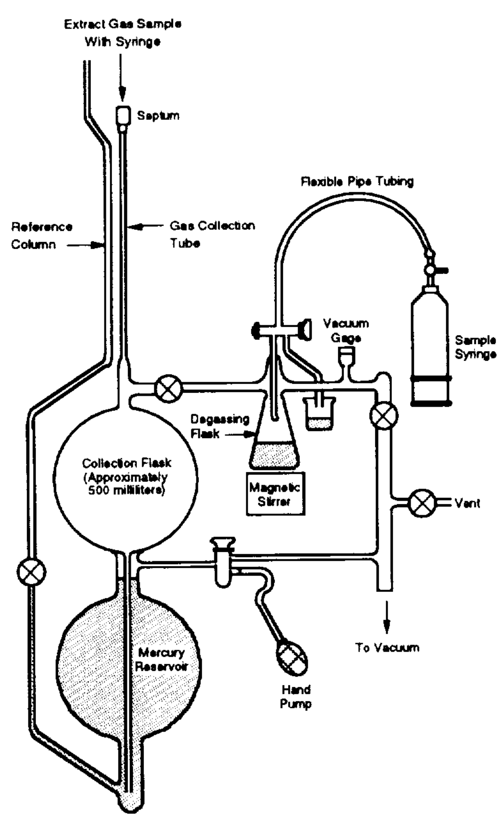
This laboratory has helped industry in the development of new and innovative materials in the electrostatics field. For example, Chemstat 919 is a unique cloth developed in a cooperative effort with the MSL to satisfy the need for a cleanroom garment that was electrostatically safe and flame retardant. Since its introduction, it has found many uses in the private sector as well as at KSC. Another cooperative effort produced Challenge 5000, a light-weight, chemically inert, light-color, electrostatically safe material widely used by the military and private industry. At this time, a new clear electrostatically safe coating is in the final stages of development in another cooperative effort with industry. It is being evaluated by the MSL to solve the electrostatic problems encountered with the suits used during fueling operations.

Contact: Dr. R.H. Gompf, LO-MSD-2T, (407) 867-4619

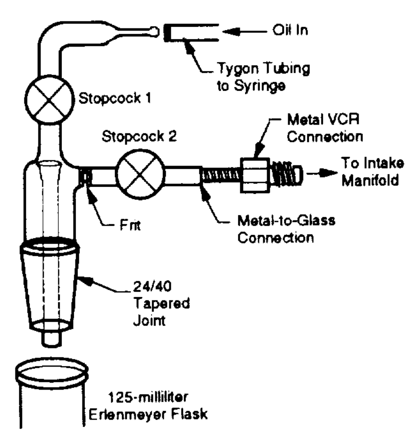
Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography

The Microchemical Analysis Laboratory at KSC was requested by the Center's electrical power coordinators to perform the analysis of the dissolved gases in all the major power transformers with the aim of preventing critical failures on the launch pads and control centers, along with reducing maintenance cost by determining transformer condition. The accepted American Society for Testing and Materials (ASTM) analysis method D-3612 (see the figure "ASTM Procedure Apparatus") requires a customized glass pressurizing transfer system that used a large volume of mercury to compress a small volume of gas at a low pressure to a smaller volume at or above atmospheric pressure for analysis. The frailness of the rather large glass transfer system coupled with the hazards associated with mercury in the Operation and Checkout Building prompted the development of an alternative method.

A vacuum transfer system, switching column, high-sensitivity ultrasonic detection, gas chromatograph has been used in the laboratory for the analysis of the air in the aft fuselage during the ascent of all Space Shuttle missions. The system consists of a custom-made vacuum inlet with a low-volume capacitance manometer to determine the total sample pressure in a 5-milliliter sampling loop. Sensitivities for all the gases of interest as a function of the total pressure are updated regularly by the analysis of known value, mixed standards. An oil degassing apparatus had to be designed and developed that would provide an air-free transfer of the oil to a low-volume evacuated degassing flask, then from the flask to the low-volume subatmospheric sampling loop and pressure measurement inlet system. This

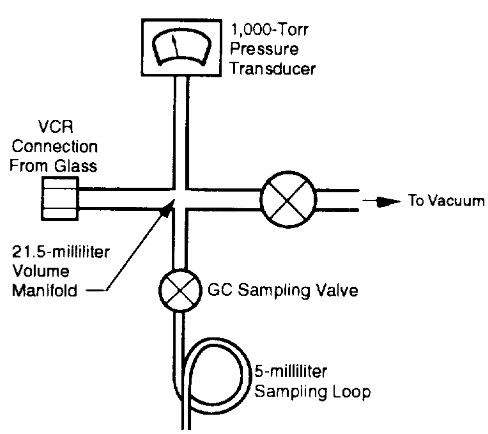


ASTM Procedure Apparatus



New Analysis System (New Outlet Apparatus) was accomplished with a valved 125-milliliter flask utilizing a glass frit to prevent oil from entering the sampling loop and a glass-to-metal connector for attaching to the inlet system.

Verification of the method was accomplished by obtaining five samples from one of KSC's transformers, analyzing one with the Microchemical Analysis Laboratory method, and sending samples to four other laboratories that perform the ASTM D-3612 gas analysis routinely for a round-robin analysis. Although the round-robin test was a very small sampling, the high level of agreement between the five independent analyses indicates the alternative method was worthy of consideration of adoption to the ASTM. The Subcommittee D27.03 chairman was sent a brief report describing the method. The method is continuing to be used as a normal routine analysis at KSC, creating a history of all transformers. Therefore, changes in the gas composition can be used to schedule shutdowns for maintenance at desirable times



New Analysis System (GC Inlet System)

and before serious damage can occur from a catastrophic failure.

Key accomplishments:

- The analysis method was used to determine the Shuttle aft fuselage gas composition was expanded to provide a preventive maintenance tool for large power transformers.
- A sampling device was designed and developed to reduce the hazards of handling mercury in a fragile glass system.
- A round-robin test was organized to determine the feasibility of incorporation into ASTM procedures.
- A condition history was established on most of the transformers at KSC.

Key milestones:

- Test to include all the required gases in KSC's procedures (hydrogen, carbon dioxide, ethylene, ethane, acetylene, oxygen, nitrogen, methane, and carbon monoxide).
- Design a suitable sample gas expansion apparatus.
- Fabricate the device.
- Test the device with a developed analysis procedure.
- Monitor the transformers at KSC to maintain a reasonable maintenance schedule.
- Submit the procedure to ASTM for adoption into standards.

Contact: T.A. Schehl, LO-MSD-1C, (407) 867-3080

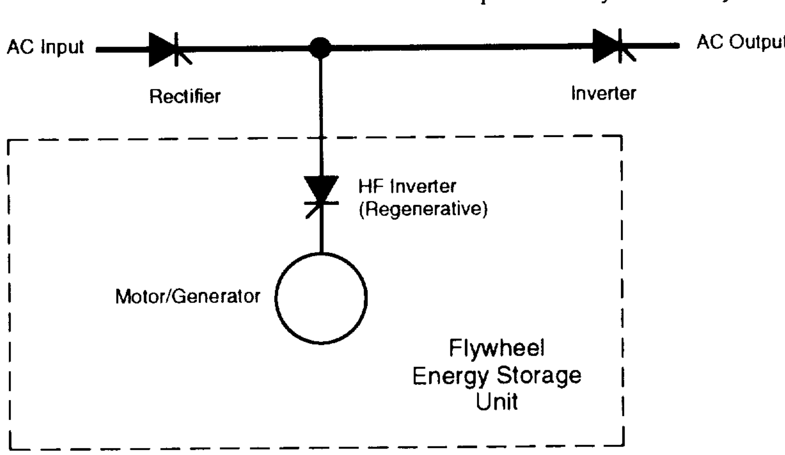
Participating Organization: EG&G (A.M. Rose)

Flywheel Uninterruptible Power Supply Applications for the Space Shuttle GSE and Ground Processing Systems

Chemical batteries are used at KSC in uninterruptible power supply (UPS) systems. These batteries have been a source of problems to the organization responsible for maintaining these systems. These problems include replacement of sealed batteries due to failures earlier than expected and periodic load tests of the battery banks to ensure proper performance. Also, environmental issues such as disposal of lead in batteries and the possibility of chemical spills are of concern.

A released study, KSC-DF-4055, prepared for the Engineering Development Directorate, discusses the feasibility of applying flywheel technology developed by NASA for satellite power systems to Shuttle ground support equipment (GSE) UPS systems. The study concluded that the technology exists and can be applied to the UPS systems presently in use at KSC.

The study investigated several flywheel energy storage systems in development by various companies. Flywheel energy storage devices (flywheel battery), energy conversion systems, and power regulation modules were packaged and fully demonstrated in developmental systems. System sizing, performance, and true operational experience remain to be accomplished.



Proposed UPS

The study identified candidate UPS systems in use at KSC that could be replaced by the flywheel UPS system. These sites would provide a testing environment for the system where performance data can be collected and optimized.

Key accomplishment:

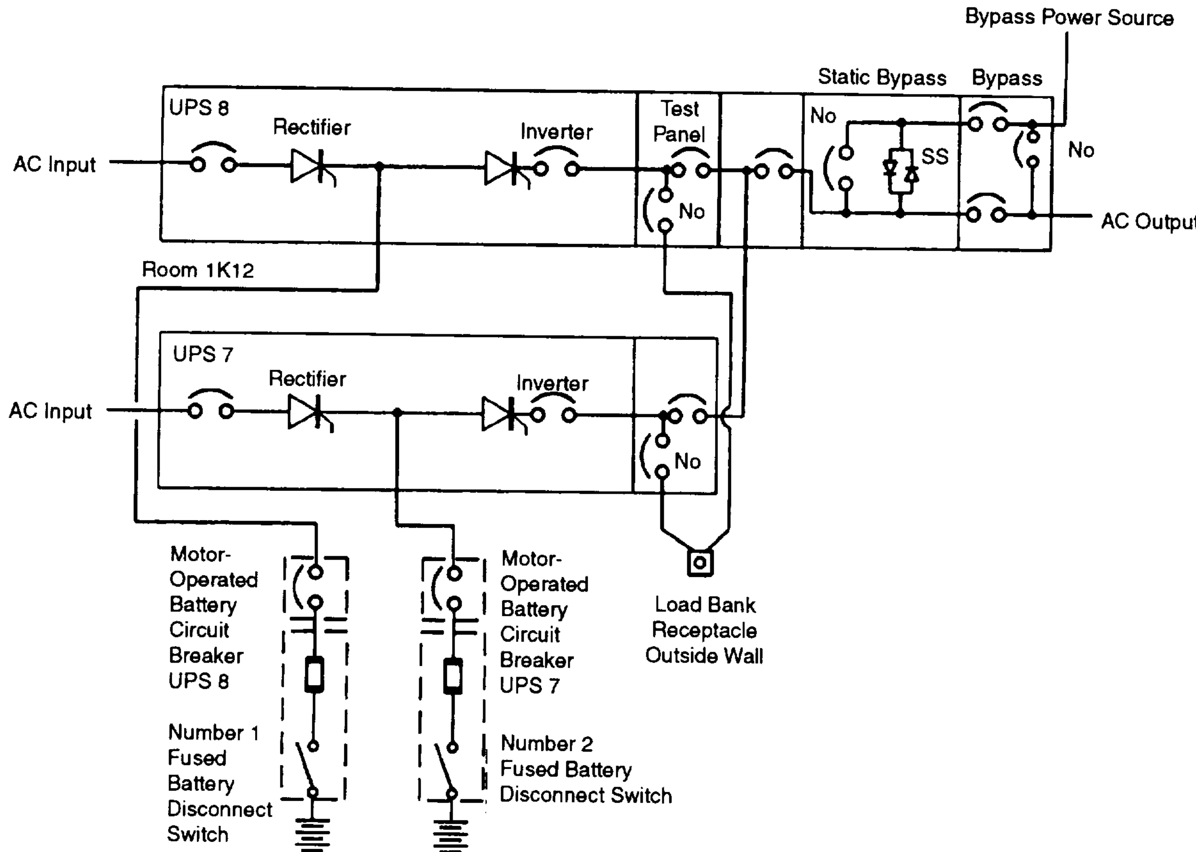
- September 1995: Feasibility study.

Key milestones:

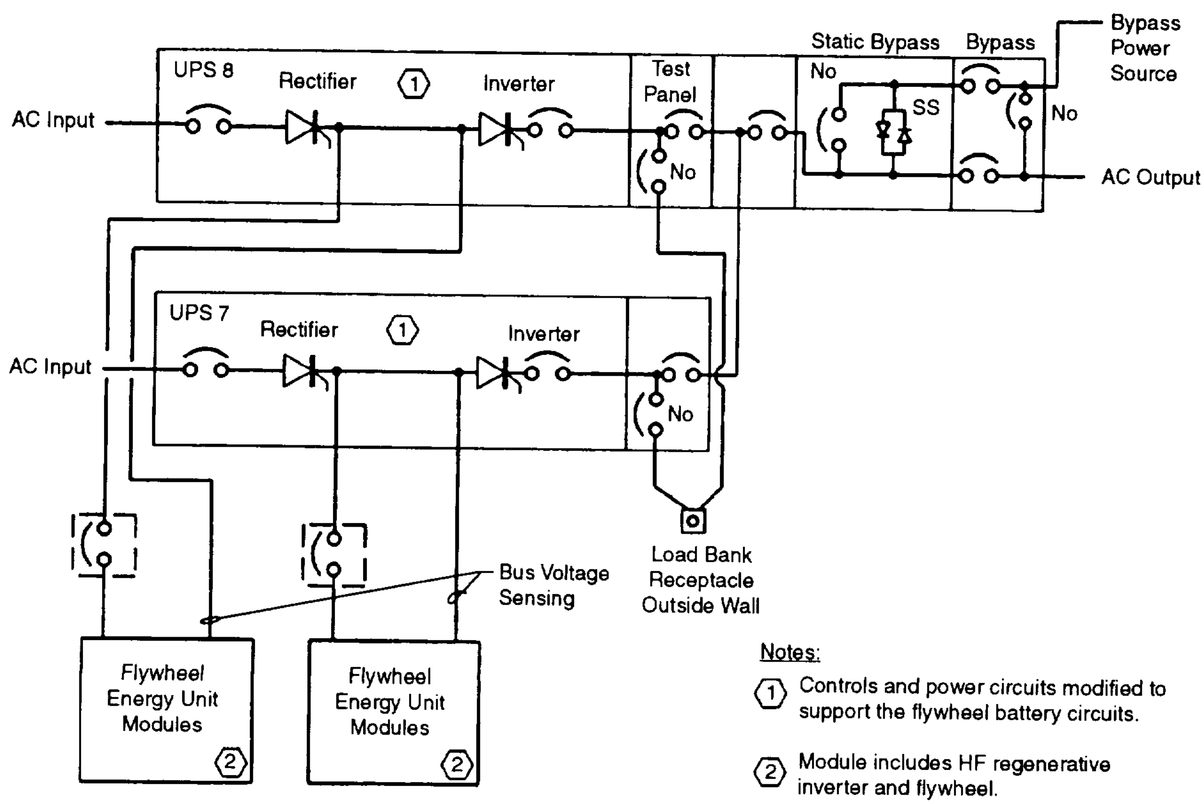
- Prototype acquisition and testing.
- Selection of UPS system for parallel testing.
- Flywheel UPS system design.
- Flywheel UPS system fabrication, installation, and acceptance testing.
- Flywheel UPS system upgrade to fully operational status.
- System operational performance data collection.

Contacts: N.V. Alers, DF-ELD, (407) 867-4564; M.A. Cabrera, TE-FAC-1, (407) 861-3283; C.J. Iannello, TE-FAC-1, (407) 861-3276; C.D. Shelton, DF-ELD, (407) 867-4564; C.M. McCleskey, TV-GDS-3, (407) 861-3775; and R.E. Rhodes, TV-FSD-4, (407) 861-3874

Participating Organizations: Fred Wilson & Associates; Forensic and Research Engineers, Inc. (J.A. Kirk, Ph.D.); United Technologies Research Center (T.W. Grudkowski, Ph.D.); SatCon Technology Corporation (J. Downer, Sc.D.); American Flywheel Systems (B. Bartlett); NASA Goddard Space Flight Center (B. Beaman); NASA Lewis Research Center (R. Beach); Trinity Flywheel Batteries, Inc. (J. Eastwood); and Thortek, Inc. (D.G. Thorpe)



UPS 7 and UPS 8 Existing

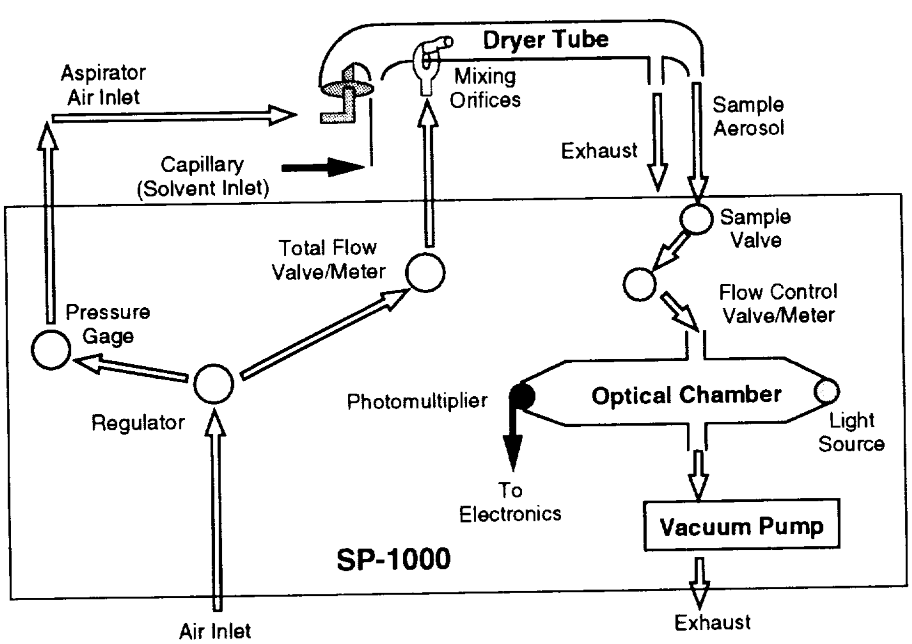


UPS 7 and UPS 8 Modified

Modification of a Solvent Purity Meter for Use in NVR Analysis With Non-Freon Solvents

Spacecraft flight hardware and ground servicing equipment must be free of contamination, particularly contamination that is not compatible with the various fluids used to launch and operate the spacecraft. A particular class of contamination that is not compatible with liquid oxygen systems is called nonvolatile residue (NVR). The previous practice has been to flush parts with precision cleaning solvents until NVR concentrations in the solvent are acceptable and no further NVR can be removed from the components.

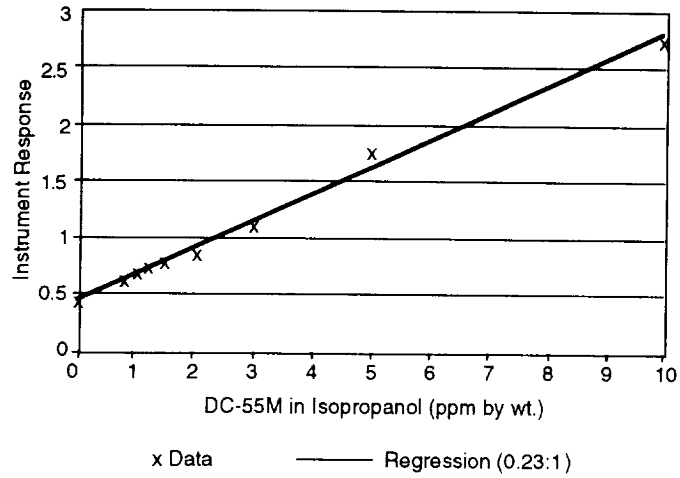
The standard measurement of NVR content in the wash solvent is by a gravimetric method (KSC-C-123). This method requires at least 30 minutes of analysis time. The SP-1000 Solvent Purity Meter (Virtis Instrument Company) was designed to provide real-time instantaneous measurement of NVR in 1,1,2-trichloro-1,2,2-trifluoroethane (CFC 113) solutions. The SP-1000 accomplishes this measurement by using an aspirator to atomize the CFC 113 along with any NVR into a drying tube that utilizes a closely controlled air flow to evaporate the solvent and to carry suspended contaminate particles to the optical system of the SP-1000. The SP-1000 optical system utilizes the principle of forward-scattered light to provide extremely accurate and sensitive measurements of minute particles suspended in a gaseous medium.



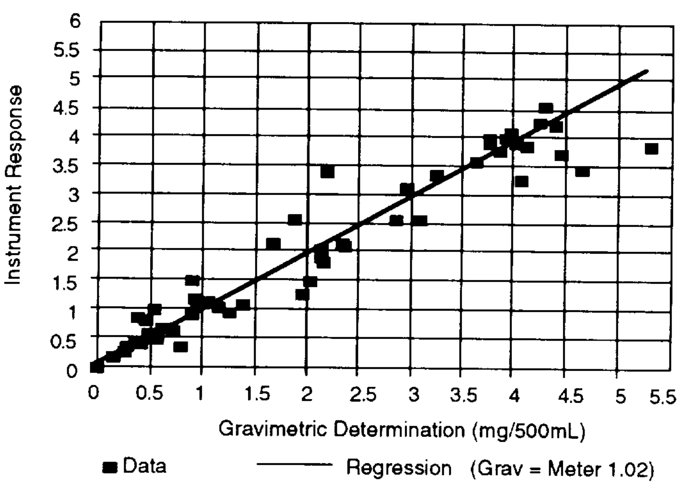
Simplified Diagram of a Modified SP-1000 Unit

The SP-1000 system previously had been optimized to analyze CFC 113 solvent-based samples. With CFC 113, all the solvent is evaporated in the drying tube, and the NVR condenses to form aerosol particles. When another solvent that has a higher boiling point and/or heat of vaporization than CFC 113 is substituted for CFC 113 in the SP-1000 unit, complete vaporization of the solvent does not occur. The unvaporized aerosol particles scatter light and are thus counted as NVR.

Because CFC 113 has been linked to ozone depletion in the upper atmosphere, its production and sale have been banned after 1995. Thus, there is a need for an instantaneous method to measure NVR concentrations in solvents other than CFC 113. The objective of the project was to modify the SP-1000 unit so it could be used with solvents such as isopropyl alcohol (IPA) and/or trichloroethylene (TCE).



