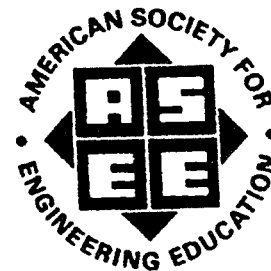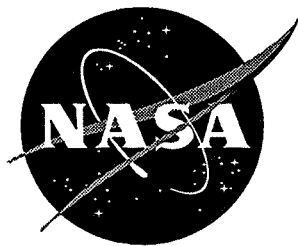NASA CR-207197

1997 Research Reports

NASA/ASEE Summer Faculty Fellowship Program

John F. Kennedy Space Center
and
University of Central Florida

1997 RESEARCH REPORTS

NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER

UNIVERSITY OF CENTRAL FLORIDA

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PREFACE

This document is a collection of technical reports on research conducted by the participants in the 1997 NASA/ASEE Summer Faculty Fellowship Program at the John F. Kennedy Space Center (KSC). This was the thirteenth year that a NASA/ASEE program has been conducted at KSC. The 1997 program was administered by the University of Central Florida (UCF) in cooperation with KSC. The program was operated under the auspices of the American Society for Engineering Education (ASEE) and the Education Division, NASA Headquarters, Washington, D.C. The KSC program was one of nine such Aeronautics and Space Research Programs funded by NASA Headquarters in 1997. The basic common objectives of the NASA/ASEE Summer Faculty Fellowship Program are:

a. To further the professional knowledge of qualified engineering and science faculty members;

b. To stimulate an exchange of ideas between teaching participants and employees of NASA;

c. To enrich and refresh the research and teaching activities of participants institutions; and,

d. To contribute to the research objectives of the NASA center.

The KSC Faculty Fellows spent ten weeks (May 27 through August 1, 1997) working with NASA scientists and engineers on research of mutual interest to the university faculty member and the NASA colleague. The editors of this document were responsible for selecting appropriately qualified faculty to address some of the many problems of current interest to NASA/KSC. A separate document reports on the administrative aspects of the 1997 program. The NASA/ASEE program is intended to be a two-year program to allow in-depth research by the university faculty member. In many cases a faculty member has developed a close working relationship with a particular NASA group that had provided funding beyond the two-year limit.

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JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

Calibration Data Management Support

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ABSTRACT

The Calibration Data Management System was developed to help labs track the calibration status of their equipment. The resulting database system was designed implemented using Designer/2000 and an Oracle database server. The final application programs were developed to run via an internet browser. The system was designed so that it could be integrated into a work control system under development.

Calibration Data Management System

Catherine C. Bareiss

1. Introduction

The Calibration Data Management Support system (CDMS) has been developed to help labs track calibration data associated with their equipment. The current amount of automation varies from lab to lab anywhere from a paper-based system to a small database developed by one specific lab. The CDMS project was designed to eventually allow different labs to use the same automated system.

The system was developed to work over the internet via any standard browser. This was done using the Oracle database software which supports database access via the web. The development of the CDMS system included the study and use of Designer/2000 (an Oracle case tool). Finally, the system was designed so that it can be integrated into an additional system that is being design to aid in the work control area. The combined system will allow engineers to track the use of equipment and calibration data, especially when equipment is determined to be out of tolerance. Additional (detailed) information that is beyond the scope of this report can be found in the complete system documentation.

2. Calibration System

The CDMS system development started with studying the current system to understand how things were done, to determine the requirements for any new system, and to identify areas for possible improvement. After the initial study, the requirements were formalized and analyzed. Then the system was developed via a prototyping methodology where the system was designed, implemented, and presented for feedback. This cycle (starting with design) was then repeated to implement any indicated changes and improvements.

2.1 Motivation

The CDMS system was chosen for this project for a number of reasons. Those reasons are listed below.
    a) ISO 9000 required studying the system which provided an opportunity to improve it in the process.
    b) There was a desire to increase information and access.
    c) The system could eventually be expanded to support reverse traceability.
    d) The system would serve as another prototype for other web-based systems.
    e) The system was small enough to be developed by two people (one faculty member and one student) during a 10 week period.

2.2   Environment

An additional reason for the development of the CDMS system was to further learn the capabilities of the development environment that was being used. Oracle provides an environment to allow database access over the world wide web. It also has a case tool (Designer/2000) to allow for rapid prototyping of new systems.

Designer/2000 was used to develop entity-relationship diagrams along with dataflow diagrams. In the process of trying to use to tool to convert entity-relationship diagrams to actual database tables, it was determined that the version of the Oracle database server that was being used (7.3.2.2) was not compatible with Designer/2000. Version 7.3.2.3 or 7.3.3 was needed. However because of the complexity of upgrading the server while it was being used for a multiple of different projects, primary use of Designer/2000 stop with its diagramming tools, and work was continued via manual procedures for converting entity relationship diagrams and dataflow diagrams into actual working systems.

2.3   Current System

The existing system is use by the lab studied is PC-File based. While the current system was a working system, the development of a new system with more powerful technology allowed for an increase in functionality. Additional information can be found in the system documentation.

2.4   Requirements

There are eight primary requirements for the CDMS system. They are listed below. The detailed requirements can be found in the system documentation.
1.   The system is to be web based and use an Oracle database server.
2.   The system is to be easy to use.
3.   The system is to include the ability to generate the following reports:
      a)   List equipment currently at calibration.
      b)   List equipment currently due for calibration.
      c)   List equipment currently in calibration and available for use.
      d)   List equipment that was out of calibration (tolerance).
      e)   List equipment being sent for calibration.
4.   The system is to support ad-hoc queries and reports.
5.   The system is to provide the ability to plan the use of equipment around calibration.
6.   The system is to provide the ability to track the borrowing of equipment.
7.   The system should use email to notify engineers that equipment is due for calibration.
8.   The system should provide electronic copies of reports, manuals, pictures of equipment, etc.
9.   The system should support ISO 9000 compliance.

2.5   Implemented System

The implemented system has two main components. The first is the database itself. This component contains the data about the equipment and users along with supplemental data used to support the system and aid in user-friendliness. The second component is the packages and procedures developed that build web pages to allow access to the database and allow engineers to perform necessary tasks.

2.5.1   Database

2.5.1.1 Primary Data

Figure 1 contains an entity-relationship diagram for the final database implemented. It does not include any supplementary tables. Cal_Equip is used to store information associated with a piece of equipment. Emp is used to store information associated with each employee. History_Log is used to store a record of each change to the database. It stores the equipment that was changed, the type of the change, the id of the employee associated with the change, the date the change was entered in the database, up to two additional dates associated with the change, pre and post fields for each of the status flags (calibration, location, and condition) of the equipment, a comment field, and a string field to be used by the work control system when it is integrated later.

While the final database is not in Domain/Key Normal Form (i.e (room, building) -> calibration engineer), the lack of complete normalization is not a problem since all "non-normalized" data is extremely static.

2.5.1.2 Supplemental Data

The supplemental data includes a table (CODES) which maps a code to a comment for a given type of code. This is used to provide options for the type of activity, the current calibration status of a piece of equipment, the current location of a piece of equipment, and the current condition of a piece of equipment. Details for the type of activity can be found in the system document. The others values are below. The supplemental data also includes a table used to describe each field (COMM) and a table (LIT_MAP) that is used to contain constants (such as how close to a calibration due date are users informed to turn in equipment).

LAB
BUILDING
ROOM
o CALIBRATION ENGINE

has

needs accessory

is accessory for

is assigned to

is located in

CAL_EQUIP
* ID
* METROLOGYNUM
* DOESITEXIST
o MODELNUM
o SERIALNUM
o NASAPROPERTYNUM
* EQUIPMENTDESCRIPTI
o MANUFACTOR
o BUILDING
* ROOM
* LOCATION
* CALIBRATIONENG
* PRIMARYUSER
* PROPERTYCUSTODIAN
o COMMENTFIELD
* CALSTATUS
* WHERESTATUS
* CONDSTATUS
* CHECKOUT
* INSITU
* SYSTEMCALIB
o STANDARDCALIBRATO
o CALIBRATIONCYCLE
* CALIBRATIONDUEDATE
o CALIBRATIONTIMEREQ
o CALIBRATIONCOST
o OTHERACCESSORIES
o ACCESSORYFOR
o PURCHASECOST
o PURCHASEDATE
o REPLACEMENTCOST
o REPAIRCOST
o EXPECTEDLIFE

is in charge of

maintains calibration

EMP
ID
* NAME
* USERID
* OFFICE
* PHONE
* MAIL CODE
o CALIBRATIONCOD
o HANDRECEIPTNU

calibration is maintained by

uses

primary user

maintains

is initiated by   initiates

is maintained by

HISTORY_LOG
ID
* CE_ID
* ACTIVITY TYPE
* INSERT DATE
o DATE1
o DATE2
* EMP_ID
o PRE_CAL_STATUS
o POST_CAL_STATUS
o PRE_WHERE_STATUS
o POST_WHERE_STATUS
o PRE COND STATUS
o POST COND STATUS
o COMMENT FIELD
o STRING FIELD

records

is recorded by

Figure 1

1.   Calibration Status Codes
   a)   IC - in calibration
   b)   CD - due for calibration
   c)   PD - past due for calibration
2.   Where Status Codes
   a)   AC - at calibration
   b)   BO - borrowed
   c)   AV - available
   d)   AR - at repairs
3.   Condition Status Codes
   a)   OK - okay
   b)   NU - not in use
   c)   SP - calibrated as spare equipment
   d)   CU - calibrate prior to use
   e)   NR - needs repair

2.5.2 Applications

The applications are divided into six main areas: user and task identification, calibration tasks, user tasks, reports, maintenance tasks, and supporting procedures/functions. The final system is an entire web package (URL: http://ashley:8200/ or http://ashley:8200/ows-bin/owa/calib.General.MainPage). This system is currently available on the intranet of KSC. Brief explanations of each of the areas follows. For more details, see the system documentation.

2.5.2.1 User and Task Identification

The first area involves two procedures. The task of the first one (MainPage) is to identify the user and his/her category (engineer, calibration engineer, or property custodian). This category is used by the second procedure (ProcessMainPage) whose task it is to allow the user to determine what task he/she wishes to perform. The tasks available are controlled by the type of user he/she is. All users can perform user tasks and look at the reports. Only calibration engineers can perform calibration tasks. Calibration engineers and property custodians can perform maintenance tasks.

2.5.2.2 Calibration Tasks

There are four calibration tasks. The first task is recording that equipment is being shipped to calibration. This involves creating an entry in the history log where the activity type is 'CS' (calibration sent) and changing the where status of the equipment to 'AC' (at calibration).

The second task is recording that equipment has returned from calibration. This involves creating an entry in the history log with an activity type of 'CB' (calibration back in tolerance) or 'CO' (calibration back out of tolerance). The where status of the equipment is changed to 'AV' (available) and the calibration status is changed to 'IC' (in calibration). The calibration engineer inputs three dates: date back in the lab, date of calibration, and the next due date for calibration. The last two are used to determine the calibration cycle. If the equipment was calibrated as a spare, the condition status is set to 'SP' (spare calibration). If the condition of the equipment was 'CU' (calibrate prior to use), it remains 'CU'. The engineer is informed to deliver it to the user for use. CU equipment is usable if its calibration status is 'IC'. Once used, the calibration status should become 'CD' (calibration due).

The third task involves informing equipment users that equipment was out of tolerance. Until the system is integrated with the work control system, all that is involved in this task is creating a history log entry (activity type of CD - calibration notification) indicating that users were notified. Once this is integrated, this task will be expanded so that the users are notified by the system via email.

The last task in the calibration subsystem is to notify users (both primary users and borrowers of equipment) that specific equipment is due or past due for calibration. The system currently produces a report (when told to) that includes all the information necessary to inform the users via email. This needs to be changed so that the system will automatically create email messages instead.

2.5.2.3 User Tasks

The users tasks involve recording the borrowing and returning of equipment. It also allows engineer to look at the entire status of a piece of equipment (including its complete history log) by metrology number or NASA property number. The fourth task allows the engineer to view any and all equipment via a partial metrology number, NASA property number, model number, serial number, equipment description, manufacturer, building, room, and/or location. It displays the complete information associated with all equipment meeting the condition(s) specified.

2.5.2.4 Reports

There are currently six reports for the CDMS system. The first one lists the equipment currently due or past due for calibration. The second is a list of equipment currently being sent to calibration and has a place for signatures (if printed). The third report lists the equipment currently at calibration. The next report indicates what equipment is in the lab and is calibrated and okay to use. The fifth report lists the equipment in need of repair. The last report is a list of equipment currently being repaired.

2.5.2.5 Maintenance Tasks

There are six maintenance tasks. The first two record the sending of equipment to be repaired and the receiving of equipment back from repairs. The next allows the engineer to add new equipment to the database. The fourth allows the engineer to remove (either by deleting or the use of a flag) information from the database. The fifth allows the engineer to modify information in the database. The last will allow the user to browse the database in almost any way he/she desires. While this last task has been implemented in other systems, it has not been ported to the CDMS system.

Currently, the engineer must be careful when changing the database (by adding or modifying information). The system currently allows the engineer to place the database into an invalid state (such as equipment being at calibration with no entry in the history log recording it being sent). A complete list of these assumptions and possible problems can be found in the system documentation.

2.5.2.6 Supporting Procedures/Functions

There are many supporting procedures/functions. These include fetching specific values from specific portions of the database, error checking, error reporting, displaying of information, and routines to create portions of a web page (especially those that contain information from the database). A complete listing and additional documentation can be found in the system documentation.

3.   Results and Benefits

The development of the CDMS system has resulted in a number of things. First of all, the final system has the following benefits (or is designed so that those benefits can be incorporated with minimal efforts). Also, the level of system documentation should be a great use in future work on the system. The work has also allowed the exchange of knowledge and skills between all personnel involved.   Much of the work done this summer will aid in the improvement (and creation) of three classes at Olivet Nazarene University: Systems Analysis and Design, Database Management, and a new 4Gl and User Interface class.

1) The CDMS system can be easily expanded to notify appropriate personnel in a timely and efficient manner of all equipment due and past due for calibration.
2) The system allows for the tracking of historical information including calibration data, borrowing data, and other desired events.
3) The system can to easily expanded to integrate all the data, reports, and associated manuals into one repository making it easier to find and used the information.
4) The system has been implemented on the web providing complete platform independence and can be easily expanded to include capabilities for ad-hoc queries.
5) The final system can help the labs become more ISO 9000 compliant.
6) ESC engineers can use the system to plan their use of the equipment around the calibration schedule of a piece of equipment.
7) This system is ready to be integrated with the work control system to provide for the development of the reverse traceability package.
8) By developing the system for the web, the system demonstrates the potential of other web-based applications for other systems.

4.   Future Work and Conclusions

There are a number of areas left for future improvement. The first four (actual email notification to users, the development of the ad-hoc package, the development of the reverse tracability package, and the initial load of the actual data) will be accomplish during the integration into the work control system. Other areas of improvement include adding the ability to store electronic copies of documents and pictures associated with the equipment, training of the final users, improving the database integrity (see 2.5.2.5 -

Maintenance Tasks), and possible performance enhancements. The need for performance enhancement will not be known until the implementation with the final machine that will solely be used for the entire system (as opposed to sharing a machine with development and use of a number of tasks).

In conclusion, this work has been a positive experience for all involved. The engineers have a system that will help them track calibration information (when it is released with the work control system). The system development personnel have part of the work control system (calibration data) ready for integration and examples of different forms of documentation, and have benefited along with the faculty member from the exchange if knowledge in the area of system development using Oracle and Designer/2000. The student has benefited from learning about database systems. I (the faculty member) have been able to increase my knowledge of Oracle and Designer/2000 along with gaining some more "real-life" experience. I also now have another running example (and additional knowledge) to integrated into many of my courses back at Olivet Nazarene University.

NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

ANALYSIS, SPECIFICATION, AND IMPLEMENTATION OF
AN AUTOMATED PROGRAMMABLE CONTROL SYSTEM AND VIRTUAL INSTRUMENTATION
TO IMPROVE AND ADVANCE THE OPERATION OF
THE SLACK THERMAL HIGH VACUUM CHAMBER

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Nap Salvail, NASA Colleague

ABSTRACT

The Slack Thermal Vacuum Chamber was designed to process spacecraft and ground support equipment for the Materials Science Laboratory at Kennedy Space Center (KSC). The chamber recently became inoperative and was thus identified to be equipped with a modern control system to enable support of the launch of the Space Shuttle, expendable rockets, and their respective payloads. Installation of a modern computerized programmable control system was performed, which included connection of new control hardware and complex programming of the controller. Furthermore, a virtual instrumentation system was created with the use of an additional computer and the incorporation of virtual instrumentation software. This report characterizes the evolution and successful completion of this modernization process.

Acknowledgments

I would like to thank Nap Salvail for providing me the opportunity to engage in the research activities involved during my summer at Kennedy space Center.

Big thanks to Bill Dearing for getting me something every time I needed it and finally deciding just what he wanted this chamber to actually do. I will not forget his "magic smoke has escaped" meter.

Thanks to Andy Finchum for his enlightening assistance in operating the chamber, investigating BFRs, and introducing me to "pneumatic fluid".

Kurt Leucht deserves thanks for cheerfully helping me with things which weren't necessarily his area of concern.

I appreciate overhearing Larry Ludwig speak of his entertaining insight into the three phases of electricity.

Thanks to all those who were helpful to my team throughout the summer in providing support for our operation.

Thanks to Gregg Buckingham, Ray Hosler, and Kari Stiles for their efforts in maximizing the summer experience at KSC.

A very special thanks to Adam Crowder, Jarret Hudson, Mike Martinie, and Paul Wright; the students who joined with me to form the Pitt State Swat Team for the purpose of attacking the Slack Thermal Vacuum Chamber with a vengeance. Thrown into a world of NASA acronyms, the students felt it necessary to create our own acronym for the project. They called it Project BEAVIS. These students were placed in a technical and demanding milieu, and functioned at the level of high-tech contractors. It is due to their efforts that this project was successful. This paper is dedicated to their unfaltering dedication and achievement.

Author Notes

ANALYSIS, SPECIFICATION, AND IMPLEMENTATION OF AN AUTOMATED PROGRAMMABLE
CONTROL SYSTEM AND VIRTUAL INSTRUMENTAION TO IMPROVE AND ADVANCE THE
OPERATION OF THE SLACK THERMAL HIGH VACUUM CHAMBER

Randy K. Buchanan

1. INTRODUCTION

The Slack Thermal Vacuum Chamber within the Materials Science Physical Testing Laboratory at Kennedy Space Center, FL, was identified to be in urgent need of a new control system to enable tests used to support the launch of the Space Shuttle, expendable rockets, and their respective payloads. A plan was developed which consisted of the specification of hardware and software during the 1996/1997 academic year, and the ultimate installation, implementation and activation of the new control system during the summer of 1997. Four students were successful in competing for the opportunity to participate with the author in the applied research project and were instrumental in its implementation.

2. CHAMBER BACKGROUND AND SIGNIFICANCE

The Slack Thermal Vacuum Chamber was designed to conduct tests involving varying levels of temperature and vacuum to support the space program. The majority of tests conducted in the chamber require a quick turnaround and are critical in terms of money and effects on the launch schedule.

Designed characteristics of the chamber include a working volume of 12 ft^3, and the ability to produce a vacuum of 10^{-7} Torr and an environmental temperature of up to 450° F. Complex control capabilities are required to provide regulation of pressure and temperature in accordance with predetermined setpoints, and to ultimately provide the desired controlled characteristic response. The chamber is designed with nine distinct temperature zones controlled by a legion of heaters and thermocouples, and constructed of materials with high thermal conductivity such that with proper control it can provide a uniform chamber temperature with minimal temperature gradients. (ref. 1)

Prior to the author's arrival at KSC a year earlier, upon readying the chamber for operational purposes laboratory personnel discovered the system to be inoperable, and the original controller was deemed permanently defective. Without the controller, the chamber was completely nonfunctional and all processing and testing destined for the chamber could no longer be performed. The preeminent solution was to replace the defective unit with a more modern and sophisticated controller. Additionally, it was considered advantageous to implement some form of computerized virtual instrumentation to increase the flexibility and capabilities of the system as a whole. Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW) was chosen to fulfill this need. Search of available literature and documentation resulted in finding no other instance where LabVIEW and a Programmable Logic Controller (PLC) had been combined to control a thermal high vacuum chamber process.

A redundant, supervisory virtual control system was established using LabVIEW, in parallel with the physical hardware portion of the control system. LabVIEW is a powerful and flexible instrumentation and analysis software based on the programming language "G". The language "G" is, in a rudimentary way, similar to traditional languages such as Pascal or C. Routines may be created in part or by function, similar to sub-routines, regardless of order, and then compiled into a singular fully functional high-level program.

3. ANALYSIS & SPECIFICATION

During the 1996/1997 academic year, all available documentation for the Slack Thermal Vacuum Chamber was reviewed. Each input and output device, as well as the chamber's overall functionality, was examined to enable the establishment of criteria which would determine the type of controller necessary to successfully operate the system. With a list of detailed criteria available, all known major manufacturers and/or distributors of PLCs were contacted and the field was eventually narrowed to the controller which was ultimately purchased for the project.

Students majoring in Electronic Engineering Technology from Pittsburg State University were solicited to apply for summer positions which would enable them to participate in the project. Selectees were chosen on a competitive basis based on academic achievement, work experience, and their interest and abilities in areas applicable to the undertaking. Through the duration of the project, students were assigned tasks and performed as if they were independent contractors. Although all work was organized and directed by the faculty in charge, students were responsible for, and held accountable for various aspects of the project. Student performance was held to exacting professional standards.

4. IMPLEMENTATION

Defective Control System Removal. Initial project activities included removal of the defective control system. All physical components were traced and identified, and mechanical components, electrical components, and electronic circuitry were investigated and associated with documentation previously reviewed. Wiring leading to the defective controller was methodically marked and complete graphical documentation was produced before any wiring was detached or augmented. Wires were disconnected and the controller was removed from the chamber cabinet.

New Control System Installation. The new programmable controller was installed into the equipment housing located next to the chamber, and associated wiring connections were established. Although some of the wiring was obviously traceable, many components required being detected or activated singularly to correctly identify hardware association. It was imperative that this operation be performed before writing any programming or applying power to the system. Interfacing with a dedicated computer was instituted and communication ultimately established.

Determining Method of Operation. All modes of process execution and possible operating conditions as well as familiarization with the chamber were considered before initiating programming activities. (Figure 4-1.) The chamber assemblage was found to consist of, in essence, a vacuum system and a heating system. Vacuum down to about 150 milliTorr is produced by a mechanical roughing pump, with lower pressure reduction down to 10^{-7} Torr provided by a cryogenic pump. Heating is realized by 16 heaters grouped into 9 zones and monitored by 10 thermocouple arrays.

The two vacuum systems used to generate a high vacuum are independent of each other and required careful consideration when programming the PLC. Plumbing, pumps, valves, and additional components form a labyrinth of pipes and hardware, the bulk of which are located behind the chamber and computer console. There were found to be many combinations of hardware element activation which were not only undesirable, but may have proven to be catastrophic to the integrity of the chamber and its contents. Initiation of the mechanical and the cryogenic vacuum pumps simultaneously, for example, would result in the immediate failure of the cryogenic pump as well as filling the entire system with oil backstreamed from the mechanical roughing pump. Extensive safety measures were incorporated into the PLC logic to ensure scenarios such as this never occur during operation of a process sequence.

Controller Programming. Means by which to control connected inputs and outputs were incorporated into the PLC program. Each input was assigned a user-identifiable alphanumeric appellation and an address related to a location in PLC memory. The PLC utilizes the numeric address while the alphanumeric identifier is designed to allow human interface to function with little difficulty through the use of intuitive labeling. Program statements were created through graphical menu selection and mnemonic code to create what is termed a ladder logic program. A ladder logic program is a graphical representation of a computer program with all input conditions related to a single output condition concatenated on one horizontal line, also termed a rung, in a manner very similar to electrical ladder diagrams historically used for electrical control circuits.
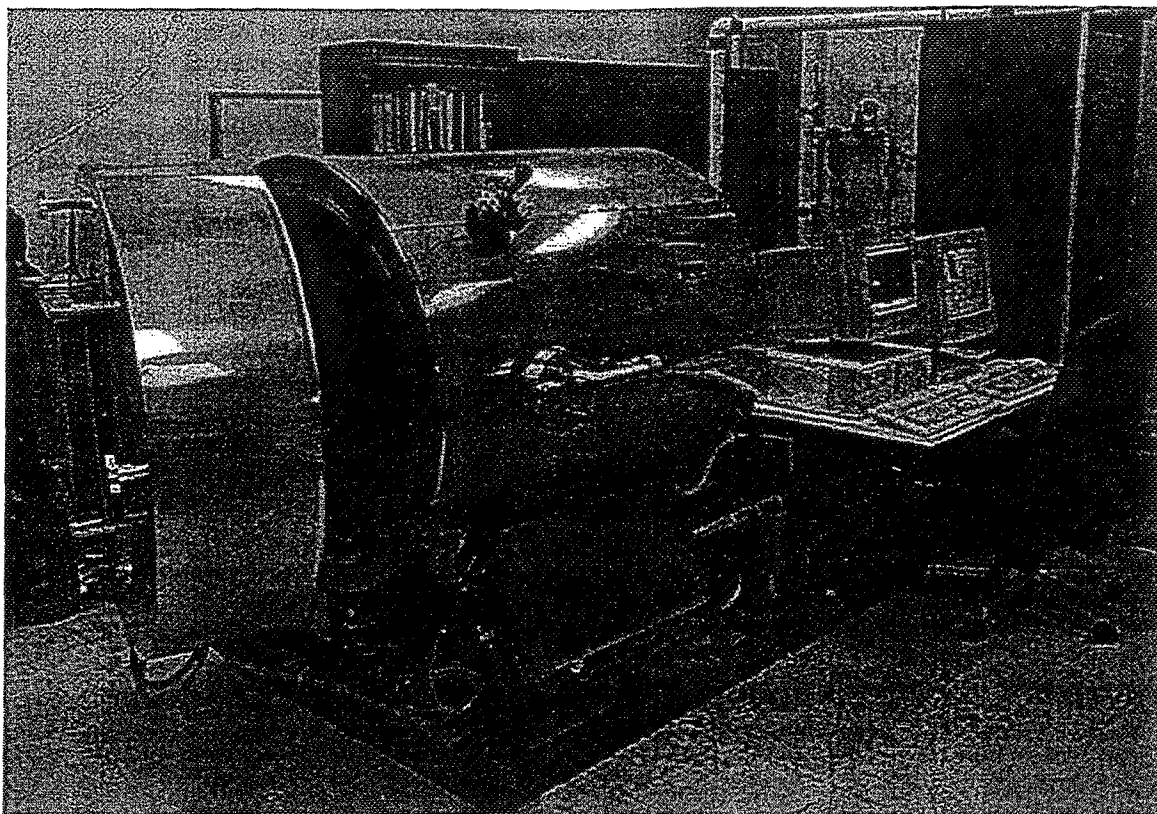
Figure 4-1. Slack Thermal Vacuum Chamber

All process inputs and outputs were connected to the PLC input/output (I/O) interface modules installed into the PLC racks located in the equipment housing. In all, 168 discrete, 16 thermocouple, and 8 analog I/O were eventually interfaced to the controller. The program assigns all I/O to a specific place in PLC memory called the I/O tables. These table values are in turn placed in internal registers which make them available for external control and/or monitoring. Laboratory staff were closely involved with specifying parameters which aided the process of determining exact chamber operation sequence and behavior. The resulting customized PLC program was thus conceptualized without regard to any previously used programs.

The collaborative effort resulted in a program comprised of 6 major process sequences: safe power-down, vacuum standby, automatic vacuum sequence, cryogenic pump regeneration sequence, cold trap change-out sequence, and cascaded proportional integral derivative (PID) heater control. These processes are controlled by 11 separate subroutines: safe mode, vacuum stand-by, automatic vacuum, cold-trap change-out, regeneration, cascade, PID control, real output control, real input control, indicator control, and data maintenance which resulted in 647 rungs, or lines of enhanced ladder program.

Programming precise heater and temperature control proved to be a challenging venture. Each heater is controlled by its own PID routine, which consists of a block of instructions in the PLC program that compares the process variable feedback with a desired setpoint and updates a control variable output based on the amount of error. The complexity in this programming procedure is a result of configuring the PID algorithm with the proper parameters, such as sample period, slew time, and the gain of the proportional, integral, and derivative components of the algorithm. Before parameters could be selected, all heaters had to be subjected to an open-loop response test and the respective data recorded. From this data, parameters

such as the process time delay (time it takes for the heater to provide a temperature change after activation) and the process time constant (time it takes for the heater to settle at a steady temperature under open loop conditions) were derived.

Due to the differing operating characteristics of the individual chamber heaters, various methods of calculating PID parameters were tested. Experimentally it was determined that the method best suited for calculating the proportional gain was based upon graphical analysis (see Fig. 4-2) of the lumped system time delay and the maximum slope of the curve, such that

$$\text{Proportional Band} = T_d * (\text{maximum slope}) * (100/\text{span}) = \% \text{ of span}$$

where the proportional band is the temperature band expressed in % of full scale or degrees within which the controller's proportioning action takes place, Td is the process time delay, and the span indicates the typical operating temperature range. (ref. 3, p. Z-86) The chamber process application dictated adapting this equation to system parameters, such that

$$K_C = t_d * (\Delta T/\Delta t) * (500/350)$$

where K_C is the controller gain, t_d is the process time delay, $\Delta T/\Delta t$ is the maximum heat rate, 500 corresponds to full-scale output for each PID loop, and 350 represents the approximate span of operation of the temperature control system, or $450°$ less $100°$ F.
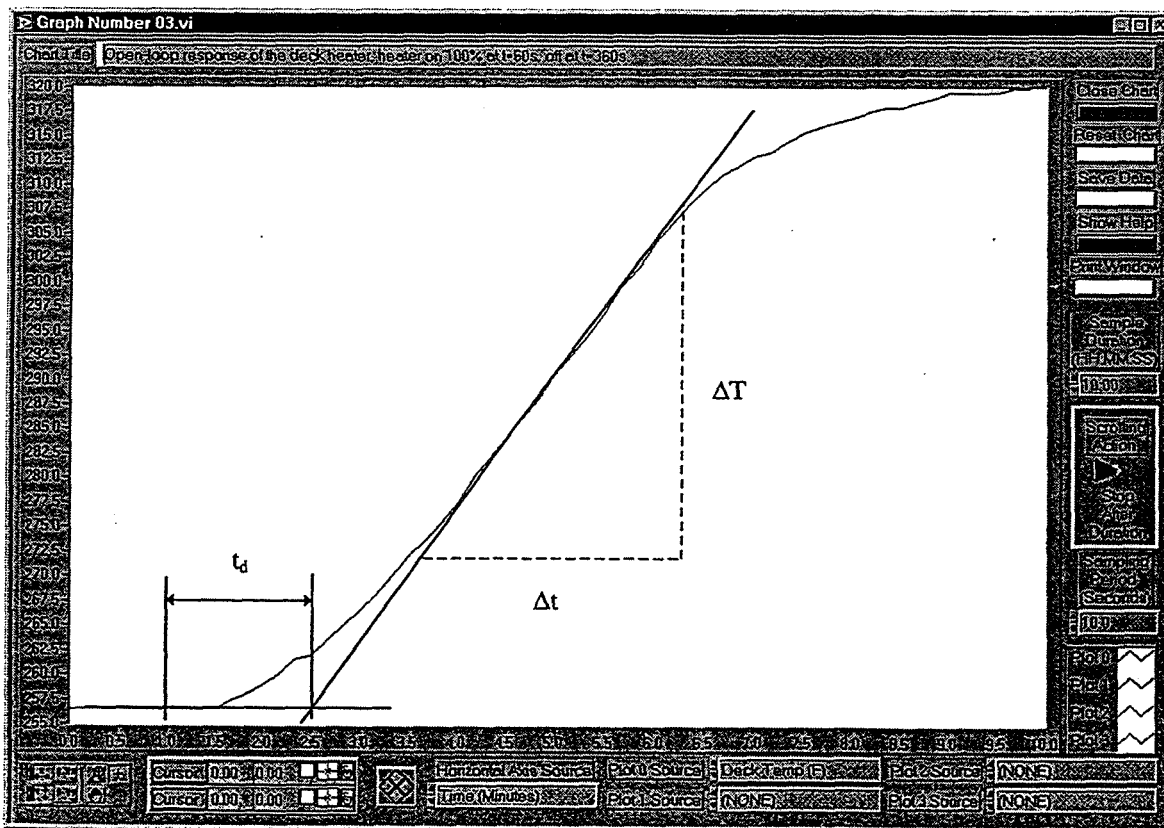

Figure 4-2. System Open-Loop Time Delay

With each PID control loop configured, the heaters could then be operated in the closed-loop configuration and respective response curves plotted, as seen in Figure 4-3. All heater response tuning and thus

modifications in PLC program configuration parameters were performed via the LabVIEW virtual instrumentation platform.

The method of PID control chosen uses the standard International Society of Measurement and Control (ISA) algorithm. "The advantage of ISA is that adjusting the K_c changes the contribution for the integral and derivative terms as well as the proportional one, which may make loop tuning easier." (ref. 2, p. 4-149)
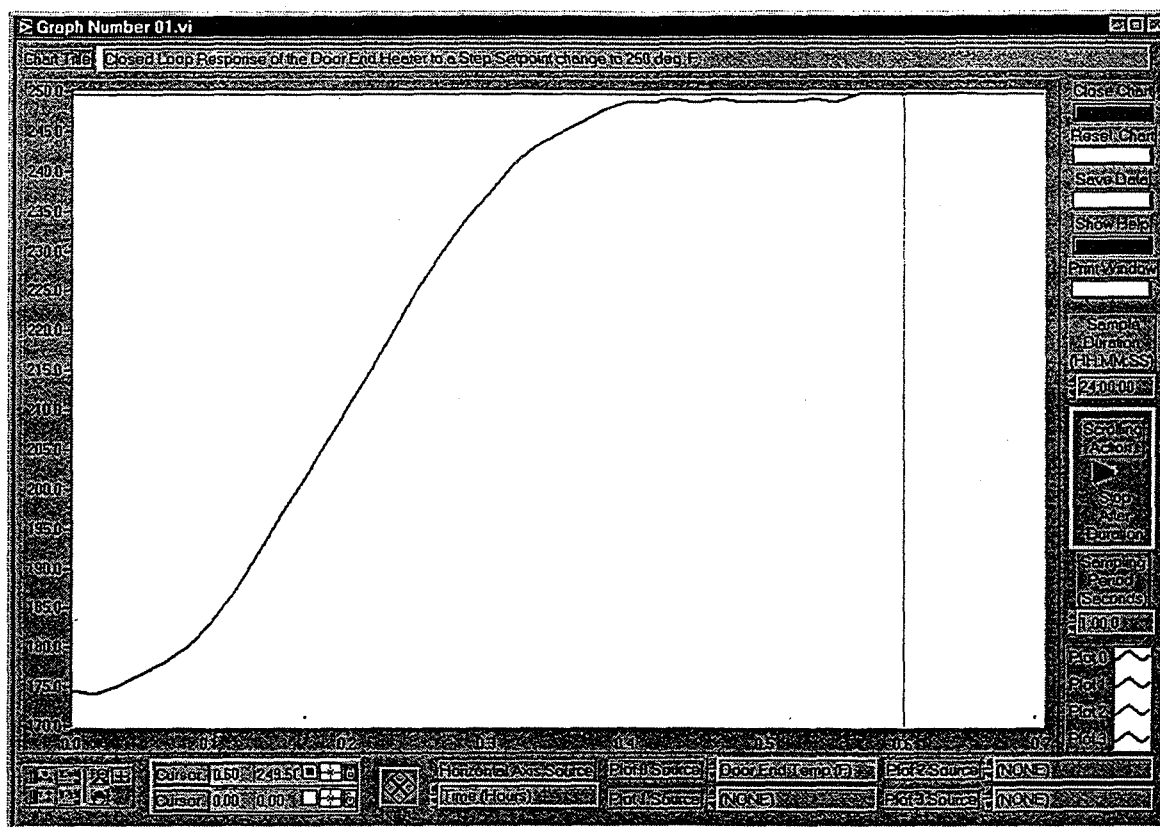
Figure 4-3. PID Closed-Loop Heater Response Curve

The ISA algorithm may be stated as

$$PID\ Output = K_c * (Error + Error * dt/T_i + T_d * Derivative) + CV\ Bias$$

where K_c is the controller gain, *Error* is the difference between the process variable input and the setpoint, dt is the current PLC elapsed time clock minus PLC elapsed time clock at last PID solution, T_i is the integral time, T_d is the derivative time, *Derivative* is the Error minus Previous Error/dt, and *CV Bias* is the selectable controlled variable output offset. (ref. 2, p. 4-149) Process criteria dictated accurate temperature attainment, minimum chamber temperature gradients, selectable zone temperature differential, and no overshoot. The resulting PID control approach which was utilized resulted in the realization of these all these stipulations.

Virtual Instrumentation. Virtual instrumentation interfacing provides a method of parallel computer supervisory control and monitoring. An additional computer was installed to facilitate executive control in the LabVIEW graphical environment. In preparation for virtual interfacing, a communication coprocessor module was specified for the installation. The Communications Control Module (CCM) protocol was chosen to establish peer-to-peer communication between the PLC and the virtual system. In the peer-to-peer mode, either device may initiate or respond to another peer device with neither designated as master or slave.

Knowledge of the specific PLC Central Processing Unit (CPU) information and communication protocol was required to program the communications request instructions. Successful communication was contingent on criteria mandated by the CCM protocol and ultimately required the formation of specially coded packets for header and data blocks. These blocks included control characters to delimit the beginning and end of data, and Longitudinal Redundancy Check (LRC) to detect transmission errors. The header packet included information regarding address, memory type, length of data, and identification information for source and target CPUs.

Virtual Instrumentation Programming. A Graphical User Interface (GUI) was created with soft controls and indicators redundant in function to the physical control panel, with the addition of elaborate graphical management capabilities. The GUI is comprised of what is generally designated in LabVIEW terms, Virtual Instruments (VIs). A VI in LabVIEW consists of a graphical program, or diagram, and a graphical user panel as shown in Figure 4-4. Although some of the functions of the GUI are redundant, many additional functions were made possible by its accretion. Additional VIs were created to oversee system functions such as vacuum, temperature, data recording, alarms, and system setpoint control and monitoring, trending, charting, and graphing functions. A unique aspect of the virtual panel in comparison to the physical panel is its capability to interface with an operator from a remote location.
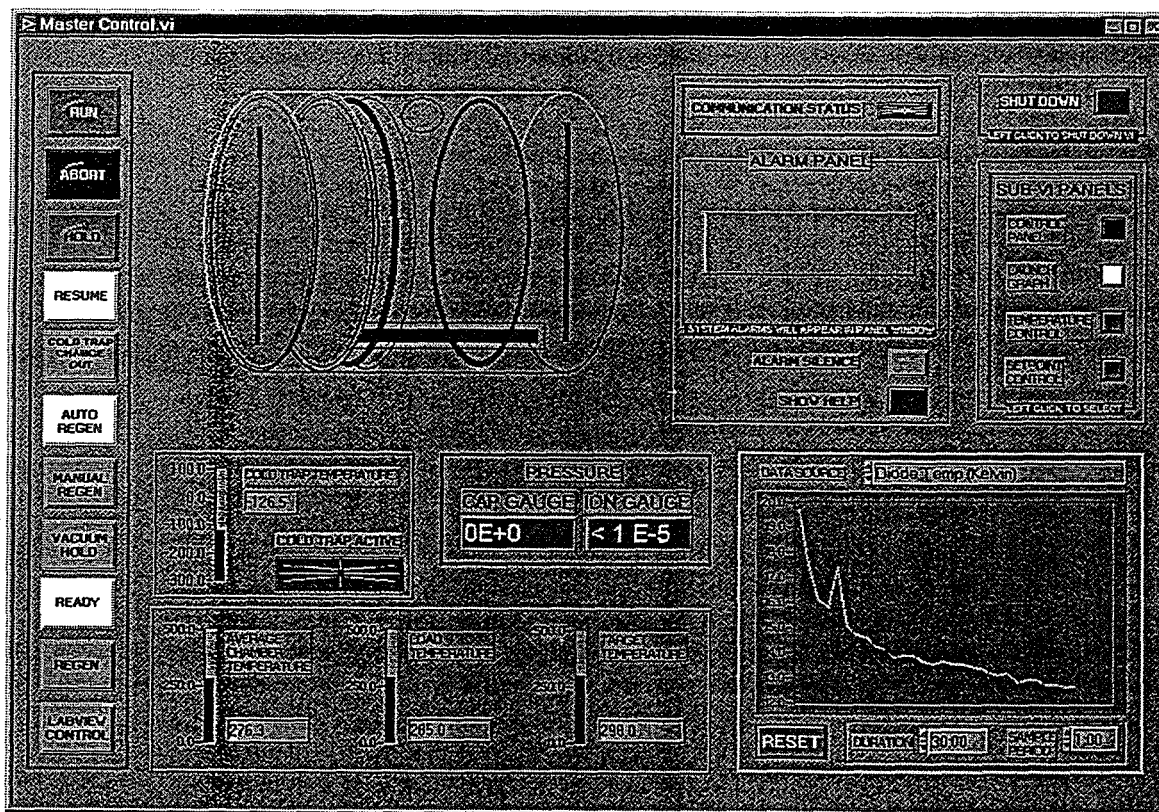
Figure 4-4. Virtual Instrumentation Graphical User Interface Panel

The LabVIEW GUI notifies the PLC when it is ready to accept or provide information relative to the control process. The PLC was configured to not initiate communication since it is programmed to control the complete vacuum and heating process independent of LabVIEW supervision or intervention. When executed, the GUI panel will initiate CCM communication and maintain a continuous dialog with the PLC. Via this connection, the communication VI periodically updates a local image of the PLC memory and is able to service limited writes to it. PLC register reads and writes are performed by a number of task-oriented VIs designed to oversee different of aspects of chamber operation.

