NASA Technical Memorandum 207196

Research and Technology 1997 Annual Report

John F. Kennedy Space Center

About the Cover

The launch plume in the outgoing arrows and the technologies in the inner arrows represent the transfer between NASA-developed technologies at Florida's John F. Kennedy Space Center to private industry for use in commercial applications.

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Engineering Development Contract

NASA Technical Memorandum 207196

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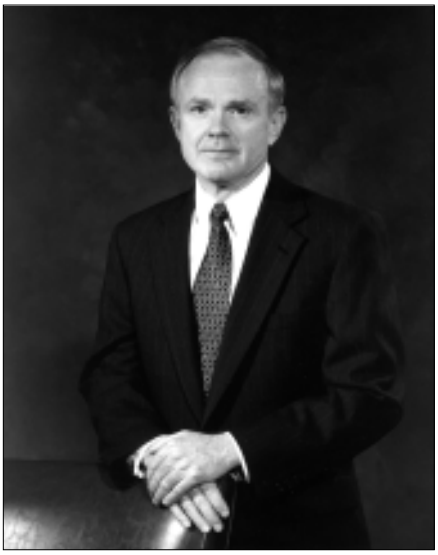
Foreword



As the NASA Center responsible for preparing and launching space missions, the John F. Kennedy Space Center (KSC) is placing increasing emphasis on its advanced technology development program. This program encompasses the efforts of the entire KSC team, consisting of Government and contractor personnel, working in partnership with academic institutions and commercial industry. This edition of the KSC Research and Technology 1997 Annual Report covers the efforts of these contributors to the KSC advanced technology development program, as well as our technology transfer activities.

Gale Allen, Chief, Technology Programs and Commercialization Office, (407) 867-6226, is responsible for publication of this report and should be contacted for any desired information regarding the advanced technology program.

Roy D. Bridges, Jr.
Director

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Technology Programs and Commercialization

Introduction

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

Focusing predominantly on applied research leads KSC to the 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.*

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

Images of clipboards and stop watches come to the minds of many people when the term "industrial engineering" is mentioned. A time and motion study, however, is just one example of an IE technology. Technologies include methods, tools, techniques, and processes as well as hardware and software. Performance metrics, process simulation modeling, statistical process control, benchmarking, and scheduling systems are additional IE-related specialties and technologies. The articles in this section are divided into 5 areas: Management Support Systems, Process Analysis and Modeling, Human Factors, Work Measurement and Methods, and General.

Industrial Engineering

Industrial engineering is typically used to optimize the operational phase of a program. To enhance overall performance and quality in most programs, it is necessary to continually improve and reengineer the processes of how work is done. When hardware and software systems are upgraded, an overall systems approach that considers the hardware, software, workers, processes, and work environment is required to maximize the return on the investment. The Space Shuttle is NASA's first major program with a long-term operational phase, and many current and potential future programs (i.e., the International Space Station, X-vehicles, and human space flight to Mars) also are projected to have lengthy operational phases. Therefore, IE technologies and capabilities are becoming even more strategically important to NASA.

Most IE technologies evolved from the need to improve shop floor productivity to remain competitive in the marketplace. IE technologies are now being successfully applied to every type of process in Government agencies, production industries, service industries, and academia. The growing need to do things "better, faster, and cheaper" throughout Government and industry has improved the market for IE technologies and capabilities. Research and development in the technologies associated with the major engineering discipline devoted to process management and improvement is an integral component of NASA's mission.

Your feedback to the contacts listed in these articles is appreciated. General questions and comments on the IE section may be directed to: Tim Barth, (407) 861-5433, or e-mail at Timothy.Barth-1@ksc.nasa.gov.

Management Support Systems: KSC Benchmarking Clearinghouse

The KSC Benchmarking Clearinghouse (KBC) team, chartered in 1994, is a collaborative effort of NASA and all major KSC contractors. The KBC is designed to facilitate effective benchmarking, optimize efficiencies, and leverage quality improvements across the Center. The team developed a consortium approach to benchmarking to integrate the best features of proven benchmarking models for use with multiple companies and agencies.

The consortium approach to benchmarking recognizes and builds on the synergy of contractors and NASA working together to understand common operational processes. This cost-effective alternative to conventional benchmarking approaches has provided a foundation for continued benchmarking at KSC through the development of common terminology, tools, and techniques. In addition to enhancing benchmarking skills among members, the KBC is strengthening a KSC culture that values continual improvement and teamwork to achieve excellence.

In its continuing activities to improve KBC processes and services to the KSC community, the KBC team developed a benchmarking roadmap (see the figure). The roadmap provides a step-by-step process to use during any benchmarking project. It is written to address the special considerations of a consortium approach to benchmarking, to provide the specific tools and techniques for a successful benchmarking study, to provide a detailed sequence of activities, and to be adaptable to any internal or external benchmarking study. The roadmap is a vehicle for transferring the collective knowledge and experience of the KBC team to benchmarking study participants and to others interested in applying this technique to their processes.

To provide up-to-date access for NASA KSC and its contractors, the KBC also developed a web site with useful information, tools, and techniques for effective benchmarking studies. It also serves as a focal point for data on completed benchmarking studies Centerwide and includes Internet links to other sites with benchmarking content. This provides KSC personnel with access to data generated by benchmarking efforts at KSC as well as best practices from around the world.

The KBC team is currently facilitating its second major benchmarking study. Upon completion of its consortium benchmarking approach, the KBC team conducted an initial “pathfinder” benchmarking study of the Government property management process. This first study validated the consortium approach and resulted in process improvements for all participants. For its second major benchmarking study, inputs were solicited on the process of highest overall Center priority. The result was the selection of the environmental management process. An environmental benchmarking team was assembled with representatives from the major KSC contractors and NASA. The environmental team then selected hazardous waste management as the operational process to benchmark. The KSC hazardous waste management process is being benchmarked with external partners. Potential partners were identified and represent commercial as well as Government organizations. Final partner selection was based on responses to a questionnaire. The results of the study will be used to assess the hazardous waste management program at KSC and to identify and implement improvements to operational efficiency and to reduce liability.

The efforts of the KBC team during 1998 will focus on continuing to provide additional benchmarking services to customers across KSC to promote effective, cost-efficient benchmarking studies in order to maximize the benefits of those studies for all participants. The KBC will research methodologies for effectively identifying and partnering with organizations demonstrating world-class performance in the specific process being benchmarked.

Key accomplishments:

- 1994: Team charter, formation, strategic planning, and development of the consortium benchmarking model.
- 1995: Completed the path-

finder Government property management benchmarking study with KSC organizations. Received Silver Medal Award in Applied Research from the International Benchmarking Clearinghouse.

- 1996: Revised the team's strategic plan. Initiated environmental management benchmarking study. KSC benchmarking was recognized as a "best practice" by the Best Manufacturing Practices Center of Excellence.
- 1997: Selected hazardous waste management as a specific operational KSC process for a consortium study. Developed a web site and provided benchmarking tutorials for several KSC organizations supporting site visits and formal benchmarking efforts. Recognized as the focal point for NASA benchmarking initiatives.

Key milestones:

- 1998: Complete hazardous waste management study. Initiate a third consortium study. Apply for a second benchmarking award from the International Benchmarking Clearinghouse. Revise roles and responsibilities of the KBC team.

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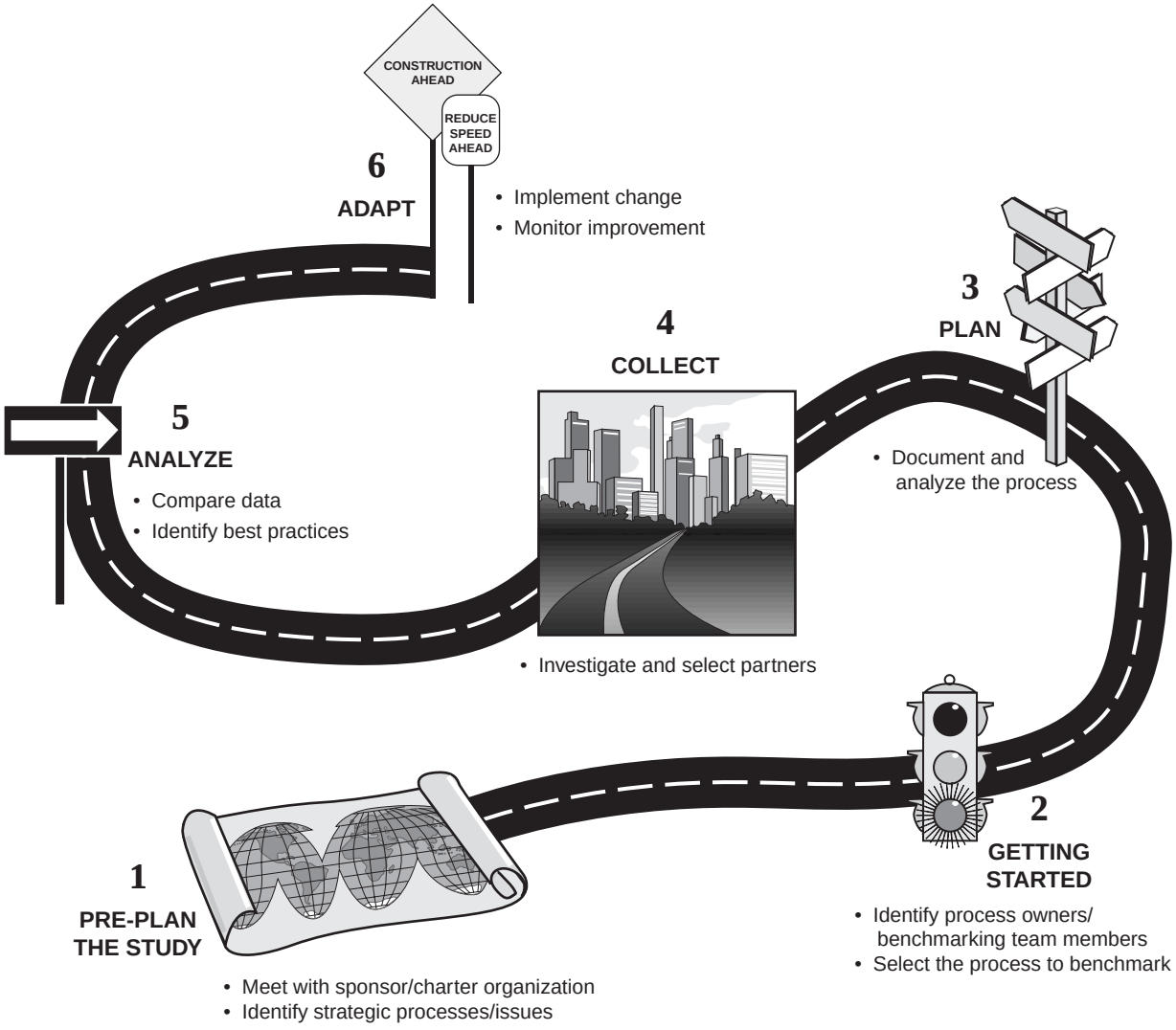
Participating Organizations: NASA KSC (M.A. Bell), The Boeing Company (D.M. DeVito), Dynacs Engineering Co., Inc. (N.A. Leavitt), EG&G Florida, Inc. (A. Goetzfried), Lockheed Martin Michoud Space Systems (F. Lockhart), and United Space Alliance (S.C. Morrison)



KSC Benchmarking Clearinghouse Roadmap for Successful Benchmarking

Management Support Systems: Goal Performance Evaluation System

"Strategic planning establishes the long-term direction of the organization in the context of a vision of the future, organizationally unique mission, and a specific set of goals, objectives, and policies developed in response to customer requirements, external mandates, and the external and internal environments" (from the NASA Strategic Management Handbook). Fundamentally, strategic planning represents the vision of the Agency's or program's senior management. A magnitude of information and literature exists on the basic approach to strategic planning. However, the execution of those plans and their supporting goals and objectives are the responsibility of every employee in the organization. Individual performance and the management of those employee action plans are the focus of the Goal Performance Evaluation System (GPES) and its software application.

The purpose of this research is to respond to the direction outlined in the NASA Strategic Management Handbook, which identifies the "Center Implementation Plan as the communication tool used to enable the Center's customers to see that their requirements are being addressed and to ensure that employees understand their contribution to the highest level strategies and objectives of NASA. The final linkage is made through each individual's Performance Plan and appraisal." The GPES was developed to successfully accomplish these objectives and maximize the involvement of every employee in the future direction of the Agency.

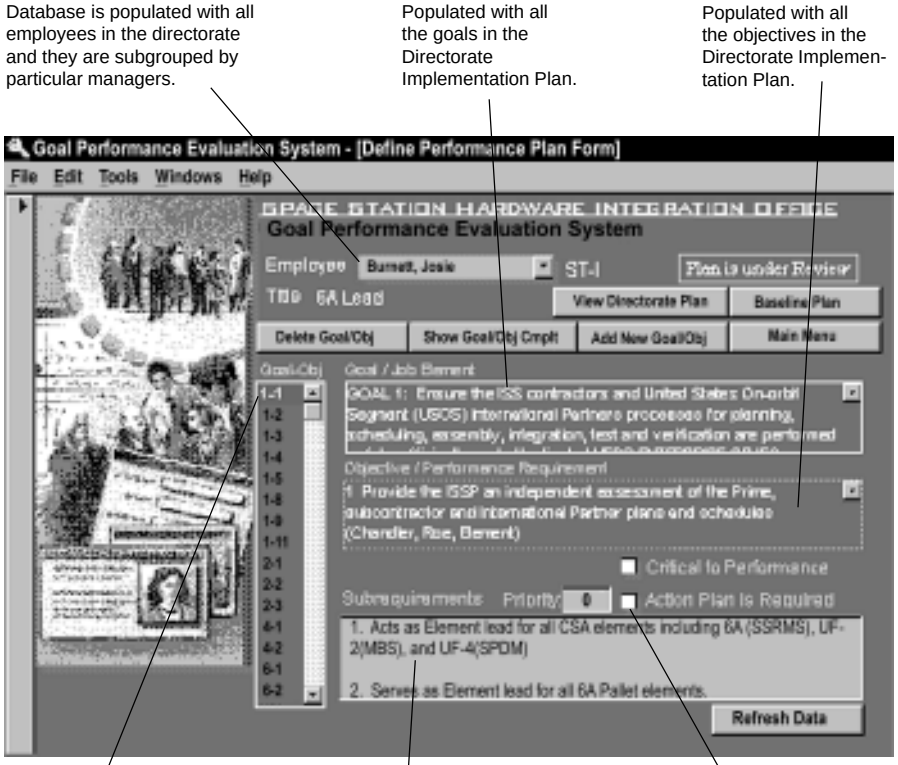
The GPES consists of three dependent parts:

- Directorate Implementation Plan
- Performance Management Process
- Database Tool

The GPES is a management system designed to implement through automation the Directorate Strategic Plan and Employee Performance Plan/ Appraisal. The basic objectives of the system were defined as follows:

- Provide a direct link of every employee to the KSC Strategic Implementation Plan and Enterprise Plans
- Develop and implement a Strategic Plan to manage the organization
- Emphasize advanced planning for objectives
- Centralize data and action plans for the directorate
- Automate the Performance Planning Cycle
- Clearly define expectations from supervisor to employee

In addition to achieving these objectives, the GPES also provides an overview and "quick look" at the distribution of roles and responsibilities within the organization. Therefore, management can take action if there are potential areas of duplication or omissions. Overall, the management sys-



Define Performance Plan

tem is more flexible and responsive to change due to the automated tool. The GPES also contributes to the empowerment of employees because employees define action plans and report status. It is clear that employee efforts are required to achieve the unified goals of the organization. The figure "Define Performance Plan" is an example of one of the screens in the GPES.

The GPES is a relational database designed in Microsoft Access. Some of the features of the system include automatic data backups, metrics reports (derived from activity monitored on the system), and GPES direct feed of information into the NASA Employee Performance Communication System forms for performance planning and evaluations.

Key accomplishments:

- 1997: Successfully deployed the GPES during the 1997 to 1998 Performance Planning Cycle in the Space Station Hardware Integration Office. Populated the Process Engineering Directorate Implementation Plan in the GPES and deployed it for the 1997 midterm evaluation period.

Key milestones:

- 1998: Deployment of the KSC application derived from the GPES. Possible Agency application in response to the NASA Strategic Management Handbook.

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Management Support Systems: Organizational Change Models for Strategic Management

As part of NASA's efforts to perform "better, faster, cheaper," KSC has begun a large-scale organizational change effort. To help lead this change, KSC is implementing a strategic management process to define a new role to react to the changes in the Agency and to ensure KSC will be more proactive and forward looking in their planning activities.

The purpose of this research was to describe strategic management and to develop a set of recommendations for implementing a strategic management process at KSC. To accomplish this purpose, the following questions were addressed: What is strategic management? What are success criteria for implementing a strategic management process? What is a process for implementing a strategic management system?

Strategic management is a continuous process aimed at aligning everyday actions with the long-term direction of the organization based on the needs of the customer. The process of strategic management includes the functions of strategic planning, implementation planning, execution, and performance evaluation. The components or outputs of the process include: strategic plan/direction, implementation and budget plans, measurements, lessons learned, and corrective and preventative action steps.

Strategic planning is a group process by which the organization defines or refines the organization's vision (i.e., ideal future state), mission (i.e., core business statement), goals, and objectives of the organization. Part of the process involves understanding both the internal and external environments (e.g., strengths, weaknesses, opportunities, and threats). The output of strategic planning is an integrated set of goals, objectives, strategies, and performance indicators. The strategic plan becomes real through the implementation planning process. Implementation planning is the process by which the organization develops specific strategies or actions to implement the strategic direction and defines the specific measures of performance that will determine the progress of the planned actions. An organization uses the implementation plan to guide day-to-day behavior or execution. Execution is the carrying out of the implementation plan. Performance evaluation is the process by which the organization "measures whether the Agency achieved intended results as stated in its plans" (NASA Strategic Management Handbook). The use of performance measurement and evaluation produces tangible results that can be studied to produce lessons learned and recommendations on how to improve the organization and adjust the strategic plan.

Five components are shown in the model (organizational context, process of strategic management, organizational support, characteristics of outputs, and characteristics of outcomes) that an organization must address when designing and implementing a strategic management process. Managers need to understand these issues to define a process for designing and implementing a strategic management system in an organization. The following steps address these components:

1. *Understand the nature of the organizational context.* The purpose of this step is to understand the organization for which the strategic management process is being implemented. The planner must answer and address questions such as: Why is the organization conducting strategic planning? What are the external requirements, if any, that the organization must meet with its planning process? What has the senior management and the organization's experience with strategic management been? How well does senior management work together as a team?

2. *Define output requirements for the strategic management process.* The purpose of this step is to explicitly define the content and format of the final products. These products include all phases of the process (i.e., strategic planning, implementation planning, and performance evaluation).

3. *Define outcome requirements for the organizational support process.* The purpose of this step is to determine the nature of the outcomes the organization desires. The outcomes are the less tangible results of producing the strategic management process. The outcomes would include a senior

management and organizational unified view, buy-in/support, use of plans to drive everyday decision actions, alignment throughout the organization, and commitment to the directions and actions defined in the products. Understanding the desired outcomes helps judge the amount of energy to place in the effort and the approach to the organizational support process.

4. *Design the organizational-specific strategic management process.* The purpose of this step is to define the strategic management process for the organization. A review of the theory and potential approaches to strategic management should be completed. A review of the literature, understanding other organization processes, and bringing in outside knowledgeable people can help increase the knowledge about strategic management.

5. *Design organizational support processes.* The purpose of this step is to provide the organization with the knowledge, processes, and tools to allow the organization to be self-reliant in strategic management. The focus of this effort includes executing the process for designing and implementing strategic management, preparing and conducting senior management retreats, providing educational/training needs, assessing progress and making improvement interventions, and developing the communication materials.

6. *Implement the strategic management process and provide ongoing organizational support.* The purpose of this step is to implement the defined strategic management and organizational support processes to produce the desired outputs and outcomes. The organization is supported by defining tasks to be completed by the senior management group, integrating products and concerns of the senior managers, supporting subgroups of managers in their tasks, presenting materials to the larger group, and interacting with the process owner to discuss progress made and any needed interventions.

7. *Refine both the strategic management and organizational support processes for improvement.* The purpose of this step is to continuously improve the strategic management and organizational support processes by assessing progress and making improvement interventions. Regular interaction and discussion with the senior management who owns the strategic management process are required.

Key accomplishments:

- 1997: Application of the models to develop a strategic direction for KSC. Development of a guide to facilitate the development of strategies for achieving the strategic direction.

Key milestones:

- 1998: Continued use of the models by KSC to understand and manage organizational change. Complete further applied research into the steps necessary for successful organizational change.

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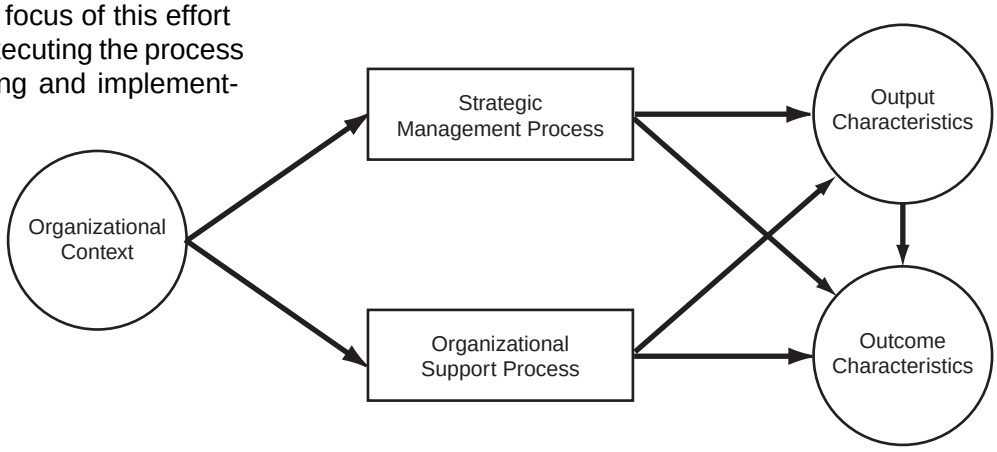
Participating Organization: University of Central Florida (T. Kotnour)



Components of Strategic Management Process Design and Implementation

Management Support Systems: Computer-Assisted Performance Metrics Identification

The use of measurement to improve organizational performance at KSC, in the Federal Government, and in the private sector continues to increase. This increase has created a widespread need to assist managers who have been asked to identify and use performance measures to manage their work process but who are not practiced in measurement identification and development. This project explored the feasibility of creating an innovative software product to facilitate the development of organizational performance measures and to provide timely training in measurement knowledge and skills. The result of the project is a software prototype that demonstrates this facilitation process.

In conducting the research, the project team applied its expertise in industrial engineering and performance measurement to a selected NASA work process to:

1. Identify a procedure for facilitating the development of performance measures

2. Design and develop a prototype software product that assists an individual in developing organizational performance measures

3. Determine the appropriate system architecture for developing a commercial version

Study methods included drawing on the principal investigator's own experience as a practicing consultant in organizational performance measurement, reviewing selected bodies of literature, field testing alternative approaches on a NASA work process, and developing and field testing a software prototype. Two different approaches—expert system and deliberation—were studied by attempting to construct a facilitation model under each approach. The rule-based expert system approach proved inappropriate. The deliberative approach, in which the manager is guided to identify performance criteria and convert these into performance measures for a specific work process, proved feasible. A commercial product designed to manage deliberation was used to develop the software prototype.

The expert system and deliberation approaches each contain a role for an expert, but what each expert does is very different. The project team concluded that the problem being addressed when developing performance measures is not one that an expert system can contribute to solving. A procedure was formulated to facilitate the development of performance criteria and measures in the deliberation model, and a software prototype was developed for this procedure. The project team concluded that the role of the expert in the delibera-

tion model is a feasible basis for computer-assisted facilitation of the identification of organizational performance measures. Results also showed that a full production system would require the use of a database development tool such as Microsoft Access™.

In summary, this project successfully broke new conceptual ground in the field of measuring organizational performance. It created a comprehensive framework for identifying performance criteria for a work process and developed a detailed procedure for defining performance measures. It successfully encoded these innovations in a software prototype.

Key accomplishments:

- 1997: Completion of the Phase I feasibility study and development of a software prototype.

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Participating Organization: OMNI Engineering and Technology, Inc. (Dr. R. Wise)

Process Analysis and Modeling: Variable-Form Data Analysis

As the role of NASA/KSC Shuttle Processing shifts from oversight to insight of the contractor's primary processes for preparing Shuttles for launches (i.e., work instruction generation, requirements control, and task execution) through the use of metrics-based surveillance activities, the significance of variable-form data has increased. Several successful applications of statistical process control (SPC) principles to Space Shuttle system performance data were developed during recent years through applied research activities. During the 1997 Summer Faculty Fellowship Program, the first comprehensive effort to train system engineers in the collection, analysis, and interpretation of variable-form data was initiated.

A series of three workshops was provided for system engineers. During these workshops, the engineers received guidance in the selection of statistical process control tools appropriate for the short-run and low-volume processes common in Shuttle operations, and the variable-form data analysis methodology was updated based on engineering feedback. Among the SPC tools covered during the workshops were process flowcharts, process capability analyses, X-bar and R charts, individual X and MR charts, DNOM charts, P charts, U charts, and C charts. A multivariate control chart was also presented for use with monitoring processes involving multiple variables. Specialized SPC software (Statgraphics) was used to generate control charts and quantify process capability. Example charts developed using the software on a system performance data set are shown in the sample charts.

Another major area of project activity involved the collection of variable-form data by the system engineers. These data were analyzed using the appropriate SPC tool, and the results of the analyses were discussed in a subsequent workshop. Members of the industrial engineering group were also provided training on advanced SPC tools so they could effectively assist the system engineers.

Key accomplishments:

- 1994: Completion of variable-form data collection and analysis on two Thermal Protection System processes. Estimated savings associated with process changes were approximately 200 direct labor hours per processing flow (plus reductions in support labor hours and material costs).
- 1995: Statistical process control procedures were applied to variable-form data from several additional orbiter systems and support processes. Collaboration with USBI for analysis and improvement of solid rocket booster processes resulted in additional savings. The orbiter structural bonding process improvement project was initiated. Phase I experimental analyses of factors related to bond strength were designed and performed.
- 1996: Phase II of structured

experimentation supporting orbiter structural bonding process improvement was completed. A sample of operations and maintenance requirements and specifications scrub activities was reviewed to identify additional candidate variables for analysis in quality improvement activities.

- 1997: System engineers participated in three workshops to develop skills in collecting, analyzing, and interpreting results from variable-form data. Additional experiments were designed for the structural bonding process.

Key milestones:

- 1998: Implementation of the SPC approach to process analysis throughout system engineering. Implementation of structural bonding process improvements and measurement of the effectiveness of process changes.

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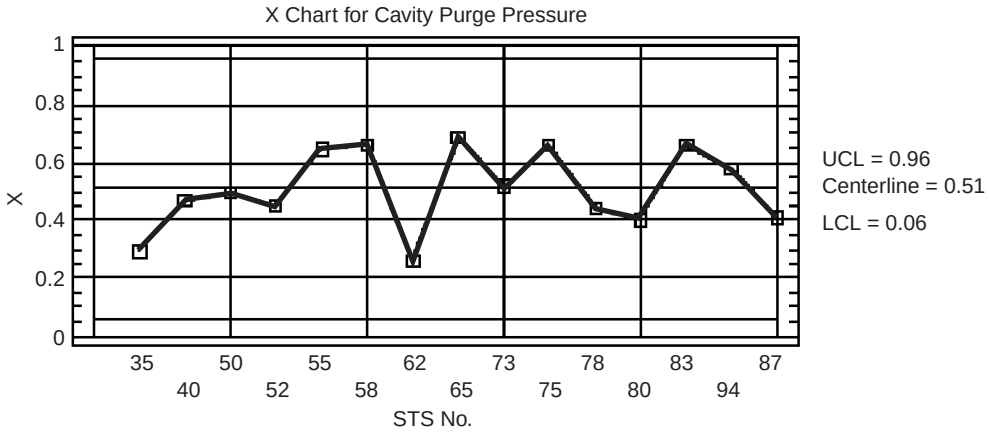
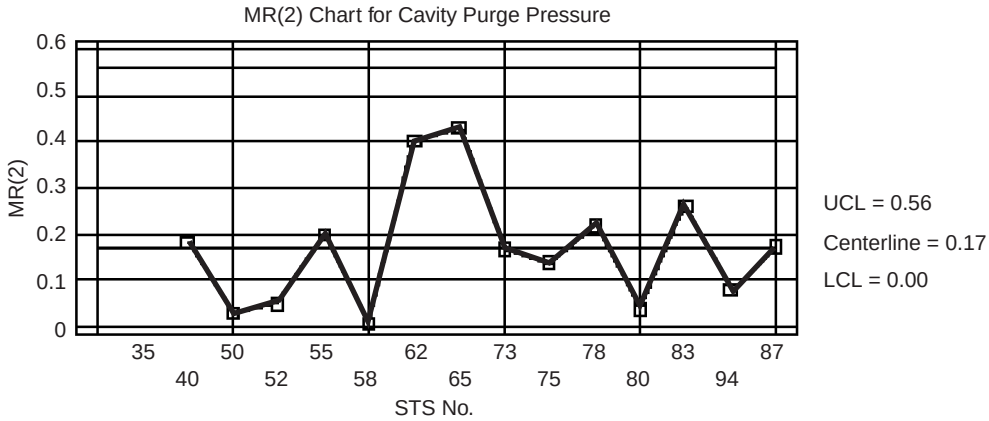
Participating Organizations: Embry-Riddle Aeronautical University (D. Osborne) and NASA/KSC Shuttle Processing (S. Minute)





Process Analysis and Modeling: Intelligent Assistant for Optimization Modeling

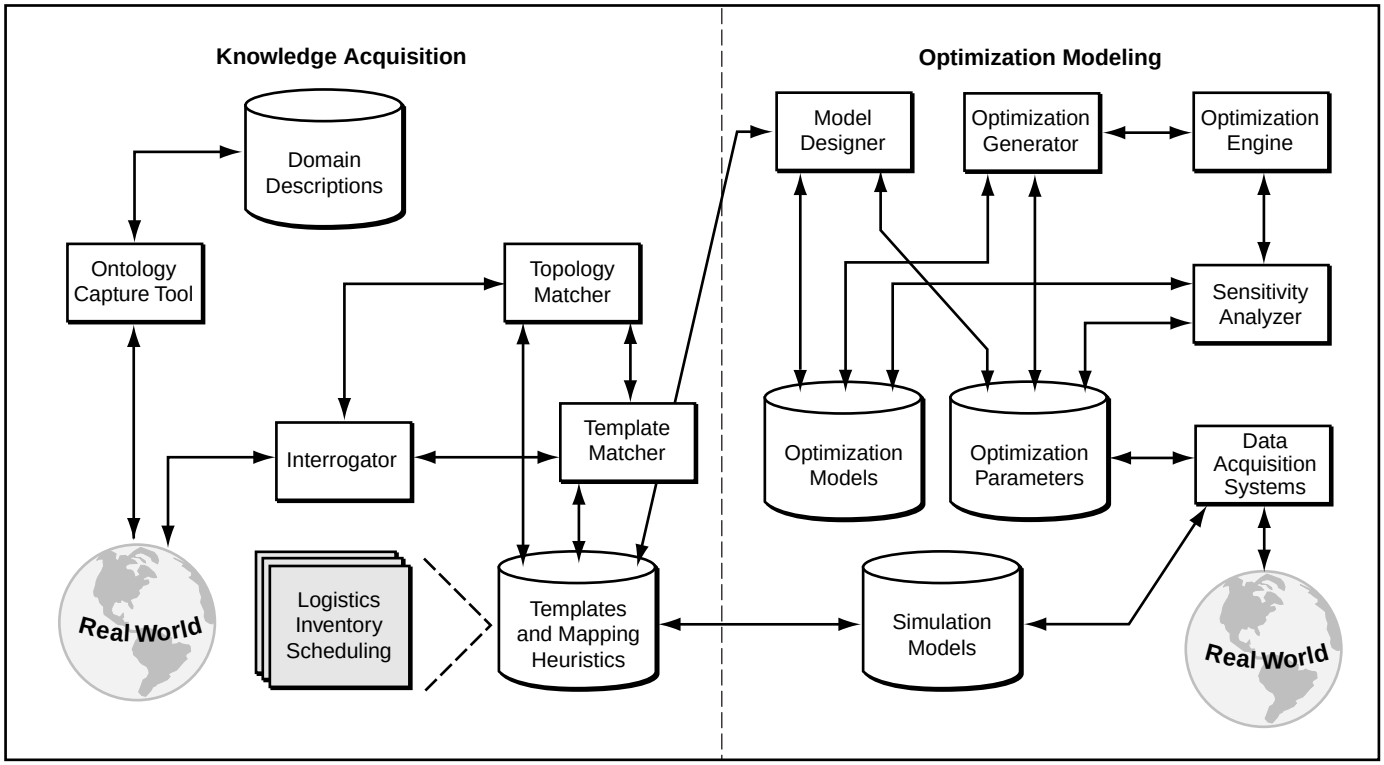
The versatility of optimization modeling has established it as a popular decisionmaking aid over the last 40 years. Optimization encompasses a suite of powerful decision support paradigms that enable modeling any decision-making environment in terms of the objectives, decisions influencing the objectives,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

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

Preliminary research to alleviate these difficulties was conducted under a Phase I Small Business Innovation Research (SBIR) contract. This effort is a prototype implementation of the Optimization Modeling Assistant (OMA). Several key Phase I objectives were realized during this initial effort. The research team developed a structured method of optimization model development and created a structured, ontology-based method for knowledge acquisition and analysis. Another primary objective was to develop a set of heuristics, principles, and rules that encapsulate optimization knowledge and form the knowledge base that assists in optimization model development. Templates were created that encapsulated the knowledge of optimization modeling paradigms for both application-specific and generic modeling.

The 1997 Phase II technology hardening efforts identified another important factor that limits widespread use of optimization techniques to practical problems – the unavailability of much of the information needed for developing optimization models. While optimization techniques provide analytically sound solutions, their success hinges on the availability of accurate input data. Often, the input data required to develop valid optimization models does not exist or is inaccessible in most domains. Recognizing this, KBSI expanded the architecture of the Phase II OMA to include simulation-based optimization. Thus, simulation will be used to generate the necessary input data, which is then used by the OMA for optimization. Using the two powerful decision support techniques together, the OMA will deliver comprehensive decision support analysis capabilities to managers and decisionmakers.

A concept of the OMA operation and architecture (see the figure), in addition to the prototype implementation, was established during the Phase I



Conceptual Architecture of OMA

research. The prototypes and the templates are being refined in Phase II. Phase II has also extended the OMA architecture to include simulation-based optimization. Ongoing Phase II activities are targeted at developing a precommercial OMA product and demonstrating OMA benefits at KSC.

Key accomplishments:

- 1996: Completion of Phase I SBIR contract. Development of prototype OMA. Selection for Phase II follow-on research.
- 1997: Refined OMA prototype and templates. OMA extensions for simulation-based optimization. KSC process models for OMA application.

Key milestones:

- 1998: Complete refinements to OMA optimization model design knowledge base and OMA templates. Complete implementation of simulation-based optimization. Complete OMA implementation and test and validate the OMA with KSC applications.
- 1999: Target commercialization of the OMA in various commercial sectors as well as Government agencies.