Response of the SP-1000 to Solutions of DC-55M in Isopropanol With 50-°C Aspiration Air



Instrument Response Versus Gravimetric Determinations Performed During Field Trials

A simplified schematic diagram of the modified SP-1000 units is shown in the figure "Simplified Diagram of a Modified SP-1000 Unit." The major modifications that were performed to the unit were to provide a means of heating the vaporizing air to a temperature of 65 degrees Celsius (°C) and to reduce the rate of sample aspiration to less than 2 milliliters per minute. The effectiveness of the various modifications was tested by producing calibration curves for various NVR standard solutions such as shown in the figure "Response of the SP-1000 to Solutions of DC-55M in Isopropanol With 50-°C Aspiration Air." Calibration curves for 15 different NVR's were generated with IPA and TCE solvents. This data served to document that the modifications were successful and that field trials could be conducted. Field trials were performed at KSC's Precision Cleaning Laboratory to compare the modified SP-1000's response to real-time gravimetric analyses of NVR content in IPA. Data from these trials were used to produce the calibration line from 0 to 5 milligrams per 500 milliliters that is shown in the figure "Instrument Response Versus Gravimetric Determinations Performed During Field Trials." The data show that the modified SP-1000 instrument can be used to perform quick and accurate NVR analyses in solvents other than CFC 113.

Key accomplishments:

- The SP-1000 instrument was modified to use solvents with boiling points higher than CFC 113.
- The modified SP-1000 instrument has proven to give efficient and accurate NVR measurements in field tests.

Key milestone:

- Continue to monitor the use of the SP-1000 with IPA and TCE with possible applications to other solvents.

Contact: G.J. Allen, LO-MSD-1, (407) 867-3911

Participating Organization: University of Central Florida, Department of Chemistry (C.A. Clausen and P.S. Fowler)

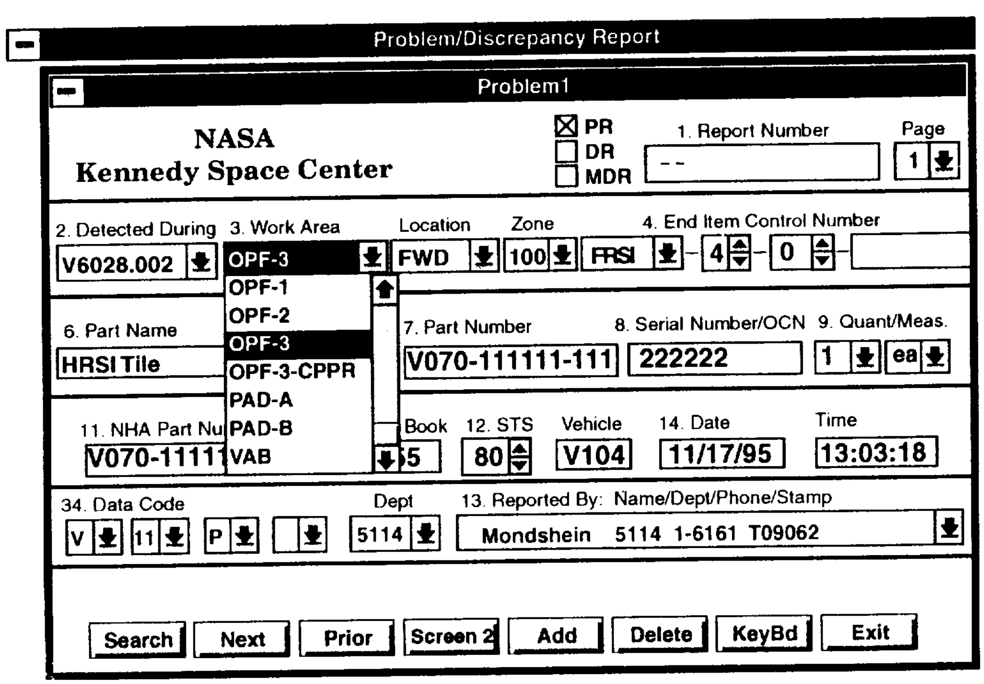
Automated PR/DR Program on Portable Pen-Based Computers

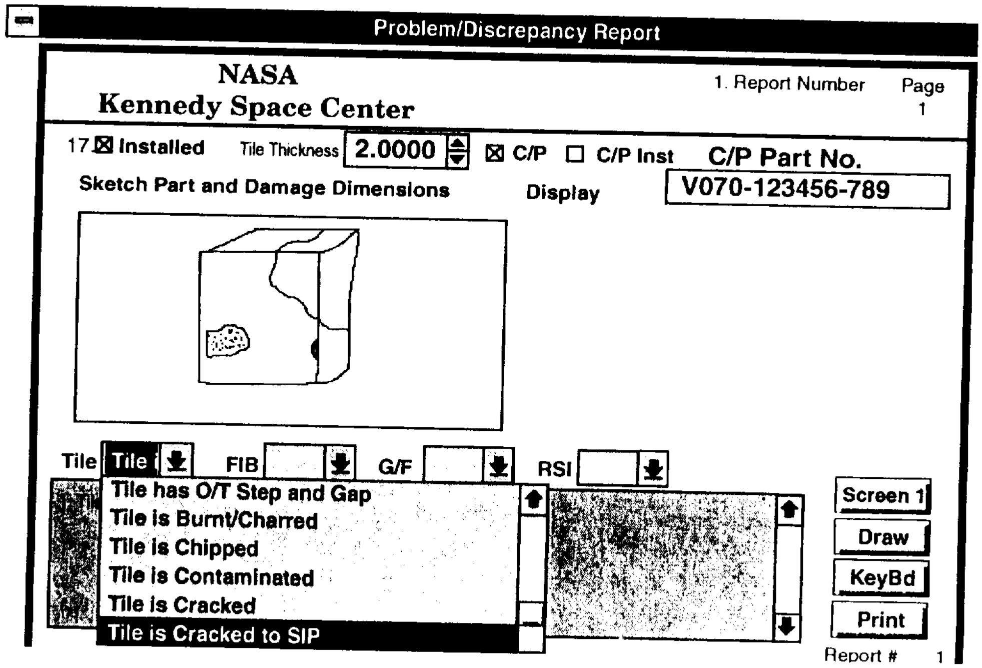
At the end of a Space Shuttle mission, each orbiter under goes a mandatory "micro-macro" inspection of the Thermal Protection System (TPS). The TPS consists of tiles, thermal blankets, Nomex felt, and other high-temperature soft goods. This inspection process generates hundreds of problem reports/discrepancy reports (PR's/DR's) per flow. The traditional standard manual process was labor intensive with the potential to impact orbiter processing.

When the orbiter enters the Orbiter Processing Facility, quality inspection personnel examine all TPS components. Inspectors would document discrepancies by handscribing personal notes on a scrap sheet of paper on a clipboard. These personal notes, unique to each inspector, introduced nonstandardized descriptions. The inspector would later transcribe these notes to an official problem report (KSC Form 2-151A). This serial duplication of effort consumed time, provided an opportunity for transcription error, and perpetuated unverified, invalid, and inconsistent data.

The software developers recognized the advantages of automating the TPS PR/DR effort with a handheld pen-based computer supported by sophisticated software and onscreen graphics capability. The developers used a Toshiba T200CS 486/40 pen-based computer with 20 megabytes of RAM as the hardware platform. The machines use Microsoft DOS 6.22 and Microsoft Pen for Windows version 1.0 as the operating system. The systems analyst uses Microsoft FoxPro 2.6 as the program database and "Sign-On for Fox" for hand graphic input.

The automated PR program features onscreen popups, check boxes, and spinners for primary





An onscreen popup keyboard permits users to input typed data when necessary. The "Sign-On for Fox" program by Sign-On Systems provides the software library that allows FoxPro to access the Microsoft Windows Pen Application Program Interface graphics functions.

The program allows users to input damage description data with virtually no keyboard input. Screen popups provide standardized lists and restrict the user to the displayed choices. Elements of artificial intelligence automatically change the configuration of the screen popups based on the selected user input. For instance, a user who specifies an "AFT" location will then see only appropriate AFT selections under the orbiter ZONES and End Item Control Number screen popups. This adds another level of error checking.

The graphics capability allows the user to hand draw a picture of the tile damage directly on the computer screen. The software saves the image and later prints it within a PR.

The automated PR/DR program achieved implementation on November 6, 1995, with the completion of Columbia's STS-73 mission. The quality inspectors complimented the new software. Using the pen came naturally to users who found the change from manual to pen-based input comfortable. This highly successful effort initiates a fundamental change in the processing of orbiter support paper for TPS.

Future plans include linking the pen-based computers to a server via a radio frequency (RF) local area network. This will allow real-time printing of problem reports and simultaneous updating of mainframe tracking databases. Preliminary RF tests have encouraged this next step in technology, which should be completed this year.

Key accomplishment:

- 1995: Integration of handscribed graphics into the database and reports.

Key milestone:

- 1996: Program designed, coded, and fully implemented.

Contact: R.M. Davis, DE-TPO, (407) 867-3017

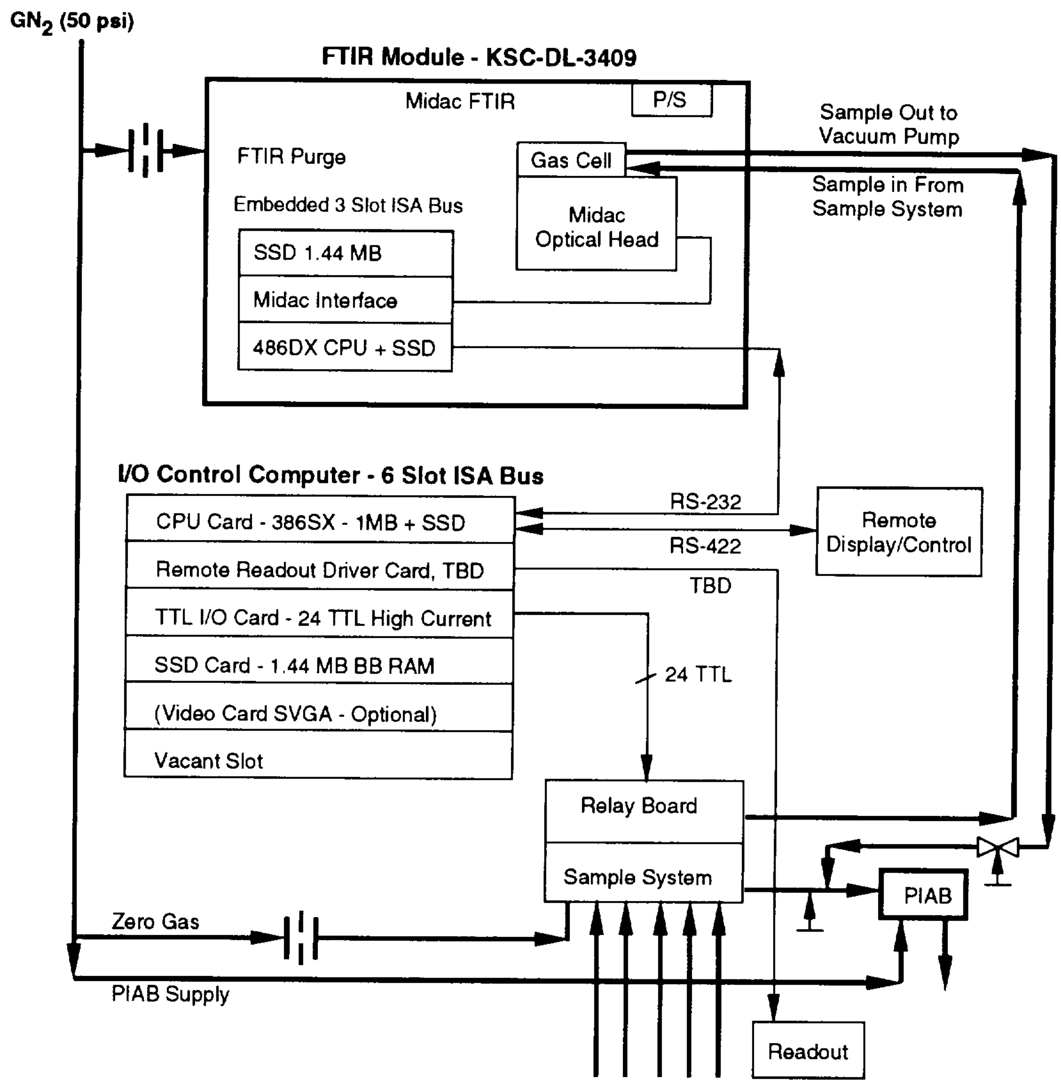
Participating Organization: Lockheed Martin Space Operations (S.M. Schneider, D.B. Mondshein, H.R. May, and M.G. Hadley)

Application of Fourier Transform Infrared (FTIR) Spectroscopy to Hydrocarbon Detection in Spacecraft Processing Facilities

Minimization of molecular contamination during spacecraft and payload processing is critical for mission success. The performance of many experiment package and satellite sensor systems can be compromised if they become contaminated by even small amounts of foreign substances. Molecular contamination can be loosely divided into two classes. First, if the volatility of the substance is low enough, it tends to accrete on surfaces and becomes what is called nonvolatile residue (NVR). Second, for the higher volatility substances, the substance tends to be more prevalent in the facility as a vapor. Both of these classes can cause problems. The classes of compounds to be considered here are the more volatile ones. The original intent of the study was to look into hydrocarbon contamination monitoring, but the technology discussed here can be applied to a much wider variety of compounds.

During processing, safeguards are implemented to protect the sensitive surfaces, sensors, etc., from contamination. However, many of the spacecraft processing activities have the potential for producing molecular contamination and must be monitored to ensure the protective measures taken remain adequate for the processing environment. Current practices for monitoring of hydrocarbons in a facility depend upon the sensitivity of the payload or spacecraft to hydrocarbon contamination. When the hardware in a facility is deemed to be relatively insensitive, monitoring is accomplished simply by taking air samples at several week intervals and analyzing the sample at an off-line laboratory, usually with a flame ionization detector (FID) that in principle counts the carbon content of the burned sample. The result is expressed as a "methane equivalent" and contains no information about what the substance might have been. For sensitive payloads, one or more FID's might be placed within the facility and monitored in real time. Typical thresholds for allowable hydrocarbons are in the single-digit part-per-million range.

A new instrument was developed at KSC that has the ability to continuously sample and analyze the facility environment. To date, three applications of this technology have been realized: for hypergol monitoring, for tile rewaterproofing compound monitoring, and for Space Station Processing Facility ammonia monitoring. The same basic technology is now being applied to monitor hydrocarbons and other chemical vapors in facilities. The FTIR-based hydrocarbon vapor monitor can provide qualitative identification and quantitation of substances in the environment. Up to 20 compounds can be monitored simultaneously with the current version of the instrument. The current effort includes establishing a training set of compounds for this new application. Potential uses for this instrument include monitoring the processing of the Hubble telescope refurbishment and AXAF missions. Current plans are for a single-FTIR cart that can service



Hydrocarbon FTIR Cart Block Diagram, Two Computers

up to six sample sites up to 200 feet away from the unit. The design base of the previous three applications of this instrument includes hazard-proof designs, electromagnetic-interference-compliant designs, complex sampler manifolds, self-zeroing, and real-time remote communication by radio link. Calibration cycles for this type of unit in normal operation can be up to 1 year. Internal health checks can alert personnel when maintenance or recalibration is necessary. In all, the technology is quite powerful, bringing the capabilities of an automated analytical laboratory into the field.

Key accomplishments:

- Defined the preliminary training set and set up the instrument to recognize common solvents and some additional compounds.
- Produced a videotape presenting the FTIR concept for distribution to other NASA centers.
- Presented the concept to an ASTM representative.
- Presented the concept to operations representatives.

Key milestones:

- 1996: Acceptance of concept (second quarter) and prototype cart delivery (third quarter).
- 1997: Final cart delivery (first quarter).

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

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

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 multiphase mixtures with a practical device. Some examples include: (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. Bi-directional 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 I-NET-developed configuration.

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 for 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 with each measuring the average capacitance of the mixture around each end of the probe. A personal computer is used to store and analyze the 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 LCD 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 real-time display. Displayed quality meter at Technology 2003.
- 1994: Tested meters in series using liquid nitrogen tanker. Presented technical paper at Technology 2004 conference. Submitted Technology Brief.
- 1995: Submitted patent to Patent Office. Evaluation of two commercial proposals for dual use. Selected technology transfer program.

Key milestones:

- 1995: Selection of dual-use commercial partner.
- 1996: Receive patent. Develop (redesign/test and evaluate) commercial meter for production.

Contact: R.J. Werlink, DM-ASD, (407) 867-3478

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

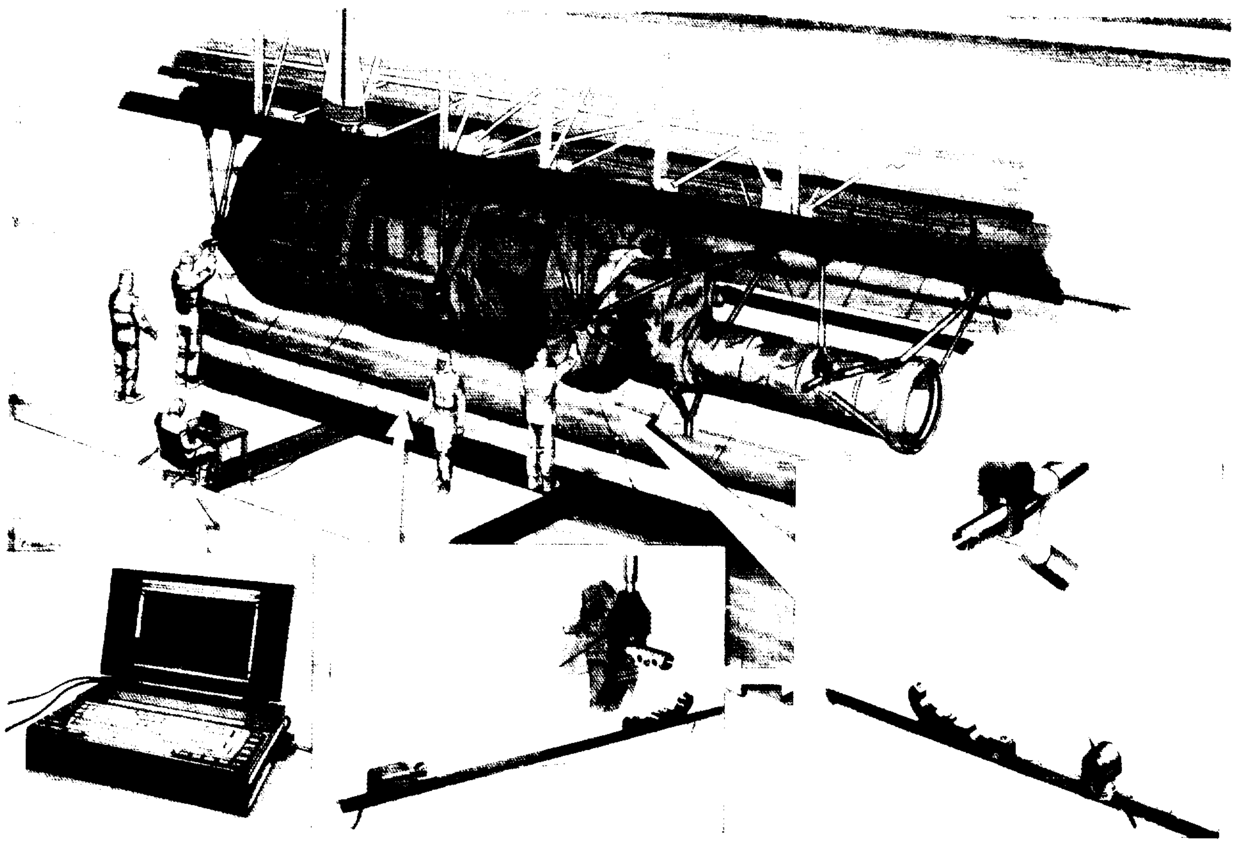
Advanced Payload Transfer Measurement System

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 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 very fast 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: Develop the production coordinate measurement unit. Develop the software to calculate move commands.
- Third quarter 1996: Develop and perform the test plan on the production system.
- Fourth quarter 1996: Initiate facility modifications required for installation of the system.
- 1997: Complete facility modifications and validation testing of the operational system.

Contacts: E. López del Castillo and T.A. Graham, DM-ASD, (407) 867-7890

Participating Organizations: NASA, Advanced Systems and Analysis Division; 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

Unique Method of Testing Surface Acoustic Wave Microbalances Using Langmuir-Blodgett Layers

Surface Acoustic Wave (SAW) device microbalances are currently being investigated as potential monitors for nonvolatile residues in spacecraft processing facilities at KSC. In order to enable onsite validation of instrument sensitivity, an investigation was launched to find a suitable means for depositing a known quantity of substance on the SAW device sensor.

In conjunction with the Physics Department at the University of Central Florida (UCF), a cost-effective device was designed and fabricated to deposit Langmuir-Blodgett films on SAW devices. Langmuir-Blodgett films are molecular monolayers, and, using a proven technique, multiple monolayers can be built up layer by layer to the desired thickness. Because the properties of the monolayer are well known, the deposited mass can be calculated to a high degree of accuracy.

Langmuir-Blodgett Deposition Troughs normally require a tensiometer, a device for measuring surface tension of liquids, in order to deposit the layers. The total system can be very expensive. The UCF-developed device eliminates the need for a tensiometer through the use of a carefully designed procedure and the use of unique compounds. After a long search for the best compound for ease of use and compatibility with the SAW device materials, a compound was found that was well suited to the job. Layers have been successfully deposited, and the SAW sensitivities determined from them are found to be within 2 percent of the accepted values as determined by effusion cell deposition, considered to be the primary calibration technique.

Key accomplishments:

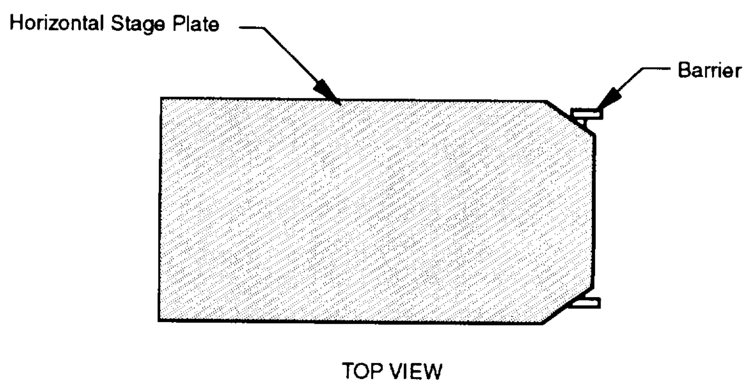
- Best compound for use was determined.
- Langmuir-Blodgett trough was designed to eliminate the need for a tensiometer.
- Repeated successful application of the trough and the technique.