<u>Documentation & Training.</u> Documentation began at the point of initial evaluation of the defective control system removal. Due to the presence of such a multitude of wiring conglomerations, the specific nature of each and every item was documented which in turn made connection of the new controller easier and helped to minimize errors. Although most hardware connections were fairly straight-forward, much of the software development was an evolutionary, customization process which was aided by cumulating documentation.

Technical details associated with each project task were recorded in project log books and cumulatively, all project related details which were later deemed relevant were incorporated into formal documents. A user manual and a technical manual with related drawings were ultimately produced for future reference (unpublished guide, see Author Notes).

5. DISCUSSION

The development of a control system to operate a sophisticated process such as the Slack Thermal Vacuum Chamber requires the coordination and implementation of many collaborative labor-intensive tasks. Equipped with a controller which was severely out-dated, the chamber was essentially handicapped -- operational or not. The control system, in part due to its vintage, was configured to be an inflexible and user-unfriendly system, which made using previous control strategies undesirable. Further, the inoperative status of the chamber hindered the ability to determine operational details, and lack of installation and modification documentation hampered the capacity to identify component connection details before removing the old controller.

When determining details of operation, special attention was given to events which involved some critical singular utility and/or produced especially precarious conditions when occurring simultaneous to other system functions. The extent to which these additional constraints would place on programming resources was previously inconceivable. However, in anticipation of some programming complexity, operation and programming were divided into functions which resulted in many separate subroutines. This proved to be a successful method of program error tracking, de-bugging, and editing for such a extensive program.

In effect, two control systems were installed for the Slack Thermal Vacuum Chamber - a real PLC and a virtual LabVIEW environment. The use of two concurrent systems created a third system to surmount -- the interface which facilitated the concurrent yet conjunctive operation of the two systems. Each system had to function in a precise manner individually, with the chamber, and each other simultaneously. Much programming effort was applied toward achieving this culmination.

Although the defining of process sequence and critical functions were instrumental in facilitating PLC control of chamber, programming to comply with communication and protocol-specific criteria proved to be central to virtual control execution. It was required that communication be established and complex software drivers written to manipulate PLC memory usage, which in turn enabled the exchange of data between the PLC and the virtual platform, and hence ultimate control of the system by virtual presence.

6. CONCLUSIONS AND RECOMMENDATIONS

Modern computerization is the key to utilizing the latest technology and the ability to increase process control capabilities. Programmable controllers fulfill this need by providing flexible yet powerful solutions to any process control application including vacuum chambers.

LabVIEW provides a sophisticated yet amazingly user-friendly environment for process control and specifically, for control of the Slack Thermal High Vacuum Chamber. In addition to its alluring graphical characteristics, current versions of LabVIEW are equipped with innumerable shortcuts, options, and time-saving features to make implementation of applications faster and easier.

The use of university personnel to conduct applied research activities, normally conducted by a private contractor, proves to be an all-win situation. The university benefits from the notoriety of its faculty and

students conducting applied research within an internationally recognized research organization. Faculty are afforded the opportunity to apply theoretical solutions to real problems and learn from being directly involved in the process. Students are presented with a once-in-a-lifetime opportunity to participate in significant research activities in an environment most probably paralleled by none.

Benefits to NASA and KSC are numerous. University participation provides benefits in the form of laboratory modernization tailored specifically for Kennedy Space Center. In this instance, tests conducted in the chamber will now be more easily performed and process parameters more accurately controlled. This arrangement also provides the ability to actively involve KSC personnel in the implementation process. Faculty and students are readily able to work side by side with staff. Laboratory personnel benefit from the infiltration of "new blood" into the lab environment and the exposure to new technology and its applications. Cost for the Slack Vacuum Chamber project proved much less than if a private contractor had been hired to perform the same task. Kennedy Space Center personnel estimated their total savings at two man-years, minimum, in consideration of the level of the delivered product and the man-hours spent. (W. L. Dearing, personal communication, July 30, 1997)

Future implications of findings from this investigation include complete process control from an area remote to the chamber. Potentially a total virtual presence could easily be created from a totally remote location via phone lines, radio communication, and/or the Internet. Personnel could monitor the system during times when they were not present in the lab, such as when they are at home, and potentially solve problems or adjust process parameters from a distance. System monitoring from another location at KSC and from nearby Merritt Island, Florida, have already been successfully demonstrated.

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1997 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

ACCELERATED TESTING OF COATINGS CONTAINING POLYANILINE BY
ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY

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ABSTRACT

Electrochemical Impedance Spectroscopy (EIS) was used to investigate the corrosion protection for steel performance of seven proprietary coatings containing polyaniline (PANI) under immersion in 3.55% NaCl. Corrosion potential as well as Bode plots of the data were obtained for each coating at various times of immersion in 3.55% NaCl. The longest immersion time for each coating corresponded to the time it took for visible signs of corrosion to appear. The corrosion potential for all coatings decreased in the direction of the corrosion potential of bare steel as visible signs of corrosion appeared. The EIS spectra of the seven coatings were characterized by an impedance that is higher than the impedance of bare steel. The low frequency impedance for all coatings decreased before visible signs of corrosion developed. The equivalent circuit $[R_e(C_c[R_c(QR_a)])]$, where circuit elements enclosed in parentheses are in parallel and those enclosed in square brackets are in series, provided a satisfactory fit for the EIS data. With the exception of two coatings, the behavior of C_c and R_c with immersion time correlated with performance. The low-frequency impedance (at 0.05 Hz), Z_{lf}, which is simpler to obtain than parameters based on the time-consuming determination of an equivalent circuit, was found to correlate with coating performance. All coatings included in this investigation exhibited a trend in which Z_{lf} decreased as visible signs of corrosion began to develop with immersion time. Coatings 20003 and 20013 differed from the others in that the decrease in their Z_{lf} values was preceded by an increase observed during the early immersion times. Additional experiments using multiple samples of each coating with the same thickness, are suggested in order to confirm that the low-frequency impedance, Z_{lf}, is the optimal parameter to evaluate coatings containing PANI because it correlates with visual performance and is simpler to obtain from EIS data than parameters based on the determination of an equivalent circuit.

ACCELERATED TESTING OF COATINGS CONTAINING POLYANILINE BY ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY

Luz Marina Calle

1. INTRODUCTION

Electrically conductive polymers have attracted a great deal of interest since their discovery about two decades ago. Soon after their discovery, it became clear that their unique properties could be used in several technological applications, such as the development of a new class of superconductors, light emitting plastics, polymer-based switching devices, and sensing devices. The sheer volume of fundamental and applied research in this field makes it inevitable that conductive polymers will find an increasing range of applications.[1]

Polyaniline (PANI) has attracted much attention as a unique electrically conductive polymer.[2] Many publications revealed that this material exhibits unusual electrical and optical properties. The reversibility of these properties combined with its good environmental stability and its low cost of production makes this polymer suitable for the development of the aforementioned technological applications.[3] Another possible application of PANI involves its use in protecting metals and semiconductors from corrosion.[4,5] Investigations aimed at following the improvement of this application are justified.

Research has been ongoing for over 20 years at KSC to find coating materials to protect launch site structures and equipment from the extremely corrosive conditions present at the launch complexes. The combination of proximity to the Atlantic ocean and acidic combustion products from solid rocket boosters results in corrosive stresses unique to KSC. In the mid 1980s, researchers at the Kennedy Space Center (KSC) in Florida became interested in PANIs as protective coatings for metallic surfaces.

Extensive coating testing at KSC lead to the conclusion that inorganic zinc-rich primers (ZRPs) significantly outperformed organic zinc-rich type primers in the marine atmosphere of Florida. This was partially attributed to the increased conductivity of the inorganic ZRP coating film. The materials typically used to produce the organic zinc-rich films (e.g., epoxies, vinyls, etc.) produced an undesirable insulating effect on the zinc particles. This effect resulted in decreased galvanic activity of the zinc for protection of the carbon steel substrate. On the other hand, the organic zinc-rich primers had the advantage of allowing for less than perfect surface preparation on steel to achieve performance. The organic polymers provided better adhesion to marginally prepared substrates than the inorganic materials. This result led researchers at KSC to the idea of using conductive organic materials to formulate these zinc coatings in order to develop a conductive organic zinc-rich primer. The idea being that the conductive organic vehicle would provide both the increased conductivity needed for superior galvanic protection of the steel substrate and the better adhesion to less than perfectly prepared surfaces. Hence the work on

conductive organic polymers and the search for materials that would allow the production of a new generation of protective coatings based on this technology began.

The main objective of this work was to use Electrochemical Impedance Spectroscopy (EIS) to evaluate the corrosion protection performance of recently developed proprietary coatings containing PANI.

2. EXPERIMENTAL PROCEDURE

Test Samples

The test samples were supplied by Akzo Nobel Coatings Inc. Research and Development Center (P.O. Box 37230, Louisville, KY 40233). Specimens were PANI coatings on roughened steel substrate, KTA Tator flat panels 0.45 cm (3/16 in) x 10.16 cm (4 in) x 15.7 cm (6.2 in), blast cleaned, coated on both sides and edges. Table 1 shows the number identification and information that was provided.

Table 1. Polyaniline containing coatings

Panel	Description
20003	Monsanto "polyaniline conductive polymer 5866243" diluted 3:1 with butyl cellosolve, spray coated; dried in ambient conditions for 4 days
20013	Zipperling Kessler Corrpassiv 900226/32 lot 13, used as received, spray coated; dried in ambient
20016	PANI-EB prepared by PS (1170-82B) dissolved in NMP, barcoated with #32 rod, baked in 550°F oven, 120 seconds; barcoated on both sides
20024	PANI-EB prepared by PS (1170-82B) dissolved in NMP, barcoated with #26 rod, cured in forced air oven 120°F overnight; subsequently coated on reverse side with same procedure
20026	PANI-O in toluene, 10% solids in toluene, filtered through 25 μm felt funnel; barcoated with #32 rod, baked in 550°F oven, 120 seconds; barcoated on reverse side with same procedure
20031	PANI-O in toluene, 10% solids in toluene, filtered through 25 μm felt funnel, barcoated with #32 rod, cured in forced air oven at 120°F for 2 hours; barcoated on reverse side with same procedure
20039	PANI-O in HV 6156 epoxy resin with melamine hardener; prepared from grind base 1264-2B, p/b = 0.44; spray coated and cured in forced air oven at 400°F for 1 hour 15 minutes; quenched by immersion in water; second side coated in same manner

The panels were photographed for documentation purposes prior to any testing or exposure.

Coating thickness measurements were performed using a magnetic pull-off thickness gauge and found to be in the range between 1 and 6 mils (0.003 cm - 0.015 cm).

Corrosion Potential Measurements

Corrosion potential measurements were performed using a system manufactured by EG&G Princeton Applied Research Corporation. The system used includes: (1) the Model 273 Computer-Controlled Potentiostat/Galvanostat, (2) the Model 5210 Computer-Controlled Lock-In Amplifier, and (3) the Model 352/342 SoftCorr™ II Corrosion Measurement Software. The electrochemical cell included a Ag/AgCl (silver/silver chloride) electrode, a platinum counter electrode, the sample working electrode, and a bubbler/vent tube. The flat specimen holder in the electrochemical cell is designed such that the exposed surface area is 1 cm^2. Corrosion potential values were gathered for one hour in aerated 3.55% NaCl before the first set of EIS measurements was obtained. Subsequent corrosion potential values were collected before each set of EIS measurements. All solutions were prepared using deionized water. Aeration with dry air was maintained throughout the tests.

Electrochemical Impedance Measurements

A Model 378 Electrochemical Impedance system manufactured by EG&G Princeton Applied Research Corporation was used for all EIS measurements. The system includes: (1) the Model 273 Computer-Controlled Potentiostat/Galvanostat, (2) the Model 5210 Computer-Controlled Lock-In Amplifier, and (3) the Model M388 Electrochemical Impedance Software including circuit modeling routines. Data were gathered in the frequency range from 100 kHz to 0.01 Hz. Three experiments were performed in a sequence covering the specified frequency range, and the data were automatically merged and saved. The frequency ranges for the three experiments were 100 kHz to 5 Hz, 10 Hz to 0.1 Hz, and 0.1 Hz to 0.01 Hz. The AC amplitude used for the experiments was 10 mV. Each sample was studied at various immersion times in aerated 3.55% NaCl. The longest immersion time was determined by how long it took to observe visible signs of corrosion on the area of the coating exposed to the electrolyte.

Bode magnitude plots of the data (showing the logarithm of the modulus of the impedance, $\log |Z|$, as a function of the logarithm of frequency and phase angle, alpha in degrees, as a function of the logarithm of frequency) were obtained for each coating after various immersion times in 3.55% NaCl. The impedance data were analyzed using the Equivalent Circuit computer simulation program by B. A. Boukamp.[6]

3. RESULTS AND DISCUSSION

Corrosion Potential Measurements

Corrosion potential values gathered during the hour immediately preceding the first set of EIS measurements for each coating indicated that an hour was sufficient to allow the potential to

equilibrate. Subsequent values of the corrosion potential were obtained immediately before each set of EIS measurements was obtained. The change in corrosion potential for all coatings as a function of immersion time followed a trend of decreasing values in the direction of the corrosion potential of a bare steel panel. Similar results have been reported for PANI coated metals like iron, steel, and stainless steel in salt water[7]. Panels 20013 and 20003 differed from the others in that their corrosion potentials were initially higher (Figure 1). Both coatings approached the corrosion potential of steel at longer times of immersion. The corrosion potential of coating 20013 dropped to - 0.451 volts after 1440 hours of immersion (not shown in Figure 1). It is possible that this difference could be attributed (at least in part) to the fact that coating 20013 is a lacquer and was significantly thicker than the others.
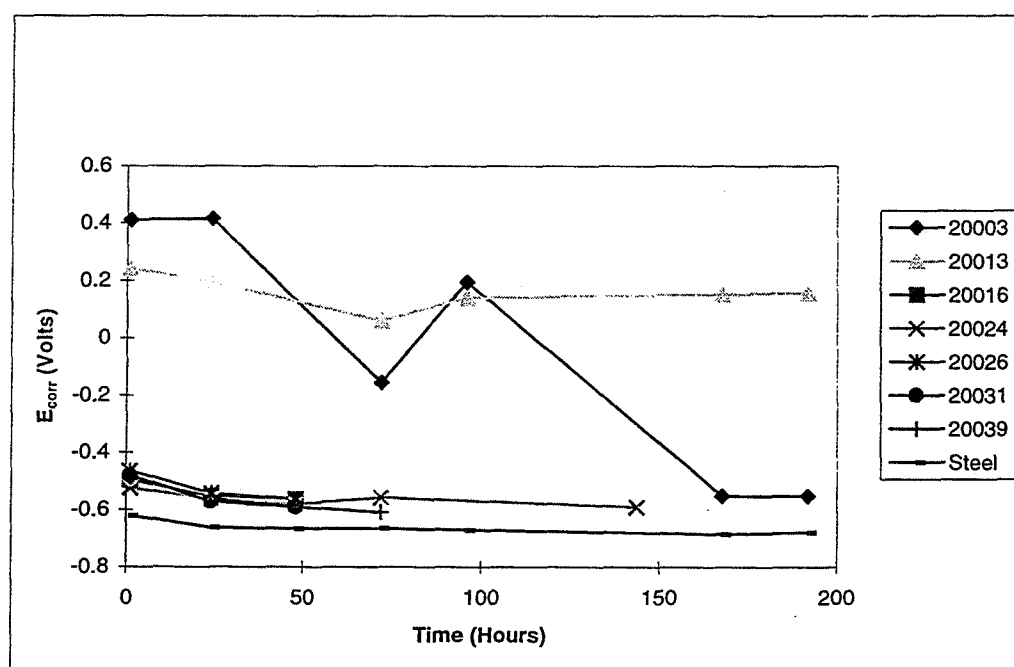
Figure 1. Corrosion potential as a function of immersion time in 3.55% NaCl

Electrochemical Impedance Measurements

Bode magnitude plots of the data for all 7 coated and 1 bare steel panels were obtained. A qualitative comparison of all plots revealed that the coated panels have a higher impedance than the uncoated panel as shown in Figure 2 for a representative number of panels after one hour of immersion time in 3.55% NaCl. When Bode plots for the same coating at different immersion times were compared, the following trends were identified: Bode plots for coatings 20003 and 20013 exhibited a shift towards higher impedance followed by a decrease as the time of immersion increased; Bode plots for the other coatings showed various degrees of change toward lower impedance as the time of immersion increased. This change was small for coatings 20026 and 20031. All EIS spectra were analyzed to find the corresponding equivalent circuit. The best
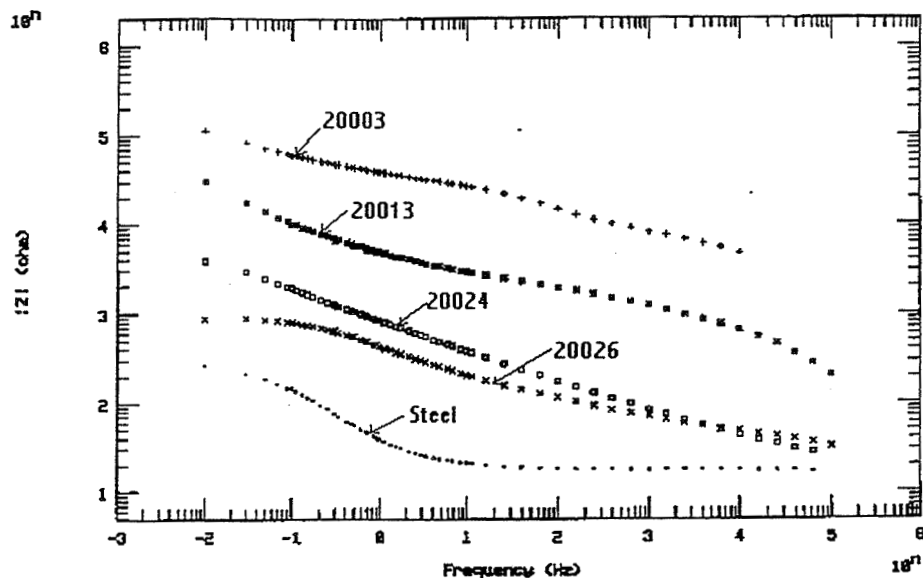
Figure 2. Bode plots for selected coatings after one hour of immersion in 3.55% NaCl

fit was obtained for the circuit described in Figure 3. Figure 4 shows the experimental as well as the fitted data using the aforementioned equivalent circuit for one of the coatings. The equivalent circuit allows for the determination of parameters associated with the performance of the coatings. These parameters include the coating capacitance, C_c, and the coating resistance, R_c. Coating failure requires the transport of water, ions, and a reducible species through the coating and involves oxidation and reduction reactions at the metal interface. An increase in C_c with immersion time, which is associated with water uptake and subsequent failure of the
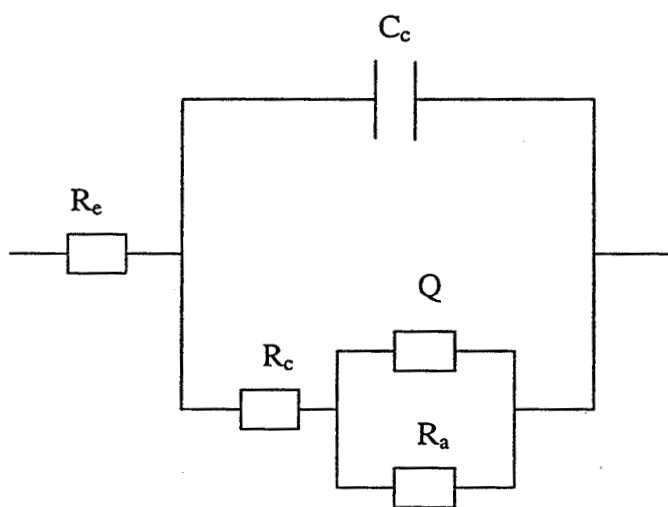
Figure 3. Equivalent circuit for conductive polymer coatings
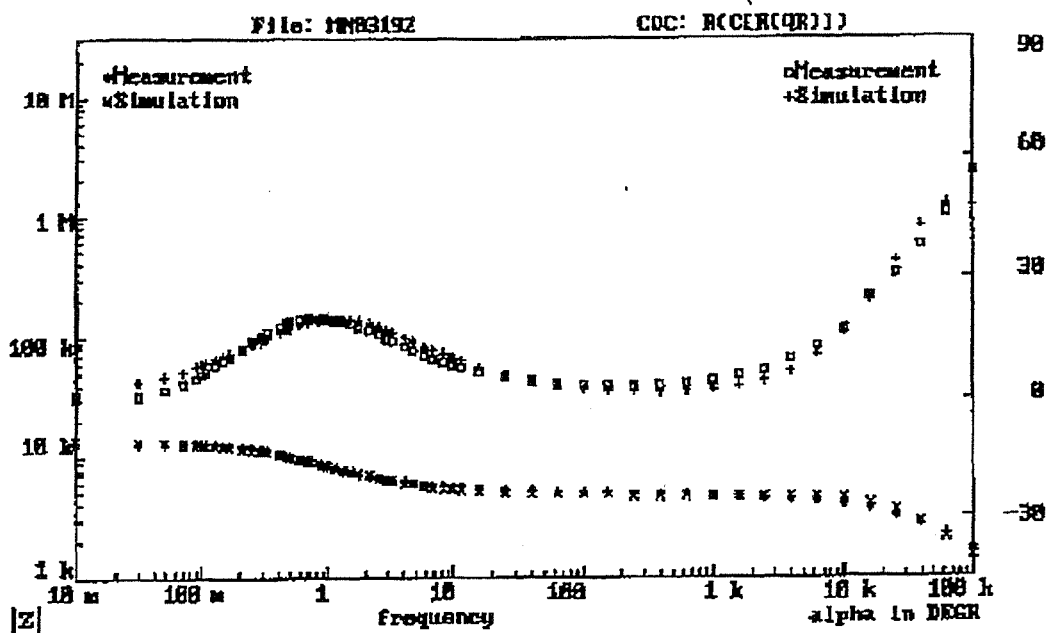
Figure 4. Experimental and simulated EIS data for coating 20003

coating, was observed for all the coatings included in this investigation with the exception of coating 20013. C_c for this coating decreased by an order of magnitude during the first hour of immersion and remained constant thereafter. R_c is inversely proportional to the rate of corrosion and should decrease by orders of magnitude as a coating degrades. Coatings 20003 and 20013 did not exhibit an identifiable trend in R_c. All the other coatings exhibited the expected trend towards lower values of R_c as the time of immersion increased and the coating failed. The changes of the Bode plots for the coatings included in this investigation suggest that the low-frequency impedance (at 0.05 Hz), Z_{lf}, would be a useful parameter to correlate with coating performance. The low frequency region on the Bode magnitude plot represents a plateau that includes the impedance of the coating. All coatings included in this investigation exhibited a trend in which Z_{lf} decresed as a function of immersion time. Coatings 20003 and 20013 differed from the others in that the decrease in their Z_{lf} values was preceded by an increase observed during the early immersion times.

4. CONCLUSIONS

Measurements of corrosion potential as a function of time are useful in the evaluation of proprietary coatings containing polyaniline. A decrease in the corrosion potential in the direction of the corrosion potential of bare steel is indicative of coating failure and it correlates well with

the appearance of visible signs of corrosion. Bode plots of the EIS data reveal that as the time of immersion increased, the low frequency impedance decreased. This decrease correlates well with the appearance of visible signs of corrosion.

The equivalent circuit $[R_e(C_c[R_c(QR_a)])]$ where circuit elements enclosed in parentheses are in parallel and those enclosed in square brackets are in series (Figure 3) provided a satisfactory fit for the EIS data of proprietary coatings containing PANI. C_c appears to be a suitable parameter for evaluating these coatings. With the exception of coating 20013, an increase in C_c with immersion time correlates well with the appearance of visible signs of corrosion. R_c also appears to be a suitable parameter for evaluating the performance of coatings containing PANI. With the exception of coatings 20003 and 20013, a decrease in R_c with immersion time correlates well with the appearance of visible signs of corrosion.

The correlation between C_c and R_c behavior and the appearance of visible signs of corrosion is useful. However, curve fitting of the data to determine them can be extremely labor intensive and time consuming.

A decrease in the low-frequency impedance, Z_{lf}, correlates with the appearance of visible signs of corrosion. In addition to being obtained more easily than parameters based on an equivalent circuit, this parameter can be acquired quickly.

Additional experiments using multiple samples of each coating prepared in such a way that all panels have the same thickness are needed in order to confirm the above conclusions.

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1997 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

PROJECT TITLE:
SAFETY & MISSION ASSURANCE MANAGEMENT TOOLS
FOR A PERFORMANCE BASED CONTRACT ENVIRONMENT

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ABSTRACT

NASA-KSC is undergoing a culture change. The Space Flight Operations Contract with United Space Alliance requires that work performed by the contractor be reported by the contractor through data and metrics. Then NASA will analyze the data and metrics for validity, proper reflection of the data, and additional need for surveillance. If further surveillance is needed or the metrics provided by the contractor are troubling for whatever reason, NASA performs surveillance to determine the problem areas. Then the contractor system of reporting is updated and the NASA surveillance on that problem is phased out. This report details the manner in which this effort is recommended to be done, gives a sample analysis of existing First Time Quality reporting by Safety and Mission Assurance (EC) versus a recommended method of the same analysis, shows what interactive Statistical Process Control training has been developed in web-based form, and details a proposal for EC to be a training and consulting source for Kennedy Space Center.

SAFETY & MISSION ASSURANCE MANAGEMENT TOOLS
FOR A PERFORMANCE BASED CONTRACT ENVIRONMENT

Roger G. Ford, Ph.D., P.E.

1. INTRODUCTION

NASA at Kennedy Space Center has entered into a new culture. The old atmosphere is gone and has been replaced with the performance based contract environment. In the past, NASA has worked side-by-side with contractors involved in the Space Shuttle Program. Two sets of eyes, one from the contractor and one from NASA, viewing and performing all duties of getting the Shuttle into space has been the norm. With the beginning of the United Space Alliance performance based contract in October of last year, NASA is faced with becoming a management group in a surveillance role. This transition has not become a complete reality as of this date, but it is inevitable and will happen soon.

NASA had an old role commonly referred to as oversight. Oversight meant working alongside contractors in the refurbishment and readying of the orbiters, solid rocket boosters, and fuel tank into the Space Shuttle. Under the Space Flight Operations Contract (SFOC), the United Space Alliance (USA) now will perform all of the work on the Shuttle except for launch, flight operations, solid rocket booster recovery, and orbiter landing. NASA's role now becomes insight.

Insight is the term used to describe the role that NASA will play in all future Shuttle flights. Insight means several different things that will be discussed later, but, essentially, insight means that NASA will analyze the data and metrics that the contractor (USA) sends to them on the work being done on the Shuttle. It is then up to NASA to determine if the contractor is doing well, if further analysis is warranted, if the metrics and the data from the contractor is reliable and reflective of the actual situations, and if the contractor is worthy of award fees. In other words, NASA becomes a hands-off manager rather than a hands-on partner.

This summer's effort has concentrated on this transition from oversight to insight, on reporting by Safety & Mission Assurance (EC) of First Time Quality by the contractors, on further statistical training available from I-NET and their Web Interactive Training Site, and a proposal for EC to become leaders in continuous improvement through the establishment of a training and consulting group within EC.

2. OVERSIGHT TO INSIGHT

Any successful enterprise in today's highly competitive world must be concerned with quality. The rise in the desirability of Industrial Engineers as leaders in the quest for higher quality at low cost and high efficiency is no accident and certainly no short term trend. ISO 9000 certification is used today as a benchmark as well as an entry tool into the worldwide competitive markets. Certification is a medal of viability and is sought by companies representing all industries as well as government entities such as NASA. Industrial Engineers and the skills that they possess assist in the attainment of high quality standards regardless of how they manifest themselves. Quality, however, has a different definition as to how it is attained, depending on what kind of organization and what type of enterprise is striving for it.

In the case of NASA, a governmental agency, quality is and has been admirable and second to none. The Space Shuttle, and all of the space efforts before from Mercury to Gemini to Apollo, is an extremely complex machine that has literally millions of interacting systems that must perform flawlessly. With very few problems, although even a small problem is manifested in a space program in a dramatic way such as Challenger and Apollo 13, NASA's record of high quality in what they do is amazing. The interesting thing about their high quality, however, is that it is achieved in a manner that all other private industries cannot duplicate nor would want to. That is because NASA simply continues to work on the project until it is perfect, or as humanly perfect as it can be, without regard to cost or efficiency. If a private company did business in this manner, they would succumb to competition almost immediately because of high costs, time delays in delivery, and customer dissatisfaction. NASA generally has no competition and time delays are only sometimes important when public relations or Congressional budgets are considered. Therefore, NASA, in the past, kept working on the Shuttle until it is ready to go, maintained quality at an extremely high level, and sent the bill to the taxpayer.

This situation is no longer NASA's privilege. Budget problems in Congress, taxpayer concern over increasing pressure for all things needing more money, and the model of business in its use of Total Quality Management (TQM) have all contributed to the new approach that NASA now faces. ISO 9000 registration, which various portions of NASA's organization nationwide is trying to gain, is closely tied to TQM philosophy. Proper treatment of SFOC surveillance is a good training ground for ISO 9000.

A performance based contract whereby NASA becomes not a partner but a manager means that NASA must now become aware of and assume control of two things that they have never had to worry about in the past: namely, cost effectiveness and work efficiency. An easy way to monitor these items is through the tracking of First Time Quality (FTQ). Essentially, FTQ is 'doing it right the first time'. This means that there are no perceived problems with the tasks or procedures or processes that are performed on the Shuttle Program. If there are problems, additional work must be done which means lower efficiency or utilization of employees, materials, facilities, etc., lost time which should be looked at as expensive even for a governmental agency, and increased costs. The quality does not suffer, but budgets and schedules do.

Shuttle program surveillance is the end result of the SFOC for the directorate known as Safety & Mission Assurance (EC) at Kennedy Space Center. SFOC has three main parts: (1) transition of work from the old NASA/contractor partnership to the new NASA manager role over the contractor who does all of the work; (2) assessment of performance of SFOC wherein the determinations of who performs assessment, where the assessment is performed, how often the assessment is performed, how the assessment is to be performed and with what tools is accomplished and implemented; and (3) that NASA retains complete control over the aspects of the Shuttle program when it relates to launch, flight operations, landing, and solid rocket booster recovery. USA has determined that there are nine ground operation core processes and NASA and USA have agreed on which directorates will have assessment responsibility in those core processes. EC has responsibility for work quality assurance for the Shuttle program. The SFOC details that the contractor must provide NASA with performance demonstration products or metrics to show how and to what degree of efficiency the work is being performed. It is then NASA's responsibility to assess the validity of the contractor provided data, determine if the contractor provided metrics are reflective of the data, and then assess the metrics. If the metrics are acceptable, nothing else needs to be done except for continuation of the contractor data and metric validation and assessment. If metrics are not providing sufficient insight, are revealing some trends that are troubling, or if there are areas that in NASA's judgment the contractor is not reporting on sufficiently, then NASA must perform 'check and balance' activities such as in-depth observation of contractor work, acceptance sampling of critical areas of work, surveys and audits of processes and procedures, and inspection before further work is authorized.

Figure 1 is a graphic depicting the process that EC will go through in order to carry out the SFOC requirements and the insight function. Step 1 is to do a critical process/task/procedure determination activity whereby all aspects of the Shuttle Program are assessed as to the degree of criticality that they are perceived to have. In this manner, NASA will know what aspect of the contractor provided data is important to scrutinize in more detail or to monitor 100% of the time. Before this task is accomplished, NASA will have no basis on which assessment is to be made. At the present, Mandatory Inspection Points or MIPs are identified by Process Engineering for the Quality Assurance Specialists to monitor. These MIPs need to be a part of the critical task assignment, but should be abandoned after the critical task assignment is made. Presently, MIPs are a problem area since no one seems willing to take the responsibility to begin a critical task determination and do away with the MIPs. A secondary problem with MIPs is that there are two general types of MIP - one is a verification MIP when all that needs to be checked by Quality Assurance is the end result of the task or procedure, and the other is a witness MIP when the Quality Assurance Specialist must be present throughout the task or procedure. A time problem is encountered when a witness MIP is required. Since personnel in EC is reducing and will for some time to come, the witness MIPs are a time problem for Quality Assurance managers.

Another problem with the implementation of proper quality assessment is the knowledge by Quality Assurance of just what tasks or procedures are going to be accomplished on a given day at a given ground processing location. This problem can be addressed with making the Ground Processing Scheduling System (GPSS) available on the web for anyone to access on a daily basis.
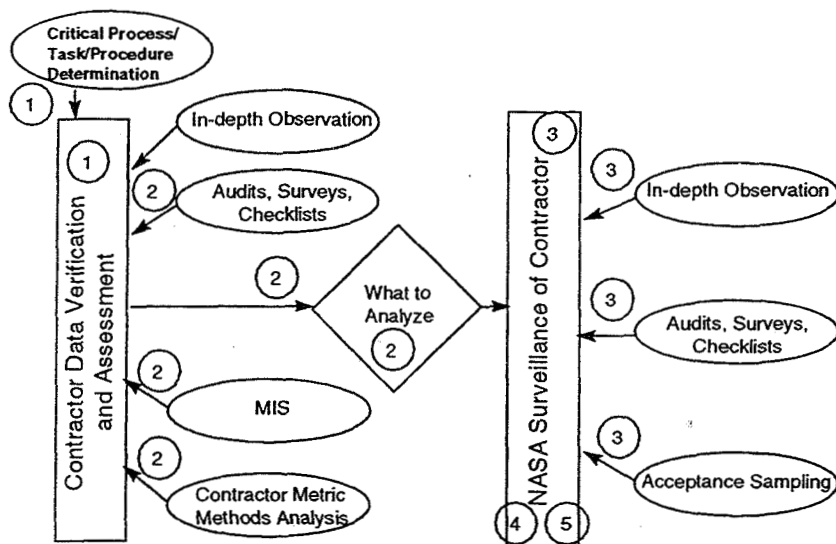
Figure 1. EC Surveillance Tasks

Step 2 is the contract data verification and assessment step where tools such as in-depth observation, audits, Management Information Systems, and contractor metric methods analysis are used to verify the contractor provided data and contractor provided metrics for validity, proper reflection of the data, and assessment of the metric itself. From these assessments, NASA then determines if additional surveillance is needed. It is possible, too, that NASA determines that additional surveillance is needed from an independent point of view and not as a result of assessment of contractor data or metric. When this determination is made, Step 3 is initiated.

Step 3 is when NASA is really performing contractor surveillance because problems have occurred in the reporting of contractor data, trends from the contractor metrics indicate that there could be problems in the future, or there are areas of concern to NASA that they wish to do surveillance upon. All of the tools mentioned before are utilized for this surveillance including acceptance sampling. From the critical process determination and the GPSS daily schedules, EC Quality Assurance Specialists can perform the sampling. Details of the sampling as to how many samples to take, when to take them, etc., can be determined at a later and more appropriate date. The intent, and this is very important for long-term work scheduling purposes, of this EC surveillance is to determine if there are really problems, to get the contractor to address the problems, to monitor the problems until they disappear and for some time after they do, and to make sure that the contractor's metric reporting system changes to reflect the needed updates so that further monitoring can be done from contractor provided metrics. In this way, NASA will constantly be initiating surveillance procedures and eliminating no-longer-needed surveillance procedures of contractor activities.

Step 4 is the actual updating of the contractor metric reporting system to reflect the NASA desired changes as a result of NASA surveillance activities. This step is essential to assure current and accurate contractor provided metrics and to eliminate unneeded NASA surveillance activities when their usefulness has ceased. It also requires the cooperation of the contractor. Step 5 is the determination and the carrying out of procedures to eliminate no-longer-needed NASA surveillance procedures. As a starting point, it is suggested that surveillance of a problem area that has been solved and the contractor metric system has been updated be continued for no longer than three flows. In that period of time, verification of new procedures and reporting of results will have been proven to be correct and trustworthy. After three flows, NASA can drop the surveillance of those specific procedures and simply monitor the contractor provided metrics.

3. FIRST TIME QUALITY

Safety & Mission Assurance publishes charts monthly reporting First Time Quality (doing it right the first time) for the contractor activity on the Space Shuttle Program. The FTQ charts are derived from the Quality Surveillance Record (QSR) database. Figure 2 shows a representative example of the data in the QSR database.

HARDWARE	QSRDATE	ACC	FAIL CODE	NARRA	IAS
OV-104/STS-81	03-Dec-96	0	F08	PERFORMED SHAKEDOWN INSPECTION OF AFT FUSELAGE. FOUND 2 EA. CONNECTORS WITH LOOSE SPLIT BACKSHELL. WROTE PR #OEL-4-18-1307.	I
OV-104/STS-81	03-Dec-96	10		PERFORMED ORBITER SHAKEDOWN INSPECTION OF AFT FUSELAGE.	I
OV-104/STS-81	03-Dec-96	1		SURVEILLANCE OF FINAL MEASUREMENTS OF EXTERIOR OF 'C' HATCH	S
OV-104/STS-81	03-Dec-96	109		OBSERVED ASSY OF V 5127-H--ET UMBILICAL STUDS/HARNESS-CONNECTORS/SAFETY WIRE INSTALLATION-& COMPLETE ELECTRICAL VERIFICATION FOR FLT. OV 104/18/STS 81. VISUAL/CONFIGURATION/CLAMPED ON FLT. ASSY BOARD FOR CHANGEOUT TO INSTALLATION. ALL SEQUENCES COMPLETE	I
SRB/STS-81	04-Dec-96	0	E04	NASA QA REVIEW OF K5NA DATA SHEETS (BI082R SYSTEM TUNNEL CLOSEOUTS) NOTED THE FOLLOWING DISCREPANCIES: 1) RUNS 1-4 HAD A K5NA EXPIRATION DATE OF 2-7-96 RECORDED. 2) RUNS 2-4 RECORDED THE PYROMETER EXPIRATION DATE AS 12-01-96. WORK PERFORMED 12-03-96.	A
OV-104/STS-81	06-Dec-96	1	B02	AREA SURVEILLANCE OF THE D-2 LEVEL 2 PEOPLE WERE OBSERVED IN A FALL HAZARD AREA WITH OUT A SAFETY HARNESS. THIS WAS BROUGHT TO THERE ATTENTION AND CORRECTED REAL TIME.	A
OV-104/STS-81	10-Dec-96	57		ET/SRB PRE ROLL OUT INSPECTION OF LEVEL D2 NORTH & SOUTH AND MLP SURFACE.	I
OV-104/STS-81	13-Dec-96	3	E04	PERFORMED GENERAL WORKMANSHIP EXAM OF SRB UPPER POSITION HOLDDOWN POSTS. PROBLEM: FOUND ONE PIECE OF FOD (A 3" PIECE OF TWISTED .041 SAFETY WIRE) BEHIND HDP #2 BLAST CONTAINER. CONTRACTOR SUPERVISION NOTIFIED AND FOD WAS REMOVED.	A

Figure 2. QSR Database Information

NASA MONTHLY FIRST
TIME QUALITY SUMMARY

NASA Inspection and Sampling Failure Codes Trends for KSC Overall
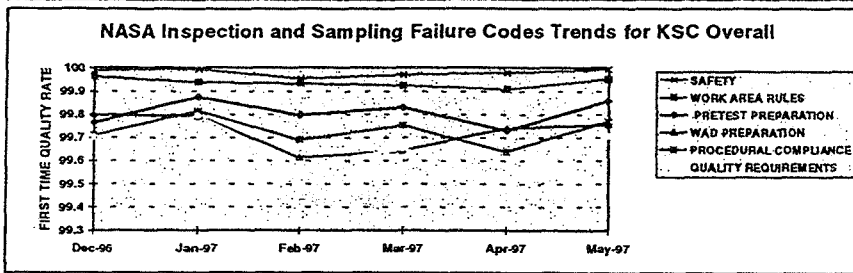
Executive Summary

The First Time Quality rate for the month of May increased from a value of 98.51% in April to 99.02%. Analysis of the six problem categories reveals an improvement in all six catagories. A review of the problems reported in April did not reveal any specific negative trends in hardware or procedures.