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

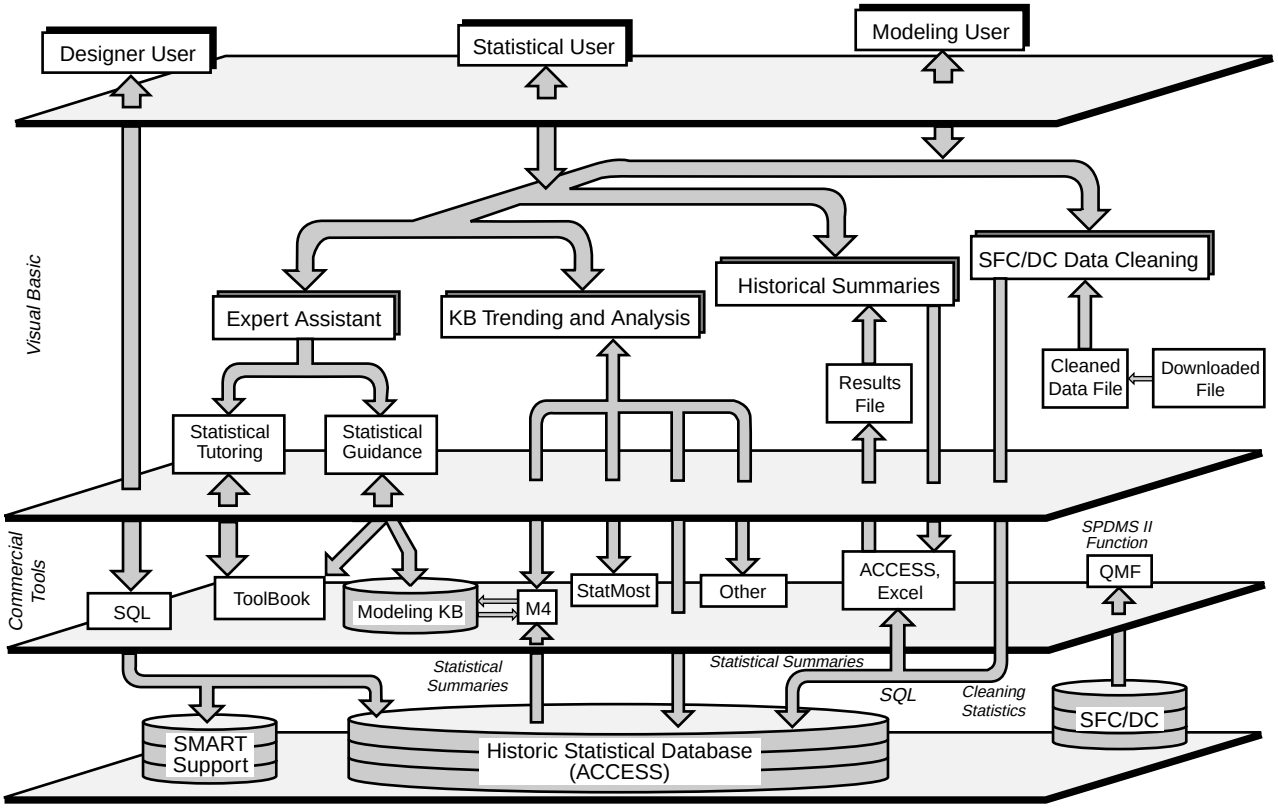
Process Analysis and Modeling: Data-Based Framework for Modeling Shuttle Processing Operations

This effort seeks to utilize task delay and duration data collected during ground processing of the Space Shuttle for modeling these activities. The Shop Floor Modeling, Analysis, and Reporting Tool (SMART) framework relies on knowledge derived from the database containing the delay and duration data (Shop Floor Control) as well as on other operational procedures. Derived knowledge will become part of a knowledge base managed through an M4 application, whereas operational characteristics are part of a relational database managed through an ACCESS application.

The figure depicts the various modules of SMART. Various commercial tools are integrated through a customized user interface written in Visual Basic to enable the capabilities of the framework. The framework collects statistical information regarding work time, delay duration, and other historical summaries of relevance for future inferential analysis. A knowledge-based trending and analysis module will utilize several data mining techniques to synthesize trends in the historic behavior of certain measures of interest. Such trends will also become part of the knowledge base and/or part of the historic database.

The various capabilities of SMART were conceived to accommodate various data modeling needs of three types of users:

1. Designer user, who interacts with SMART through the various commercial tools



SMART Framework

Cleaning Criteria for Each Type of Record

1. **If** *wadname* begins with an STS number, **Then** *wadtype = IPR*
Example: 062V . . . ; 047V . . . .

1. **If** *wadname* begins with **P**, **Then** *wadtype = ROMI*
Where: **P =** {V1047, V1171, V1264, V1269, V1270, V3570, V5057, V5067, V5069, V9001, V9002, V9019, V9023, V9028, V9045}

1. **If** *wadname* begins with **P AND** the *wadname* does not have a *"I"* in it, **Then** *wadtype = OMI*
Where: **P =** {V1047, V1171, V1264, V1269, V1270, V3570, V5057, V5067, V5069, V9001, V9002, V9019, V9023, V9028, V9045}

integrated under it to modify the structure of the support and historical databases and to develop new "canned" reports and new data entry forms

2. Statistical user, who becomes a "student" of SMART (to learn about statistics) or an engineer who needs descriptive and inferential summaries

3. Modeling user, who uses preset procedures in conjunction with customized ones to support a new modeling activity such as risk analysis or process simulation

SMART takes its inputs from Shop Floor Control in an indirect fashion. Data from Shop Floor Control must be downloaded using a query language such as QMF. The table resulting must be moved to a PC file so SMART can process it for completeness and usefulness. This approach was taken to avoid security conflicts with KSC's information systems. SMART seeks to enable analysis for planning and decision-making. It is not a data acquisition system that needs to be online.

Various studies of the Shop Floor Control data have yielded rules that the current prototype uses to ascertain whether a record is complete and statistically useful. If the record is incomplete, the current prototype can repair the record based on the actual number of the task or work authorization document associated with the record. If the record is complete, SMART checks it to decide whether the record could be used in statistical analysis. The table gives some examples of these rules.

Key accomplishments**:**

- 1993: Understanding of the accessibility of the Shop Floor Control 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: Design and implementation of a SMART prototype using Visual Basic in conjunction with ACCESS. Record assessment capability enhanced to handle SFC data for purposes other than those set by SMART and SCRAM.
- 1996: Various statistical models added to SMART. Designed a KBS analysis module. Designed an autonomous statistical interpreter for inclusion as part of the expert assistant module. Developed a statistical tutorial.
- 1997: Various data mining algorithms were identified for implementation. Initiated implementation of an inductive logic approach for knowledge derivation. Industrial survey to assess the impact of a tool like the autonomous interpreter. Incorporation of additional modeling capabilities into SMART.

Key milestones:

- 1998: Implementation of a prototype autonomous interpreter of statistical analysis. Testing of the prototype at KSC in preparation for its delivery at the end of June 1998.

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Participating Organization: Florida International University (M. Centeno)

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

Enhancement of the Ground Processing Scheduling System (GPSS) was the focus of a 1997 NASA and American Society for Engineering Education (ASEE) Summer Faculty Fellowship Program. The GPSS is an artificial intelligence-based scheduling tool developed to support the complexity and dynamics associated with the scheduling of Space Shuttle ground processing at KSC. The GPSS currently supports the development of Shuttle processing schedules at KSC, which demands the integration of the processing requirements for the major Shuttle systems with the following:

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

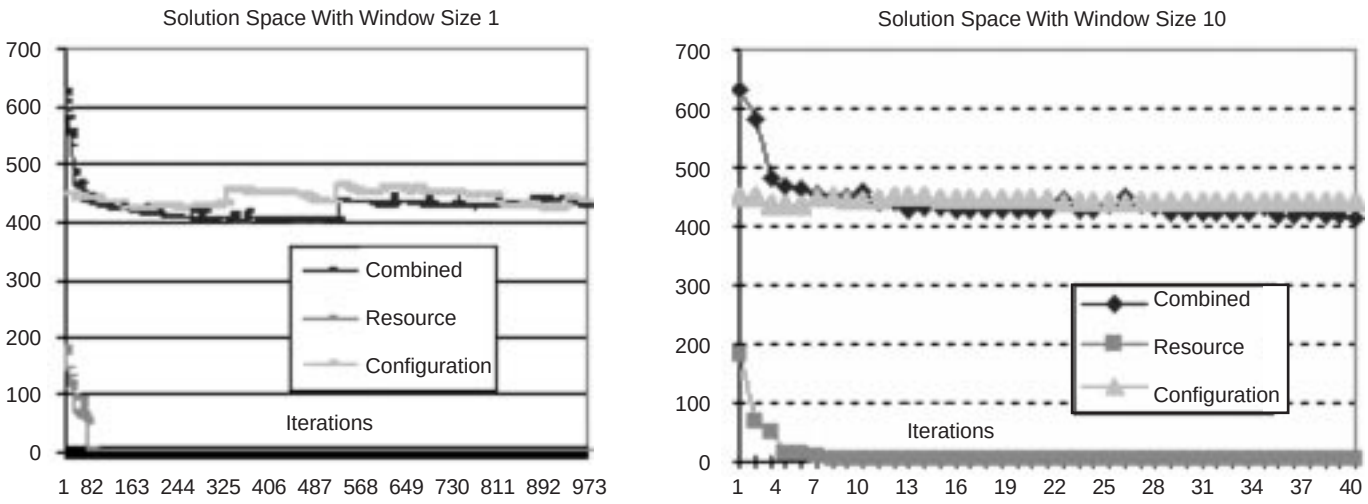
4. The need for timely communication of schedule information

By improving the GPSS, the goal is to provide the means to achieve more efficient Shuttle ground processing, therefore decreasing vehicle turnaround time. Significant computational bottlenecks were successfully investigated and appropriate solutions were proposed. A prototype was completed to support the investigation. The GPSS was probed and sample solution spaces were constructed.

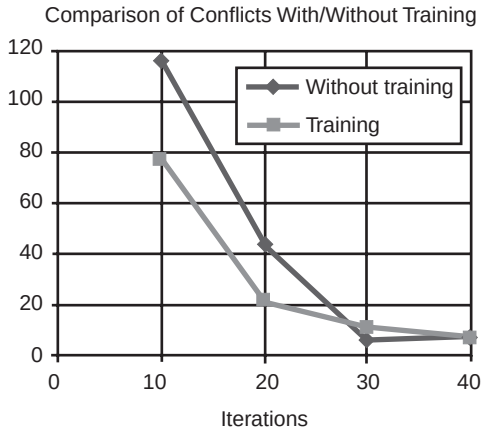
An investigation was conducted to determine the effectiveness of simulated annealing applied to the GPSS. The preliminary results show the number of conflicts reduces rapidly (see the figure "Solution Space"); therefore, the possibility of having a local minimum trap is minimal. Further examination of the GPSS code revealed that simulated annealing was not being used effectively. A solution was proposed showing how to set the initial virtual temperature and how to reduce it gradually to achieve the annealing effect.

The computational bottleneck lies in the GPSS deconfliction process. The computational time and the quality of the overall schedule can be improved by finding a suboptimal solution to the resource-constrained schedule. A genetic algorithm and its interface to GPSS were designed and developed so off-line preprocessing can be done to reduce the schedule length. When applied to the STS-85 flow data, the application of this approach reduced the schedule length by 24 days (only the resource conflicts were considered).

The GPSS uses a set of heuristics to select a task to move in order to resolve resource conflicts. The heuristic parameters are uniformly weighted to 1. The resource deconfliction process was investigated and an evolutionary machine learning technique was designed and implemented that helped determine the correct weight combination. The



Solution Space



Reduction of Resource Conflicts After Learning Heuristic Strategy

initial focus was on deconflicting the resource allocation determined by the GPSS. The preliminary results, which are summarized in the figure "Reduction of Resource Conflicts After Learning Heuristic Strategy," are very promising for improving the resource deconfliction process.

Key accomplishments:

- 1996: Completed the assessment of the commercial product during the first Summer Faculty Fellowship period.
- 1997: Investigated the bottleneck in the GPSS deconfliction process. Designed and developed an evolutionary learning method to combine a set of heuristics in order to reduce overall computation time.

Key milestones:

- 1998: Further research, development, and application of the promising machine learning technique to resolve configuration conflicts and determine the resource to be deconflicted.

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

Human Factors: Human Factors Event Evaluation Model

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

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

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

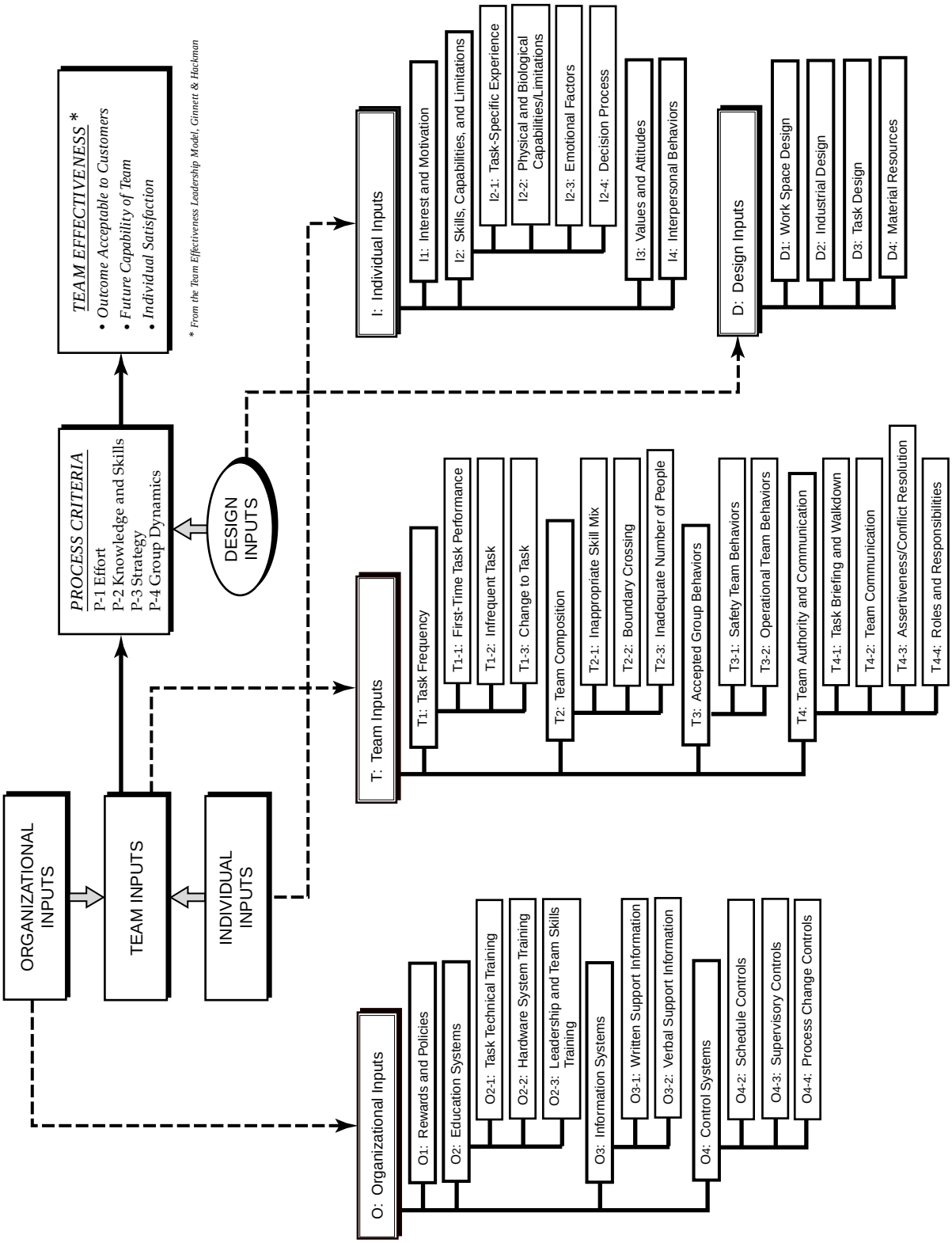
Valuable feedback on the model was received from several presentations within KSC and at external conferences. A process was established within the team to monitor data collected by various team members for accuracy and consistency. Current efforts have included the development of a user's manual for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

Key accomplishments:

- 1991 to 1992: Initial team effectiveness leadership model development efforts at KSC.
- 1993: Formation of the Shuttle Processing Human Factors Team. Refinement of the team model using data from observations of Shuttle processing work teams.
- 1994: First annual report published by the Human Factors Team based on the initial year of investigations. Continued refinement of the team model in Shuttle processing.
- 1995: Development of the initial diagnostic tool for investigating accidents in Shuttle processing.
- 1996: Validation and refinement of the diagnostic tool. Recognition of a "best practice" by the Best Manufacturing Practices Center of Excellence. Development of a database using causal factors from the model. Initial reports to Shuttle processing management.
- 1997: Published Human Factors Team "Time-Out" newsletter. Development of user's guide. Disseminated first validated data from database established through use of the model. Application of modified model to analysis of close-calls. Development of software for demonstration of human factors model concepts.

Key milestones:

- 1998: Refine user's guide. Continue to refine and disseminate data/information from applications of model. Support software development to assist in model applications.



KSC Human Factors Event Evaluation Model

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Participating Organizations: United Space Alliance (M. Nappi, D. Blankmann-Alexander, J. Jamba, K. Pisula, B. Potteiger, B. Parker, J. Ewald, D. Smith, and L. Santana); NASA Shuttle Processing (C. Orr and T. Barth); NASA Safety, Reliability, and Quality Assurance (J. Medina); Ames Research Center (B. Kanki); and Center for Creative Leadership (R. Ginnett)

Human Factors: Human Factors Trend Analysis System

The Human Factors Trend Analysis System (HF-TAS) helps analysts understand the root causes of process anomalies due to human factor issues at the organizational, team, and individual levels (e.g., incidents that cause personnel injuries, damage facilities, incur additional costs, and/or delay processing). The system is being developed under a Phase II Small Business Innovation Research (SBIR) contract.

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

The HF-TAS has many possible KSC, NASA, and commercial applications. The first application of the HF-TAS at KSC is assisting the Human Factors Team in investigating and analyzing the contributing causes of Shuttle ground processing accidents. (Refer to the article titled “Human Factors Event Evaluation Model.”) The major technical innovation of the HF-TAS is the anomaly process diagram (APD). The APD is a new, theoretically well-founded methodology for root-cause analysis focused on the representation of causal, probabilistic relations between process variables.

The project began in February 1997 and will last for 2 years. An initial version of the software was delivered in May and a second update was delivered in October. The system is being developed through rapid prototyping with significant design inputs from the eventual user community (i.e., the Human Factors Team). In December, a prototype system was delivered for operational use by the Human Factors Team. Example HF-TAS screens are shown in the figures. The system helps human factors analysts perform event analyses, communicate their analyses electronically, and understand the trends in the mishap data using on-line analytical processing technology. Future versions of the system will support qualitative event analysis through event components, as well as quantitative event analysis through anomaly process diagrams.

Key accomplishments:

- 1995: Award of the Phase I SBIR contract.
- 1996: Completion of the Phase I feasibility study and demonstration software.
- 1997: Award of the Phase II SBIR contract. Delivery of a functional HF-TAS prototype for KSC testing and evaluation.

Key milestones:

- 1998: Completion and delivery of the operational HF-TAS system.
- 1999: Commercialization of the HF-TAS and anomaly process diagram technologies.

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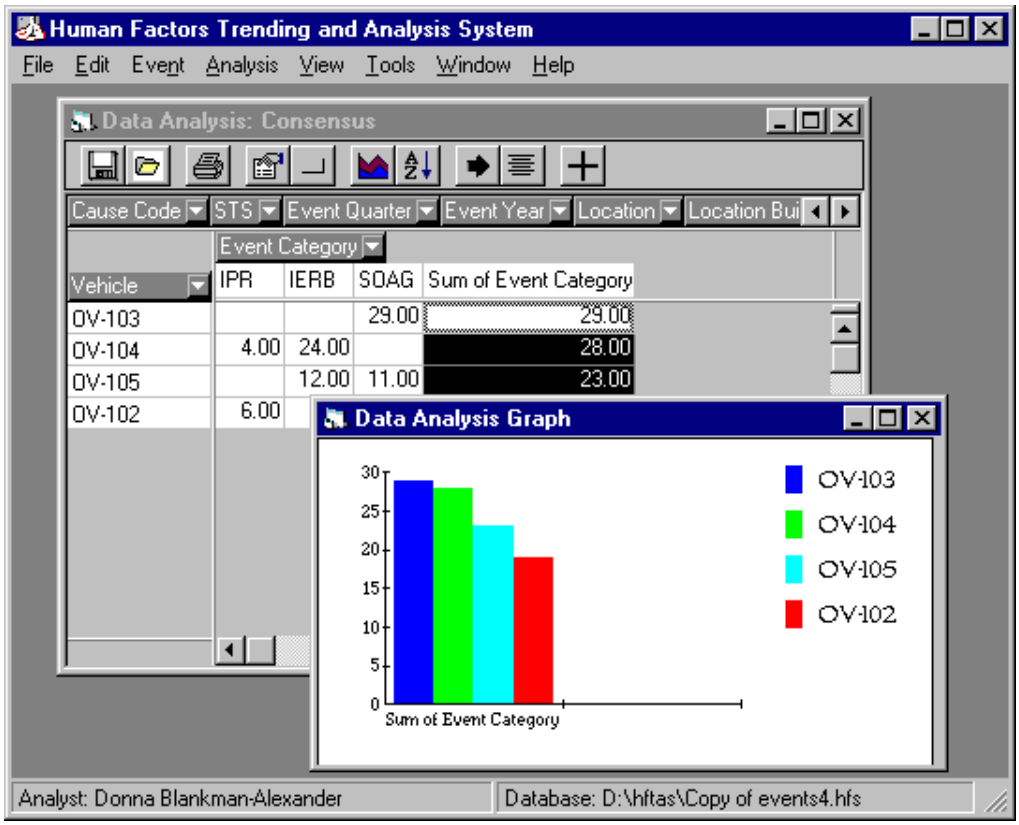
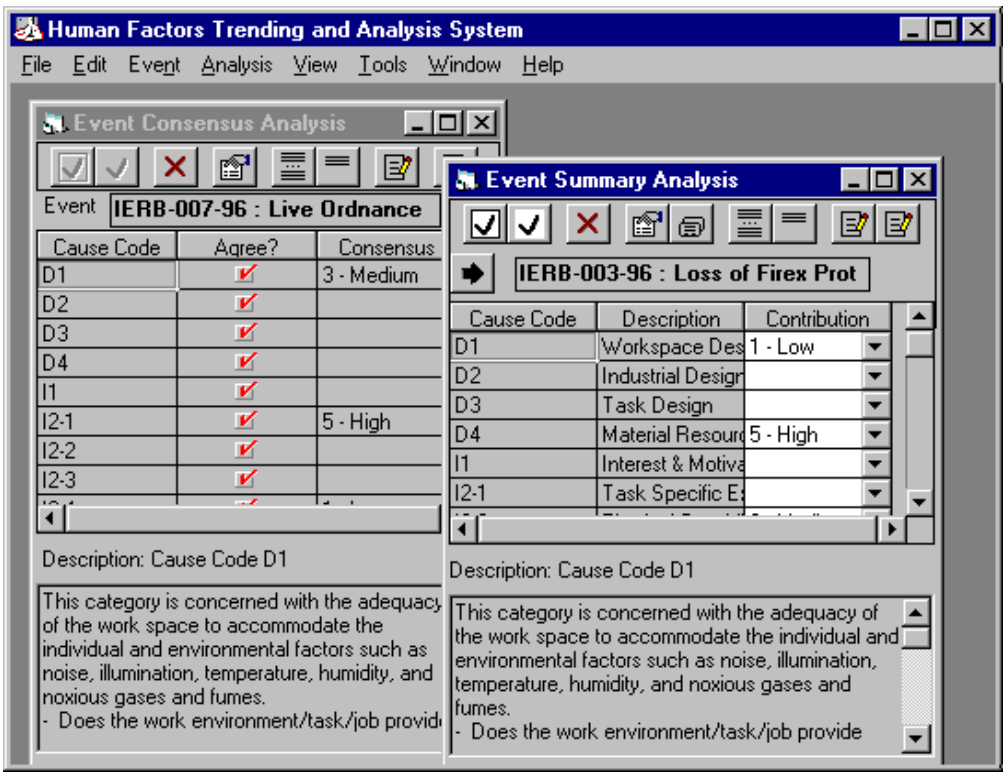
Participating Organizations: Prevision, Inc. (R. Fung and B. Del Favero) and the KSC Shuttle Processing Human Factors Team (NASA KSC and United Space Alliance Ground Operations)



HF-TAS Data Analysis Capabilities



HF-TAS Analysis Displays

Human Factors: Human Error Research in Spacecraft and Aircraft Maintenance Operations

Numerous safety studies have shown that the causes of aviation accidents and incidents are more likely to be related to human error than mechanical failure. However, human error may occur both in flight and in ground operations. Nearly a dozen recent aviation accidents have determined the probable cause to be maintenance related.

Therefore, recognition of the importance of maintenance human factors and the need for operational research is growing. Past accidents have dramatically demonstrated the potential impact of human error problems in maintenance areas such as: training for maintenance and inspection, tracking of maintenance responsibility, procedures and task documentation, work environment conditions, verbal and written communications, and leadership and teamwork.

Although the aviation industry has been innovative in developing flight-training technologies, human-centered automation, multimedia information and decision-aiding systems, the adaptation and transference of human factors tools, techniques, and principles to ground operations have been limited. The goal of this research is to better understand human error in maintenance operations in order to improve procedures, training interventions, and other maintenance task aids that will ultimately reduce human error and enhance safety in maintenance operations.

Striking similarities in human factors issues across Shuttle and aircraft maintenance have led to technology transfer meetings on topics of mutual interest. The photograph shows the Shuttle orbiter maintenance facility, which has a work environment and work processes similar to those in depot-level aircraft maintenance centers.

This Ames Research Center (ARC) and KSC joint collaboration is intended to (1) promote human factors awareness, (2) exchange research information and results, and (3) when feasible, conduct joint human

factors research. This is being accomplished in the following ways:

- Technology transfer workshops. The overall goal is to identify issues, problems, and "lessons-learned" in common interest areas across spacecraft processing and aircraft maintenance. Topics such as human error and incident analysis, risk analysis techniques, human factors training, and human performance measurement are included.

- Human factors research. The goal is to combine research efforts that involve similar human factors goals and issues across multiple operational settings. For example, KSC provides a test bed for operational research in Shuttle processing while participating airlines provide an aircraft maintenance test bed. Current joint efforts include the development of human factors analysis tools for incident analysis, database development, and procedure and task evaluation.

These efforts demonstrate an area of synergy between NASA's Aeronautics enterprise and Human Exploration and Development of Space (HEDS) enterprise. The collaboration between ARC and KSC is producing valuable results supporting the goals and objectives of both enterprises.

Key accomplishments:

- 1991 to 1993: Initial application of human factors technologies developed for flight crews to aircraft maintenance crews. Team effectiveness research on Shuttle maintenance crews.
- 1994 to 1995: Initial collaboration with the KSC Shuttle Processing Human Factors Team in the area of human error investigation and analysis.
- 1996: Human Factors Workshop I was hosted by ARC. This workshop focused on human factors aspects of incidents, accidents, mishaps, and close calls in spacecraft and aircraft maintenance.
- 1997: Human Factors Workshop II was hosted by KSC and focused on human factors training issues.

Key milestones:

- 1998: Human Factors Workshop III will focus on procedures and task/work methods analysis. Update memorandum of understanding between ARC and KSC. Develop human factors/risk analysis tools for analyzing incidents, tasks, and procedures.

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Participating Organizations: NASA ARC and KSC, United Space Alliance, Transport Canada, National Transportation Safety Board, Aerospace Safety Advisory Panel, Northwest Airlines, United Airlines, Continental Airlines, U.S. Airways, and Idaho National Engineering and Environmental Laboratories

Work Measurement and Methods: Expert System To Generate Job Standards

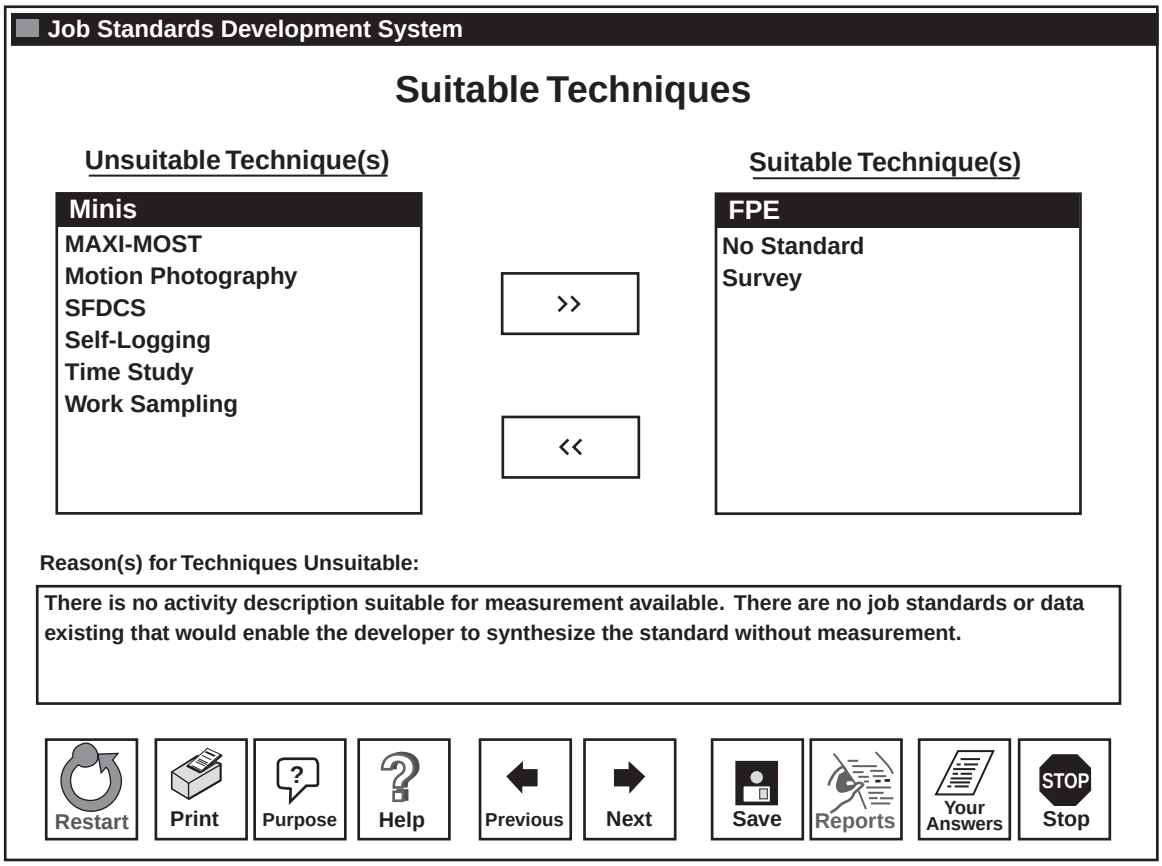
KSC industrial engineers are actively engaged in identifying techniques to improve the efficiency and effectiveness of Space Shuttle ground processing. One approach that has demonstrated a high potential for success is the industrial engineering area called work measurement. Although many work measurement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

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

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

Key accomplishments:

- 1994: Successfully demonstrated the prototype expert system to select an appropriate work measurement technique (see the figure).
- 1995: Identified the work measurement techniques to include in the expert system.
- 1996: Conducted a small-scale test of a work measurement technique in the KSC environment.
- 1997: Conducted a comprehensive field trial of the work measurement technique tested in 1996.



Available Techniques Based on User Input

Key milestones:

- 1998: Test and install the Job Standards Development System (JSDS). The JSDS will include expert systems to select the work measurement technique, guide the work measurement, and compute the job standard.

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Participating Organizations: OMNI Engineering and Technology, Inc. (N. Schmeidler), OXKO Corporation (S. Oxman), United Space Alliance, and NASA KSC Shuttle Processing (C. Orr)

Work Measurement and Methods: Portable Data Collection

Work procedures for payload processing and checkout operations at KSC are currently executed using a paper system. With this system, a procedure is generated using a word processor. The procedure is then printed out, copied, and distributed to members of the task team. When the work procedure is executed, a single master copy is kept up to date by using a pen to record test data and notes and by using quality and technician ink stamps to verify the work steps as they are performed. Test team members maintain their own copies of the procedure. Deviations to the work instructions that occur during the execution of the procedure must be documented on a paper form. These deviations require approval signatures. Once approved, the deviation is then copied and distributed to the task team. The completed master work procedure, including deviations, is scanned into a computer and stored electronically.

The objective of the Portable Data Collection (PDC) system was to automate this procedure process. A Small Business Innovation Research (SBIR) contract was awarded to Sentel Corporation to develop the capability to capture technician and quality stamps and test data electronically. This project was developed by Sentel Corporation and KSC, the lead center for payload processing.

With the PDC system, the procedure is converted from a word processor document to a database. It is then executed using portable computers. Data is entered electronically, either with a keyboard or a pen, using handwriting recognition. The system distributes this data to all other terminals. The ink stamp is replaced with an electronic stamp that meets the form, fit, and function of the old ink stamp. A programmable memory chip inside the electronic stamp stores a unique identifier. All team members have their own electronic stamp.

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

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

- All test team members see changes to the document instantly, providing greater assurance that all team members are properly informed and data is accurate.
- Accuracy of the procedure is improved as deviations are incorporated directly into the appropriate sequence of the procedure. The time to process, approve, and distribute a deviation is also reduced.
- Information availability is improved. Test data can be searched and retrieved through standard database queries for management reporting or incident investigations.
- The need to print and distribute procedures prior to testing is eliminated.
- The need to scan the procedure for storage is eliminated.
- Emergency procedures can be accessed immediately.
- The amount of paper is reduced.

The system was modeled after the existing paper system, using the existing business rules. It would be possible, if approved in the future, to add control features that would validate the work practices. Presently, the system is being developed to support Space Station processing.

Key accomplishments:

- 1993: Completed the Phase I study of the SBIR contract.
- 1996: Completed Phase II of the SBIR contract. The proof of concept for this system was demonstrated.
- 1996: Received the NASA SBIR Technology of the Year Award in the computer/software category.
- 1996: Completed pilot study 1. The first pilot study was conducted in the Operations and Checkout Building using the PDC electronic system in parallel with the paper system.
- 1997: Upgraded system from proof of concept to an operational system.

Key milestones:

- 1998: Test and implement the PDC system in the KSC Space Shuttle Main Engine shop. Test and implement the PDC system for use in Space Station processing.
- 1999: Enhance the operational system. Include an interface to the Payload Data Management System. Provide Internet access to the PDC. Support all types of work authorization documents.

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Participating Organizations: Sentel Corporation (K.L. Jackson and M.R. Kappel) and Auburn University (L.K. Moore)

General: Center for Applied Research in Industrial and Systems Engineering (ARISE)

This effort seeks to establish a combined research and educational partnership between KSC and Florida International University. The main purpose is to set up a program that attracts and retains women, Hispanics, African Americans, and other minority individuals to engineering and NASA-related career paths. A state-of-the-art center is planned that will provide students of industrial engineering and related disciplines with the following opportunities:

1. To apply the concepts learned in the classroom to real-world projects.

2. To investigate issues that, as of yet, are not well understood by industry practitioners and academicians.

3. To be ready to fully participate as a member of the diverse workforce of the 21st century.

Students participating in the program will be exposed and trained in NASA's mission; be given seminars on a variety of issues, including seminars on the realities of the workplace, diversity, and gender issues; and participate in applied research projects. In addition, participating students will be instructed on the benefits of pursuing postgraduate studies to increase their chances to succeed in the workplace as well as increasing their stature as role models for future generations. Students participating in this program will attend to their regular curriculum during the academic year, but some of the projects for their required courses will have a focus related to NASA's mission and the practice of industrial engineering in accomplishing that mission.