Key milestones:

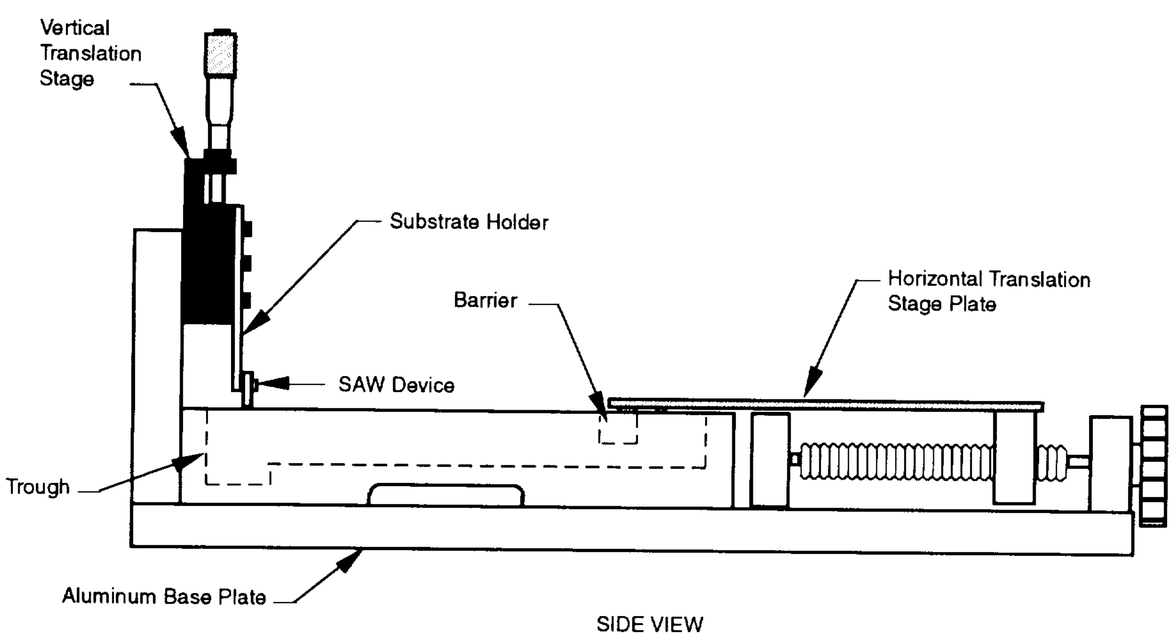
- Compound determination.
- Design and fabrication.
- Langmuir-Blodgett trough testing.

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

Participating Organizations: I-NET, Inc. (C.J. Schwindt) and the University of Central Florida



Horizontal Stage Plate With Barrier



Manually Controlled Langmuir-Blodgett Trough (With SAW Device)

Fourier Transform Infrared (FTIR) Instrumentation To Monitor Vapors From Shuttle Tile Waterproofing Materials

The Space Shuttle Thermal Protection System (TPS) tiles and blankets are waterproofed using dimethylethoxysilane (DMES) in the Orbiter Processing Facility (OPF). DMES has a threshold limit value (TLV) for exposure of personnel to vapor concentration in air of 0.5 part per million (ppm). 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 TLV. On several occasions, the high bay has remained cleared of personnel for up to 8 hours. There was reason to believe that some of the high DMES concentration readings were caused by interference from water and ethanol vapors. Earlier test results reported in the Research and Technology 1994 Annual Report demonstrated that the single wavelength infrared (IR) instruments did respond to ethanol and water vapors more or less depending on the analytical IR wavelength selected. An FTIR spectrophotometer instrument developed for an earlier project was reprogrammed to measure DMES vapor along with ethanol, water, and several common solvent vapors. Three portable FTIR-based instrument systems were designed and built on carts (DMES carts) to provide permanent field measurements of DMES for the OPF (see the figure "DMES Cart for Operational Support of Shuttle TPS Waterproofing").

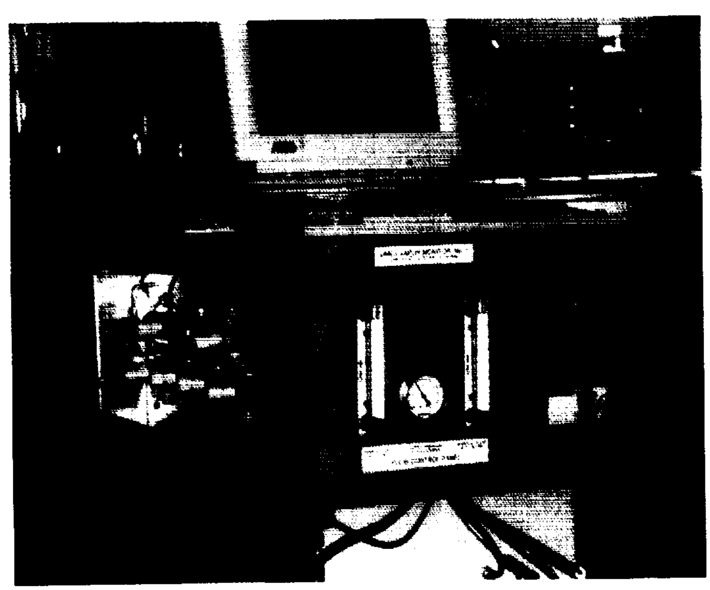
The DMES cart samples six points (five fixed locations at distances up to 200 feet and one movable sample tube with a movable display). The DMES cart begins operation automatically when power is turned on. The sample system cycles automatically through all six sample points during normal operation. On user command, the sample system samples only the movable line, while transmitting readings to a movable display. The fixed display has two screens: (1) a display of the OPF floor plan with readings displayed at each sample location and (2) a display of six graphs, one for each sample location of DMES concentration versus time. In order to ensure instrument drift does not cause false positive readings, a built-in zero-gas source is used. A new reference spectrum is acquired automatically or on user command.

The sample pumps are gas-driven eductor pumps with no moving parts. The gas supply provides drive gas for the sample pumps, zero gas for the built-in zero reference, and instrument purge for the FTIR. Reference spectra are acquired automatically using the zero-gas source. All gas consumption, except the FTIR purge, is turned off automatically when power is removed from the cart.

The DMES carts were tested to demonstrate that performance

DMES Cart for Operational Support of Shuttle TPS Waterproofing

Shown is the left front view of the DMES cart showing the flow control panel, sample manifold (left side), FTIR Module (bottom shelf), control computer (behind the right side of the flow control panel), keyboard, mouse, and monitor. Sample and manifold flows are controlled by valves on the two rotameters. Not visible is the gas supply panel with a quick disconnect for nitrogen supply connection. The user interface uses screen "buttons" to switch between display modes with password protection on most functions. The monitor display is the six-graph screen. An alternate screen shows measurements located on an outline of the orbiter.



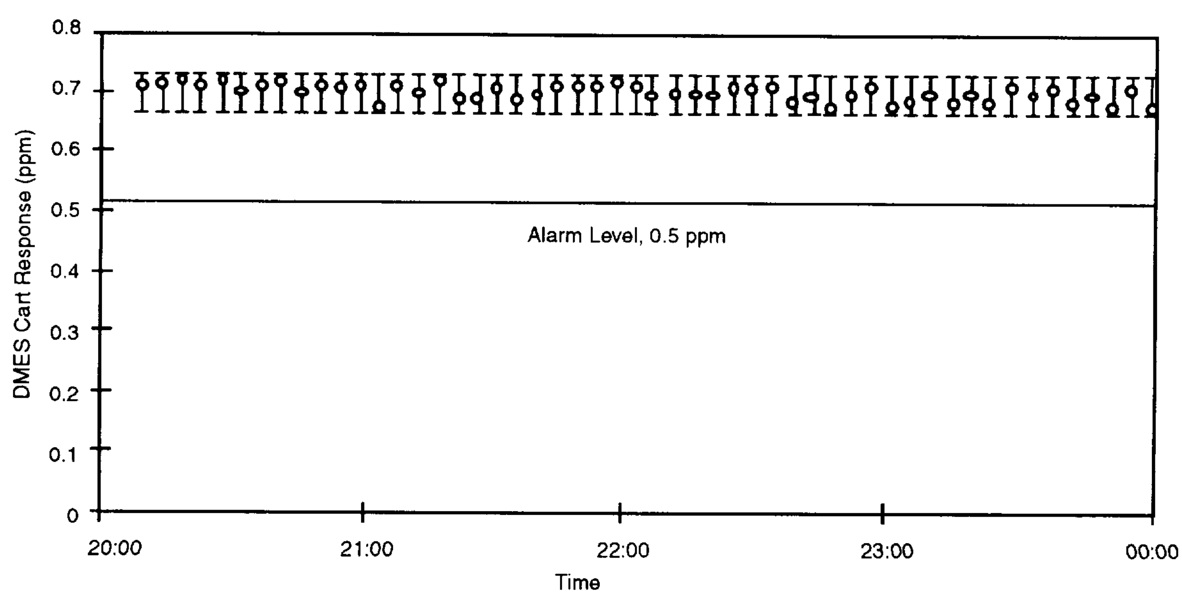
meet customer requirements. The tests included low-level measurements (less than 1 ppm) for noise performance and high-level tests (greater than 50 ppm) for response and recovery times. The required parameters and the measured performance are summarized in the table. See the figure "DMES Cart 2 Noise Performance" for the DMES cart readings over a 4-hour period with error bars of 3 standard deviations of the data over the 4-hour period.

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

Participating Organization: I-NET, Inc. (C.B. Mattson, C.J. Schwindt, and D.E. Counts)

Summary of DMES Cart Performance

Parameter	Performance Requirement	Typical Performance
Range minimum	0.1 ppm	0.09 ppm at 3 standard deviations
Range maximum	100 ppm	125 ppm ±4.5 ppm at 3 standards deviations
Noise at 0.5 ppm	Less than 0.1 ppm	0.09 ppm at 3 standard deviations
Response time to sample to 90 percent of input	Less than 60 seconds	30 seconds
Recovery time 80 ppm to less than 0.1 ppm	Less than 60 seconds	45 seconds
Accuracy at 0.5 ppm	Less than 0.1 ppm	0.09 ppm at 3 standard deviations
Drift in 4 hours	0.1 ppm	Less than noise band after warmup



DMES Cart 2 Noise Performance *(The data points were sampled from 200 feet of a 1/4-inch-inside-diameter Teflon tube over a 4-hour period. The sample spacing in time is approximately 5 minutes, the time required to sample all six lines.)*

Real-Time Monitoring of Nonvolatile Residue Contamination

Deposition of molecular contaminants on the surfaces of satellites and other payloads can seriously degrade their performance. Monitoring of the deposition of these nonvolatile residues (NVR's) is currently performed by placing a witness plate near a payload for 2 weeks and then collecting the plates for laboratory analysis. Monitoring the deposition of NVR every 2 weeks does not allow any proactive measures to prevent payload contamination.

For this reason, the NASA Contamination Monitoring Laboratory initiated a contract with Femtometrics, Inc., of Costa Mesa, California, for the development of a real-time detector for NVR's. This instrument is now being sold commercially.

The Surface Acoustic Wave (SAW) sensors use a measurement crystal and a reference crystal in an arrangement similar to the traditional quartz crystal microbalance (QCM) sensor. The SAW sensor is based on the changes in propagation of a wave along the sensor surface as NVR mass is deposited rather than a change in mechanical oscillation frequency as in a QCM sensor. SAW sensors are much more sensitive than QCM sensors and, thus, make far superior real-time monitors for molecular deposition.

The SAW sensor shows a sensitivity of approximately 50 hertz per nanogram per square centimeter (50 $Hz/ng/cm^2$). This allows the deposition and reevaporation of various surface contaminants to be monitored in real time.

Key accomplishments:

- Final field testing of the instrument at KSC.
- Repackaging the final commercial product.
- Closeout of the development contract.

Key milestone:

- Development project ended September 30, 1995.

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

Participating Organizations: I-NET, Inc. (C.J. Schwindt and C.B. Mattson) and Femtometrics, Inc. (Dr. W.D. Bowers)

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.

Magnetic Heat Pump Containing Flow Diverters

A proposed magnetic heat pump would contain flow diverters for suppression of undesired flows. If left unchecked, these undesired flows would mix substantial amounts of partially heated and partially cooled portions of a working fluid, effectively causing leakage of heat from the heated side to the cooled side. By reducing the leakage of heat, the flow diverters would increase the energy efficiency of the magnetic heat pump, which potentially offers an efficiency greater than that of a compressor-driven refrigerator.

In a magnetic heat pump of the type in question, a magnetic rotor would play a role analogous to that of the compressor in a compressor-driven heat pump. The outer surface of the rotor would include circumferential channels lined with and separated by walls and partitions containing a magnetic material. Pumps would circulate the working fluid between the heated-side and cooled-side heat exchangers. These pumped flows would be coupled into and out of the circumferential channels of the rotor via stationary ports in a housing in which the rotor turned.

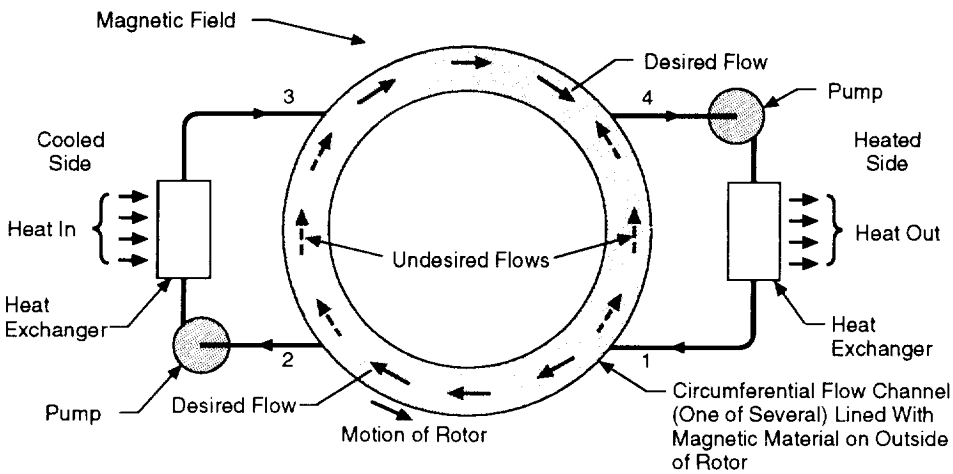
The direction of rotation of the rotor would be opposite the intended direction of the pumped flows. At one location in its circumferential travel (between points 4 and 3 in the figure), the magnetic material would pass through a magnetic field, which would align magnetic moments of electrons in the magnetic material and, thereby, heat the electrons. The heat thus generated would be transferred to the rest of the magnetic material and then to the working fluid flowing toward the heated-side heat exchanger. The heated-side heat exchanger would transfer heat to the environment on that side.

When the magnetic material left the magnetic field at point 3, the freeing of the magnetic moments of the electrons would cool the magnetic material. Because this magnetic cooling would occur immediately after the transfer of heat to the fluid during travel through the magnetic field, the magnetic material would emerge from the magnetic field cooler than it was before it entered the magnetic field. Continued rotation would carry the cooled magnetic material through the region between points 2 and 1, where it would cool the working fluid flowing toward the cooled-side heat exchanger. In the cooled-side heat exchanger, the working fluid would absorb heat from the environment on that side. From there, the fluid would flow into the rotor at point 3, then enter the portion of the rotor in the magnetic field, completing the magnetic heat-pump cycle.

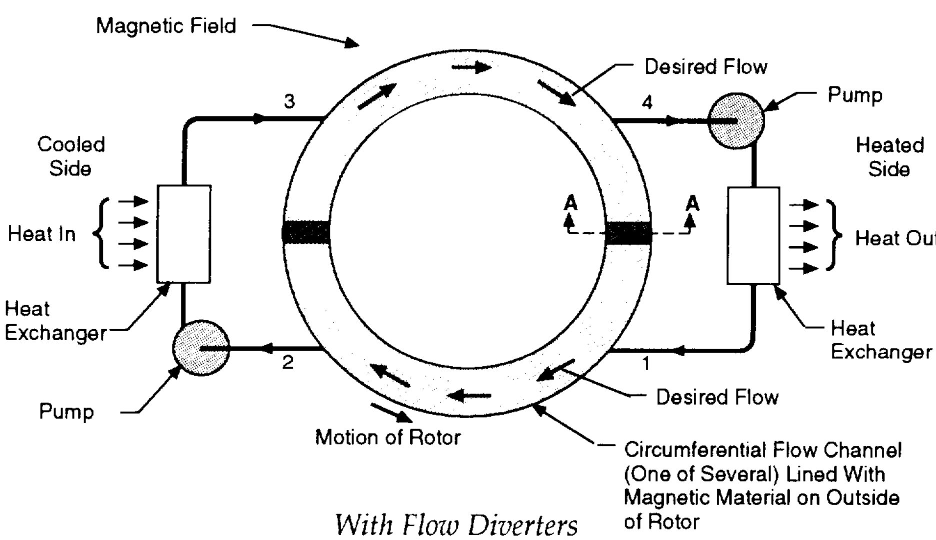
In the absence of flow diverters, there would be spurious flows along two paths through the rotor: from point 2 to point 3, bypassing the cooled-side heat exchanger; and from point 1 to point 4, as part of a short circuit through the heated-side heat exchanger. Accordingly, two flow diverters would be mounted at diametrically opposite points. Each flow diverter would be a comblike object with tangs that would fill most of the cross sections of the circumferential channels in the rotor. The gaps between the flow diverters and the walls of the channels would be just large enough to allow the rotor to turn freely and small enough that there would be very little flow through them.

Thus, the flow diverters would almost completely block the undesired flow paths, forcing most of the fluid to follow the desired long path through both heat exchangers and the rotor.

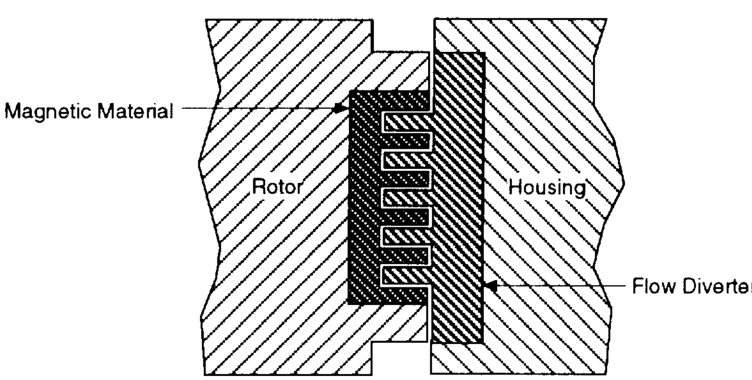
Contact: F.S. Howard, DM-ASD, (407) 867-3748



Without Flow Diverters



With Flow Diverters



Section A-A Magnified

Atmospheric Sciences

The Atmospheric Sciences program at the John F. Kennedy Space Center (KSC) addresses the impacts of weather on ground, launch, and landing processing with a view to increasing safety of personnel, protecting resources, and reducing lost work time by improving detection, analysis, and prediction of weather events and protection from weather events. Many of the weather impacts are of a specialized nature, differing from those felt by the public and even aircraft operations, and require studies and development that cross the lines of conventional scientific disciplines. Weather events focused upon by the program include lightning and cloud electrification, convective cloud growth, atmospheric surface and planetary boundary layer circulations and processes, wind shear effects, severe weather phenomena, rain, wind, and fog. Short-term attention is being directed to: (1) mesoscale numerical weather prediction models; (2) numerical models for prediction of transport and diffusion of hazardous materials; (3) improvement and development of weather detection instrumentation and protection methods; (4) use of expert knowledge and artificial neural network techniques; (5) improvement of decision-making processes; and (6) improvement of the processing and synthesizing of the voluminous data sets needed for accurate description of weather events and processes to effectively display the information and aid in its assimilation by weather forecasters and operations and safety decisionmakers.

Long-term attention will be given to encouraging the evolution of more powerful numerical prediction models and computer systems, advanced detection and analysis of weather processes, advanced protection methods, and systems to support the processing and protection of future space vehicles and launch systems.

Coordinated Approach to Mesoscale Numerical Weather Prediction

Sophisticated models, adequate high-resolution data, and affordable computer power are becoming available to attack two difficult weather prediction problems attending operations at KSC: thunderstorms and toxic diffusion. Three separate efforts are being integrated by the Applied Meteorology Unit (AMU). The AMU is a joint venture of NASA, the U.S. Air Force, and the National Weather Service and is operated by ENSCO, Inc. This is the third year of a coherent multiyear approach to solve these problems.

The efforts are each derived from Small Business Innovation Research (SBIR) programs. The Mesoscale Atmospheric Simulation System (MASS) model from MESO, Inc., was delivered as the result of a NASA Phase II SBIR contract. The model is a three-dimensional, hydrostatic nested grid model with cloud physics. The smallest grid is 11 kilometers. It has the ability to continuously "nudge" the model forecasts with real data.

The Emergency Response Dosage Assessment System (ERDAS) model is a three-dimensional, nonhydrostatic nested grid model with toxic diffusion capability but without cloud physics. It was developed under an Air Force Phase II SBIR contract by Mission Research Corporation, ASTeR Division, and has a fine grid resolution of 3 kilometers.

The Parallelized Regional Atmospheric Modeling System (RAMS) Operational Weather Simulation System (PROWESS) is a three-dimensional, nonhydrostatic nested grid model based on the same model as ERDAS; but its fine grid resolution is 1.25 kilometers and includes cloud physics without toxic diffusion. It is a follow-on to a NASA Phase I SBIR program developed by ASTeR with NASA advanced development funding.

The AMU evaluated MASS for transition to operational forecast use and is evaluating and tailoring ERDAS for operational support to operations involving toxic or radiological hazards. The AMU also supervised the PROWESS subcontract. Each model has advantages and weaknesses. The unified approach is expected to result in a single operational numerical weather prediction system on the 1.25-kilometer scale with both cloud physics and toxic diffusion. It will have most of the advantages of each of the three systems and few of their weaknesses.

Key accomplishments:

- 1991 to 1993: MASS and ERDAS models developed under SBIR contracts.
- 1993: MASS model delivered to AMU and configured to accept real-time data from meteorological data systems. PROWESS requirements specified and work begun.
- 1994: MASS and ERDAS models running in real-time operational configuration. PROWESS running on multiple parallel processors with MASS/ERDAS-compatible data formats.

- 1995: Evaluated MASS and ERDAS accuracy and utility. Began transition planning. Completed PROWESS prototype and delivered to AMU for detailed evaluation.

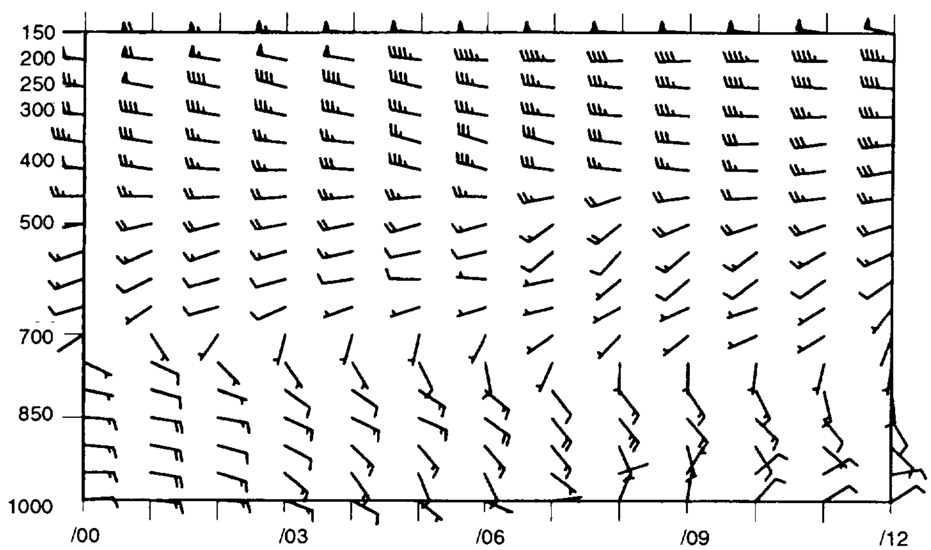
Key milestones:

- 1996: Implement ERDAS operationally. Decide whether to implement MASS operationally. Begin evaluation of PROWESS.