Overall, the First Time Quality rate is within acceptable parameters.

Figure 3. First Time Quality by Failure Code

NASA FIRST TIME QUALITY
AND ASSOCIATED ERRORS

NASA FIRST TIME QUALITY
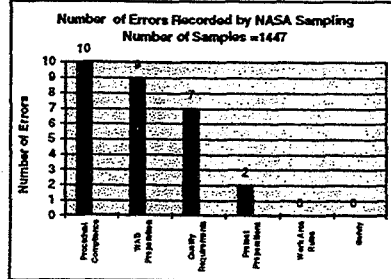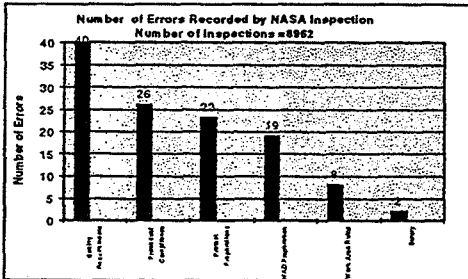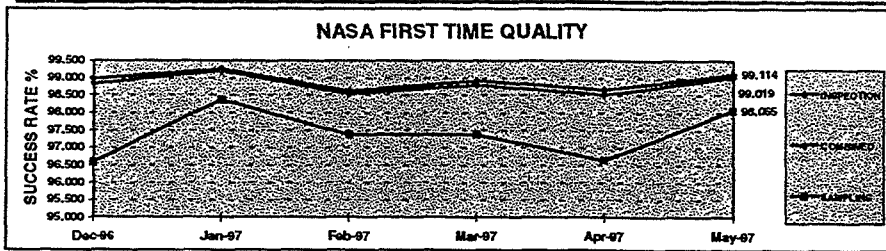
Figure 4. First Time Quality by Inspection and Sampling Data

Figures 3 and 4 show typical FTQ charts from a recent S&MA monthly report. This FTQ analysis is meant to be a guide as to the methodology of analysis that needs to be undertaken by EC in the surveillance plan for the verification of contractor provided data.

An attempt was made to determine the method used in the calculation of the data that went into the FTQ charts of Figures 3 & 4. From the QSR database, there are in fact three types of inspections performed, not two as the above charts indicate. There is: Inspection (I) which involves the inspection of MIPs in the work being performed at the ground processing stations for the Shuttle program; Sampling (S) which is a surveillance sampling effort that is an old one and not monitored for accuracy or validity; and Area Surveillance (A) which is a random spot check that a Quality Assurance Specialist (QAS) performs on work being done anywhere. All three of these inspections are recorded on a Quality Surveillance Record sheet and entered into the QSR database.

Inspection of the data in the QSR database yields a confusing array that is difficult to use. The number of "accepts" on the QSR can be recorded, but the total number of failure code violations cannot. Only the kind of failure codes can be recorded. A cursory reading of the commentary associated with the fail codes shows that often more than one fail code is found, but the total number of fail codes cannot be recorded. Therefore, when a First Time Quality calculation is attempted from the QSR database information, an accurate count of the total number of fail codes cannot be found accurately. This makes the charts above suspect as to a true depiction of the real First Time Quality. But, using each line in the database as one fail code and FTQ calculated by the formula

$$1 - \frac{\text{Total Number of Fail Code Lines}}{\text{Total Number of "Accepts"} + \text{Total Number of Fail Code Lines}}$$

and looking only at Inspections (I) and Sampling (S) data, Figure 5 is the result for the dates 7/96 through 5/97 - a period that covers flows STS 80-84 landing to launch. This chart closely approximates Figure 4 from the S&MA
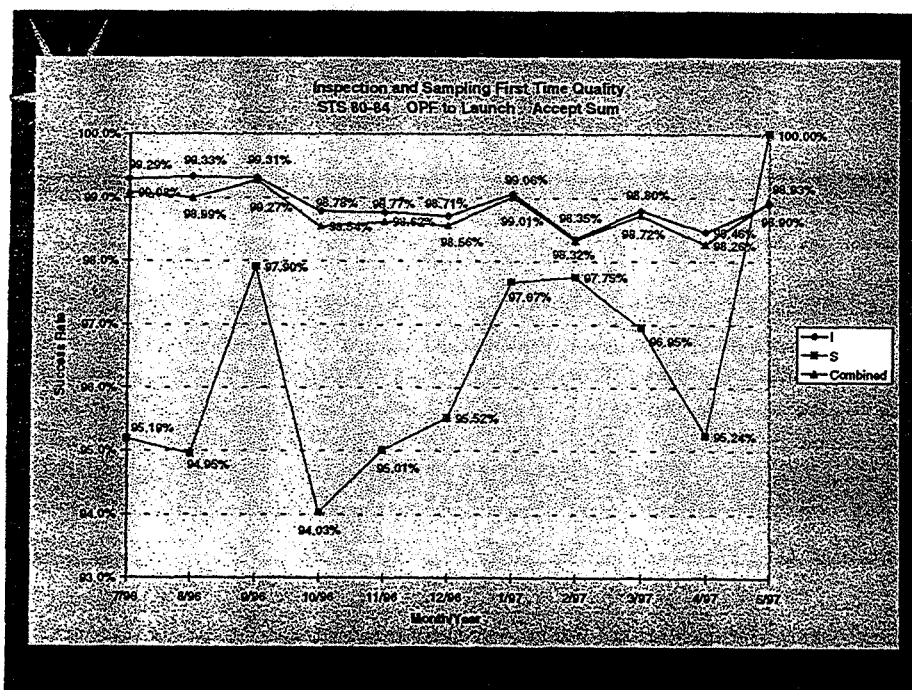
Figure 5. FTQ STS 80-84 Accept Sum I & S Only
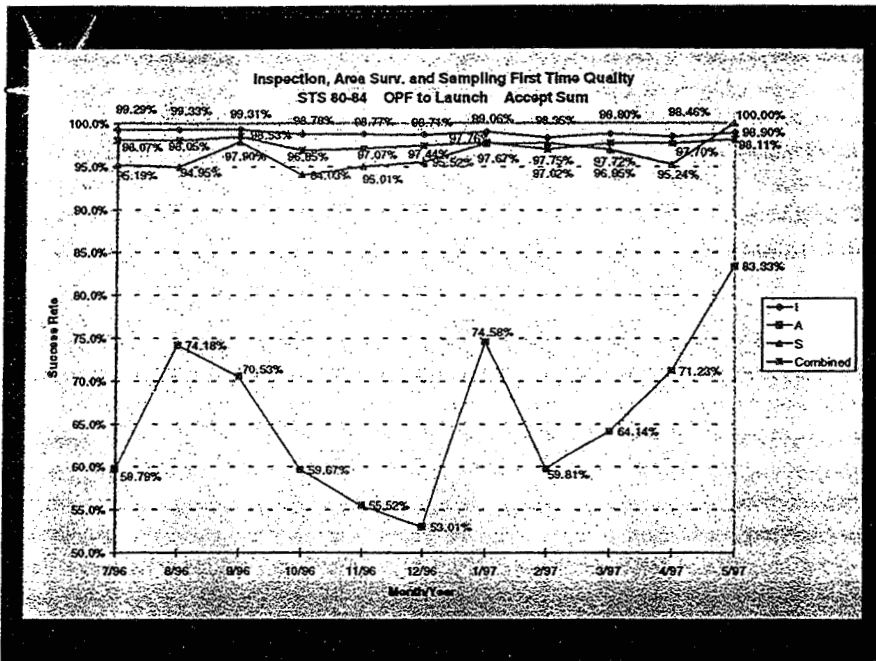
Figure 6. FTQ STS 80-84 Accept Sum I, A, & S
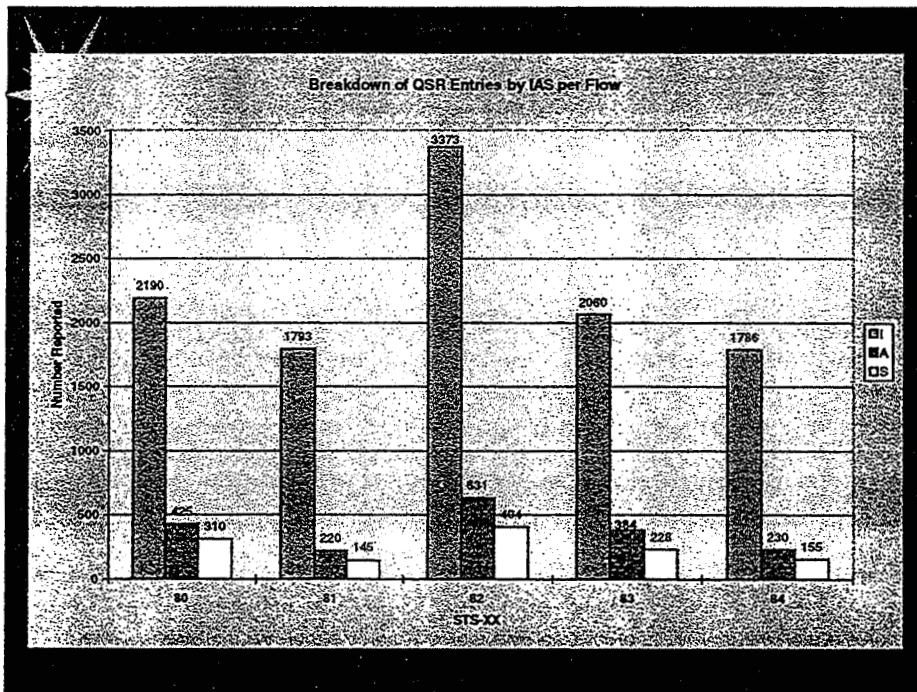
Figure 7. QSR Entries by IAS per Flow

monthly report. Figure 6, however, shows the complete dataset that includes the Area Surveillance (A) data that was left out of Figure 4. The Area Surveillance (A) data is especially poor and casts a much poorer light on FTQ. But, it represents a true picture of First Time Quality and should be reported. A combined IAS line as compared to

a combined IS line shows a 97% FTQ for the IAS data versus a 99% FTQ for the IS data. The reason for the relatively small impact of the Area Surveillance (A) data on the overall is the small number of (A) data taken (see Figure 7).

The problem of the lack of a count for the number of fail codes per QSR line can be overcome. In a true representation of First Time Quality, a Quality Surveillance is either acceptable or unacceptable the first time it is inspected regardless of the number of things that are inspected. It is a binary decision - either good or bad. In this way, each line in the QSR database is a decision. If no fail codes are recorded, then it is a "good". If one or more fail codes are recorded, it is a "bad". The data from the QSR database was calculated in this manner to obtain an FTQ:

$$1 - \frac{\text{Total Number of Lines Where a Fail Code Appears}}{\text{Total Number of Lines Without a Fail Code} + \text{Total Number of Lines With a Fail Code}}$$

Figure 8 shows a chart with the First Time Quality for IS combined data and IAS combined data calculated on a "per Flow" basis. This "per Flow" basis reveals information that was previously hidden in the "per month" data that has been the norm. In this way, each Flow can be compared to the others to determine if one orbiter is presenting more problems, if one orbiter maintenance crew is a problem, etc.
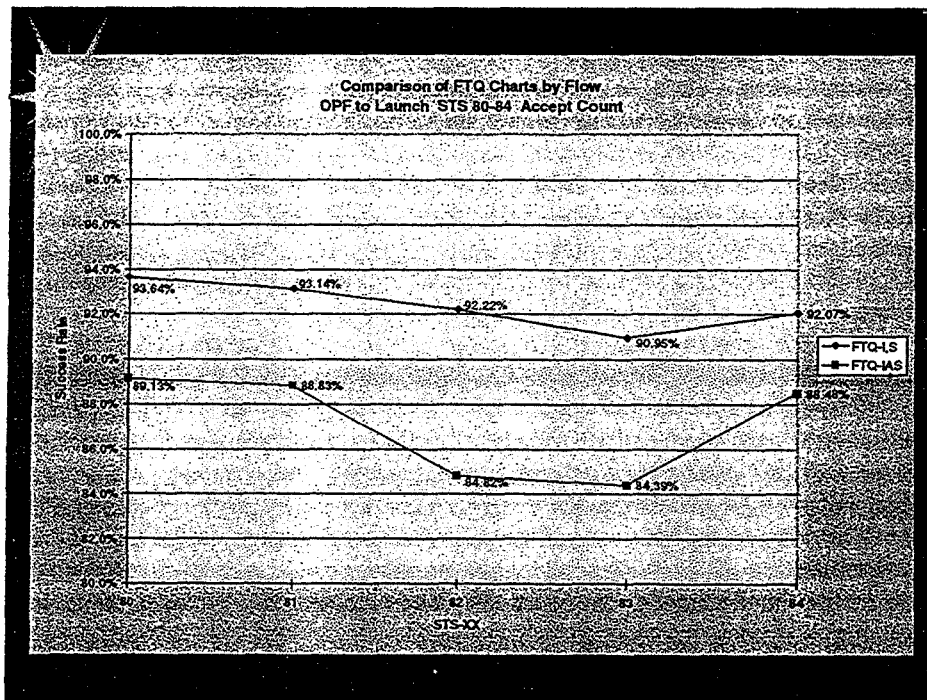
Figure 8. FTQ by Flow Line Count

Further analysis can be provided by showing the I, A, & S data separately for each Flow as shown in Figure 9. Each Flow may be monitored on a monthly basis from landing to launch as depicted in Figure 10. The QSR database may not be completely designed in the proper way for maximum analysis output, but much more meaningful data analysis may be drawn from the present condition. Of course, any analysis from such a database is only as good as the data within the database. Therefore, an extreme effort must be on-going to be assured that the data that is being entered in the QSR database is accurate, complete, and timely. There is evidence to the contrary.

4. DATA ANALYSIS TRAINING

In the summer of 1996 and year one of this Summer Faculty Fellowship, a web-based Statistical Process Control training course was developed by the author and I-NET Services. It is available from the NASA KSC Homepage under "Additional KSC Servers" and "Web Interactive Training Project. Figure 13 shows how the SPC training web page looks when it is accessed.

The present summer, in year two of the Summer Faculty Fellowship, a second SPC course is ready to be launched on the web as a secondary and more detailed course that covers acceptance sampling and design of experiments. This second course should be available on the web at the same address in the next few weeks. Through the use of these two courses, interested personnel in EC and other directorates can be brought up to speed on the basic tools that are needed to perform basic analysis on contractor provided data as per SFOC. Without these tools, the analysis will be insufficient and could be incorrectly interpreted. Everyone, from top management on down to QAS personnel, should avail themselves of these two courses.

5. CONTINUOUS IMPROVEMENT PROPOSAL

The Total Quality Management and ISO 9000 concept of continuous improvement is attained through knowledge of Quality improvement techniques. Statistical control of procedures, processes, and tasks at NASA-KSC is the source of continuous improvement. Without basic metric analysis, process control, and sampling knowledge, NASA cannot be expected to improve their cost effectiveness, their efficiency, or their time and project management.

EC has the chance and the beginnings of ability to be the source Center-wide for knowledge in Quality techniques and the use of them. Training in their use and help with applications of their use Center-wide could be a resource that EC would provide under the temporary title of "University of S&MA." Consulting would be provided to those areas in KSC that needed help in data analysis, training in all areas that EC has expertise in (such as Safety, Quality, Reliability, Risk Assessment, Process Improvement, Government Acceptance, etc.) would be made available to anyone needing it, and interaction with universities and their programs and students would be coordinated through this proposed organization.

6. CONCLUSIONS

The culture change that the SFOC represents for NASA-KSC is a formidable one. But, the changes necessary for NASA to comply with SFOC and to analyze the work performed by USA are going to bring about the beginnings of the transformation of NASA to a Total Quality Management oriented agency thus bringing NASA into the age of continuous improvement. Cost effectiveness and efficiency have not been in the NASA vocabulary until now. The culture change will transform those willing to gain the knowledge required. The old way of doing things is no longer acceptable. New methods of analysis, detailed and full disclosure of trends like First Time Quality are requisite for continuous improvement and cost effectiveness, and on-going training for all people involved in the SFOC surveillance are the stepping stones to longevity in the new NASA.

1997 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM
JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

INTEGRATED DISTRIBUTED DIRECTORY SERVICE FOR KSC

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ABSTRACT

This paper describes an integrated distributed directory services (DDS) architecture as a fundamental component of KSC distributed computing systems. Specifically, an architecture for an integrated directory service based on DNS and X.500/LDAP has been suggested. The architecture supports using DNS in its traditional role as a name service and X.500 for other services. Specific designs were made in the Integration of X.500 DDS for Public Key Certificates, Kerberos Security Services, Network-wide Login, Electronic Mail, WWW URLs, Servers, and other diverse network objects. Issues involved in incorporating the emerging Microsoft Active Directory Service MADS in KSC's X.500 were discussed.

1. INTRODUCTION

A directory service (DDS) is a fundamental component of any *transparent* distributed system. Such a system provides an efficient way for users to locate and obtain information about objects (people, network resources, etc.) automatically. An integrated DDS is a DDS that is a central repository of most information about most network objects. For example, it can be used to store encryption keys used for authenticating principals involved in a communication, used as an electronic telephone book, or used to centralize computer accounts and e-mail. Such a DDS should also provide ability to perform an application involving complex queries such as *"mail to all managers at KSC"*, automatically. The query is complex because it will force a search of domain names or actual email addresses of all managers at KSC.

NASA KSC currently has several different directory services. An X.500 directory service which can be used to obtain information (eg. Full name, address, etc.) about people, a second messaging directory service used for handling e-mail, a third directory service (DNS) used for locating network objects and a fourth future directory service that is envisaged for handling public key certificates. In general, the future calls for more directory services to handle different applications.

The goal of the research is to develop a directory services architecture that will integrate messaging (ie. E-mail), security (ie. Public key certificates) and network objects (clients, servers, etc) directory services.

This paper describes an integrated distributed directory services (DDS) architecture as a fundamental component of KSC distributed computing systems. Specifically, an architecture for an integrated directory service based on DNS and X.500/LDAP has been suggested. The architecture supports using DNS in its traditional role as a name service and X.500 for other services. Specific designs were made in the Integration of X.500 DDS for Public Key Certificates, Kerberos Security Services, Network-wide Login, Electronic Mail, WWW URLs, Servers, and other diverse network objects. Issues involved in incorporating the emerging Microsoft Active Directory Service MADS in KSC's X.500 were discussed.

The rest of the paper is organized as follows. Section 2 discusses the status of directory services at KSC. Section 3 discusses planned and future directory services at KSC. In section 4, an architecture for designing an integrated DDS for KSC is elaborated. Finally, section 5 concludes the paper.

2. CURRENT DIRECTORY SERVICES STATUS AT KSC

Currently, the following directory services exist at KSC.
  1. DNS is used in the traditional way for name-to-IP address mapping and for e-mail routing.

2. X.500 which is connected to the world's X.500 system is used only for electronic white pages. It stores employee information such as names, telephone numbers, fax numbers, email addresses, etc.
3. The X.500 is also used by KSC's email program (KMail) for resolving ambiguities if an incoming email message bears an incomplete unique address.

The current state of affairs is that the KSC directories are not well integrated. The only apparent integration seems to be X.500's integration with email (implying DNS) as explained above.

3. FUTURE DDS OBJECTS AT KSC

A proper integrated DDS will allow the following planned objects (and other future objects) to be easily included in the directory service

1. Storage and retrieval of public key certificates to enhance private communication and verifying signatures.
2. Repository of private keys for handling digital signatures.
3. Login information. This would enhance administration of user accounts.
4. Other network objects. E.g. Printers, WWW URLs, etc.
5. Email mapping tables (see figure 1). This will hopefully help alleviate delays in establishing email accounts at KSC.
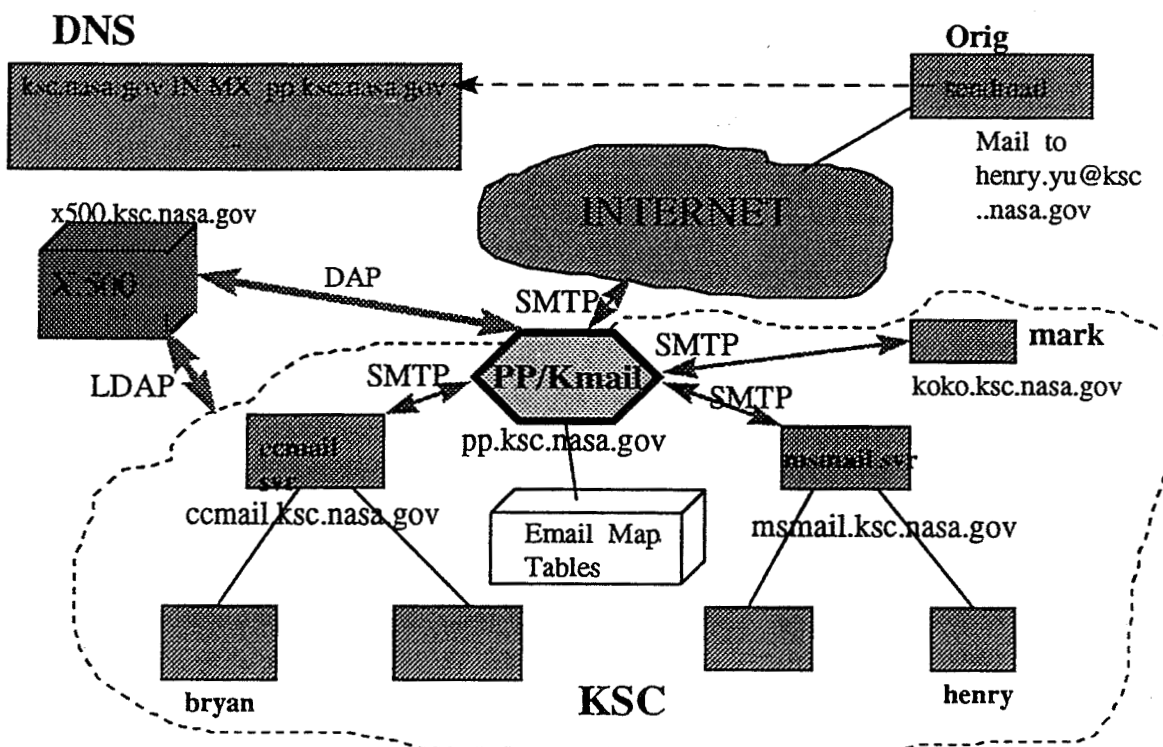
Figure 1. Email and Directory Services Environment at KSC

4. INTEGRATED DDS DESIGN FOR NASA KSC

The approach taken in our integrated directory design is to use DNS the way it is currently used (name-IP address mapping and email exchange and X.500 for storing all other objects. With this option we will look into extending KSC's X.500 directory for public key certificates, login information, URLs etc. The key to using X.500 to store all kinds of objects is to define attributes for each object. Although individual organizations can define their own attributes it is better to use standard attributes such as defined in [RFC1274] for interoperability reasons. Let us now look at the individual extensions in more detail.

4.1. Using X.500 Directories for storing Public Key Certificates

X.509 defined the standard for public key certificates and determined its components. IETF extended this idea and developed a hierarchical trust scheme for handling these certificates in developing the PEM standard. Our approach follows this line and is the same approach taken by ISODE in developing OSISEC [ISODE94].

KSC will designate a DSA that stores public keys. This DSA is called **certification authority (CA)** since it certifies public keys. The CA is a trusted, secure, server. Although it can serve other purposes we recommend dedicating the DSA as CA for security reasons.

A CA Manager is needed to establish a CA, create/distribute user certificates, post CRLs, and replace keys and/or certificates. The CA Mgr. must be registered in the directory as a user with special privileges by the appropriate ACL in the directory entry. A directory entry for the CA Mgr should be created before proceeding to build the CA. A possible directory entry for the CA Mgr for KSC is shown in figure 2 using QUIPU notations.

```
cn = CA Manager
objectClass = top & organizationalRole & pilotObject & simpleSecurityObject ---
                            & quipuObject
description      = Certification Authority Manager
roleOccupant    = c=us, o=nasa, ou=ksc, cn=CA Manager
userPassword    = SECRET
acl = others # read # child
acl = self # write # child
acl = others # read # entry
acl = self # write # entry
acl = others # read # default
acl = self # write # default
acl = others # compare # attributes # userPassword
acl = self # write # attributes # userPassword
```

Figure 2. CA Manager entry in X.500 directory at KSC.

The figure shows that the CA Mgr has modify rights for all attributes in the CA node and for each user entry served by the CA. The CA Mgr shall ensure that the CA is a non-leaf node. A directory entry for the CA must exist and be placed there by the CA Mgr. The CA organizationalUnit Entry is shown in figure 3.

```
ou = ksc
ou = ca
objectClass = top & organizationalUnit & quipuObject & quipuNonLeafObject &
domainRelatedObject
description = Node to hold CA Information
business category = Government Research Institution
seeAlso = c=us, o=nasa, ou=ksc, cn=CA Manager
cAPublicKey = <this attribute value could be inserted by system commands>
CRL = <this attribute value could be inserted by system commands>
acl = others # read # child
acl = group # c=us, o=nasa, ou=ksc, cn=CA Manager # write # child
acl = others # read # entry
acl = group # c=us, ou=nasa, ou=ksc, cn=CA Manager # write # entry
acl = others # read # default
acl = group # c=us, o=nasa, ou=ksc, cn=CA Manager # write # default
associatedDomain = ksc.nasa.gov
masterDSA = cn=X500
```

Figure 3. CA Organizational Unit Entry

The CA Mgr must be authorized to write user attributes. This is ensured by adding the ACL in figure 4 to each CA user's ACL entry. Notice the specific right the CA Manager has to modify both the objectClass and userCertificate attributes of each user under the CA.

```
acl = others # read # child
acl = self # write # child
acl = group # c=us, ou=nasa, ou=ksc, cn=CA Manager # write # entry
acl = self # write # entry
acl = others # read # entry
acl = others # read # default
acl = self # write # default
acl = others # read # attributes # objectClass$userCertificate
acl = self # write # attributes # objectClass$userCertificate
acl = group # c=us, o=nasa, ou=ksc, cn=CA Manager # write # attributes
            # objectClass$userCertificate
acl = others # compare # attributes # userPassword
acl = self # write # attributes # userPassword
```

Figure 4 ACLs for CA User entry.

Notice in figure 4 that both the user and the CA manager can modify the userCertificate attribute. Because the certificate is a user's public key signed by using the CA's private key, the certificate can be produced off-line and given to the user. In this case the user can put it in the directory. On the other hand if all certificates have to be published by the CA

the user will not need to write certificate attributes. Only the CA manager would have that authority.

4.2. Using X.500 for Storing Login Information to ensure single Network-wide Login.

To provide for single network-wide login via single user accounts, the login attributes are placed in the X.500 DDS. This means information such as userId, userPassword, etc. are added to each user's entry. Figure 5 is a partial list of user account attributes for a user called Bryan Boatright.

> *Userid = boatrightb*
> *userPassword = SECRET*
> *GroupID = commnet*
> *HomeDirectory = /usr/boatrightb*
> *Limit Grace Logins = 2*
> *Last Login Time = 19970101000000*
> *Login Disabled = no*
> *Login Expiration Date and Time = 20200101000000*

Figure 5 Partial User Account Attributes for Bryan Boatright's entry.

Note that the attributes in the figure are used for pedagogical purposes and are not intended to be standard attributes. A list of some standard attributes can be found in [RFC1274]. However, only userID and userPassword are in RFC1274.

During the login session, the login program contacts the X.500 DDS instead of conventional password file to do an LDAP search with compare, UserID, userPassword, and User's Distinguished Name as parameters. If the compare operation is successful the client is informed and a login script is.

4.3. Using X.500 and Kerberos for secure login

The disadvantage of the above scheme is that the password is sent in the clear. Even if the password is encrypted, someone can use a password-guessing attack to impersonate a real user. Kerberos can be used to solve this problem. With Kerberos, the user's password is not sent by the user's workstation. Instead the client sends the userID which a key distribution server (KDS) uses to form a cryptographic ticket (called TGT) which is delivered to the client. The client uses the password to receive the TGT and a session key. The password is erased from memory. This completes the user's network-wide login. Thereafter, if the user needs to contact any server for any application, it contacts the KDS with TGT to receive application tickets (see figure 6). The KDS uses X.500 to obtain the following attributes as needed. All except the kDCMasterKey are stored in the user's entry.

Attribute   **Meaning**

maximumLoginSession	TGT Lifetime
sessionLifetime	maximum application session lifetime
krbMasterKey	Kerberos Master key for each user
kDCMasterKey	Master Key of KDS. Must be stored in Mgr's entry.
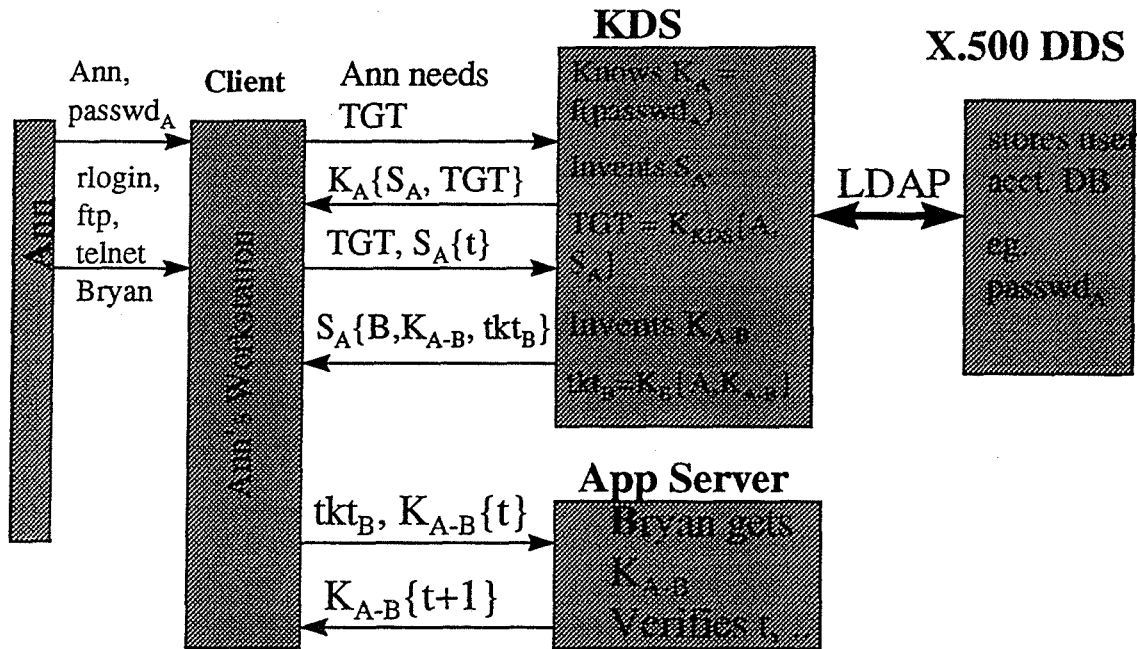
Figure 6 Technical details on Using Kerberos + X.500 for Secure Login + Applications

4.4. Using X.500 and Kerberos with Public Keys for Secure Login

One way in which Kerberos can be combined with public key as follows. Ann's PC client requests an initial TGT by digitally signing the request using her private key, while the KDS verifies the request using the public key obtained from an X.509 certificate stored in Ann's entry in the X.500 Directory Service. Ann's stored certificate could be issued either locally or by a third-party Certificate Authority. After the initial private-key authentication, standard Kerberos protocols for obtaining session tickets are used to connect to network services (see figure 7). The advantage of using public keys is that the X.500 does not have to keep user's secrets. It also takes advantage of public key infrastructure which may exist already.
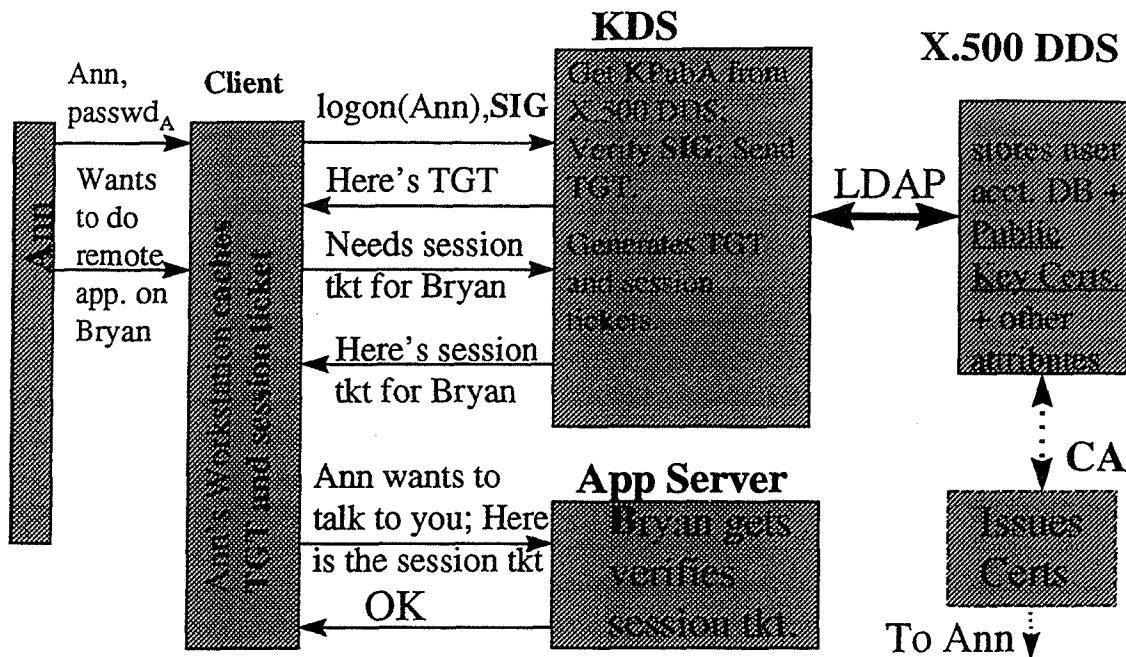
Figure 7. Kerberos Secret Key + Public Key Systems + X.500 DDS.

4.5. Using X.500 for Storing Email Address Attributes

In this case we are interested in using X.500 DDS in storing email addresses. This can be done by using the rfc822MailBox attribute. This attribute could be stored in a Bryan Boatright's user's entry as *rfc822MailBox = Bryan.Boatright-1@ksc.nasa.gov*. This is currently being stored in each user entry in the KSC X.500 directory. There are two ways in which this attribute is currently being used. One way (the most common) is to let users discover a KSC employee's email address from the KSC web page. Another way is to allow PP (email program) to use it for fuzzy search in cases where the local part of the rfc822 email address of the KSC recipient is not uniquely specified properly. This use of the X.500 is not common (according to Henry Yu [YU96]).

With this kind of arrangement we can do complex email operations such as *mail to 'all DE managers at KSC'* provided we have LDAP functionality built into the email program. If that is the case the mail program will use an LDAP search shown in figure 7.
The figure assumes that there is an attribute called 'title' stored for each KSC employee and "DE Manager" is a valid value for such an attribute. The search will return the Internet email addresses of all DE Managers under the KSC subtree.

```
LDAP search using LDAP API [RFC1823]

ldap_search ("ou=ksc, o=nasa, c=us",
LDAP_SCOPE_SUBTREE, (&(objectClass=Person) (Title=DE
Manager) (cn=*), rfc822Mailbox, ! attrsonly, ..)

or using QUIPU (KSC implementation of X.500) DUA notation
as

search -object "ou=ksc, o=nasa, c=us" -subtree
    -filter "(objectClass=Person) and  (Title=DE
    Manager) and (cn=*)"
    -type rfc822Mailbox -show
```

Figure 7. LDAP search for multiple email addresses.

The sendmail utility or PP or whatever email utility can take this list and use it to retrieve the corresponding IP addresses from DNS.

4.6. Using X.500 for Storing Email Mapping Table Attributes

The Email mapping tables we are interested in are *alias, users,* and *822 local channel.* These tables and the email configuration at NASA KSC were discussed in figure 1. Every week each mail administrator at KSC sends new mail accounts to PP administrator whose job is to create these tables. Thus it takes a week to establish email accounts. Let us look at how email account information sent by the individual administrators can be stored in X.500 DDS. This can help reduce delays in email account establishment. Information from a mail administrator used to update mapping table regarding mail account for Henry Yu is of the form

XXXXXXXX:Henry W Yu: henry@kscgws00.ksc.nasa.gov: Henry.Yu
XXXXXXXX:Henry Yu: henry@koko.ksc.nasa.gov: Henry.Yu

Now let us define the following attributes associated with the information sent by each system administrator.

UniqueID: Unique identifier = hash(SSN)

CN: Common Name
UserID: User's login account ID
MTAname: Name of the host that delivers mail to user
EmailName: Firstname.Surname

Then the format of each message sent by the mail administrator to PP administrator is of the form:

$$UniqueID:CN:UserID@MTAname:EmailName$$

Clearly, by storing these attributes in X.500, PP can read it as needed. What is needed is to provide each mail administrator with the rights to create entries (using LDAP Add Entry command) and/or modify attributes in the X.500 database via appropriate ACL. The entry creation could involve filling the appropriate form after typing in a privileged-user password. Using LDAP will allow this to be done quickly and using a good GUI client will simplify the creation and modification of attributes by reducing the learning curve for managers. The best way we see is to allow the manager to use a password to invoke a form which they fill out and send to the X.500. Note that for all of this to work, the current KSC PP has to be modified to read the Messaging information from the X.500 DDS rather than from mapping tables.

It is clear that the advantage of storing these messaging attributes in X.500 DDS is reduce the time it takes to establish email accounts. However, that produces a disadvantage: PP has to consult X.500 DDS every time it receives a mail. Since PP communicates with X.500 using the DAP this slows down email processing. Indeed, we understand that PP used to contact X.500 each time a mail was received but the idea was dropped for speed reasons. We propose three solutions to this problem.

- Use LDAP instead of DAP for communication between PP and X.500. LDAP is much faster than DAP and is the principal why X.500 is being deployed by many organizations nowadays.
- Replicate the X.500 DSA. This approach should only be used if LDAP is used and X.500 is still a bottleneck. This approach requires a replication update protocol.
- PP should cache the information obtained from X.500 DDS for a few days. This approach can be used in addition to using LDAP. The cache should be discarded after a few days in order to incorporate any changes that occur in the X.500 database.

4.7. Using X.500 DDS for Storing Diverse Network Objects

Here we are interested in looking at using X.500 for storing information about diverse network objects such as servers, URL of web documents, IP addresses. The general way of doing this in X.500 is to define the attributes associated with each of these objects. Then the corresponding attribute values and their structure (schema) are also defined. This is then installed in the X.500 database.

The **URL attribute** has been defined in [RFC2079] as *labeledURI*. The optional label can be used to describe the object referred to by the URL. The URL attribute is powerful because it provides a way of integrating directory services with the ubiquitous WWW. For example an LDAP search could be used to retrieve the labeledURI attribute from Henry Yu's X.500 directory entry assuming the path in figure 8 is correct. This URL can be used to go to Henry Yu's homepage. Furthermore, since an LDAP URL has already been defined (in [RFC1959]), this search can be done from a web document. The advantage here is that you only have to know Henry's name, not his URL which could be hard to remember. Thus with this scheme, we can go to Henry's homepage just by using his name.