The initial timeframe of this effort is 2 years; however, this time will be used to demonstrate to industry the effectiveness of the program so industry will continue the sponsorship of the ARISE Center beyond the second year. Specifically, it is planned to develop by the end of the first year a proposal that would be presented to local industry. The proposal will highlight the benefits local industry may derive from the ARISE Center and the impact their sponsorship will have in shaping the lives of future community leaders.

Key accomplishments:

- 1997: Established an applied research center where participating students have access to the necessary tools to start and complete industrial and systems engineering projects related to NASA operations and processes at KSC. Selected hardware and software and purchased other equipment needed for the ARISE Center. Recruitment of

students, which involved the development of a brochure and the development of a web site for advertising the existence of this opportunity (www.eng.fiu.edu/ie/arise/arise.htm).

Key milestones:

- 1997: Identification of the areas for the projects in conjunction with KSC personnel and development of seminars: (1) history of NASA, its purpose, its beginnings, Apollo mission (manned missions), etc.; (2) history/process of the Space Shuttle; (3) Shuttle processing; (4) engineering tools; (5) nontechnical subjects such as working in groups and gender issues in the workplace and classroom; and (6) careers with NASA.

- 1998: Discussion of projects in early January. Project development over the spring and summer semesters. Projects conference in April to showcase some of the projects to industry. Industrial portfolio to recruit industrial partners.

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Participating Organization: Florida International University (M. Centeno, J. Jacko, and M. Resnick)

General: Methodology To Harvest Intellectual Property at KSC

Information and data obtained through problem-solving and decisionmaking can be converted into intellectual capital. The need to acquire intellectual capital created the knowledge management movement, which aims to develop new practices and tools to capture knowledge. Knowledge management in general tries to organize and make available important know-how, wherever and whenever it is needed. This includes processes, procedures, patents, reference works, formulas, "best practices," forecasts, and fixes. One kind of knowledge management project attempts to manage knowledge assets from a financial perspective. KSC's focus for this project is on intellectual capital and harvesting little-used patents and intellectual assets. As the NASA Center responsible for preparing and launching space missions, KSC is placing increasing emphasis on its technology development program. KSC maintains a vigorously 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. Focusing predominantly on applied research leads KSC to the development of new technologies and expertise directly applicable to commercial products and manufacturing needs.

Technology commercialization is a primary goal of NASA's Technology Transfer Program. Patent and copyright licensing is a key mechanism for accomplishing this goal. In order for NASA to continue to increase the number of successfully commercialized technologies, NASA must identify commercial applications for its new technology and effectively seek out commercialization partners.

Key accomplishments:

- 1997: Identified alternative commercial applications for eight NASA-developed technologies. These advanced technology development projects have been proposed, are currently under development at KSC, have been completely developed, or have already received intellectual property protection. Investigated potential markets associated with the new applications and provided profiles of key companies that may be interested in partnering with NASA. Investigated the current state of similar or applicable commercially available technology and potential for dual-use development with industry. Provided assistance in identifying and characterizing qualified leads associated with commercializing NASA technologies. Companies were categorized primarily on the basis of capabilities, interests, and areas of expertise. Prepared a comprehensive report containing a synopsis of each advanced technology project as well as a review of possible partners and applicable commercially available technologies.

Key milestone:

- 1998: Ongoing identification of alternative commercial applications for additional NASA-developed technologies.

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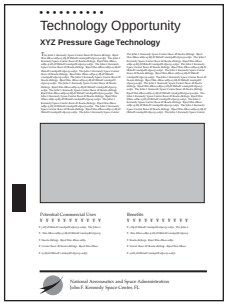
Participating Organizations: NASA Technology Programs and Commercialization Office (K.W. Poimboeuf) and Florida International University (I. Becerra-Fernandez)



Review assigned KSC Technology Opportunity Sheet (TOS) and develop a list of searchable codes

Weekly staff meeting and brainstorming session

Research by contracting NASA inventors

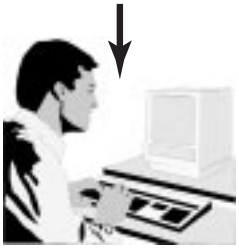
Search for potential markets

Use information resources to research information related to the TOS

Research additional applications that resulted from the brainstorming session

Identify and categorize potential markets for the technology

Contact potential leads to complete the "Information about Companies" form



Compile and submit NASA reports for assigned TOS

General: Enhancement of Fire/Rescue Dispatching Operations

The dispatchers for fire stations and rescue squads perform a difficult task under strenuous conditions. While handling several cases simultaneously, they take limited data from phone calls and their computer (usually entered by 911 operators) and rapidly make decisions about the specific fire or rescue unit to dispatch to the scene. All the work is performed at their computer workstations, so it is imperative that ergonomic issues be addressed in order to maximize dispatcher effectiveness. The work described in this article was initiated through a Technology Transfer Agreement with Metro-Dade County, Florida. The methodology developed during the study, however, can also be applied in a variety of similar situations. The study consisted of three major components: an ergonomic assessment of the computer workstation, a process analysis, and a team effectiveness assessment. Data was obtained through documentation, a videotape, interviews, direct observation, and surveys.

Ergonomic Assessment

The dispatchers were concerned about a wide range of ergonomic workstation issues in four general categories: computer information input, computer information output, workstation design issues unrelated to the computer system, and audio problems. Existing ergonomic checklists and guidelines provided some value to the study, but they typically addressed a situation where an operator uses a single display terminal and standard keyboard/mouse data entry. The dispatcher workstations include two separate terminals, four methods of data entry (including a touch screen), and several other nonstandard characteristics. A customized survey was developed to prioritize the major ergonomic issues identified by the dispatchers. The survey addressed the impact of 22 separate ergonomic problems on dispatcher comfort/health and operational performance. Fatigue issues were also considered. The survey data was analyzed with a risk analysis approach to combine the frequency a dispatcher experienced a specific ergonomic problem with its impact when it occurred. The results of the comfort/health risk ranking are shown in the figure "Effect of Ergonomic Workstation Problems on Dispatcher Comfort/Health." The ranking was used to prioritize the ergonomic problems in order to formulate cost-effective recommendations.

Process Analysis

The inputs and outputs to the dispatching process are both information. The primary measure of effectiveness is cycle time — the length of time between the initial emergency phone call and arrival of the fire/rescue unit on the scene. In any process, rework between steps and organizational boundaries commonly increases the cycle time and process variability. Since several instances of rework were observed due to inaccurate information input and output, a process analysis team including representatives from both suppliers (911 operators) and customers (fire/rescue units) was suggested. The team will collect data on process rework and develop strategies to reduce or eliminate error sources. The dispatching process is illustrated in the figure "High-Level Dispatching Process."

Team Effectiveness Assessment

The dispatching function requires a high level of teamwork. Individual dispatchers constantly communicate verbally with each other and use interconsole computer messaging and visual cues while working with their customers. These interdependencies present additional constraints when trying to resolve ergonomic issues. Specific strengths and opportunities for improvement (in addition to the ergonomic design issues previously identified) in dispatching teamwork were identified using the KSC Human Factors Event Evaluation Model, which is described

High-Level Dispatching Process

in a separate article in this report.

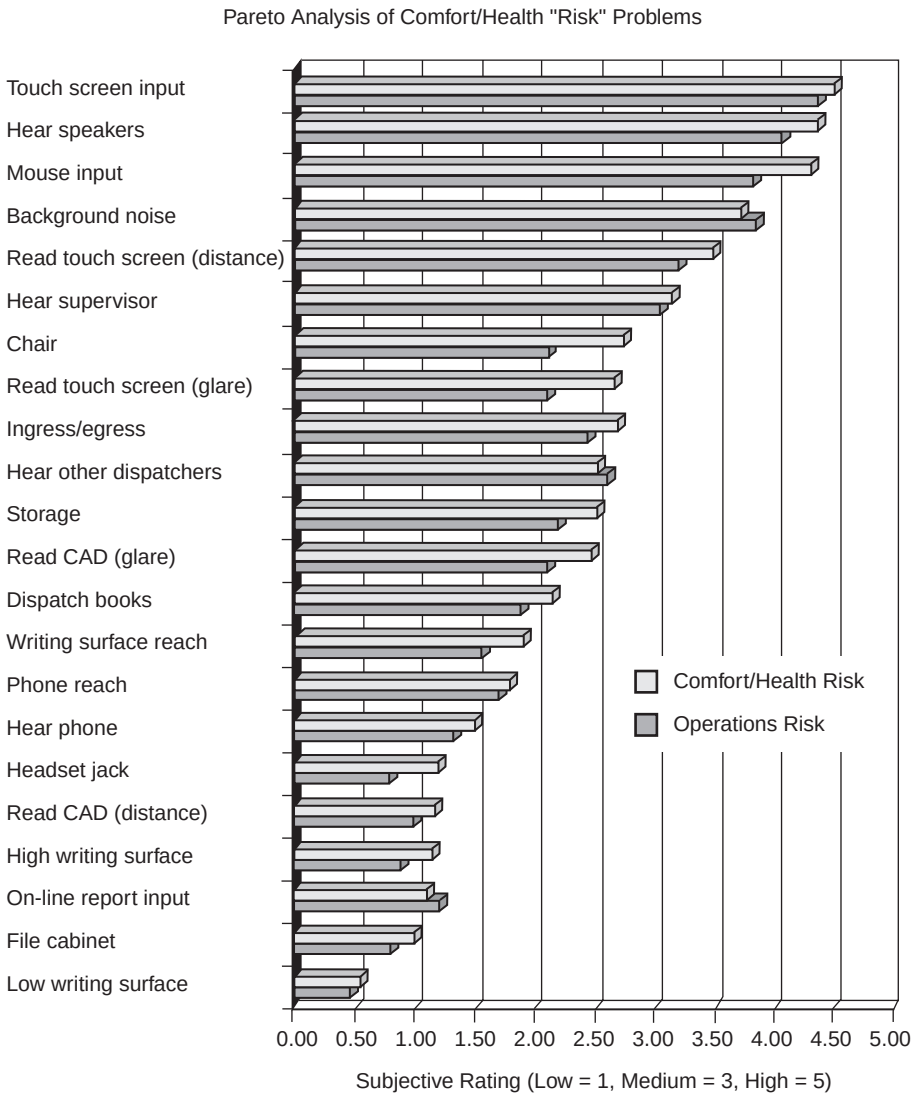
The insights generated from the results of the three study components were used to develop an integrated set of short- and long-term recommendations. A dispatcher team was formed to implement the recommendations in order to improve the quality of the work environment and establish a goal to reduce process cycle time by 20 percent, which significantly improves the ability of the fire/rescue units to limit property loss, personal injuries, and loss of life.

Key accomplishments:

- 1997: Completion of the industrial engineering study. Formation of an internal dispatcher process improvement team.

Key milestones:

- 1998: Implementation of recommendations. Collection of process data to reduce (or eliminate) error sources resulting in process rework. Potential support through the NASA/Florida International University Center for Applied Research in Industrial and Systems Engineering (ARISE).



Effect of Ergonomic Workstation Problems on Dispatcher Comfort/Health

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Participating Organizations: Metro-Dade Fire/Rescue Communications Division (Chief D. Keyes), University of Central Florida (R. Safford), and NASA Ames Research Center (B. Kanki)

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 operational requirements and to ensure requisite technologies will be available to fulfill future vehicle, payload, and launch requirements.

To meet the challenge of becoming more efficient in all aspects of KSC work, technologies are being extracted from the expanding technological base; and these capabilities are being utilized to improve performance, save time, and increase productivity. This year's Advanced Software program employs a broad range of disciplines and technologies ranging from programs that process vast quantities of data (which makes it available for Operation's use through tools such as the Internet) to advanced mathematical techniques that enhance capabilities for imaging and wave analysis.

Three-Dimensional Modeling for Prediction of Transport and Diffusion of Hazardous Materials

Eastern Range safety engineers currently use transport and diffusion models that predict downwind concentrations of hazardous propellants and oxidizers in a single surface layer at KSC and Cape Canaveral Air Station (CCAS). However, the meteorological regime at KSC is complicated by the sea and land breezes and the varying wind flows caused by the numerous land/water interfaces. The Applied Meteorology Unit (AMU) has been evaluating and assisting in the technology transfer of the Eastern Range Dispersion Assessment System (ERDAS) to operational status. ERDAS is being incorporated into the recently upgraded Meteorological and Range Safety Support (MARSS), a system that displays, analyzes, and predicts toxicological hazards associated with spacelift operations.

ERDAS is a software and hardware system configured to produce routine mesoscale meteorological forecasts and enhanced dispersion estimates on an operational basis for the KSC/CCAS region. It was developed under a United States Air Force Phase II Small Business Innovation Research (SBIR) contract by Mission Research Corporation. ERDAS uses a graphical user interface to access the Regional Atmospheric Modeling System (RAMS), a three-dimensional multiple-nested grid prognostic mesoscale model, and a pollutant trajectory and concentration model [the Hybrid Particle and Concentration Transport (HYPACT) model]. An example of output from HYPACT is shown in the figure "Example of Rocket Exhaust Plume Generated by HYPACT in ERDAS."

As part of the transition to operations, ERDAS is being upgraded by hosting the RAMS model on a powerful multiprocessor workstation. Multiple users connected to a network at CCAS and KSC will be able to display RAMS forecast data, along with actual data from many of the local observing systems. Users will also be able to run HYPACT or other operational diffusion models for planning, launch scenarios, or emergency purposes. Primary features of the upgraded system, scheduled for delivery in late 1998, include:

- The existing local area network will be upgraded to use a higher speed distribution mechanism known as the Fiber Distributed Data Interface to support the larger data transfers. A diagram of the ERDAS-MARSS configuration is shown in the figure "Upgraded MARSS System Including the ERDAS."
- A series of Hewlett-Packard K460 workstations will be used as dedicated RAMS processors. The K460 will utilize a symmetric multiprocessor architecture to provide RAMS model execution for a complete 24-hour period within 4 hours.
- The RAMS will be run with microphysics activated, four nested grids with the finest grid set to 1.25-kilometer grid spacing.
- Additional meteorological data sources will be ingested. ERDAS currently ingests data from rawinsondes, coastal buoys, surface observations, local meteorological towers, and gridded National Centers for Environmental Prediction model output. New data sources include a 50-megahertz radar wind profiler, 915-megahertz radar wind profilers, and jimspheres. New data quality control procedures will be implemented.

Key accomplishments:

- 1991 to 1994: ERDAS developed under an SBIR contract.
- 1994 to 1996: ERDAS evaluated by AMU.
- 1995 to 1997: MARSS system upgraded by NASA and U.S. Air Force.

Key milestones:

- 1998: ERDAS upgraded and integrated into the MARSS system. ENSCO, Inc., is the prime contractor and Mission Research Corporation is the subcontractor performing ERDAS upgrades.

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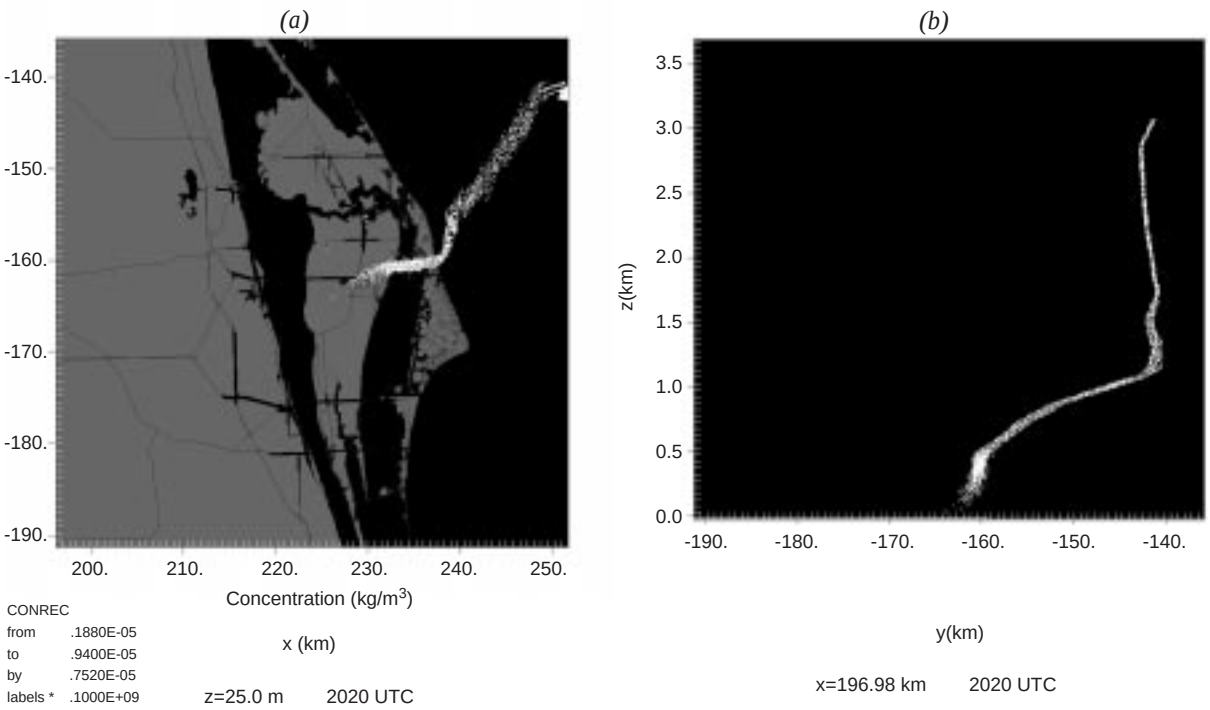
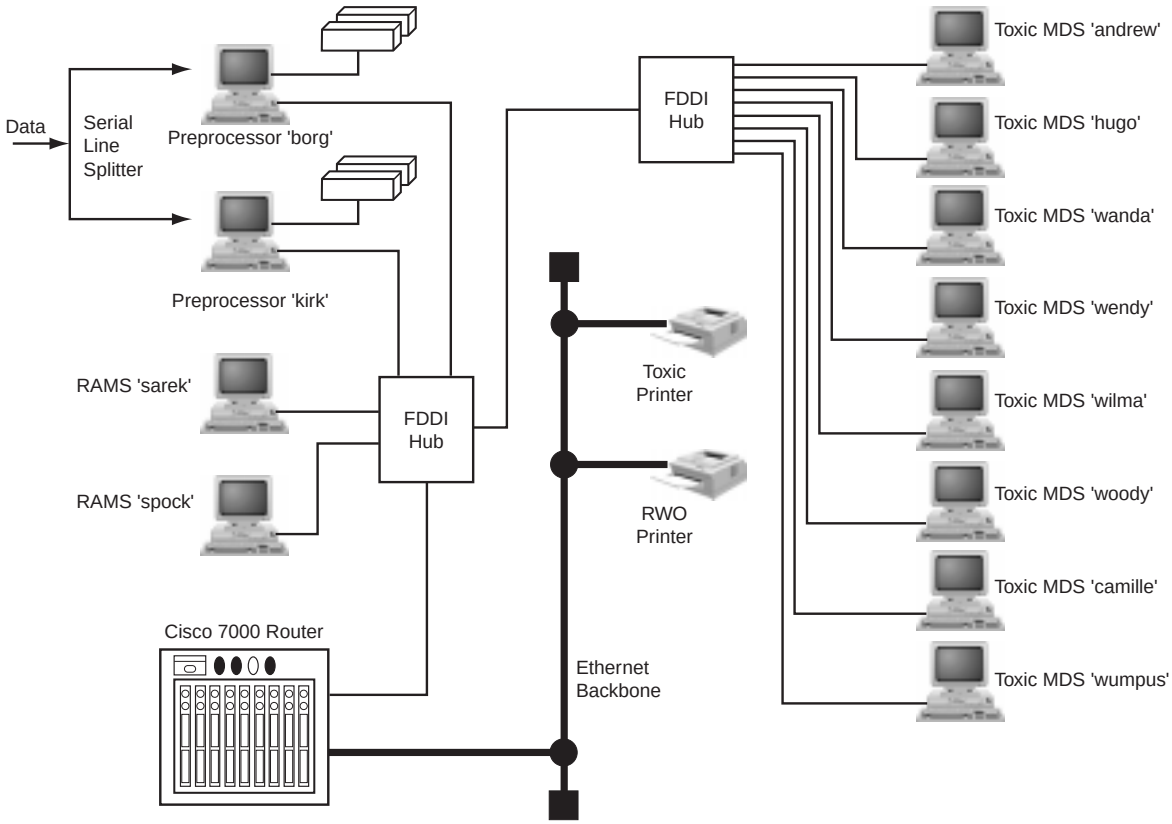
Participating Organizations: ENSCO, Inc. (R. Evans and A. Dianic) and Mission Research Corporation (C.J. Tremback, Ph.D.)



Example of Rocket Exhaust Plume Generated by HYPACT in ERDAS
[A map view of the plume is shown in (a) while a cross-section view looking to the west is shown in (b).]



Upgraded MARSS System Including the ERDAS
(The Toxic MDS workstations are monitoring display stations.)

NASA/KSC Industrial Computed Tomography (CT) System

The NASA CT System was tasked to perform nondestructive evaluation of many Space Shuttle and aerospace components since its inception in August 1985. The first industrial CT to be installed at a NASA center, the KSC system is used for the noninvasive inspection of component integrity as well as a tool for the accurate determination of internal density and dimensions (applications never before realized by any other inspection device). The system is operated for NASA by the EG&G Base Operations Contract (BOC) Nondestructive Evaluation Laboratory.

A major achievement was the development of an automated computer program that acquires CT data and fully profiles the density of Shuttle tile production blocks from which tiles are subsequently manufactured. The CT is used as a significant part of the process control of the acceptance criteria of the blocks, producing nearly 100 percent density profiles of the silica and alumina fiber composition. The profiles indicate if the blocks are within the required specification for ultimate use in producing a tile. Blocks not within the specified density are rejected since Shuttle tiles produced from them might fail.

As a result of the ability of the CT to perform densitometry through the preparation of specialized computer programs, the following projects have been tasked to the NASA/KSC CT System even though the sponsoring NASA centers [George C. Marshall Space Flight Center (MSFC), Langley Research Center, and Lewis Research Center] have CT systems.

Key accomplishments:

- Tile density analysis for process control of Shuttle tile production (1998 and to follow)
- At MSFC and Langley, CT of crystal materials for the microgravity space laboratory and examination for preflight and postflight material analysis, particularly the ongoing development of mole fraction analysis of teluride compounds in crystal materials. The CT will potentially replace an existing electrodischarge spectroscopic method that requires several more hours of destructive analysis. This CT project is funded by MSFC as an add-on to the existing BOC and has been approved for 1998.
- Mechanics of Granular Materials (MGM), a project also sponsored by MSFC. The NASA/KSC CT is used to inspect the effects of microgravity stress analysis of sand columns whose distortions relate to certain aspects of geologic stresses experienced in the Earth's crust.
- At NASA Lewis Research Center, the feasibility CT analysis performed on composite materials that the CT system is not able to accommodate.
- The BOC propellants division used the CT to locate internal tubing in liquid oxygen vaporizer canisters in order to provide a clear site for drilling into the units for the placement of thermocouples. The ability of the CT to provide exact internal dimensions that provided clear drilling locations was estimated to have saved tens of thousands of dollars. Other canisters will be scanned as needed. The only alternative was to purchase new canisters with the required thermocouples.
- The KSC CT was also used to provide images of the internal structure of critical U.S. Air Force Titan rocket motor flow control valves. The CT was used to inspect nearly 100 valves, finding about 12 that had critical manufacturing anomalies that could have resulted in valve failure.

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Participating Organizations: EG&G (M. McDaniel, P. Engel, and M. Myrick); United Space Alliance (S. Hadoulias); George C. Marshall Space Flight Center (Dr. D. Gillies and J.R. Cantrell); Langley Research Center (Dr. A. Fripp); Lewis Research Center (Dr. G. Basaklini); United Technologies; and Pratt and Whitney (D.K. Tubbs)

Technical Documentation Archive System

The Technical Documentation Archive System (TDARCHIVE) is a client-server application that supports the scanning and archiving of Payload Processing Work Authorization and Problem Report as-run documents that are stored in the KSC Technical Documentation Center. This application was developed to replace the need for microfiche and is the archival database for payload documentation.

The current system is the repository of over 40,000 documents and is growing at an average of 2,500 documents per month. The documents are stored in a multipage tagged image file format (TIFF) group IV format and are converted to a portable document format (PDF) on demand for the end user.

The application was developed in Java 1.0 using Microsoft SQL Server 6.5 as the database. The application can reside on a variety of platforms; however, the database requires Windows NT software. This application was designed so the database can be changed and the only portions that need to be updated are the stored procedures. All the routines that were platform specific have been isolated to make the system more portable.

An applet was also developed using the same application objects for the WWW interface. This is the primary interface for the end user. From this interface, the user can retrieve attribute information and the actual document in either TIFF or PDF format. The PDF format is produced on demand from the TIFF file using software developed with this project.

TDARCHIVE is currently in use by The Boeing Company on the Payload Ground Operations Contract. The NASA development team plans to make some modifications to the software to provide a generic imaging/scanning solution for an office environment.

Key accomplishments:

- April 1997: Development began.
- July 1997: Development completed.
- October 1997: System operational.

Key milestone:

- July 1998: Complete generic office solution.

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Participating Organization: Prevo Technologies, Inc. (J. Prevo and T. Duerr)

Materials Science Division Using a New Web-Based Work Control System

The Logistics Operations Directorate's Materials Science Division (MSD) has a new software system running in real time on the World Wide Web. Named the Work Control System (WCS), it demonstrates the integration of common Web browsers with a commercially available relational database management system to create a single, user-friendly means of controlling work flow.

The MSD laboratories were established during the Gemini era to provide quick laboratory support to vehicle and facility operations at KSC. The MSD was Government- and contractor-operated but was converted to a 100-percent Civil Service operation in 1968 so unbiased investigations could be provided.

Prior to this new application, each group in the MSD kept a separate report log containing unique fields, such as investigator name, date started, date completed, and report number. The WCS offers a single means of maintaining the report log and tracking the work flow, resulting in a much more efficient operation for both laboratory investigators and their customers. The WCS also aids the MSD in its effort to become ISO 9000 compliant.

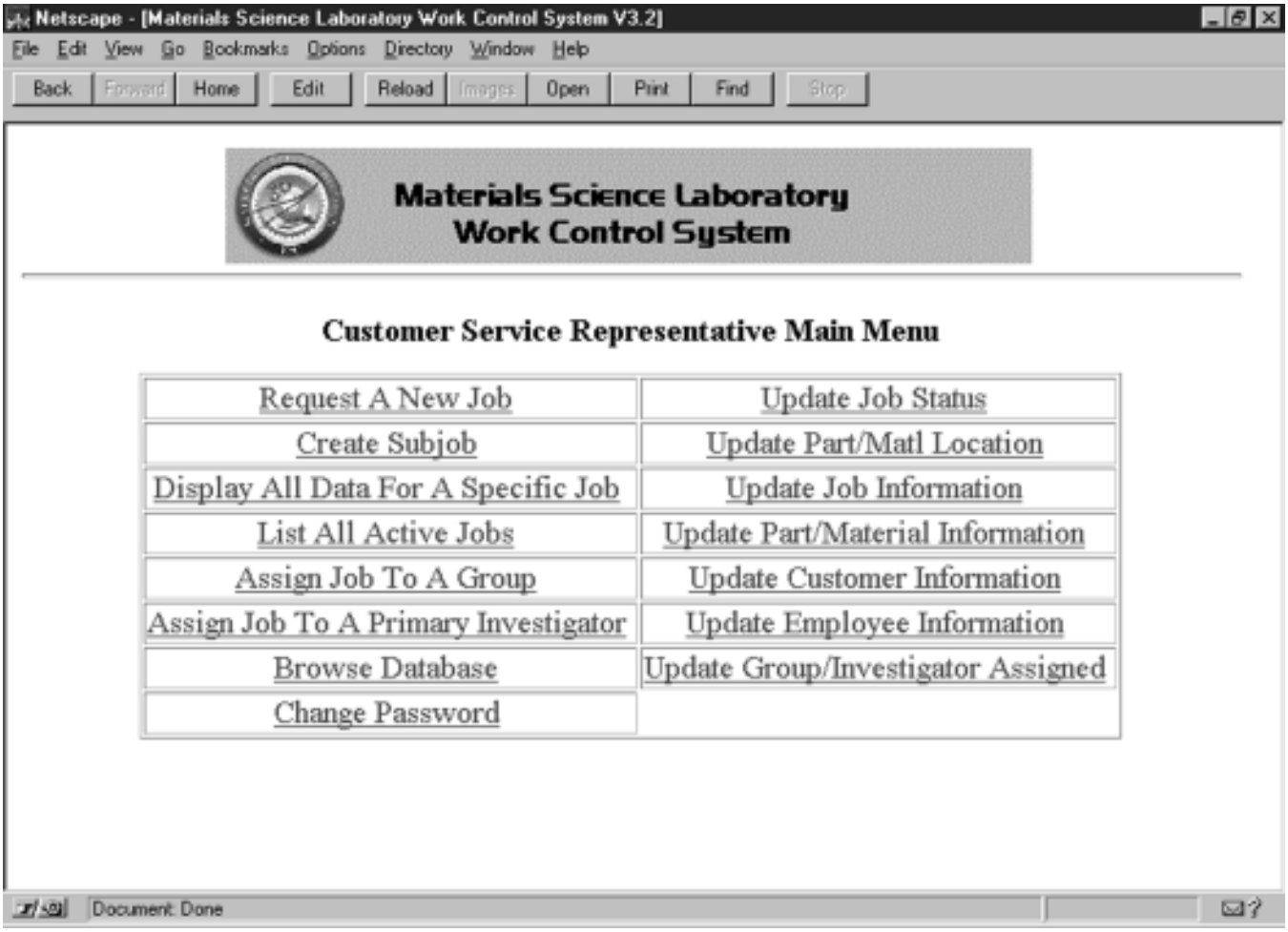
The benefits and features of the WCS are many. The system is hardware and software independent on the server side – practically all server manufacturers and operating systems can run it. On the client side, practically all desktop computers, including Macintoshes, PC's, and UNIX work stations, can use WCS with a Web browser.

WCS offers a full-function, relational database management system (RDBMS). Features include referential integrity checking, security, transaction logging, and a distributed database. The RDBMS selected for the WCS implementation is Oracle because of its wide usage at KSC.

The Web pages are dynamically created in real time, based on user inputs using Procedural Language/Structured Query Language (PL/SQL), which is stored in the database itself. Browser tables are also produced dynamically. The use of PL/SQL for WCS implementation results in fast system response time.

The WCS's current server configuration is a Sun Sparc II, running Solaris 2.5.1 (UNIX), Oracle Enterprise RDBMS, and Web server software. The client needs only a PC, Mac, or UNIX work station and a Web browser such as Netscape or Internet Explorer to access the system. Other WCS demonstrable features include:

- Automatic e-mail to customers with status changes, such as job on hold, job complete.
- Automatic notification to MSD personnel for new jobs and status updates.
- Ad hoc reporting.
- Security and access control with password and firewall.



- Automatic file transfer (ftp).
- Transaction logging.
- Electronic signatures.
- Add and display of job documents including pictures and reports.
- Job splitting.
- Equipment calibration tracking.
- Part/material tracking.

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Participating Organizations: NASA (S. Murray) and Dynacs Engineering Co., Inc. (W. Spiker and N.M. Tuttle)

Analysis of Nonstationary Signals Using Wavelets for Extracting Resonances

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

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

Key milestones:

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

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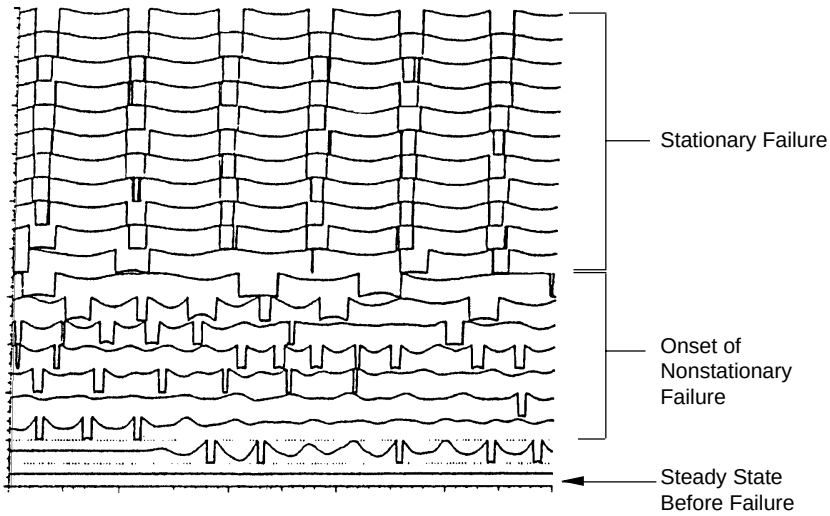
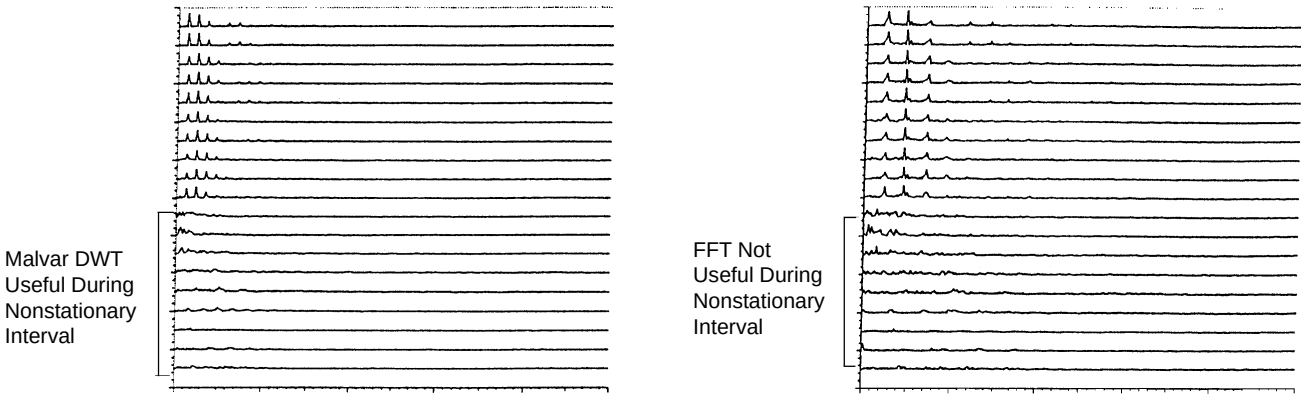
Participating Organizations: Dynacs Engineering Co., Inc. (R.N. Margasahayam) and EG&G Florida, Inc. (O.J. Varosi)



Time Domain Signal for Impending Bearing Failure



Comparison of DWT and FFT

Mechanical Engineering

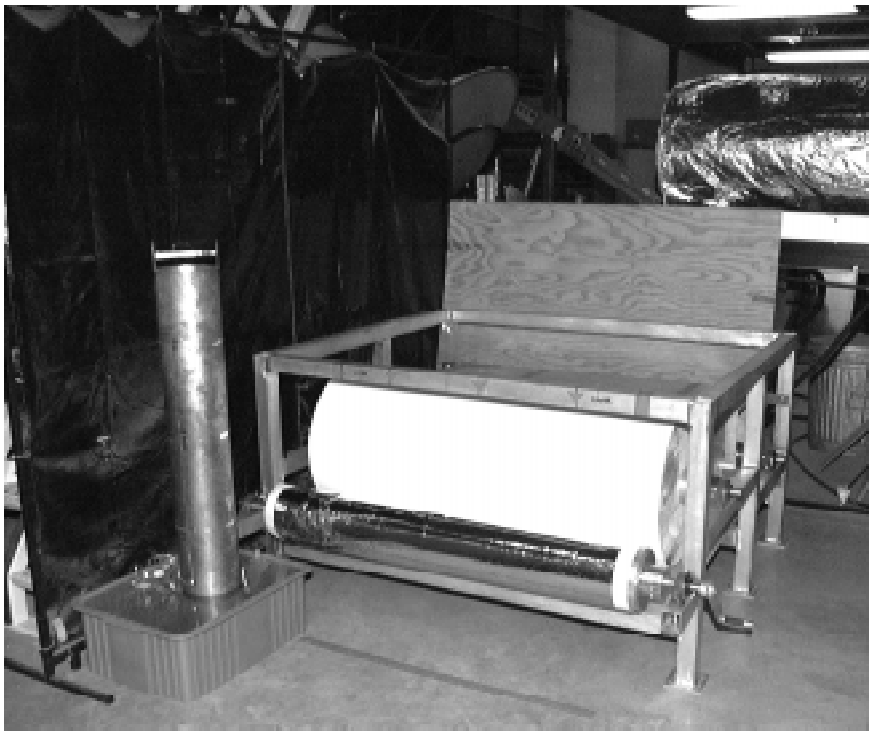
The Mechanical Engineering program at the John F. Kennedy Space Center (KSC) supports the development of technology with analysis, design, and operation of launch and ground support equipment for space flight vehicles. Technology is advanced by a broad variety of analysis including structural deflection, 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.