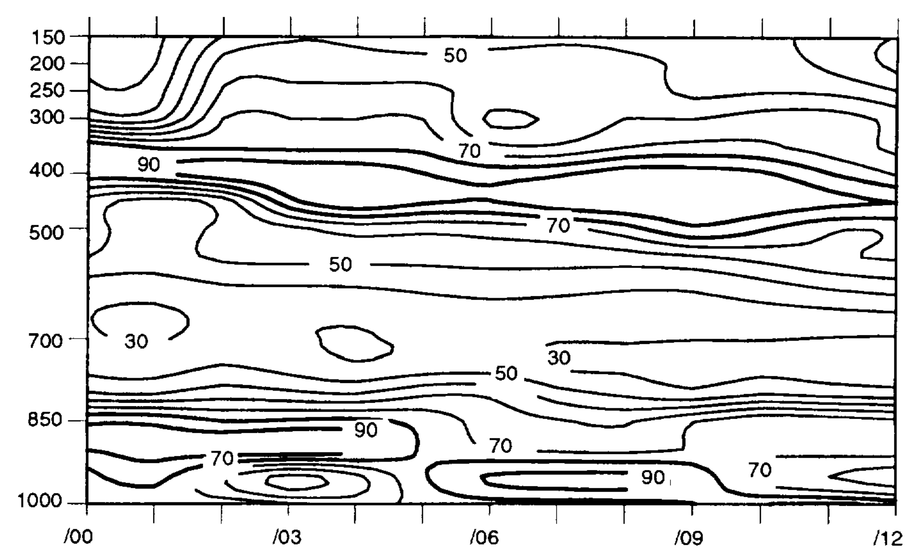
Contact: F.J. Merceret, Ph.D., TM-SPO-3, (407) 867-2666

Participating Organizations: ENSCO, Inc. (R. Evans; J. Manobianco, Ph.D; A. Yersavich; and G. Taylor, Ph.D.); MESO, Inc. (J. Zack, Ph.D.); and Mission Research Corporation, ASTeR Division (W. Lyons, Ph.D.)

MASS Model 11 km Run—Start 00Z 10-31-95 for TTS



Wind Direction and Speed (kt)



Relative Humidity (%)

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.

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 suits, 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 materials used in breathing gas systems be evaluated for flammability, impact sensitivity, odor, and offgassing.

Unfortunately, many commercially available devices contain materials that do 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.

Discussions with the National Institute of Occupational Safety and Health (NIOSH) revealed that NIOSH does not attempt to control the materials used in these devices because of the lack of test data on the reactivity of materials in compressed air and other oxygen-enriched gases.

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 would then be provided to aid 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 diene monomer (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 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 20-, 25-, and 30-percent oxygen. The auto-ignition 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.

During the first year, the majority of tests were completed on Teflon and Viton. Kel F and nitrile rubber tests are about 50 percent complete. Silicone rubber, Neoprene, and EPDM tests have begun.

An optional part of the program is the analysis of the pyrolysis products of the materials using a tube furnace equipped with a Fourier Transform Infrared (FTIR). This will produce data of interest to toxicologists and polymer chemists.

NIOSH is interested in this program and has indicated the results may be used in the future in the evaluation of emergency breathing air devices.

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

Thermally Sprayed Zinc Coating To Mitigate Concrete Rebar Corrosion

Zinc has been known for decades to have the capability to protect steel from corrosion. Galvanizing is the most common application of this principle. A test program is in progress to utilize the same approach to mitigate the corrosion of reinforcing steel in concrete.

Concrete is compatible with steel both chemically and electrochemically; therefore, it provides an ideal environment for reinforcing steel tendons. When salt intrudes concrete, this ideal environment is disrupted and steel starts to corrode, resulting in the spall of the concrete. In this situation, the principle of the zinc/steel couple can be applied theoretically. Corrosion of zinc thermally sprayed on the concrete surface generates an electrical current flow into the reinforcing steel (via an appropriate conduction path), thereby lowering the electrochemical energy of the reinforcing steel (or making it more stable). However, there are numerous technical issues that should be investigated for successful application of this principle.

One of the key issues that needs to be resolved is the stability of the concrete/zinc interface. Ideally, a zinc coating should corrode from the exterior only; however, salt in concrete, the electrical potential difference between zinc and reinforcing steel, and the change of pH of concrete are conducive to deterioration of zinc at the interface. This would increase the electrical resistance between the coating and reinforcing steel, lowering the efficiency of the corrosion protection.

A study is in progress to elucidate the mechanism of interface deterioration, specifically the identification of influential parameters and the quantitative characterization of the parameters. Effects of coating porosity, coating thickness, the salt content of concrete, the moisture level of concrete, and the current density are under study. Once this task is accomplished, efforts will be made to develop a technique that allows minimal interfacial deterioration with maximum corrosion protection efficiency.

Key accomplishments:

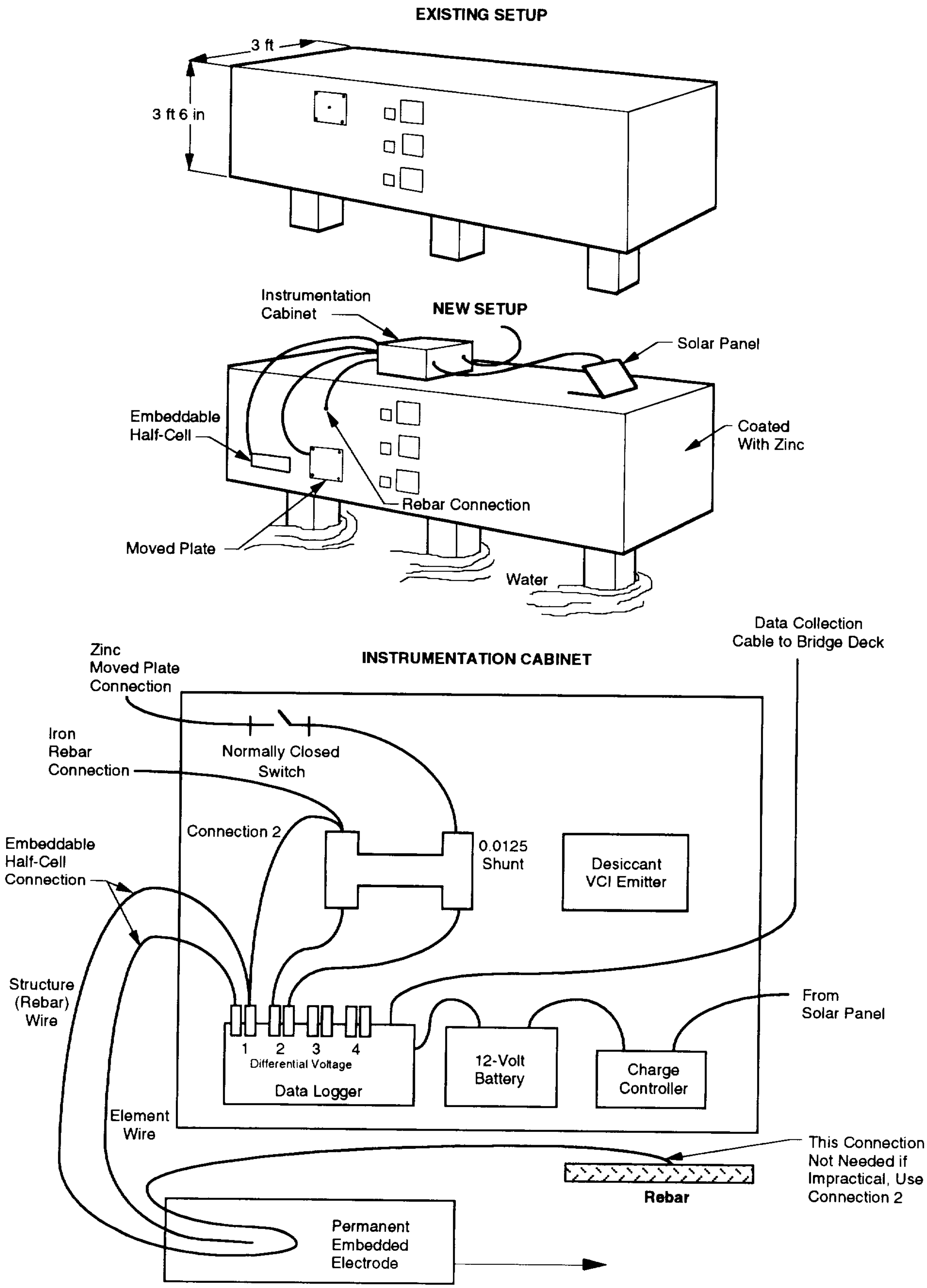
- Acquired engineering support from a contractor for 0.5 man-year. Test is in progress.
- Located a supplier of concrete test blocks fabricated to various mix designs.

Key milestones:

- A method will be developed to characterize the concrete/zinc interface based upon an electron microprobe.
- The effect of the current density on the interfacial degradation will be completed in 1996.

Contact: R.U. Lee, LO-MSD, (407) 867-3400

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



Interface Deterioration Study

VAB Roof Deck Rehabilitation

The roof deck of the Vehicle Assembly Building (VAB) is in the early stage of deterioration due to the corrosion of reinforcing steel. As launch-critical operations are performed in the VAB, any remedial measures to mitigate the corrosion should be minimally disruptive to the operations. Therefore, conventional cathodic protection-based approaches cannot be employed.

The VAB roof deck poses other unique situations: access is available from the underside only and the concrete cover on the underside is less than 1 inch. A corrosion mitigation method based upon a corrosion-inhibiting chemical applied from the underside is, therefore, a logical choice. Ammonium quartenary salts, initially tested by SRI International, were selected. Laboratory tests showed promising results.

Concrete Test Coupons Curing in the Temperature/ Humidity-Controlled Chamber

The study plan includes inhibitor penetration in the absence of an electrical field, assisted by the capillary action of fine cracks present in the deteriorating concrete. Also, the duration of the corrosion-inhibiting effect after treatment will be studied.

This study has another testing component based upon the silicate concrete sealer applied after the inhibitor treatment. This is a joint development effort between NASA/KSC and an industry partner under the Space Act Agreement.

Key accomplishments:

- Obtained engineering support for 0.5 man-year.
- Proved a 1-week treatment provided adequate corrosion mitigation.
- Signed a Space Act Agreement for a joint development project between NASA/KSC and an industry partner.

Key milestones:

- Inhibitor penetration via cracks and pores will be tested and quantified.
- Longevity of a 1-week treatment will be tested.
- Inhibitor efficiency will be compared to that of inorganic nitrite (calcium nitrite).

Contact: R.U. Lee, LO-MSD, (407) 867-3400

Participating Organizations: NASA, IM-FFO-A (T. Yang); I-NET, Inc. (J.J. Curran and R.G. Barile); and University of Central Florida (V. Desai)

Effects of Chemical Aging of Polymers on Performance Properties

The project seeks to measure the changes in performance properties of polymeric materials due to 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 stabilizers can retard some effects but sometimes the effect is temporary. Skin effects are frequently not considered but can frequently 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 unaged 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. The areas studied were chemical structure, morphology, and properties of materials of interest.
- Test materials were specified and procured.
- Chemical exposures were started.

Key milestones:

Second Year:

- Chemical exposures will be completed.
- Fluid permeation and diffusion tests, chemical and morphological change studies, and performance tests will start.
- Correlations will be identified.

Third Year:

- All work started during the second year will be completed.
- 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

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.

The project seeks to develop and deliver to KSC a fully functional prototype PHE based on materials and components recently introduced to the market. Under an earlier grant, materials and components were procured and evaluated for physical properties and chemical resistance. The most promising material, glove, and boot were selected for the prototype construction. Tasks to be completed include suit design, integration of components, and evaluation of the finished 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

Propellant Handlers Ensemble Coverall [a Self-Contained Atmospheric Protective Ensemble (SCAPE) designed to protect the propellant handlers from exposure to toxic hypergol propellants]

Fracture Morphology of Selective Polymer Systems Under Monotonic and Fatigue Loading

An important activity at KSC is failure analysis of nonmetallic components. 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, which makes analysis difficult.

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 in order to establish their general mechanical behavior. Specimens will also be subjected to tension-tension cyclic loading. The 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.

The research is in the first year of a 3-year effort. Polymer specimens have been procured, and the research team has been assembled.

Key milestone:

- Four polymer systems will be fully evaluated each year.

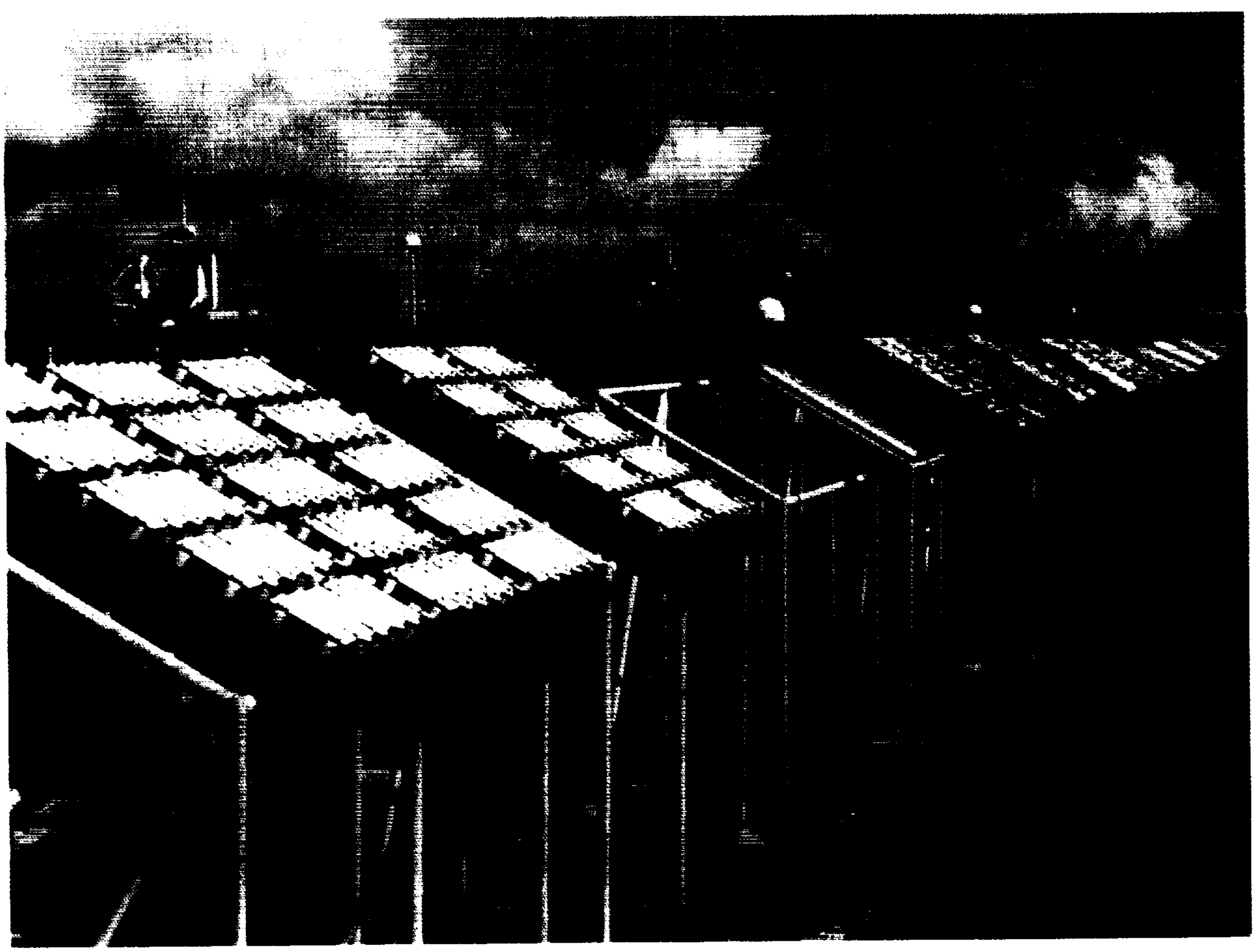
Contact: P.D. Faughnan, LO-MSD-1M, (407) 867-3400

Participating Organization: Tuskegee University (H.A. Aglan, Ph.D., P.E.)

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 is producing



Test Panels at the Beach Corrosion Test Site environmentally compliant, inorganic zinc coatings such as high-volume solids and water-based systems. New topcoat systems are also 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. The test panels were exposed in May 1991 to atmospheric contaminants at the KSC beach corrosion 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 are currently nearing the 54-month point, and a final report detailing the 60-month exposure results will be 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 54 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:

- Continue to monitor the test panels for the required 5-year exposure period and apply the acid slurry at regular intervals to simulate launch site conditions.
- Produce a final report at the end of the 60-month exposure period to document the performance of the coating systems.
- Continue to monitor the state of the art in environmentally compliant coating technology and evaluate new products as required.

Contact: L.G. MacDowell, LO-MSD-1M, (407) 867-3400

Accelerated Testing of Inorganic, Zinc-Rich Primers

Inorganic, zinc-rich coatings are used for corrosion protection of carbon steel structures at KSC. To be considered for use at KSC, a primer must successfully withstand exposure at the KSC beach corrosion test site. Primers are periodically rated for rusting on a scale of 1 to 10 in accordance with ASTM D-610, with a rating of 10 being the best. For preliminary approval, primers must achieve a rating of 9 or better after 18 months of exposure and continue to provide this level of protection for 60 months for final approval. Unfortunately, this process requires a considerable amount of time to place new products on the KSC Approved Products List contained in KSC-STD-C-0001.

Alternating current impedance measurement techniques, also known as electrochemical impedance spectroscopy (EIS), are being studied as a possible method for determining the corrosion resistance of inorganic, zinc-rich primers before exposing them to long-term testing at the KSC beach corrosion test site. A reliable accelerated laboratory test method such as EIS could save time for preliminary approval of primers.

For this method, primers are sprayed on test panels for use in the laboratory experiments. The test panels are exposed at the beach corrosion site for various intervals before being brought back to the laboratory for testing. The panels are immersed in a 3.55-percent sodium chloride solution that is aerated during the test to provide oxygen necessary for corrosion reactions. Test results have yielded trends between several EIS measurement parameters and atmospheric coating performance. Measurements of the change of polarization resistance, pore resistance, phase angle, and coating capacitance can be used to gain understanding of the complex behavior of these materials. By aging the coatings in a natural atmospheric exposure prior to laboratory testing, a correlation has been found between the experimental results and the long-term field results. A final report was prepared with the equivalent circuit model for these coatings and data analysis to support the accelerated test method for prediction of long-term coating performance. This work was submitted, accepted, and presented at an international corrosion conference dealing with industrial and atmospheric corrosion problems.

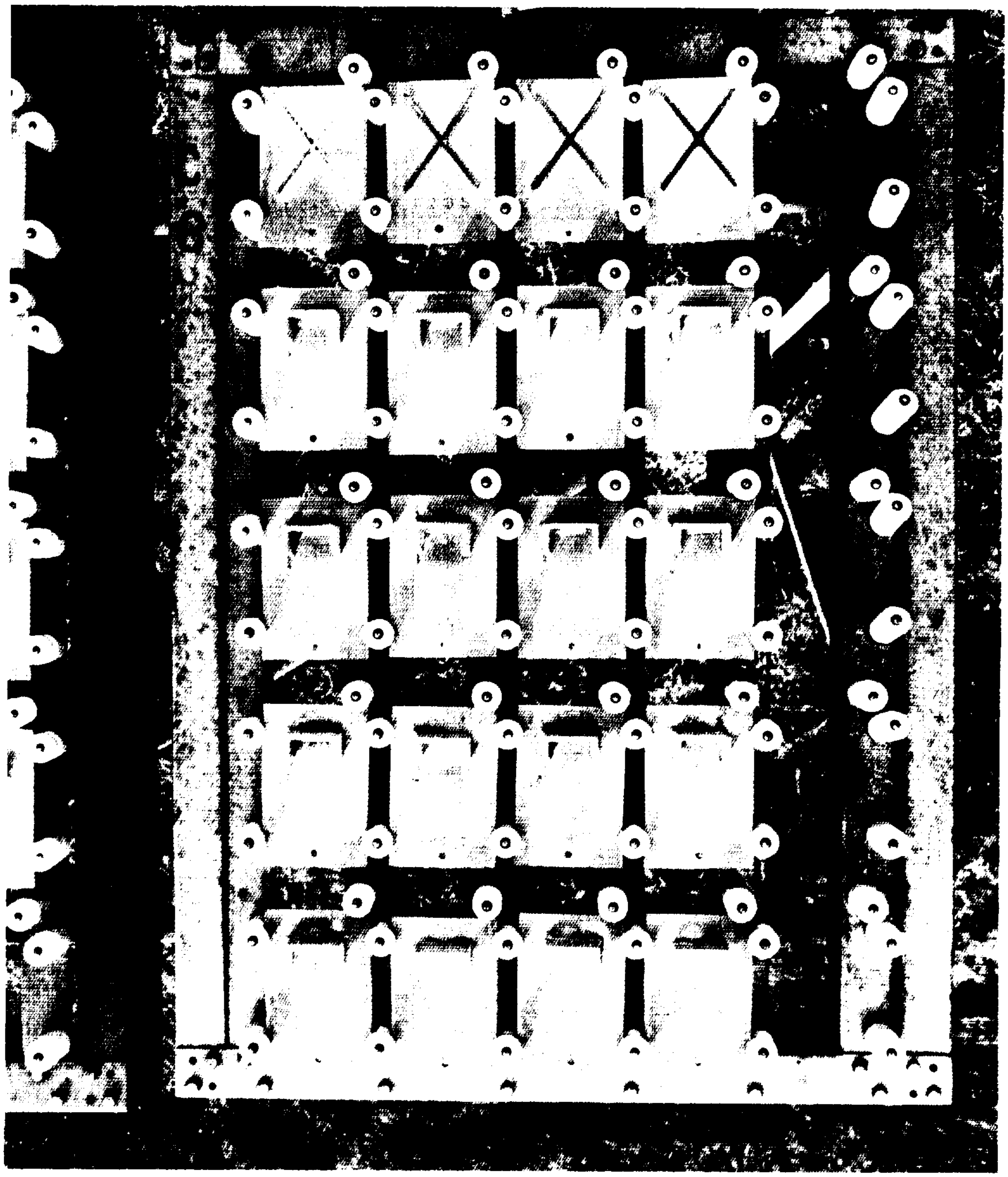
Key accomplishments:

- Test program was started in July 1993.
- Testing was conducted on primers that have already been exposed at the beach corrosion site for 54 months.
- Results were compared to similar work conducted in 1989.
- Twelve-month exposure cycle was completed, and the results were analyzed.
- Final report detailing predictive techniques was published, and the report was presented at an international corrosion conference.