A **server** can be defined as an object with a name and one or more IP addresses. The name can be an X.500 distinguished name such as *cn=koko, ou=ksc, o=nasa, c=us* or simply with its RDN which is *cn=koko*, if it is referred to locally at KSC. Its **IP address** can be specified with the *ipNwNumber* attribute defined in [RFC1608]. It can also be referred to by its DNS name using the *domainName* attribute [RFC1608]. A **printer** object can similarly be named. If it is not a network printer, its server name can be specified as one of its attributes.

```
URLs [RFC2079]

labeledURI = http://X500.ksc.nasa.gov/x500.html X.500 homepage at NASA KSC
labeledURI = ftp://ds.internic.net/rfc/rfc822.txt
labeledURI = http://X500.ksc.nasa.gov/%7Eyuh/henry.jpg Henry Yu [photo]

Server X.500 name

cn = koko
cn = kmail

Server DNS hostname

domainName = koko.ksc.nasa.gov
domainName = X500.ksc.nasa.gov

IP Addresses

ipNwNumber = 192.77.1.1          [RFC1608]
```

Figure 8. Some attributes for storing network objects in X.500

4.8. *Integrated DDS for KSC based on MADS and X.500*

In order to use MADS at KSC we have to resolve at a number of issues.

The first issue is naming. We understand that each NASA center has been allocated a single Windows NT domain. Thus we expect the KSC NT domain to be named something like *ksc.nasa.gov*. ADS further divides each domain into X.500-type organizations (O) and organizational units (OU). For example O DSA's can be set up for

DE, Payload, Shuttle, etc. Below these are OU's. The OU's under DE could be EE, ME, etc. Under EE could be leaf nodes such as CN=Bryan Boatright (a person), CN=koko (a server), etc.

The second issue is how do we integrate MADS naming scheme with that of KSC's in-house X.500? One aspect of it is to make sure that the X.500 hierarchy is merged with the ADS hierarchy. In the current KSC implementation of X.500 names, *nasa* is of *objectClass O*, *ksc* is of *objectClass OU* whereas ADS expects *ksc* to be of *objectClass O*. In general, since both O and OU are subclasses of *top* [RFC1274], *ksc* can belong to either objectClass. Thus the relative distinguished name (RDN) for KSC would be either *o=ksc* or *ou=ksc*. If ADS does not insist that the top level of an NT domain is of class *O* then the current RDN of *ou=ksc* should be kept for X.500. Regardless of which option is taken, a related issue is that the children should be created at the *ksc* tree to match the ADS tree. This will require reorganization of the current X.500 database.

The third issue is how do we ensure that an attribute referred to by the ADS LDAP is referring to the same attribute defined in X.500? The key to this is to use standard schema. We believe that the in-house X.500 is based on standard schema since the authors of the ISODE product also were involved in publishing the standard schema specified in RFC1274. However, we do not have sufficient detailed knowledge of Microsoft's ADS to determine if it uses exactly the same schema as KSC's ISODE X.500. If not, changes will have to be made in the schema definition in either ADS or X.500 to force a match. A suggested schema organization for KSC is summarized in figure 9. The figure shows standard object classes and their relationships. In each case mandatory as well as some optional attributes are given as necessary. Some of the object classes have been implemented at KSC, others are proposed.

With all the above problems solved, the operation such *ldap://dc1.ksc.nasa.gov/c=us, o=nasa, ou=ksc, ou=de, ou=ee, cn=koko* should return all attributes of *koko*. The steps to be followed are as follows.

1) The DNS name *dc1.ksc.nasa.gov* (where *dc1* is the name of a domain controller at KSC) is used as a key to search DNS. DNS should return the IP address of *dc1*.

2) The IP address is used to do the LDAP search on the domain controller called *dc1*. The domain controller should return the search results. Assuming that *cn=koko* is the name of a server, attributes such as IP address, public key, full name, description, etc. for *koko* can be returned to the client.

3) The IP address of *koko* can subsequently be used by the client to go to the server to perform a specific application.

On the other hand if *c=koko* is the name of a printer object then attributes returned could be OU, server name for the printer, its IP address, queue directory, user, etc. This information could be used to access the print queue.
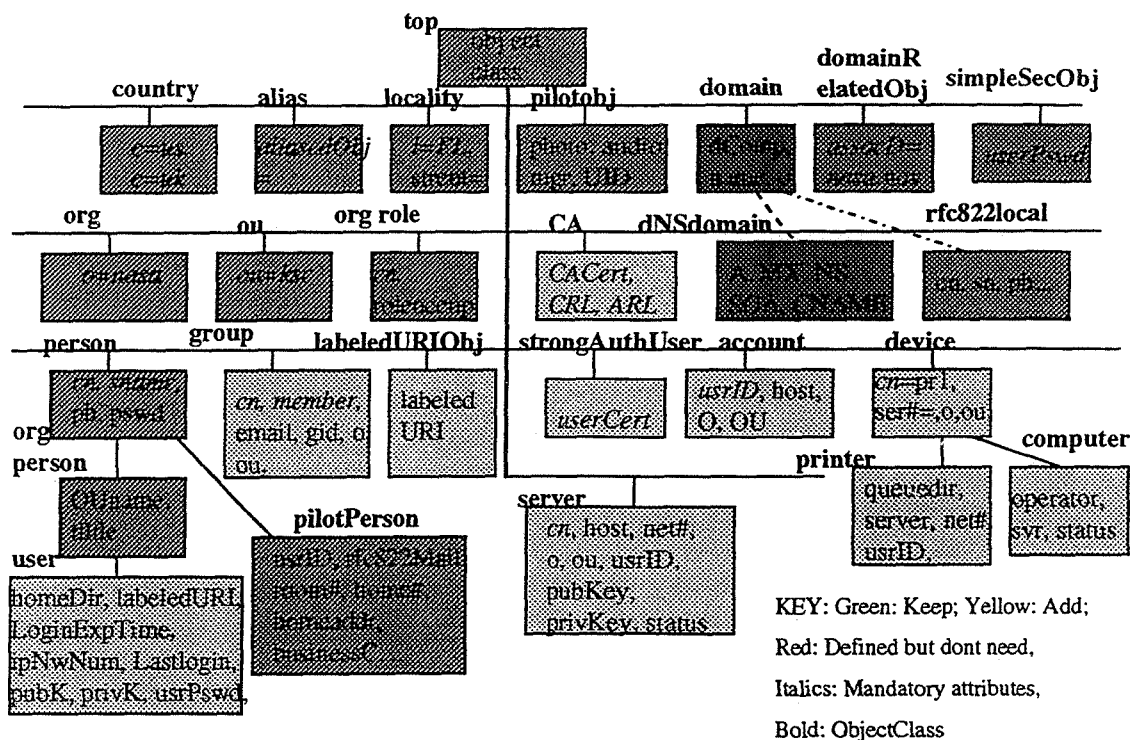
Figure 9. Suggested X.500 Schema Organization for KSC

5.   CONCLUSIONS

The objective of this research was to design a high level architecture of an integrated directory service for KSC such that planned and future objects could be incorporated into the directory service. Objects to be stored in the directory includes network address, electronic phone book, public key certificates, and user account. Integrated DDS is needed to simplify user account and to simplifying administration of objects because it serves as a means of centralizing administration of the objects even though not one machine has all of the information contained in the directory service.

The option based on open standards, that is both cost-effective and can satisfy KSC needs, is a combination of DNS and X.500. DNS will be used for its traditional job i.e. Mapping names to IP addresses, and X.500 will be used for everything else. Indeed, the current X.500 at KSC uses DNS. We discussed how new attributes such as public key certificates can be included in the current X.500, how login accounts can be centralized using simple password and using strong authentication based on Kerberos login together with X.500 DDS (for storing secret key, public key, etc as appropriate). We looked at how general purpose network objects such as URLs could be incorporated in X.500 directories. We looked at how LDAP could be used to access such directories. Although LDAP URL was the method used for accessing directories, other ways of doing the same thing includes LDAP API and form method from a web page (this is the way X.500 is accessed from LDAP in KSC's X.500).

Finally, because NASA is committed to the Windows NT environment we discussed issues that need to be resolved in order to incorporate Microsoft ADS into KSC's X.500.

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CORROSION OF REINFORCED CONCRETE STRUCTURES

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ABSTRACT

The purpose of this research was to develop a methodology for assessing corrosion control techniques which can be applied to existing reinforced concrete structures at KSC. The results of electrochemical tests on migrating corrosion inhibitors and on flame-sprayed zinc coatings are presented along with assessments of several structures in the Kennedy Space Center/Cape Canaveral area.

ACKNOWLEDGEMENTS

CORROSION OF REINFORCED CONCRETE STRUCTURES

Robert H. Heidersbach

1. INTRODUCTION

Concrete structures are subject to failure or deterioration due to the corrosion of their reinforcing, post-tensioning, or prestressing steel. The problem is common on highway structures and, to a lesser extent, buildings and other structures. While it can cause collapse of buildings (Figures 1a-b), most damage is detected before the corrosion reaches catastrophic stages (Figure 1c).

| 1a | 1b | 1c |
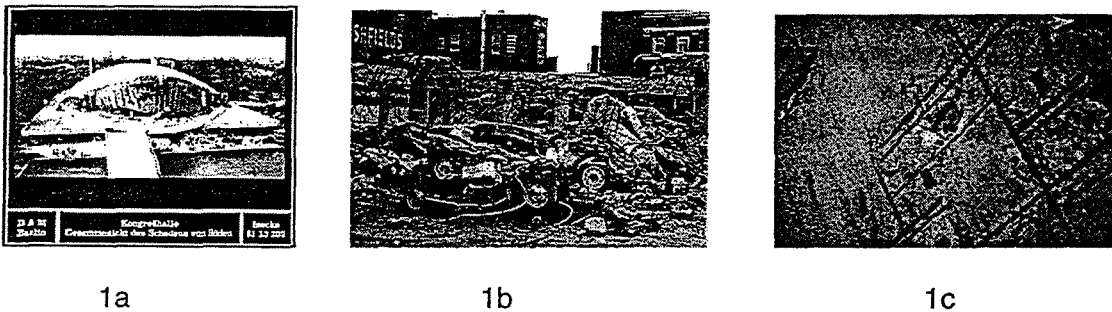
Figure 1: 1-a: Collapse of the Berlin Congress Hall due to corrosion of post tensioning cable, [1] 1-b: Collapse of a parking garage in St. Paul, Minnesota, due to corrosion of reinforced concrete,[1] 1-c: Corrosion of reinforcing steel in ceiling of dormitory in Oklahoma.

Reinforced concrete buildings and other structures at the Kennedy Space Center are subjected to a very corrosive environment, and corrosion could cause major impacts on the Kennedy mission if critical buildings were to become unavailable due to corrosion. The Vehicle Assembly Building (VAB) is a unique building at KSC, and in 1988 concrete from the roof of this building fell over 500 feet to the floor. (R. Lee, NASA KSC, private communication, June 1997.) This spalling was supposedly due to corrosion of reinforcing steel. Other structures at KSC which have corrosion problems include bridges and special launch facilities.

Most corrosion in concrete literature concentrates on the effect of salts, especially chloride salts, on accelerating corrosion in concrete. This effect is shown in Figure 2, which shows how corrosion in water increases the corrosion rate up to a maximum at approximately 3 ½% salt, coincidentally the salt concentration of sea water, and then the corrosion rate decreases.[2-3] Similar effects are known to occur in reinforced concrete.[4]

Figure 2: Effects of salt concentration on corrosion of steel in water. [3]
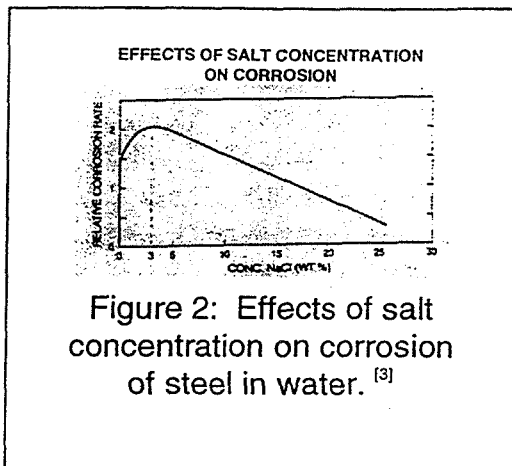
Because chloride salts are known to be associated with corrosion in many structures, several researchers have sought to determine a critical chloride concentration above which corrosion becomes significant.[5] Table 1 shows the results of some of this research and compares the results with the chloride levels found by the U.S. Army Corps of Engineers in the concrete of the Vehicle Assembly Building. The salt levels at the spalled location in the VAB were less than half the supposed "threshold" levels necessary to promote corrosion. Either the "threshold" has not been accurately determined or, more likely, corrosion can occur in concrete in the absence of salt, and salt merely accelerates corrosion. The failure of the Berlin Congress Hall, Figure 1a, is one example of a concrete structure that experienced corrosion in the absence of chloride salts. While corrosion in low-salt environments is of interest in some locations, it is not applicable to the environment at KSC.

Table 1: Comparison of chloride levels at spall in KSC Vehicle Assembly Building with reported "threshold" levels necessary to induce corrosion

Researcher	Year	"Threshold" lb. Cl/yd³ of concrete	"Threshold" ppm Cl- in concrete	"Threshold" minimum percentage Cl- (0.0001Xppm)	Chlorides percent at VAB spall*	Spall/Threshold
Lewis	1962	1.2	300	0.03	0.014	47%
Hausman	1967	0.3-4.7	75-1175	0.0075	0.014	187%
Berman	1972	1.3	325	0.0325	0.014	43%
Clear and Hay	1973	1-1.5	250-370	0.025	0.014	56%
Clear	1974	1.12	286	0.0286	0.014	49%
Stratfull, Jaukovich, and Spellman	1975	1.12	286	0.0286	0.014	49%
Cady	1978	1-2	250-500	0.025	0.014	56%
Browne	1982	2.24	572	0.0572	0.014	24%
Pfeifer, Landgren, and Zoob	1986	0.9-1.5	230-380	0.023	0.014	61%

Published literature data from Table 2, M. Funahashi, Predicting corrosion-free service life of a concrete structure in a chloride environment, ACI Materials Journal, v. 87, p. 581-7, 1990.

*VAB chloride analysis from Table 2 of Vicksburg, Corps of Engineers report.

Purpose: The purpose of this research was to develop a methodology for assessing corrosion control techniques which can be applied to existing reinforced concrete structures at KSC.

The results of electrochemical tests on migrating corrosion inhibitors and on flame-sprayed zinc coatings are presented along with assessments of several structures in the Kennedy Space Center/Cape Canaveral area.

2. EXPERIMENTAL PROCEDURE

Figure 3: Concrete "lollipop" specimen used in EIS measurements
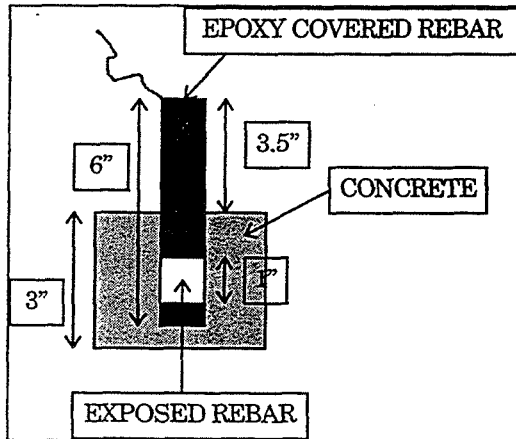
This summer's research followed two parallel approaches:

Laboratory evaluations of concrete samples using electrochemical techniques.

Field evaluation of actual concrete structures.

Laboratory evaluations used electrochemical impedance spectroscopy (EIS) to determine the average corrosion rate of steel embedded in concrete "lollipop" samples (Figure 3) similar to those used by other corrosion in concrete researchers. While the interpretation of the mechanism of corrosion in concrete using EIS is controversial, it is generally accepted that the electrochemical impedance, Rp, is a rough indicator of the amount of electrochemical corrosion occurring on a metal sample.[6-8] The measurements were made using the EIS equipment located at the Complex 34 Toxic Vapor Detection laboratory.

Concrete samples with a 0.5 water/cement ratio were fabricated. Once the samples were cast, they were cured for 10 days, and cut into the "lollipop" shape shown in Figure 3. The samples were then soaked in water for two weeks to "activate" corrosion. Most of the samples were soaked in 3 ½ % sodium chloride and two control samples were soaked in deionized water. Because both of these waters could leach chemicals from the concrete, the water was changed whenever the pH of the water was noted to change.

After the two-week soaking period, the samples were treated with three different corrosion protection techniques:

Sika Ferrogard 903 migrating corrosion inhibitor
Surtreat V. C. migrating corrosion inhibitor
Flame-sprayed zinc at approximately 10 mils total thickness.

Field evaluations involved inspection of a number of concrete structures at Cape Canaveral Air Station, where the launch pads used in the 1960's are located. Figure 4 shows support structures for liquid hydrogen lines at Launch Pad 34. These structures were chosen for detailed analysis, because they are easily available, have been located within ½ mile of the ocean for over 30 years, and have been abandoned. Analysis of the corrosion occurring on these structures should give information on the degradation processes likely to occur on KSC structures in the future.
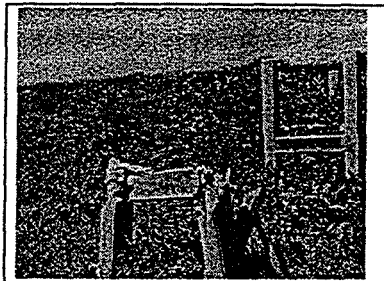
Figure 4: Fuel line supports

We received approval for removal of 10 of the horizontal members like those shown in the background of Figure 4. Because of time constraints, only one sample was removed and shipped to Cal Poly for forensic analysis using the scanning electron microscope.

The results of field inspections of other concrete structures are presented later in this report.

3. RESULTS AND DISCUSSION

Laboratory experiments: Tables 2-5 show the results of the laboratory EIS experiments.
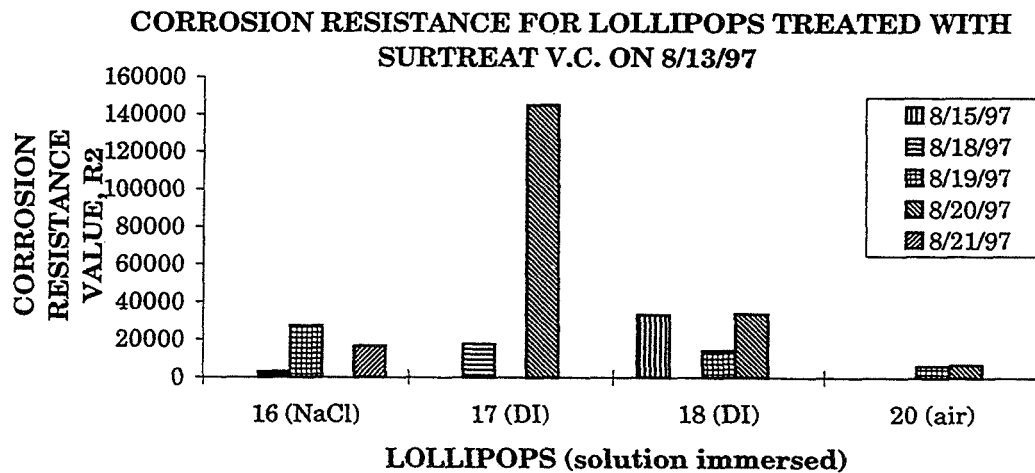
Table 2: EIS data for concrete treated with Surtreat V.C. migrating corrosion inhibitor

CORROSION RESISTANCE FOR LOLLIPOPS TREATED WITH SIKA FERROGARD 903 ON 8/14/97
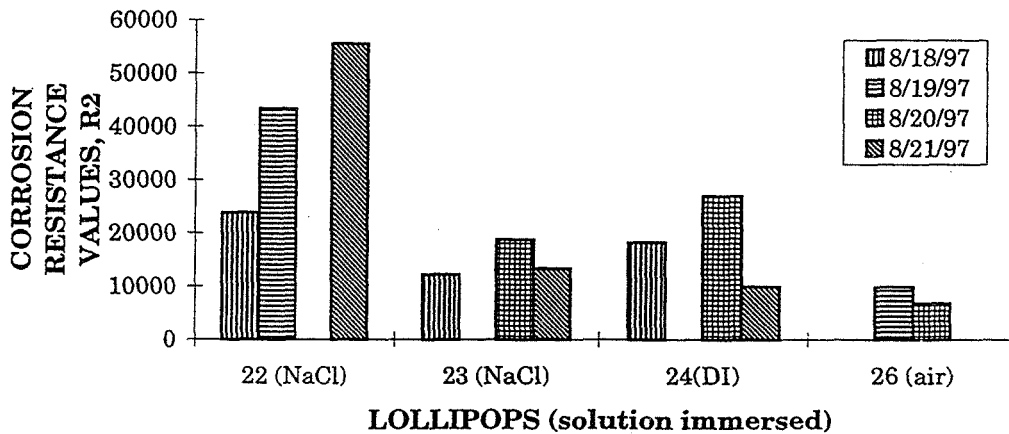
Table 3: EIS data for concrete treated with Sika Ferrogard 903 migrating corrosion inhibitor

CORROSION RESISTANCE FOR LOLLIPOPS ZINC FLAME SPRAYED ON 8/11/97
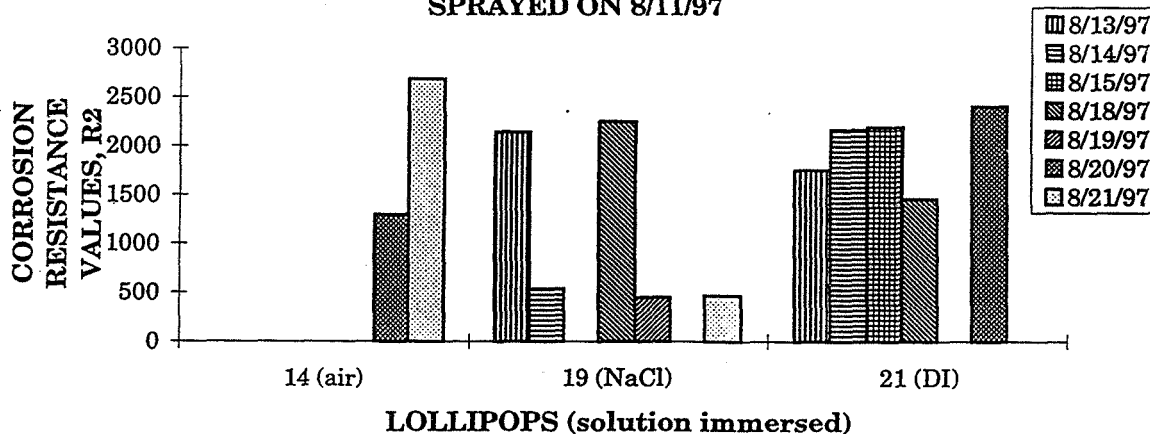
Table 4: EIS data for concrete treated with a 10-mil coating of flame-sprayed zinc

CORROSION RESISTANCE FOR UNTREATED LOLLIPOPS IMMERSED IN SOLUTION ON 7/23/97

Legend:
- 8/1/97
- 8/4/97
- 8/12/97
- 8/13/97
- 8/14/97
- 8/15/97
- 8/18/97
- 8/19/97
- 8/20/97
- 8/22/97

Y-axis: CORROSION RESISTANCE VALUES, R2 (0, 5000, 10000, 15000, 20000, 25000, 30000)

X-axis: LOLLIPOP (solution immersed): 27 (NaCl), 30 (DI), 31(DI), 32 (air)
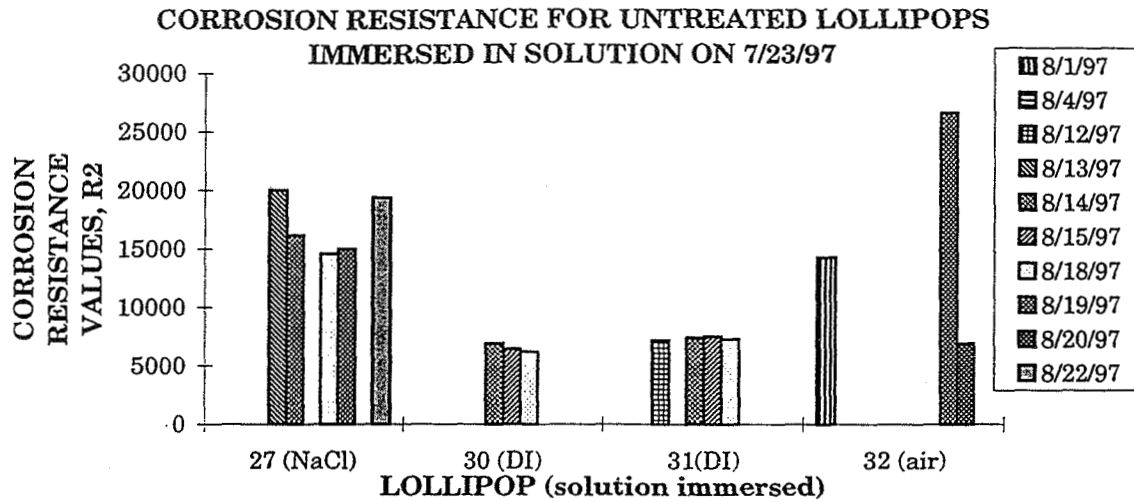
Table 5: EIS data for untreated concrete

The results of the EIS investigations were inconclusive—either the time available for exposure was too short or the test protocol was deficient in some undefined way.

Field evaluations: Figures 5 and 6 show corrosion of aluminum which has caused cracking and spalling of the adjacent concrete. This can be
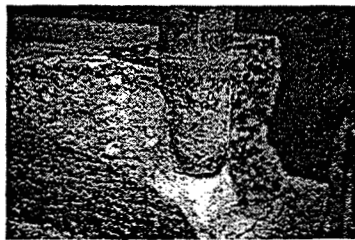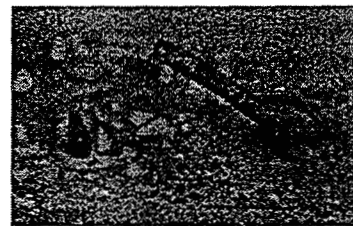
5   6   7

Figure 5: Spalling at corroded aluminum bridge railing on Highway 510 near Orchid, Florida.
Figure 6. Close-up of aluminum pitting on the same bridge as shown in Figure 5.
Figure 7: Steel stud protruding from concrete bridge abutment. Note the lack of cracking on the concrete surrounding the steel.

contrasted with the lack of cracking on a nearly bridge where a corroded steel stud (Figure 7) has not caused corrosion and cracking. Similar cases of corrosion were identified at numerous locations throughout the Cape Canaveral/Kennedy Space Center region. These examples of corrosion will be correlated with the results of failure analyses on the samples removed from the location shown in Figure 4 in a future study.

CONCLUSIONS

1. Electrochemical impedance spectroscopy has been used to evaluate the corrosion of steel in concrete, but the technique is not ready to compare the efficiencies of alternated approaches to control of corrosion in concrete.

2. Migrating corrosion inhibitors may slow the corrosion of metals in concrete, but this cannot be demonstrated with the EIS results shown in this report.

3. Flame sprayed zinc reduces the corrosion rate of steel embedded in concrete. Since this effect is observed in the absence of connections between the embedded steel and the zinc surface metal, at least part of the effect must be due to blocking oxygen ingress to the steel.

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The Development of a User Inclusion Strategy For CLCS Display Design

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Contract Number NASA

July 31, 1997

The Development of a User Inclusion Strategy For CLCS Display Design

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ABSTRACT

This report summarizes a ten week effort to evaluate the software development process in the CLCS for the presence of user inclusion in the design operation. A background is presented that highlights the value of achieving usability through user inclusion, progress-to-date is described, and future work is suggested so that a user inclusive design environment can be accomplished.

1.0 INTRODUCTION

1.1 Introduction to Usability and User Inclusion

A user interface represents the sum total of all design decisions made to enable humans to use a computer product. It is generally composed of input devices, output devices, visual displays, auditory displays, and tactile displays. The challenge for software developers is to construct and integrate the various components of the interface to enable it to be highly usable. An interface that is considered usable provokes high levels of user performance and acceptance. User inclusion is the primary vehicle developers use to learn everything they need to know from the users' perspective to design a highly usable computer interface. In order to accomplish usability, users must be involved in every stage of the design process so that qualitative and quantitative assessments can be made of users' performance with, and acceptance of, the interface.

Usability is a major software development cost factor. In fact, about 20-60% of the code written during software development pertains directly to the user interface (Perlman, 1997). Inadequate use of usability engineering methods in software deployment projects have cost the US economy about $30 billion per year in lost productivity (Landauer, 1995). Thus, early detection of problems with the interface is critical before major investments in time and manpower have been made. Furthermore, fixing the problems early in the development process is relatively easy from a coding perspective as opposed to fixing them later in the process. Creating highly usable interfaces is also cost effective because users will be more productive and more willing to use the interfaces to their full potential. In addition to the cost justification for usability, there are several motivating factors for embracing the concept of user inclusion in the software development process. Developers have inadequate intuition about quality when it comes to interface design. They tend to overestimate and underestimate user performance when attempting to make such predictions. This arises from the fact that developers are not ordinary users and are too close to the development process to be able to see things from the users' perspective.

1.1 Introduction to CLCS

The Checkout and Launch Control System (CLCS) at Kennedy Space Center (KSC) combines personnel from United Space Alliance (USA), Lockheed Martin, Boeing, and NASA. Software developers in CLCS are engaged in a large scale software development effort that involves creating visual displays for a large variety of applications and tasks. The user interface development tool that is being used is *SL-GMS*, a data visualization tool that provides dynamic data representation and visualization within a graphical user interface. First, designers use a drawing editor to design static displays with standard or custom objects. Then, dynamic behavior is attached to the objects (Valaer & Babb, 1997). Given the current CLCS environment, a unique opportunity exists to instantiate fundamental usability engineering methods into the visual display design process.

1.2 Objectives

This report describes a ten week effort to evaluate the existing software development environment for the presence of user inclusion. Given that the investigator's long-term goal is to develop a user inclusion strategy that can be utilized throughout all phases of the software development process in CLCS, a background describing usability and user inclusion will be provided as well as the progress to-date and the activities required in the future to accomplish this long-term objective.

2.0 BACKGROUND

Usability is a coveted entity in software development. Generally, designers value usability in a conceptual sense and ponder what would make a display more usable as displays are developed. Unfortunately, user inclusion is not recognized as the primary vehicle to achieve usability because it is not understood and it is mistakenly perceived as time-consuming and costly. Ben Shneiderman, recognized worldwide as a leader in human-computer interaction, states (1998),

> *"Many software development projects fail to achieve their goals. Some estimates suggest that the failure rate is as high as 60 percent, with about 25 percent of projects never being completed and perhaps another 35 percent only achieving partial success. Much of this problem can be traced to a lack of attention to design issues during the initial stages of development."*

Shneiderman (1998) describes The Logical User-Centered Interactive Design Methodology (LUCID) (Kreitzberg, 1996) which identifies six stages in a user-centered design methodology that can be employed to counteract the grim statistics cited above.

Stage 1: Develop the product concept
- create a high concept
- establish business objectives
- set up the usability design team
- identify the user population
- identify technical and environmental issues
- produce a staffing plan, schedule and budget

Stage 2: Perform research and needs analysis
- partition the user population into homogeneous segments
- break job activities into task units
- conduct needs analysis through construction of scenarios and participatory design
- sketch the process flow for sequences of tasks
- identify major objects and structures which will be used in the software interface
- research and resolve technical issues and other constraints

Stage 3: Design concepts and screen prototypes
- create specific usability objectives based upon user needs
- initiate the guidelines and style guide
- select a navigational model and design metaphor
- identify the set of key screens: login, home, major processes
- develop a prototype of the key screens using a rapid prototyping tool
- conduct initial reviews and usability tests

Stage 4: Do iterative design and refinement
- expand key-screen prototype into full system
- conduct heuristic and expert reviews
- conduct full-scale usability tests
- deliver prototype and specification

Stage 5: Implement software
- develop standard practices
- manage late stage change
- develop on-line help, documentation and tutorials

Stage 6: Provide rollout support
- provide training and assistance
- perform logging, evaluation, and maintenance

The key to the success of this methodology is that usability requirements are adequately specified, that prototypes are constructed quickly and cheaply, and that usability evaluations are conducted in an iterative manner so that usability specialists can measure whether the design is better or worse than it used to be. This design methodology should be coupled with a collection of solid guidelines and standards that address general display design issues. A good example of such guidelines is Shneiderman's (1998) Eight Golden Rules of Interface Design:

1) Strive for consistency
2) Enable frequent users shortcuts
3) Offer informative feedback
4) Design dialogs to yield closure
5) Offer error prevention and simple error handling
6) Permit easy reversal of actions
7) Support internal locus of control
8) Reduce short-term memory load

3.0 Accomplishing User Inclusion in CLCS

In order to ultimately accomplish user inclusion in the display development efforts in CLCS, the environment needed to be evaluated for current user inclusion practices. Based upon the degree of inclusion, a strategy could then be developed for current and future development efforts.

The first step in the inclusion evaluation was to determine how requirements were identified and to what degree they reflect user needs and to what degree they are simply system specifications. The second step was to identify the design dilemmas that developers were faced with as they constructed displays to determine if there were any commonalties among developers within groups or between groups. The third step was to conduct a usability workshop for developers to educate them about user inclusion and to address specific design dilemmas in a participatory manner. The fourth step will be to develop and facilitate user-developer focus groups where the mission is preference-based and performance-based usability testing. The fifth, and final step, will be to construct a user inclusion strategy document that can serve as a template for subsequent development work for CLCS.

3.1 User requirements

Upon our arrival at KSC on May 27, 1997, the requirements specification process has been completed. The outcome of that effort was a series of domain-specific requirements documents. An example is the HMF Application Software Functional Requirements Document (FRD). The FRD states that its purpose is to "establish the requirements for the Orbital Maneuvering System/Reaction Control System (OMS/RCS) Application Software Set in the Hypergol Maintenance Facility (HMF) as well as reflect the needs of the users." The application software set requirements comprise pages 4 through 80 of the FRD. The requirements for the displays and controls (pertaining to interface usability) comprise pages 81 through 84. Based upon conversations with developers, the FRD is quite useful for the application set requirements. However, it was found not as useful for the actual design of the displays and controls. Thus, developers have relied upon other style guides and intuition for actual display design.

3.2 Identification of design dilemmas

Design dilemmas were identified through discussions and interviews with developers in various application software domains and through discussions and interviews with users in various domains. In the context of these discussions, partially constructed displays were examined and evaluated. Design dilemmas were classified as being either "macro-level issues" or "micro-level issues." Macro-level issues concerned more global, across domain issues and micro-level issues concerned more domain-specific issues.

3.2.1 Macro-level design issues

Selected issues include dilemmas concerning windowing, peripheral choice, and data representation. Developers and users were concerned with the global decision to embrace a windows environment without considering the usability implications associated with such a decision. For example, task-based evaluations have not been conducted to determine how much windowing is sufficient and what the effects are of reduced window size on data visibility and the users' ability to process the information on the screen.

Applications are currently being constructed with the intention of using the mouse as the input peripheral. Yet, research has shown that mouse input can be less accurate and slower than keyboard input. Users seem particularly concerned that mouse entry may introduce a new error component to the interaction.

Data representation was a commonly cited dilemma by developers. Specifically, there is uncertainty about whether data should be coded alphanumerically, numerically, or in some cases, dual coded. Many discussions ensued about this point and it was concluded that usability testing would answer these questions.

3.2.2 Micro-level design issues

It is impossible to characterize the countless micro-level design issues that were uncovered during our investigation. What follows is a list of the most commonly cited micro-level design dilemmas that were discussed.

1) dynamic valve representation
2) visual differentiation between different valve types
3) background color schemes of the displays
4) color choices for reverse video
5) mated versus unmated quick disconnect representation
6) flow representation in pipes
7) pipe width choices
8) dialog box design

3.3 Usability workshop

On July 7, 1997, the investigator conducted a usability workshop that was titled, "Computer Interfaces: Iterative Design and Evaluation." Approximately 20 developers participated in the workshop. The first half of the workshop consisted of a presentation designed to introduce and reinforce the principles of user centered design. The second half of the workshop consisted of a participatory design experience where participants had an opportunity to engage in low fidelity prototyping and usability testing.

3.3.1 Results of the usability workshop evaluation

The workshop was received quite positively as evidenced by the results of an evaluation that was circulated to the participants after the workshop. The results of the usability workshop evaluations are as follows:

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1. How useful was the information provided in this seminar for performing your job? (average=5.5/7.0)

    1   2   3   4   5 **X** 6   7
not useful   very useful

2. How would you rate the overall organization of the seminar? (average=6.4/7.0)

    1   2   3   4   5   6 **X** 7
unorganized   very organized

3. Which information did you find most useful?

analysis - 1 yes response
design - 7 yes responses
implementation - 7 yes responses
evaluation - 7 yes responses

4. Which topics were not covered that you wish had been covered?

- "published studies and texts on human factors"
- "Issues dealing with user conflict"
- "Trade-off analysis of user interaction choices"

5. If given the opportunity again, would you attend the seminar?

100% responded yes

6. How useful was the participatory design portion of the seminar? (average=6.3/7.0)

    1   2   3   4   5   6 **X** 7
not useful   very useful

7. Additional comments:

-"very well done!"
-"participation was enjoyable and educational."
-"loved the hands-on component."

The workshop accomplished more than simply good reviews, however. It opened the lines of communication between users and developers, between developers and the faculty fellow and between users and the faculty fellow. Subsequent to the workshop, the fellow received regular requests from user groups and developer groups to discuss usability, evaluate displays and initiate paper prototyping activities.

3.3.2 Example of paper prototyping efforts already underway at KSC

Conversations with developers revealed that John Dockendorf, Senior Systems Analyst in The Advanced Software Lab, had already engaged in user inclusion while developing displays during the Automation of S9002. This was accomplished through an iterative design effort that involved six paper prototypes and five design iterations.

In this process, subjective preference assessments were elicited from users regarding specific displays under development. The users were presented with paper displays and asked to make suggested design improvements. Suggestions were noted on the paper prototype and then incorporated into the display design in the next iteration. John's success with this process serves to reinforce the claim that there is significant value in iterative evaluation through paper prototyping.

3.4 Future work: usability testing

Currently, users have the opportunity to express their needs and desires through a series of Design Panel Meetings. The purpose of the meetings is to establish requirements, elicit feedback on initial displays and approve displays in their final design stages. Unfortunately, users do not have the opportunity to work one on one with developers during these panels to proactively exchange ideas and engage in dialogue about the designs.

Task-based evaluations that include usability tests and are designed to engage the users in actual display use are sorely needed in the CLCS design process. Such a mechanism would tremendously enhance the developers' ability to recognize good and bad aspects of the display design.

3.5 Future work: a user inclusion strategy

A comprehensive user inclusion strategy would provide developers with a process-oriented approach to user inclusion. It would spell out, for every stage of the development process, what needs to happen to ensure good display design. The process would be heavily laden with iterative prototyping and usability testing of the human-computer interfaces. It would demonstrate how statistically valid sample sizes could be employed to empirically determine the usability of the interfaces. The strategy would appeal universally to all design areas and could serve as a template for software application development across all areas of CLCS.

4.0 References

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CAN HYDROPONIC LIFE SUPPORT SYSTEMS RESIST INVASION BY PATHOGENS?

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ABSTRACT

Hydroponic plants are grown at KSC to develop life support capability for long-term space missions. Such systems can be invaded by plant- and human-pathogens, potentially causing plant disease (and consequent disruption of life support) or human disease. This project experimentally tested one method of resisting pathogen invasion: the presence of complex microbial communities in the plant root zone (rhizosphere). For both plant and human-pathogens, data collected to date show microbial community complexity resisted pathogen invasion, independent of microbial density effects. This result suggests that attempts to mitigate pathogens and their effects in hydroponic life support systems should include early inoculation with complex microbial communities, and provides experimental evidence for ecological theory and the value of complexity in ecological systems.

CAN HYDROPONIC LIFE SUPPORT SYSTEMS RESIST INVASION BY PATHOGENS?

David G. Jenkins, Ph.D.

1. INTRODUCTION

Ecological theory has long held that more complex communities should resist invasion better than less complex communities (Elton 1958). Complexity was originally intended to refer to the number and variety of interactions among species within a community, but such interactions are difficult to quantify and record. Many researchers have studied the number of species present, and trophic levels (e.g., primary producers, primary consumers, etc.) with mixed results. The number of species does not equate to the complexity of interactions among those species: consider a room full of people that interact regularly with each other vs. the same room of people that refuse to work with each other. Despite the many insights gained through such studies, the original concept of complexity and invasibility has not been tested experimentally and separately from the partial measures of complexity (species, trophic levels, etc.).