Cryostat Test Apparatus for Thermal Insulation System Development

The KSC Cryogenics Test Laboratory includes a liquid nitrogen boiloff calorimeter (or cryostat). This cryostat test apparatus provides thermal conductivity measurements of different insulation systems at various vacuum levels. The top-opening configuration of the apparatus allows for convenient access to the cryostat and quick changeout of the insulation test articles.

The cryostat consists of a 22-inch-long, 6.5-inch-diameter test chamber (approximately 10 liters in volume) oriented vertically with a thermal guard chamber on each end. Heavy-wall stainless-steel construction provides a cold mass with high thermal stability and minimal temperature gradients. The cryostat is then enclosed by a 14-inch-diameter by 48-inch-long vacuum can of about a 100-liter volume. An overall view of the insulation test apparatus is shown in the figure "Cryostat Test Apparatus." Insulation test articles may be wrapped around a copper sleeve, instrumented with specific type K thermocouples with reference junctions, and then simply slid over the cold mass of the cryostat for the testing. A multilayer insulation wrapping machine, shown in the figure "Multilayer Insulation Wrapping Machine," is also available for custom application of radiation shielding. The test

Cryostat Test Apparatus



Multilayer Insulation Wrapping Machine

articles, 6.5-inch inside diameter by 36-inch length, may be up to 2.5 inches in total thickness.

In operation, all three chambers of the cold mass are filled to capacity and maintained full until a steady-state thermal equilibrium is achieved. The test chamber is then isolated while replenish flows of liquid nitrogen are continuously supplied to the two guard chambers (top and bottom) at less than 0.5 pound per square inch gage. The vacuum level is measured using calibrated MKS Baratron capacitance manometers and adjusted using the appropriate combination of gas metering valves, a roughing pump, and a turbopump. Full range pressure monitoring from high vacuum (below $5x10^{-5}$ torr) to atmospheric pressure (760 torr) is provided. The boiloff gas is routed to one in a series of calibrated MKS flowmeters; the measurable flow range is 0.1 to 10,000 standard cubic centimeters per minute. A thermal shroud is provided on the exterior of the vacuum can for maintaining a prescribed warm boundary temperature or for bake-out of the system. All measurements are recorded on a 40-channel data acquisition system using LabView software.

The boiloff flow of nitrogen gas is directly proportional to the radial conduction of heat through the insulation. Steady-state conditions are achieved when the chamber pressures and then the insulation temperatures are stabilized. Boundary temperatures can be set from 77 to 300 kelvin and the annular space can be filled with different gases. The apparent thermal conductivity of the insulation is thus computed from the boiloff rate, the chamber geometry, and the temperature difference across the insulation thickness.

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Participating Organizations: Dynacs Engineering Co., Inc. (M.J. Ynclan) and MVE Inc. (S. Augustynowicz)

Orbital Welder With Automated Preweld Alignment Check and Postweld Inspection

The Space Transportation System design has many different fluid systems and uses many different tubing connection techniques. A considerable number are subject to leakage and require different levels of process control during assembly. An all-welded design would be the most operationally reliable but requires much intrusive process control during assembly; therefore, it is not the choice of design today. The mechanical fitting allows greater assembly ease that is less disruptive to manufacturing and assembly or operational maintenance. The welded or brazed technique is mostly used for toxic fluids because of safety reasons. This welded or braised technique requires the use of x-ray, which is a cleared-area serial operation and subject to some rework that again requires a serial, cleared-area, x-ray verification process control. This is very manpower intensive and time consuming.

The need for a totally automated welding process was solicited through the Small Business Innovation Research program, which is now entering the final quarter of Phase II (2 years in length) in designing and building a prototype system. Technolink of Ontario, California, provides the principal investigator for the project, which is progressing well. Funding was shared by a welding equipment manufacturer that is expected to market this new fully automated welder commercially. A market survey indicated a large demand for this capability.

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Participating Organization: Technolink (M. Sisson)

Liquid Oxygen Field Cleaning Project

Concern about the global warming/ozone connection resulted in a ban of chlorofluorocarbon (CFC) (Freon 113 precision-cleaning solvent) manufacturing. This created a need for a replacement solvent for liquid oxygen (LOX) storage and transfer system field maintenance contamination control. The goal is for a user-friendly drop-in replacement that is nontoxic, nonflammable, easily applied, but yet an effective solvent.

This project was a 2-year university grant that just completed its second year. It was funded by Code M the first year and by the Center Director's Discretionary Fund the second year. The Pennsylvania State University effort has yet to provide an existing commercial drop-in replacement product. Most candidates were toxic, flammable, or required thermal or mechanical energy to be applied, which contributes to making this task challenging.

The grant was extended for another year with a focus on developing blends or an azeotrope-like solvent that meets the requirements. Reassessing the limits of toxicity for some existing solvent options is also underway.

Contact: C.E. McCaskey (Edward.McCaskey-1@ksc.nasa.gov), PK-G4, (407) 861-3447

Verification Test Article Project

During a Shuttle launch, ground support equipment and structures in the proximity of the launch pad are subjected to intense vibration due to acoustic pressure generated by rocket exhausts. Continuous monitoring of launch-critical loads (acoustics) and simultaneous structural response (vibration and strain) is vital for design of new and proactive maintenance of existing structures. By the end of 1996, the collection of acoustic, vibration, and strain data from seven launches from Launch Pad 39A was completed on a cantilever beam, called the Verification Test Article (VETA). Analyzed data from these launches was crucial for validating a random vibration response model based on the deterministic approach developed at KSC. A detailed report outlining the validation methodology was released in 1997.

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

Key accomplishments:

- 1997: Presented a technical paper at the Fifth International Congress on Sound and Vibration in Adelaide, Australia, on the validation of the deterministic model. To record launch-induced acoustics, installed on the launch pad a totally self-contained acoustibox (operates on batteries) that has: (1) the capability to "wake up" prior to launch and to store the recorded data and (2) post-launch retrieval software.

Key milestone:

- 1998: Collect data for five launches from Launch Pad 39A.

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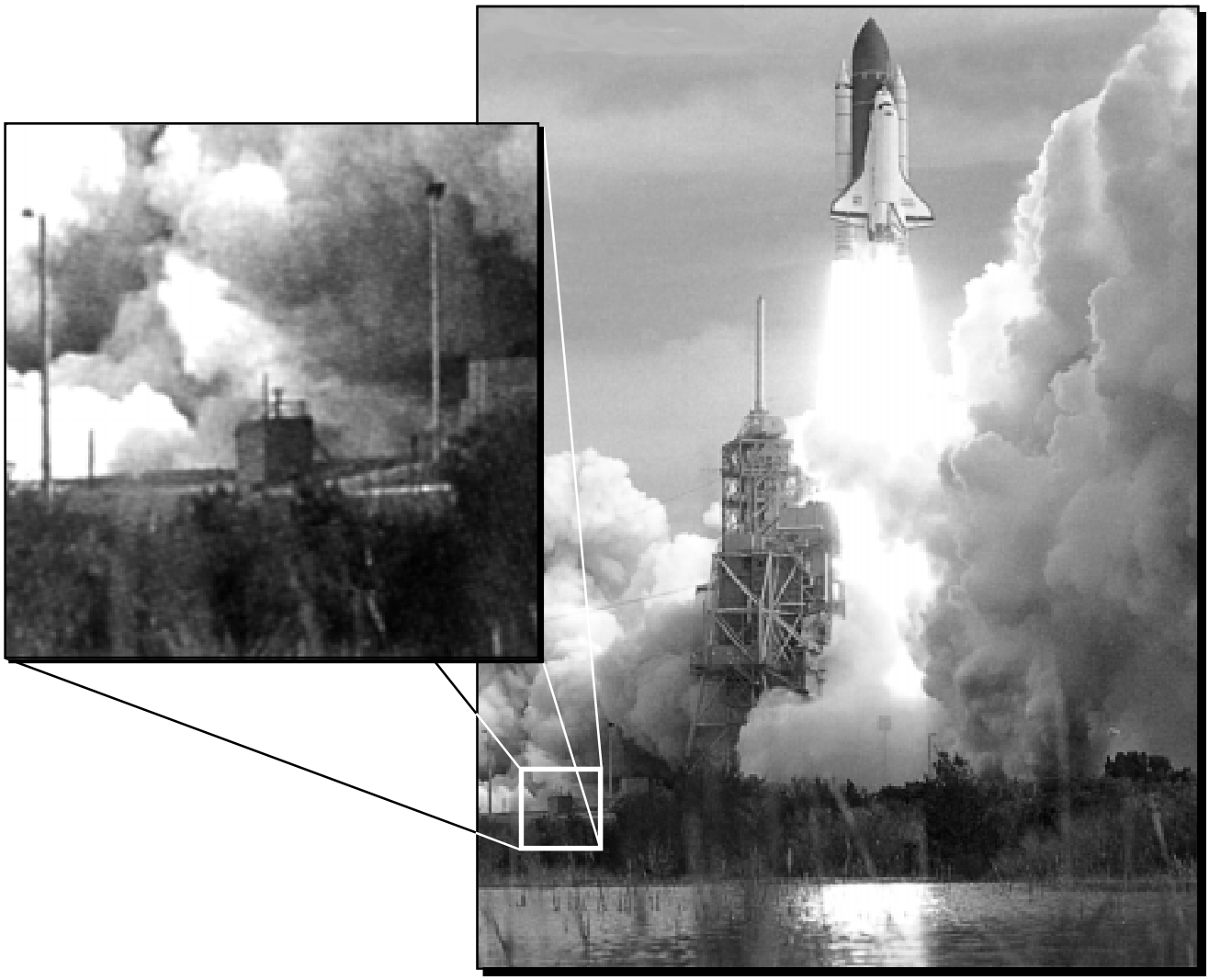
Participating Organizations: Dynacs Engineering Co., Inc. (R.N. Margasahayam), United Space Alliance (F. Walker), and EG&G Florida, Inc. (O. Varosi and L. Albright)



Comparative Study of Cryogenic Vacuum Insulation Systems

In February 1997, NASA KSC and MVE Inc. signed a Space Act Agreement for a comparative study of cryogenic vacuum insulation systems. Divided into Phase I and Phase II stages, the partnership is for up to a 24-month duration. The effort is directed toward developing cryogenic vacuum insulation systems that are efficient, easy-to-use alternatives to the present evacuated multilayer insulation (MLI) systems. The main goal is to deliver superinsulation system designs for rough vacuum that have performance comparable to MLI systems at high vacuum.

Thermal insulation systems for cryogenic applications typically consist of an evacuated annular space filled with layers of radiation shields and space materials, fine powders, or fiberglass blankets. MLI systems represent the benchmark for thermal performance. These superinsulation systems can provide apparent thermal conductivity (k) values below 0.4 milliwatt per meter-kelvin (mW/m-K) if residual gas pressures below $1x10^{-4}$ torr are maintained. However, MLI is highly anisotropic by nature, requires careful attention during installation, and often causes awkward structural complexities in application. Systems using evacuated powders or fibers can provide k-values in the range of 1 mW/m-K but also require a high vacuum level (below $1x10^{-3}$ torr) be maintained for full insulating effectiveness. Evacuated powder systems have the tendency to settle and compact due to vibration or thermal cycling, which in turn leads to degradation of thermal performance and possible structural damage.

The advanced superinsulation systems should operate at vacuum levels above 0.1 torr (moderate to rough vacuum) with performance comparable to MLI systems at vacuum levels below $1x10^{-4}$ torr (high vacuum). This study addresses the use of both conventional and novel insulation materials in a variety of combinations. Suppliers of these materials include Aspen Systems, MVE, Cabot, Composite Technology Development, Owens-Corning, and others. Preliminary designs of the new insulation systems are currently being developed and tested at the KSC Cryogenics Test Laboratory (located in M7-581). The thermal performance testing is being accomplished using a cryostat test apparatus and a special dewar test apparatus. The cryostat test provides the thermal conductivity data as a function of the vacuum level while the dewar test provides the “real world” data for performance comparison. A sample plot of cryostat test data is given in the figure. This plot shows the improvement of an aerogel-based superinsulation design over the conventional MLI system design.

The goal in the design of a superinsulation system is to minimize the heat leak to the cryogen by considering all modes of heat transfer for a given set of operating conditions. Equation (1), the basic equation for heat leak under steady-state conditions, is based on Fourier’s law of heat conduction.

$$q = kA(T_1 - T_2)/L \qquad (1)$$

The proportionality constant, k, is the apparent thermal conductivity of the material. The total thermal conductivity, neglecting natural convection within the insulation, is given in Equation (2).

$$k_{total} = k_{solid\ conduction} + k_{gas\ conduction} + k_{radiation} \qquad (2)$$

The optimization of the insulation system requires an understanding of the three individual heat transfer contributions. Of equal importance is the overall cost effectiveness of the system. The primary design considerations can therefore be listed as follows: (1) thermal performance (for a given set of operating conditions), (2) flexibility and durability, (3) ease of use in handling, installation, safety, and maintenance, and (4) overall cost (including operations, maintenance, and life-cycle costs).

The anticipated result from this project is a set of advanced superinsulation system designs that are applicable to a wide variety of cryogenic equipment on Earth or in space. Three base designs are envisioned: one for high vacuum, one for soft vacuum, and one for the ambient pressure case. The new insulation systems will benefit NASA and any industry that deals in the storage, transfer, or handling of cryogens. These insulation systems should lower the manufacturing costs and the life-cycle costs for cryogenic equipment. The advanced insulations should also allow for more flexibility in the design and implementation of cryogenic systems – a key benefit in the aerospace industry for both ground and flight systems. This technology, if successfully developed, may serve to accelerate the already increasing growth in demand for cryogens in the food processing, semiconductor, medical equipment, electrical powers, and manufacturing industries.

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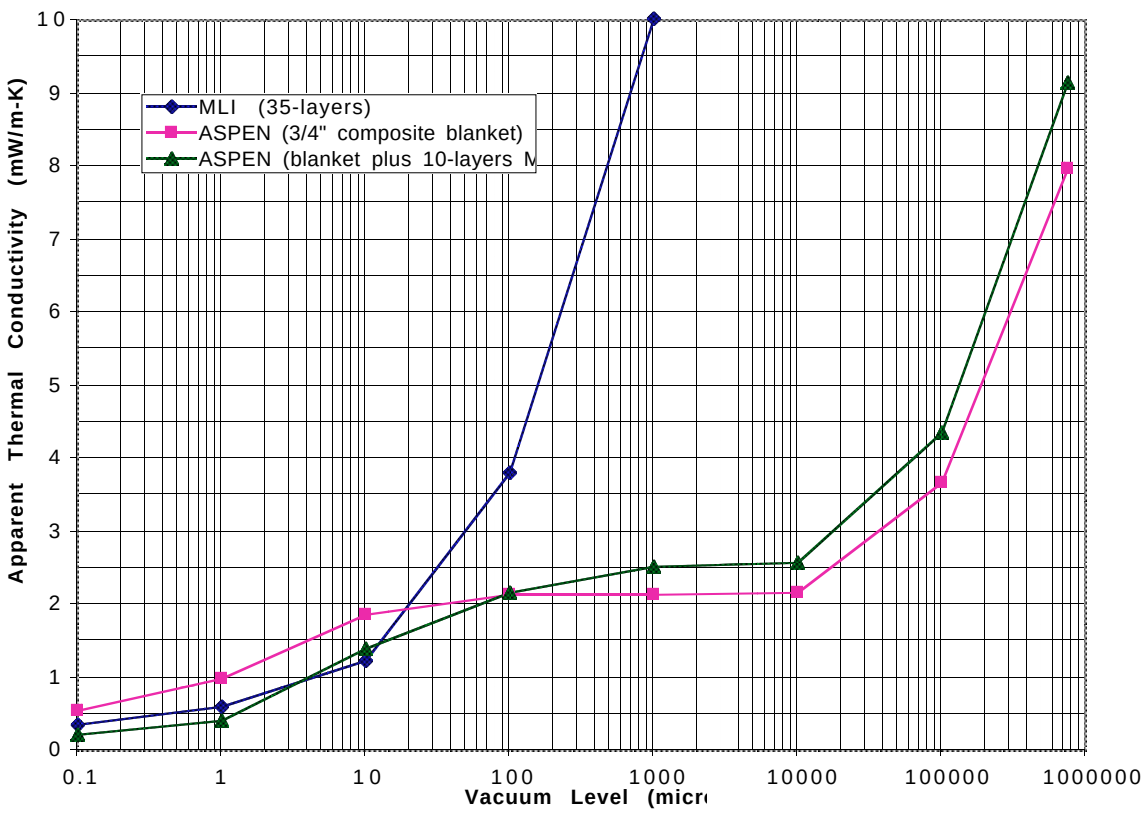
Participating Organizations: Dynacs Engineering Co., Inc. (M.J. Ynclan) and MVE Inc. (S. Augustynowicz)

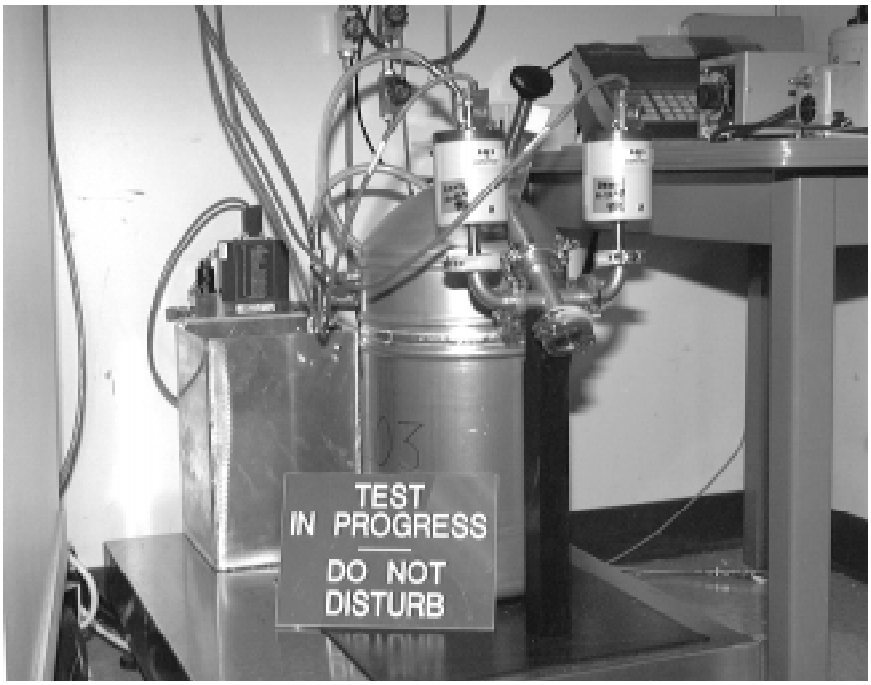


Insulation Comparison: Thermal Conductivity as a Function of Vacuum Level

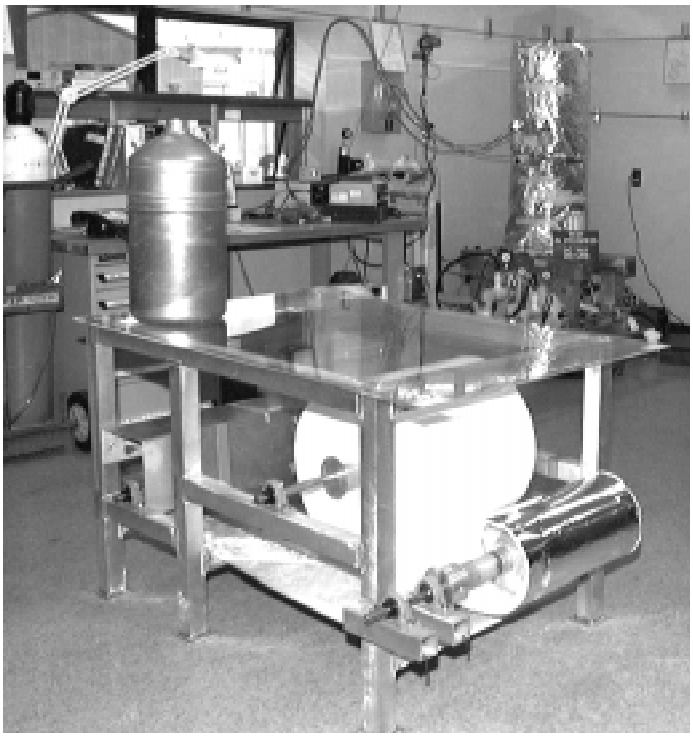
Dewar Test Apparatus for Thermal Insulation System Development

The KSC Cryogenics Test Laboratory includes a dewar boiloff apparatus. This dewar test apparatus provides a reliable means of measuring the thermal performance of a vacuum insulation system at liquid nitrogen temperature. The main purpose of the dewar test is to determine the "real world" performance of an insulation system, with full consideration given to the actual fabrication, quality control, checkout, and operation of the cryogenic storage device. The total performance valve "k" is calculated by the measurement of weight of liquid nitrogen boiled, cold vacuum pressure, and mass flow rate of evaporated gaseous nitrogen.

The dewar itself may be up to approximately a 40-liter liquid nitrogen capacity. A 10-liter vacuum-jacketed aluminum vessel (Lab10 design manufactured by MVE Inc.) is currently being used. The dewar includes a test plug and two vacuum ports. An MKS flowmeter and thermal conditioning coil are connected to the test plug. A pair of MKS Baratron capacitance manometers, connected to the first vacuum port, is used for measuring vacuum levels from $5x10^{-5}$ torr to 100 torr. A vacuum pumping station (molecular drag pump) with a shutoff valve and a bake-out system with a temperature controller are connected as required for test preparations. The entire setup is mounted on a Mettler precision weight scale. In addition, the ambient conditions (temperature, barometric pressure, and humidity) in the laboratory are monitored using a weather station. An overall view of the



Dewar Test Apparatus



Multilayer Insulation Wrapping Machine for Dewar

dewar test apparatus is shown in the figure "Dewar Test Apparatus." A multilayer insulation wrapping machine, shown in the figure "Multilayer Insulation Wrapping Machine for Dewar," is available for custom application of radiation shielding materials. All measurements are recorded on a 10-channel data acquisition system using LabView software.

The boiloff flow of nitrogen gas is proportional to the conduction of heat through the insulation plus the heat transfer through the inner vessel's neck tube. Steady-state conditions are typically achieved approximately 24 hours after filling the dewar with liquid nitrogen, after which the test is allowed to run for several days. Thermal conductivity values for a given cryogenic tank design can then be calculated for comparing insulation performance.

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Participating Organizations: Dynacs Engineering Co., Inc. (M.J. Ynclan) and MVE Inc. (S. Augustynowicz)

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.

Evaluation of Multigas Analyzers

During confined space operations as well as Shuttle safing operations, United Space Alliance (USA) and NASA Safety Assurance personnel use a variety of portable instrumentation to monitor for hazardous vapor levels of compounds such as nitrogen dioxide (NO_2), monomethylhydrazine (MMH), Freon 21, ammonia (NH_3), oxygen (O_2), and combustibles [such as hydrogen (H_2)]. Except for O_2 and H_2, each compound is monitored using a single analyzer. In many cases, these analyzers are 5 to 10 years old and require frequent maintenance. In addition, they are cumbersome to carry and tend to make the job of personnel monitoring physically taxing. The NASA Toxic Vapor Detection Laboratory (TVDL) completed an evaluation of commercially available multigas instruments that combine the analytical capabilities of several analyzers into one small portable unit.

During the initial phase of the evaluation, the TVDL located 27 manufacturers of portable multigas instruments that might be viable candidates to replace the currently used single-gas analyzers. A set of criteria was established to compare analyzer capabilities to determine which instruments would be used during laboratory and field testing. These criteria were based on requests made by USA/NASA Safety Assurance personnel in order to meet requirements within their respective areas and included weight, physical size, measurement range, humidity and temperature constraints, minimum detectable levels, and the number of sensors that could be placed in each instrument. Based on vendor feedback, nine manufacturers were selected for inclusion in both the laboratory and field portions of the testing. Each vendor included in the final evaluation process was requested to configure each of two analyzers with NO_2, NH_3, O_2, and combustible sensors.

The laboratory tests completed on each analyzer included linearity, repeatability, zero and span drift, response and recovery, operational humidity range, and instrument response to common interferences. In addition, the software package available with each analyzer, the maintenance characteristics, and the overall user interface were evaluated. An individual ranking was assigned to each of these features along with a corresponding vendor ranking for each selected feature. The totals for each vendor are the summations of the feature rankings multiplied by individual vendor rankings. The overall rankings for each vendor are summarized in the table.

Based on the laboratory results presented in the table, the ENMET OMNI 4000, National Draeger MultiWarn II, and AIM 4501 analyzers were recommended for further field testing. All three analyzers were tested at two field locations (the Orbiter Processing Facility and Launch Pads 39A and 39B). Additional field information was gathered from the Wiltech calibration facility on potential maintenance and calibration

Overall Vendor Ranking

Feature (Rank)	National Draeger	AIM	ENMET	Gastech	Biosystems	RKI	RAE	Crowcon	Metrosonics
Linearity repeatability (7)	9	8	7	1	3	2	4	5	6
Zero drift (2)	7	8	6	3	4	9	2	5	1
Span drift (3)	8	9	5	5	3	7	2	6	1
Sensor response (1)	8	7	9	2	4	6	3	5	1
User interface (6)	7	9	3	6	4	8	5	2	1
Software (4)	9	1	3	7	8	2	6	5	4
Maintenance (5)	5	4	7	9	8	3	6	2	1
Total	**212**	**184**	**150**	**139**	**138**	**130**	**125**	**110**	**75**

issues. The AIM 4501 analyzer was chosen as the preferred multigas analyzer by the end users based on a compilation of both laboratory and field test results.

Key accomplishments:

- Evaluation of several commercially available multigas instruments as candidates for replacement of currently used single-gas analyzers.
- Selection of the AIM 4501 as the instrument of choice for use in both confined space and Shuttle safing operations.

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Participating Organization: Dynacs Engineering Co., Inc. (D.N. Bardel, B.J. Meneghelli, and T.A. Hammond)

New Process for Waste Minimization: Conversion of Nitrogen Oxide Scrubber Liquor to Fertilizer — Phase IV

This is Phase IV of a five-phase project to develop a new scrubber liquor and control system to eliminate the oxidizer scrubber liquor waste stream, lower nitrogen oxide (NO_x) emissions, and lower oxidizer scrubber operating costs. The oxidizer scrubber waste stream will be eliminated by using the oxidizer (nitrogen tetroxide) to produce potassium nitrate, a commercial fertilizer. The new system utilizes hydrogen peroxide to increase the efficiency of the scrubber by oxidizing nitrous produced in the scrubber reaction to nitric acid, which reduces the formation of nitric oxide. The control system will also keep the scrubber liquor at a nominally neutral pH value, thus reducing the hazards of loading and unloading the scrubber liquors. This new system has value to KSC, the Air Force, and commercial users of NO_x scrubbers. Installation of this system at KSC would replace the current 25-weight-percent sodium hydroxide scrubber liquor, which produces the second largest waste stream at KSC. The project is based on experience gained on the Engineering Development Contract in the development of a new method for monitoring emissions for KSC hypergolic scrubbers and on previous experience that developed uses for pyrotechnic byproducts as fertilizers. The effort conforms to the requirements stated in Executive Order No. 12856 (Federal Compliance With Right-To-Know Laws and Pollution Prevention Requirements, dated August 6, 1993) and Executive Order No. 12873 (Federal Acquisition, Recycling, and Waste Prevention, dated October 20, 1993).

Phase I, the laboratory proof-of-concept study, found that a scrubber liquor based on a 1-percent hydrogen peroxide solution controlled to a pH of 7 with potassium hydroxide would produce the desired product (potassium nitrate) and lower the scrubber emissions. Phase II was conducted at Launch Pad 39A oxidizer storage farm to demonstrate that the system would work on a full-size oxidizer scrubber. The test produced 525 gallons of 4-percent solution of potassium nitrate, no potassium nitrite, 1-percent hydrogen peroxide, and a pH of 7.9. Phase III consisted of a refinement of the design of the control system and a field test at the Hypergol Maintenance Facility (HMF). The field test produced approximately 800 gallons of a potassium nitrate solution that averaged 12 weight-percent. The solution had a pH of 6.7, except for three barrels that were removed at the beginning of the test that had a pH of 13.3. The three barrels with the high pH were adjusted to a pH value between 6 and 8. All of the fertilizer that was produced in Phases II and III will be applied to the orange groves at KSC in the spring of 1998. The efficiency of the scrubber at the HMF was measured at an average value of 99.7 percent without the use of the aspirators. The scrubber was not as efficient when the aspirators were in use, but the overall efficiency of the scrubbers during this test averaged greater than 90 percent.

The objectives for Phase IV were to develop a fieldable control system and to test it, first under controlled conditions and then under actual field conditions at an oxidizer scrubber at KSC. The control system was redesigned for Phase IV to eliminate problems from previous phases. A filter system was added to the sample loop to prevent sediment from clogging the sample intake lines, which had occurred in the Phase III field test. The time sequencer in the previous version of the control system was replaced with a programmable logic controller (PLC) to allow more control of the hydrogen peroxide system. The system now senses pressure leaks, valve closure failures, and sample flow. After sensing a failure three times, the system goes into an automatic safing mode and pumps an excess of hydrogen peroxide into the scrubber allowing operations to safely continue without interruption. The pH meter used in this prototype also includes several internal diagnostics. A new addition to this prototype is a conductivity meter to give real-time measurement of the potassium nitrate concentration. The number of electrical components was also minimized by using air-driven valves and pumps. This system has valves on the exterior of the control unit that allow for complete manual operation and was designed to isolate the wetted parts in separate boxes from the electrical parts. The system is designed to automatically pump the potassium nitrate scrubber solution to storage, which permits continuous operation. This feature eliminates the current need to stop and change out the scrubber liquor when it has reached maximum capacity.

The controlled condition field tests are still underway. In the tests conducted so far, the system performed very well. The efficiency of the system ranged from 96.47 to near 100 percent and averaged 98.94 percent efficient. The pH was maintained at a nominally neutral level. The current concentration of potassium nitrate in the system is near 7 weight-percent. When these field tests are completed, the system will be installed at the HMF for an extended test under real operating conditions. The only problem encountered in the field test was a valve that remained open when the system was shut down, which allowed an excess amount of water to flow into the scrubber. This problem was corrected with a manual shutoff valve in the current system. The long-term correction will be to replace the dual-actuated pneumatic valve that remained open with a pneumatic spring return valve that will automatically close.

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 tanks and then prepares potassium nitrate).
- Production of potassium nitrate, a fertilizer currently purchased by KSC for use on lawns and citrus groves.
- Demonstration that the process control system worked on full-scale scrubbers.
- The target concentration of potassium nitrate is 5 weight-percent; however, the capacity is only limited by saturation (approximately 24 weight-percent).
- Development of a system with internal diagnostics and safety features to allow continual operation even in the event of system failure.
- Development of a scrubber system that will not halt operations due to exhausted system capacity.

Key milestones:

- Installation at the HMF for testing under actual operating conditions.
- Phase V will produce and deploy the control system on all oxidizer scrubbers at KSC.

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Participating Organization: Dynacs Engineering Co., Inc. (C.F. Parrish, R.G. Barile, T.R. Hodge, and P.H. Gamble)

Habitat Management and Ecological Risk Assessment Modeling

Monitoring and definition of habitat quality for biodiversity, threatened and endangered species, and environmental risk assessment require state-of-the-art information collection and analysis capabilities to minimize costs. Land management practices in many ecosystems, including KSC, are based on controlled burning for habitat enhancement and wildfire fuel reduction. Available ecosystem models and fire and smoke models provide some guidance; however, no system currently exists that incorporates these tools with operational schedules such as payload or vehicle processing system, real-time meteorological data, and remote sensing data for use in environmental decision support and risk assessment.

The approach to this project involves development of a diverse set of information tools including rule-based expert systems, numerical models, time series, and fusion of a variety of data collection systems and databases to enhance the decision process. The project is based on the extensive existing Geographic Information System (GIS) data layers and other information developed in the Mapping Analysis and Planning Systems (MAPS) project, experiential rules, fire prescriptions and fuel data, ecological and fire models, real-time meteorological data, and high spatial and spectral resolution remote sensing data available from instruments such as the NASA Airborne Visible and Infrared Imaging Spectrometer (AVIRIS), the Airborne Data Acquisition and Registration (ADAR) system, and the future Small-Sat program. The program will:

1. Provide data and information to optimize the management of resources at KSC and the Merritt Island National Wildlife Refuge.

2. Incorporate NASA remote sensing and advanced GIS technology into local scale decisionmaking processes.

3. Provide information and methods to reduce the potential for wildfires at KSC.

4. Enhance NASA capabilities to comply with Federal and State environmental laws such as the Endangered Species Act.

Key accomplishments:

- 1996: Obtained a high spectral resolution image of the KSC area using the NASA AVRIS sensor (222 bands). Initiated development of a deterministic model for estimating plant canopy biochemical and biophysical characteristics.
- 1997: Conducted an experimental controlled burn at KSC in association with the United States Fish and Wildlife Service (USFWS), Los Alamos National Laboratory, U.S. Air Force, and Los Angeles County Fire Department to develop data on fire spread, intensity, and smoke production. Obtained high spacial resolution images (1 to 2 micrometers) of the KSC area using the ADAR sensor (four bands) and the United

States Geological Survey digital false color infrared ortho-quad images. Obtained field measurements of plant canopy biophysical and biochemical features and plant canopy and leaf spectral characteristics for model development and parameterization.

Key milestones:

- 1996: Initiated GIS database integration in ORACLE and development of image processing methods for use of high spectral resolution data in wildlife habitat mapping. Presented two papers at the Eco-Informa Conference in Orlando, Florida, on remote sensing modeling in plant canopies.
- 1997: Coordinated a multiagency experimental controlled burn to obtain data on fire and smoke behavior in coastal environments.

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Participating Organization: Dynamac Corporation (C.R. Hall)

Threatened and Endangered Species Monitoring

The habitats on KSC 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 on marine turtles, gopher tortoises, indigo snakes, wading birds, shorebirds, scrub jays, beach mice, and manatees. These studies contributed to more than 20 scientific journal articles and were used to develop rangewide species recovery efforts.

The influence of habitat on habitat use and demographic success is quantified at different spatial scales. Monte Carlo simulation models are used to quantify the influence of habitat quality, population size, and catastrophes on populations. Declining habitat quality was found to be a critical factor influencing extinction risk so more frequently prescribed fires are needed.

The table shows correspondence between mean habitat suitability index (HSI) predictions and Florida scrub jay demographic performance index (DPI). The DPI (potential breeder production minus breeder mortality) was indexed from 0.0 to 1.0. The entries in the table represent the percent of scrub found within each residual class.