Key milestone:

- Data analysis techniques will be refined to allow predictive results based solely on EIS experiments.

Contact: L.G. MacDowell, LO-MSD-1M, (407) 867-3400



Exposure Testing at the KSC Corrosion Test Site

Development of Silicone Ablative Coatings for Protection of Launch Structures

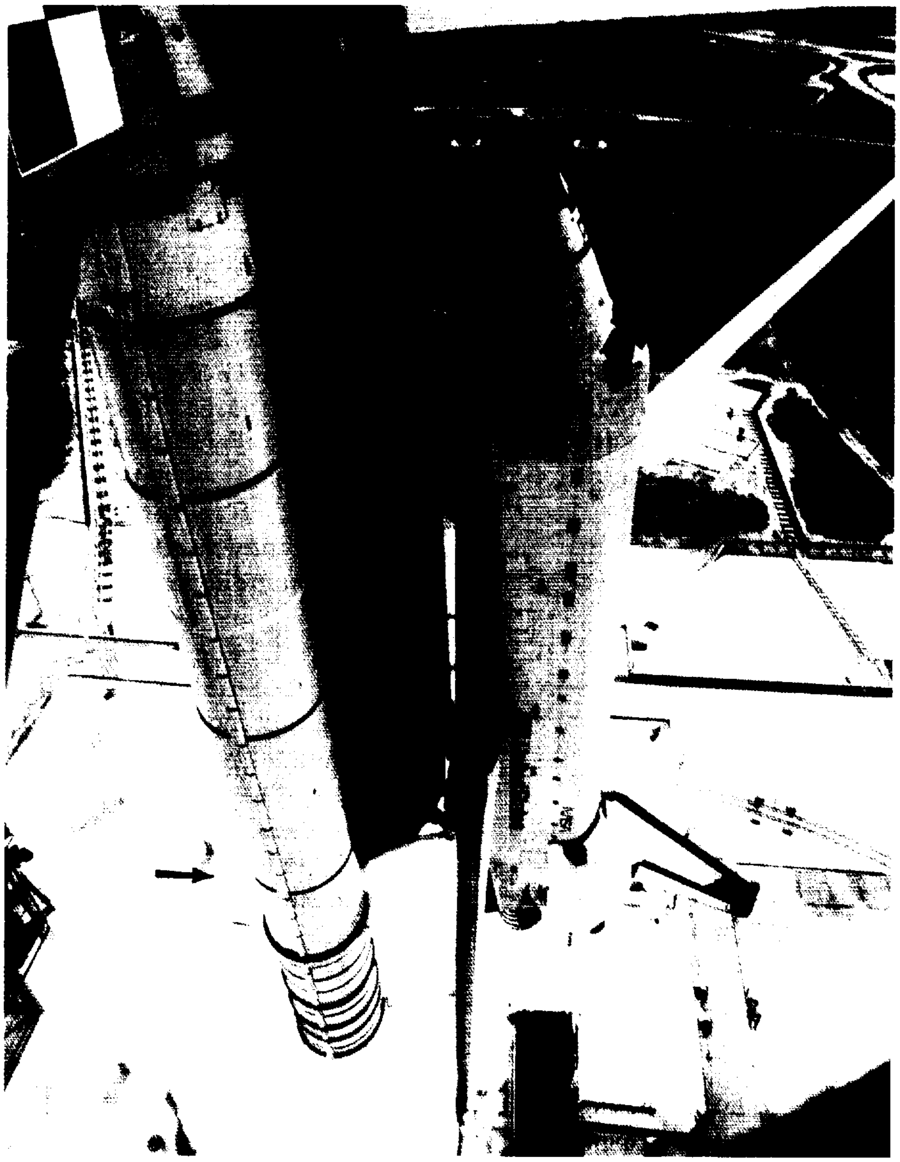
When the Space Shuttle is launched from Launch Complex 39, it produces extreme heat, abrasion, and chemical exposure that severely stresses protective coatings on nearby equipment and structural components. The inorganic zinc (IOZ) coatings used to protect the structural steel from salt corrosion cannot withstand this abuse in several areas on the pad. After each launch, surfaces located at the 95-foot level, the interface tower, the hydrogen bridge structure, and the east stair tower receive a lot of heat and burnoff of the IOZ. These areas require expensive refurbishment after each launch to protect the structure, which accounts for a majority of the overall structural work costs.

As a possible solution to this problem, ablative-type silicone-based coatings were investigated based on the success of these types of materials used on other systems in the blast zone at the pad. At that time, the approved silicone ablative coatings were only in a trowelable form that also required the application of sensitive silicone primers to the surfaces for adhesion purposes. The study focused on the development and approval of new-generation silicone coatings that were not only sprayable but self-priming as well. The ability to spray coat rather than trowel-apply surfaces would allow the application of these materials to large surface areas with relatively low labor costs.

In conjunction with several industry partners, these new-generation materials were formulated, sprayed, evaluated, and approved for use on Launch Complex 39 structures. These silicone ablative materials held the promise of forming a tough surface film when subjected to intense heat and eroded only slightly from the effects of a Shuttle launch. Even though these ablative materials would initially cost more to install than the IOZ coatings, the time and effort saved by not having to recoat after each launch would allow payback in a relatively short time. The reduction in refurbishment after each launch would also reduce turnaround time for use of the launch pad structures and systems.

For this effort, the materials were sprayed onto steel test panels and mounted on a carrier plate. This plate was attached to the Mobile Launcher Platform deck (see the photo). After exposure to launch, the panels were removed and evaluated for approval. Based on the results of these tests, several materials were approved for use at KSC launch facilities and will be included in the current revision of KSC-SPEC-C-0006.

As part of a major refurbishment to Launch Complex 39B in 1994, an approved ablative silicone was applied to areas of the 95-foot level and the weather protection system in preparation for STS-64. Following that launch, the ablative coating was found to have performed very well. Since that time, the material has resisted the effects of five more launches and has significantly reduced launch damage, associated refurbishment costs, and turnaround time. The materials have also been applied



Arrow shows the location of the evaluation panels installed on the launch deck as part of the qualification tests.

at Launch Complex 40 at Cape Canaveral Air Station with similar successful results. Details of the laboratory testing and exposures at Launch Complex 40 can be found in several publications under document numbers FAM 92-2150 and FAM 93-2057. Results of this work were also documented in a manufacturer's newsletter in 1994 and in the Journal of Protective Coatings and Linings of the Steel Structures Painting Council in July 1995.

Key accomplishments:

- Test program began in 1990 to develop new-generation sprayable silicone ablative.
- Materials were evaluated in 1992 and 1993 with several materials being approved for use at KSC.
- Full-scale application on Launch Complex 39B was conducted in 1994.
- Postlaunch evaluation revealed exceptional performance of the material.
- Material has continued to provide protection for five launches.

Key milestones:

- Materials will continue to be evaluated for long-term durability and effectiveness.
- Material application equipment will continue to be refined for ease of use.
- Application of material to other launch structures such as Launch Complex 39A.

Contact: L.G. MacDowell, LO-MSD-1M, (407) 867-3400

NASA/KSC-Approved Material List

The Logistics Directorate's Materials Science Division has the responsibility for maintaining an approved list of plastic film and adhesive tapes used throughout KSC. The NASA office has initiated a program to test the various materials submitted by KSC personnel for flammability resistance, electrostatic discharge potential, and hypergolic ignition resistance. This program helps to develop a quick reference guide on how the materials perform when tested against KSC safety acceptance criteria.

With the assistance of the KSC Safety Office, an approved material list for both plastic films and adhesive tapes has been developed. The list is published in GP-1098, KSC Ground Operations Safety Plan, Volume I, Safety Requirements, and is updated quarterly. Based upon their ability to meet the various acceptance criteria, the materials are categorized into four groups:

1. Group I: These materials have met the acceptance criteria for flammability, electrostatic discharge, and hypergolic ignition resistance. They are approved for use in all KSC flight hardware processing facilities.
2. Group II, Subgroup A: These materials have met the acceptance criteria for flammability and electrostatic discharge but not for hypergolic exposure.
3. Group II, Subgroup B: These materials have met the acceptance criteria for flammability and electrostatic discharge for an operational environment that is at 45-percent relative humidity or higher. They may or may not be suitable for hypergolic exposure.
4. Group II, Subgroup C: These materials have met the acceptance criteria for flammability but not for electrostatic discharge. They may or may not be suitable for hypergolic exposure.

The Materials Science Division will continue to update and expand the list as required to suit the needs of KSC operations. This list has proven to be a valuable tool for the selection of various materials for specific aerospace applications.

Contact: R.J. Frankfort, LO-MSD-2T, (407) 867-4619

Flammability Test

Evaluation of Various Abrasive Grits for Replacement of Silica Sand in Sandblasting Operations

In 1990, a research project was undertaken to study a number of abrasive grits used for sandblasting to find a viable alternative to silica sand. Recent years have seen an increased concern over the associated health hazards resulting from silica sand use. When silica sand impacts a surface at high velocities, the sand particles break up releasing free silica into the air. This free silica, suspended in the air, can be carried downwind where it may be ingested into the lungs. The result of long-term exposure to free silica in the lungs — silicosis — has a similar health impact as does asbestosis. In 1993, silica sand use in sandblasting was banned at KSC.

This abrasive grit study analyzed silica sand and 27 grits using a number of tests and measurements. The grits were categorized into the three types of grit: steel, mineral, and slag. Four steel, seven mineral, and seventeen slag grits were selected for testing. A complete list of the grits, types, and manufacturers is shown in the table. Seven 4- by 6-inch carbon steel panels were blasted to a white metal condition for each candidate grit. Three of these panels were then coated with Cathacoat 302 for salt fog and beach exposure tests. Testing also included two high-humidity tests on bare panels, surface profile measurement, soluble contaminants, grit composition, geometry profile, and Toxicity Characteristic Leaching Procedures (TCLP's) for heavy metals.

Results yielded that overall the grits performed well in the coated panel exposure testing, and no relationship between grit type and coating performance could be determined. However, the most critical aspect of selecting a grit appears to be chemical analysis in the form of TCLP and soluble contaminants. Several of the grits had high readings of lead or other heavy metals, making them poor selections for use. Using a grit with readings close to the allowable limits for heavy metal content would most likely make the postblasting cleanup a hazardous waste problem. In addition, a few of the grits had high levels of chloride or sulfate, increasing the chances to accelerate corrosion of the base steel. There is a correlation between the grit particle size and the surface profile for the grits. Surface profile can also be controlled by adjusting the pressure of the air/grit passing through the nozzle.

Key accomplishments:

- Determined grit types comparatively had little impact on coating performance.
- Heavy metal content and soluble contaminants in the form of sulfate and chloride should be considered first when selecting an abrasive grit.
- Confirm that slag or mineral grit that contains silica is in the amorphous phase to avoid free silica problem.

Contact: C.A. Finchum, LO-MSD-2T, (407) 867-4619

Abrasive Grits Used in Evaluation Project

Grit Name	Type	Manufacturer
Amasteel 40	Steel	Ervin Industries, Inc.
Amasteel 50	Steel	Ervin Industries, Inc.
Black Beauty 20/40	Slag (coal)	Reed Minerals Division
Blastite 46	Slag (aluminum oxide)	Washington Mills Electro Minerals Corp.
Blastite 54	Slag (aluminum oxide)	Washington Mills Electro Minerals Corp.
Copper Blast All-Purpose	Slag (copper)	Union Pacific Resources
Copper Blast Medium	Slag (copper)	Union Pacific Resources
Exolon ESK 16/30	Slag (silicon carbide)	Exolon ESK Company
Exoblast 24/48	Slag (aluminum oxide)	Exolon ESK Company
Fairmount Coal Slag	Slag (coal)	Fairmount Abrasive Systems
Fairmount Silica Sand	Mineral	Fairmount Abrasive Systems
FastBlast 20/40	Slag (aluminum oxide)	Exolon ESK Company
FastGlass 20/40	Slag (glass)	3R Mineral and Manufacturing Co.
Flintabrasive	Mineral	MDC Industries
Garnet (GMA)	Mineral	Barton Mines Corp.
Green Lightning 40	Mineral	Applied Industrial Materials Corp.
Met Grain 40	Steel	Chesapeake Specialty Products
Niagara Blast 40	Slag (aluminum oxide)	Washington Mills Electro Minerals Corp.
Niagara Blast 50	Slag (aluminum oxide)	Washington Mills Electro Minerals Corp.
Poly-Grit 40	Slag (copper)	MDC Industries
Stan-Blast Fine	Slag (coal)	Stan Blast Industries
Stan-Blast Medium	Slag (coal)	Stan Blast Industries
StarBlast	Mineral	DuPont Company
Staurolite, Coarse 15/54	Mineral	DuPont Company
Steel Grit RG 50	Steel	3R Mineral & Manufacturing Co.
Tri-Mix 20/40	Slag (glass)	3R Mineral & Manufacturing Co.
Tufblast 24/36	Slag (aluminum oxide)	Abrasive Materials Inc.

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.

Verification Test Article (VETA) Project: Validation of Random Vibration Response Models

During a Shuttle launch, ground support equipment and structures in the proximity of the launch pad are often subjected to intense vibration due to acoustic pressures generated by rocket exhausts. Simply stated, vibroacoustics or vibroacoustic coupling is a measure of a structure's affinity to vibrate when subjected to broadband acoustic loads, leading to degradation of structures and, thereby, increasing operational maintenance costs. Thus, continuous monitoring of launch-critical loads (acoustics) and simultaneous structural response (vibration and strain) is vital for maintaining KSC's leadership role in preparing and launching Shuttle missions and for ensuring operational safety and long-term reliability of existing and future pad structures.

Decade-long research at KSC has focused on development of unique analytical tools, both to characterize noise and predict vibroacoustical behavior of structures. Two analytical models (probabilistic and deterministic) for the random vibration problem have been proposed. The choice of a particular model is governed by observations drawn from simultaneous acoustics and vibration measurements and accuracy with which the model predicts vibration response. Appropriate models would then aid in optimizing the design of new ground support structures and equipment and modifications to the existing ones. This present research is part of a multiyear test and validation project titled Verification Test Article (VETA).

Key accomplishments:

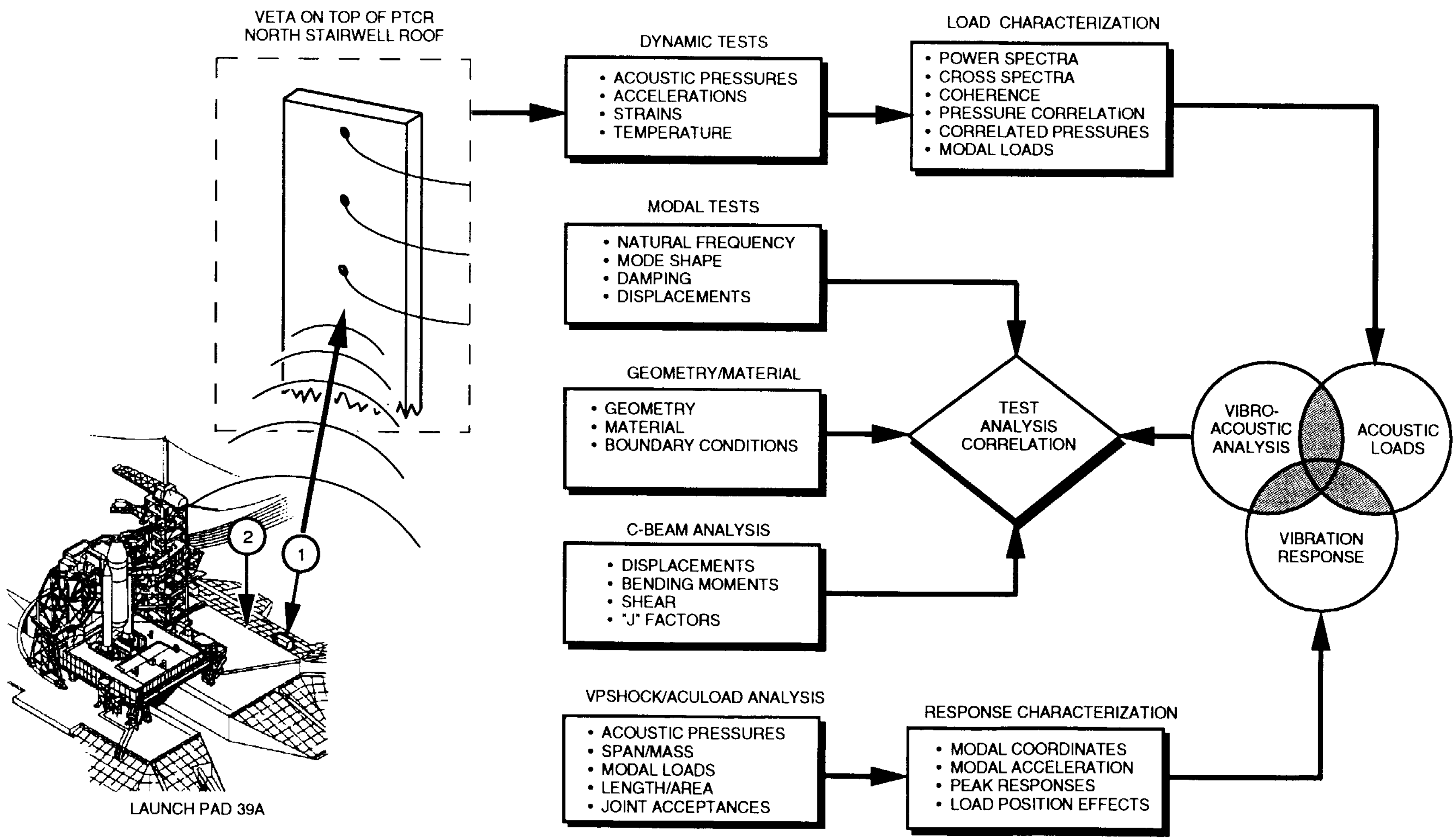
- 1994: Developed a low-cost, remote control, real-time data acquisition system to monitor and acquire launch data.
- 1995: Acquired acoustics and vibration data on a controlled test article (VETA) for seven launches from Launch Pad 39A.

Key milestone:

- 1996: Use analytical models to predict VETA structural response and compare this data with acquired data from Shuttle launches.

Contact: R.E. Caimi, DM-ASD, (407) 867-4181

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



Verification Test Article (VETA) Program
Real-Time Data Acquisition and Monitoring of Shuttle Test Analysis Correlation

Fourier Transform Infrared (FTIR) Microanalysis of Space Shuttle Orbiter/Payload Molecular Contamination

Surfaces when exposed to a vacuum environment, as experienced in space, can outgas low levels of nonvolatile residue (NVR). These outgased materials can easily polymerize and redeposit on critical optical surfaces, resulting in degradation. For sensitive instruments such as the Shuttle Solar Backscatter Ultraviolet (SSBUV) experiment that is used to measure stratospheric conditions, the concern of optical degradation initiated the development of a method whereby this contamination can be measured.

The advent of infrared microscope spectroscopy has opened many doors to different techniques for the analysis and characterization of materials by infrared spectroscopy. The method of reflection-absorption spectrometry (a double pass through a thin film on a reflective metallic surface) allows for a stainless-steel coupon to be used as a matrix to obtain qualitative and quantitative infrared (IR) data of molecular contamination.

In attempting to address preflight and postflight molecular contamination on the Space Shuttle bay and payloads, a method of applying sample solvent directly to and collecting from subject surfaces was developed. Isopropyl alcohol (hardware and solvent were baselined) was applied to the surfaces, collected (approximately 50 cubic centimeters), and evaporated on small preweighed stainless-steel mirrors (see figures 1 and 2). The resulting NVR was weighed and analyzed by IR reflectance microscopy (see figure 3). Wipe samples using another solvent mixture were also taken (contamination extracted), and IR results were compared.

Analysis results showed quantities ranging from low-microgram to full-milligram quantities. IR microanalysis revealed molecular species ranging from simple aliphatic hydrocarbons to complex urethanes found in the Shuttle paint and phenyl methyl silicone compounds found in the thermal control surface (see figure 4). Rinse-and-wipe sample data indicated consistent and complimentary results.

Data suggest this type of molecular contamination can be monitored. SSBUV performed at its efficiency peak on its first contamination monitoring STS-56 mission. In other missions, preflight contamination concerns from blankets of the Remote Manipulator System arm and from the support frame of the United States Microgravity Payload were detected and corrected before launching. This sensitive technique can be used to measure contamination levels on highly sensitive payloads.

Key accomplishments:

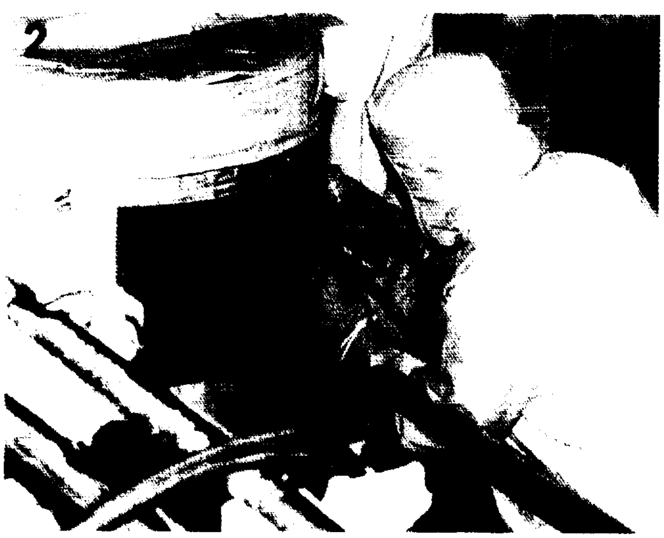
- A new technique was developed for providing a preflight profile of payload bay and payloads.

Figure 1. Evaporation Method

Figure 2. Rinse Method on Payload

Figure 3. Digilab FTIR Microscope Accessory and Mirror

Figure 4. Infrared Spectra From Bay-Liner



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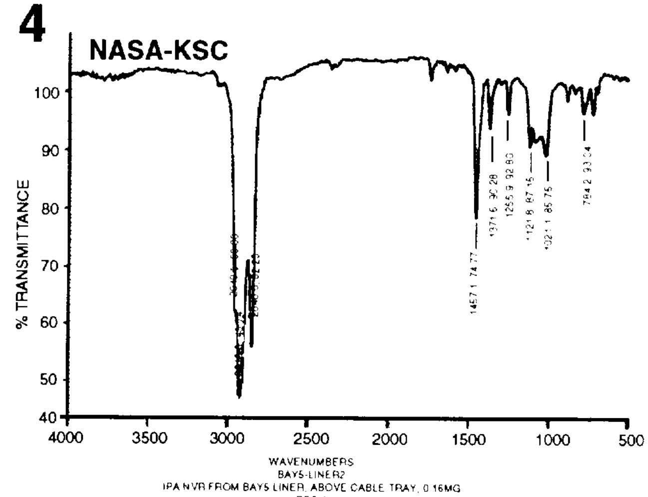


- Results show that NVR can be detected at low levels and corrective actions can be made if required. The technique is beneficial to highly sensitive payloads.
- Postflight analyses can detect any transfer of contamination and can profile the payload bay and payloads.