This project experimentally tested the relationship between ecological community complexity and invasibility. It did so without measuring species richness or trophic interactions. Instead, it used the patterns and richness of carbon source use by the microbes to assess phenotypic complexity, and used DNA extracted from the communities to assess genetic complexity. Other data were collected as well (described below).

It should be noted that many of the samples generated as a result of this project remain to be processed and analyzed. This project consisted of 4 separate experiments, the first of which began June 4 and and the last ending August 1. Partial results and analyses of all experiments are available at this time, and the last experiment to be conducted (Pseudomonas Invasion) is the least complete at this time (August 6): few results and essentially no discussion on that experiment can be presented in this report. It should also be noted that further analysis may lead to different conclusions than those stated in this report based on preliminary and partial findings.

2. MATERIALS AND METHODS

Four separate experiments were conducted and were organized as 2 pairs of sequential experiments. The first pair of experiments was Complexity 1 (C1) and *Pythium* Invasion (Pyth). The second pair of experiments was Complexity 2 (C2) and *Pseudomonas aeruginosa* Invasion (Pseu).

The overall goal of each experiment pair was to: 1st develop a gradient of microbial community complexity in hydroponic rhizospheres; and 2nd, use that gradient to set up an experiment testing the effects of complexity on rhizosphere invasibility by pathogens. The complexity gradient was established by diluting a rich microbial community, on the assumption that a community consists of species that are not equally dense. A dilution would therefore eliminate some, initially rare species. However, dilution also decreases

density, meaning that diluted samples would vary in both complexity and density. To equilibrate density while retaining complexity differences, diluted samples were inoculated into plant rhizospheres and permitted to grow . The end result was intended to be a series of microbial rhizosphere communities that varied in complexity but that were all similar in density.

All experiments used the basic procedures summarized below. However, each experiment was unique in its purpose and experimental design: individual experiments are explained as to their design and variations from the basic procedures below.

Basic Procedures

Wheat (*Triticum aestivum* cv. Apogee) seeds were sterilized with HgCl and hydroxylamine hydrochloride (Morales 1995) and sprouted in sterile DI H_2O for 5 days. All preparation and sampling of hydroponic systems described here was performed using sterile technique and sterilized materials. Three seedlings were placed in split foam plugs with a strip of 60-μm Nitex mesh adjacent to the seedling and roots. The foam plugs were inserted into holes in the screw-cap top of a 2.2 L Nalgene jug, and the jug was sealed. Jugs contained 2.2 L of sterile, ¼-strength Hoagland's nutrient solution. Wicks permitted seedling roots access to medium until roots grew long enough to contact medium themselves. Plants were then placed in a growth chamber equipped with sodium lamps (mean intensity = 206 μmol $s^{-1}m^{-2}$) on a 20L:4D photoperiod. Light intensity was increased to 591 μmol $s^{-1}m^{-2}$ after 3 days in order to mitigate seedling shock. Humidity was maintained with DI H_2O mist between 48 and 89 % RH. Temperature was maintained at 23 C.

Plants were grown for various intervals, depending on the experiment (see below), after which plants were sampled. Roots were cut below the seed and placed into a flask containing 50 or 100 mL DI H_2O (depending on root size) and approximately 5 mL of 5mm-diameter glass beads. Flasks were shaken for 2 min to extract attached microbes. The suspension was filtered through a 6 μm effective pore size glass fiber filter (Whatman #3) to remove plant debris and eukaryotic organisms from further analyses. Filtrate was then processed for the following analyses:

- Community-Level Physiological Profile (CLPP). This analysis uses BIOLOG plates (Garland and Mills 1991) to analyze metabolic potential of microbial communities, and provides a measure of phenotypic complexity of a community.
- Genetic complexity. DNA was extracted from microbial communities per the protocol provided with Qiagen Genomic DNA Isolation kits. DNA was prepared for analysis by reassociation kinetics, which uses the absorbance properties of double- and single-stranded DNA to analyze complexity of a DNA sample (Britten and Kohne 1968, Johnson 1985).
- Culturable bacteria. Dilutions were spread on R2A agar plates and cultured at 37 C for 96 hrs. Total colony-forming units (CFUs) and number of CFU's per each colony type were analyzed.
- Total bacteria density. Subsamples were preserved for later microscopic enumeration, using acridine orange (AO), according to standard procedures.

- Active bacteria density. Subsamples were stained with CTC and preserved for later enumeration, according to standard procedures. CTC stains actively respiring cells, permitting counts of active cells (vs. total cells by AO).

Plants were also dried ≥ 24 hr at 70 C and weighed for root and shoot dry weights. Nutrient medium was analyzed for pH, dissolved oxygen, conductivity, and volume.

Complexity 1

The Complexity 1 experiment consisted of inoculation of a soil suspension dilution series into sterile hydroponic rhizospheres of young seedling wheat plants (cv Apogee). Plants were then grown, harvested, and analyzed as above. Selected dilution treatments were then used as inocula for the *Pythium* experiment.

Soil samples were obtained from a mature live oak canopy forest (Happy Creek Rd) on the Merritt Island National Wildlife Refuge. Samples were collected by pushing open, sterile 50-mL centrifuge tubes into topsoil. A plug of soil inside the tube was thus collected and sealed with a screw cap. Six samples were collected from arbitrarily designated points within the canopy. The soil samples were pooled and mixed, using sterile technique, upon return to the lab. Soil was then combined with sterile deionized (DI) water to make a slurry that could be accurately pipetted: the slurry contained 0.175 g soil / mL. This slurry was vortexed thoroughly to ensure dispersion of particles, and used as an inoculum for experiments. The soil slurry was used as a full-strength inoculum, and dilutions of 10^{-2}, 10^{-4}, 10^{-6}, and 10^{-8} were used to serve as inocula as well. Inocula (2 mL per jug) were added to rhizospheres prepared as described above.

Experimental units (jugs) were divided into 2 blocks: Block 1 was sampled at Day 21 and analyzed as above. Block 1 contained 3 replicates of each treatment, as did Block 2. CLPP results from Block 1 samples were used to decide which Block 2 treatments would be used as inoculum sources for the *Pythium* experiment. Block 2 was sampled at Day 22 and processed as above.

Pythium Invasion

Jugs and plants were set up as described above, except that experimental design was as shown in Table 1. In short, plant rhizospheres were inoculated at Time 0 with Lo or Hi complexity microbial communities from the Complexity 1 experiment. Control (No complexity) jugs were also established and not purposely inoculated, although bacterial contamination was possible. Some rhizospheres were also inoculated with *Pythium* at Time 0, and others were inoculated with *Pythium* after 1 week. Three replicates of each treatment combination were used. All plants were harvested after 20 days, as described above. Rhizospheres were also analyzed for *Pythium* by immunoassay (Agri-Screen ELISA multiwell kit; Neogen Corp., Lansing MI).

Table 1. Experimental Design of Pythium Invasion Experiment.

Residents	No Pythium	Pythium @ Day 0	Pythium after 1 Wk
No	No,No	No,P0	No,P1
Lo	Lo,No	Lo,P0	Lo,P1
Hi	Hi,No	Hi,P0	Hi,P1

Complexity 2

The Complexity 2 experiment was similar to the Complexity 1 experiment, in that a dilution series was made of a microbial community, the dilutions were inoculated into rhizospheres, and plants were harvested after some time, with root extracts used as inocula for further experimentation (*Pseudomonas* invasion). A full-strength microbial community was generated by mixing filtered, full-strength extract from the Complexity 1 experiment with bioreactor effluent (ISAB #3). A dilution series of 10^{-1} through 10^{-5} was generated from this full-strength mixture and used as inocula for the Complexity 2 experiment. Non-inoculated rhizospheres were also used as controls. Four replicates of each dilution (including full-strength) were used, and 3 replicate controls were used.

Plants were grown for 2 weeks, after which samples were processed as described in Basic Procedures above. As in the Complexity 1 experiment, filtered extracts of full-strength and 10^{-4} dilution treatments were used as Hi and Lo complexity inocula, respectively, for the *Pseudomonas* invasion experiment.

Pseudomonas Invasion

Jugs and plants were set up as described above, except that experimental design was as shown in Table 2. Thise experimental design permitted evaluation of the effects of microbvial community complexity and community succession (and/or palnt age) on Pseudomonas invasibility. In short, plant rhizospheres were inoculated at Time 0 with Lo or Hi complexity microbial communities from the Complexity 2 experiment. Control (No complexity) jugs were also established and not purposely inoculated, although bacterial contamination was possible. Some rhizospheres were also inoculated with *Pseudomonas* at Time 0, after 1 week, and after 2 weeks. *Pseudomonas aeruginosa* was genetically engineered to contain the lux gene (University of Guelph, provided under agreement to University of South Florida). The lux gene-bearing organisms luminesce in the presence of aldehyde, and therefore provide a method to assay population density of invading organisms separately from *P. aeruginosa* that may already reside in the rhizosphere. In all cases of *P. aeruginosa* inoculation, plants were harvested 1 week after *P. aeruginosa* addition. Plants not inoculated with *P. aeruginosa* were also harvested at the same time to serve as controls. Three replicates of each treatment combination were used.

Table 2. Pseudomonas Invasion Experimental Design.

Treatment	1 Week	2 Weeks	3 Weeks
No/Lo/Hi, No Pseu	————————▶		
No/Lo/Hi, w/ Pseu	P————————▶		
No/Lo/Hi, No Pseu	——————————————————▶		
No/Lo/Hi, w/ Pseu	————————————P———————▶		
No/Lo/Hi, No Pseu	———————————————————————————————▶		
No/Lo/Hi, w/ Pseu	———————————————————·————————P————————▶		
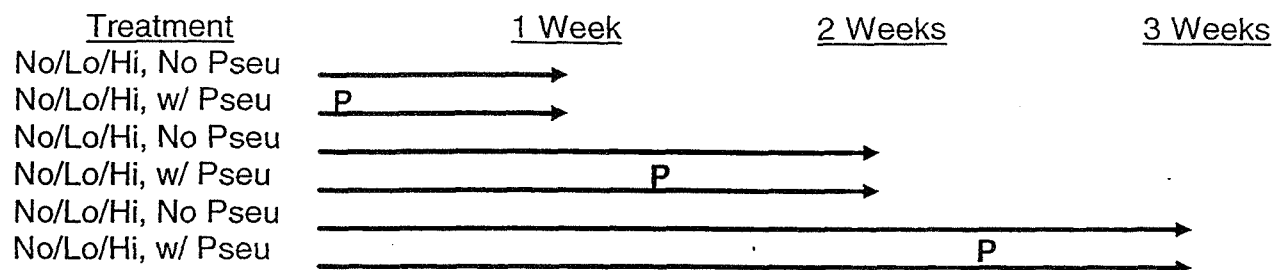
All plants were harvested according to the schedule shown in Table 2; plants were grown 7, 14, or 21 days, and *P. aeruginosa* was in rhizospheres for 7 days in each case. Samples were processed as described above, plus enumeration of *P. aeruginosa* density by Cetimide + Rifampin selective media plates and by fluorescence luminometry of *P. aeruginosa* labelled cells by a modified liquid scintillation detector.

3. RESULTS AND DISCUSSION

Data collected to date indicate that both experiments designed to generate a complexity gradient (Complexity 1 and Complexity 2) were successful. Figures 1 and 2 are principal component analyses of CLPP data from Complexity 1, based on average well color development (AWCD). In both figures, the Full, 10^{-4}, and Control treatments are distinctive. These analyses indicate that dilution series of a single community generated distinct microbial communities that metabolized carbon sources in different patterns, and that those unique patterns persisted through a second inoculation and growth on rhizospheres (during the follow-up experiment). This persistence demonstrates that differences among treatments were not due to transient inactivity of certain microbes; instead, these results indicate that certain microbes had been diluted away and that this treatment affected community complexity throughout the paired experiments.

In addition to analyses of AWCD, CLPP data were analyzed for the number of carbon substrates metabolized (Figure 3). This analysis reinforces the conclusion that a complexity gradient was formed during Complexity 1: more dilute communities had less metabolic capabilities than more concentrated communities, despite having grown to equal densities on plant roots (Tukey's HSD, $\alpha = 0.05$). The gradient in Figure 3 is not an effect of density: microbes were diluted, inoculated, and grown on rhizospheres prior to this analysis. This was the desired effect of growing microbes on plant rhizospheres and permitted tests of complexity effects on invasibility without confounding effects of density differences.

Finally, evidence of a complexity gradient was obtained after the Pythium Invasion experiment by making dilutions of the microbial community extracts from No, Lo, and Hi complexity, No *Pythium* treatments. Those diluted samples were processed for CLPP, and number of carbon sources were tallied as before. The goal was to detect an extinction series of rare species, if present, in the Hi complexity treatments, a lesser extinction series in the Lo complexity treatments, and potentially no extinction series in a very simple community (No complexity), in which but a few species may exist. Figure

4 shows the result of that dilution series. Clearly, the Hi complexity treatment exhibited the greates extinction of carbon source use with dilution, indicating a loss of physiological capability with dilution. The Lo complexity treatment exhibited a lesser extinction of carbon source use, comparable to the loss shown by the No complexity treatment. Also, the Lo and Hi treatments had a greater number of carbon sources used at full strength than the No treatment, and Lo and Hi were almost identical at that point. This result indicates a greater complexity in the Hi than in the Lo treatments, and that the Lo treatment was likewise more complex than the No treatment.

Complexity 2 Experiment data are still being collected and analyzed, but available results of the follow-up *Pseudomonas* Invasion experiment (presented below) are consistent with the presence of a complexity gradient similar to that of Complexity 1.

The *Pythium* Invasion experiment yielded results that showed: (a) *Pythium* was most infective to plants that were not inoculated with microbial communities, (b) microbial complexity resisted *Pythium* invasion of wheat plants, and (c) young plants were more vulnerable to *Pythium* infection than older plants with rhizosphere microbes. The experimental design permitted and analysis of variance for the Resident (No, Lo, Hi), *Pythium* (None, at Time 0, after 1 Week), and Resident X *Pythium* interaction. The interaction term was of particular interest, because the experiment was designed to test for the effects of residents on *Pythium*.

Plant-related variables analyzed in the Pythium experiment included: root, shoot, and total dry weights, and number of tillers (shoots) produced. Analysis of variance p values are shown in Table 3; all p values < 0.05 indicate significant effects of the experimental treatment. The only non-significant treatment effect was the interaction of residents and *Pythium* treatments on number of tillers, which was marginally significant (p=0.07). The general significance of Resident X *Pythium* interaction effects demonstrate the importance of resident treatments (No, Lo, and Hi complexity) on the effects of *Pythium* on plants.

Table 3. ANOVA p values for Pythium Invasion Experiment.

Variable	Residents	Pythium	Res X Pyth
Root DW	0.008	0.012	0.022
Shoot L	0.0001	0.003	0.0002
Shoot DW	0.0004	0.001	0.002
Total DW	0.0004	0.001	0.003
Tillers	0.0001	0.003	0.07

The interaction of the two main treatments is also apparent in Figure 5, which shows root dry weights from the *Pythium* Invasion experiment. The negative effects of *Pythium* were most pronounced in the plants that received *Pythium* at Time 0, but those effects were most severe in treatments with No microbes added, and less severe to negligible in treatments with Lo or Hi complexity of microbial communities. Because the "No" complexity treatment included bacteria that colonized rhizosphere by contamination, the complexity gradient may be considered as "Very Low," Low and High complexity.

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The effect of microbial complexity on *Pythium* success in the rhizosphere is also indicated by Figure 6, which shows the raw (uncalibrated as yet) absorbance values from the *Pythium* immunoassay relative to root dry weights. The negative slope of the regression demonstrates that *Pythium* density (as indicated by immunoassay absorbance) was related to root vigor (mass). Also, the pattern of treatments within the regression demonstrate the effect of treatments (resident complexity and *Pythium* timing) on *Pythium* density, and therefore root mass. Plants that were not protected by complex microbial communities had greatest *Pythium* density and lowest root mass. Also, Pythium inoculation after a week of microbial community development and/or plant growth was less harmful to plants than inoculation of new microbial communities on young plants.

In summary, data collected to date from the *Pythium* Invasion experiment showed that microbial community complexity in plant rhizosphere resisted infection by this potent pathogen. The effect of microbial community inoculation was not due to bacterial density differences among treatments: experimental design maintained similar densities while establishing different complexities. This result is important for several reasons:

(1) Community complexity was indicated as the factor that resisted invasion, not other factors (e.g., density, key species presence) that might be otherwise expected to modify invasibility. Although complexity has long been considered related to invasibility (Elton 1958), complexity alone has not been empirically tested to date. This experiment comprised a novel approach to an old question, and provided clear results. As such, it should be a major contribution to ecological scientific literature upon completion of remaining data acquisition and analysis.

(2) Complexity was measured by techniques independent of traditional measures (eg., species richness, food web connectedness). Therefore, the indications of complexity from this experiment are not confused with usual measures of ecological complexity. Indeed, such measures are not possible for microbial communities - many species cannot be cultured for identification, and trophic interactions are unknown. Complexity was assessed by physiological capability of the aggregate community, without concern with which species may individually or collaboratively provide those physiological signals. This result supports efforts to maintain ecological complexity *per se* (and by implication habitat diversity, species diversity, etc.) to provide better ecological services in natural resources.

(3) *Pythium* invasion, and its deleterious effects on plant growth, were resisted by having more complex microbial communities present. Pathogen infection of hydroponic life support systems is a concern for NASA. This experiment inhibited a pathogen from damaging plants; a pathogen that would wreak havoc in a plant-based life support system in space and that has caused difficulties in experiments in the Biomass Production Chamber at KSC. This result indicates that hydroponic plant production experiments would benefit from inoculation of rhizospheres with complex bacterial communities. Such inocula could be obtained from stock hydroponic rhizospheres that are maintained for that purpose, or from previous experiments.

The *Pseudomonas* Invasion experiment was recently completed, and most data are yet to be collected and analyzed. Data available to date include *Pseudomonas aeruginosa* density per gram dry weight of root (Figure 7). Those results indicate that complexity of the microbial community reduced population size of the invading bacteria, and that community complexity continued to exert an effect into the second week of community development and/or plant age. This result indicates that a complexity gradient was present and effective, and is consistent with the results of the Pythium invasion experiment. Of course, much data remains to be processed and analyzed.

4. CONCLUSIONS

Microbial community complexity resisted invasion by both a plant pathogen (Pythium) and a human pathogen (*Pseudomonas aeruginosa*). This preliminary conclusion confirms a long-running but untested ecological theory, and provides evidence to support development of an approach to controlling potential problems with plant- and human pathogens in bioregenerative life support systems based on hydroponic plant production. Further analysis of data from this project and additional experiments may confirm this conclusion, and would indicate that bioregenerative life support *ecosystems* could provide dependable, infection-resistant crops, water and air for NASA's mission.

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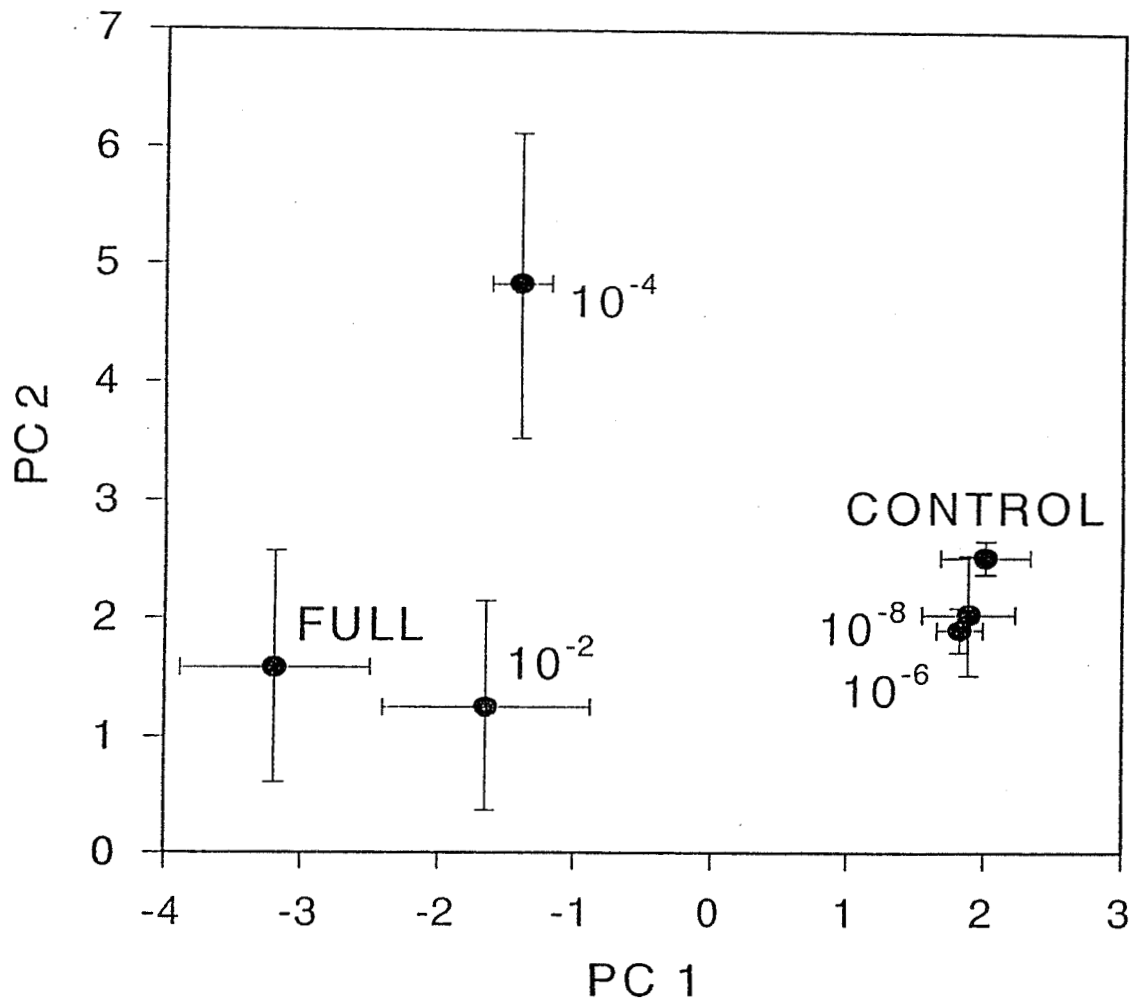
Figure 1. Principal Components Analysis of CLPP Data, Complexity 1 Experiment. See text for further explanation.
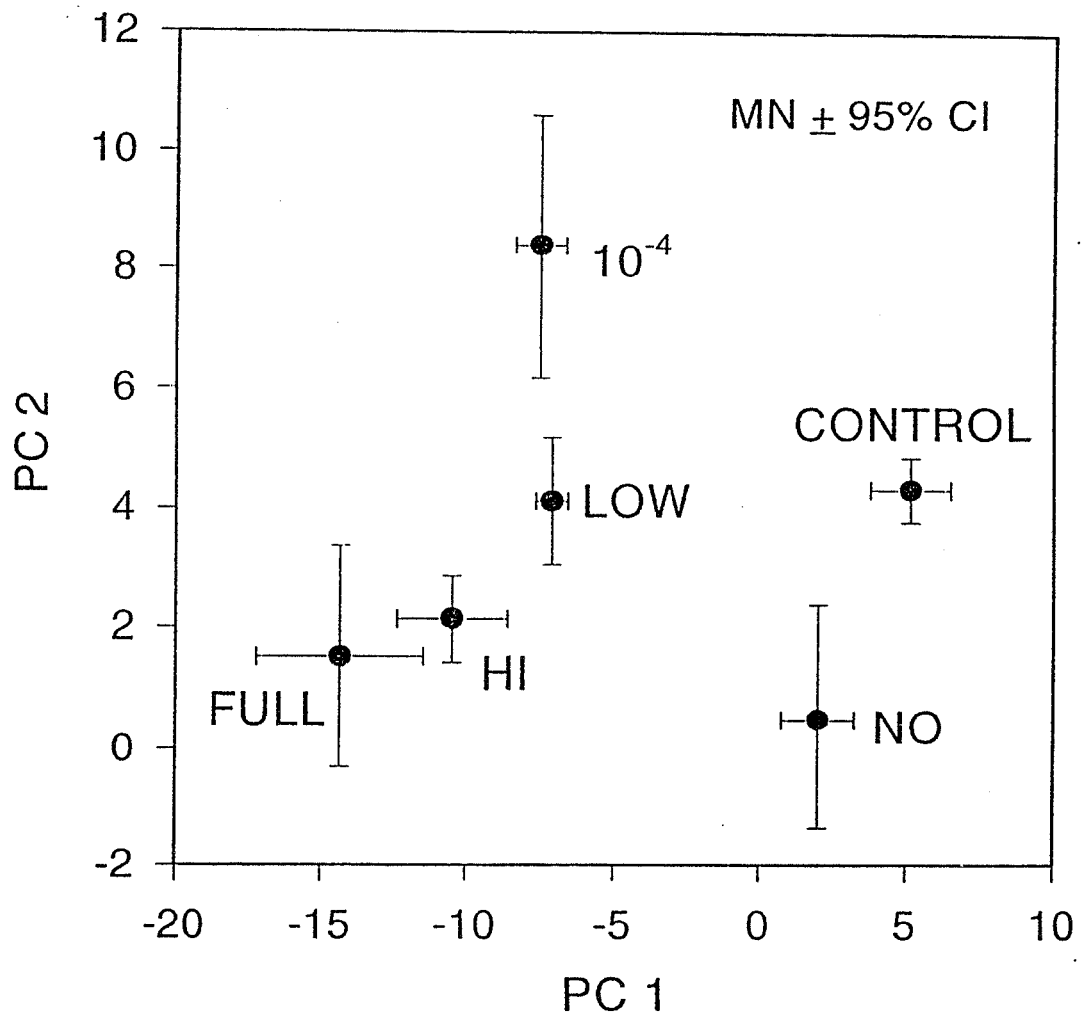
Figure 2. Principal Components Analysis of CLPP Data, Complexity 1 and Pythium
Invasion (non-invaded treatments) experiments. See text for further explanation.
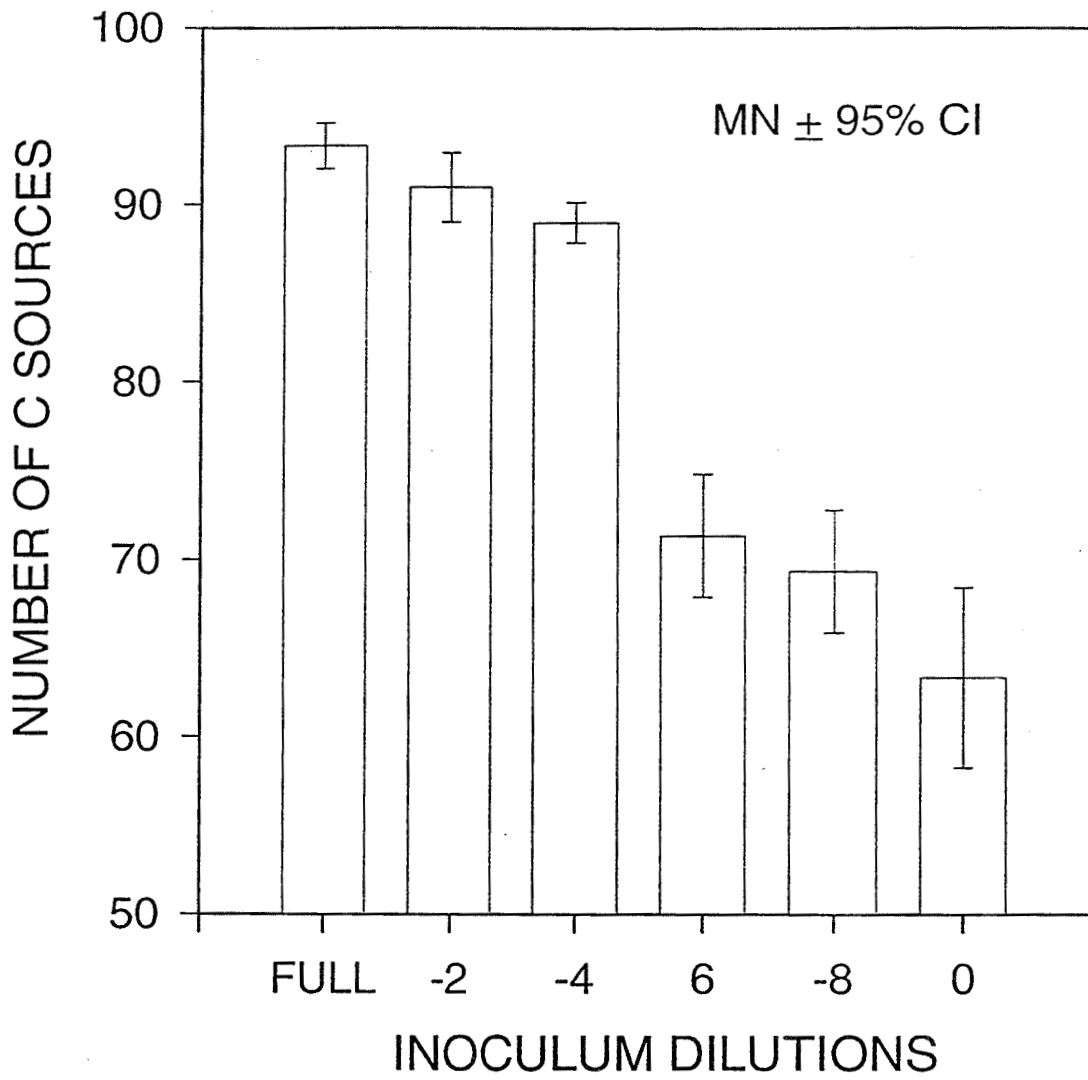
Figure 3. Number of Carbon Sources Used per Treatment, Complexity 1 Experiment.
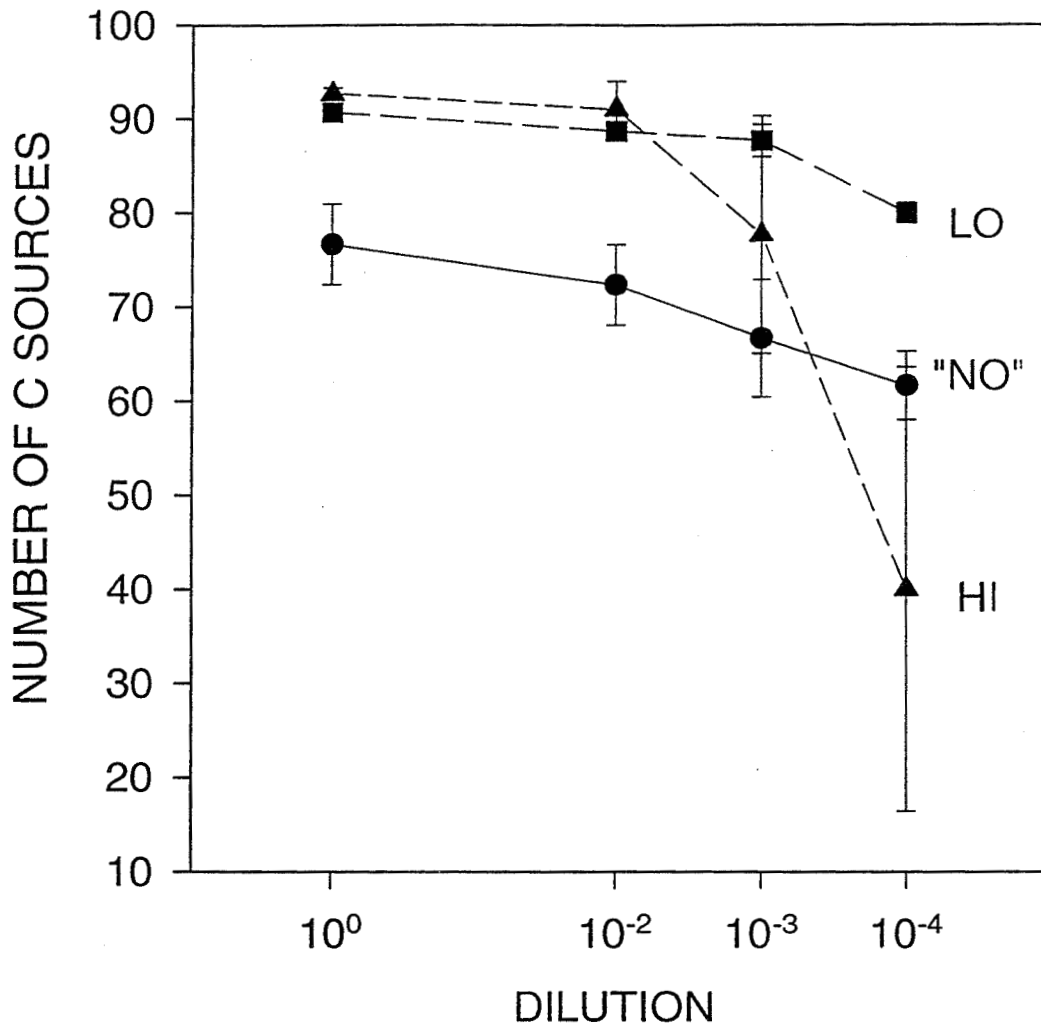
Figure 4. CLPP Carbon Source Use Across Dilution Gradient. Hi = Hi complexity, Lo = Llo complexity, No = No complexity treatments. Values are mean ± 95% CI. Note starting values (left) and slope of lines across dilutions.
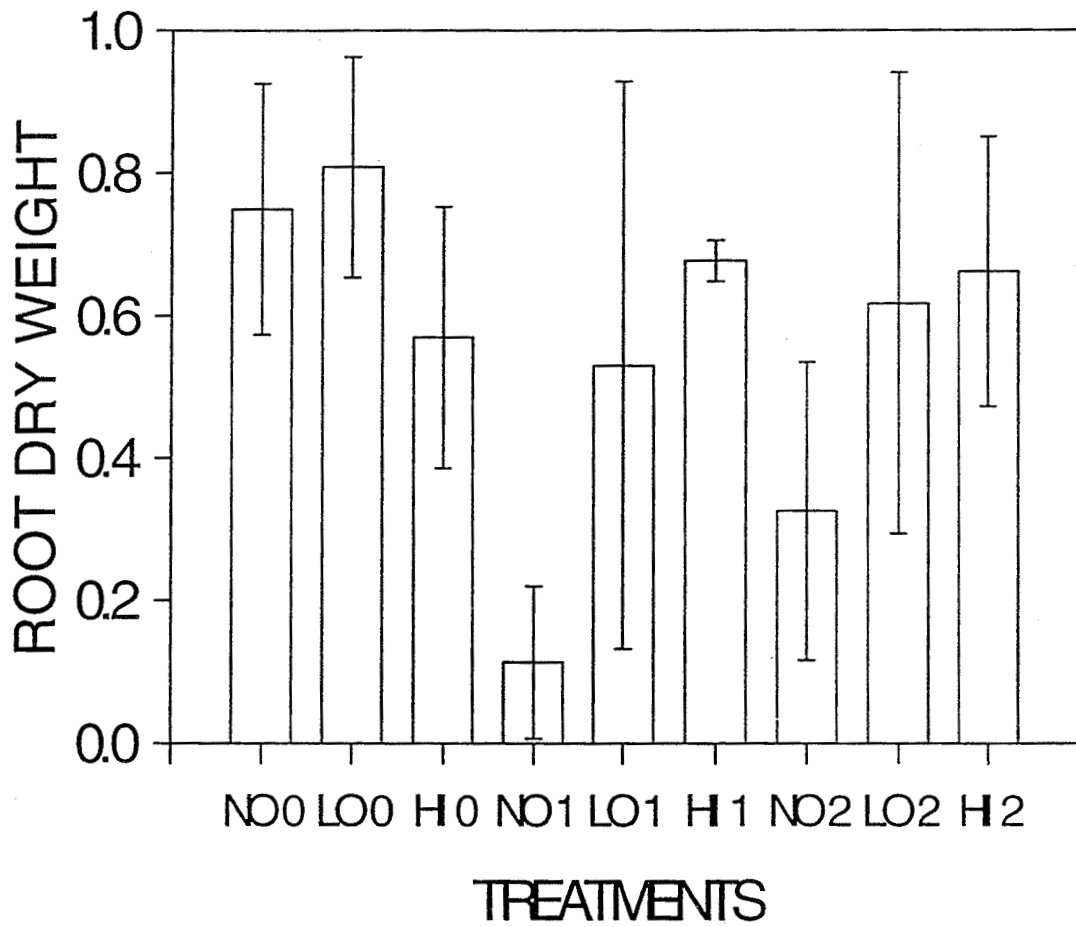
Figure 5. Effects of *Pythium* and Resident Treatments on Root Dry Weights. No = No residents added, Lo = low resident complexity, Hi = high resident complexity, 0 = No *Pythium* added, 1 = *Pythium* added at time 0, 1 = *Pythium* added after 1 week. Values are mean ± 95% confidence intervals.
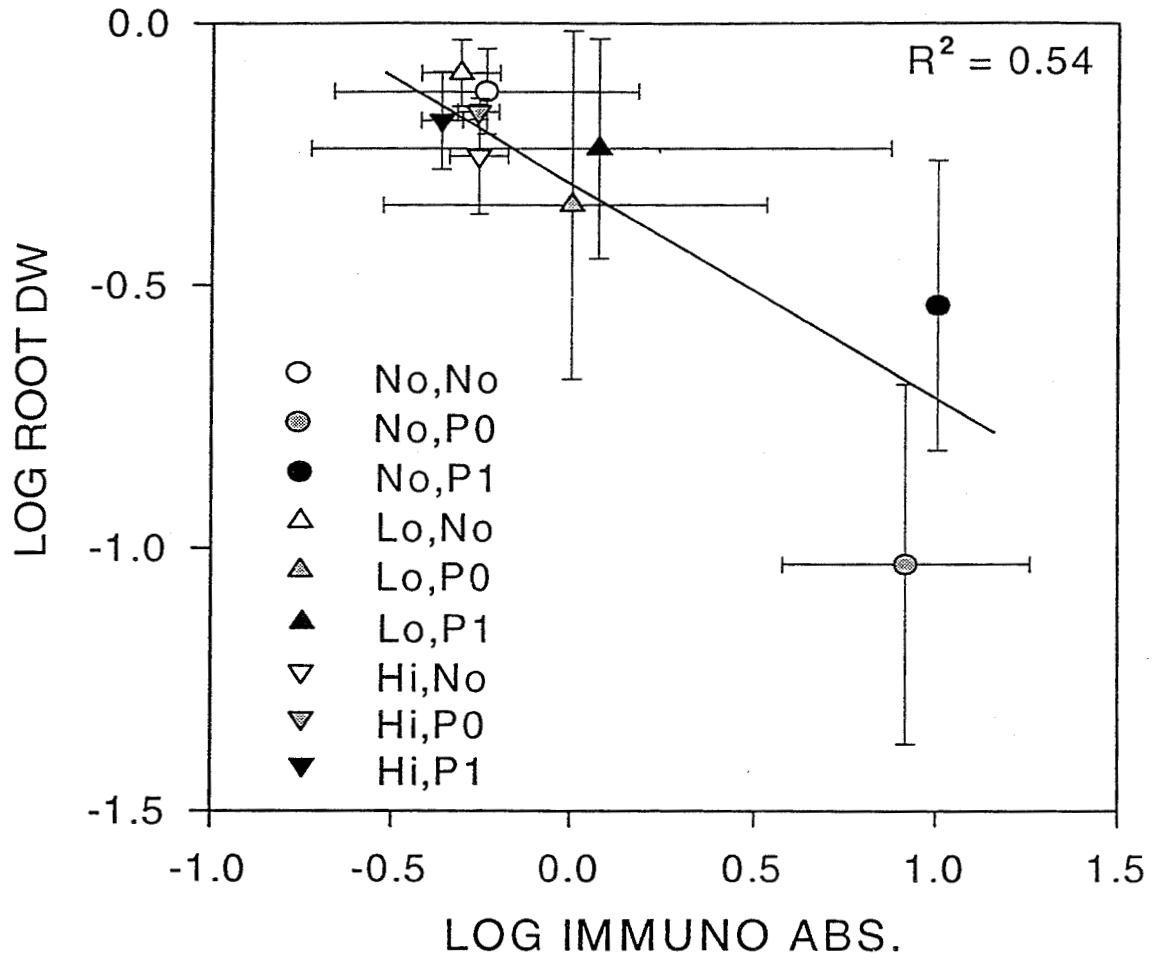
Figure 6. Pythium Immunoassay Absorbance Values Relative to Root Dry Weight. Symbols denote different treatment means ± standard deviation.
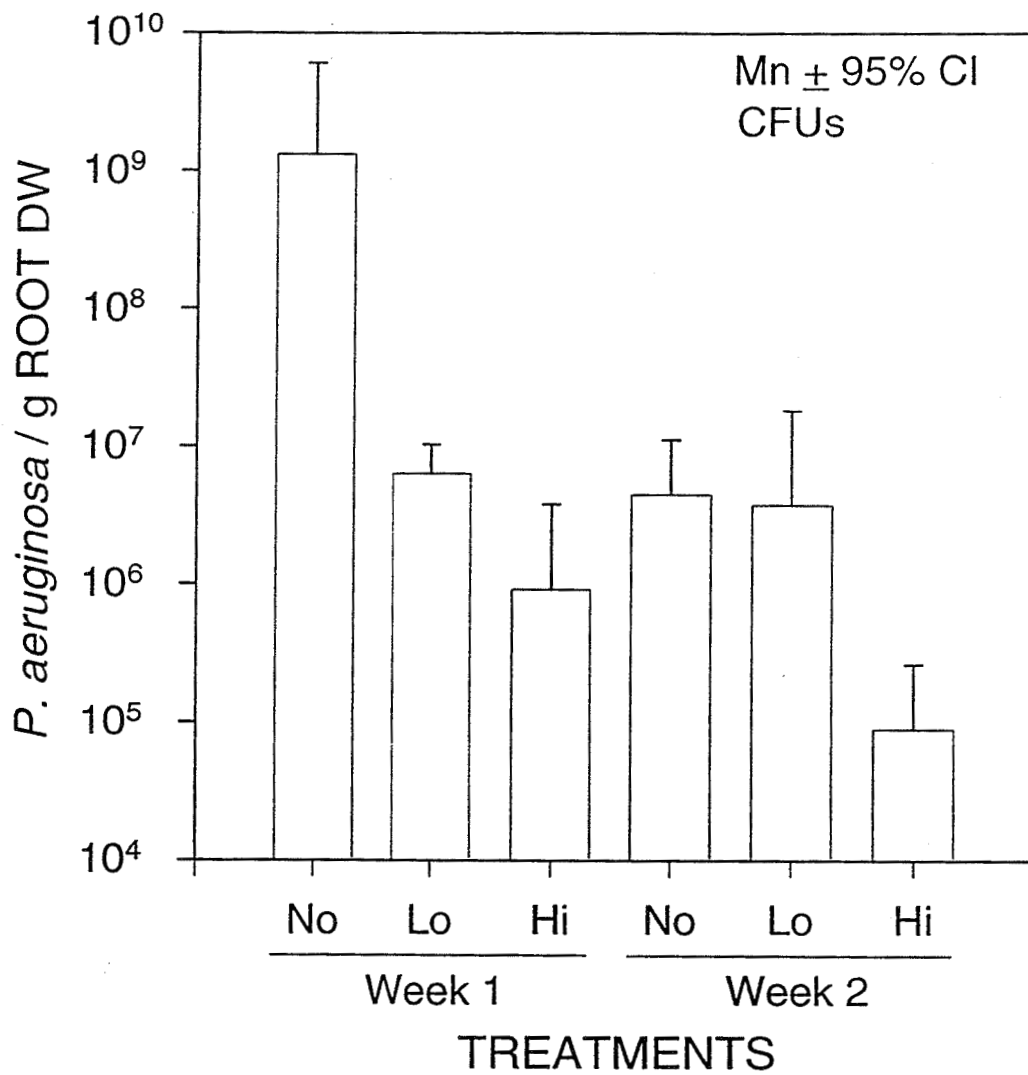
Figure 7. *Pseudomonas aeruginosa* densities per treatment. No, Lo, and Hi   refer
to Resident Complexity treatments.