The figure shows the monitoring priorities of potentially endangered wildlife taxa on KSC. Taxa were scored based on their vulnerability to extinction, their potential role for maintaining faunal integrity, and the relevance of KSC for maintaining their populations in Florida and the rest of the U.S. Taxa in bold were not listed by U.S. Fish and Wildlife Service (USFWS) or Florida Game Fresh Water Commission (FGFWFC). Taxa in priority one had the highest scores, which were between 195 and 148. Taxa in priority two had scores between 147 and 100. Taxa in priority three had scores between 99 and 52. Taxa in the fourth priority (not shown) had scores between 51 and 7.

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.
- 1995: Developed techniques to map habitat suitability.
- 1996: Developed models to predict demographic success using maps.
- 1997: Tested the ability of maps and models to predict populations.

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.
- 1997: Biological diversity prioritization analyses published.

Residual Class	HSI - DPI =	Scale		
		Small Patch (0.1 ha)	Large Patch (1.0 ha)	Territory (5.5 ha)
Agreement	-0.20 to 0.20	62	68	75
Minor underprediction	0.21 to 0.40	8	6	0
Major underprediction	>0.40	1	0	0
Minor overprediction	-0.21 to -0.40	21	22	25
Major overprediction	<-0.40	8	4	0

PRIORITY ONE

Eastern Indigo Snake
Southeastern Beach Mouse
Florida Scrub Jay
Atlantic Green Turtle
West Indian Manatee
Florida East Coast Terrapin

PRIORITY TWO

Wood Stork
Southern Bald Eagle
Reddish Egret
Atlantic Salt Marsh Snake
Florida Pine Snake
Florida Longtailed Weasel
Diamondback Rattlesnake
Gull-Billed Tern
Bobcat
Eastern Kingsnake
Caspian Tern

Gopher Tortoise
Roseate Spoonbill
Black Rail
Royal Tern
Atlantic Loggerhead Turtle
River Otter
Arctic Peregrine Falcon
American Avocet
Least Tern
Eastern Coachwhip

PRIORITY THREE

Sandwich Tern
Mole Kingsnake
Glossy Ibis
Eastern Brown Pelican
Round-Tailed Muskrat
American Alligator
White Ibis
Black-Necked Stilt
Tricolored Heron
Short-Billed Dowitcher
Northern Harrier
Marbled Godwit
Black-Bellied Plover
Florida Pairie Warbler
Wild Turkey
American Oystercatcher
Great Horned Owl

Whimbrel
Little Blue Heron
Atlantic Hawksbill Turtle
Black-Whiskered Vireo
Red Knot
Common Loon
Kirkland's Warbler
Florida Sandhill Crane
White-Tailed Deer
Florida Gopher Frog
Black Skimmer
Florida Mouse
Osprey
Cooper's Hawk
Pileated Woodpecker
Common Barn Owl

Snowy Egret
Red-Shouldered Hawk
Western Sandpiper
Wilson's Plover
Barred Owl
Merlin
Eastern American Kestrel
Dusky Pygmy Rattlesnake
Gray Fox
Red-Tailed Hawk
Atlantic Ridley Turtle
Bottlenose Dolphin
Roseate Tern
Leatherback Turtle
Piping Plover
Black-Crowned Night-Heron

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

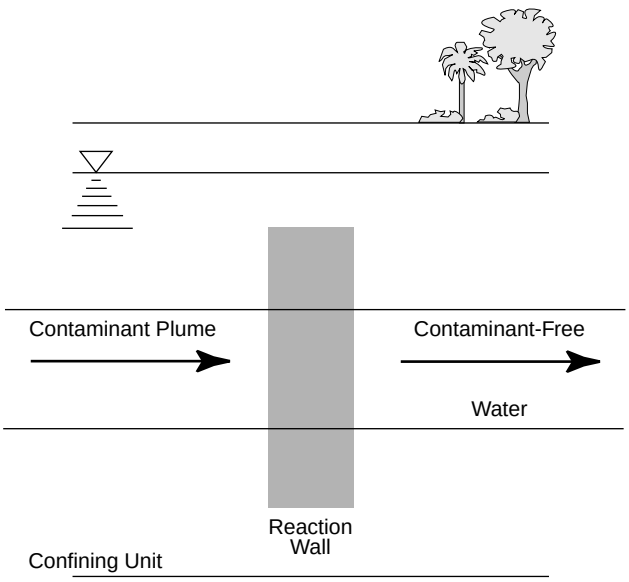
Enhanced In Situ Zero-Valent Metal Permeable Treatment Walls

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

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

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

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



Permeable Treatment Wall

Key accomplishments:

- June 1996: Batch studies completed.
- July 1996: Column studies completed.
- July 1997: Patent application submitted.
- August 1997: Field-scale design completed.

Key milestone:

- Kinetic constants were determined from laboratory column testing and used in the field-scale design to be implemented at NASA's Launch Complex 34 at Cape Canaveral Air Station.

Results of Batch Tests Using Iron and Ultrasound

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

* Normalized to 1 m^2/mL

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

Results of Column Studies

Column	TCE Half-Life, Min	No. of Pore Volumes Passing Through Column
50 mesh iron	240 289 618	1 to 20 200 to 235 300 to 315
Peerless iron	246 720 to 805	50 to 60 80 to 140
Master builder iron	225 800	50 to 60 80 to 140
Unwashed peerless iron	2,567	50 to 60

Ultraviolet/Oxidization Process for the Treatment of Hazardous Waste

Hazardous waste management of wastes derived from hypergol propellants presents both a regulatory responsibility and a strategic challenge to the KSC community. An Advanced Oxidation Process (AOP) in the treatment of hazardous hypergol waste was activated and enhanced with the use of iron-based photocatalysts, thereby achieving a cost reduction for hydrazine wastewater of 90 percent. Monomethylhydrazine (MMH) fuel rinsates, characterized as a hazardous waste, are generated as propellant decontamination or spill residues and treated by the RAYOX ultraviolet/oxidation system at KSC in lieu of off-site disposition by a hazardous waste contractor. The AOP treatment uses ultraviolet radiation in conjunction with the standard oxidant, hydrogen peroxide, to achieve greatly increased treatment performance over that obtained with the oxidant alone.

The wastewater treatment equipment located at M6-897 in the vicinity of Sewage Treatment Plant No. 1 (STP-1) consists of a photoreactor unit (3 x 30 kilowatts), recirculating tank/pump, reagent chemical feed system, and heat exchanger — all integrated with PLC controls. The RAYOX process serves as an Environmental Protection Agency approved pretreatment operation, rendering the hydrazine-based waste acceptable for discharge and final treatment by the microbial process at STP-1.

An indepth test program using prepared MMH standards provided both a process activation and optimization phase that progressed to the functional treatment of field-generated waste in August 1997. Previous testing demonstrated a lengthy treatment cycle with a resultant increase in manhours, electric power, and chemicals. KSC personnel investigated the use of iron-based catalysts applied to the batch treatment in order to reduce treatment costs. The successful catalyst types — either as the inorganic iron (Fenton's Reagent) or the organic ferrioxalate — consistently achieved a five- to eight-fold reduction in treatment time, yielding a cost reduction from the previous uncatalyzed treatment of $1.50 per gallon to the current $0.30 per gallon MMH rinsate. The greatest cost saving potential is realized in comparison to the off-site hazardous waste disposal rates of $3 to $4 per gallon, which will be deferred by the RAYOX treatment.

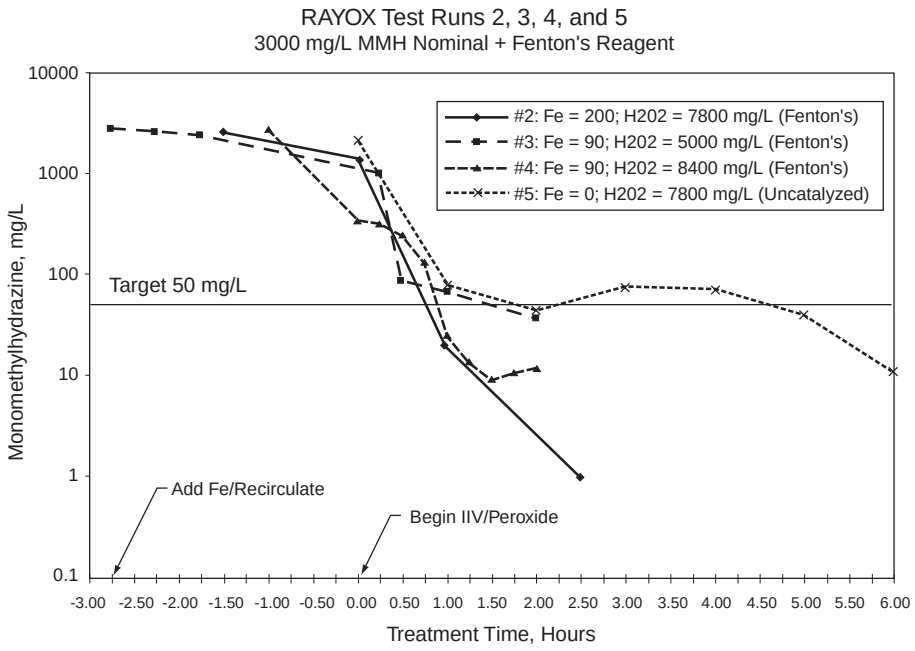
Key accomplishments:

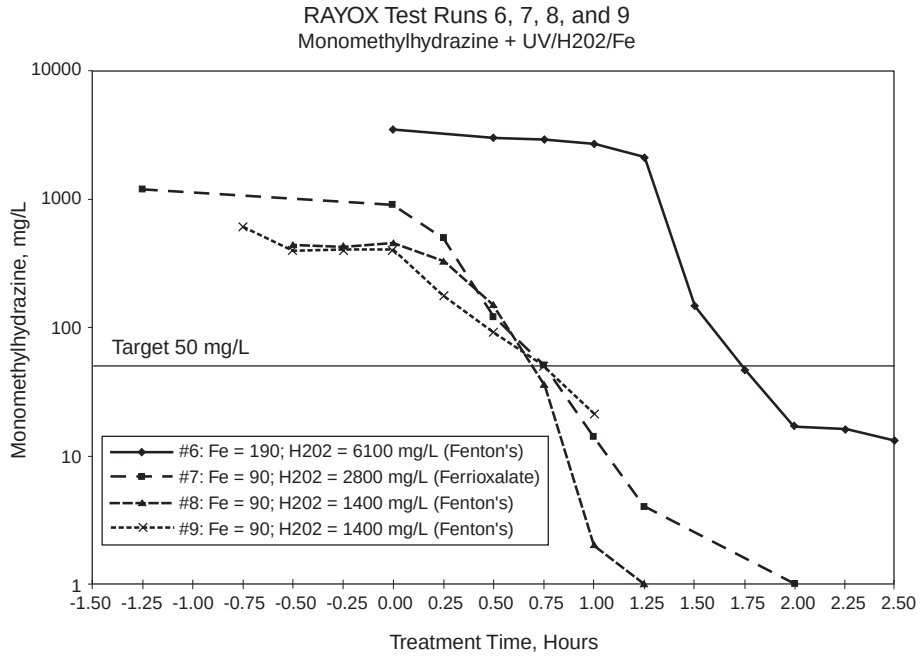
Although the RAYOX process is commercially available/proprietary hardware, KSC personnel have fostered the merits of this technology and contributed to its success in the following areas:

- 1990: Investigated an effective and compliant treatment technology for hydrazine-based wastewaters.
- 1992: Conducted an interactive technology exchange with the manufacturer in the custom design for a KSC-specific process and unique waste type.
- 1993: Conducted subcontract performance/acceptance testing and validation.
- 1994: Developed an effective permitting strategy conforming to regulatory compliance with a no-permit-required status.
- 1997: Extensive test program provided activation and process enhancements by optimizing the treatment regimen through process parameters, chemical reagents, and catalysts. Established a hydrazine treatment target endpoint with no resultant impact to the STP. Began the functional treatment of field-generated wastes.

Key milestones:

- Treatment of all KSC field-generated MMH-based waste.
- Treatment of additional candidate hazardous wastestreams such as chlorinated solvents and other wastes.





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Participating Organization: EG&G Florida, Inc. (D. Tierney and G. Hooper)

Pilot-Scale Evaluation of a New Technology To Control Nitrogen Oxide (NO_x) Emissions From Stationary Combustion Sources

NASA entered into a 3-year cooperative agreement with the University of Central Florida (UCF) of Orlando, Florida, to perform a pilot-scale study of a new control technology for nitrogen oxide (NO_x) emissions from industrial-size boilers. UCF has been conducting laboratory-scale testing on hydrogen peroxide (H_2O_2) injection into high-temperature air streams containing the aforementioned pollutants. NO_x reductions of up to 98 percent were realized. The byproducts of the NO_x reaction with the H_2O_2 are then controlled using a liquid scrubber producing a nitrogen-rich water-based waste stream.

The testing completed at UCF demonstrated a threefold increase in NO_x removal when operating with no hydrogen peroxide injection versus 1,200-part-per-million (ppm) hydrogen peroxide injection. However, an optimal hydrogen peroxide to nitrogen oxide ratio was not achieved. It was thought that surface effects were causing recombination of the hydroxyl radical. The surface of the reactor was treated with boric acid and resulted in a significant increase in nitric oxide (NO) destruction, corroborating the surface effects theory.

The current study is expected to limit the surface effects through scaleup, and it includes a scrubber system similar to those commercially in use. The pilot-scale study consists of five major components:

1. The inlet to the system is from one of KSC's natural gas boilers (see figure 1). The boiler size is 35 million British thermal units per hour (mmBTH), and it typically operates at an average of 9 mmBTH. The flue gas flow rate is approximately 3,400 actual cubic feet per minute, 385 degrees Fahrenheit (°F), and 2-percent oxygen. One-sixth of the flue gas stream is directed into the pilot-scale system. The auxiliary natural gas burner is used to heat the flue gas up to temperatures exceeding 1,000 °F (necessary to convert the hydrogen peroxide efficiently to hydroxyl radicals).

2. Downstream of the auxiliary burner is the injection and reaction zone. The test parameters are temperature and NO, sulfur dioxide (SO_2), and H_2O_2 concentrations. NO and SO_2 gases are injected prior to the reaction zone to vary the concentrations in the gas stream. Water and hydrogen peroxide are injected using a thermally insulated ultrasonic nozzle at the entrance to the reaction zone. Liquid and gas samples are taken at 10 points along the 8-foot reaction zone to determine the reaction rates. Thermocouples are located at each sampling point.

3. The next component is the section of the system where a temperature-correcting mass flowmeter is installed to accurately determine the flow rate. A quench system is installed at the end of this section of pipe to cool the gases prior to entering the scrubber system (see figure 2).

4. The bottom of the quench zone and the scrubber tower make up the next component (see figure 3). Pressure transducers and thermocouples are installed at the entrance and exit of the scrubber system to allow for study and optimization of the scrubber system. The scrubber is designed to operate at a gas flow rate of 500 standard cubic feet per minute and a water recirculation rate of 0 to 35 gallons per minute.

5. The induced draft fan is used to draw the flue gas from the boiler through the system and out of the facility (see figure 2). The Florida Department of Environmental Protection has issued written permission for the liquid and gas discharges during this study. The liquid is collected in an onsite location, sampled, and discharged to KSC's sewage treatment plant.

A data acquisition system, utilizing LabView software, is tied into the entire system to allow for control, recording, and automatic emergency shutdown. An industry partner, EKA

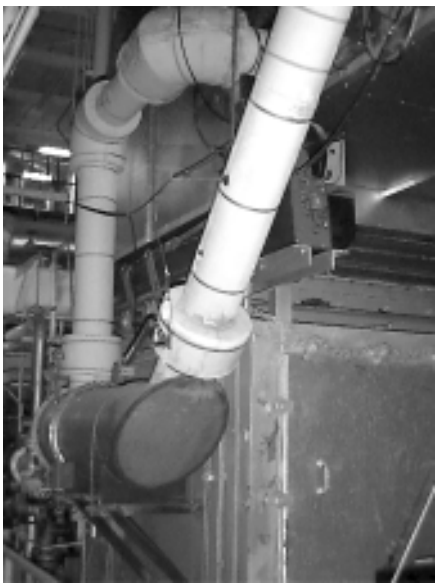

Figure 1. Auxiliary Burner

Chemicals, has joined this research by providing engineering consulting and hydrogen peroxide supplies and materials.

Key accomplishments:

- 1997: Phase I design and installation of a high-temperature injection system. Preliminary testing and report.

Key milestones:

- 1998: Phase I modification, final testing, and final report. Phase II design and installation of a low-temperature injection system.
- 1999: Testing, final report, and technology transfer.

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Participating Organizations: University of Central Florida, (Dr. C.D. Cooper; Dr. C.A. Clausen, III; and Dr. J.D. Dietz) and EKA Chemicals, Inc. (J. Tenney and D. Bonislawski)

Figure 2. Quench Section and Induced Draft Fan – Exit Gases

Figure 3. Gas-to-Liquid Scrubber

Less Toxic Waterproofing Agent

The orbiter thermal protection system (TPS) consists of flexible insulation blankets (FIB's), felt reusable surface insulation (FRSI), and rigid tiles. The TPS is waterproofed at the factory during fabrication before it is installed on the orbiter. The waterproofing thermally decomposes in the insulation where temperatures exceed 1,050 degrees Fahrenheit (°F). The FIB and tile experience temperatures above 1,050 °F; therefore, they must be rewaterproofed in situ on the vehicle after every flight. If rewaterproofing was not performed, the insulation could absorb hundreds of pounds of water. This could result in damage to the rigid tiles, compromising safety. It could also be an unacceptable weight penalty.

The current TPS rewaterproofing process uses an agent known as dimethylethoxysilane (DMES). Due to the physical irritations DMES causes to personnel, a threshold limit value-time weighted average (TLV-TWA) over 8 hours of 0.5 part per million (ppm) was established. The bay must be cleared of all nonessential personnel, and the technicians must wear specialized breathing equipment and clothing to protect them from the DMES vapors during the rewaterproofing process. Rewaterproofing must be performed on the third shift and weekends.

The objective of this project was to develop a less toxic TPS rewaterproofing agent with a more compatible TLV-TWA. This could decrease physical irritations to highbay personnel, in turn reducing protective equipment and costs of operation. It could also minimize clearing of the highbay, thus reducing rewaterproofing flow impacts to long-term program manifest requirements.

The test plan consisted of choosing candidate agents, screening them for rewaterproofing performance, conducting TPS material compatibility studies, optimizing rewaterproofing variables (injection/spray concentration and volume, solvent composition, and cure time), and conducting rewaterproofing performance testing on tile and blanket materials.

Some candidate agents were studied by development of analytical methods and discussions with other NASA centers and contractors who have experience in this area. The chosen agents to date are methyldiethoxysilane (MDES), dimethyldiethoxysilane (DMDES), and tetramethylcyclotetrasiloxane (TMCTS). These agents will be tested full strength, combined, and diluted with ethanol/water. Analytical methods development resulted in three chemical structures that could be successful rewaterproofing agents. Research into any existing agent compounds that may contain any of the three structures is currently being performed.

To date, screening for rewaterproofing performance is in progress. DMES was used as a control agent to validate the procedure. Material compatibil-

ity studies and optimization of rewaterproofing variables will occur once the agent screening is complete. Throughout the test plan, information on the toxicology of the candidate agents is being gathered. A final rewater-proofing performance test will be performed on both tile and blanket materials once the best candidate agent is chosen.

Key accomplishments:

- 1997: Candidate agents chosen.
- 1998: Development of analytical methods.

Key milestones:

- 1998: Choose best rewaterproofing agent. Perform final rewaterproofing test on tile and blanket material.

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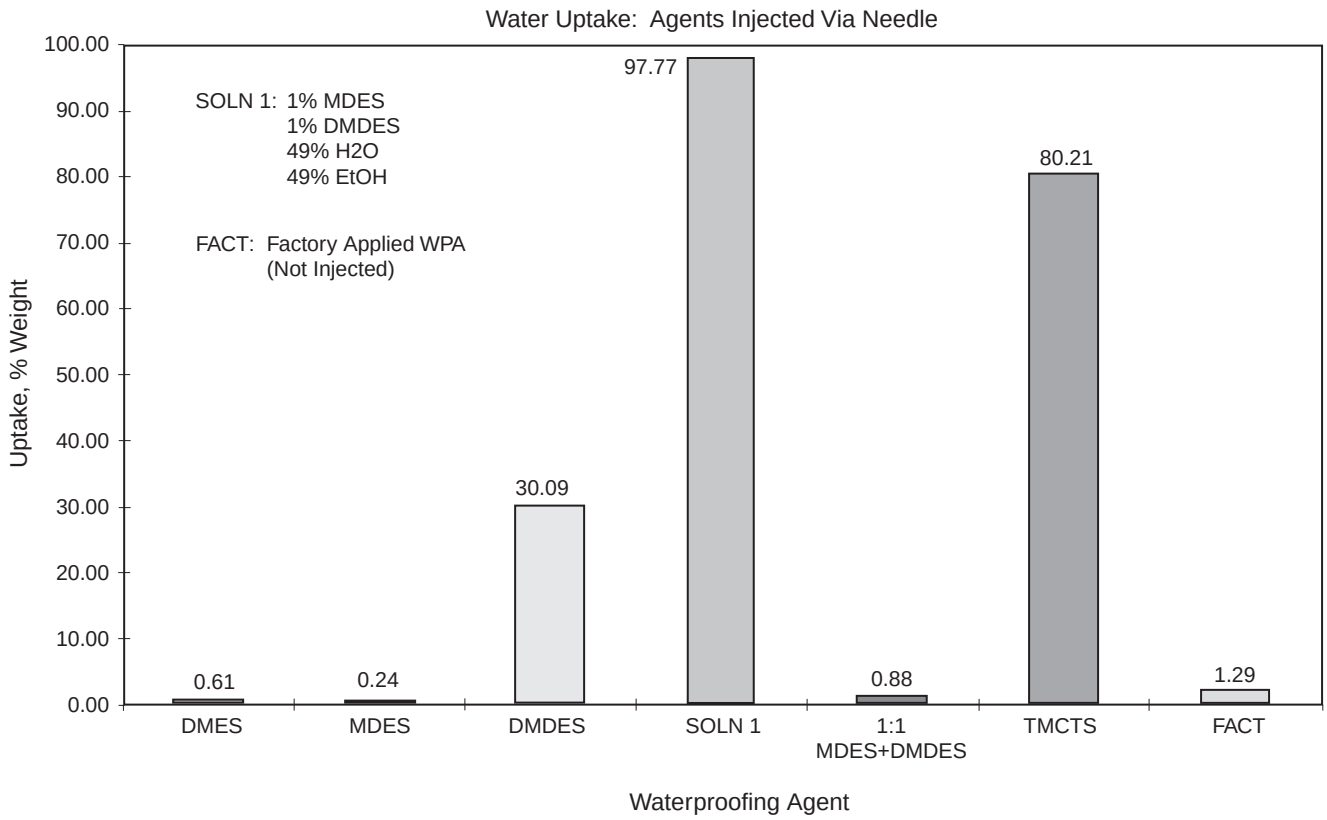
Participating Organizations: NASA KSC (F.E. Jones, R.E. Sweet, J.E. Tinsley, J.J. Branard, D.E. Lueck, and M.A. Cardinale); NASA JSC (C. Schomburg, J. James, and C. Ortiz); United Space Alliance (M.D. Scarbrough, D.A. Paniale, and R. Jackson); Boeing - North American - Downey (S. Kumar and D. Bell); Boeing - Seattle (K. Blohowiak and C. Newquist); Boeing - North American - KSC (R.H. Frittier); Dynacs Engineering Co., Inc. (C.B. Mattson, R.G. Barile, T.A. Hammond, C.F. Parrish, and B.J. Meneghelli); EG&G (J.R. Taffer); and Ames - Eloret (J.B. Pallix)



Rewaterproofing Performance

Air Quality and Biogenic Emissions Monitoring

Environmental Protection Agency (EPA) criteria air pollutants at KSC have been monitored since January 1983 as part of the ecological program for the KSC Biomedical Office. This monitoring is conducted to fulfill the requirements of the National Environmental Policy Act commitments made in the KSC Environmental Impact Statement and to provide data for use in permitting, compliance, and impact analysis.

The monitoring of priority pollutants, including ozone, sulfur dioxide, carbon monoxide, nitrogen dioxide, and particulates, as well as local meteorological conditions continued at the permanent air monitoring station (PAMS). Instrumentation used for sampling employs different analytical techniques, including ozone (ultraviolet absorption), sulfur dioxide (pulsed ultraviolet fluorescence), carbon monoxide (gas filter correlation infrared absorption), and nitrogen oxides (gas chemiluminescence). The data are collected once per minute by a Hewlett Packard 9000 series mainframe computer and validated using the EPA and Department of Environmental Regulation (DER) quality assurance guidelines. There were no exceedances of the Federal or State air quality standards during the year for the KSC area.

Another activity included the sampling of plant biogenic emissions of volatile organic compounds (VOC's) using SUMMA-polished, 6-liter canisters and analysis on a gas chromatography/mass spectrometry (GC/MS) system. This was done on different types of plants in different habitats, including oaks, pines, and willows. The data is being processed to assess the contribution of natural versus anthropogenic sources to the KSC airshed.

Key accomplishments:

- 1991: Acquisition and installation of the new replacement trailer and the new monitors for ozone and nitrogen oxides.
- 1992: Acquisition of new PM-10 monitors and a portable gas chromatograph.
- 1993: Deployment and use of the PM-10 monitors and the portable gas chromatograph. Began looking at the spatial distribution of rainfall data for KSC.
- 1994: Continued monitoring of the ambient criteria pollutants (including PM-10 particulates) and began a KSC-wide monitoring of light hydrocarbons and other VOC's.

- 1995: Continued monitoring of the above pollutants and began analysis of the VOC and spatial rainfall data.
- 1996 and 1997: Continuation of projects and software development.

Key milestones:

- Internet-based software development to allow access to real-time air quality and meteorological data [3-D viewer using Virtual Reality Markup Language (VRML)]. Contributed to linking the output of the EPA Screen3 dispersion model to be displayed in an Arcview environment. Software developed (C++) to reduce the raw spatial rainfall dataset.

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Participating Organization: Dynamac Corporation (J.H. Drese)

Automation and Robotics

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

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

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

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. The BPC is operated by the Advanced Life Support project office. The ALSARM is 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 meets all the system and BPC requirements. The project is complete and will be officially turned over to the Advanced Life Support project office in January 1998.

The BPC consists of two separate levels used to grow crops in an almost totally enclosed environment. The BPC will help NASA understand how to grow crops in space for Moon or Mars bases. During the course of study, technicians have to enter the chamber to measure environmental parameters such as air temperature, infrared 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 the chamber daily leak rate. The technicians contaminate the environment by their respiration, which expels carbon dioxide and organic products. The mere presence of the technicians can modify the air flow 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 that will eliminate 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 will be developed during Phase II of the ALSARM project that started in late November 1997.

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

The accomplishments for 1997 include the final design details on the 3-degree-of-freedom manipulator, completion of laboratory testing, and installation and operational testing of the ALSARM in the BPC.

Completing the ALSARM testing was the major effort for the remainder of 1997. 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) were completed by late November 1997. The remainder of the basic ALSARM work will complete the operator and maintenance manuals and as-built drawings.

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 and 30-percent design review completed.
- November 1994: 60-percent and 90-percent design reviews completed.
- December 1994: Final review.
- March 1995: Redesign of horizontal telescoping arm started.
- August 1995: Redesign of horizontal telescoping arm finished.
- October 1997: Fabrication of the ALSARM complete.
- December 1997: Laboratory testing of the ALSARM complete.
- July 1997: Installation of the ALSARM into the BPC.
- August through November 1997: Activation and validation testing of the ALSARM.
- Mid-1998: Development of the ALSARM end-effector.

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

ALSARM in the BPC

Cable and Line Inspection Mechanism (CLIM)

The objective of this project is to design and develop a system that remotely inspects the 3/4-inch-diameter emergency egress cables (i.e., slide wires), 3/4-inch-diameter egress lightning cable, and 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 not currently inspected because no capability exists to inspect them.

A production unit to be built will provide a remote video picture of the cable under inspection, test the diameter of the cable with a laser micrometer, and allow the user to capture images of suspect cable sections. This will eliminate the hazardous job of inspecting the cables from the emergency egress personnel carriers. This system can also be used to inspect all the lightning protection cables, a new capability.

A prototype system was developed and is planned for testing at Launch Pad B in January 1998. 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. Mirrors on each side of the cable provide a 360-degree view for inspection. A COTS radio frequency (RF) system is integrated to allow remote control and viewing of the cable inspection process. The camcorder records the entire inspection process for off-line viewing and detailed analysis in an office environment. The prototype system size is 24 by 10 by 10 inches and weighs 43 pounds.

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 1998: Test prototype system on emergency egress cables at Launch Pad B.
- Third quarter 1998: Development of the production system complete.
- Fourth quarter 1998: Implement use of production unit at Launch Pads A and B.

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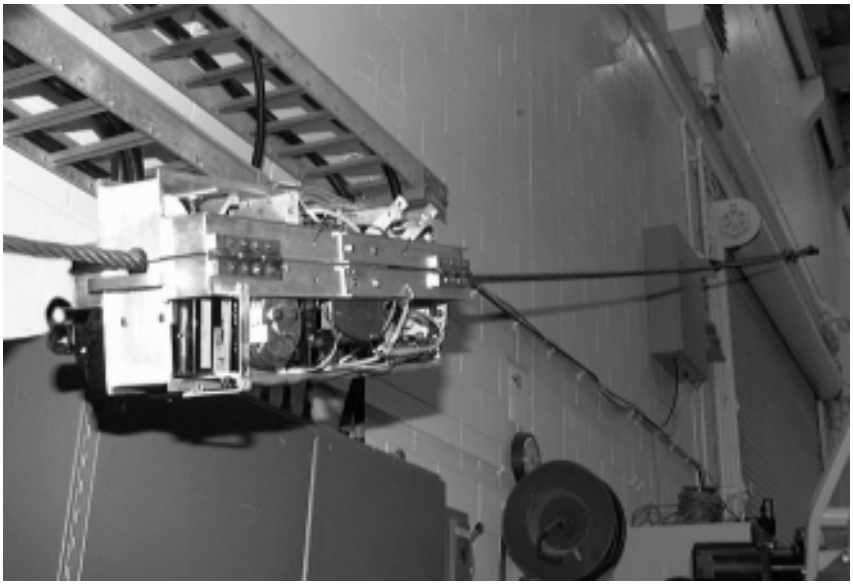
Participating Organization: United Space Alliance (B.H. Smith)

View From LC-39 Launch Pad of Emergency Egress Cables



View of the CLIM Prototype Unit on Test Cable in the Laboratory Facility

Development of a Portable Platform for Operating an Electronic Procedure

The test procedures of the future will be performed electronically instead of on paper. A platform will be required to allow technicians and engineers located in small workspaces (i.e., flight deck of the Space Shuttle) or precariously positioned (suspended in a hang-glider harness) to be able to see their procedure and enter any information that might be required.

Body Wearable Computers (BWC's) can satisfy all of these requirements. A BWC is a battery-powered computer system worn on the user's body (on a belt, backpack, or vest). It is designed for mobile and predominantly hands-free operations, often incorporating head-mounted displays and speech input.

Key accomplishments:

- Acquisition of a minimal amount of equipment to evaluate the technology's potential.

Key milestones:

- Incorporate BWC technology into actual payload processing.
- Expand the usage to incorporate new technologies (i.e., Augmented Reality technology).

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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 non-intrusive 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.

Development of a Portable Instrument To Determine the Total Normal Emittance of a Surface

NASA currently uses multilayer insulation (MLI) blankets to provide thermal control for spacecraft such as the Space Shuttle, its payloads, and the Space Station. These MLI blankets are required to protect the spacecraft and its sensitive instruments from the intense cold of space and heat radiation from the sun. However, proper preflight and postflight inspections of the MLI blankets are critical to the blanket's ability to perform its job of protecting a spacecraft's or payload's successful mission. Upon returning from flight, if a blanket's performance measurement has degraded, it must be replaced so damage to future flight hardware will be avoided. The measurement of a blanket's performance is determined by its emittance value. A blanket's reflectance value is measured using an infrared reflectometer instrument. From that value, emittance is calculated. The value of emittance determines whether or not the blanket passes and can be used to protect flight hardware. Not all blankets can be removed so their reflectance value can be tested in a laboratory; some must be measured while installed in place on the flight hardware.

The instrument presently used to measure reflectance is a two-piece, 1960's unit that weighs almost 50 pounds and is very time consuming to use. The unit's weight, short cable length, and lack of handholds also make it difficult and cumbersome to handle and maneuver, therefore posing a safety hazard to flight hardware.

The challenge was to somehow develop a smaller, more portable instrument that would meet NASA's needs now and in the future. The technical approach to solving this problem was to first write an infrared reflectometer specification with the help of one of the equipment users, The Boeing Company. With the specification, NASA KSC was able to write a Dual-Use Technology Opportunity Announcement document. This document published NASA's intention to seek a company with which to initiate a dual-use development project for a portable instrument to determine the total normal emittance of a surface. A dual-use project is where NASA joins with a commercial partner to share costs, risks, and successes on a project.

The received project plan proposals were then reviewed by a team of engineers, equipment users, and a representative from the Technology Programs and Commercialization Office against a predetermined criteria for selection. AZ Technology, Inc., from Huntsville, Alabama, was chosen as the commercial partner on the project and entered into a technology partnership agreement with NASA KSC on the development of a Total Emittance and Solar Absorptance (TESA) instrument. Since the instrument represents the technology for the future, the instrument has been named the TESA 2000.

The objective of the TESA 2000 agreement is to design and

Item	Old Unit	New Unit
Probe size	6-inch diameter by 10 inches high	5-inch diameter by 8 inches high
Probe weight	10 pounds	7 pounds
Readout unit size	24 by 18 by 12 inches	7.5 by 6 by 3 inches
Readout unit weight	33 pounds	4 pounds
Cable length	5 feet	10 feet
Operation	two persons	one person
Memory	no memory	800 measurements storage capacity
Power	120-volt alternating current	battery
Spectrum	only infrared	infrared and solar spectrum
Warm up time	30 minutes	5 minutes

manufacture a smaller, lighter weight, easier to handle, and portable infrared and solar absorptance reflectometer to determine the total normal emittance, hemispherical emittance, and solar absorptance on MLI blankets and other flight hardware surfaces. The combination of these optical property measurements in a small portable instrument is unprecedented and represents a significant leap forward in technology. This will allow NASA to replace two outdated, cumbersome, and time-consuming pieces of equipment with one unit that is improved in physical size and portability, in performance, and in operational maneuverability and is designed and built of the latest technology. In short, the use of this instrument will tremendously improve the productivity of measuring flight hardware and should pay for itself in less than 1 year.

This next-generation inspection device will be able to detect imperfections in thermal insulation materials in about half the time of the existing equipment. Due to the lighter weight and new method of operation of the new device, the issue of operator and flight hardware safety should all but be eliminated. Other improvements are listed in the table.

The next-generation infrared reflectometer's design is almost complete. The first prototype is under construction and due to be delivered to KSC in April 1998. KSC will then begin a month-long test using actual flight hardware to determine if KSC's design goals have been met. If the prototype testing proves successful, AZ Technology, Inc., will begin production of the commercial infrared reflectometer right away.

Key accomplishments:

- November 1996: Cooperative agreement signed between NASA KSC and AZ Technology, Inc., for development of a portable instrument to determine the total normal emittance of a surface.

- 1997: Design completed to incorporate the probe's ability to measure reflectance in both the infrared and solar portions of the light spectrum.

Key milestones:

- 1998: Perform prototype testing, take delivery of the first commercial unit, and begin using equipment for Space Station node testing.