Contacts: M.K. Williams, LO-MSD-1C, (407) 867-3910, and J.J. Palou, TV-MSD-5, (407) 867-2906

Participating Organizations: Ball Aerospace Systems (R.R. Manning), Lockheed Payload Integration Engineering (D.W. Bartelson), and Goddard Space Flight Center Photoimaging Support (S.W. Huff)

Surface Defect Analysis

Inspection of flight hardware at KSC is a normal portion of each flow process that ensures Space Shuttle safety. Critical surfaces of flight hardware are inspected routinely for surface defects such as gouges, scratches, dings, or corrosion pits. Typically, two methods are used to evaluate the depth of these surface defects: mold impression and optical micrometry. Mold impressions are labor intensive, usually taking 4 hours to completely evaluate a surface defect, and the measurement is documented as a notation on a problem report. Optical micrometry is not as labor intensive as mold impressions, but the measurement is also documented as a notation on a problem report.

On the average, 300 surface defects must be evaluated and documented during each flow process for the orbiter alone. The members of the nondestructive evaluation groups that must perform these evaluations have expressed a desire to be able to perform these measurements in a more timely fashion, thus providing better documentation. It was requested that a near instantaneous method of electronic mold impression be developed.

The goal of this project was to develop a device that could perform surface defect analysis on flight hardware in a time-effective fashion. The device was to be portable and safe for contact with flight hardware. Finally, the device was to make documentation of the defect easier. A portable system that utilized structured light microscopy was designed, built, and tested. Structured light microscopy involves projecting a line on the surface to be evaluated at an acute angle, while observing the surface with a video camera at the perpendicular to the surface. A computer captures this video image, and the operator makes the measurement. If the projected line strikes a flat surface, the image will have a straight line on it. If the projected line strikes a surface with some type of surface defect, the line will be deflected along the contour of the defect. Measuring the deflection of the projected line is indicative of the depth of the defect.

To use the device, the operator takes a pair of suitcases containing the equipment to the location of the defect. The device is set up, which normally takes 2 or 3 minutes, and the operator holds an optical device over the defect. The operator positions the optical device over the defect with one hand and with the other hand holds the small monitor that displays the defect. Once the optical head is positioned satisfactorily, the operator captures the image on the monitor and sends it to the computer in the suitcase. Using this image and the software built into the computer, the operator determines the deflection of the line. The computer determines the depth of the defect using this information. The width of the defect can also be determined by the system. A printer built into the second suitcase can then be used to print a problem report for the defect, which includes a hardcopy printout of the image captured by the computer and the depth and width of the defect.

A field-friendly prototype has been built and tested and is much more compact and easier to use. It can measure surface defects from 0.0002 to 0.02 inch deep and 0.0002 to 0.02 inch wide with a resolution of 0.0002 inch in both cases. Field evaluation testing was performed by the various nondestructive evaluation inspectors. The response to this second-generation prototype was very favorable. Future objectives of this project are to design and build certified units that can be used operationally. In addition, special optical probes will be designed and built to work in areas where the basic unit cannot be used because of limited space or cramped geometry or areas that require a larger measurement range. These will be designed as special end-effectors that can be plugged into the standard computer box.

Key accomplishments:

- 1993: First proof-of-concept prototype was built and tested.
- 1994: Second prototype was built and tested.
- 1995: Designed and built special optical end-effectors for difficult access areas. Began to revise the design of the system to meet the ground support equipment (GSE) design requirements. Designed special-purpose probes for difficult access areas.

Key milestones:

- 1996: Complete the design of the system to meet GSE design requirements.
- 1997: Build and document two GSE versions of the surface defect analysis device.

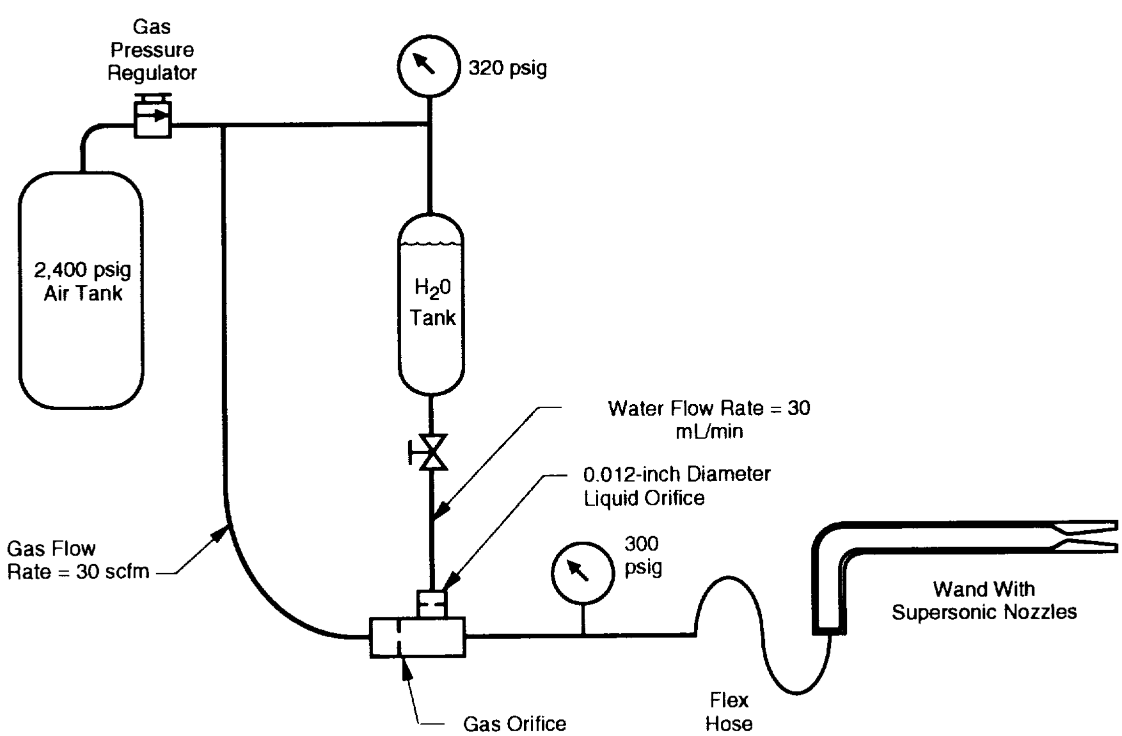
Contacts: J.D. Collins and M.J. Verdier, DL-ICD-A, (407) 867-4438, and C.G. Stevenson, TV-MSD-1, (407) 861-3603

Participating Organization: I-NET, Inc. (Dr. S.M. Gleman, D.L. Thompson, C.G. Hallberg, and S.W. Thayer)

Chlorofluorocarbon (CFC) Replacement Cleaning System Using Supersonic Nozzles

The CFC replacement cleaning system provides cleaning and cleanliness verification of mechanical and fluid components. It is intended to replace solvent cleaning and verification methods using CFC 113 (Freon 113). CFC 113 is being phased out due to ozone depletion problems associated with the CFC family of solvents and refrigerants. Traditional cleaning and verification methods use large quantities of CFC 113, which then become an environmental problem. The components to be cleaned and verified include valves, pipes, compressed gas cylinders, and flex hoses.

The system operates by flowing high-pressure air or nitrogen through a throttling valve to the nozzle. Water is injected into the gas flow stream through an orifice upstream of the converging-diverging section of the nozzle. The mixed gas-liquid flow then enters the converging-diverging nozzle where it is accelerated to supersonic speeds. The supersonic gas-liquid stream is directed onto components that require cleaning or cleanliness verification. The velocity imparted to the water by the gas flow gives it sufficient momentum at impact to remove contaminants on the surface of the component being cleaned or verified while simultaneously dissolving the contaminant into the water, which can be captured for cleanliness verification. The flow parameters for the gas-liquid nozzle can be set so virtually any gas and liquid may be used for a desired flow and mixing ratio. In addition, the size and number of nozzles are adjustable. This adjustability makes it possible to create not only small handheld cleaning nozzles but also very large multiple nozzle configurations.



A working version of the system has been transferred to the KSC cleaning facility (Wiltech) for transitioning the system from the development to routine operational use. In addition, new nozzles were designed and fabricated for use in smooth bore and convoluted flex hose cleanliness verification. A study to characterize the internal flow of the nozzle was completed as a joint effort with the Florida Technology Research and Development Authority, NASA, Precision Fabricating and Cleaning (PFC), Embry-Riddle Aeronautical University, and Bethune-Cookman College. A second study to characterize the external flow was initiated as a cooperative agreement with the University of Florida. A nonexclusive license agreement with PFC was signed. This initiated the effort to derive a commercial cleaning system from this technology. There are other companies currently pursuing licensing agreements with NASA/KSC.

Key accomplishments:

- Handheld system for large components was transferred to the KSC cleaning facility.
- Flex hose cleanliness verification nozzles were designed and fabricated.
- Internal flow nozzle characterization study was completed.
- External flow nozzle characterization study is in progress.
- Nonexclusive license agreement was signed with PFC to commercialize the system.
- Other nonexclusive license agreements are being processed.

Contacts: R.E. Caimi and E.A. Thaxton, DM-ASD, (407) 867-3748, and G.S. Melton, LO-MSD-2M, (407) 867-7048

Participating Organizations: Florida Technology Research and Development Authority, Precision Fabricating and Cleaning, Embry-Riddle Aeronautical University, Bethune-Cookman College, and University of Florida

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 Controlled Ecological Life Support System (CELSS) Breadboard Project is biomass production improvement and resource recovery development. The Plant Space Biology effort is investigating lighting and nutrient-delivery hardware systems, the efforts of environmental conditions (i.e., carbon dioxide and temperature) on plants growing in flight-type chambers, and microgravity effects on plant production. The effort is directed toward evaluating components of bioregenerative life support systems in an integrated fashion and investigating the effects the space environment has on photosynthesis and carbon metabolism in higher plants.

Threatened and Endangered Species Monitoring

KSC's natural habitats represent an area of biological diversity unsurpassed among Federal facilities. Under the Endangered Species Act and the National Environmental Policy Act, all operations require evaluation and impact minimization. Approximately 100 wildlife species on the Merritt Island National Wildlife Refuge are vulnerable to extinction. Monitoring focuses on combining field and remote sensing data with predictive/interpretive models for marine turtles, gopher tortoises, indigo snakes, wading birds, shorebirds, scrub jays, beach mice, and manatees.

The influence of habitat on scrub jay reproduction and survival is quantified at different spatial scales by using attributes collected from habitat patches, nest sites, territories, and colorbanded jays. Monte Carlo simulation models are used to quantify the influence of habitat quality, population size, and catastrophes on populations. Declining habitat quality has been found to be a critical factor influencing scrub jay extinction risk indicating that more frequent prescribed fires are needed.

Wading bird population surveys are done at feeding, roosting, and nesting sites. Population trends and habitat preferences are investigated to determine the effectiveness of wetlands restoration efforts and the importance of KSC to Florida's wading bird population.

Sixty-two gopher tortoises from across KSC, Cape Canaveral Air Station, and Canaveral National Seashore were tested for upper respiratory tract disease, a highly contagious, often fatal bacterial infection. This was the first time a wild population of tortoises had been tested. The infection rate was greater than 60 percent, and 4 of the 62 tortoises showed active signs of the disease.

Key accomplishments:

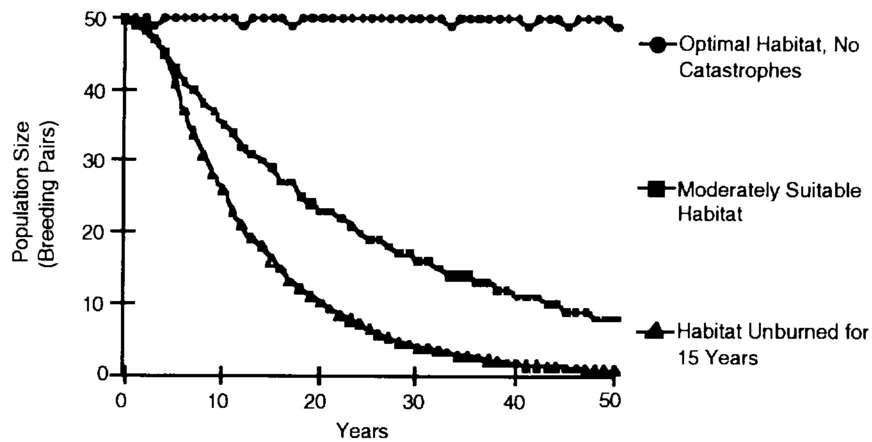
- 1991: Developed habitat maps of the most important areas on KSC for scrub jays, wading birds, and other species.
- 1992: Developed a scrub restoration and monitoring program.
- 1993: Developed a wetlands restoration program plan.
- 1994: Developed a KSC biological diversity evaluation summary.

Key milestones:

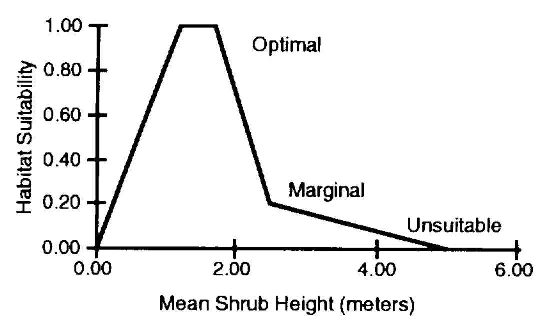
- 1995: Population and habitat status trends summarized for gopher tortoise, wading birds, and scrub jays.
- 1996: Development of scrub jay population recovery strategy; quantification of the effects of wetlands restoration on wading birds; and detailed studies on the effects of upper respiratory tract disease on natural gopher tortoise populations.

Contact: W.M. Knott, Ph.D., MD-RES, (407) 853-5142

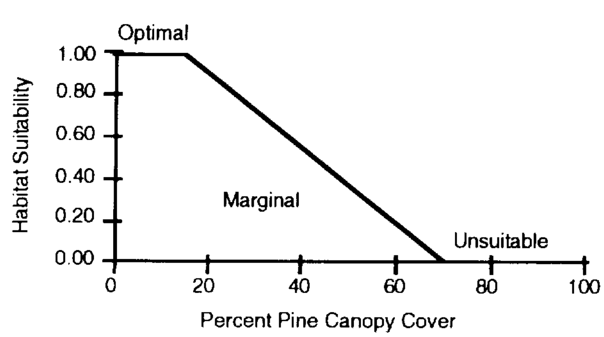
Participating Organization: Dynamac Corporation (D.R. Breininger)



Influence of Habitat Quality on Scrub Jay Population Subunits



Influence of Shrub Height on Scrub Jay Habitat Suitability



Influence of Pine Canopy Cover on Scrub Jay Habitat Suitability

Organic Analytical Chemistry Research

The organic analytical chemistry laboratory supports environmental, space biology, flight, and Controlled Environmental Life Support System (CELSS) programs. Associated research facilities include the NASA Specialized Center of Research and Training (NSCORT) at Kansas State University, the Wisconsin Center for Space Automation and Robotics (WCSAR), and the U.S. Department of Agriculture (USDA) laboratory in Orlando, Florida.

Environmental studies included determination of leaf chlorophyll in the native species of oak as one phase of an assessment of hyperspectral remote-sensing applications. Air samples, collected from Permanent Air Monitoring Stations (PAMS) A and B and the elevated carbon dioxide (CO_2) chamber sites developed with the Smithsonian Environmental Research Center, were analyzed for volatile organic compounds.

Space biology projects include carbohydrate on STS-67 Arabidopsis samples from biological research in canisters 01 and 03 (BRIC-01 and BRIC-03), STS-63. Air samples of low oxygen levels in plant growth chambers were quantified for oxygen and CO_2. Indole acetic acid (IAA) in plant tissue samples was quantified by gas chromatography/mass spectrometry (GC/MS) using the ^{13}C labeled isotope dilution technique.

Characterization of organic constituents of the plant growth chamber atmosphere in KSC's Biomass Production Chamber (BPC) continued. Weekly measurements were taken for volatile organics in air by GC/MS. Anthropogenic volatiles from materials continue to be predominant (see figure 1). Concentrations of the plant hormone ethylene were measured at 6-hour intervals for the 15-month study of BPC white potato crops.

Flight investigations included analyses of gases in the STS-69 BRIC-06 slime mold study and the STS-63 chromosome experiment (CHROMEX)-06. Astroculture-04 and -05 studies with KSC's space biology program were initiated and NSCORT studies from STS-63, STS-69, and STS-73 were characterized as CO_2 and ethylene.

Investigations of volatile components from tissue culture samples provided information that may be used in selecting vigorous strains of tissue-cultured Citrus sinensis *var. Hamlin Sweet Orange* (see figures 2 and 3). Techniques may be developed to select genetic strains with high concentrations of acetaldehyde and ethanol, possible indicators of vigorous plant growth.

Key accomplishments:

- 1989: Initial laboratory development.
- 1990: On-line ethylene studies.
- 1991: GC/MS analysis of volatile organics in BPC water solutions.
- 1992: Developed method for volatile organic contaminants in air.
- 1993: Data compiled for ethylene from soybean, potato, wheat, and lettuce.
- 1995: Characterization of volatile components of 15-month potato study in BPC.

Key milestone:

- 1996: Complete the volatile component analysis in BPC soybean/tomato study.

Contact: W.M. Knott, Ph.D., MD-RES, (407) 853-5142

Participating Organization: Dynamac Corporation (B.V. Peterson)

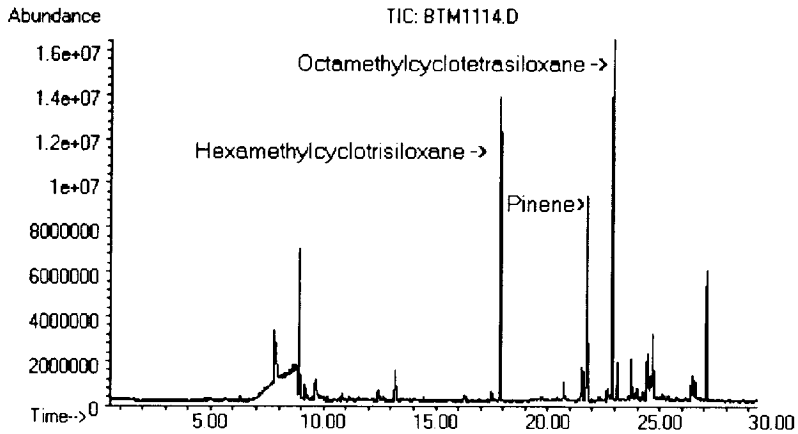


Figure 1.

Total Ion Chromatogram of Air Sample Taken From BPC. (This is day 41 of the tomato crop study. Significant abundance of siloxane compounds is from sealant used in the plant growth chamber. Pinene, a terpene from the tomato plants, is quantified at 900 ppm.)

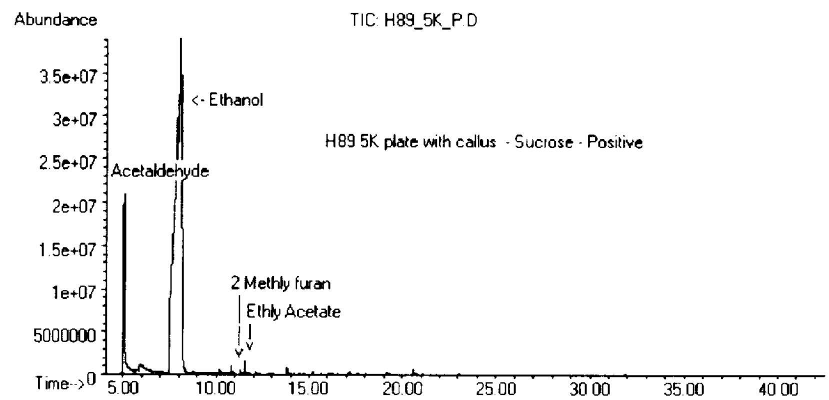


Figure 2.

Components Identified in More Vigorous Tissue Culture Samples of Citrus Sinensis Var. Hamlin Sweet Orange. *(Ethanol and acetaldehyde are major constituents of the total ion chromatogram.)*

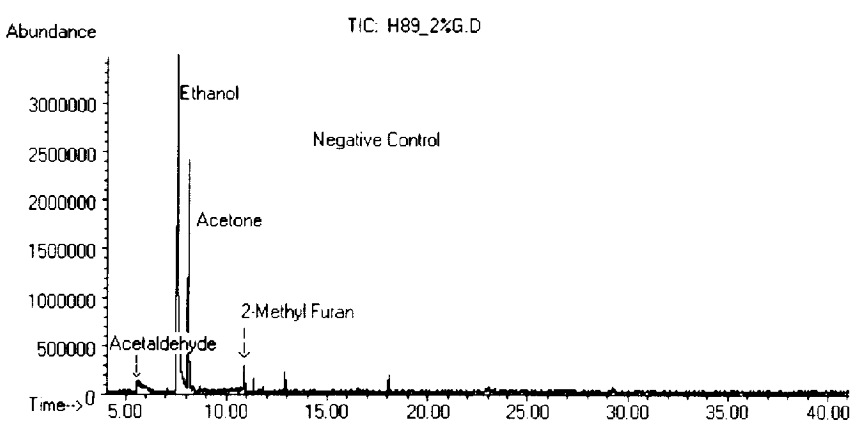


Figure 3.

Components Identified in Less Vigorous Tissue Culture Samples of Citrus Sinensis Var. Hamlin Sweet Orange. *(Acetaldehyde is a minor constituent of the total ion chromatogram.)*

Controlled Ecological Life Support System (CELSS) Engineering

The main purpose of the CELSS engineering group is to determine the engineering techniques and hardware required to successfully operate a CELSS. This includes maintaining the physical systems for biological research, performing engineering analysis of existing systems, and designing and testing new systems.

The engineering group studies CELSS operations both from a system standpoint and by looking at specific system components or processes. Current CELSS breadboard research focuses on biomass production (plant growth) and resource recovery (recycling of nutrients). Biological processes involved with CELSS operation are viewed in engineering terms (production rates, consumption rates, system reliability and maintainability, etc.) to determine the effect on the total system. In addition, performance of the physical components is constantly monitored with an eye on improvement. These efforts are documented in several reports and publications.

The CELSS engineering group also supports smaller experiments that support the overall CELSS Breadboard Project and Plant Space Biology. This ranges from simple monitoring of one environmental parameter to control of several experiment parameters.

Key accomplishments:

- 1988: First atmospherically closed operation of the Biomass Production Chamber (BPC).
- 1990: Metal halide lamps tested as a BPC lightning 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 experiments. Completed the 14-month continuous operation of the breadboard.