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PROJECT MANAGEMENT FRAMEWORK TO ORGANIZATIONAL TRANSITIONS:
ENGINEERING A STRATEGIC MANAGEMENT SYSTEM

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ABSTRACT

The contribution of this paper is a process for applying (i.e., designing and implementing) a strategic management process in a technical, government agency undergoing a large scale change. Strategic management includes the processes of strategic planning, implementation planning, execution, performance measurement, and evaluation. Requirements for successful implementation of strategic management are developed using the evolution of strategic management efforts at the Kennedy Space Center. An overall conceptual model and implications are given. This overall conceptual model was developed from models used to understand, develop, communicate, and use a common framework to guide implementation of strategic thinking at KSC. Managers can use the results (conceptual model, process, and implications) to help implement a strategic management process unique to their organization. Change leaders can use the results to drive the change to a strategic management system. Researchers can use the results to further research the effect of different approaches to implementing strategic management on strategic management and organizational performance.

1. INTRODUCTION—THE CONTEXT OF KSC'S STRATEGIC MANAGEMENT EFFORTS

The Kennedy Space Center (KSC) as part of the National Aeronautics and Space Association's (NASA) efforts to perform "better, faster, cheaper" has begun a change to a strategic management process. This change is being driven by two forces. First, NASA is implementing a strategic management process to manage the Agency in synergistic fashion [6]. This implementation requires each center to be aligned with the Agency direction. Second, KSC is undergoing a large-scale organizational change effort. The drivers for KSC's change include: the reduction in NASA's budget, the development a space flight operations contractor (SFOC) for shuttle processing, and a definition of KSC's roles based on NASA's plans (e.g., strategic, HEDS, and enterprise). These drivers have led to the change in role of and reduction of the civil servants at KSC. KSC is implementing a strategic management process to define a new role aligned with changes in the Agency and to ensure KSC will be more proactive and forward looking in their planning activities.

The objective of this paper is to describe strategic management and to develop a set of recommendations on implementing a strategic management process. This paper aims to answer the question: "How can a technical, government organization successfully engineer (i.e., design and implement) a strategic management system?" To answer this question we will address the following sub-questions:
- What is strategic management?
- What are success criteria for implementing a strategic management process?
- What is a process for implementing a strategic management system?

The first question is answered via the literature with emphasis on the NASA Strategic Management process. Current literature focuses on the strategic management process and the "ten" steps to strategic management. We answer the second and third questions by extending this literature through the development of a conceptual model and related process. The model and process reflect the issues senior management is concerned about and needs to address during the implementation of strategic management. The issues are grouped into 1) organizational context 2) process of strategic management, 3) organizational support, 4) characteristics of outputs, and 5) characteristics of outcomes. The model provides an analysis of the steps necessary to make the strategic management process work in an organization. The purpose is to help managers understand the issues they need to address when changing to a strategic management process.

2. STRATEGIC MANAGEMENT

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 [6]. 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, strategic results, lessons learned, and corrective and preventative action steps.

Strategic planning is a group process by which the organization defines or refines the organization's mission (i.e., core business statement), vision (i.e., ideal future state), goals, and objectives of the organization. Part of the process involves understanding both the internal and external environments (e.g., strengths, weaknesses, opportunities, threats). Strategic planning through this disciplined process "establishes the long-term direction of the organization in the context of the 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 environment" [6]. The output of

strategic planning is an integrated set of "strategies, goals, objectives, action items, action teams, and action plans to improve performance" [7, p. 39]. 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 which will determine the progress of the planned actions. Implementation planning "provides the detailed performance planning and proposed resource allocation to implement the goals, objectives, and other organizational initiatives identified during the Strategic Planning process" [6, p. 5]. An organization uses the implementation plan to guide day-to-day behavior or execution.

Execution is the carrying out of the implementation plan. This process is "the means (activities and decisions) by which NASA produces outputs and outcomes for its customers" [6, p. 5]. Performance evaluation is the process by which the organization "measures whether the Agency achieved intended results as stated in its" plans [6, p. 5]. The use of performance measurement and evaluation produces tangible results which can be studies to produce lessons learned and recommendations on how to improve the organization and adjust the strategic plan.

3. METHODOLOGY

The methodology was designed to ensure a theoretically sound, valid model and process was developed which reflected KSC's unique environment, goals, objectives, and concerns. The methodology was also designed to address validity issues associated with conducting change studies in the field aimed at meeting a specific organizational need [2, 4, 5]. A goal of the project was to understand the unique KSC environment and to ensure the model and process reflected the concerns of KSC. Three types of studies were executed: literature reviews, internal studies, and external field studies. A theoretical, literature basis was used to develop conceptual models, interpret data from interviews, and elicit best practices. KSC internal studies focus on observations and interviews from individuals associated with implementing the strategic management process. A case study approach [8] is used to document and understand the planning efforts of KSC. External interviews with individuals who have implemented strategic management in other organizations provided lessons learned.

The case study focuses on three strategic planning efforts conducted at the Kennedy Space Center. The first strategic planning effort was led by two working groups of mid-level civil servants conducted over a one year time period. In this effort, a "business plan" group and an "implementation" group studied different strategic planning efforts at other companies, and interviewed senior management for their thoughts on the strategic direction of KSC. The initial results from this effort was a definition of four goals for KSC. These goals were shared with and agreed to by the senior management team. During later parts of the process KSC experienced significant change in the senior leadership of the center. Therefore, the results were not implemented but they did provide a major foundation for the next two planning efforts.

The second planning effort focused on developing an implementation plan for KSC. The effort was led by a senior manager and a group of key people from each organization. This effort lasted three to four weeks. The result was an implementation plan which contained a list of activities that KSC is and may be conducting to support the Agency and enterprise objectives. The KSC Center Director commented on the implementation plan: "In working the next iteration of this plan, we will develop a clearer focus by prioritizing and concentrating our efforts on critical strategies to assure we achieve our objectives" [1]. This need for overall focus led to the third planning effort.

The third planning effort consisted of a series of retreats and working meetings aimed at defining KSC's core business, future state, and goals, objectives, strategies in the form of a "25 year roadmap". These three strategic planning efforts have led to the development and articulation of an ideal KSC future state and plan to achieve the future state. This third effort is leading to the use of a strategic management system at KSC.

Two important facets of the case are the context of and the concurrent nature of the planning efforts. First, KSC as described in the introduction is undergoing a large-scale change. KSC was experiencing a crisis to redefine its future or have its future defined for itself. This future was not positive for the workforce of KSC. Furthermore, KSC experienced a significant change in senior leadership including the top three positions in the center (i.e., the center director, associate center director, and deputy center director) as well as several other senior management people. Second, the third planning effort has been described as "planning to plan while planning" because of the concurrency in the design and implementation of the strategic planning process. The strategic planning staff developed the strategic planning process and retreats in real-time to reflect the needs of the organization. The organization did not have a strategic planning process in place. Practices and standard models for planning from the literature were used to guide the development of the process. However, these theoretical models needed to be adapted to the specific organization as we went through the process. In essence, KSC concurrently designed and implemented a strategic planning process while planning for responding to large-scale organizational change.

The combination of the three planning efforts show an evolution in strategic thinking and management in a government organization. Throughout the three planning efforts, a series of models was developed to help understand and explain the strategic management efforts at KSC. The author developed these models and implications in partnership with KSC employees while the author was engaged in helping define, lead, and support the strategic planning efforts at KSC. It is from these three planning efforts and associated models that the following results are derived.

4. A MODEL AND PROCESS TO HELP UNDERSTAND AND IMPLEMENT STRATEGIC MANAGEMENT

We developed and used models to understand, develop, communicate, and use a common framework to guide the implementation of strategic thinking at KSC. The overview model which integrates the models developed throughout the three planning efforts is given in Figure 1. The overview model will be emphasized in the paper. As shown in Figure 1, five components summarize the important issues for designing and implementing a strategic management system in an organization. The first circle in the picture, "Organizational Context", represents the items which describe the environment of the organization in which the design and implementation of the strategic management system is being made. The two circles on the right of the figure, "Output Characteristics" and "Outcome Characteristics", represent the desired products from the strategic management system. Understanding the inputs and outputs are necessary to design both the "Strategic Management Process" and "Organizational Support Process."

The model given in Figure 1, provides a summary of the hypotheses developed from this case study. The hypotheses include:
- successful strategic management is a function of both the outputs and outcomes;
- better organizational support will lead to a better product (i.e., outputs);

- better organizational support will lead to successful outcomes (e. g., see Table 1);
- the organizational context will drive the outcomes of the strategic management process; and
- the organizational support process must address the organizational context.

An additional hypothesis is that moving to strategic management process is an evolution and the better the organizational support the smoother the transition to a stable, well refined strategic management process.

Each of these five components will be described more fully in the next section. These five components are used to define a process for designing and implementing a strategic management system in an organization.
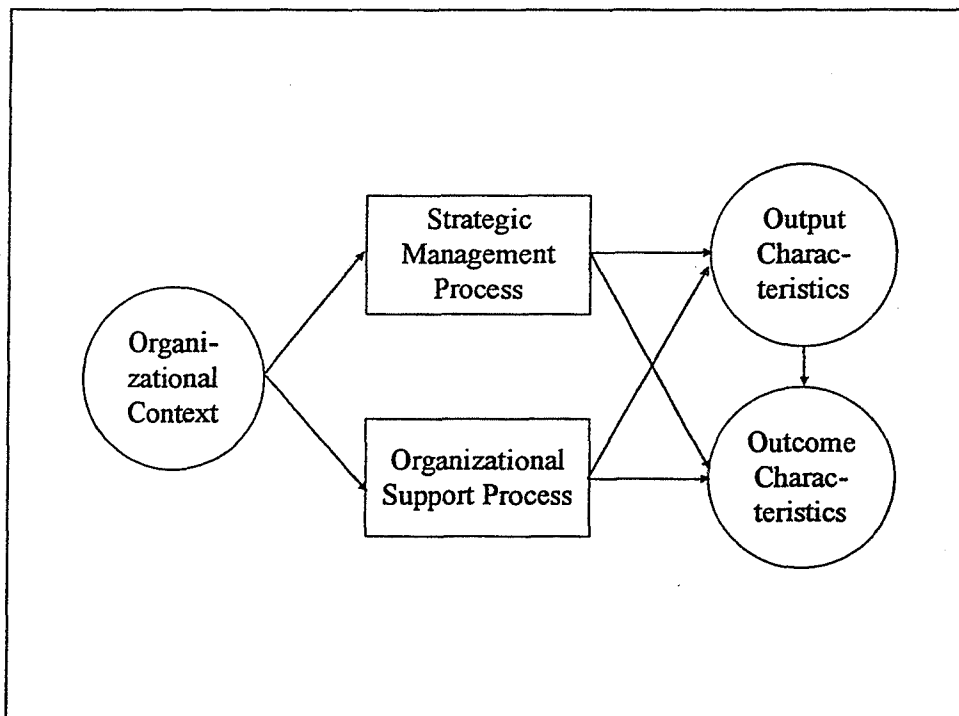
Figure 1. Components of Strategic Management Process Design and Implementation

4.1 Process for Designing & Implementing a Strategic Management Process
From this model, a process for designing and implementing a successful strategic management process can be defined. The steps to the process include:

1. *Understanding the nature of the organizational context.*
The purpose of this step is to understand the organization for which the strategic management process is being designed and implemented. The planner must answer and address questions such as:
- Why is the organization conducting strategic planning? Is there a major external or internal event the organization is reacting to or is the organization being proactive? If a major event is being responded to, then this event would need to be the focus of the planning efforts. For KSC the change in role of civil servant/contractor and budget concerns were the major events KSC is responding to.
- What are the external requirements, if any, that the organization must meet with its planning process? KSC as part of NASA must address the Agency's requirements and linkages for completing the planning process. The requirements include the content, format, and schedule of the strategic

management process outputs. The organizational support process must be aligned with these requirements.

- What has the senior management and the organization's experience with strategic management been? Senior management may be empowered to conduct strategic management for the first time. Therefore, to successfully conduct strategic planning, senior management must have the desire, knowledge, tools, and processes to be part of the strategic management effort.
- How well does senior management work together as a team? A team environment is needed to support open and honest dialogue [3] which will allow hidden assumptions to be raised. Conflicts must be dealt with in a productive and non-destructive manner. Part of the organizational support process may address both the senior management empowerment and team needs.

In this step, the organizations capabilities (e.g., knowledge, processes, and tools) for strategic management can be understood. Answering these questions will provide the context for the planning efforts and will help in the next two steps of explicitly defining the output and outcome requirements. By understanding the context and output/outcome requirements the strategic management and organizational support processes can be defined.

2.   *Defining 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, execution, and performance evaluation). The questions to address include:

- From a content standpoint, does the organization need to define the mission, vision, goals, objectives, and strategies?
- What type of objectives does the organization desire (e.g., general qualitative statements or performance measured targets with time-frames)?
- Will there be a standard template or form to define projects to implement strategies?
- What type of measures and performance evaluations will there be?

Conducting a review of other organizations (both internal and external) planning efforts can help the organization define these requirements. For example, KSC reviewed and applied a document format which had received support from the Agency for a center implementation plan.

3.   *Defining 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 senior management and organizational unified view, commitment to use of plans to align everyday decision/actions throughout the organization. Understanding the desired outcomes helps judge the amount of energy to place in the effort and the approach to the organizational support process. For example, if the organization desires a plan which looks good but is not implemented, then a less participative approach may be better than fooling people with a group process that the plan is meant to be a driving force in the organization. Table 1 summarizes some of the dimensions to address for desired outcomes. For each dimension we define the two foci of efforts: product and product/process. A "product" focus reflects the importance of a tangible output. A "product/process" focus represents the importance of the team process of a developing a unified view and commitment to the strategic plan. The values in the table represent the outcomes of each dimension for a given focus.

Table 1. Outcomes of Strategic Management.

Focus of Effort Dimensions	Product	Process & Product
Level of Team Work	Conflict, Competition	Cooperation, Collaboration
Focus of Direction	Individual Agendas	Unified
View of Organization	Functional, Fiefdoms	Cross Functional
Use of the Outputs	Check the box	Aligned Decisions & Actions
Ownership	Staff	Senior Management & Organization
Focus of efforts	Product	Process & Product
Primary Developers	Staff or Select Group of Senior Management	Senior Management as a Team & Organization
Effect on the Business	Just an Exercise, Wastes Resources	Drives Change and Leads to Success

4.   Designing organizational specific strategic management process.

The purpose of this step is to define the strategic management process for the organization based on the results of the above three steps. A review of the theory and potential approaches to strategic management should be completed. A review of the literature, understanding other organizations' processes, and bringing in outside knowledgeable people can help increase the knowledge about strategic management. For example, a team of KSC civil servants reviewed the planning documents of other organizations. From this effort, they developed a series of recommendations for strategic planning. For example, one recommendation was for the goals and objectives to be "necessary and sufficient." Three important elements KSC developed to guide the strategic management process are:

- strategic management is a cyclic, learning process (i.e., plan-do-study-act);
- strategic management must address the short-term state and actions in terms of the long-term or future state of the organization (i.e., "all-term");
- goals, objectives, and strategies must be linked and aligned throughout the organization.

5.   Designing organizational support processes.

The purpose of this step to provide the organization with the knowledge, processes, and tools to allow the organization to be essentially 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;
- developing and implementing the process and tools to help the organization implement each step (e.g., developing a template for strategy development);
- providing educational/training needs;
- assessing progress and making improvement interventions; and
- developing the communication materials.

For each step of the strategic management process, support for the step must be defined for the knowledge, processes, and tools that are needed. The organization must develop the internal support structure for the strategic management process.

6. *Implementing the strategic management process and providing on-going organizational support.* The purpose of this step is to implement the defined strategic management process to produce the desired outputs ad outcomes. Support for the organization includes: defining tasks to be completed by the senior management group, integrating products and concerns of the senior managers, supporting sub-groups 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. *Refining 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 senior management who owns the strategic management process is required.

5. CONCLUSION AND IMPLICATIONS

From the experiences in implementing strategic management at KSC, the inputs of people knowledgeable in strategic management, the academic literature and the resulting above model, we offer a set of principles or lessons learned. Senior management and change leaders given the task of designing and implementing a strategic management process can use these implications to help them in their efforts. The implications include:

- *Designing and implementing strategic management is an evolutionary process which needs to be supported.* The primary lesson learned is that the switch to a strategic management process is an evolution. A perfect system may not be put in place in the first year. However, addressing the issues given in the above model and the following lessons learned may help the evolution proceed in a timely, organized fashion.

- *Install the process in a proactive mode.* The organization, if possible, should implement strategic management as a proactive and not a reactive step to align the organization with changes on the environment. A reactive mode to a crisis adds a layer of complexity to both the design/implementation of the strategic management process and the management response to the change. The complexity is due to the organization is redefining itself while at the same time redefining the management process.

- *Senior management ownership.* Ensure both the strategic management process and the organizational support process allow and support the senior management team to be the primary customer and owner of the processes. For example, during retreats, facilitate the senior managers being responsible for as much as possible such as producing customer needs analysis and developing presentations of work completed between sessions.

- *Team development.* Design working activities for the group of managers to become and function as a team. For example, three different working groups of senior managers were developed to define different parts of the KSC's future state. Having senior managers who previously did work together responsible for a deliverable at the next meeting, forced them to work as a team. Rotating groups for assignments will also help both team and individual skill building. The use of the concepts from "cooperative learning groups" can provide guidance on how to structure group exercises to support both team and individual development.

- *Build the organization's capability to lead and sustain the process.* A desired outcome is for strategic management to be on going process. For this to be accomplished the organization must be capable of executing all phases of strategic management. All levels must be knowledgeable in: the framework for strategic management, the steps necessary to execute their responsibilities, and the tools available to help them. Conducting training in strategic management, making senior management members responsible for as much of the meeting as possible (e.g., data gathering, presenting to the group, etc.) or conducting training to their employees on the process will help build senior management capabilities.

Other steps include conducting training sessions for all involved in the process and developing a "handbook" for strategic management. We supported building capability by conducting training sessions during formal retreats, at senior staff meetings, and in a formal training setting. A group of organizational facilitators who understand the process is also needed to support individual organizations.

- *Use a project management approach when "planing to plan".* The organization support staff should complete the steps presented earlier for designing and implementing the strategic management process. Developing the process and milestones while the process is being worked is difficult for both the staff and the senior management. This step should be completed first.

- *Use models to develop a common framework and thought process.* Develop and use models to help establish a common framework and thought process for the strategic management efforts. A series of models were developed which helped explain to participants the stages of the evolution of their efforts. When using models develop new or modify existing to the organization's unique context. The models should be flexible to fit the needs of the organization. The organization should not be made to fit the model.

- *Balance process and product.* The organization needs to balance the process of team building and ownership with the need to develop a product. Throughout this exercise when a compromise had to be made we chose process over product. The team process was more important to long-term buy-in and follow through than the product itself. A deliberate, systematic approach is needed to ensure executive management team and other key players are on board with process and product.

- *Spend time creating a shared understanding about the organization's environment.* The organization spent time understanding its current responsibilities (i.e., zero-based review) and capabilities (i.e., center of excellence plans and Best Manufacturing Practices). However, during the retreats in a group discussion, we did not explicitly use the material. We could have had senior management share their thoughts on the reports to help build a common framework. Also, we used an "all-term" model to represent the current, short-term, and long-term states of the organization. We should have also spent time on understanding the history of the organization. Use of a technique such as SWOT would help the group come to a common understanding.

- *Leadership.* Senior management leadership is required for a successful strategic management process. Primary participation of senior management is needed to help both design and implement the process. Individuals who 1) are strategic thinkers, 2) understand the organization, 3) have a stake (personal and profession) in the results, 4) are credible, 5) legitimize the need for the organization and 6) provide political support are needed to support the process for the larger senior management group.

The process, model, and implications can be used to successfully design and implement a strategic management system.

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Wavelength Temperature Dependence of Laser Sources for Dense Wavelength-Division-Multiplexed Fiber-Optic Communication Systems

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Abstract
A dense wavelength division multiplexed (DWDM) system uses laser transmitters of closely spaced wavelengths transmitting on the same optical fiber in the vicinity of 1550 nm. Current technology allows the use of lasers to be used at elevated temperatures under certain conditions. Primarily, the temperature of the laser must be kept high enough so that at elevated ambient temperatures the laser cooler is not overstressed. Decreasing the laser operating temperature resulted in the cooler current limit being reached at lower ambient temperatures. Increasing the laser operating temperature allowed the cooler current limit to be reached at higher temperatures for both cooling and heating.

1.0 Introduction

Fiber optic laser transmitters for high-speed communication are being considered for installation at NASA-KSC. The transmitters are to be used in a dense wavelength-division-multiplexed (DWDM) communication system. Such a system uses laser transmitters of closely spaced wavelengths transmitting on the same optical fiber. Generally, the wavelengths of the transmitters are in the vicinity of 1550 nm because of the low loss of optical fibers, and the availability of fiber amplifiers near this wavelength. The DWDM system is being considered mainly for uncompressed digital video transmission of camera outputs from the shuttle launch pads to the launch control center. The reliability and wavelength stability of these transmitters are important aspects considering the adverse environment of their intended location.

Due to the ambient temperature, and the short distance from the exhaust at the launch pad, transmitters may be expected to operate at temperatures higher than typical applications. This is important in DWDM systems because the peak wavelength of the laser transmitter can shift due to temperature and cause crosstalk between channels.[1,2]

To provide wavelength stability, thermoelectric coolers (TE, Peltier) have been used to maintain the laser within the transmitter at a constant temperature. TE coolers are specialized semiconductors that act as heat pumps. [3] When current passes through them, they pump heat from one end of the other. If the current is reversed in the cooler the direction of heat transfer is also reversed. In spite of their advantages, the reliability of a cooled laser is less than that of an uncooled laser. [4,5] Usually, cooled lasers should be properly mounted on a heat sink with appropriate external cooling which is not possible in our application. Therefore, the range of temperatures which a cooled laser can operate properly in our application is not clear.

Another potential problem arises because the wavelength of lasers for DWDM systems are typically adjusted by setting their internal temperature with a TE cooler. Typically, lasers are supplied with about a $\pm$ 0.4 nm tolerance on the wavelength. The wavelength is then finely adjusted through changing the temperature at which the TE cooler begins to cool. Because the wavelength of the laser is temperature dependent, adjusting the temperature at which the laser operates effectively changes its wavelength. In this way, the wavelength of the laser is adjusted by setting the temperature at which the laser operates. However, if the temperature is set to low, then adequate cooling will not be possible at elevated temperatures. Considering the temperature dependence of the peak wavelength of a laser, the adverse environment of our application, and the limitations of TE coolers, rigorous testing of laser sources is needed before constructing a DWDM communication system.

We tested the wavelength dependence of two types of laser sources operating near 1550 nm for use in a DWDM system. We examined eight laser transmitters of different wavelengths that used TE coolers internally to automatically maintain a constant temperature of the laser. In addition, we tested a laser using a TE cooler that could be manually controlled. In this way we could better control the conditions at which the laser operated. In the next section we describe the sources used, followed by our experiments, results, and conclusions.

2.0 Dense wavelength division multiplexing

Dense wavelength division multiplexing (DWDM) describes multiple wavelengths (channels) of light propagating down the same fiber. The wavelengths of the channels are typically separated by a few nm or less. Because of the popularity of erbium-doped fiber amplifiers, DWDM systems operate in the vicinity of 1550 nm. Narrow linewidth lasers are required with 0.3 nm being typical. Because of the high data rate (2.5 Gb/s), and different wavelength sources, fiber dispersion must be kept to a minimum.

There are 46 channel assignments for DWDM that range from 196,000 GHz (1528.78 nm) to 191,600 GHz (1564.68 nm) with 100 GHz channel spacing. Table 1 shows the assignments in nm; the channels we were interested in were highlighted and had three channels between them not being used.

Table 1 Channel assignments for DWDM

channel	wavelength (nm)	channel	wavelength (nm)	channel	wavelength (nm)
1	1528.78 (196,100 GHz)	**17**	**1541.35** (194,500 GHz)	**33**	**1554.14** (192,900 GHz)
2	1529.56	18	1542.15	34	1554.94
3	1530.34	19	1542.94	35	1555.75
4	1531.12	20	1543.73	36	1556.56
5	1531.90	**21**	**1544.53**	**37**	**1557.37**
6	1532.68	22	1545.32	38	1558.18
7	1533.47	23	1546.12	39	1558.99
8	1534.25	24	1546.92	40	1559.80
9	**1535.04**	**25**	**1547.72**	41	1560.61
10	1535.82	26	1548.52	42	1561.42
11	1536.61	27	1549.32	43	1562.24
12	1537.40	28	1550.12	44	1563.05
13	**1538.19**	**29**	**1550.92**	45	1563.87
14	1538.98	30	1551.72	46	1564.68
15	1539.77	31	1552.53		
16	1540.56	32	1553.33		

3.0 Sources

We used two different types of sources in our experiments. The first was a digital laser transmitter module, model 55TA, manufactured by BCP Inc. It contained a TE cooler, laser driver, isolated distributed feedback (DFB) laser, and is designed for operation up to 2.5 Gb/s. It is reported to have an average output power of 1.0 dBm, maximum 3 dB spectral width of 0.3 nm, and wavelength temperature coefficient of 0.008 nm/$^{\circ}$C. Eight devices were used with the wavelengths indicated in Table 1. In addition, the transmitters were supplied so that the center wavelength could be adjusted $\pm$ 0.1 nm by applying a voltage to a pin on the transmitter; however, we did not use this feature.

We also used an Alcatel model A1915LMI laser operating at 1550.1 nm that used a TE cooler. The laser had a threshold current of 8.4 mA, and a maximum TE cooler current of 557 mA. The laser and cooler were controlled by a ILX LDC-3724 laser diode controller. The controller allowed the laser to be operated in a constant current, or

constant power mode while maintaining a constant temperature. A constant power is maintained by measuring the power of the laser with a photodiode. The calibration factor for the photodiode was 6.67 mW/μA.

3.0 Experiment

We tested all sources in a temperature chamber from 0 °C to 70 °C in increments of 10 °C. The wavelengths were measured with a Hewlitt-Packard 86120B Multi-wavelength meter. The lasers were on oven racks and no attempt at proper heat sinking was made to reflect the intended application. The BCP transmitters were specified for operation for 0 °C to 50 °C, and 0 °C to 65 °C case temperatures without and with proper heat sinking respectively. Note that we measured ambient temperature because it is related to the application, and that the case temperature of the laser and transmitters were higher than the ambient temperature.

The Alcatel laser was tested at three different temperatures, 25.0 °C, 32.5 °C, and 40.0 °C in both constant power and constant current modes. In addition, it was tested uncooled.

4.0 Results

The results for the BCP transmitters are shown in Figs. 1 and 2. In Fig. 1 we showed the change from the ITU wavelength as a function of temperature. For 0 °C to 50 °C the wavelength dependence appeared linear and the transmitters met specifications. The maximum wavelength deviation at 50 °C was 0.35 nm. At temperatures above 50 °C, the wavelengths generally increased sharply with a wide variety of slopes to the curves.

We presented the same data in a different format in Fig. 2. In Fig. 2 we showed many ITU channel wavelengths as dashed lines and the ones were using as solid lines. The wavelengths of the lasers were shown superimposed on the ITU channels. At elevated temperatures the wavelengths of the transmitters increased. Considering our eight transmitters, a few might be used without crosstalk depending on the demultiplexing scheme.

The wavelength dependence of the Alcatel laser on temperature is shown in Fig. 3. For experiments with the Alcatel laser, the constant power and constant current modes gave similar results and are indicated on all graphs. When the laser was uncooled the wavelength varied almost 7 nm in a linear fashion which would require a large spacing, and only a few channels for a DWDM system. For cooled operation, the wavelengths were quite stable with a variation of less than 0.2 nm at 40 °C. When the laser was cooled to lower temperatures, the TE current limit was met and the wavelength dependence increased sharply. When the laser was cooled to 32.5 °C and 25 °C, the TE current limit was met at about 68 °C and 60 °C respectively.

The output power dependence is shown in Fig. 4 for a constant current of 25.4 mA. For uncooled operation the output power decreased about 8 dB from 0 °C to 70 °C.

For cooled operation the power was relatively stable, then decreasing when the TE current limit was met.

The laser current dependence is shown in Fig. 5 for a constant power of about 0 dBm. For uncooled operation the current increased from 14 mA to 33 mA from 0 °C to 70 °C. For cooled operation the current varied less than 1.0 mA, then increased when the TE current limit was met.

Finally, the TE current dependence is shown in Fig. 6. The current limit for the TE cooler was 557 mA and is indicated on the graph. It can be seen that as the temperature of the laser increased, less current was needed at higher ambient temperatures to cool the laser. A laser temperature of about 40 °C appeared in the center of the graph indicating that this was a good temperature for operation between 0 °C and 70 °C.

5.0 Conclusion

Current technology allows the use of cooled lasers to be used in a DWDM system at elevated temperatures under certain conditions. Primarily, the temperature of the laser must be kept high enough so that at elevated temperatures, the TE cooler is not overstressed. Decreasing the laser temperature allowed the TE current limit to be reached at lower ambient temperatures. Increasing the laser temperature allowed the TE current limit to be reached at higher temperatures for both cooling and heating.

Laser manufactures often specify wavelengths at about 25 °C, which is probably too low for our application. For elevated temperature operation, transmitter manufacturers must order a particular wavelength at 25 °C so that the desired wavelength is obtained when the laser operates at elevated temperatures. In terms of specifications, a particular wavelength can be obtained by indicating:

1. ambient temperature (not case temperature!), 0 °C - 70 °C, still air
2. no heat sink
3. wavelength measured after 1 hour, or some time where wavelength has stabilized.

It is not clear how the higher temperature of operation of a laser affects its reliability. Because of their reliability, uncooled lasers may be used in a DWDM system; however, only a few channels would be possible because of their large wavelength drift with temperature. In addition, the lasers would have to be used in a constant power mode because of the relatively large change in current with temperature.