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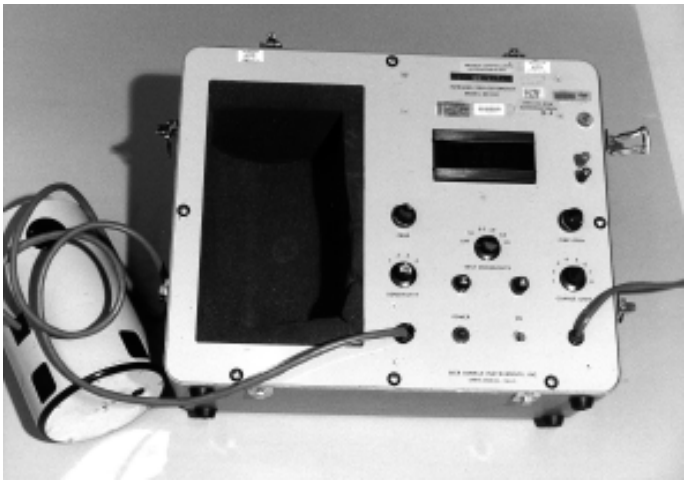
Participating Organizations: AZ Technology, Inc. (R. Tucker) and The Boeing Company (E. Banks)



Condition Monitoring and Fault Identification in Rotating Machinery (CONFIRM)

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

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

Key accomplishments:

- 1997: Implemented the liquid oxygen pump assemblage at the LETF. Validated the use of AE techniques in identifying bearing failures.

Key milestone:

- 1998: Assess condition monitoring technologies and variable frequency drives on the 300-horsepower pump assemblage.

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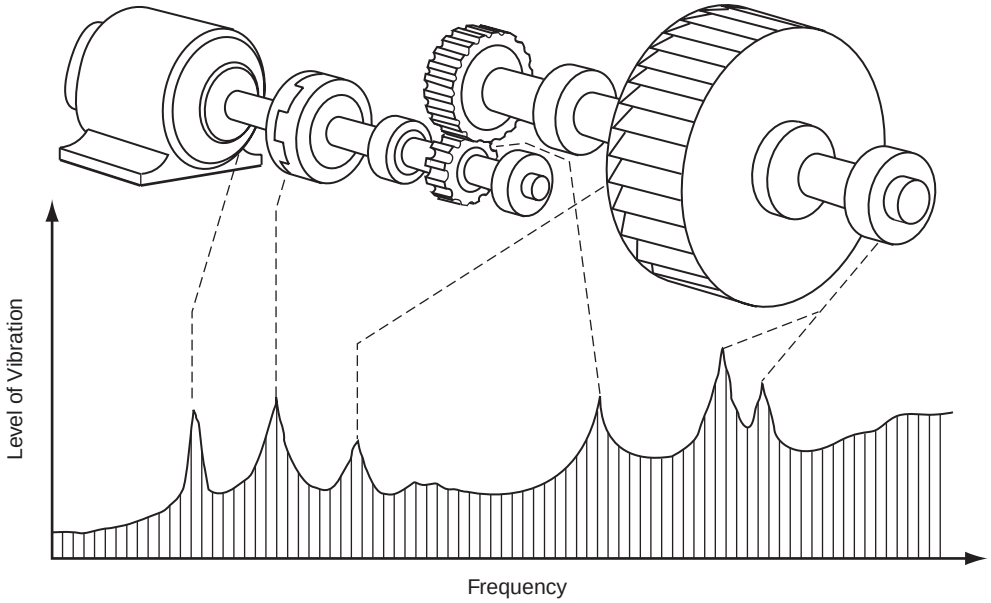

Low Frequency Range	Intermediate Frequency Range	High Frequency Range
• Unbalance • Misalignment	• Vibration due to gear meshing • Trouble due to resonance	• Vibration of rolling bearing • Fluid vibration
Speed or Displacement Mode	Acceleration (LOW) Mode	Acceleration (HIGH) Mode
10 hertz to 1 kilohertz	1 to 10 kilohertz	7 to 40 kilohertz

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

Electronics and Instrumentation

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

Characterization of the Catenary Wire Lightning Instrumentation System (CWLIS)

The objective of this project was to improve the accuracy of the lightning current measurements obtained with the CWLIS. The Space Shuttle launch pads are protected from a direct strike by lightning by means of a long wire that runs from the top of the pad to two grounding points located about 1,000 feet away. The purpose of this wire, the catenary wire, is to direct the lightning current away from the pad and into the ground.

The launch pads are equipped with sensors that measure the current at the ends of the catenary wires. The catenary wire behaves as a transmission line. If the impedance of the wire is not perfectly matched to the impedance of the ground, both voltage and current reflections will occur at the end of the wire. The real current can be directly measured only if the impedance of the catenary wire is identical to the impedance of the ground since, in this case, no reflections would occur. Because the impedance of the catenary wire is not perfectly matched to that of the ground, a transfer function must be applied to obtain the correct magnitude of the lightning current. This transfer function is a function of frequency since both the impedance of the wire and the ground are frequency dependent. The objective was to devise a method to experimentally determine the coefficient of reflection as a function of frequency and to derive a transfer function that can be applied to the recorded data to obtain the correct current measurement.

The figure shows the lightning protection wire used at the Space Shuttle launch pads. When lightning strikes the top of the tower or contacts the catenary wire at any point, current flows toward both ends of the wire. When the current reaches the end of the wire, some amount of energy is transferred to the ground, and the remaining is reflected. The amount of reflected current is determined by the “reflection coefficient.” This coefficient is given by:

$$\text{reflection coefficient} = (Zr - Zo) / (Zr + Zo)$$

where Zr is the terminating impedance and Zo is the characteristic impedance of the cable. The maximum transfer of energy from a transmission line to a load occurs when the impedance of the load is identical to the impedance of the transmission line. In extreme conditions, where the load has either infinite impedance (open circuit) or zero impedance (short circuit), all the energy is reflected.

Under ideal conditions, the reflection coefficient could be determined experimentally by applying a test waveform with a known current (or voltage) to one end of the cable and measuring the current (or voltage) at the other end. Under actual conditions at the launch pads, the energy arriving at the remote end is reduced by several factors: (1) some energy is lost by dissipation along the nonzero resistance of the steel cable, (2) some reflections occur halfway at the top of the mast, and (3) some energy is radiated by the cable. This reduced energy at the remote end makes it impossible to directly compute the reflection coefficient since the incident current (or voltage) is not known. A solution to this problem was devised, and the reflection coefficient was obtained using the following steps:

1. One end of the catenary wire (north side) was disconnected from ground, thus presenting an infinite impedance.

2. A short test impulse (250 nanoseconds) was applied across a 50-ohm resistor to the other end of the cable (south side), which was also disconnected from ground.

3. An oscilloscope was used to record the waveform at the south side of the cable, where the test impulse had been injected. A reflection was recorded about 5 microseconds after the test impulse had been applied. This is the time that the test impulse required to travel back and forth through the catenary wire. Even though the north end presented an infinite impedance and the reflection coefficient at that point was 100 percent, the amplitude of the reflected signal, as received at the south side, was much smaller than the originally applied impulse. This reduc-

tion in amplitude was caused by both losses on the cable and radiation. Although the amplitude of the reflected signal was reduced, it provided a baseline to use to compare against signals reflected when the north side had a finite impedance.

4. The north end was then connected to ground, thus presenting a finite impedance.

5. Step 2 was repeated under the new conditions.

6. The magnitude of the reflected pulse was recorded. This pulse at the most would have an amplitude similar to that obtained in step 3 since the maximum possible reflection is 100 percent. The polarity of the pulse was found to be inverted as compared to that obtained in step 3. This indicated that the impedance of the ground was lower than the characteristic impedance of the catenary wire.

7. The Fourier transforms of both reflected pulses (steps 3 and 6) were calculated. The reflection coefficient, as a function of frequency, was obtained by:

$$\text{reflection coefficient} = S_{grounded}(w) / S_{open}(w)$$

where $S_{grounded}(w)$ is the Fourier transform of the reflected impulse with the remote end grounded, and $S_{open}(w)$ is the Fourier transform of the reflected impulse with the remote end open.

Key accomplishments:

- Determined the coefficient of reflection as a function of frequency at both ends of the catenary wire at both launch pads.
- Developed an algorithm to recover the original waveshape by removing the effect of multiple reflections.

Key milestones:

- Record and process lightning current data during the next thunderstorm season.
- Compare the results with the lightning current estimated by the KSC lightning location system.

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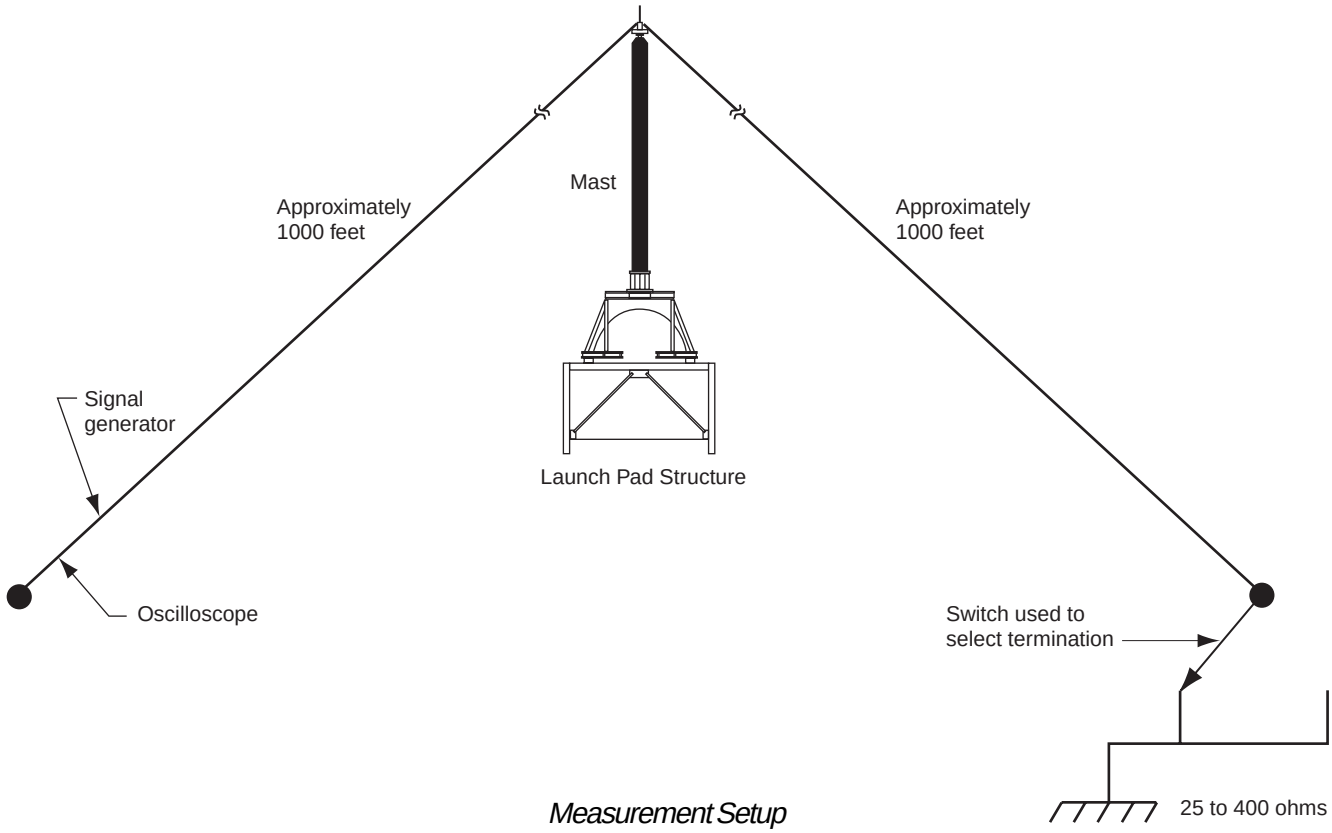

Measurement Setup

Power Factor Correction Circuits for AC-DC Converters

This project targets the declining power quality in the Shuttle's main processing centers in an effort to improve the power distribution system performance. Power quality surveys reveal high levels of harmonic distortion in many of the Shuttle's main data processing centers. As current harmonics increase the root mean square (RMS) value of the current waveform, they do not deliver any real energy in watts to the load. As a result, new system designs must account for higher harmonic distortion levels by the use of larger distribution hardware (K-factor rated transformers, larger conductors, larger breakers, etc.). When not properly planned for, high harmonic distortion in existing systems commonly causes erratic equipment operation and, in some cases, results in fire and/or electrical shock hazards.

The use of this advanced power converter will eliminate the additional stresses on the power distribution system caused by harmonic distortion. As a result, new power distribution designs will not require derating for harmonic loads and will, therefore, save on overall project costs. In the existing power distribution systems, this technology can significantly reduce the load on the electrical system (harmonic currents account for a full third of the RMS current in some Shuttle processing centers).

The focus of the current research is to develop high power density alternating current (ac) to direct current (dc) converters with power factor correction. This can be accomplished by using an active switching technique to shape the line current.

Power factor gives a measure of how effective real power utilization is in the system. It also represents a measure of the distortion of line voltage and line current and the phase shift between them. Power factor (*pf*) is defined as the ratio of the average power measured at the terminals a-a' in figure 1 and the apparent power [product of *RMS* values of v_{line}(t) and i_{line}(t)*].*

$$\text{Power Factor} = \frac{\text{Real Power (Average)}}{\text{Apparent Power}} = \frac{I_{S,RMS} \cdot V_{S,RMS} \cdot \cos\Theta}{I_{S,RMS} \cdot V_{S,RMS}} * \qquad (1)$$

**For purely sinusoidal current and voltage waveforms.*

Hence, in linear power systems, when the line voltage and line currents are purely sinusoidal, the power factor is equal to the cosine of the phase-angle between the current and voltage. However, in power electronic circuits, due to the switching of active power devices, the phase-angle representation alone is not valid, and a new quantity for nonsinusoidal systems must be defined.

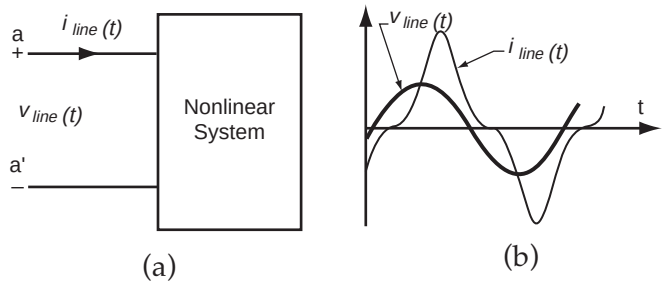

Figure 1. Nonlinear Load Draws Distorted Line Current From the Line

The above figure shows that the nonlinear load draws distorted line current from the line. For this case, note the description of the distorted line current and line voltage in Fourier expansions:

$$i_s(t) = I_{DC} + \Re_{n=1} I_{sn} \sin(n\omega t + \theta_{ni}) \qquad (2)$$

$$= I_{DC} + I_{s1}\sin(n\omega t + \theta_{1i}) + \Re_{n=2} I_{sn} \sin(n\omega t + \theta_{ni})$$

$$v_s(t) = V_{DC} + \Re_{n=1} V_{sn} \sin(n\omega t + \theta_{nv}) \qquad (3)$$

$$= V_{DC} + V_{s1}\sin(n\omega t + \theta_{1v}) + \Re_{n=2} V_{sn} \sin(n\omega t + \theta_{nv})$$

Applying the definition of power factor given in equation (1) to the distorted current and voltage waveforms of equations (2) and (3), *pf* may be expressed as

$$pf = \frac{\Re_{n=1} I_{sn,rms} V_{sn,rms} \cos\theta_n}{I_{s,rms} V_{s,rms}} = \frac{\Re_{n=1} I_{sn,rms} V_{sn,rms} \cos\theta_n}{\sqrt{\Re_{n=1} I_{ns,rms}^2 \; \Re_{n=1} V_{ns,rms}^2}} \qquad (4)$$

The above expression for *pf* can be significantly simplified if it is assumed that the line voltage is pure sinusoidal and the distortion is only limited to $i_s(t)$. Then it can be shown the *pf* can be expressed as

$$pf = \frac{I_{s1,rms}}{I_{s,rms}} \cos\theta_1 = k_{dist} \; k_{disp} \qquad (5)$$

Where θ_1 is the phase angle between the voltage $v_s(t)$ and the fundamental component of $i_s(t)$, $k_{disp} = \cos\theta_1$; $k_{dist} = I_{s1,rms}/I_{s,rms}$.

In practical application to achieve a smaller voltage ripple power supply, a large electrolytic capacitor was used in the conventional single-phase capacitive rectifier as shown in figure 2, and the current and voltage waveforms are shown in figure 3. Since the rectifier diodes conduct only when the line voltage is higher than the capacitor voltage, the power supply draws a pulsating current from the line.

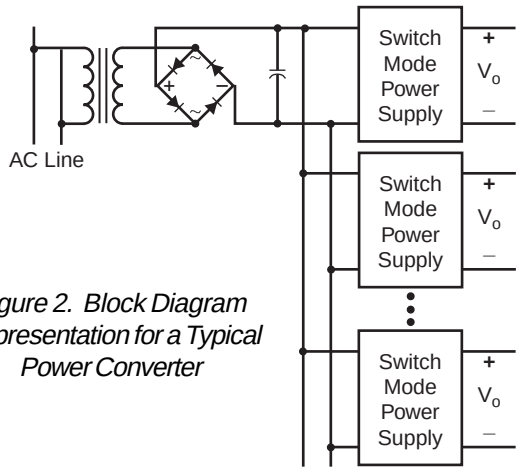

Figure 2. Block Diagram Representation for a Typical Power Converter

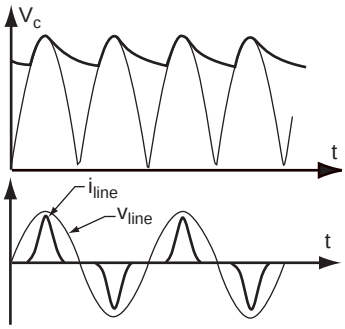

Figure 3. Typical Line Current and Capacitor Voltage Waveforms for Poor Factor Systems

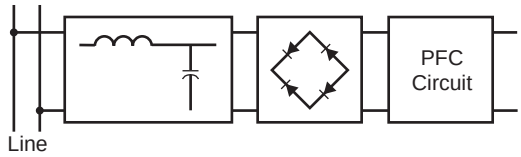

Figure 4. Power Factor Correction Scheme Using Switch-Mode Topologies

As a result, high total harmonic distortion (THD) and poor power factor (0.67) are present at the distributed power system (DPS). In recent years, using switch-mode topologies (see figure 4) many circuits and control methods are developed to meet certain standards (IEC 555-2). To achieve this, high-frequency switching techniques were used to shape the input current waveform successfully. Basically, these techniques can be realized in two forms. In a two-stage scheme, an ac/dc converter with power factor correction (PFC) is connected to the line, followed by a dc/dc converter. These two power stages can be controlled separately; thus it makes both converters possible to be optimized. The drawbacks of this scheme are lower efficiency due to twice processing of the input power, larger control circuits, higher cost, and low reliability. The one-stage scheme combines the PFC circuit and power conversion circuit in one stage. Due to its simplified power stage and control circuit, this scheme is potentially more efficient.

One of the main objectives of this work is to propose a converter topology with a single switch and provide output electrical isolation and near unity power factor. Several new converter topologies will be investigated by the University of Central Florida (UCF). For example, a new converter topology was proposed recently by the Power Electronics Research Laboratory at UCF. This new circuit combines the advantages of a flyback circuit, performs power factor correction, and provides output electric isolation, all in one power stage (see figure 5). Due to its simplified power stage and control circuit, this converter unit will potentially have better efficiency, lower cost, and higher reliability. A good power factor can be obtained with this single switch converter unit by employing flyback circuit as its input. PSPICE simulation and prototyping show this circuit yields a power factor of 0.99.

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Participating Organization: University of Central Florida (H. Wei, G. Zhu, and I. Batarseh)

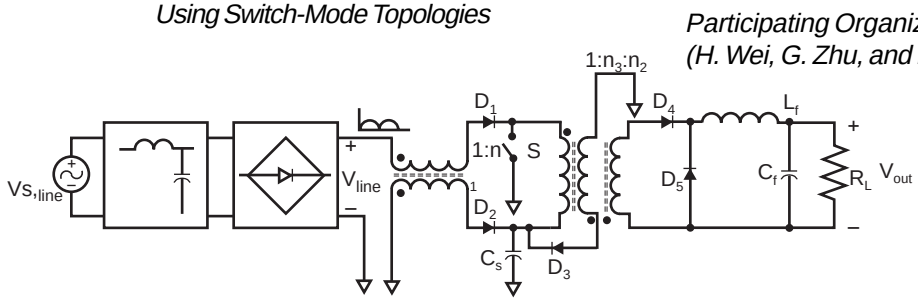


Figure 5. Basic Circuit Schematic of the Proposed Converter

Orbiter Maneuvering System Pod Alignment Tool

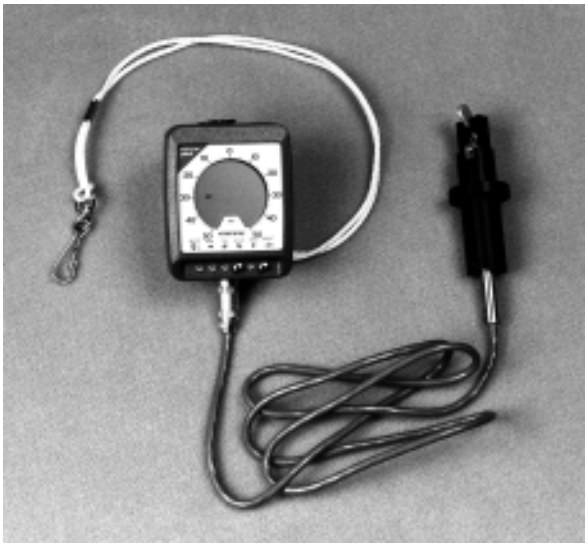
One of the processes in the orbiter flow is removing and reattaching the Orbital Maneuvering System (OMS) pod to the maintenance fixture and orbiter. The OMS pod is a large structure attached to the orbiter by eleven bolts that pass through clearance holes in the OMS pod structure and screw into captured fixed and floating nuts within the framework of the orbiter and pod. When removed from the orbiter, the OMS pod is attached to the maintenance fixture using 5 of the 11 attach points. The difficulty with these attachment processes is that the clearance holes on the OMS pod must be positioned to within two- or three-thousandths of an inch of the acceptance hole on the orbiter or maintenance fixture in order for the bolt to slide through both openings and be secured. This problem is further compounded by the presence of overhanging structures on the OMS pod that make it impossible to see down the holes to attempt a visual alignment. Consequently, operations personnel have been forced to rely on reaching into the OMS pod structure and using their fingers to estimate the degree of alignment between the two mating openings. In practice, this has proven to be a frustrating and time-consuming process, at times requiring an entire shift to achieve the precise alignment required for bolt installation.

The problem was solved by adapting an off-the-shelf linear displacement transducer (LDT) to allow the direction and degree of misalignment between the two clearance openings to be displayed quantitatively. The approach taken assumes the OMS pod clearance opening and the orbiter structure clearance opening start aligned to within 0.04 inch and the gap between the two surfaces (the OMS pod surface and the orbiter surface) is parallel and within 0.25 inch of each other. This may appear to be a severe restriction on the system; but, in practice, the equipment is in place to achieve this degree of alignment and positioning relatively easily. The difficulty was in achieving an alignment to within two- to three-thousandths of an inch, which the new equipment described can achieve.

The operation of the device is shown in the figure. Essentially, a lever system was constructed to convert the hole-offset position into an up/down motion, which can be read by the LDT and the result then can be displayed on a handheld screen. The LDT is accurately and rigidly mounted into a sleeve that can slide into the OMS pod clearance hole until a stopping lip is reached. Doing this causes the lever mechanism to be compressed as it enters the orbiter structure clearance hold. The lever mechanism is constructed of three separate elements with three rotation points: a contact piece, a connection piece, and an extension piece. When the contact piece is compressed inward due to contact with a surface, it causes the connection piece to be moved both upward and inward. This causes the extension piece to be pushed upward compressing the LDT. The resulting compression can then be read on a display. The LDT position within the sleeve can be adjusted so the compression corresponding to an aligned pair of openings corresponds to a zero offset on the display. Due to the multiple lever action, a compression on the contact piece corresponds to about twice this compression in the upward direction on the LDT. Consequently, the alignment accuracy of this system is about twice the measurement accuracy of the LDT.

In use, this device is pressed down into a pair of misaligned clearance holes and then rotated. If the holes are aligned, their edges will stay aligned for all angles of rotation and the display will read near zero during the rotation. If the holes are misaligned, there will be an angle of maximum positive misalignment and an angle of maximum negative misalignment (in between, there will be two angles where the misalignment will be zero). By noting the degree of maximum offset and the direction in which this occurs, the direction and magnitude of adjustment necessary to achieve the alignment is known. In practice, two or three iterations of this rotation process with repositioning of the hardware can repeatedly align a pair of clearance holes to within two-thousandths of an inch allowing a mounting bolt to slide easily through both of them.

The combination of the lever mechanism and the LDT yields a system with an alignment accuracy of better than five ten-thousandths of an inch, which is well within the requirements of application. A test bed was constructed with two parallel clearance holes and a pair of fine adjustment screws. Using this test bed has repeatedly shown that this device far exceeds the sensitivity of a person's fingers to align two holes. After misaligning the holes, the mechanical alignment device can be used to rapidly realign the openings so a mounting bolt can be dropped through both openings. NASA operations have used this tool on several occasions and estimated it will save an average of 2 hours of processing per flow. It is in the process of being written into the formal Shuttle processing procedure.



OMS Pod Alignment Tool

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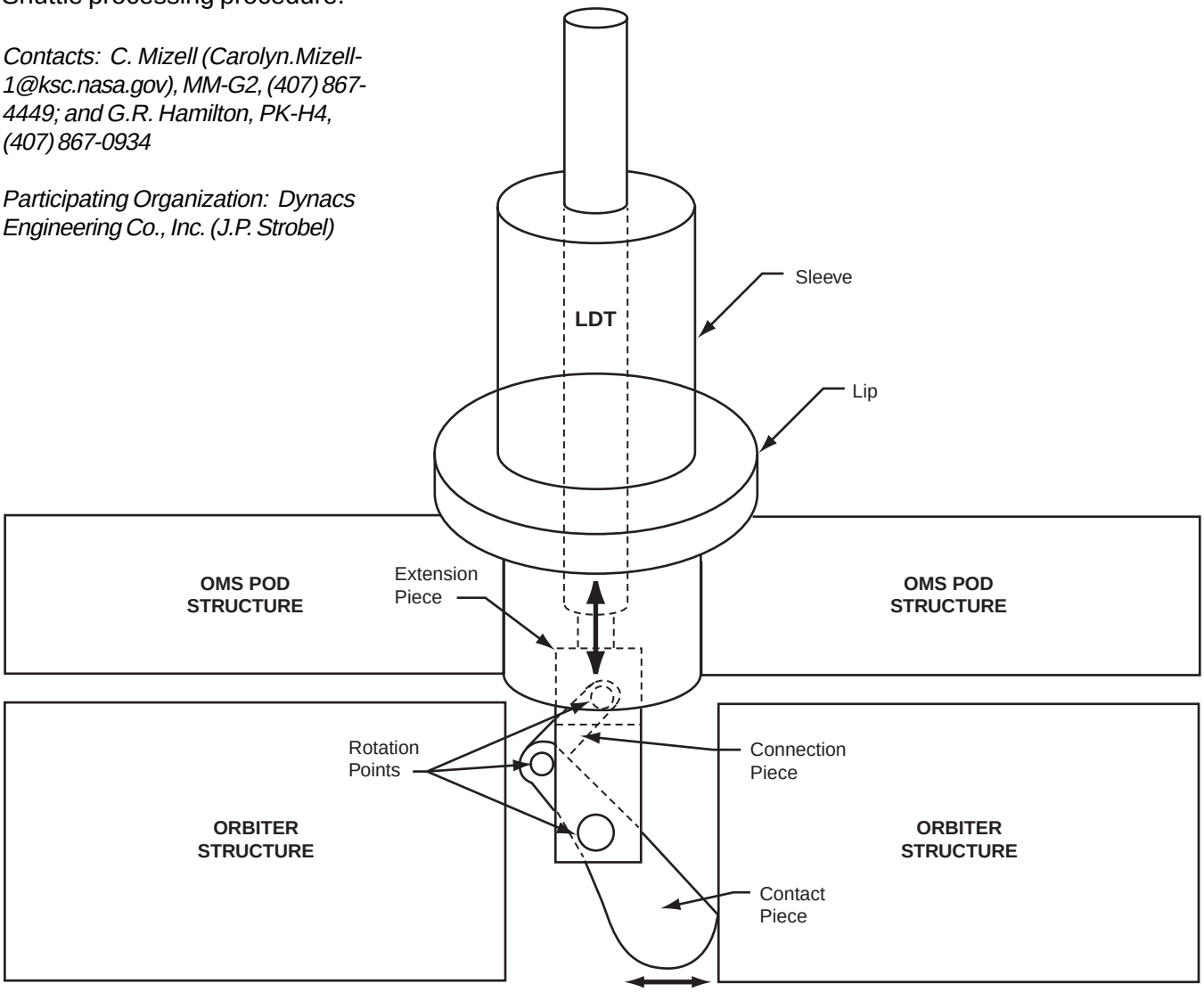


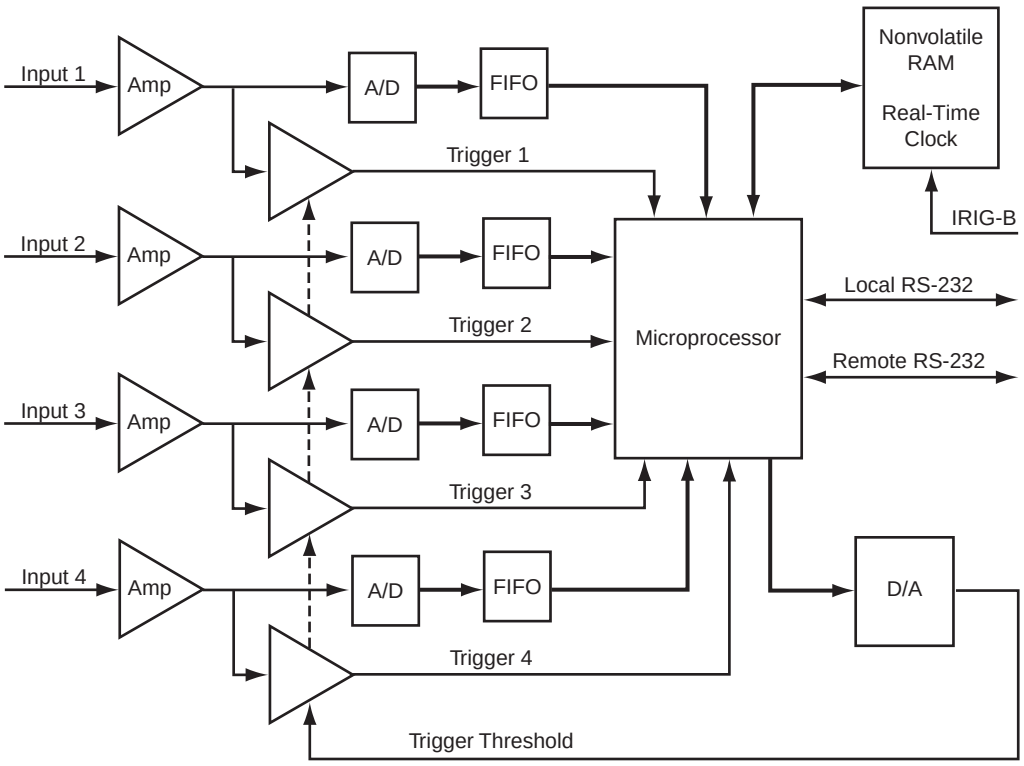
OMS Pod Alignment — Mechanical System Head Operation

Transient Voltage Recorder for Power and Data Line Monitoring

The objective of the Transient Voltage Recorder project was to design an instrument capable of monitoring the effects of lightning-induced voltages on communication and power lines. Although most electronic equipment has some form of transient protection, some limitations exist on the maximum voltage and maximum duration of the transient voltages that can be recorded. Electronic components and equipment can have an immediate failure when subject to voltages larger than their maximum rated values. Transient voltages can also alter the characteristics of an electronic component without any immediate sign of damage. Unless there is a way to determine transient voltages are present, such anomalies can remain undetected and eventually lead to a premature and unexpected failure of a component.

Transient voltage recorders have been used for many years to monitor voltage spikes in cables. Common sources of transient voltages include large electric motors, switching of power equipment, induced voltages from nearby lightning, and direct lightning strikes. The transients generated by sources other than lightning tend to have frequency components well below 1 megahertz, which most commercial transient recorders can detect and record. On the other hand, lightning-induced transients contain voltage peaks with amplitudes that can rise from 10 to 90 percent in a fraction of a microsecond and can generate multiple transients within a few milliseconds of each other. A fast transient recorder is required to accurately characterize lightning-induced voltages.

The transient voltage recorder was designed to simultaneously sample four signals at a 20-megasample-per-second rate, where voltage transients up to 50 volts can be measured. A microprocessor is used to control the operation of the recorder. A trigger circuit continuously compares the amplitude of the signals on all four channels, where independent thresholds can be preset. A trigger signal is generated when at least one signal exceeds its predetermined threshold level. All four channels are simultaneously sampled when any one trigger signal is generated. The threshold levels for the trigger can be independently set to between 5 and 95 percent of full scale. The analog-to-digital converters operate continuously and temporarily store their data on first-in first-out (FIFO) memories that are normally kept half full. When a trigger signal is received, the remaining halves of the FIFO's are filled up with data for a total of 200 microseconds. This provides a 100-microsecond pretrigger capability. After a transient has been recorded, the data is transferred to nonvolatile memory for storage. The unit is rearmed within 400 microseconds to allow for subsequent transients to be recorded. The instrument is equipped with a real-time clock and an IRIG-B decoder so each time a data record is stored, the time of occurrence is also saved. The transient voltage



Transient Voltage Recorder

recorder is equipped with batteries and can operate for up to 16 hours in case of main alternating current power loss. All data is stored in nonvolatile RAM to prevent accidental loss of information in case the power is not restored before the charge in the batteries is depleted. Data retrieval is done by means of an EIA-232 interface using a portable computer or remotely through a modem.

Key accomplishments:

- Designed and prototyped the transient voltage recorder.
- Developed the software to store and time-stamp the data.

Key milestones:

- Continue field tests on the launch pad and the mobile launcher platform.
- Evaluate the performance of the system in field tests.

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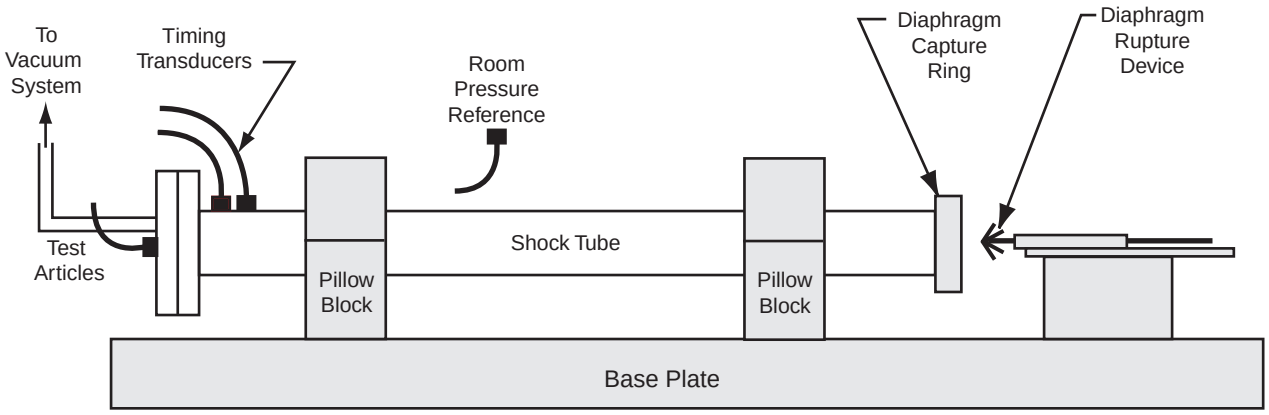
Participating Organization: Dynacs Engineering Co., Inc. (P.J. Medelius, H.J. Simpson, J.D. Taylor, and J.J. Henderson)

Shock Tube for Acoustic Pressure Transducer Dynamic Frequency Response

The development of a shock tube for use in the evaluation of acoustic pressure transducers provides an effective means of generating dynamic pressure waves. The shock tube allows for the evaluation of a pressure transducer's frequency response, an important parameter in the selection of suitable sensors for acoustic pressure measurements acquired at the Space Shuttle Launch Complex 39 (LC-39) areas. Such a shock tube has been developed at KSC, aiding in the testing of acoustic pressure transducers used for LC-39 ground support equipment.