Key milestones:

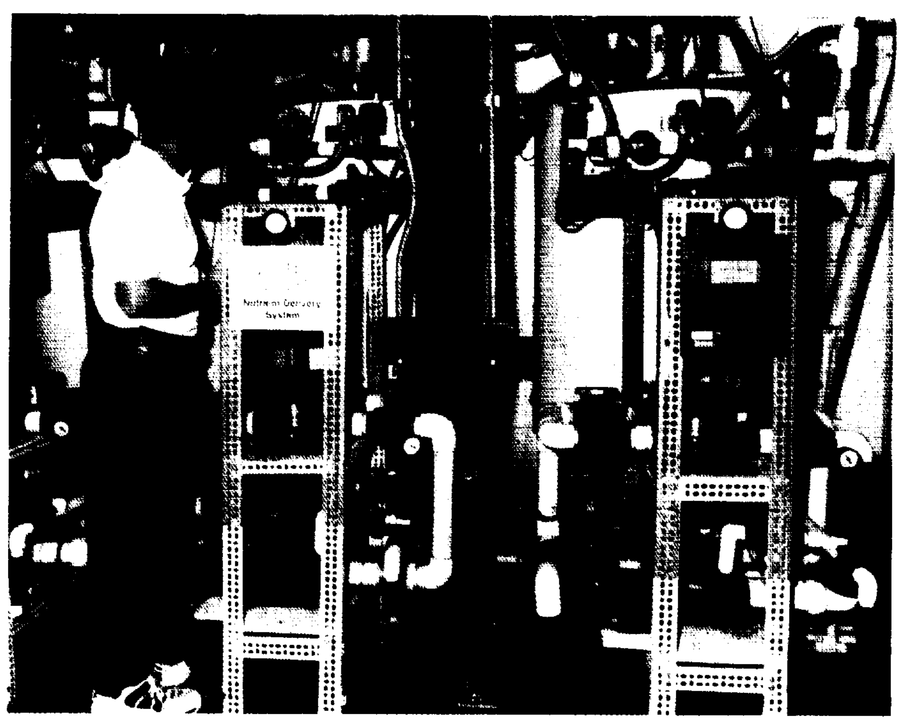
- 1996: Begin the 3-year continuous operation of the breadboard. Installation of a robotic arm for remote BPC operations. Mixed crop growth tests. Installation of

Atmospheric Gas Monitoring and Control Equipment Used for the Breadboard

the resource recovery laboratory integrated with the BPC. Development of a small, sealed plant growth chamber for plant and engineering experiments. Implementation of the updated reliability and maintainability database for the breadboard.

Contact: J.C. Sager, MD-RES, (407) 853-5142

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



Portion of the Nutrient Delivery System Used With the Breadboard

CELSS Biomass Production Chamber

A long-term (greater than 1 year) breadboard-scale experiment was completed in the Biomass Production Chamber (BPC) that tested the feasibility of using plants to purify water, generate oxygen, remove carbon dioxide, and produce food on a long-duration space mission. The experiment compared (1) the use of bioreactor effluent from inedible potato biomass as the primary source of nutrients in the BPC versus a conventional hydroponic solution and (2) the life support capabilities of a series of partial harvests versus a series of batch harvests on aging solution. This experiment was the longest continuous test (418 days) of a bioregenerative life support system with atmospheric closure and recycling of water and nutrients ever completed.

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

At the end of 418 days of operation using continuous production techniques, 13, 552 liters of water were purified, 136 kilograms of oxygen were produced, 173 kilograms of carbon dioxide were removed, and 322 kilograms fresh mass of tubers were harvested from 10 square meters of growing area. Yields of potato grown on recycled effluent have exceeded those grown on standard nutrients. Water purification, oxygen production, carbon dioxide removal, and food yields of the continuous harvest treatments surpassed those of the traditional batch harvests.

Assuming 25 square meters of growing area, 427 percent of the water, 98.6 percent of the oxygen production and carbon dioxide removal, and 59 percent of the caloric requirements for an astronaut were obtained on a continual basis using recirculating nutrient solution techniques to grow potato on recycled nutrients.

Tomato (cultivar Reimann Philipp 75/59) and soybean (cultivar Hoyt) were also grown in the BPC. This is the first time two crops have been grown simultaneously in the different compartments of the BPC.

Key accomplishments:

- 1991: Completed one lettuce and two potato tests.
- 1992: Determined the effect of photoperiod on potato growth.
- 1993: Evaluated the effect of atmospheric filtering on the

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

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.

Key milestones:

- 1996: Initiate breadboard-scale testing of wheat and potato sharing a common atmosphere.
- 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, MD-RES, (407) 853-5142

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

CELSS Biomass Production Research

In support of KSC's Controlled Ecological Life Support System (CELSS) Breadboard Project, ancillary plant studies provide information that aids in the development of production strategies for the Biomass Production Chamber (BPC) (see the article "CELSS Biomass Production Chamber").

The current focus is on resource recovery by using anaerobically processed inedible biomass for hydroponic crop production. Depending on the nutrient recovery method, nitrogen may be available as either NO_3, NH_4^+, or some combination of the two. The form of the nitrogen can affect plant growth; therefore, mixed-nitrogen nutrient solutions are being tested with wheat, potato, and spinach. So far, most crops tend to grow best under a mixed-nitrogen solution, where NH_4^+ is less than half the total nitrogen supplied.

Relative to nutrient recycling, sodium chloride budgets will need to be determined in the interactive plant and human life support systems. Unlike humans, who require relatively large amounts of sodium, plants need large amounts of potassium. These two ions can be interchanged to a limited extent, and so it is important to know whether plants can substitute sodium for potassium. If salt accumulates in the edible portions of the plant, then humans will get enough sodium from the plant subsystem, and supplemental salt may not be needed. Large additions of salt to the plant system through human waste may reach intolerable levels and reduce productivity. Salt partitioning in spinach is currently being tested to determine a salt budget for a CELSS. Spinach has a high affinity for sodium and partitions the greatest amounts in its edible leaves.

A unique characteristic in a closed system, such as the CELSS, is the potential for plant growth regulators (biogenic compounds) to be released by one plant and affect itself (autotoxicity) or other plants (allelopathy). Potato responded to its own biogenic compounds when grown over 15 weeks. Symptoms included less vegetative biomass and hastened tuberization, which are beneficial traits for a CELSS. Research to characterize the active compound and mode of action is being done with bioassays, which consist of small, in vitro potato plantlets grown on nutrient solution extracts (see the figure "Potato Bioassay Study Using Foam Supports and Gas Permeable Covers").

Key accomplishments:

- 1991: "Soybean Stem Growth Under High-Pressure Sodium With Supplemental Blue Lighting" was published in the Agronomy Journal.
- 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.

Potato Bioassay Study Using Foam Supports and Gas Permeable Covers

- 1994: Wheat was grown on mixed nitrogen sources.
- 1995: "Biological Characterization of a Naturally Occurring Potato Tuber-Inducing Factor That Occurs in Continuous Production NFT" will be published in the Journal of Plant Growth Regulation.

Key milestones:

- 1996: Determine a sodium chloride budget for a CELSS.
- 1997: Optimize nutrient recycling by growing crops on a simulated human waste stream.
- 1998: Test additional recycled waste streams (e.g., composts for use in crop production).

Contact: J.C. Sager, MD-RES, (407) 853-5142

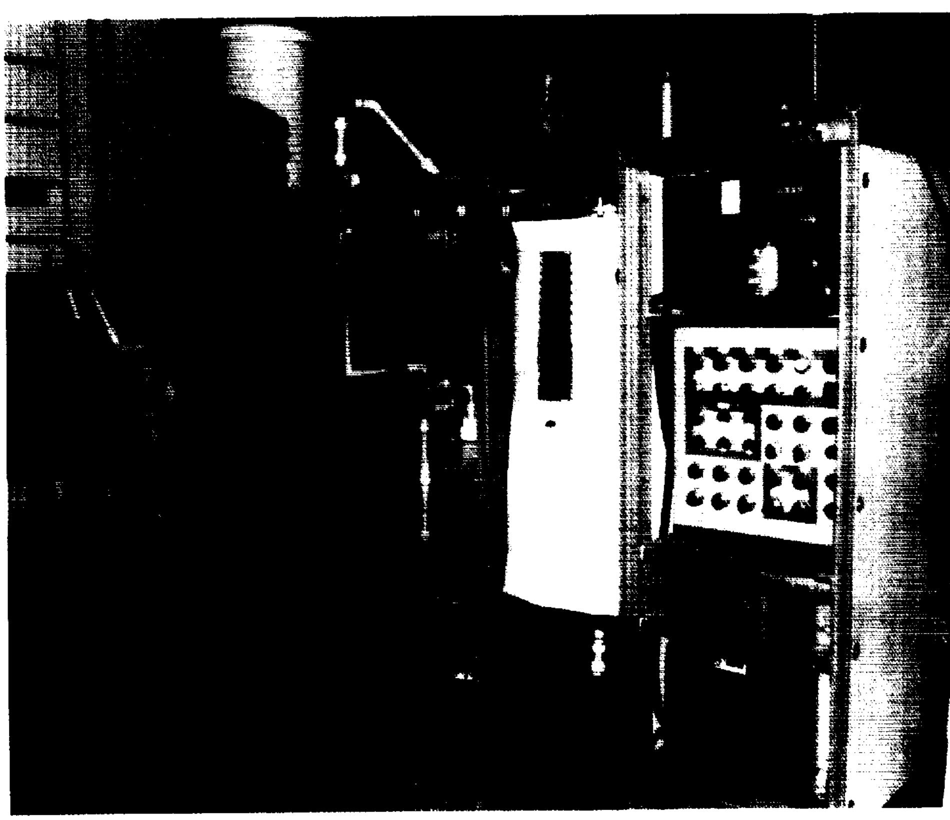
Participating Organization: Dynamac Corporation (C.L. Mackowiak and G.W. Stutte)

CELSS Resource Recovery and Biomass Processing Research

Resource recovery and biomass processing are major components of a functional Controlled Ecological Life Support System (CELSS), 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 CELSS energy, volume, weight, and crew time.

The ultimate goal has been to design, fabricate, test, and operate, at a breadboard scale, CELSS 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 CELSS breadboard.

Research this year focused on the use of a mixed microbial community to both aerobically and anaerobically (without oxygen) biodegrade inedible crop residues (stems, leaves, roots, chaff/pods, etc.). The major products of aerobic decomposition are (1) carbon dioxide and inorganic forms of



Breadboard-Scale Aerobic Bioreactor

mineral elements, which need to be recycled for further growth by the plants, and (2) microbial biomass, which will be used to produce fish (Tilapia) as an additional food source from the crop residues. The major products of anaerobic decomposition are (1) carbon dioxide and (2) volatile fatty acids (acetic, propionic, butyric, etc.), which will be used to produce edible single-cell protein (SCP) from microbes such as the yeast *Candida ingens*.

Intermediate-scale research continued to focus on process optimization: effects of retention time, crop residue concentration, and growth rate of the mixed microbial cultures. Also, a major intermediate-scale integration study utilizing the anaerobic digestor, nitrification fixed-film bioreactor, and a yeast surface film bioreactor was run with the effluent used for testing in the replenishment of nutrients in a hydroponic crop growth solution. A 418-day breadboard-scale integration test using the 120-liter breadboard-scale aerobic bioreactor was completed successfully in August. Effluent output from this bioreactor supported nutrient replenishment of two levels (8-square-meter growing area) of potato for four complete growing cycles (105-day cycle). Another breadboard-scale test will start in early 1996, with plans to operate the aerobic bioreactor continuously for 3 years. Various bioreactor inputs will be examined, including rapid processing of crop residues, crew graywater (wash water and urine) processing, and, eventually, crew solid waste processing.

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 Breadboard-Scale Aerobic Bioreactor (B-SAB).
- 1994: Integration and first operation of B-SAB, recycling nutrients to the Biomass Production Chamber (BPC). Process optimization.
- 1995: Integration of B-SAB with other crops. First run of the breadboard-scale anaerobic bioreactor and downstream processing components. Process improvement.

Key milestones:

- 1996: Integration of breadboard-scale aerobic bioreactors utilizing rapid processing of crop residues.
- 1997: Integration of graywater processing into breadboard-level resource recovery. Determine feasibility of composting of crop residue solid wastes.
- 1998: Integration of a human solid waste analog (simulated human waste) into breadboard-level resource recovery.

Contact: J.C. Sager, Ph.D., MD-RES, (407) 853-5142

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

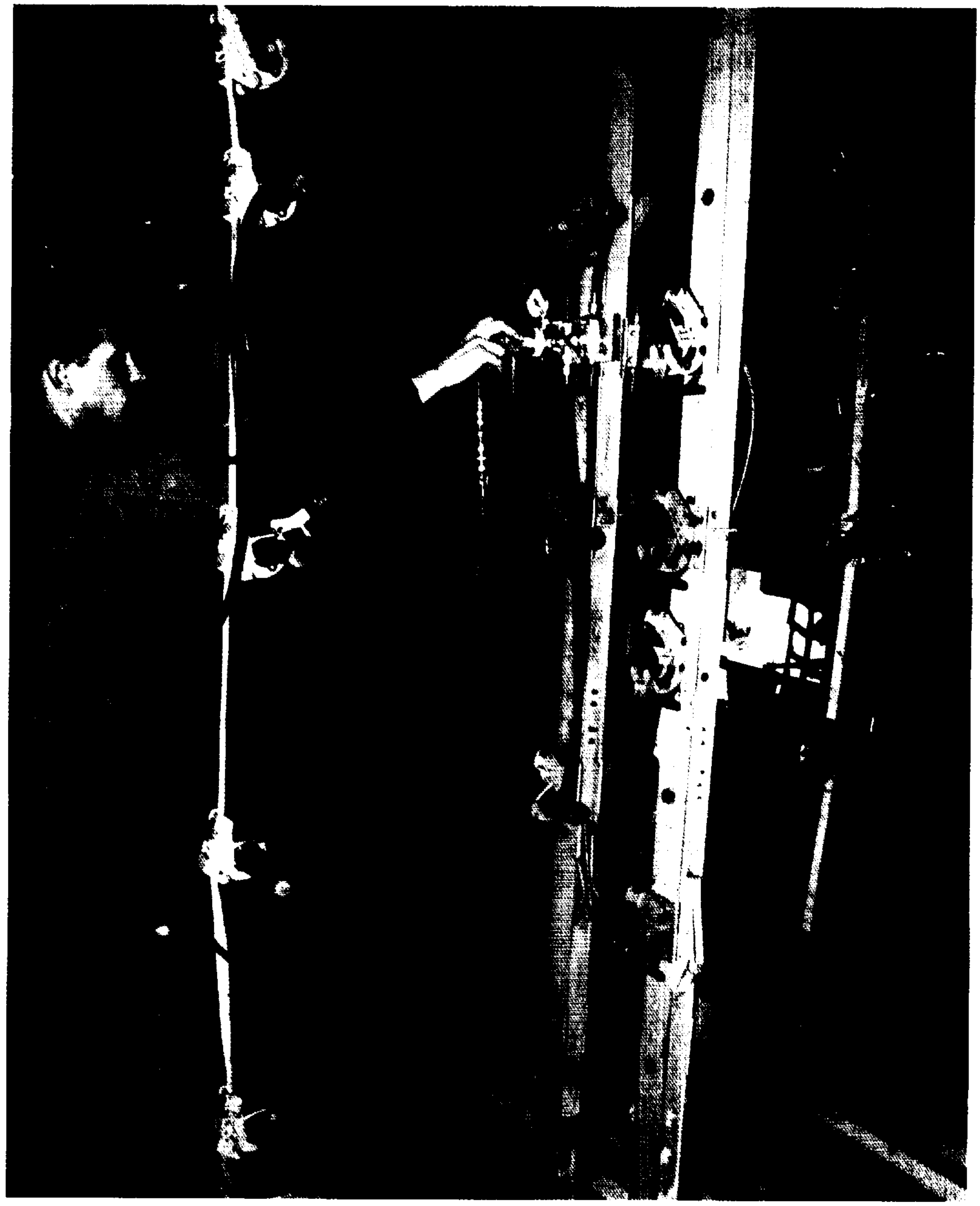
Medevac Oxygen System

The Medevac Oxygen System was designed to provide a therapeutic oxygen supply to patients being flown aboard the C-130 aircraft during a long-haul medevac scenario. These systems are currently deployed at the Space Shuttle Transatlantic Abort Landing sites aboard U.S. military aircraft.

Each Medevac Oxygen System can supply up to four patients, and systems can be joined sequentially (daisy chained) to provide for additional patients in groups of four. The C-130 provides a source of gaseous oxygen at approximately 400 pounds per square inch (psi) from its onboard liquid oxygen supply. The pressure of the gaseous oxygen is reduced by a regulator to 50 psi for distribution to each patient station. A flow controller and humidifier are provided at each station. The assembly can be attached to a litter or other patient-carrying device. The output from the humidifier connects to a nonrebreathing mask. The entire system is packed and stored in a durable, plastic, waterproof case divided and padded to prevent damage during transport.

Although originally designed to meet requirements of the Space Shuttle Program, this Medevac Oxygen System can meet needs for patient oxygen delivery on a variety of airborne and surface platforms. A supply of gaseous oxygen at greater than 100 psi is required. On this system, a standard litter stanchion attachment fitting is used to secure the regulator and distribution manifold, but other methods could be easily fitted. The most common application may be the Hercules aircraft, which is found in the inventory of 64 countries. Use aboard transport aircraft such as the C-141, C-17, and C-5 aircraft as well as various helicopters is envisioned. The system was designed by the NASA KSC Biomedical Engineering Office.

Contacts: B.C. Slack, MD-ENG-A, (407) 867-4742, and D.F. Doerr, MD-ENG, (407) 867-3152



Medevac Oxygen System Installed in the C-130 Aircraft

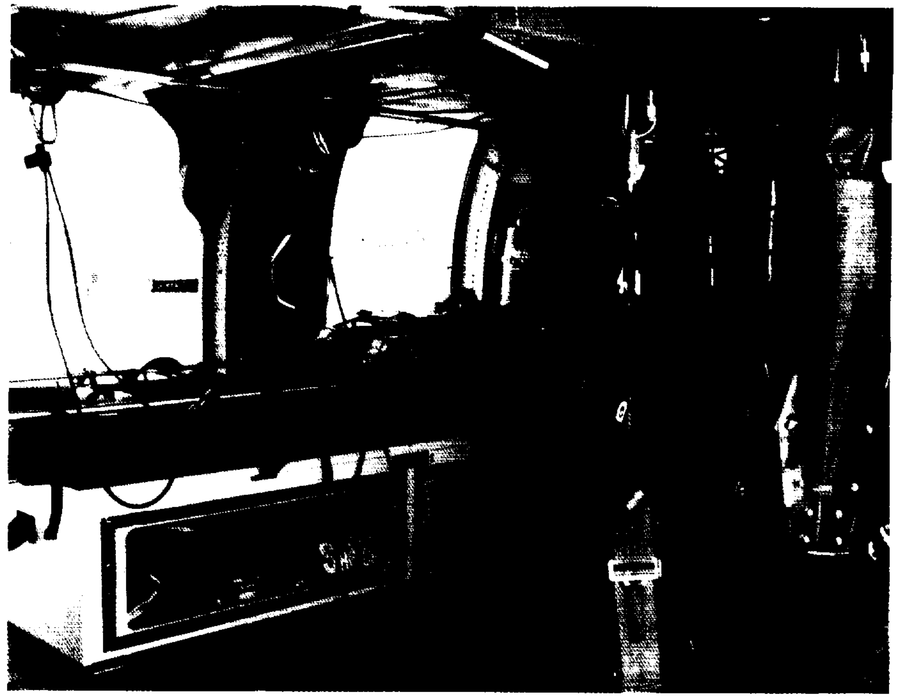
Rapidly Deployable Helicopter Medical Treatment Station

KSC relies upon the use of military helicopters to support aeromedical evacuation of potentially injured crew members during Space Shuttle launch and landing contingency operations. The formerly used H-3 helicopter became obsolete and has been replaced with the Blackhawk HH-60 G airframe. This is a much smaller combat-designated helicopter that does not have an available medevac configuration. The challenge for KSC engineers was to convert this helicopter from the combat configuration to a flying medical intensive care unit in the immediate prelaunch and prelanding timeframe. It had to meet all requirements specified in the Johnson Space Center medical operations requirements document. This includes provisions for advanced cardiac and trauma life support and robust communications for the physician and paramedic staff aboard. The medical configuration could not limit the transport of KSC fire rescuemen to the potential crash scene by the helicopter in the immediate premedevac period.

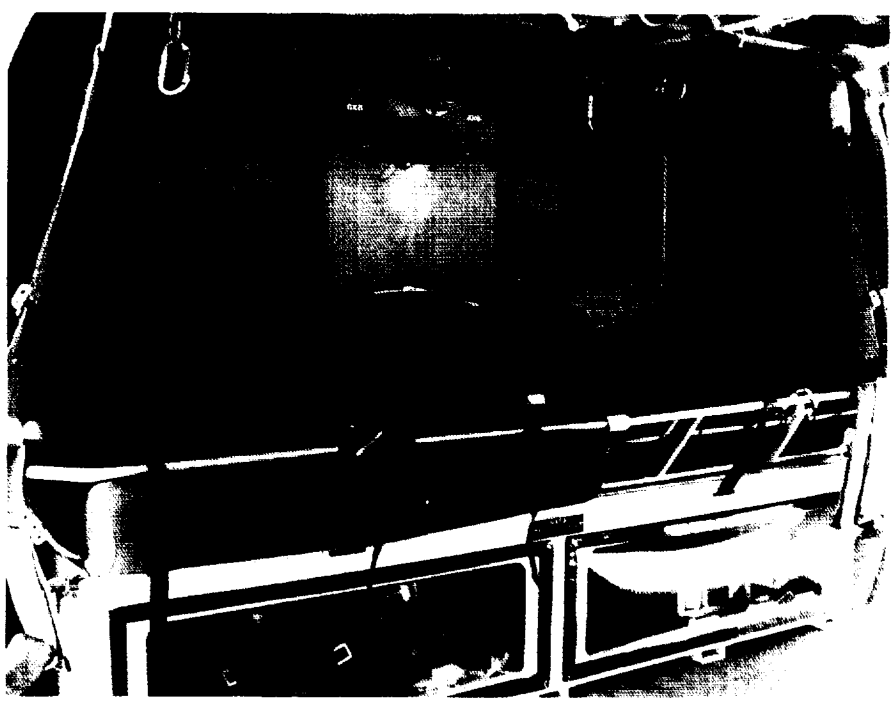
Review of the requirements, the rescue scenario, and the size of the helicopter limited the number of potential patients to two. The length of the Stokes rescue litter requires that it be lifted at least 16 inches from the deck to physically fit into the roundout of the fuselage in the athwartship position. Similarly, the port-side radio rack requires a patient litter above the deck level. A medical station was designed to support the litters at this level and provide for stowage of medical treatment equipment below. Housed beneath are a dual-E cylinder automatic/manual-triggered oxygen resuscitator, a suction pump, a pulse oximeter, an ECG monitor/defibrillator, UHF and VHF radios and audio center, shock pants, and a triage/drug kit.

The stations are secured to the deck using standard cargo attachment straps and fittings. Litters are attached to the top of the stations with straps and snap shackles. Clear vinyl covers are Velcro-attached to the front access ports to protect medical instrumentation during water-hoisting operations, while allowing visibility of the equipment. The top and the bottoms of the stations are covered with Lexan to isolate the patient should cardiac defibrillation be required. The design was accomplished by the NASA KSC Biomedical Engineering Office.