6.0 References

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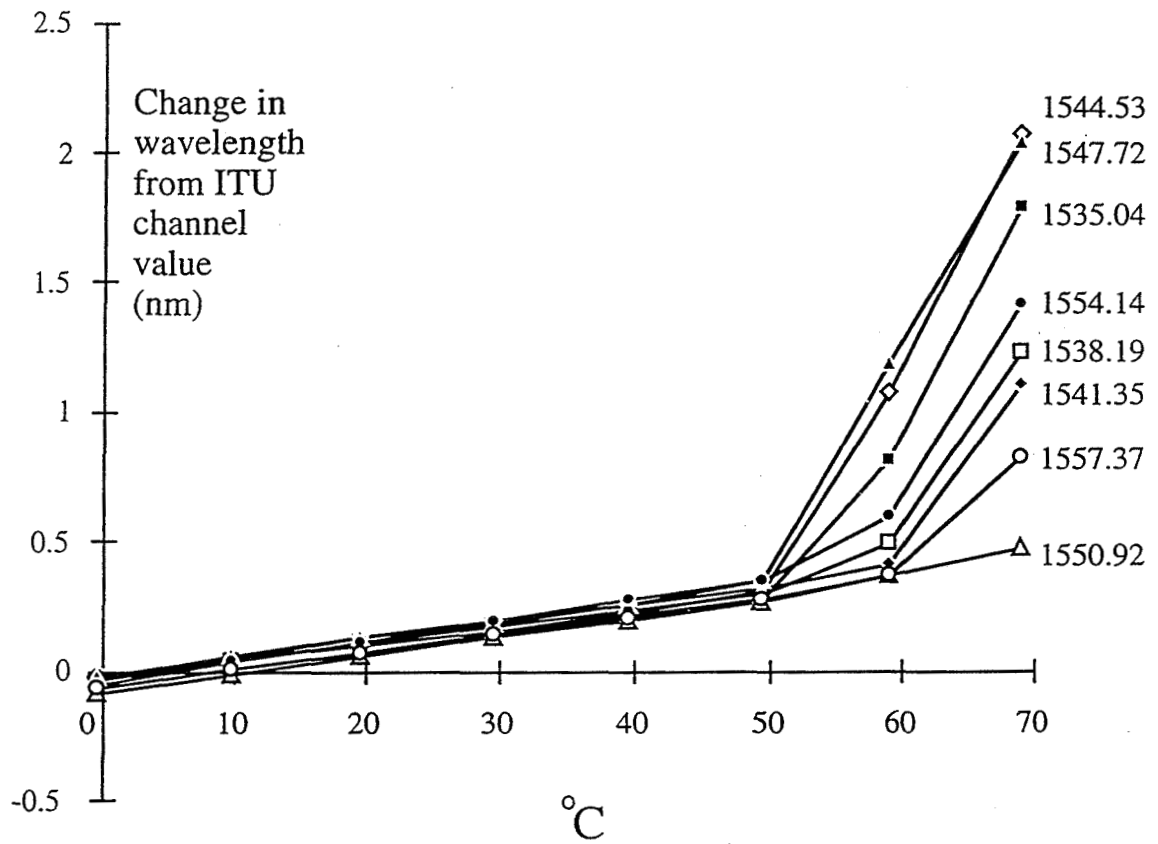
Figure 1 Graph change in wavelength from ITU channel value as a function of temperature for eight different fiber-optic transmitters of different wavelengths
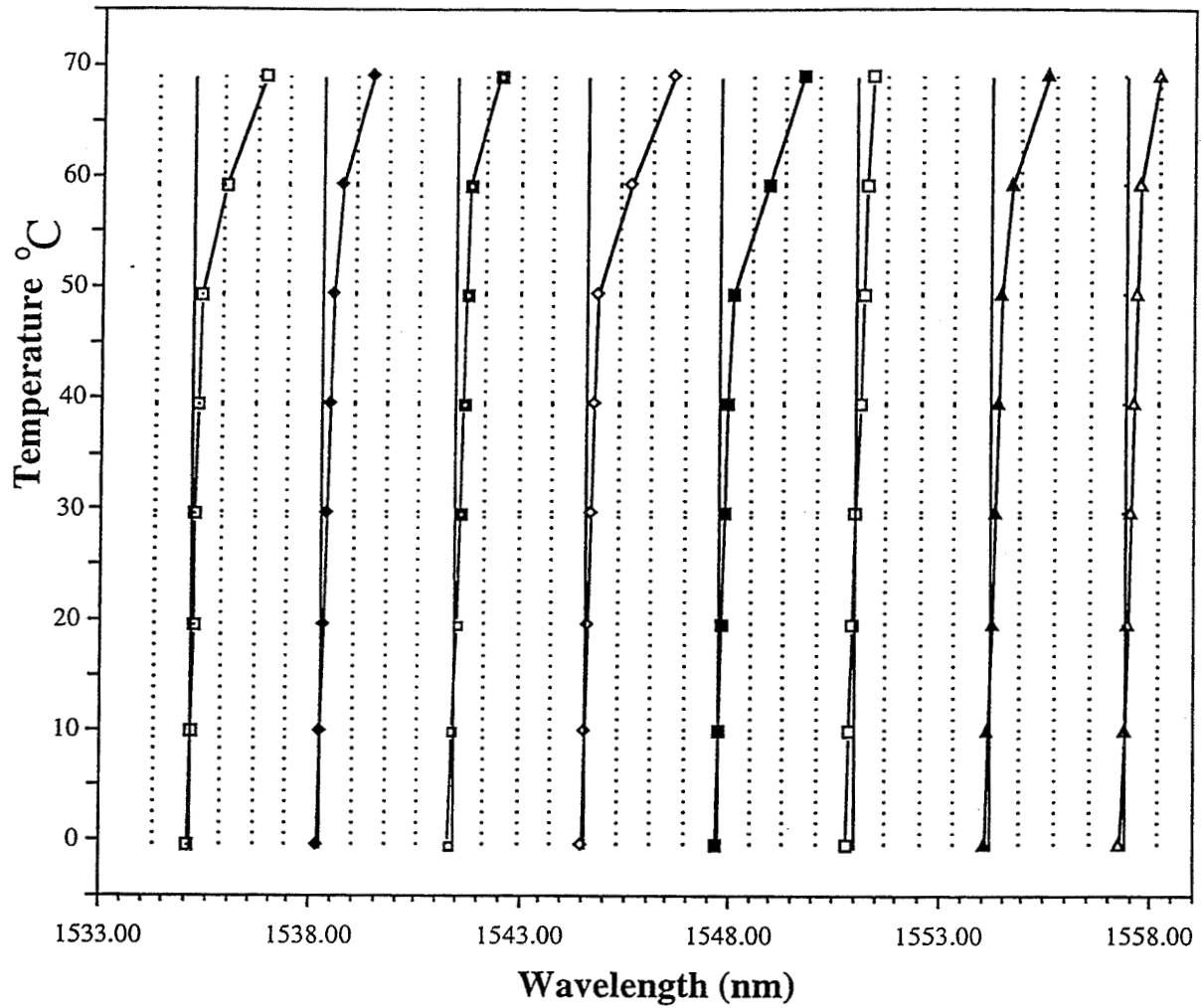
Figure 2 Graph of temperature dependence of BCP transmitters on ITU channel grid. Dashed lines are ITU channel wavelengths, solid lines are wavelengths for which transmitters were designed.
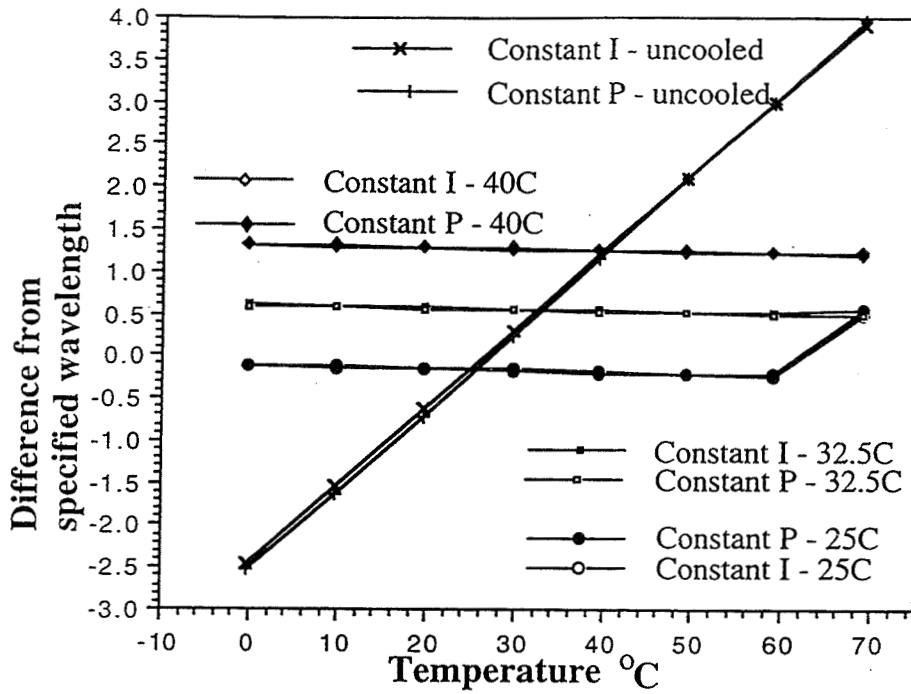
Figure 3 Graph of change in wavelength from specified value (1550.10 nm) as a function of temperature for various laser temperatures and operating modes.
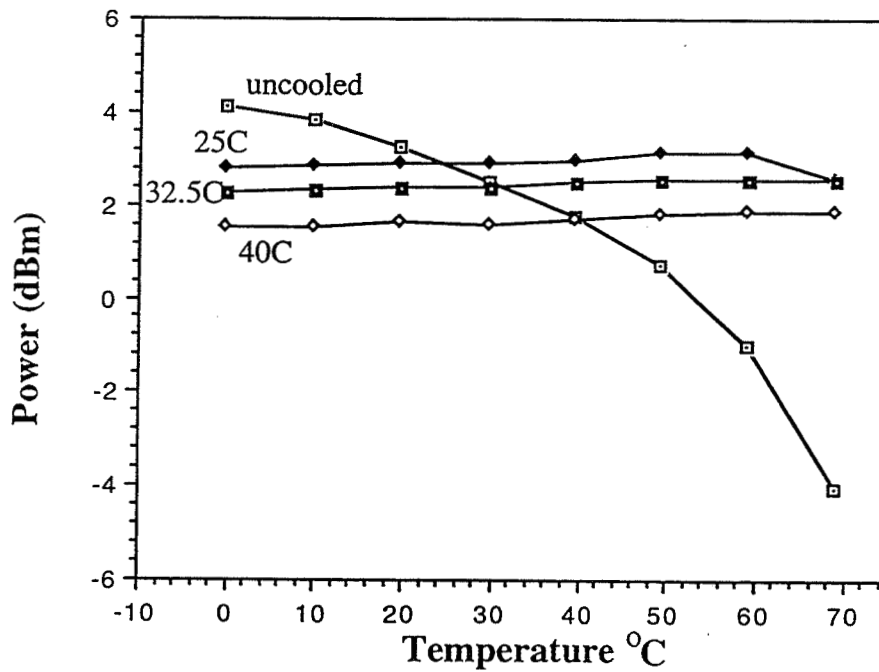
Figure 4 Graph of output power of Alcatel laser operating at constant current of 25.4 mA for various laser temperatures
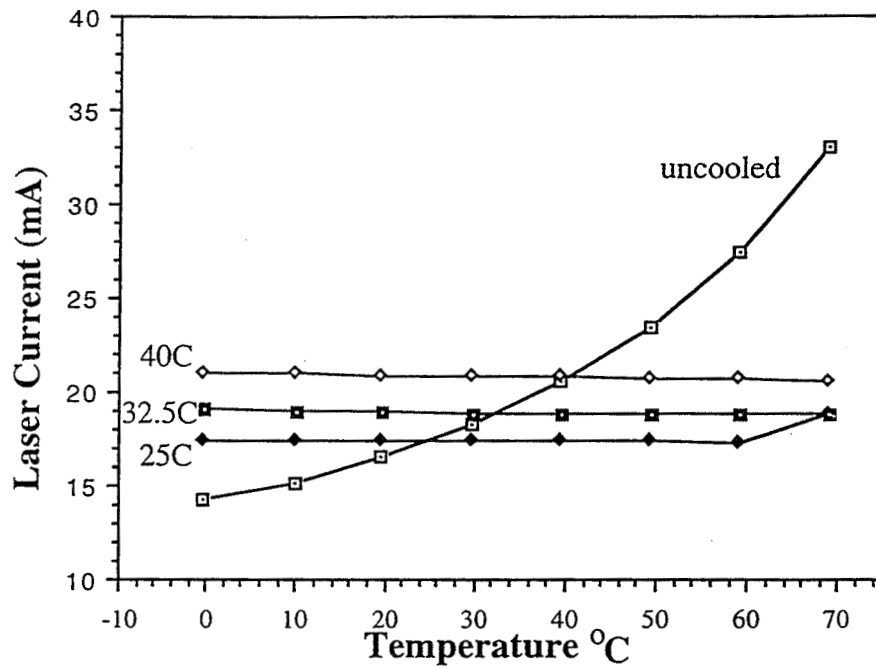
Figure 5 Graph of laser current of Alcatel laser operating at constant power of 0 dBm for various laser temperatures
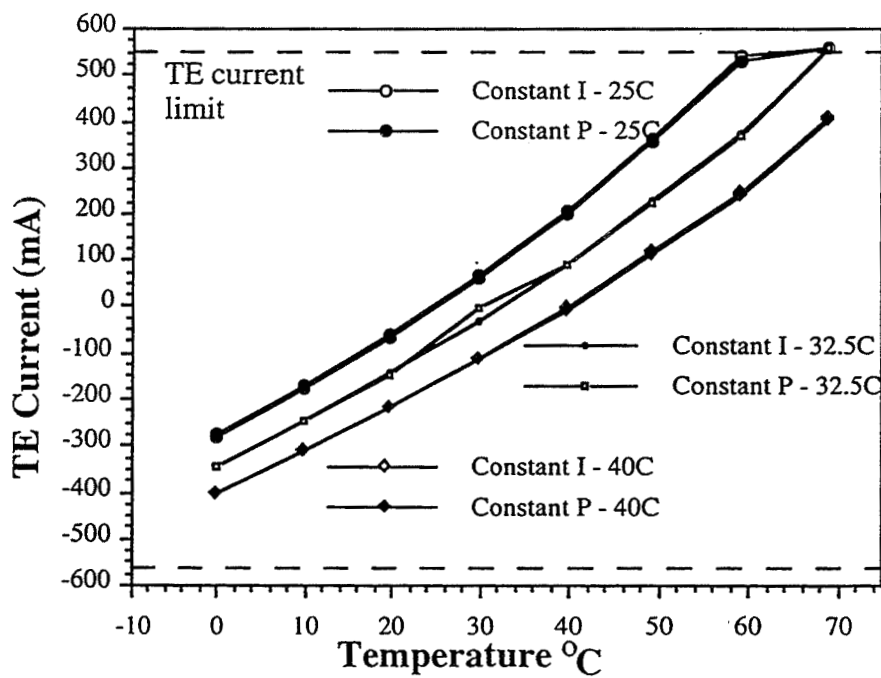
Figure 6 Graph of TE current of Alcatel laser operating in different modes for various temperatures.

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IMPLEMENTATION OF ADAPTIVE NOISE SUPPRESSION IN REAL TIME

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Abstract

A signal to noise ratio dependent adaptive spectral subtraction algorithm developed to eliminate noise from noise corrupted speech signals was implemented in real time. The noise characteristics of the two main applications, the emergency egress vehicle and the crawler-transporter, were determined under varying conditions and used to improve the algorithm. Real time tests were performed using OIS-RF microphones and results compared for no noise suppression, a commercially available device, and the aforementioned algorithm implemented on a Texas Instruments TMS320C3x DSK.

1. Introduction

It is desired to incorporate adaptive noise suppression into the communications equipment on the emergency egress vehicle and the crawler-transporter. An adaptive algorithm is necessary for both applications due to the varying nature of the noise. Furthermore, the noise frequencies produced by both applications are in the voice band range. Thus, standard filtering techniques will not work. A signal to noise ratio dependent adaptive spectral subtraction algorithm developed in [1] was improved by adding prefiltering. The algorithm was implemented in real time on a Texas Instruments TMS320C3x DSK. Real time tests were performed using OIS-RF microphones and results compared for no noise suppression, a commercially available device, and the aforementioned algorithm.

2. Frequency Characteristics of the Noise

The noise level inside the emergency egress vehicle was measured using a decibel meter. The noise level is 90 decibels (dB) with the engine idling and 120-125 dB once the vehicle starts moving. As a result, it is impossible to hear what the crew is saying during a rescue operation. The noise inside the engine rooms of the crawler-transporter are also in the 120 dB range causing the same difficulty with communication. The headsets used by both crews have OIS-RF microphones which have noise suppression of a mechanical nature and provide 15 decibels of noise suppression. Furthermore, the frequency response of the microphone and communication system attenuates frequencies outside of the voice band range of 300 Hz to 3 KHz.

The noise on the emergency egress vehicle and the crawler-transporter were measured using a data acquisition circuit. A block diagram of the circuit is shown in Figure 1. MATLAB was then used to obtain the average frequency response of the noise. The noise was divided into frames containing 256 values (approximately 17 milliseconds). The Fast Fourier Transform (FFT) of each 256 point frame was taken; then the frames were averaged. The frequency response of the average noise for the emergency egress vehicle during acceleration and at full speed is shown in Figure 2. The frequency response of the average noise for the crawler-transporter with and without the shuttle and mobile launch platform is shown in Figure 3.
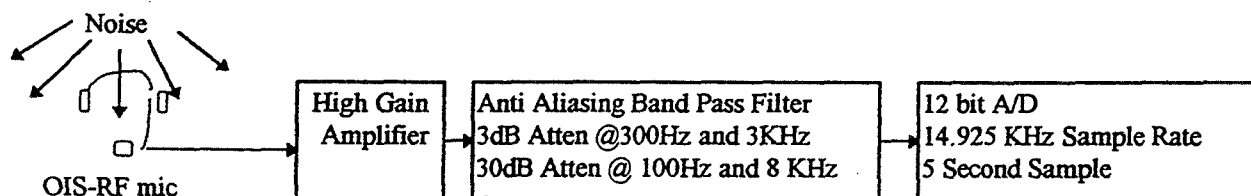
Figure 1. Data Acquisition Circuit Used for Determining Noise Characteristics
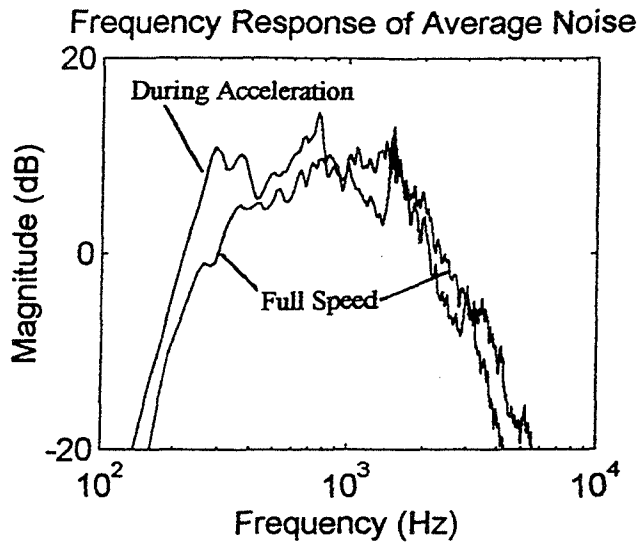
Figure 2. Frequency Response of the Average Noise for the Emergency Egress Vehicle During Acceleration and at Full Speed
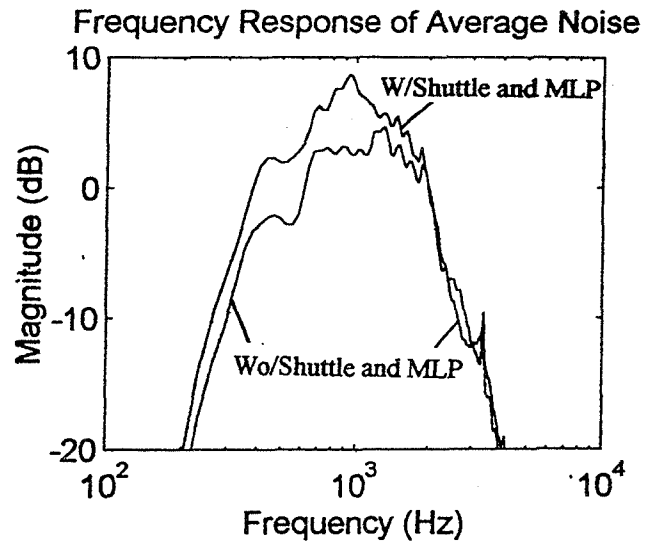
Figure 3. Frequency Response of the Average Noise for the Crawler-Transporter With and Without the Shuttle and Mobile Launch Platform

The frequency responses of the noise produced by both vehicles decreases by approximately 20 dB between 1 KHz and 4 KHz. This is important for two reasons. First, an artifact of spectral subtraction is "musical noise", random bleeps and blurbs of mid to high frequency, which can be reduced in amplitude by using a low pass filter. Second, the speech power of men and women decreases at a rate of approximately 13 dB between 1 KHz and 4 KHz [2, p.238]. Furthermore, even though the lower frequencies of speech have more power, the relative contribution of intelligibility which is measured by an articulation index shows that over 63 percent of articulation occurs in the range of 1 KHz to 4 KHz [2, p.239]. Thus, if the higher frequency components of the noisy speech are low pass filtered to remove the musical noise, the intelligibility of the speech will also be reduced. To counter this effect, the noisy speech is first prefiltered with a pre-emphasis filter which accentuates the higher frequency components of the speech and the noise. The frequency response of the pre-emphasis filter was chosen so as not to increase the high frequency components of the noise beyond the peak levels of the noise spectrum. The low pass filter frequency response is the reciprocal of the pre-emphasis filter. The discrete pulse response of both filters was considered in their design. The frequency responses of both filters are shown in Figure 4.
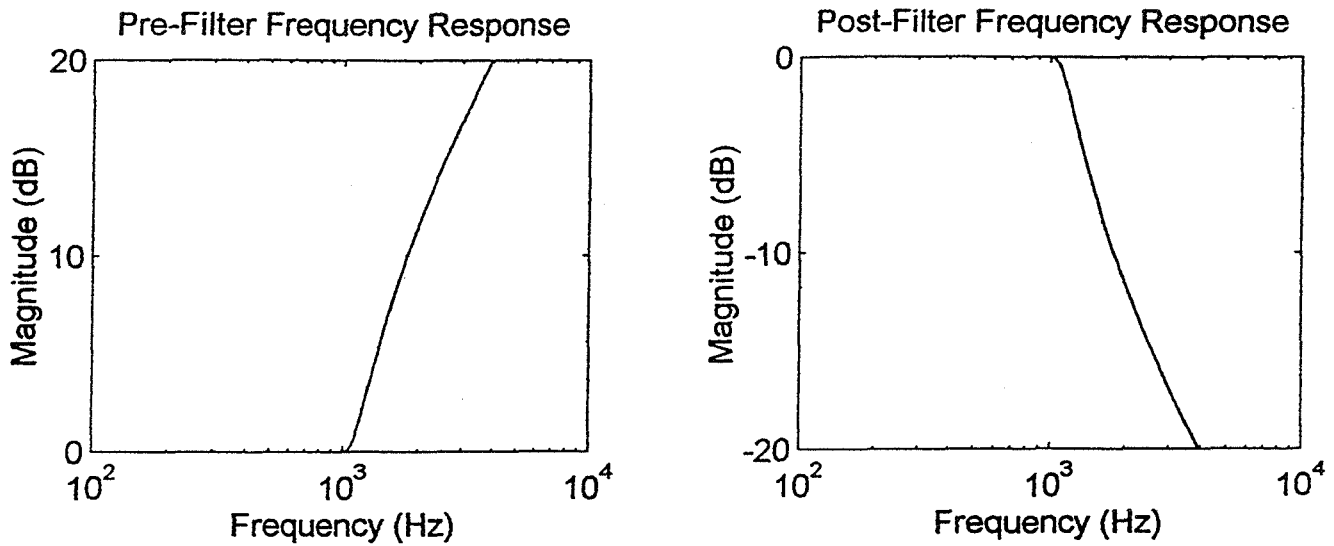
Figure 4. Frequency Response of Pre-emphasis Filter and Low Pass Filter

3. Spectral Subtraction

A signal to noise ratio dependent adaptive spectral subtraction algorithm (SNRDASS) was used to remove the noise from the noisy speech signal. The concept of spectral subtraction and description of the implementation are given in the following subsections.

3.1 Spectral Subtraction Concept

The additive noise model used for spectral subtraction assumes that noise corrupted speech is composed of speech plus additive noise.

$$x(t) = s(t) + n(t) \tag{1}$$

where:

        $x(t)$ = noise corrupted speech
        $s(t)$ = speech
        $n(t)$ = noise

Taking the Fourier Transform of equation (1)

$$X(f) = S(f) + N(f) \tag{2}$$

$X(f)$, $S(f)$, and $N(f)$ are complex so they can be represented in polar form

$$|X(f)| \, e^{j\theta x} = |S(f)| \, e^{j\theta s} + |N(f)| \, e^{j\theta n} \tag{3}$$

Solving for the speech

$$|S(f)| \, e^{j\theta s} = |X(f)| \, e^{j\theta x} - |N(f)| \, e^{j\theta n} \tag{4}$$

When using a single microphone for noise and noise corrupted speech, an estimate of the noise must be obtained when speech is not present. Thus, the phase of the noise during noise corrupted speech is unavailable, so the phase of the noise corrupted speech is commonly used to approximate the phase of the speech. This is equivalent to assuming the noise corrupted speech and the noise are in phase. As a result, the speech magnitude is approximated from the difference of the noise corrupted speech and noise magnitudes.

$$\hat{S}(f) = \left| \hat{S}(f) \right| e^{j\theta x} = \left(|X(f)| - |N(f)| \right) e^{j\theta x} \tag{5}$$

Since the algorithm is implemented on a digital signal processor (DSP) using an FFT, the signal is processed using frames of the input data. Thus, a frame of input must be determined to be voiced or unvoiced. If the frame is unvoiced, then the estimate of the average noise, $\overline{|N(f)|}$, is updated. For the algorithm developed in [1], the proportion of noise subtracted, α, is variable and signal to noise ratio dependent.

$$\hat{S}(f) = \left\{ |X(f)| - \alpha(SNR(f))\overline{|N(f)|} \right\} e^{j\theta x} \tag{6}$$

In general α is greater than one, which is termed over subtraction. Over subtraction is used to reduce the distortion caused from approximating the phase. If for any particular frequency the subtraction results in a negative magnitude, the magnitude is set to zero. The inverse Fourier Transform yields the estimate of the speech.

$$\hat{s}(t) = \mathcal{F}^{-1} \left\{ \hat{S}(f) \right\} \tag{7}$$

3.2 Real Time Implementation of Spectral Subtraction Algorithm

A Diagram of the SNRDASS algorithm is shown in Figure 5. The algorithm starts by initializing the required memory, buffers, and Analog Interface Chip (AIC). The A/D and D/A conversions are synchronized at a rate of 7891 samples per second. The sample rate is interrupt driven to insure proper timing of the input and output data flow. After initialization, the algorithm waits for the input data buffer to be filled. Once this occurs, a series of buffer transfers and the decision of whether to squelch, zero out, the output buffer must occur within one sample period, 1/7891 seconds, or data will be corrupted. The input, which is now in the workspace buffer is triangular windowed and zero padded. The FFT routine then takes the Fast Fourier Transform of the workspace buffer by using a real FFT routine modified from [3, Appendix C]. The frequency domain values are put into polar form, and then the magnitude is prefiltered using the filter shown in Figure 4. When transforming to polar form, time is saved by determining the cosine(phase) and sine(phase) instead of the phase and later arctan(phase). The first eight frames are used to get an initial estimate of the average noise. After the first eight frames, the routine checks if the frame is

voiced or unvoiced and updates the average noise estimate accordingly. The signal to noise ratio is then determined and used as a factor when performing spectral subtraction. Results of spectral subtraction that come out negative are zeroed. To reduce musical noise, the magnitude is next postfiltered using the lowpass filter from Figure 4. The result is then converted to rectangular form required for the inverse FFT. The inverse FFT routine, which is a modified version of [3, Appendix C], transforms the workspace buffer back into the time domain. During all of this time, the A/D and D/A have been interrupt driven to move input into the input buffer and output out of the output buffer. Since the algorithm completes its cycle before the input buffer is full and the output buffer is empty, it loops back to the top and waits for the A/D to finish filling the 64 locations of the input buffer, which takes approximately .008 seconds. Then the process starts all over. Required assembly language division and square root routines were found in [4, p.11-31].
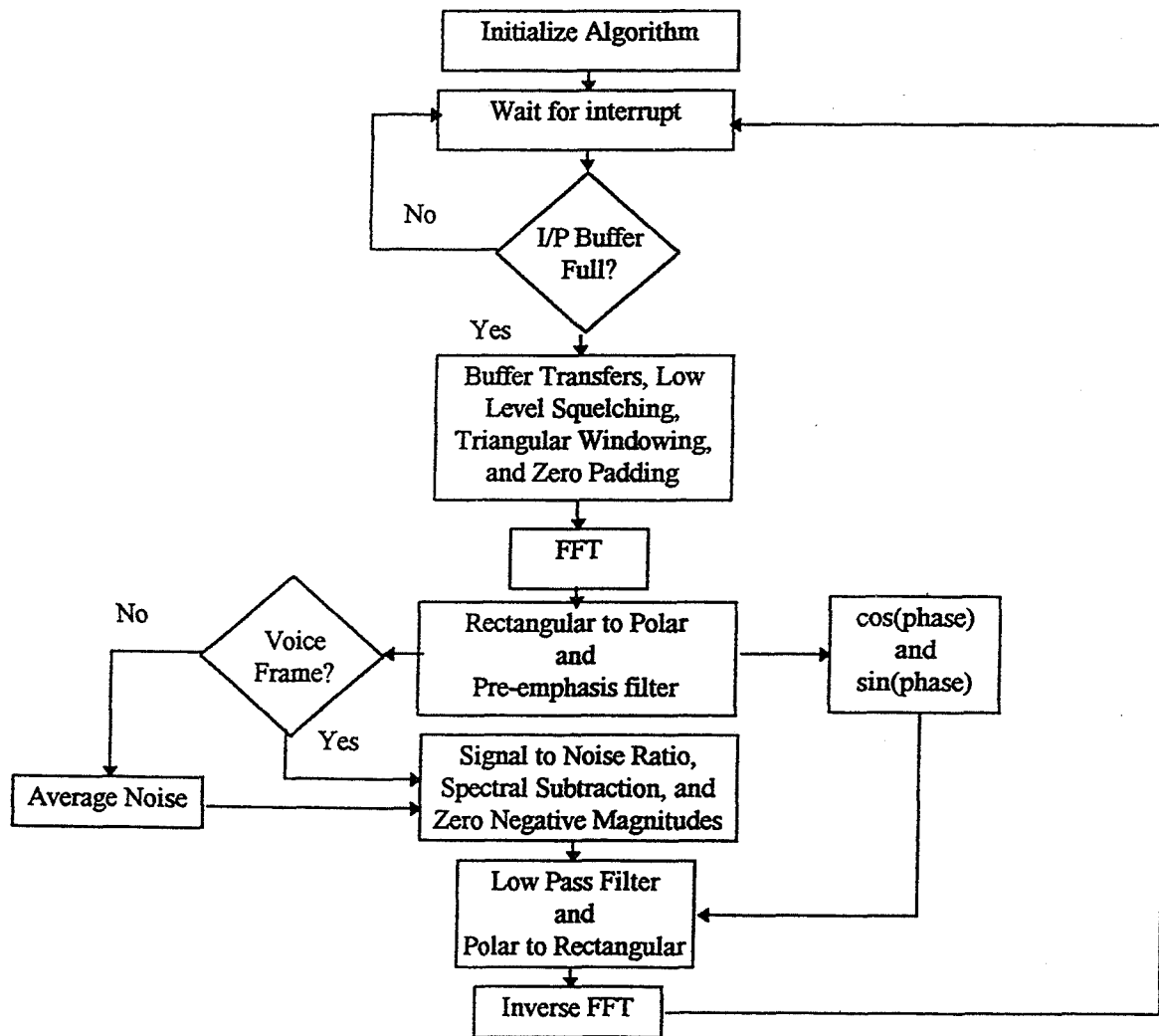
Figure 5. Diagram of the SNRDASS Algorithm

4. Tests and Results

Three tests were performed. First, the system was tested using no noise suppression. Second, the commercially available system was tested. Third, the SNRDASS algorithm described above was tested. A circuit was built to raise the microphone voltage such that the voiced signal would be in the range ±0.1 Volt for the commercial device and ±3.0 Volt range for the SNRDASS device. After noise suppression, the voltage was attenuated down to the original level. This circuit was not used for the no noise suppression test. A block diagram of the adaptive noise suppression system is shown in Figure 6. Noise corrupted speech enters the OIS-RF microphone. A step up transformer and high gain amplifier are used. The signal is digitized by an A/D converter, processed by a DSP, and returned to analog format by a D/A converter. It is then sent through an attenuator and step down transformer, which brings the voltage back down to the level at which it left the microphone. It then enters the communication system for the emergency egress vehicle. No information was available on the details of the A/D, DSP, or D/A of the commercial device. For the SNRDASS device, the signal passes through an anti aliasing low pass filter with 3 dB attenuation at 3.6 KHz and 20 dB attenuation at 4.0 KHz. It is then sampled by the A/D converter using 14 bit resolution and a 7.891 KHz sampling rate. At this point the DSP, a Texas Instruments TMS320C3X DSK with 64K words of additional zero wait state RAM, performs noise suppression. Next, the digital signal is converted back to an analog signal at a rate of 7.891 KHz using the D/A converter.
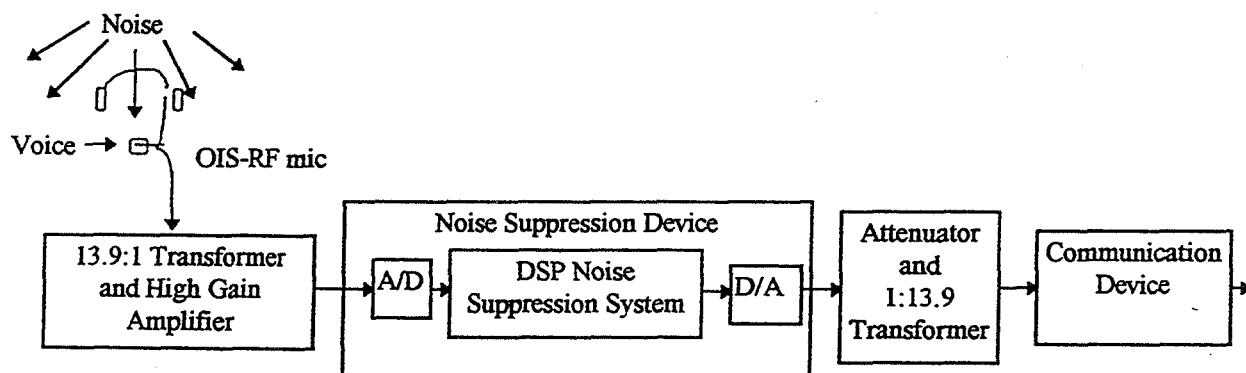
Figure 6. Adaptive Noise Suppression Block Diagram

Three tests were performed. First, the system was tested using no noise suppression. Second, the commercially available system was tested. Third, the SNRDASS algorithm described above was tested. The words "test, (device tested) one, two, three, four, end of test" were spoken into the microphone. Results from the tests were recorded from the communications channel. They are displayed in Figures 7, 8, and 9.
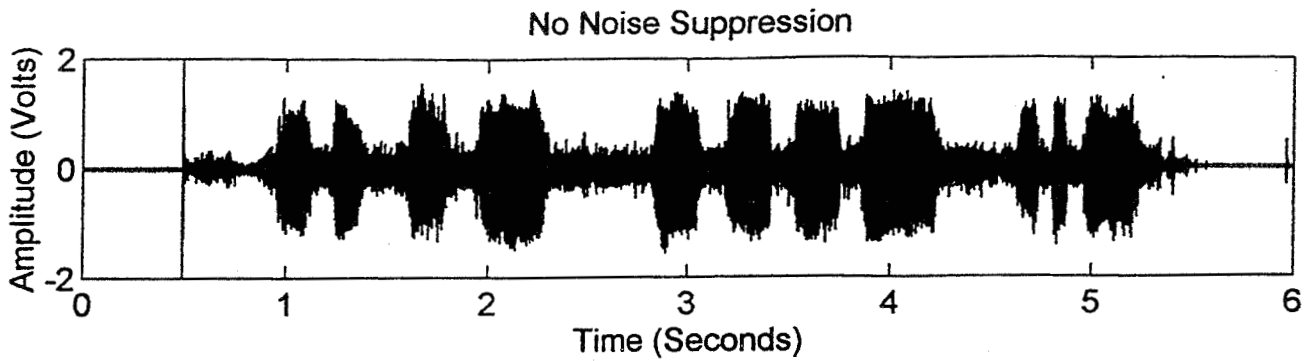
Figure 7. No Noise Suppression (Words: Test, Straight Through 1, 2, 3, 4, End of Test)
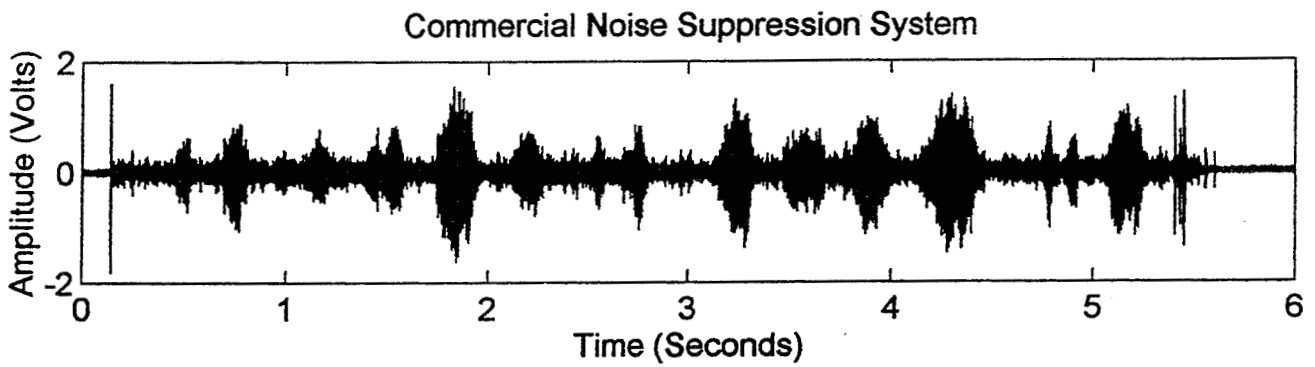
Figure 8. Commercial Noise Suppression System (Words: Test, "Company Initials" Noise Suppression System 1, 2, 3, 4, End of Test)
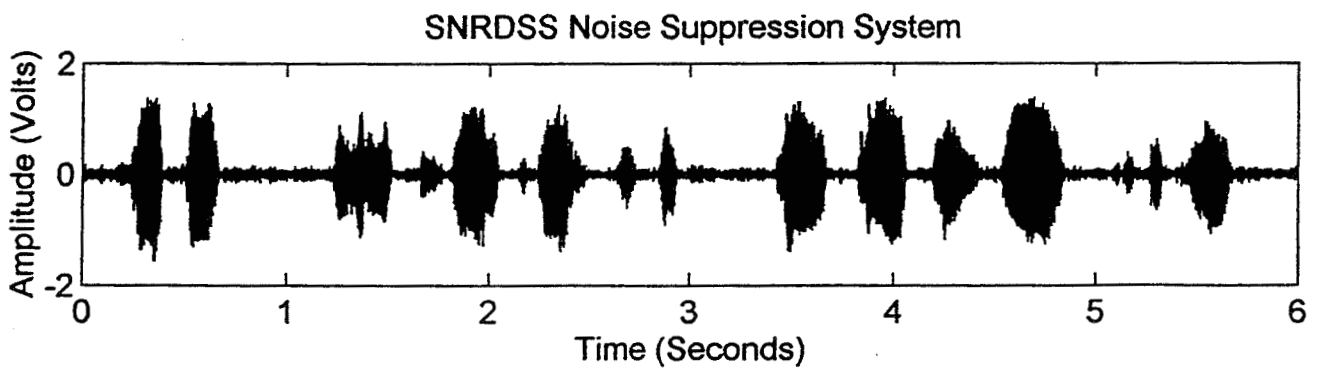
Figure 9. SNRDASS Noise Suppression System (Words: Test, DSP Noise Suppression System 1, 2, 3, 4, End of Test)

The low level noise at the beginning and end of Figures 7 and 8 are the noise in the communication channel before the input from the emergency vehicle is keyed onto the channel. The key-on time was slightly longer for Figure 9, so the start and stop do not appear in the six second interval. The amplitude of the communication channel noise without the input from the emergency vehicle was the same for all three tests. Since the commercial device attenuated both noise and voice, the level of the recorded results from the commercial device were increased to the level of the other tests. This allowed all of the tests to be heard and graphed at the same amplitude. Due to the level change, the noise in the communication channel appears larger in Figure 8. Figure 10 contains a 0.55 second section of response extracted from Figures 7, 8, and 9 containing the word "four" and the background vehicle noise with no speech.
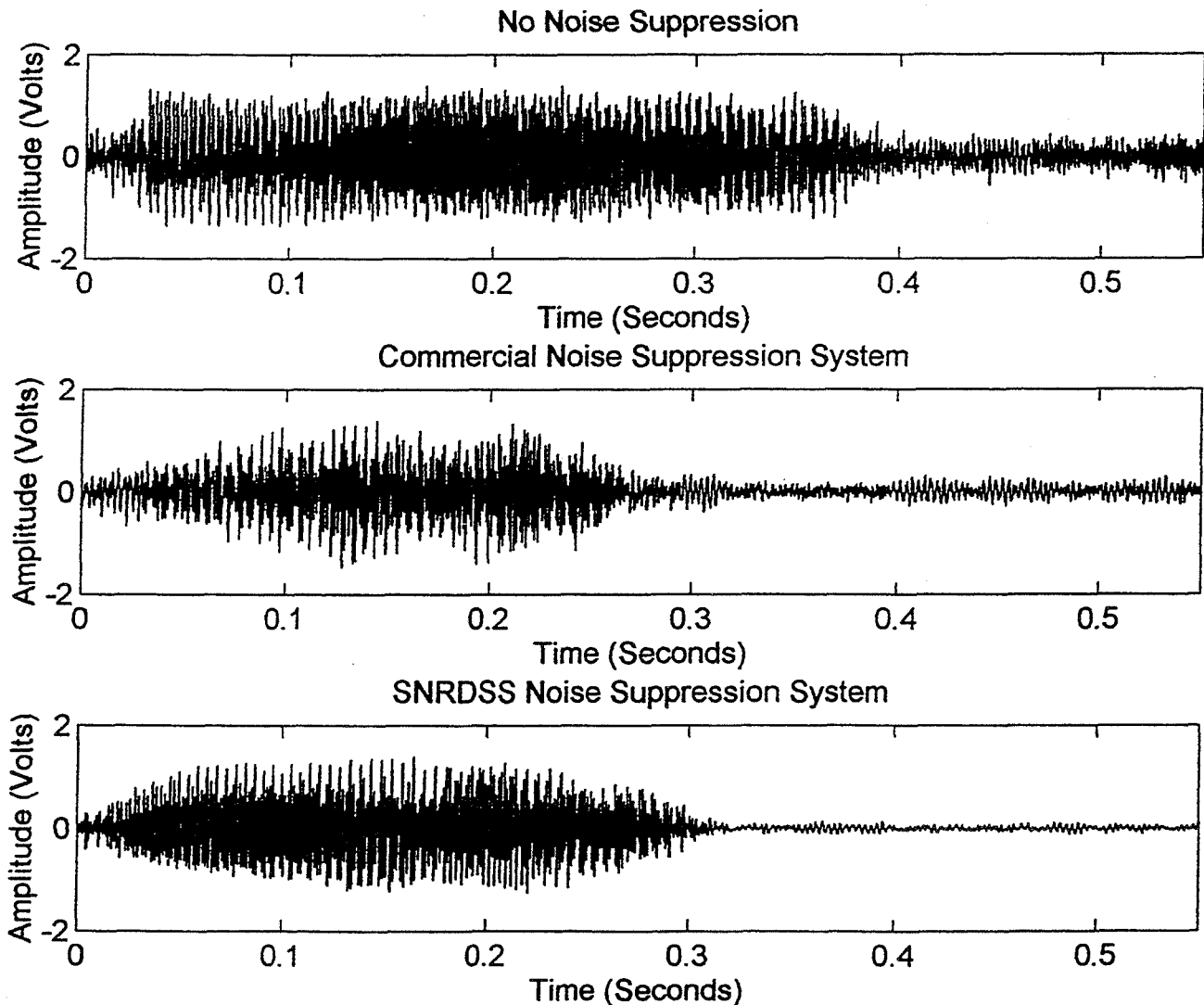
Figure 10. Word "Test" Followed By Voice Free Section of Vehicle Noise, Taken From Figures 7, 8, and 9.

Using Figure 10, the signal to noise ratio for all three tests were determined by using

$$SNR = 20Log\left(\frac{V_{RMS}(Signal + Noise) - V_{RMS}(Noise)}{V_{RMS}(Noise)}\right) \qquad (8)$$

where

$$V_{RMS} = \frac{1}{N}\sqrt{\sum_{k=1}^{N} v^2(kT)} \qquad (9)$$

and v(kT) is the voltage plotted in Figure 10. The signal plus noise information for each test was determined using the 0.1 second interval (1493 values) between 0.12 and 0.22 seconds. The noise information for each test was determined using the 0.1 second interval between 0.4 and 0.5 seconds. The results are shown in Table 1.

Test	V_{RMS}(Signal+Noise)	V_{RMS}(Noise)	Signal to Noise Ratio
No Noise Suppression	25.5	6.07	10.1
Commercial Device	19.2	4.24	11.0
SNRDASS Device	23.3	1.55	22.9

Table 1. Signal Plus Noise, Noise, and Signal to Noise Ratio for the Three Tests

Using listening tests and the above information, it was determined that with no additional noise suppression, the OIS-RF microphones and filters in the communication system produced a signal to noise ratio of 10.1 dB. Both the commercial device and the SNRDASS device greatly improved the clarity of the speech. Furthermore, both devices caused very little to no distortion due to musical noise. However, the advantage of the SNRDASS device was an improvement of the signal to noise ratio to 22.9 dB whereas the signal to noise ratio for the commercial device was only improved to 11.0 dB.