Historically, testing of the frequency response of an acoustic pressure sensor has proven to be difficult. Producing static pressures is easily accomplished through standard pressure test equipment, but generating rapidly time-varying pressure becomes challenging. Techniques are well documented for the production of both periodic and aperiodic time-varying pressures. Periodic pressure generation can be accomplished by the use of an oscillating piston, but the need for the piston to change direction at a high rate of speed made the investigation and development of such a system cost prohibitive. Aperiodic pressure generation, through the use of a shock tube, has been performed for many years in the dynamic pressure calibration field. The technique simply involves the pressurization of one chamber (high-pressure chamber) and the placement of test articles in a second chamber (low-pressure chamber). Between the chambers is a diaphragm that, when burst, creates a shock wave or step change in pressure. The key to the technique is to have a high-pressure chamber that appears as a relatively infinite source of gas in respect to the volume of the low-pressure chamber. Shock tubes have been built, but the need for large chambers to support higher pressures has led to shock tubes as much as 55 feet in length.

For the acoustic pressure sensor requirements at LC-39, pressure sensing around atmospheric pressure is all that is necessary. Therefore, it was conceived to fabricate a test apparatus consisting of only one sealed low-pressure chamber upon which a partial vacuum was drawn. Allowing the room in which the low-pressure



chamber is located to be the high-pressure, infinite source of gas, the bursting of a diaphragm seal to the low-pressure chamber would create a similar shock wave, step-function result.

At a distance of approximately 10 to 15 tube diameters downstream from the diaphragm, a well-formed shock wave develops. The shock wave continues to move throughout the remainder of the gas in the shock tube at a constant velocity. At the shock wave, the pressure suddenly rises to a higher pressure value, resulting in a positive pressure step. The length of time the pressure remains constant behind the shock wave depends on the dimensions of the shock tube, the position in which the pressure change is being monitored, the degree of smoothness of the inner walls of the tube, the type and design of the diaphragm, the diaphragm rupture technique, and the type, temperature, initial pressure, and relative humidity of the gas in both the shock tube and in the room.

The shock tube developed is approximately 4 feet long and utilizes a latex diaphragm punctured by a razor-sharp arrow head. With a 1-pound-per-square-inch differential between the shock tube interior and the room pressure, the shock tube can produce a pressure wave to the upper sensitivity of the test articles, 170.7-decibel sound pressure level.

Key accomplishments:

- Design and fabrication of the shock tube.
- Initial testing to determine the optimum diaphragm material and burst technique.
- Laboratory testing for the determination of shock wave characteristics.

Key milestones:

- Continue laboratory testing to fully characterize the shock wave.
- Develop a Fast Fourier Transform (FFT) model for frequency response.

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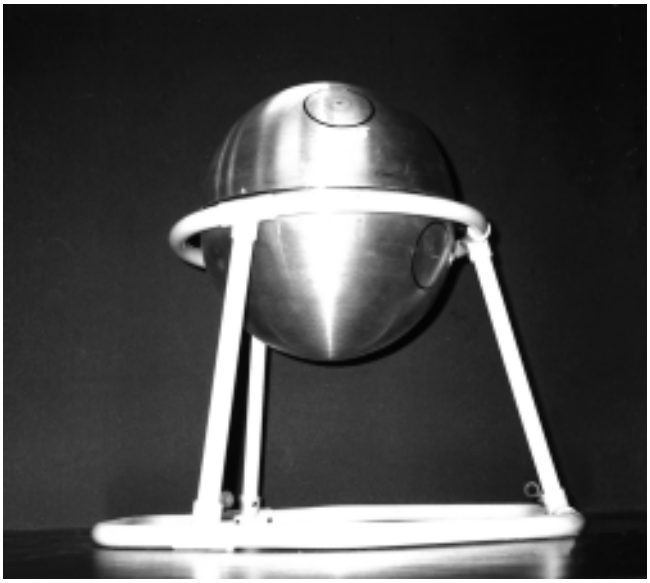
Participating Organization: Dynacs Engineering Co., Inc. (R.T. Deyoe)

Self-Contained Electric Field Sensor

The objective of this project was to develop a sensor to measure electric fields generated by lightning strikes. Electronic equipment is susceptible to damage when exposed to voltage beyond safe limits. Lightning strikes, which usually carry currents in the order of several thousand amperes, generate large electric and magnetic fields with fast rise and decay times. Fast varying electromagnetic fields result in induced voltages and currents on any conductor that, if attached to an electronic device, can cause immediate damage or significantly reduce its lifetime. Knowledge of the intensity of these electromagnetic fields and their rate of rise (electric field derivative) can provide information that can be used to assess the potential damage to any sensitive instrument.

Severe thunderstorms during the summer at KSC produce a large number of lightning strikes near the Launch Complex 39 area. These strikes may cause damage to payloads previously verified ready for launch and placed in the Shuttle cargo bay. A portable instrument, capable of measuring the electric field and its derivative (rate of change) and able to be placed near sensitive instrumentation, would provide valuable data regarding potential damage from a lightning strike. The objective is to install this instrument in the Payload Changeout Room (PCR). This way, the effects of lightning strikes on the cargo can be assessed, which will help decide whether the payloads must be rechecked prior to flight.



A self-contained instrument that records the peak value of the electric field and its derivative was designed. Three orthogonal antennas mounted on a conducting sphere are used to sense the electric fields. The electric signal received from the antennas is proportional to the derivative of the electric field; therefore, an electronic integrating circuit is used to produce a signal proportional to the electric field itself. Variations in the electric field induce a current into the antennas, given by:

$$I = k A \varepsilon_o \, dE/dt$$

where I is the electric current, A is the area of the antenna, ε_o is the permittivity of air, dE/dt is the rate of change of the electric field, and k is a constant that defines the enhancement of the electric field caused by a conducting object. A spherical conductor was used to hold the antennas since its enhancement factor is easily determined. For a sphere, k is equal to 3.

A microprocessor is used to control the operation of the sensor. This microprocessor, along with an analog-to-digital (A/D) converter samples the peak values of the electric field and its derivative within 1-millisecond-long windows. When the peak values are larger than a predefined threshold, the peak values are stored in a nonvolatile memory chip for retrieval at a later time. An additional A/D converter, sampling at 10 million samples per second, is used to record the waveshape of the electric field received by one of the three antennas. Because of power consumption constraints, only one component of the electric field is digitized at the fast rate. The instrument is equipped with a real-time clock, so each time a data value is stored the time is also saved. This allows for the correlation of other data from the lightning strike (recorded by other lightning location and current measuring systems) with the data collected by the electric field sensor.

The electric field sensor is equipped with batteries and can operate for up to 2 weeks unattended. All data is stored in nonvolatile RAM to prevent accidental loss of information in case of a power failure. Data retrieval is done by means of an EIA-232 interface using a portable computer. The batteries can be changed in the field so the sensor can stay in place to continue measuring without interruptions. The data retrieved by the portable computer includes the date and time of the occurrence of the electric field, the peak positive and negative values of both the electric field and its derivative (for all three axes), and one 100-microsecond-long waveform corresponding to one of the three components of the electric field.

Key accomplishments:

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

Key milestone:

- Continue to monitor the electric fields inside the PCR.

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Participating Organization: Dynacs Engineering Co., Inc. (P.J. Medelius, H.J. Simpson, J.D. Taylor, J.J. Henderson, and R.W. Gates)

Integrated Vehicle Health Management

The objective of Integrated Vehicle Health Management (IVHM), also referred to as Integrated Vehicle Health Monitoring depending on whether or not the system is "active" or "passive" in nature, is to reduce planned ground processing, streamline problem troubleshooting (unplanned ground processing), enhance visibility into systems operation, and improve overall vehicle safety. The "integrated" piece of IVHM describes the integrated communication between flight and ground components. The flight side of IVHM is essentially an evolution of a traditional vehicle instrumentation system, which consists of sensors (pressure, temperature, voltage, strain, accelerometers, discretes, etc.), wiring, signal conditioning devices, multiplexing devices, and recording devices. IVHM goes a step further by providing capabilities to process data versus merely recording data. This allows for onboard trend analysis to enunciate system degradation as well as control of inflight systems checkout. The ground side of IVHM consists of more integrated and automated ground support equipment for more efficient system servicing and checkout. While incorporation of an IVHM architecture into a new vehicle is a complex process in itself, implementation of IVHM into the Space Shuttle program must deal with additional considerations such as not impacting the flight manifest, cost/payback, military and commercial off-the-shelf evaluations, and hardware installation decisions.

Before commitments are made on specific approaches, it was proposed that at least two flight experiments be packaged as technology demonstrations. The specific purpose of these NASA/KSC-led IVHM Human Exploration and Development of Space (HEDS) Technology Demonstrations (HTD's) is to show competing modern, off-the-shelf sensing technologies in an operational environment to make informed design decisions for the eventual orbiter upgrade IVHM. Technologies to be demonstrated include: microelectromechanical sensing (MEMS) for hazardous gas detection and cryogenic distribution system vacuum-jacketed line pressure sensing, Bragg-Grating fiber-optic sensing systems for hazardous gas detection and structural strain/temperature determination, thermal flowmeter leak detection, Hall Effect current sensing, accelerometers for pump vibration sensing, VME bus architecture, flash card memory, and neural networks. It is planned to fly two HTD's on the same orbiter on successive flights with incorporation of additional sensors between flights. Currently, the team is working toward OV-103 Discovery on STS-95 October 29, 1998, and STS-97 April 8, 1999.

During cryogenic propellant load in terminal launch countdown, the IVHM HTD data stream will be routed out of the orbiter's T-0 umbilical for transmission, processing, and viewing in the Launch Control Center. Data will be recorded on ascent and during three planned 1-hour snapshot periods. The processor/recorder will be physically removed for dumping after the orbiter has landed and has been rolled into its Orbiter Processing Facility bay.

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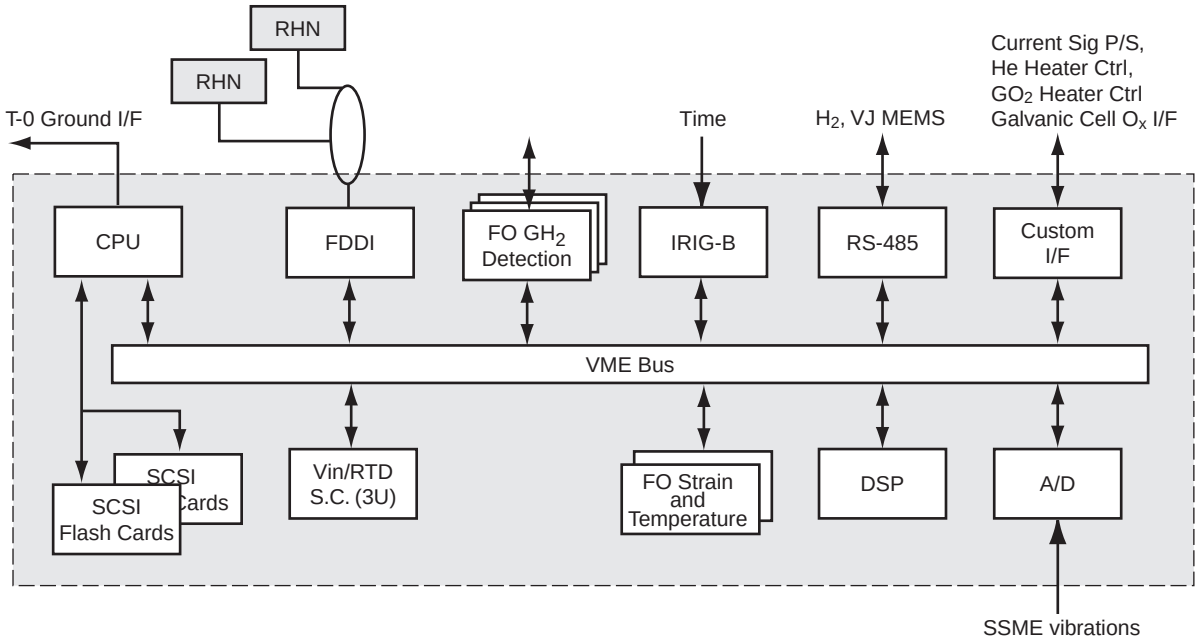
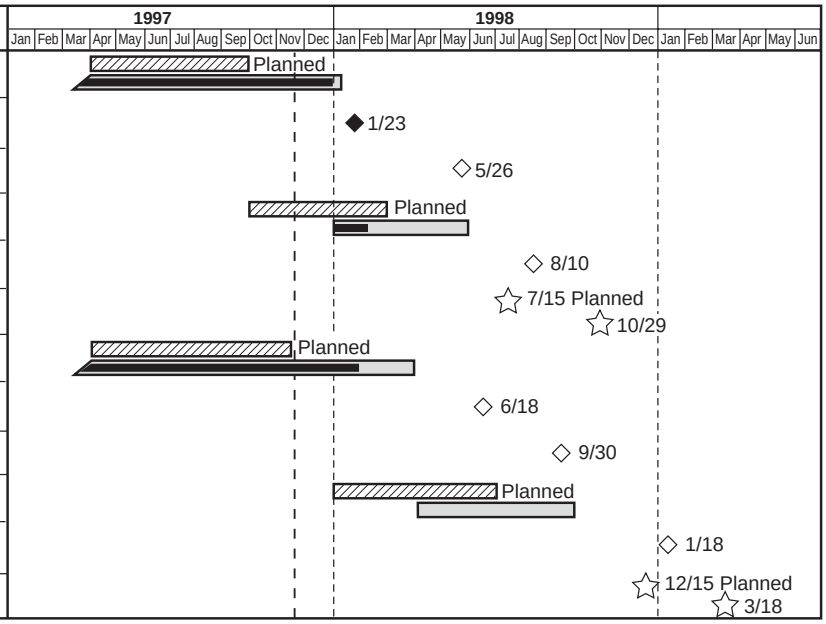
Participating Organizations: Johnson Space Center (G.R. Grush and J. Shaw), Boeing North American/Downey (J. Peck and B. Moran), Langley Research Center (J. Fedors, K. Vipavetz, and L. Melvin), George C. Marshall Space Flight Center (T. Fiorucci and W.T. Powers), Lewis Research Center (G. Hunter), Lockheed Martin Sanders (T. Hardy), and Rockwell Science Center (R. Christian)

IVHM HTD 1 and 2 Configurations



Description (* = HTD-2)	Sensor Type	Quantity	Source
1. Aft compartment GH_2 detection	Palladium	6	Case Western/Makel
2. Aft compartment GO_2 detection	Galvanic Cell	2	Teledyne/Cititechnology
3. MPS GOX interface temperature	RTD	3	Rosemont
4. MPS GHe solenoid valve port leak	Thermal flow meter	2	HyCal
5. MPS VJ line pressure	MEMS	2	Custom-BNA/KSC
6. ET/orbiter umbilical plate gap pressure	Smart Press Sensor	1	STI Stellar/Sensotec
7. ET door linkages strain and temperature	Strain/RTD	2/1	Vishay/Rosemont
8. LH_2 feed system temperatures	RTD	3	Rosemont
9. PRSD cryo valve body temperture	RTD	4	Rosemont
10. HTD-1 box temperature	RTD	4	Rosemont
11. Aft GH_2 detection w/temperature*	Bragg-Grating FO	40	LaRC/UMd
12. GH_2 FCV current signature*	Hall Effect, Neural Net	3	Honeywell -KSC, OSU
13. SSME pump vibration monitoring*	Accelerometer	8	Custom - MSFC
14. SSME 3 thrust structure strain and temperature*	Bragg-Grating FO	4/4	3M/Rockwell Science Center

ID	Task Name	Start	Finish
1	HTD-1 Development	04/01/97	01/05/98
2	HTD-1 P/L Integ. ICD	01/23/98	01/23/98
3	HTD-1 100% Engr.	5/26/98	5/26/98
4	HTD-1 Lab Integration	01/21/98	06/01/98
5	HTD-1 Ph. 3 PSRP	08/10/98	08/10/98
6	HTD-1 Launch	10/29/98	10/29/98
7	HTD-2 Development	04/01/98	05/15/98
8	HTD-2 P/L Integ. ICD	06/18/98	06/18/98
9	HTD-2 100% Engr.	09/30/98	09/30/98
10	HTD-2 Lab Integration	04/01/98	10/09/98
11	HTD-2 Ph. 3 PSRP	01/18/99	01/18/99
12	HTD-2 Launch	04/08/99	04/08/99

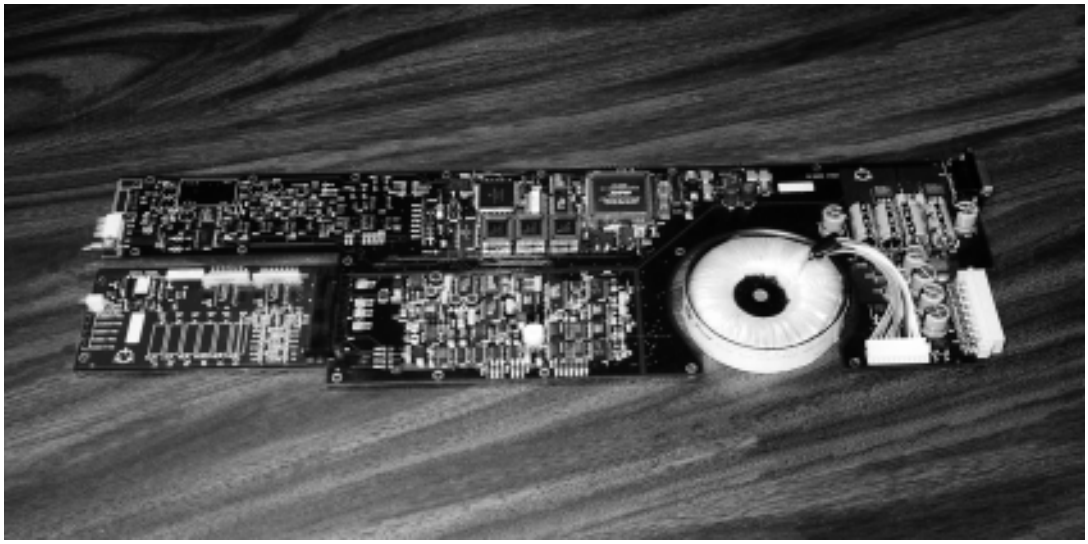


Single-Board Universal Signal Conditioning Amplifier

The goal of this project was to take the existing Universal Signal Conditioning Amplifier (USCA) and convert it from a multi-board, rugged design to a single-board, rack-mounted device. This conversion results in cost savings, increased reliability, and increased manufacturability.

The USCA is a multipurpose signal conditioner capable of working with a wide range of transducers. The USCA accepts voltage, current, or pulsed input and provides voltage or current excitation. It has gains from unity to 2,000 and low-pass filters from 10 hertz to 2-kilohertz. Linearized digital and analog outputs are provided at sample rates from 1 siemens per second to 20 kilosiemens per second. Transducer and measurement information is stored in a separate device, the tag electronic data sheet (TEDS). One TEDS is affixed to each transducer. The USCA reads the information from the TEDS when the transducer is connected and configures itself to match the transducer automatically.

USCA technology was developed with L3 Communications and is now a commercial product. The original design included three stacked circuit boards placed into a thick, cylindrical aluminum case. This allowed the USCA to be placed close to the transducer and withstand the harsh environment present during a Shuttle launch. The redesign project seeks cost savings available by removing the USCA from harsh environments and placing it in a centralized rack. The rugged aluminum case is no longer necessary. Changing from three stacked boards to a single circuit board reduces costs by eliminating the board interconnects. This also saves time in manufacturing and removes a possible source of circuit failures. Component costs were reduced by sharing power-supply circuitry



and by making the analog output optional. To increase flexibility, a secondary TEDS was included in the USCA circuit to provide fast recovery from a momentary system failure.

Key accomplishments:

- Commercialization of the USCA by L3 Communications.
- Signing of a reimbursable Space Act Agreement between NASA and L3 Communications.
- Finalization of the single-board design.
- Software modified to fit the new hardware design and L3 customer's requirements.

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Participating Organizations: Dynacs Engineering Co., Inc. (P.J. Medelius and H.J. Simpson) and L3 Communications

Nonintrusive Impedance-Based Cable Tester

The goal of this project was to design a portable instrument that can accurately measure the distance from one end of a cable to the location of a discontinuity, whether it is caused by a shorted or an opened conductor. The Space Shuttle uses dedicated signal conditioners for the purpose of conditioning transducer outputs and other signals to make them compatible with orbiter telemetry, displays, and data processing systems. When troubleshooting a potential instrumentation problem, personnel frequently have to demate cables to verify the cable is not the source of the problem. Once a cable is demated, all systems that have a wire passing through the connector must be retested when the cable is reconnected. This results in many manhours of revalidation testing on systems that were unrelated to the original problem.

The cable tester determines the location of a short or open circuit on a cable based on the impedance measured at one end of the cable. When a certain termination impedance is applied to one end of a transmission line, the impedance measured at the other end is not necessarily the same. For example, a short circuit at one end of a cable can appear to be an open circuit if the length of the transmission line is exactly a quarter wave. In a similar way, an open circuit can appear to be a short circuit.

In the tester, a test signal is injected into a cable across a resistor. When a reflected signal is in phase with the test signal applied to the cable, the amplitude at both ends of the resistor is equal since the apparent load impedance is infinite. On the other hand, when the reflected signal is 180 degrees out of phase with the test signal, the cable side of the resistor will have zero volts since the apparent load impedance is zero. When the frequency of the test signal is varied and the peak value of the test sine wave on both sides of the resistor is measured as the frequency changes, both peaks and zeros will be observed as the reflected signal goes in and out of phase.

A three-stage amplifier is used to search for the frequency at which the minimum signal on the cable side of the resistor is measured. The minimum signal is detected when the reflection is 180 degrees out of phase. This condition corresponds to either an open cable one-quarter wavelength away or a shorted cable one-half wavelength away. Three analog-to-digital (A/D) converters are used to sense the peak amplitude of the signal at each node of the three-stage amplifier. The process operates as follows:

1. The microcontroller commands the numerically controlled oscillator to output a 1-kilohertz (kHz) sine wave, corresponding to a wavelength of about 300 kilometers. The A/D converter reads the peak amplitudes on both sides of the resistor. If the readings are almost equal, the discontinuity is determined to be caused by an opened cable. If the reading

at the cable side of the resistor approaches zero, the discontinuity is determined to be caused by a shorted cable.

2. The microcontroller commands the numerically controlled oscillator to output a sweep signal from 50 megahertz down to 200 kHz in 50-kHz increments.

3. The microcontroller, by means of the A/D converters, reads the peak amplitude of the signal amplified by the first stage of the three-stage amplifier.

4. Once the occurrence of a zero (or close to zero) is obtained, the current test signal frequency is used to coarsely estimate the distance to the discontinuity.

5. The microcontroller then commands the numerically controlled oscillator to output a sweep signal ranging from 200 kHz below the frequency where the zero occurred (step 4) up to 200 kHz above that zero-occurrence frequency, in 1- or 4- kHz increments.

6. The microcontroller, by means of the A/D converters, reads the peak amplitude of the signal amplified by the three-stage amplifier. The second and last stage will most likely saturate, except when the oscillator outputs the exact frequency where the zero occurs. This allows the detector to exactly pinpoint the frequency at which the reflection is 180 degrees out of phase.

The main feature of this technology is the use of a successive approximation approach and multiple amplifiers to obtain the exact frequency at which a zero (reflection 180 degrees out of phase) is obtained. This allows the distance to the discontinuity to be determined with a high degree of accuracy.

Key accomplishments:

- Designed and prototyped the cable tester.
- Developed the software used by the microcontroller.

Key milestones:

- Conduct field tests inside the Space Shuttle vehicle.
- Evaluate the performance of the tester and refine the design if needed.

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Participating Organization: Dynacs Engineering Co., Inc. (P.J. Medelius and H.J. Simpson)

Atmospheric Science

The Atmospheric Sciences Technology 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 Baseline Lightning Detection and Ranging System

Lightning activity is a major safety concern for KSC and the adjacent Cape Canaveral Air Station due to the hazardous operations conducted, including rocket launches. Lightning activity is currently monitored using five different systems including the Lightning Detection and Ranging (LDAR) System, which locates individual lightning events by detecting the time of arrival of VHF [66 megahertz (MHz)] pulses produced during the formation of the lightning channel. The LDAR system is configured with a central antenna that triggers on high amplitude radio frequency pulses and with six remote antennas on roughly a 10-kilometer circle. These antennas continuously beam their received signals back to the central site. When the central site triggers, the remote site data records are scanned for their recorded peak amplitudes in the data window. These times are subtracted to form the time difference of arrivals through which the position of the event can be determined. For a variety of reasons, 50 to 60 percent of events produce poor position solutions and must be discarded. In addition, for reasons unknown, the system will erroneously locate lightning events. While these erroneous locations are rare, their potential cost in unnecessarily canceled hazardous operations may be high.

The Short Baseline LDAR (SBLDAR) was proposed to eliminate false solutions and potentially increase the harvest percentage of triggers by providing accurate azimuth and elevation direction to each event. The SBLDAR system is located near the central site and configured as four broadband antennas (25 to 250 MHz) laid out in a “Y” pattern with a central receiver and three remote receivers on 100-meter baselines. The SBLDAR system is triggered from the LDAR system trigger. The data is digitized at a rate of 2 gigahertz and each channel is cross correlated with the other channels to derive the time of arrival difference. The cross-correlation peak is fit with a polynomial to improve the estimate of the peak location. The data is post-processed using algorithms developed on LabView® software. This technique results in repeatability (repeated pulses from a fixed source) of roughly 10 picoseconds and an internal consistency (sum of delta T’s) of roughly 20 picoseconds.

The SBLDAR time differences are analyzed using an unweighted least-squares technique to estimate the arrival direction angles. Error analysis of the system indicates that it will achieve an azimuth error of 0.14 degree for a timing error of 1 nanosecond (at a zero elevation angle). The elevation error is 1 degree at a 20-degree elevation angle per nanosecond timing error. Storm data taken with both systems showed agreement in azimuth to 1 degree and 2 degrees in elevation. New algorithms are under development to correct the SBLDAR data for finite source distance, correct the offset of the SBLDAR system from the LDAR central site, and use a weighted

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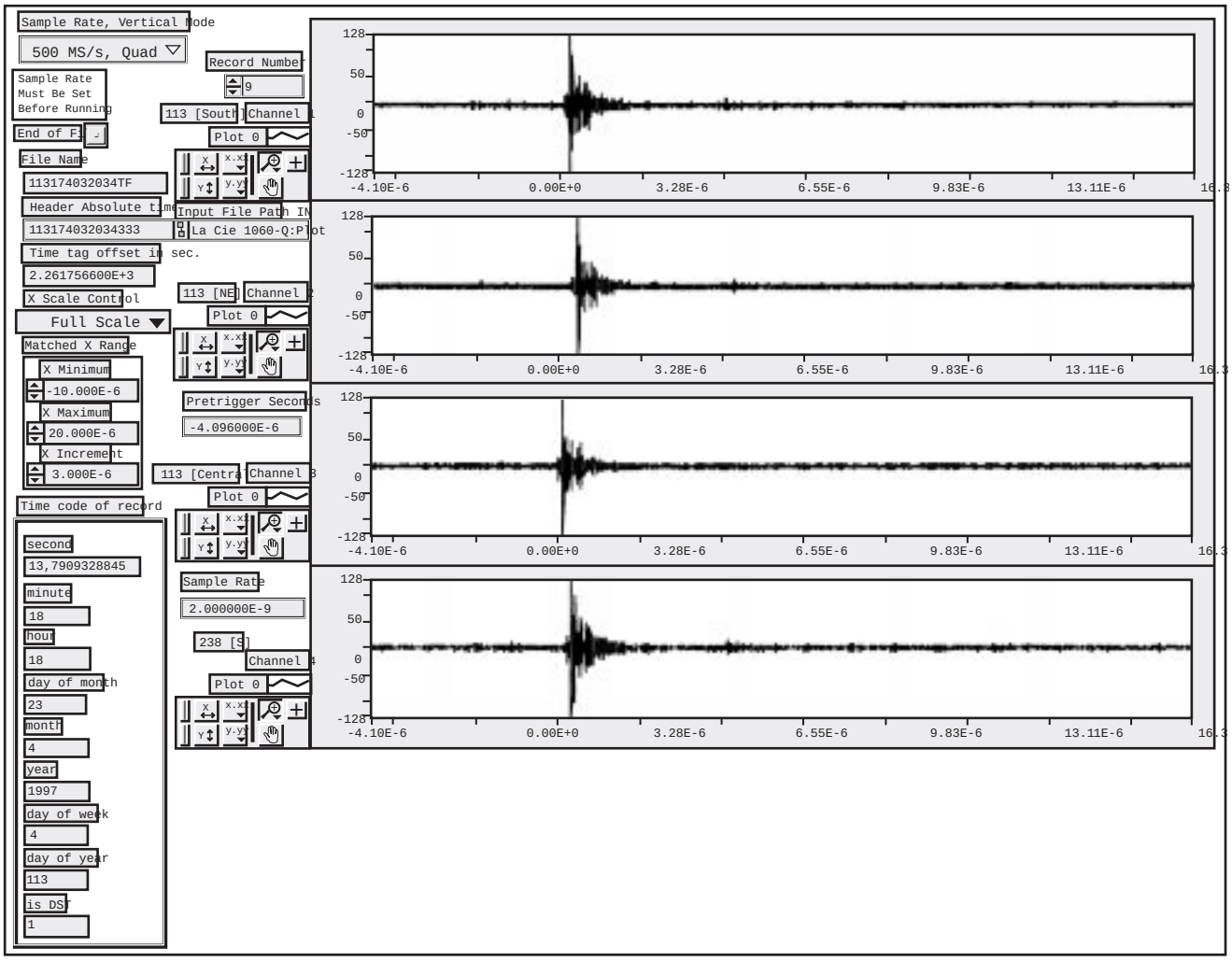

least-squares techniques. The greatest challenge in the system development has been the determination of system delay times from the moment of signal reception at the antenna until data is recorded. This seems to be the limiting factor in the system accuracy. Improved system delay values have been measured and will be tested on the existing data set.

Future work will include the development of a packaged digital signal processor to allow near real-time data analysis so the azimuth and elevation values can be used in the LDAR solution. A commercial LDAR system, under development by Global Atmospherics, Inc., in association with NASA, will have a built-in capability to use the SBLDAR system data should it prove to be useful and cost-effective.

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Participating Organization: Dynacs Engineering Co., Inc. (S.O. Starr, T. Erdogan, and M.W. Brooks)

Accurate Lightning Location System

The objective of this project is to design a system that can locate a lightning strike within the launch pad perimeter with an accuracy of a few meters. Existing lightning location systems at KSC provide coverage of a wide area extending over a 30-mile radius but have an accuracy in the order of about 500 meters within the KSC area. These systems cannot be used to determine, for instance, whether a lightning strike occurred inside or outside the perimeter of the Space Shuttle launch pads. An alternate lightning location method currently in use at the pads involves the use of a set of video cameras pointing at different locations within the pad. If a lightning strike occurs within the field of view of three or more cameras, the location of the strike can be determined. However, if the cameras are not pointing at the correct direction or their field of view is obscured by either the launch pad structure or by a heavy downpour, the determination of the striking point becomes difficult or in some cases impossible. Since electronic equipment is susceptible to damage caused by nearby lightning strikes, the accurate knowledge of the striking point is important to determine which equipment or system needs to be retested following a lightning strike.

The fast-varying electric currents associated with lightning strikes generate large electric field variations. The electric field waveform propagates at the speed of light in a radial direction from the striking point. The sudden heating of the air caused by the large currents associated with the lightning discharge produces a sudden expansion of the air near the lightning channel. This results in a sonic wave (thunder) that initially, for the first few meters, propagates at a supersonic speed and later propagates at a sonic speed. For an observer located away from the striking point, the electric field waveform arrives earlier since it travels at a speed of 300,000,000 kilometers per second, while the sonic wave travels at about 320 meters per second. The observer can determine the distance to the striking point by measuring the time between the arrival of the electric field waveform and the arrival of the sonic wave. This measurement defines a circle, with the observer at the center, where the lightning strike might have occurred. A second observer at a different location using the same type of measurement would also have a circle defined around him. At the most, these two circles would intersect in two points. With the addition of a third observer, all uncertainties are eliminated and a single striking point is determined.

The key to the accuracy of the system relies on the accurate determination of the time elapsed between the reception of the electric field waveform and the reception of the sonic waveform. The electric field waveform has a rise time in the order of a few microseconds, and its starting point can be determined with an accuracy of a fraction of a microsecond. At close distances, the sonic waveform has a sharp wave front. That is, its high-frequency content (f>10 kHz) is large. Sonic waves propagating through the air suffer a larger attenuation of high frequencies as compared to the attenuation of low frequencies. The attenuation of high frequencies is further enhanced by heavy rain. This means that at close distances the start of the wave front can be easily measured since it has a fast rise time. At distances greater than 1 or 2 kilometers, the wave front rises slower, making it difficult to tell the exact time of the start of the sonic wave.

The system consists of a network of at least three electric field and sonic sensors located at different places within the perimeter of the launch pad. A microcontroller at each receiving location is used to measure the time difference between the arrival of the electric field pulse and the arrival of the sonic wave. The timing information from each sensor is transmitted back to a central processing location, where the timing information is processed to obtain the location of the lightning strike. The accuracy of the system can be enhanced by using more than three receivers. A network of four or more sensors can be used to resolve uncertainties introduced by

variables such as wind speed, echoes, and reflections from the launch pad structure.

Key accomplishments:

- Designed and prototyped the electric field sensor, the sonic sensor, and the microprocessor-based controller.
- Developed an algorithm to combine the information received from a network of sensors to determine the exact location of the lightning strike.
- Developed an algorithm to determine the exact location of a lightning strike even when the wind is nonzero. This is important since nonzero wind results in a noncircular distance pattern around each sensor.

Key milestones:

- Conduct field tests at the launch pads.
- Evaluate the performance of the system and refine the algorithms if needed.