Contacts: D.F. Doerr, MD-ENG, (407) 867-3152, and G.R. Triandafils, MD-ENG-A, (407) 867-4742



Port-Side Medical Treatment Station



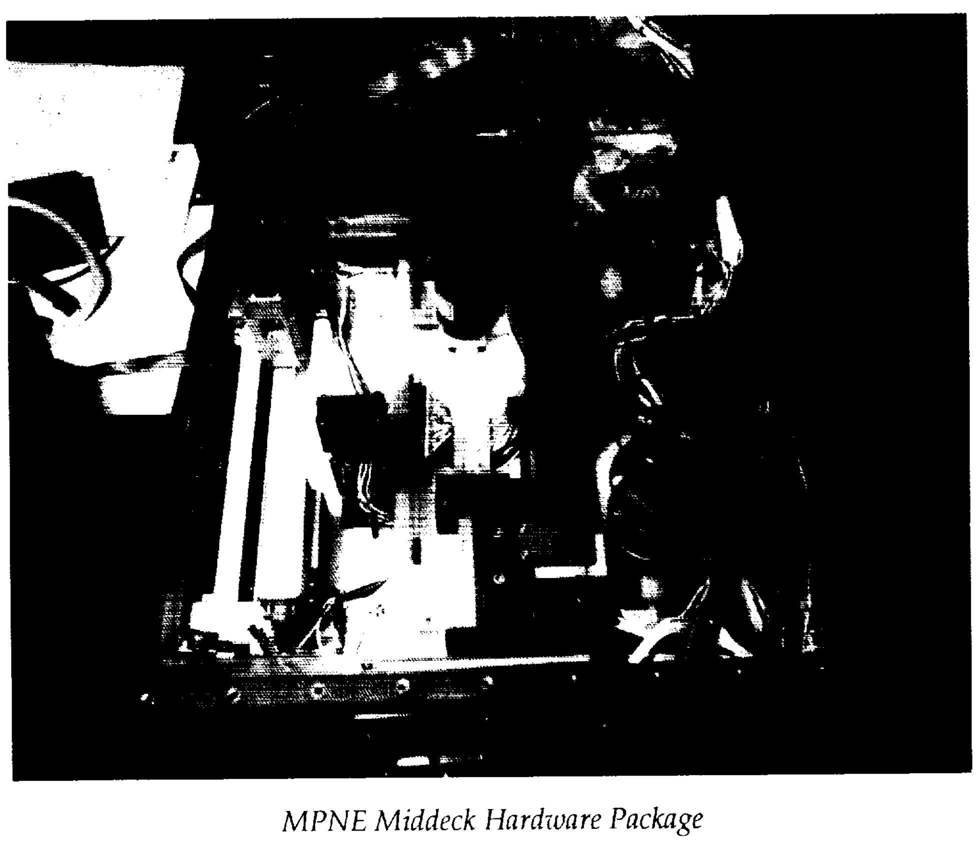
Aft Medical Treatment Station

Porous Tube Plant Nutrient Delivery System (PTPNDS)

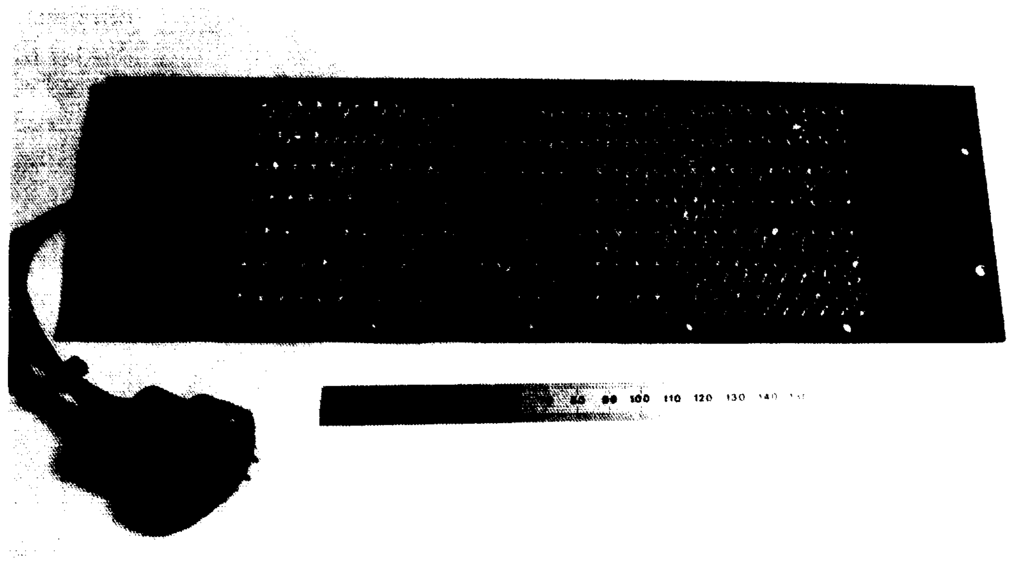
The Microgravity Plant Nutrient Experiment (MPNE) is a Space Shuttle middeck locker hardware test of a concept conceived and developed at KSC. This test will verify the PTPNDS in microgravity. Efforts during the past 2 years focused on the design of the flight hardware. A number of issues were addressed that focused on various components of the payload. The candidate plant identified to fly in the first spaceflight verification test is wheat. Plant seed cassettes for microgravity were designed and built that incorporate previously flown seed holders. Initial determinations were made for the requirements for germination within these seed holders, which have been translated to set points for infrared water availability sensors that were also built.

Video recording of plant development during the mission will be performed using an 8-millimeter charge-coupled device camera mounted within the payload outside the plant chamber. The red and blue light-emitting diodes (LED's) that will be used to light the plants have been shown to provide adequate light for photosynthesis and orientation for the given mission length. Fans will be used to bring in cabin air to cool electronic components, and another fan will circulate the air within the closed plant chamber. Humidity will be controlled by bringing in filtered cabin air.

The flight hardware has been built and is undergoing verification testing during late 1995.



MPNE Middeck Hardware Package



MPNE LED Light Bank

Key accomplishments:

- Development and testing of the PTPNDS in a ground-based KSC laboratory with modifications and improvements incorporated over the past 10 years. System testing with wheat, bean, rice, soybean, tomato, lettuce, radish, white potato, sweet potato, and *Arabidopsis* was performed.
- Miniaturization of the PTPNDS for applying the concept to Space Shuttle middeck hardware has been performed over the past 4 years.
- Construction of the test bed units (TBU's) and physical testing of the PTPNDS on the KC-135 aircraft was accomplished.
- Flight hardware fabrication was completed.
- Testing of the flight hardware was performed on the KC-135 aircraft.

Key milestones:

- 1992: Development and testing of the KC-135 aircraft's TBU's and initiation of laboratory studies in preparation for space flight.
- 1993: Design of space-flight hardware for the Space Shuttle middeck. Plant selection and germination, nutrient uptake, and plant lighting tests were performed.
- 1994: Finalized the design. Construction of prototype and space-flight hardware. Development of experimental protocol for performing the hardware test on the Space Shuttle.
- 1995/1996: Testing of space-flight hardware on the KC-135 aircraft. Complete construction and testing of space-flight hardware with final hardware and protocol completed.
- 1997: Anticipate initial space-flight test.

Contact: W.M. Knott, Ph.D., and R.M. Wheeler, Ph.D., MD-RES, (407) 853-5142

Participating Organization: Dynamac Corporation (T.W. Dreschel and C.F. Johnson)

Light-Emitting Diodes for Plant Growth

One of the main challenges for growing plants in space is supplying a sufficient quantity and appropriate quality of light. Potential electric light sources must have a high electrical efficiency, small mass and volume, an excellent reliability and safety record, and an optimal spectral output for photosynthesis and photomorphogenesis. Light-emitting diodes (LED's), particularly in the red region of the spectrum (660 to 690 nanometers), may meet this criteria. LED technology, as it applies to growing plants, is relatively new and few studies have been conducted to show its potential usefulness. Further research is necessary prior to the acceptance of LED's for supporting plant growth in

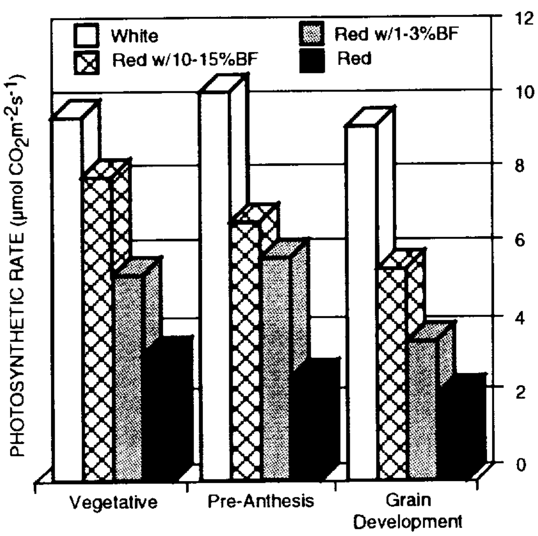


Figure 1. Photosynthesis of Superdwarf Wheat Plants During Various Stages of Growth Under Each Light Regime

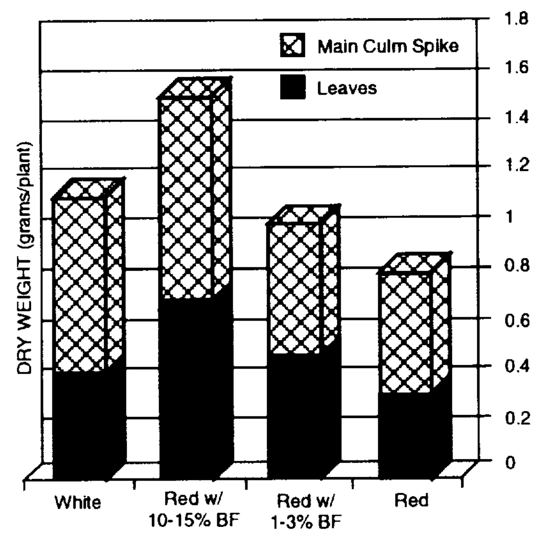


Figure 2. Final Dry Weight at Harvest Under Each Light Regime

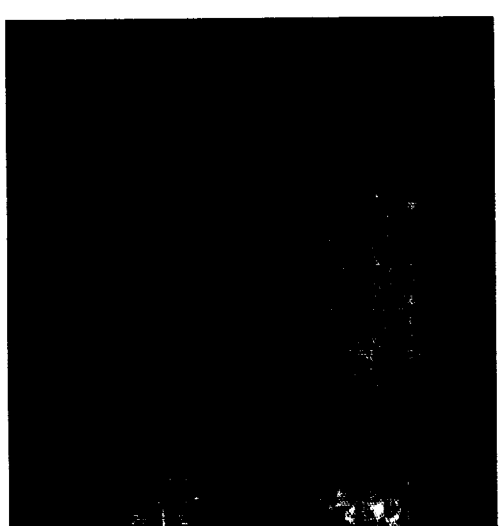


Figure 3. Arabidopsis *Plants After 65 Days Under White Light and Red LED's*

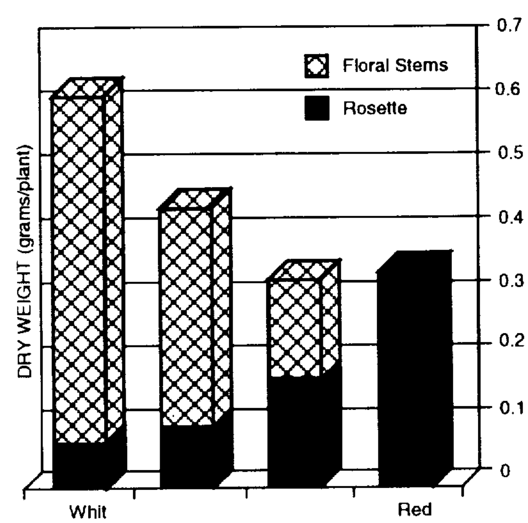


Figure 4. Final Dry Weight at Harvest Under Each Light Regime

space. Toward this end, the Plant Space Biology Laboratory at KSC, in collaboration with the Ames Research Center Space Station Biological Research Program and Dr. A.C. Schuerger at Disney's EPCOT Center, is conducting research on the growth, structural and reproductive development, photosynthetic characteristics, and disease resistance of a number of plant species grown under LED's.

During the first 40 days after planting, the rate of net photosynthesis (measured rate of carbon dioxide uptake) is consistently lower in wheat (*Triticum aestivum* L. cultivar Superdwarf) grown under red LED's as compared to control plants under cool white fluorescent lamps (see figure 1). The net photosynthetic rate, along with the vegetative and reproductive dry weights for wheat, increases when the level of supplemental blue fluorescent lighting is increased with red LED's (see figures 1 and 2). *Arabidopsis thaliana* L. has less vegetative dry weight, but more dry weight is partitioned into reproductive tissue when the level of supplemental blue light is increased in the presence of red LED's (see figures 3 and 4).

The results suggest that wheat and *Arabidopsis* reproductive development is delayed in plants grown under red LED's compared to those grown under daylight fluorescent lamps (see the figures). The addition of blue fluorescent light enhances the rate of reproductive development in the red-LED-grown plants.

Overall, these studies suggest that red LED's, in combination with a blue light source, may be a viable light source for growing plants in space. Future plans include determining the influence of red light and the threshold level of blue light on photosynthesis, chlorophyll biosynthesis, carbohydrate metabolism, and final yield.

Key accomplishments:

- 1992: Began experiments to assess LED's for plant growth.
- 1993: Continued experimentation on a number of different species under LED's. Began work on photosynthetic electron transport and chlorophyll biosynthesis.
- 1994: Began "seed-to-seed" experiments with wheat and *Arabidopsis*.
- 1995: Completed four wheat and two *Arabidopsis* "seed-to-seed" experiments. Initiated pepper (*Capsicum annuum* L.) photosynthesis and growth studies.

Key milestone:

- 1995: Complete life cycle and carbohydrate metabolism studies.

Contacts: W.M. Knott, Ph.D., and R.M. Wheeler, Ph.D., MD-RES, (407) 853-5142

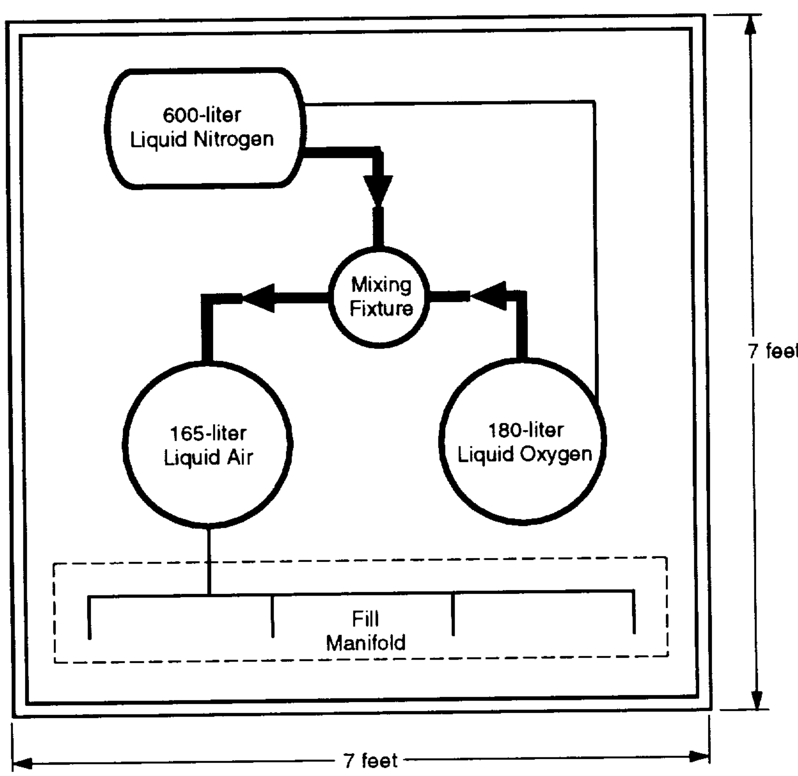
Participating Organization: Dynamac Corporation (G.D. Goins, Ph.D., and C.S. Brown, Ph.D.)

Small-Scale Liquid Air Mixing Device

The need to develop a method to produce liquid air (L/A) in small volumes is twofold. First, KSC has an economical need to scale down the current method of L/A production to reduce lost product due to oxygen enrichment. Second, commercial industry has expressed interest in using L/A-supplied respirators for protection of personnel performing hazardous functions. These functions require both breathing and cooling air respirators. Commercial demand to date has been limited due to the logistical problems associated with acquiring liquid air. Furthermore, commercial users need longer duration respirators that flow an average of 2 hours or more.

A commercially available compressed-air respirator has a maximum use time of about 1 hour, even with all the technological advancements. The L/A respirator developed by KSC provides cooling capability and the 2-hour use time at about the same weight as its compressed-air counterpart. The L/A respirator requires a lower air storage pressure [150 pounds per square inch (psig) for L/A versus 4500 psig for compressed air].

This historical method for L/A production at KSC involves mixing readily available cryogens, liquid nitrogen, and liquid oxygen to produce quantities between 600 to 4,000 gallons of a homogenous saturated fluid. KSC specifies that the L/A contain between 20- to 30-percent oxygen by volume. L/A is frequently stored before use. During this time, oxygen enrichment occurs (nitrogen possesses a lower boiling point). Once the oxygen limit is exceeded, L/A is excessed to alleviate safety concerns. Although 100 percent of the L/A produced at KSC meets specifications, approximately 50 percent of the L/A is disposed of because it ages beyond specifications during storage.



Proposed Configuration of the Mobile Liquid Air Mixing Unit

NASA Propellants (IM-FFO-D) and EG&G developed the hardware (see the figure "Small-Scale Liquid Air Mixing Fixture") and perfected the method for economical small-scale L/A production on demand. This new method produces volumes as low as 20 gallons with inline sampling for immediate use in L/A respirators. This logistical efficiency eliminates storage and minimizes waste.

IM-FFO-D and EG&G have entered into a NASA-sponsored commercial dual-use effort. The program, managed by the Technology Programs and Commercialization Office (DE-TPO), seeks to identify a commercial partner to work with NASA KSC to further refine this L/A manufacturing device to target commercial needs. IM-FFO-D and EG&G will work directly with the dual-use company as technical support for understanding the technology involved. IM-FFO-D and EG&G are anticipating commercial production of a skid-mounted small-scale L/A mixing unit (see the figure "Proposed Configuration of the Mobile Liquid Air Mixing Unit") that could be transported to the various KSC operational sites for real-time production.

Typical commercial small-scale L/A applications under study include:

1. Hazardous materials response teams

2. Fire fighting

3. Racing breathing air systems

4. Mine safety rescue operations

Key accomplishments:

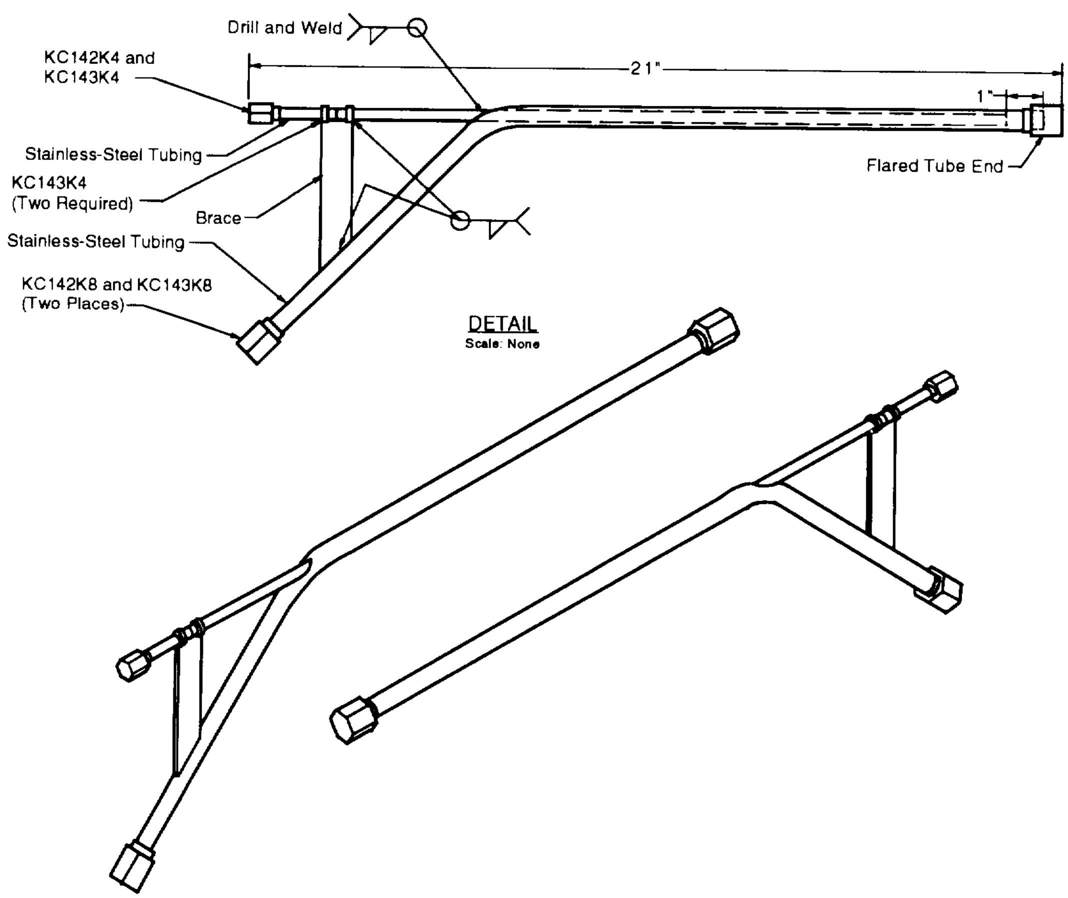
- January 1995: Production of functional prototype small-scale L/A mixing fixture.
- June 1995: Perfected the method for specification-grade L/A production using the small-scale prototype.
- September 1995: Initiated the patent application.
- October 1995: Supported the successful development of a KSC commercial NASA Dual Use Program with DE-TPO.
- November 1995: Presented the small-scale L/A fixture at a KSC-hosted commercial dual-use seminar.

Key milestones:

- 1995: Develop a successful commercial partnership through the KSC Dual Use Program.
- 1996: KSC to take delivery of a skid-mounted small-scale L/A mixing pallet for use during KSC Life Support Self-Contained Atmospheric Protective Ensemble (SCAPE) operations.

Contact: R.D. Hardin, IM-FFO-D, (407) 867-7186

Participating Organizations: NASA, DE-TPO (K.F. Harer) and EG&G of Florida (R.B. Martin)



Small-Scale Liquid Air Mixing Fixture

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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 1995 Annual Report covers efforts of all these contributors to the KSC advanced technology development program, as well as our technology transfer activities.

W.J. Sheehan, 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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John F. Kennedy Space Center
Mail Code DE-TPO
Kennedy Space Center, Florida 32899