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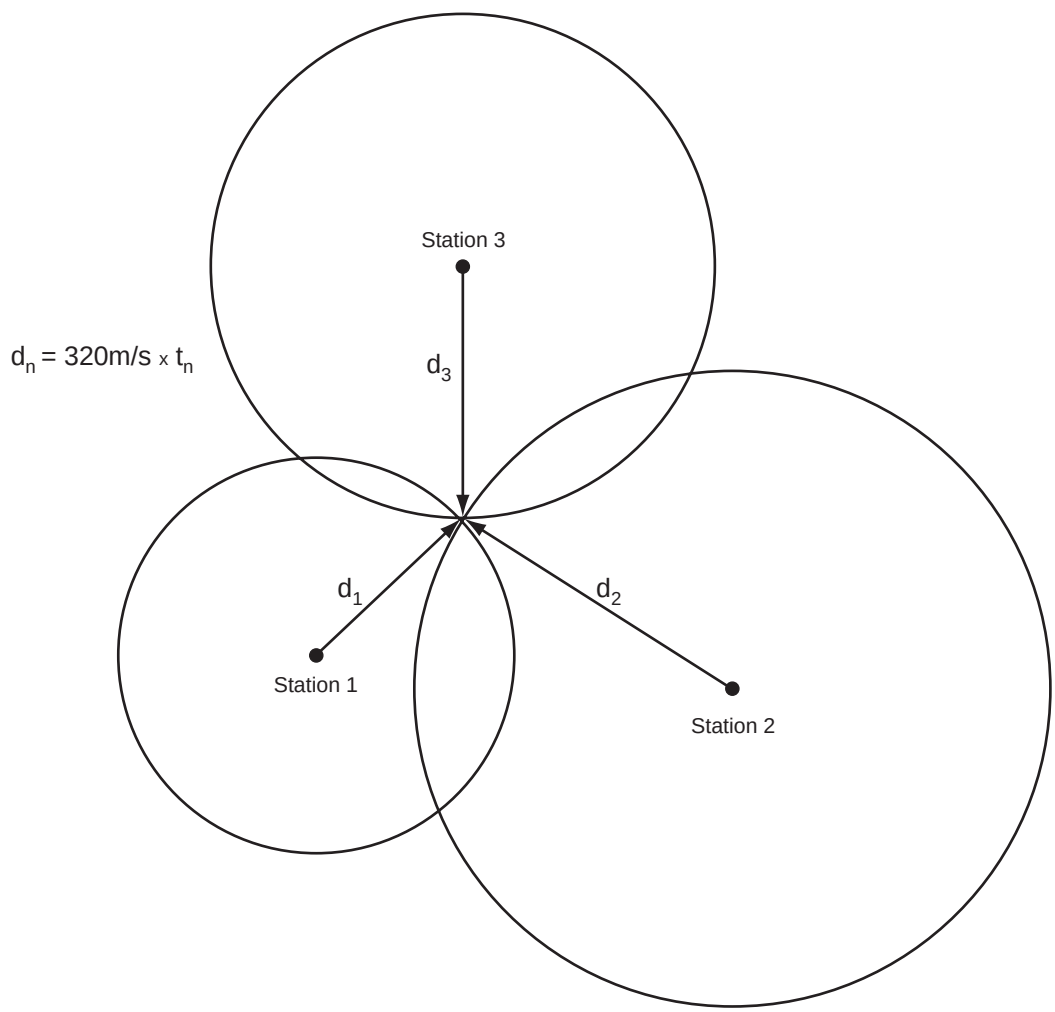
Participating Organization: Dynacs Engineering Co., Inc. (P.J. Medelius and H.J. Simpson)



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 (1) investigate materials technology that can be used to develop new launch and processing facilities for future vehicles and payloads, (2) reduce the cost of maintenance, (3) provide higher safety and reliability, and (4) provide more environmentally friendly systems.

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

The objective of this project was to investigate whether perchloroethylene (PCE) can be used as an extraction solvent for the detection of industrial hydraulic fluids residue on small aerospace hardware as nonvolatile residue (NVR) material at low (approximately 1 milligram per liter) concentration levels by infrared spectroscopy for meeting the strict NASA KSC specifications of approximately 2 milligrams per square foot for the NVR material in precision-cleaning verification. This work was carried out to investigate whether PCE can be used as an alternative clean validation and extraction solvent for the quantitative analysis of industrial hydraulic fluids residue as nonvolatile residue material by infrared spectroscopy.

Carbon-hydrogen stretching (generic) and ester absorption spectral peaks were evaluated for quantification of low milligram-per-liter concentration levels of industrial hydraulic fluids in PCE. The results indicate that when monitoring peak areas in the ester infrared spectral (from approximately 1,753 to approximately 1,708) cm^{-1} region with a mercury-cadmium-telluride detector, it is possible to detect approximately 1 milligram per liter of hydraulic fluids in PCE.

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

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, some 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, the possibility that the inorganic, zinc-rich primers and topcoat systems presently approved at KSC will be prohibited and unavailable for use is very real.

In response to this circumstance, the current study was expanded to search for inorganic, zinc-rich coatings and topcoat systems that provide superior protection to KSC launch structures and ground support equipment and fully comply with environmental regulations. Currently, the protective coating manufacturing industry produces 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, and the test panels were exposed in May 1991 to atmospheric contaminants at the KSC Beach Corrosion Test Site with concurrent applications of an acid slurry to simulate the conditions experienced at the launch site. The results of the 18-month exposure and laboratory data were compiled in a report available under document number FAM-93-2004. The results of this testing identified many environmentally compliant coating systems to be used on KSC launch structures and ground support equipment. The successful coating materials were included on the Approved Products List contained in KSC-STD-C-001. The panels completed the final 60-month exposure cycle in May 1996, and a report documenting the results is complete. The results of the 60-month exposure were compiled in a report available under document number 96-1M100.

Key accomplishments:

- Successfully applied the environmentally compliant coating systems to over 300 test panels and exposed them at KSC Beach Corrosion Test Site for 60 months.
- Conducted laboratory tests of 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.
- Evaluated the coating systems at the final 60-month point and prepared a report detailing the beach exposure.

Key milestones:

- Continue to monitor the state-of-the-art in environmentally compliant coating technology and evaluate new products as required.

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Inorganic Coating Systems for Carbon Steel Exposed to the Space Transportation System (STS) Launch Environment

This study was conducted to document the performance of several inorganic coating systems for carbon steel exposed to the STS launch environment. This evaluation program was initiated in 1994 to identify alternative inorganic topcoat coating materials for use at KSC and to study the performance of a new high-gloss polysiloxane topcoat for inorganic zinc-rich primers.

This evaluation program was started to identify inorganic coating systems to prevent corrosion of carbon steel structures in the STS launch environment. These systems include inorganic zinc primers coated with inorganic topcoats and high-gloss polysiloxane finish coats. The exposure of the test panels for these studies was conducted at the KSC Beach Corrosion Test Site. This site is located approximately 2 kilometers south of Launch Complex 39A and is approximately 30 meters from the mean high tide line of the Atlantic Ocean. The panels were installed on stainless steel racks that use porcelain insulators as standoffs. The racks were mounted on zinc-coated test stands at a 30-degree angle facing the ocean.

Two different conditions were used in the field exposure testing: (1) inorganic topcoats over zinc exposed to normal seacoast conditions, and (2) inorganic topcoats over zinc exposed to normal seacoast conditions plus alumina (Al_2O_3) slurry applications. The slurry was produced by combining 0.3-micron Al_2O_3 particles in a 10-percent (by volume) hydrochloric acid solution. This slurry was periodically applied to the lower two-thirds of the panels using a polyethylene squeeze bottle.

Topcoat gloss performance has been a concern at KSC for many years. Due to variations in gloss retention performance of polyurethanes in many studies, the polysiloxane material was tested to determine the gloss retention of this new material during this study. The polysiloxane panel was measured for initial gloss prior to exposure at the beach site and at 6-, 12-, and 18-month intervals of exposure. The gloss readings were conducted on the topcoat in the final coating system configuration, not panels specifically produced for gloss measurements. The panels were removed from the exposure rack at the beach site, rinsed with deionized water to remove surface contaminants, allowed to dry, measured for gloss, and replaced in the exposure rack. The polysiloxane material was measured for gloss retention at the KSC Beach Corrosion Test Site using a portable multiangle gloss meter manufactured by BYK Chemie GmbH. All gloss measurements were performed at the 60-degree angle.

The results of the 18-month exposure and the laboratory data have been compiled in a report available under document number 96-1M0167. The results of this testing have identified several new inorganic 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-001.

Key accomplishments:

- Successfully applied the inorganic coating systems to test panels and exposed them at the KSC Beach Corrosion Test Site for 18 months.
- Conducted laboratory tests on the polysiloxane material to determine the gloss retention of the coating in the Florida sun.
- The coating systems have been evaluated at the 18-month point, and a report detailing the beach exposure and laboratory data is available.

Key milestones:

- Produce a final report at the 60-month exposure period to document the performance of the coating systems.
- Continue to monitor the state of the art in coating technology and evaluate new products as required.

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Photochemically and Thermally Cross-Linkable Polyconjugated Systems

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

The University of Arkansas at Little Rock is conducting this project based on electrically conducting polymers such as polyaniline, polypyrrole, and polythiophene that were modified to enhance water solubility during processing. Subsequent to processing, the modified polymers were then converted to insoluble materials via thermal or photochemical cross-linking. A key innovation in this program was the development of techniques to effect polymerization in sulfonated lignin to yield doped, waterborne conducting systems. The polymers were characterized using ultraviolet/visual (UV/VIS) spectroscopy, thermal analysis, infrared spectroscopy, near-infrared spectroscopy, nuclear magnetic resonance spectroscopy, and electrical conductivity measurements.

The electrical conductivity of the polyanilines was studied by using varying ratios of aniline to lignosulfonates. Conductivities ranged from 10^{-5} siemens per centimeter (S/cm) to 0.3 S/cm. Various methods of purifying the lignosulfonates were also investigated to determine the effect on the polymerization rates, yields, and electrical properties. Some fabrics coated with the polyaniline maintained the ability to disperse static electrical charges after as many as 25 washings.

Work will continue on the characterization and development of these polymers.

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

Solvent Recovery and Purification System for Calibration-Related Cleaning

The production ban on trichlorotrifluoroethane (CFC-113), an ozone-depleting chlorofluorocarbon, has resulted in an emphasis to maximize conservation efforts while potential replacement solvents are developed and tested. In addition to reducing losses involved in the cleaning operations, another approach is to reuse the solvent to the maximum extent possible. One way this is done is through recirculation systems that utilize filtration to remove particulate contamination from the solvent.

In order to remove non-particulate contamination from the solvent, a reclamation/purification process (such as distillation) is required. This has been implemented at KSC in noncalibration-related component cleaning operations by utilizing a solvent distillation system. However, the product from this system is not of a quality suitable for the cleaning of calibrated equipment. Because of this, virgin CFC-113 has been used at the KSC Calibration Laboratories for cleaning. A recirculation system with filtration is used to remove particulate contamination. However, after the nonparticulate contamination reaches a specified level, the solvent is no longer usable in calibration-related cleaning operations. In order to maximize the use of this valuable commodity until a suitable ozone-friendly replacement solvent is implemented, a suitable recovery/purification system was needed.

Over the past several years, various manufacturers developed potential replacements for CFC-113 and presented them for testing. Among the issues that surfaced during this development period was the high cost of these replacement solvents, in many cases, exceeding the ever-increasing cost of CFC-113 these solvents would replace. Cost is a driving factor in the efforts to maximize solvent conservation and reuse even after a suitable ozone-friendly replacement for CFC-113 is implemented in calibration-related cleaning operations.

The purpose of this project was to develop a reclamation/purification system where solvents used for calibration-related cleaning operations could be reclaimed and purified to levels suitable for cleanliness certification (specified by KSC-C-123, Level 100A). In addition to developing the process for CFC-113 (the solvent currently in use), the system was tested to determine the reclamation/purification potential of HFE-7100, a low-toxicity hydrofluoroether produced by 3M as a CFC-113 replacement in precision oxygen-compatible cleaning operations.

Preliminary testing indicates that HFE-7100 may be suitable for calibration-related cleaning operations, subject to further testing. Like many of the replacement solvents under study, the high cost of HFE-7100 will require maximum conservation and reclamation/purification of the commodity to be cost effective. The promising potential of HFE-7100 as a future replacement solvent resulted in its inclusion in the project study.

Originally scheduled for a 1-year period, late release of funding required the project to be completed within a 5-month period to meet the completion deadline for the end of 1997.

The project consisted of the procurement of all necessary hardware for the reclamation/purification system and development of processes for reclamation/purification of both CFC-113 and HFE-7100. This completed system would then be integrated into the solvent-cleaning process in use. The resulting system developed consisted of a distillation system with a 5-gallon capacity capable of processing both CFC-113 and HFE-7100. The system was placed into operation with CFC-113 during the last month of the project to allow for CFC-113 reuse at the earliest opportunity.

Key accomplishments:

- CFC-113 and HFE-7100 were found to be feasibly reclaimed and purified to levels suitable for certifying the cleanliness of components to specifications defined in KSC-C-123, Level 100A.
- Reclaimed/purified HFE-7100 was produced at a purity better than vendor specifications for a virgin product.
- Recovery efficiencies approaching 90 percent for CFC-113 and 95 percent for HFE-7100 were obtained along with reclamation rates approaching 1.5 gallons per hour.
- Integration of the reclamation/purification system into the existing CFC-113 component cleaning process showed a 50-percent reduction in virgin solvent use during the 2-week trial period at the end of the project. Additional reductions are expected as the process is refined.

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Participating Organization: The Bionetics Corporation (V. Miller, M. Maxwell, and C. Sammett)

Life Sciences

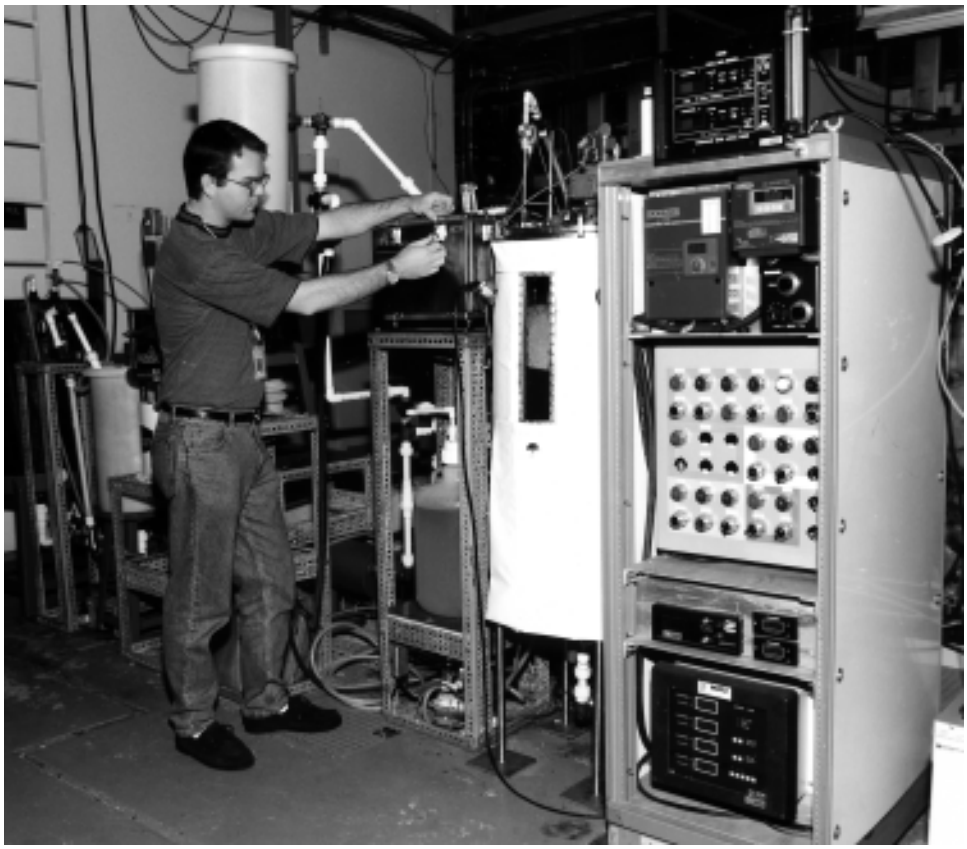
The Life Sciences Technology program at the John F. Kennedy Space Center (KSC) primarily supports the development of advanced technologies for application in long-term human habitation in space. The near-term focus of the Advanced Life Support (ALS) Breadboard Project is biomass production improvement,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

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

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

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

- Laboratory-scale studies of composting crop residue solid wastes in addition to a simulated human solid waste were continued.



Breadboard-Scale Aerobic Bioreactor

- The potential role and costs/benefits of aerobic composting of inedible crop residues were initiated at the intermediate scale.
- The use of biological resource recovery components to biodegrade soaps in gray water (i.e., crew wash water, laundry water, and dishwater) was also initiated at the intermediate scale.
- The nutrient recycling study of crop production at Johnson Space Center (JSC) was integrated with large-scale bioprocessing of crop residues at KSC. Crop residues from the JSC ALS growth chamber were sent to KSC for bioprocessing in the Breadboard-Scale Aerobic Bioreactor (B-SAB). Recovered crop nutrients were sent back to JSC and incorporated into the 90-day phase 3 test of the Lunar-Mars Life Support Test Project (L/MLSTP).

Next year, resource recovery will continue to focus on aerobic composting of inedible crop residues with process optimization studies and integration studies at the intermediate-scale leading to incorporation of composting at a larger scale (JSC BIO-Plex or L/MLSTP). Biological processing of gray water will also continue at the intermediate scale next year, and plans for processing of urine and human solid wastes will be developed.

Key accomplishments:

- 1986 to 1988: Initial cellulose conversion research.
- 1989: Cellulose conversion process optimization studies.
- 1990: Flask-scale studies of cellulose conversion.
- 1991: Completed biomass processing studies on cellulose conversion with five breadboard-scale runs.
- 1992: Initiated flask-scale studies of microbial aerobic decomposition of crop residues.
- 1993: Design, fabrication, and operation of intermediate-scale aerobic bioreactors. Design and fabrication of the B-SAB.
- 1994: Integration and first operation of the B-SAB, recycling nutrients to the Biomass Production Chamber. Process optimization.
- 1995: Integration of the B-SAB with other crops (white potato). Completion of integration studies encompassing anaerobic biological processing of crop residues with downstream processing components. Process improvement.
- 1996: Completion of intermediate-scale tests of the effects of bioreactor retention times on aerobic biological processing of crop residues. Initial studies of aerobic composting for recovery of minerals and carbon from crop residues.
- 1997: Integration of gray water processing into intermediate-level biomass production studies. Continued laboratory-scale composting of crop residue solid wastes and initiated composting of simulated human solid waste. Integrated large-scale bioprocessing of crop residues with nutrient recycling during the 90-day phase 3 test of the JSC L/MLSTP.

Key milestones:

- 1998: Integrate biological processing of gray water into intermediate-scale composting. Integrate intermediate-scale composting of crop residues with crop nutrient recycling. Initiate intermediate-scale studies of human solid waste bioprocessing. Initiate studies of the effects of inoculation of bioreactors (continuously stirred tank reactors, composters, fixed-film bioreactors) to increase crop fiber degradation.
- 1999: Continue the integration of composting of solid wastes with nutrient recycling to hydroponic production of crops. Integrate intermediate-scale biological processing of urine and human solid wastes with crop production. Continue process optimization with focus on crop fiber degradation.
- 2000: Integrate large-scale composting of crop residues into BIO-Plex level studies at JSC. Integrate large-scale biological processing of urine and human solid wastes into BIO-Plex level studies at JSC.

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

Advanced Life Support and Space Biology (ALSSB) Engineering

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

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

Key accomplishments:

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

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

- 1996: Supported mixed-crop growth tests using wheat and potato. Began a 3-year continuous operation of the breadboard. Added in situ atmospheric temperature and relative humidity control system sensors inside the BPC. Installed the Breadboard Resource Recovery Integration Laboratory. Fabricated Micro-Environmental Monitoring and Integrated Control System (MEMICS), a small, sealed plant growth chamber for plant and engineering experiments. Implemented a reliability and maintainability database for the breadboard. Installed the breadboard gray water (shower, wash, and clothes washer) production and collection system. Initiated processing of gray water through the biomass production system.

Key milestones:

- 1997: Completed composter for intermediate scale tests. Combination of wheat and potato nutrient solution (50-percent reduction in nutrient water volume). Supported baseline rice experiment in the BPC. Installed a robotic arm for remote BPC operations. Increased automation of the breadboard processes. Developed a remote manipulator end-effector for the robotic arm in the BPC. Supported the Lunar Mars Life Support Test Project (LMLSTP) Phase III 90-day human test with bioreactor effluent for the wheat crop.
- 1998: Incorporate processing of human metabolic waste in the breadboard resource recovery system. Install the breadboard solid-state fermentor for biological processing of Controlled Ecological Life Support System (CELSS) solid waste (nutrient recovery and carbon dioxide production). Support of Space Biology experiments using light-emitting diodes and microwave-powered lamps.
- 1999: Support BIO-Plex with bioregenerative data and NASA's Mars mission.

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Participating Organization: Dynamac Corporation (M.S. Simpson)

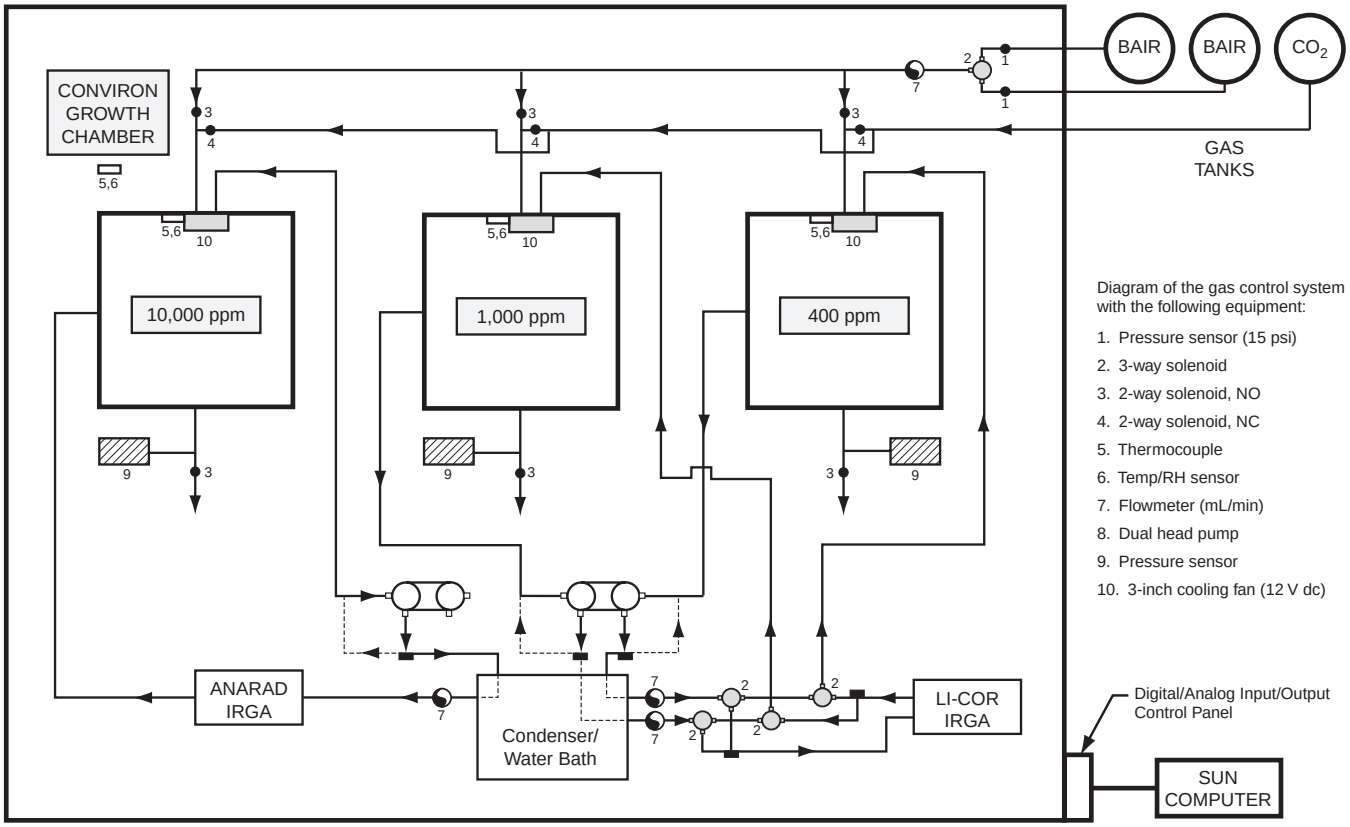
Intermediate-Scale Composter Design Complete

Engineers Remotely Monitor and Control Breadboard-Scale Projects in a Control Room

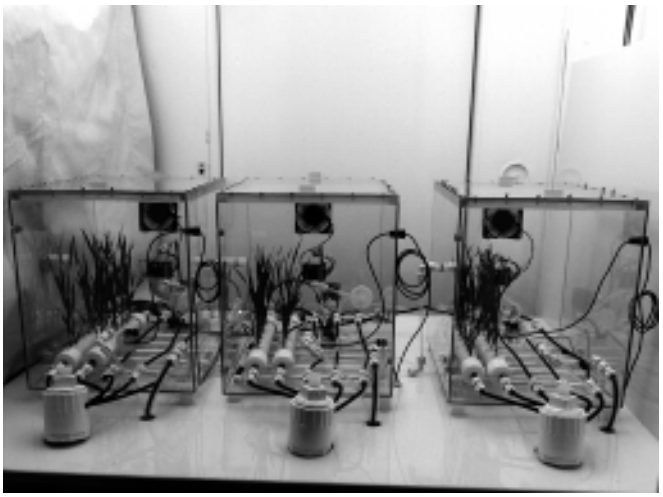
Super-Elevated Carbon Dioxide ($SECO_2$) Experimental Plant Growth Chambers

The growth of plants in a microgravity environment, such as the Space Shuttle or proposed Space Station, is challenging due to the peculiar environmental conditions found onboard orbiting spacecraft. Current and proposed chambers for growing plants in space are by necessity contained within the closed atmosphere of the orbiting space vehicle. Plants grown within these chambers can be expected to experience different atmospheric conditions due to human, mechanical, or environmental control system activities as well as normal plant growth and metabolism. A consistent problem is the necessity of either a sealed growth chamber atmosphere or a chamber atmosphere that is recirculated with spacecraft cabin air. In both cases, atmospheric carbon dioxide (CO_2) concentrations can fluctuate widely from subambient (<350 $\mu mol \cdot mol^{-1}$) to super-elevated levels of 10,000 to 50,000 $\mu mol \cdot mol^{-1}$. Plants are sensitive to changes in both major and minor components of the surrounding atmosphere. Fluctuations in oxygen, carbon dioxide, and humidity levels can affect the rates of photosynthesis, respiration, and reproduction, while minor organic constituents can either cause direct damage or alter plant response at the molecular level. An understanding of the effects of different atmospheric conditions, including exposure to super-elevated CO_2 concentrations on plant growth, morphology, and metabolism, is necessary prior to determining the influence of gravity on these parameters.

The $SECO_2$ series of ground-based studies in the Plant Space Biology Laboratory at KSC utilizes 38-liter polycarbonate chambers with atmospheric gas components monitored and controlled by custom software on a UNIX workstation. Both nutrient delivery and humidity control systems are based on the porous tube nutrient delivery system (PTNDS-NASA TM 107546). Biological testing of the system has shown that growth of *Arabidopsis thaliana* at continuously elevated and super-elevated CO_2 levels affects a



Super Elevated CO_2 Control Loop



21-Day-Old Super Dwarf Wheat Under Fluorescent Light at 400, 1,000, and 10,000 ppm CO_2 (Right to Left)

21-Day-Old Super Dwarf Wheat Under Red LED Lighting at 400, 1,000, and 10,000 ppm CO_2 (Right to Left)

wide range of plant characteristics including morphological development, starch and chlorophyll content, and enzymes in the carbon assimilation pathway. Subsequent experiments have demonstrated significant changes in developmental timing and biomass yield in response to elevated and super-elevated CO_2 levels. The addition of red light-emitting diodes (LED's) allows the chambers to be used at test beds for environmental conditions similar to those proposed for plant growth chambers on the International Space Station.

Key accomplishments:

- 1993: Chamber hardware design and controlling computer software development.
- 1994: Chamber fabrication, control system integration, biological testing of system with four 30-day growth cycles of *Arabidopsis thaliana*, and installation of humidity control system.
- 1995: Separation of nutrient delivery systems to allow each chamber to be controlled separately. Growth studies of *Arabidopsis thaliana* at elevated CO_2 levels with controlled humidity. Growth studies of *Arabidopsis thaliana* at elevated CO_2 levels with low atmospheric oxygen (7 percent) content. Initiation of water-stress experiments under elevated CO_2 conditions using transgenic *Arabidopsis thaliana* with molecular markers for indication of environmental stress.
- 1996: Expansion of system to six chambers allowing six different CO_2 levels to be tested simultaneously and/or allowing incorporation of different light levels.
- 1997: Incorporation of red LED's as lighting parameter. Development of seed cassettes to support monocot growth such as dwarf wheat. Closure of water loops to monitor and quantify water movement through the system and plants. Installation of LI-COR light sensors to monitor the photoperiod and light intensity. Completed four studies of Super Dwarf wheat under three CO_2 levels (400, 1,000, and 10,000 parts per million) using both fluorescent and red LED lighting.

Key milestones:

- 1998: Repeat red LED studies using other crop species (lettuce, radish, and spinach). Incorporate supplemental blue lighting with red LED studies. Examine movement of microorganisms in closed plant growth chambers.
- 1999: Complete studies of ethylene formation and effects at elevated CO_2 in several crop species and *Arabidopsis thaliana*.

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Participating Organization: Dynamac Corporation (W.C. Piastuch, Ph.D., and T.W. Dreschel, Ph.D.)

Advanced Life Science Control and Monitor Unit (ALSCMU)

Automated control and monitor systems are a vital element in the Biomedical Project Office's Advanced Life Support (ALS) project. Computer-based control systems are indispensable components of plant growth experiment chambers. The closed environmental systems being studied require a high degree of monitoring and control of the elements necessary for successful plant growth (such as light, temperature, relative humidity, carbon dioxide, oxygen, and nutrient pH). An environment conducive to robust plant growth in a closed chamber must be maintained on a 24-hour basis, particularly when the ALS support engineering staff is not present to monitor the support equipment. Automated control is essential to allow scientists to go about higher priority tasks. The ALSCMU project is an effort to design and implement a prototype system that will capture the control capabilities of the current Universal Networked Data Acquisition and Control Engine (UNDACE) while incorporating elements of commercial off-the-shelf technology, next-generation hardware and software platforms, and advanced computing concepts (e.g., artificial intelligence and fuzzy logic) into plant growth experiments. The primary objective of the project is to enhance operations for research investigation by providing a real-time intelligent control system exhibiting a high degree of autonomy.

The ALSCMU prototype effort underway at the Life Sciences Support Facility (LSSF) is designed to maximize the use of existing growth chamber hardware, while minimizing the impact of implementing new hardware and software on experiments already in place. The growth chamber chosen, the Micro-Environmental Monitoring and Integrated Control System (MEMICS), is a small portable chamber that has been used to date primarily for Space Life Science Training Program projects during the summer months but has not been used often. The MEMICS chamber is equipped with a range of sensors and effectors, lights, nutrient delivery subsystems, and temperature and relative humidity controllers and is wired to OPTO22 OptoMux RS-422 protocol-based data communication hardware. The goal for interfacing ALSCMU with MEMICS is to connect the bidirectional OptoMux communication line directly into ALSCMU's serial port and to not otherwise disturb the configuration of the chamber.

The prototype processor chosen for ALSCMU is a Digital Equipment Corporation (DEC) Alpha Station 500-333 workstation and is configured to communicate with MEMICS. The Alpha contains a 333-megahertz CPU, 128 megabytes of random access memory, and a 2.1-gigabyte (Gb) hard drive. It was upgraded by adding a second 2.1-Gb internal hard drive and a total of 12.9 Gb in external drives to accommodate development software packages. Atop the UNIX operating system layer on the Alpha, the ALSCMU software resides in two layers. The control and

monitor unit (CMU) is at the lower layer. The CMU, developed by NASA and McDonnell Douglas, provides real-time data acquisition, processing, distribution, archiving and retrieval, and command processing and output. The application layer consists of the Gensym Corporation G2 package, a graphical-user-interface-based development environment that supports rapid prototyping and artificial intelligence programming.

The goal of the ALSCMU project is twofold. First, successful completion of the prototype will provide developers with the requisite skills to build and implement a production system designed to replace the current UNDACE control system that is aging and is increasingly difficult to maintain and upgrade. Second, it will provide the technology needed for future NASA projects requiring low-mass, high-performance control systems. One such project, BIO-Plex, is a joint project between KSC, Johnson Space Center, and Ames Research Center that is currently in the planning stages. BIO-Plex is being designed to test and prove technologies for providing future astronauts with a safe life support environment in a human-tended mission to the Moon or Mars. By building an intelligent control system with a minimum of hardware and a maximum of software intelligence and autonomy, the KSC team hopes to help provide the tools to ultimately establish a permanent human presence beyond the current terrestrial bounds.

Key accomplishments:

- 1997: Integrate the G2 development environment with CMU software on a DEC Alpha platform. Interface the DEC Alpha/CMU platform with the OptoMux hardware, MEMICS. Design the G2 software to monitor and control the MEMICS environment. Test hardware and software capabilities to control and monitor the MEMICS chamber environment.

Key milestones:

- 1997: Test and validate the ALSCMU/MEMICS interface and control capabilities.
- 1998: Migrate ALSCMU capabilities to other plant growth chambers and environments at the LSSF.
- Future: Provide ALSCMU technology for the BIO-Plex project and other human-tended projects designed for offworld missions.

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Participating Organizations: KSC Payload Processing Directorate and KSC Biomedical Office

Chemical Characterization of Aqueous Leachates From Hydroponically Grown Potato Biomass

Bioregenerative life support systems that provide food, water, and oxygen for long-duration space missions require recycling of wastes and nonedible plant products. An ongoing project with the Advanced Life Support Systems (ALSS's) involves growing plants under hydroponic conditions. The plants of focus include wheat, soybeans, lettuce, and potatoes. Recycling inedible biomass from plants minimizes waste product buildup and recovers minerals to support the plant growth cycle.

Microbial bioreactors reduce inedible leaves, roots, skins, and stems from food crops to an aqueous leachate. Degradation of any phytotoxic or allelopathic organic compounds in the reactor must be adequate before the effluent is added back in the plant growth cycle. Air samples were analyzed for volatile organic constituents. The leachate was characterized to delineate chemical classes of the bioreactor effluent prior to addition of the effluent back into the plant nutrient solutions.

This research was focused toward gaining a basic understanding of the chemical characterization of potato biomass residues with specific emphasis on compounds that may exhibit phytotoxicity. Potato plants contain important phenolic compounds including free phenolic acids, phenolic acid esters, and isoflavones and their glucosides. Phenolic acids are believed to play an important role in a plant's general defense mechanism in resistance to microbial infection. Some phenolic components are known to have phytotoxic and allelopathic characteristics.

Quantitative determination of the phenolic acids and related compounds was investigated. A simple, rapid, and accurate high performance liquid chromatography (HPLC) method using ultraviolet detection for chlorogenic acid was accomplished. Chlorogenic acid was determined to be a major phenolic acid in potato residues.

Chlorogenic acid is a representative indicator of the presence of phenolic compounds in potato biomass residues. It is proposed that this compound may be used as a signature compound for the determination of the suitability of the leachate for reintroduction into the plant nutrient solution with a loss of the phenolic constituents.

Key accomplishments:

- 1992: NASA and the American Society for Engineering Education (ASEE) Summer Faculty Fellowship Program; Method Development for Characterization of Bioreactor Effluent by B.C. Madsen.
- 1993: Development of sparging techniques for volatile emissions from potato.
- 1995: NASA/ASEE Summer Faculty Fellowship Program; Chemical Characterization of Some Aerobic Liquids in CELSS by B.C. Madsen. Characterization of volatile components of 15-month potato study in the Biomass Production Chamber.

Key milestones:

- 1997: Completion of thesis, Chemical Characterization of Some Aqueous Leachates From Hydroponically Grown Potato Biomass, by J. Qian.

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Participating Organizations: University of Central Florida, Department of Chemistry (B.C. Madsen, Ph.D., and J. Qian) and Dynamac Corporation (B.V. Peterson)

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