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1997 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

USING NEURAL NETWORKS FOR PREDICTING
SHUTTLE GH2 FLOW CONTROL VALVE FAILURE

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Advanced Developments and Shuttle Upgrades

ABSTRACT

This effort was aimed at determining the health and predicting failure of the Gaseous Hydrogen Flow Control Valve (GH2FCV) using neural networks. For safety reasons procedure is to replace the valve at the first hint of a problem. Replacing a good valve is an unnecessary expense, not replacing a failing valve can be very dangerous in addition to being expensive. Presently, valves are examined by experts using ground based tests. These tests are only intended to verify that the valve is flight worthy. In order to predict failure, more is needed. To this end, neural networks were designed and trained to look for signs of degradation in the valve operation. The networks, using flight data, can be made to evaluate the valve during or post flight. The data needed for training is, however, generally unavailable. To obtain representative data depicting different conditions, computer programs were used to model the valve and generate data. Modeling allows faults and anomalies to be introduced under controlled conditions. Networks were designed and trained to recognize good, bad and degrading valve operating conditions using real and simulated data. By recognizing unusual characteristics in the signatures a variety of conditions which precede failure could then be detected. The aim of the work was to detect subtle system degradation and other anomalies that precede system failure. With proper training, the network will assist experts in determining the condition of the valve and make better decision on when to affect repairs. This application of neural networks can reduce system maintenance costs and improve knowledge of the orbiter's health. To verify the feasibility of this approach it is recommended that a hardware model of the system be built to more clearly identify hardware and processing needs.

USING NEURAL NETWORKS FOR PREDICTING GH2FCV FAILURE

By Carl D. Latino

1. INTRODUCTION

Knowing the health of the orbiter is a desirable upgrade to the space shuttle program. To this end, the Integrated Vehicle Health Monitoring (IVHM) system is being developed. Evaluation of how key systems are performing helps better decide when to make repairs, or replace parts, before they actually fail. Unnecessary repairs are expensive and time consuming. Having components fail in flight can be dangerous and even more costly and time consuming.

Predicting failures improves safety and reduces costs. One of the systems currently requiring considerable maintenance is the Gaseous Hydrogen Flow Control Valve (GH2FCV). This valve controls the external tank liquid hydrogen pressure. Failure to properly pressurize this container could cause its rupture or collapse. For this reason, at the first hint of a valve malfunction, procedure dictates that the valve be replaced. The suspect part must then undergo lengthy processing.

The anomaly that necessitated these operations may have been caused by some condition not directly related to the valve. A sluggish poppet, for example, might be the result of some contaminant temporarily lodged in the valve. Once the contaminant leaves the valve, it may return to normal operation or may be slightly degraded. Other conditions may also cause anomalous looking current signatures in otherwise normal valves. It is therefore important to be able to distinguish between temporary anomalies, such as instrumentation problems and dust particles and conditions indicating real system degradation.

2. GASEOUS HYDROGEN FLOW CONTROL VALVE SYSTEM OPERATION

There are three Gaseous Hydrogen Flow Control Valves on the orbiter. Each is located between a main engine and the liquid hydrogen tank as shown in Figure 1. The GH2FCV is a single flow path, dual position valve. Gaseous hydrogen from the main engines is sent back to the tank via the GH2FCV to maintain the tank pressure within acceptable levels. As the tank pressure drops below some level, the valve is switched to the high flow position, increasing gaseous hydrogen flow. When the pressure exceeds some other level, the valve is switched to reduce the hydrogen flow. With loss of electrical power, the valve is designed to fail in the high flow position.

3. VALVE CURRENT SIGNATURES

The GH2FCV is an electro mechanical valve which may be modeled as interacting electrical and mechanical systems. The valve is commanded by a voltage input, the resulting

current has a unique signature which is used to determine whether the valve is nominal or nor. The electrical system is an inductor resistor circuit with varying components, while the mechanical system is a mass spring damper with a variety of nonlinear components.

Under controlled laboratory conditions and with properly operating valves, the signature traces for repeat cycles are almost identical. For the H2FCV typical curves resemble Figures 2 and 3. During the energize cycle, current increases at an exponential rate until the poppet begins to move. The poppet movement induces electrical circuit changes causing the current to decrease until the poppet hits the stop. When the poppet stops moving the circuit changes also stop. The current then begins to increase with a time constant of the new electrical circuit until it reaches the steady state value. In the de-energize cycle, the current decays exponentially until the spring force exceeds the magnetic force and the poppet begins to move. This movement induces changes which cause the current to change with poppet motion. When the motion stops, the current again decays but with a new time constant.

This behavior can be simulated with appropriately developed models. Simplified models of the electrical and mechanical systems are shown respectively in Figures 4 and 5. Under actual flight conditions, vibrations, pressures, external accelerations, particle contamination etc. will cause the curves to look different. Since current signatures are the primary way that these valves are monitored, it is important to be able to distinguish good from bad traces.

4. VALVE SYSTEM TESTING

Prior to installation in the orbiter the valves are tested in the lab. These tests certify that the valve meets the design requirements but are not representative of performance under normal operating conditions. The valve is activated and de-activated with a laboratory power supply and the recorded current trace visually inspected. Many of the tests are not conducted under pressure, vibration, acceleration or flow conditions. The tests are intended to make a yes or no decision and not for quantifying the state of the valve or for predicting the onset of failure.

Failure modes are difficult to quantify under these circumstances since each valve is unique in construction and performance. Because valves are unique, each may need its own neural network. With a unique neural network, performance is measured by comparing the valve to its history rather than to some arbitrary standard. This is accomplished by using the valve data to train the network. This way the valve is tested against the appropriate standard.

With the neural network properly trained, each valve can be evaluated in flight during every energize and de-energize cycle in real time. Testing in flight (or post flight using flight data) is more realistic and provides more information than ground based tests alone. Automating testing in flight enhances accuracy and the efficiency of ground based evaluation.

5. VALVE SYSTEM DEGRADATION

The purpose of the neural network is to detect a trend in the valve operating life. It is desirable to extend the operating life of the valve while retaining high safety standards. If the valve wears out in some progressive manner, an acceptable threshold could be determined and

the valve replaced when this value is exceeded. An example of this is if the poppet becomes more sluggish with use, and this sluggishness could be quantified. The approach seems reasonable but is hampered by the lack of data available. There is no real data available of a valve which has been operated until failure.

Based on the limited available data, system degradation is difficult to quantify. This is so because as valves are found suspect, they are immediately repaired or replaced. There have been cases where the poppet action was sluggish then on subsequent cycles acted nominally. This might be indicative that a contaminant entered and left the system. It could, however, be a clue to a more serious problem. Monitoring the frequency of such occurrences and the relative sluggishness of the poppet can be real clues to measuring actual valve system degradation. Other varying parameters acting in concert can vary the current trace making the non catastrophic conditions more difficult to evaluate visually.

To better answer the questions of how the valve is failing will require considerable amount of data depicting many different conditions. Since real data was not available, models were used to generate data. This helps predict the effects that varying conditions have on the valve. As more real data becomes available, the models can be refined.

6. ACCOMPLISHING THE GOAL

It seems reasonable to use Neural Networks in this application because the error conditions are not easily quantifiable and the interactions of all the variables are nonlinear and complex. This is an ideal situation for neural networks since they can be trained. Neural networks are given inputs and shown the appropriate response. The problem with this approach is that there are a large number of possible combinations of conditions and data for all of these is not readily available. The data can, however, be made available by understanding the valve system operation in a mathematical sense and generating the needed data for the desired conditions.

Simplified versions of the models are shown in Figures 6 and 7. These base models were modified as needed to simulate the different conditions of interest. The data thus produced was then used to train the neural networks. If the model can be used to produce real looking data, real data could then be used to verify the performance of the network. Based on the findings, appropriate adjustments would then be made to the model and the network. Given adequate models and associated neural networks, performance can be quantified as parameters are changed in a controlled environment. The model allows repeatability and the acquisition of unlimited amounts of data. Once the data is generated, each condition is issued a figure of merit.

Given the desired inputs and associated outputs, neural network can be designed and trained. Once properly trained, the network may be used in or post flight given real data. Installing a neural network really means writing a computer program that performs the appropriate mathematical operations. The output of the network can give a running account of the health of the valve being evaluated. The data thus generated is then reviewed on the ground to help scientists and engineers decide whether to replace the valve. If the network does not

produce the proper results, the training set can be enhanced and the network retrained with the modified data.

The next logical step is to construct a hardware prototype to demonstrate the efficacy of the neural network approach and to determine what resources are needed. The prototype will collect the data, process it, calculate the neural network functions and output a valve performance figure. This prototype will help answer questions about resolution, sampling rates and processing needs.

7. THE VALVE SOFTWARE MODELS

Computer models are easier and cheaper to use and manipulate than real systems. Accurate models can assist in giving a very good idea as to real system performance without actually having to design hardware. The electrical model of the GH2FCV is a resistor with a variable inductor. The mechanical model is a mass spring damper system. Figure 6 depicts the transfer function relating the input voltage to the solenoid current. This represents the mathematical equivalent of the electrical circuit.

Figure 5 depicts the poppet mechanical system as acted on by electromagnetic and spring forces. These figures show fixed component values, however, the actual models used include other forces and are, therefore, more complex. The complications induced in the models by the variation of component values and systems interactions were omitted for reasons of clarity. With an accurate model the data can be used to train a neural network to deal with a wide range of contingencies. The first order model generated was for an idealized solenoid. Complexity was added to better approximate the system. As the GH2FCV system is better understood, the model can be modified to better deal with pertinent situations.

8. THE VALVE SYSTEM HARDWARE PROTOTYPE

To progress from idea to finished product, it is necessary that a hardware valve monitoring system be constructed. This system consists of a real or simulated solenoid, data acquisition system, memory, communications link and neural network. This hardware prototype will serve both as a demonstrator and a laboratory tool. Constructing a scaled down version of the IVHM system is the next logical step that will help answer questions that cannot be answered adequately by other means. To be useful, the prototype must be capable of collecting data at an acceptable rate, with acceptable resolution and perform all the required computations.

The hardware system must be capable of receiving, storing and processing the data and perform the functions within some time constraints. It must also be capable of accepting and processing real GH2FCV data. A working system of this kind will give a clear picture of the resources needed by this portion of the health monitoring system. Constructing this hardware prototype requires mathematical knowledge, understanding of the valve operation as well as knowledge of the system hardware needs. This design can be realized with a combination of custom and off the shelf hardware and customized software. This effort requires solutions to many subtle problems and should be undertaken by qualified personnel.

9. NEURAL NETWORK STRUCTURE

A variety of feed forward neural network structures were tried to determine networks that produced the most acceptable results. One such structure, which uses raw data, was an R-2-1 tansig, tansig network (Figure 8). The network shown has R inputs, 2 neurons in the hidden and one neuron in the output layer. The transfer functions for both layers was tansig. Tansig is only one of several transfer functions that are part of the software package used in this effort. This function is described as:

$$Tansig(n) = (e^n - e^{(-n)})/ (e^n + e^{(-n)})$$

The inputs of this function can be infinite but the output ranges between +1 and -1. The inputs used for one neural network structure consisted of raw data selected at fixed sample rates. Other options include selecting raw data at different rates (higher rates where more resolution was desired etc.). Using raw data required more inputs but little or no pre-processing. The number of inputs to the network can be greatly reduced when data is pre-processed. Possible types of pre-processing could be determining rise and fall times, maxima and minima and/or other pertinent information. Although pre processing reduces the number of necessary inputs, the filtering effects might conceal some pertinent information from the neural network. It was decided that, at least in the beginning, use of raw data and little pre processing would be preferred until the problem demanded greater neural network complexity.

The aim is to solve the problem using the simplest possible network. To try to answer these questions, ground test data and computer generated data were tried on networks with one and two hidden layers with a varying number of neurons. A network with two neurons in the hidden layer seemed both simple and adequate for this application. Networks with fewer inputs and more neurons were also tried. Since failure modes are not known, conclusions about the relative merits of the different networks cannot yet be drawn. To learn more about neural networks, the textbook by Hagan et. al. is an excellent reference.

10. NEURAL NETWORK TRAINING

The network is only useful when properly trained. It is, therefore, necessary to train the network to solve the problem accurately. This implies that the network be capable of differentiating between acceptable variation from nominal and undesirable situations. Training was accomplished by presenting the network with the inputs and the target output values. The training varies the network weights and biases until acceptable performance is achieved. Training is successful if the network give correct results even if the inputs applied are different than those with which it was trained. To this end, the curve trace data should be divided into three different groups, training, evaluation and testing.

Training data is used to get the weights and biases. As training is conducted, evaluation data is used to ensure that the network is generalizing the problem correctly. If errors with

training data decrease while error with evaluation data increase, this may indicate over fitting. At the end of training, the test data is used to determine if training was successful. The ideal neural network minimizes neurons while accurately evaluating the system response. If all possible examples are presented to the network during training, it will always return good results during testing. This is not a reasonable assumption to make due to the large number of possible inputs. Therefore, the network should be trained then tested with inputs that it has never seen before.

If the network has successfully generalized the problem, it responds correctly to a broad range of inputs. Depending on the actual hardware used in implementation, the GH2FCV current data may need pre processing to accommodate the network. Training the networks is accomplished with real and simulated data.

11. SOME COMPLICATIONS

Since valve operation is a function of many variables and unknowns, it is difficult to quantify the results. Even experts have difficulty defining what constitutes acceptable or nominal operation. This complicates the problem of quantifying test results for generating training data. There is also the question of whether the current trace is by itself sufficient information to evaluate valve performance. Other variables which may serve as inputs to the neural network may be available on the orbiter but as variables are added evaluation becomes even more difficult.

Anticipating failure requires that conditions change in some predictable manner. If this is in fact the case, neural networks can be taught to predict failure. At present such conditions are not known with certainty. A laboratory setup with a hardware prototype will be an essential tool for obtaining answers to some of these difficult questions.

12. CONCLUSIONS

Hardware and software models are necessary tools to study effects of varying conditions on the GH2FCV system. Software models can provide training data and neural networks can be taught to detect system changes. A combination of these are powerful tools useful in solving the GH2FCV health monitoring problem. To this end a variety of network structures were applied to the problem. Networks with larger number of inputs but few hidden layers were the easiest to use and train. They did require relatively large number of multiplications and additions for function evaluation, but required little pre processing. Networks with smaller number of inputs but with the same number of neurons required less evaluation time but the training was made more difficult and pre processing required some subjectivity on the part of the user.

Since in flight test data was not available, all data used for training and testing was data simulated or collected on the ground. Although promising, the methods need to be verified on real hardware using real flight data. This will be possible when sensors are installed on the orbiter and large quantities of flight data collected. To better understand the resources needed

by a neural network monitoring system it seems most advisable to construct a hardware prototype of the system.

The ultimate system intended for flight described here is non invasive requiring only an on board data collection system. The neural network training is done on the ground and valve monitoring and evaluation can be done in or post flight. By knowing more about the GH2FCV status, safety levels are maintained while unnecessary maintenance and costs are reduced.

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ACKNOWLEDGMENTS

Fig. 1 GH2 Flow Control Valve

Fig. 2 Energize Sig. Trace

Fig. 3 De-Energize Sig. Trace
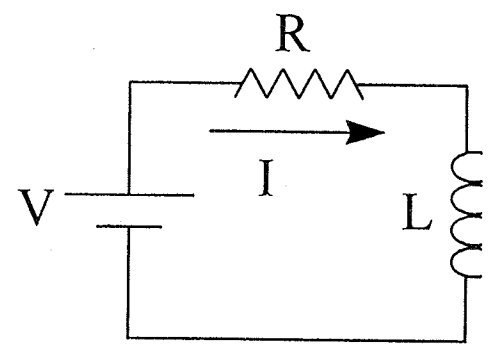
Fig. 4 FCV Electrical Model
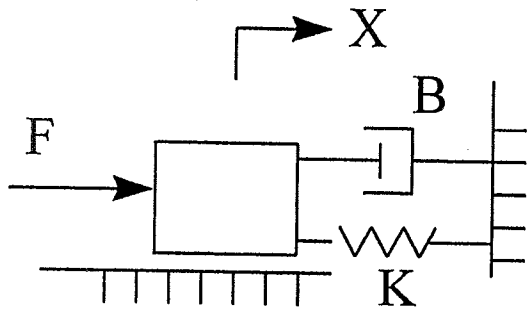
Fig. 5 FCV Mechanical Model
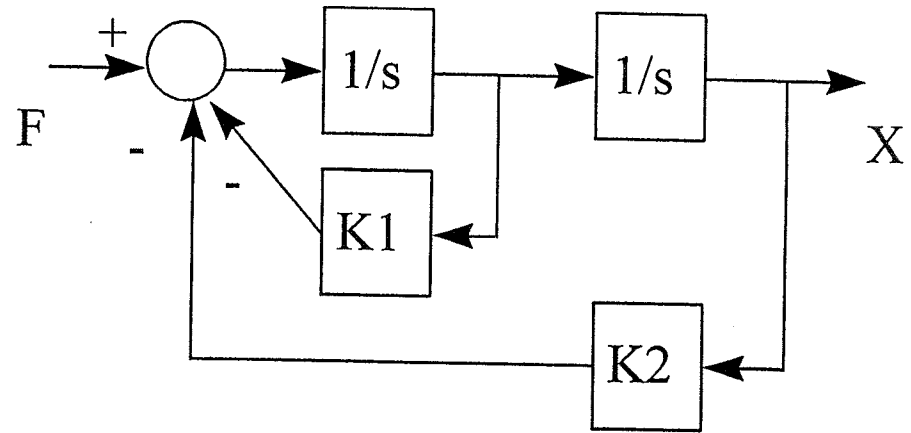
Fig. 7 Mechanical Math Model
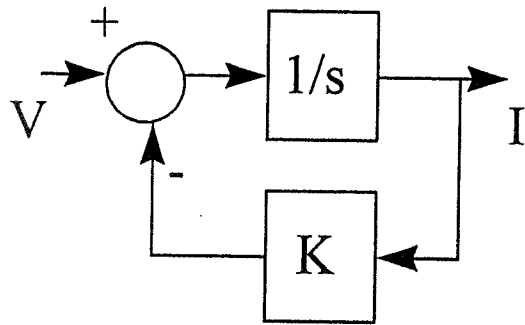
Fig. 6 Electrical Math Model
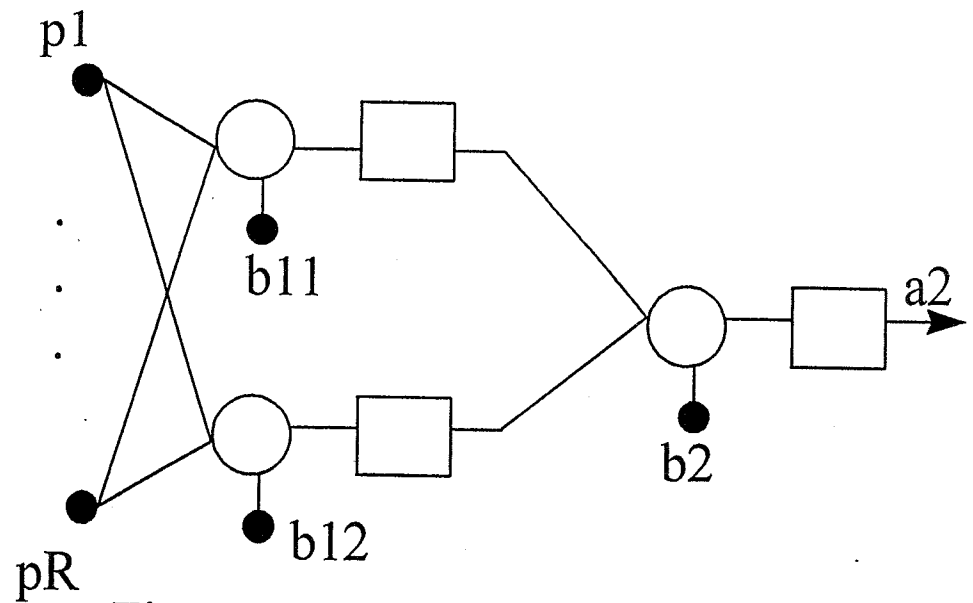
Fig. 8 Feed Forward Neural Network

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1997 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

STRATEGIC CONSIDERATIONS IN PLANNING FOR
THE USE OF THE INDUSTRIAL ENGINEERING RESOURCE AT THE
KENNEDY SPACE CENTER

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Many thanks to all of you for helping to make this summer both enjoyable and professionally interesting and expansive. I wish the best of everything to all and continued success in your life and work endeavors, and God Bless you all!

ABSTRACT

This paper reports on the results of the author's 1997 NASA/ASEE Summer Faculty Fellowship work. In the current environment of re-invented government and the changes it imposes at NASA's Kennedy Space Center, the Industrial Engineering resource has vast potential to positively affect the strategic goals brought on by that change. The author has developed a series of considerations and issues that could be addressed in planning for the use of the IE resource at KSC. Issues such as group objectives, IE message focus, a process improvement methodology, potential current projects, organizational placement, personnel selection, project management and leadership issues are addressed to insure that through the planning and implementation activities the use of the IE resource is maximized. Several final recommendations are given as a part of the issues and items discussed.

STRATEGIC CONSIDERATIONS IN PLANNING FOR THE USE OF THE INDUSTRIAL ENGINEERING RESOURCE AT THE KENNEDY SPACE CENTER

Jerome P. Lavelle, Ph.D.

1. INTRODUCTION

At the NASA Kennedy Space Center (KSC) the civil servant role in the space shuttle program is changing. The current shuttle contract (Space Flight Operating Contract-SFOC) with the United Space Alliance (USA) calls for a reduced government role in the processing and launching of space shuttles and payloads. This action frees up government resources for use in other programs, such as the International Space Station, the X-33/34 orbiter, the space shuttle upgrades program, and the mars/lunar program. This action also re-aligns the KSC workforce with agency strategic plans of becoming more research and development focused and re-focusing resources away from the operational phases of mature programs. In the "safer, better, faster and cheaper (less expensive)" environment that pervades NASA-KSC, the use of the Industrial Engineering (IE) resource has been somewhat limited. Now is the time to address the utilization of this important resource whose underlining tenets are to make the most effective use of organizational resources through analysis and improvement methodologies. This work details a series of considerations and issues that could be addressed in planning for the use of IE at KSC.

2. BACKGROUND

There is much change at KSC as a result of the 1993 Performance and Results Act. This legislation formally initiated the re-inventing government process through the National Performance Review [1]. It stipulated the use of formal strategic planning processes for government agencies in defining and mapping their goals and the use of government resources. NASA leadership, in responding to this challenge, has been active in defining its vision for the agency and in formulating means to achieve that vision. The strategic planning process and change environment has affected KSC in very tangible ways, including: movement toward a single prime contractor concept, transition to a much reduced civil service role in the shuttle program, and the re-alignment/re-assignment of personnel to accomplish center goals.

Documents have emerged from the center's strategic planning process that identify goals and explain the type work to be done to accomplish those goals. These goals set forward work plans that are ripe for the application of IE competencies, which include: simulation, process analysis, statistics and data analysis, methods analysis, operations research techniques, process flow and improvement, risk and economic analysis modeling, decision analysis, and others. There exist many areas for improvement and much potential brought about by the change-environment and current center leadership, and in this context there is a vast potential for the use of the IE resource at KSC.

There has been an IE group at KSC since 1989 when 0.75 FTE was assigned to begin looking at how IE skills could be used. Since that time the IE group has ranged from a maximum of 6.0 FTE to its present day 5.0 FTE. It is important to recognize that any future plans for the use of the IE resource at KSC must incorporate constraints brought about by the change-environment. In the current environment such constraints include: a center-wide hiring freeze, a focus on headcounts and how those headcounts are proportioned center-wide, directorate and center-level re-organization efforts, and an organizational structure that historically has not provided a clear promotion and career path for IEs.

A survey was conducted of the present members of the group to characterize past projects and the work environment. This survey included questions regarding: demographics, project characteristics, group workplace questions and open-ended questions. This data provided insight into how the group has operated and was considered in developing the issues and recommendations discussed in the following section.

3. IE USAGE ISSUES

From the inputs discussed above a series of considerations and issues were developed for the use of the IE resource at KSC. These are described in detail below.

3.1 Group Objective

It is important in considering the role of the IE group at KSC to explicitly delineate the mission, goals and objectives of the group. These should be considered and developed in conjunction with all interested stakeholders (management, group members, clients/customers, etc.) in the usage and growth of the group. As a starting point the group may consider that their mission/goal/role is to:

- be proactive in creating real added value (not just perceived) to the goals of the center
- use IE skills and resources in creative ways to advance these goals
- be concerned with being "cost effective" as a resource
- focus ongoing work and strategies toward a methods of continuous improvement

Some of the things the group should not be used for:

- to do anything/everything to keep the center alive
- to do anything/everything to keep the group alive
- to micro-manage
- to create a fiefdom

3.2 IE Message Focus

Individuals within the IE group and management have been "beating the IE drum" for several years and promoting the successes enjoyed by the team. In the "change" environment many throughout KSC are beginning to hear and understand the potential that this group could have at the center. However, it is important that the message not be misinterpreted or diluted. It is important to "keep the IE message clear and simple" to focus the group on some current and anticipated competencies and domains and to deliver measurable products that create successes for the clients.

3.3 Process Improvement Methodology

In order to take advantage of the opportunities that do and will exist for the use of the IE resource it is important to develop and establish a formal working model for the group for managing projects from a life-cycle perspective. The group should have a mechanism for identifying potential projects, evaluating projects in terms of impact and skill fit, selecting potential projects, loading selected projects onto group resources, directing and monitoring projects during their design and implementation phases, and terminating such projects including technical reporting. A model developed around Dr. W. Edwards Deming's continuous improvement cycle (Plan-Do-Check-Act) could be used for this purpose. Table 1 below explains the role and IE skills used within each of the P-D-C-A phases. This model provides one potential platform for accomplishing the goal of more completely organizing the work that the group performs. One of the common "less positive" responses from the group survey was that project management was not utilized to the fullest extent throughout the life-cycle of the projects that the group takes on. Such a model forces a focus on planning, deliverables and outcomes.

3.4 Potential Current Uses

In looking at the various strategic planning initiatives at the center and the areas in which the IE resource could be utilized, a list of potential current domains was developed. The list, given in Table 2, provides both the names as well as possible current and future involvement in those areas by the IE group. Table 3 provides brief details of the "what" and "why" of the IE involvement in each of these domains.

Table 1: Modified P-D-C-A Cycle for IE Project Work at NASA-KSC

PLAN

Problem	Tools & Skills	
• problem identification	• checklists	• simulation
• project goal definition	• pareto charts	• baselining
• evaluate impact potential	• statistical analysis	

Role	Tools & Skills
• IE group & others role definition	• project management
• deliverables definition & time table	• informal contracting
• formalize relationship	

Alternatives & Decisions	Tools & Skills	
• identify all potential alternatives	• brainstorming	• simulation
• evaluate project risk/economic impact	• decision analysis	• statistics
• design of solution	• economic analysis	• benchmarking
	• methods analysis	• experimental design

DO

	Tools & Skills
• implement design choice	• project management

CHECK

	Tools & Skills	
• collection of data	• data analysis	• statistical analysis

ACT

	Tools & Skills
• iterative actions identified	• decision analysis
• identification of design refinements	
• continue with next phase of solution	
• continue with next priority problem	

Table 2: Current Potential Project Domains and Possible IE Involvement

Activity Domain	Now	Later
• shuttle transition	high	some
• shuttle upgrades	high	some
• contractor "shop floor"	high	high
• advanced initiatives	high	high
• KSC-at-large - transition	medium	high
• tool development	medium	medium
• KSC-at-large - consulting	med-low	med-high
• outside consulting	low	med-high

Given the constraint (and assumption) of slow growth of the IE resource at KSC the general overall strategy being promoted is to focus on deliverables and successes within the shuttle directorate in the short term and expanding outward from that position. These include shuttle surveillance planning, shuttle upgrades involvement and contractor "shop floor" projects. The group should build on measurable successes and expand its "sphere of impact" to include work at KSC-at-large in terms of transition and in a consulting role, and then beyond KSC to NASA, other government, and outside organizations.

Table 3: Description of Potential Domains in Use of IE Resource

SHUTTLE TRANISTION	
What:	**Why:**
• facilitate, steer, shepherd toward transition	• STS not going away tomorrow
• focus toward system, integrative process	• transition is a current emphasis
• ensure maintainable/sustainable system	• in-line opportunity, anchor
• iterate with a re-engineering approach	• create successes

SHUTTLE UPGRADES	
What:	**Why:**
• concurrent engineering approach	• mitigate downstream costs
• focus efforts on processes and modeling	• new technical learning
• utilize analysis of design issues	• create successes

CONTRACTOR SHOP FLOOR	
What:	**Why:**
• CI projects on contractor shop floor/interface	• enhance team concept, win-win
• drive efforts toward cost avoidance	• balance of traditional IE skills
• formalize relationship and access	• SFOC cost avoidance sharing

ADVANCED INITIATIVES	
What:	**Why:**
• concurrent engineering, X-vehicle, mars/lunar, ISS	• opportunities for tool development
• analysis tools in design/planning work	• mitigate downstream costs
	• economies of efficiency

KSC AT-LARGE — TRANSITION	
What:	**Why:**
• lead/consult in center transition efforts	• create successes, evangelize
• leverage lessons learned	• KSC prospers, IE prospers
• develop and apply generic transition model	• create contacts

TOOL DEVELOPMENT	
What:	**Why:**
• COTR for SBIR projects	• keep current with tools
• technical input and priorities in advanced technology	• drive products toward deliverables
• lead summer faculty, university and co-op work	• integrate user-driven design

KSC AT-LARGE — CONSULTING	
What:	**Why:**
• utilize IE skills in larger KSC sphere	• expand circle of influence
• problem solving through IE process at KSC	• create successes
	• outlet for projects and developed tools

OUTSIDE CONSULTING	
What:	**Why:**
• utilize IE skills in larger outside sphere	• create re-imbursable projects
• includes NASA, government, industry	• unique/new job experiences
	• build client base, expand influence

3.5 Organization Placement

Organizational placement is a key issue in developing a plan for the usage and growth of the IE resource at KSC. Scenarios at the two extremes of a placement continuum would be to implement the group within one of the in-line functions or to establish the group as a staff support organizational unit at the center level. Implementation in an in-line unit begs the question "what unit?". Currently the IE group is placed in the shuttle directorate. This placement supports the recommendation to make an impact and create successes in the shuttle domain first (transition, upgrades, contractor shop floor) and expand this sphere of impact outward to other domains. Such placement keeps the group close to the local problems and there is a recognition within the shuttle directory that the group is "our people". However, such placement tends to "bury" the group and somewhat limit its potential on a center-wide basis. Placement as a staff unit would provide access to center-wide problems and facilitate work toward integrative, organization-wide solutions to common problems. Care must be taken with such a staff-level placement that the group is not viewed as "flying at 30,000 feet". In other words it is important to stay in tune with the problems at the local levels and to integrate these problems and provide comprehensive center-and-organization wide solutions. This approach creates economies of scale in the use of the IE resource and the impact that such work makes.

Between these two extremes are various interim placements for the group that include combinations of center-staff and in-line placements. A model that might be particularly useful as the group grows would be to place the group organizationally at the center staff level, and maintain satellite offices (cubicles) in several key in-line organizations where IE members/teams can be close to the in-line problems and "mine the gold". For longer duration assignments IE members could be matrixed or detailed to local organizational units. However, in such cases group member/team would maintain physical contact with the IE unit through periodic visits to the staff group for communication, sharing and planning. This framework of having a central recognized organization from which to plan and farm out work as it fits with the overall objectives for the use of the IE resource appears to be a good one. It takes advantage of the positive attributes of the two placement extremes.

3.6 Personnel Selection

The ability of an organizational unit to achieve objectives and efficiency in completing work is greatly affected by human resources in that unit. As the IE group plans and prepares for expansion several issues may be useful in evaluating future group members and their potential impact. It is useful to consider candidates across three primary dimensions: KSC background, IE specialty, and outside contacts. In looking at the KSC background of members in the IE group it would be useful to have as broad a base of experience as possible. If possible, potential candidates should add unique backgrounds in shuttle systems (hypergol, electronics, etc.), organizational units (logistics, engineering, payloads, etc.) and facilities (crawler/transporter, OPF, VAB, etc.). In terms of IE specialty the issue is uniqueness versus the complementary nature of the IE skills added by new members. If the group is being focused (simulation, statistical analysis, etc.) then complementary skills with others in the group are desirable. If the group is expanding domain experts then a unique skill (methods analysis, OR techniques, etc.) would be more desired. However, given this effect most IEs are skilled in more than one area of specialty and have a certain breadth dimension as well as a depth dimension.

Lastly, in looking at potential candidates it may be useful to consider experiences and contacts outside the walls of KSC and NASA. An outside perspective and outside experiences tend to enrich the way in which one accomplishes work and addresses problems. These are valuable perspectives to share with the overall group. It is important to seek excellent candidates who:

- are excellent communicators
- are self starters (take initiative, see opportunities)
- know how to manage a project life cycle
- are people-persons who help to create a positive work environment

- are confident high achievers
- are motivated and motivate others
- are results and product oriented

3.7 Project Management Issues

It is important to use a project management methodology in technical projects. It provides the framework and template for ensuring that appropriate tradeoffs can be considered when time, quality and cost constraints conflict. It provides a mechanism to plan for the usage of resources and the matching of those elements to project requirements. It provides a means to map projects to employees with appropriate skills. As the IE group grows it becomes more important to standardize project work around a project management template so that employees and technical management can actively assess their work from a life-cycle perspective. Table 4 provides an outline of the questions asked as part of a project management approach.

Table 4: Questions Asked as Part of a Project Management Approach

<u>**Project Selection**</u>
- what are available competencies?
- what are resources current/future availability?
- what are current organizational priorities?
- what are potential payoffs and risks associated with this project?
- what are the start-up requirements of the project?

<u>**Project Organization, Tracking and Reporting**</u>
- what are the project tasks and relationships?
- how do I tie resources to those tasks?
- what are the project milestones or review points?
- what mechanism is used to track status?
- who will identify variances to plans and act on deviations?
- how are human resources organized and managed?
- what mechanism is used to report interim/closure issues?
- what structure is used to communicate and act project-wide?
- what are the project termination requirements?

3.8 Group Leadership Issues

Effective technical management is perhaps the greatest asset that NASA could have. Technology and technical people (along with money) are the machinery that ultimately accomplish the objectives of this agency. If one maximizes the effectiveness and efficiency of this machinery it follows that the organization will be successful. What works for other technical units at NASA (and elsewhere) also works for the IE group. Below are given several qualities for successful leadership/management in technical environments:

♦ The technical manager should be dedicated and work tirelessly to improve the technical expertise of their people. They should be visionary and have a plan for moving the unit in a direction that creates a positive work atmosphere that enhances the goals of the overall organization.

♦ The technical manager should be in tune with the needs and motivations of the workers in their unit. They should recognize that individuals with different backgrounds, different personalities and employees at different stages in their career have different needs from their technical manager and work in unique ways. The manager should recognize that not all employees fit "their" notion of how work should be done and that unique and creative designs/solutions/methods should be encouraged.

• The technical manager should be active in developing and managing processes within the office that "facilitate" work not "constrain" it. They should be active in being a funnel point for potential projects and new work domains for the group's expertise and cultivate such opportunities. In considering projects they should be aware of the "cost/benefit" of engaging group resources. A portfolio approach of projects with varying duration, involvement, payback potential and risk could be used. It is important for the technical manger to realize that such characteristics exist for all projects.

♦ The technical manager should have in place a system that actively develops and promotes "stars" within the group. Most individual workers are motivated to achieve and be recognized as an expert and "high achiever" within their organizational units. However, sometimes they may lack knowledge, or have a misunderstanding, of how to accomplish that goal. A research study that looked at the differences between "star" and "middle" performers at AT&T Bell Labs found that although workers in these categories identified the same core skills and strategies for being successful, theie order of importance and definitions were opposite [2]. Figure 1 below describes an Expert Model that the Bell Labs stars used in accomplishing their technical work. The middle performers had the skills and strategies inverted, that is they put their effort into the outer ring of the model first. Thus, they emphasized a different strategy for accomplishing their work. Furthermore their definitions for the skills and strategies were different than the stars. For example, middle performers replaced the definition of "taking initiative" from Figure 1 with one focused more on "being busy" versus identifying new and meaningful projects. This is not to say that this model is the best for creating star performers at NASA, rather the point to be made is that the technical manager should be aware of the uniqueness of individual workers and facilitate their respective growth and development to make everyone a potential "star".

♦ Technical managers set the mode and tempo for work as it is accomplished in their units. In that role it is important for the manager to create an environment free of obstacles where skills and challenges converge — such environments produce what researchers have called "flow" experiences [3]. These experiences occur when there is an appropriate mapping between skills and challenge, where creative potential is realized and where tasks are intrinsically rewarding. Flow experiences are said to be *autotelic* meaning: self (*auto*) goal (*telos*). Such tasks energize versus drain the individual, and in team environments build synergy between members in achieving the goal. The interesting thing found by researchers of flow experiences is that the workplace holds the greatest potential for these experiences (versus hobbies, or family, or other aspects of life). Work is the place where tasks and goals most often converge. For technical managers flow experiences are created by:

• establishing clear work goals	• insuring employees have the right skills
• providing ownership of tasks	• providing immediate feedback
• insuring action and awareness merge	• developing *esprit de corps*

Overall the technical manager should be aware of their influence on the environment in which work is accomplished by their units. Being active in creating a workplace where flow experiences are commonplace could be one of the most important functions that the contemporary manager can perform. The role is shifting, even at NASA, from one as technical expert and top-down domain manager, to one of facilitator and enabler of the technical human resource.

Dr. W. Edwards Deming states that 95% of all problems within an organization are "management's problems". That is to say that 95% of all problems can be eliminated if management makes the right choices and creates an environment in which the human potential of everyone in the organization can be realized.
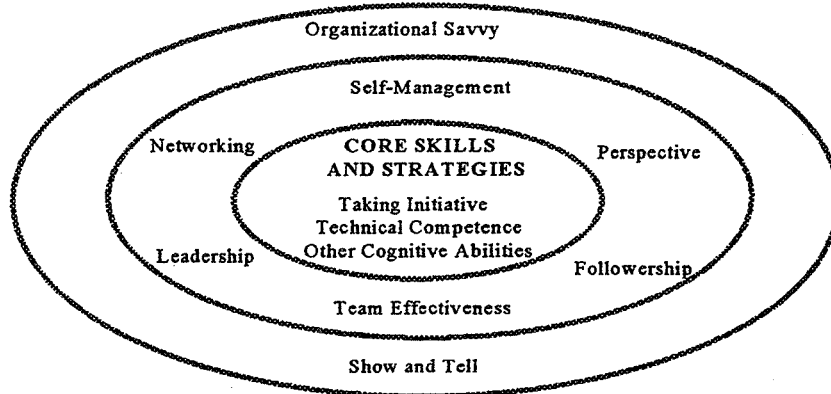
The Nine Work Strategies

Taking Initiative: accepting responsibility above and beyond your stated job, volunteering for additional activities and promoting new ideas.

Networking: getting direct and immediate access to coworkers with technical expertise and sharing your own knowledge with those who need it.

Followership: helping the leader accomplish the organization's goals and thinking for yourself rather than relying solely on managerial direction.

Perspective: seeing your job in its larger context and taking on other viewpoints like those of the customer, manager, and work team.

Self-Management: regulating your own work commitments, time, performance level, and career growth.

Team Effectiveness: assuming joint responsibility for work activities, coordinating efforts, and accomplishing shared goals with coworkers.

Leadership: formulating, stating, and building consensus on common goals and working to accomplish them.

Show and Tell: presenting your ideas persuasively in written or oral formal.

Organizational Savvy: navigating the competing interests in an organization, be they individual or group, to promote cooperation, address conflicts, and get things done.

Figure 1: An Expert Model for Engineers (from [2])

4. RECOMMENDATIONS

Given the description of the issues above several tangible recommendations are made below:

4.1 Recommendation #1

In order to continue to create star performers in the IE group and maximize the effectiveness of the individuals within the group it is important to:

♦Create an overall shared vision within the group and map this vision to individual motivation. The group's vision can be captured through the use of a mechanism like the participative design workshop [3]. In such sessions the people who *do* the work within organizations *design* the work in those organizations. Such a design is sometimes preceded by a *search conference* in which a participative strategic planning process is used where workers achieve full and active adaptation between themselves, their work organizations and their environments. Motivation, contribution mapping and buy-in are all common results of such sessions.

♦In the process of managing and developing the group, incorporate explicit plans and tools for creating star performers and creating an environment in which flow experiences are commonplace. Also, foster an open and communicative style with shared goals and motivations, which recognizes the uniqueness of each individual.

4.2 Recommendation #2

Given the following: the usual lead times associated with making changes in organizations, the set of potential projects identified through the planning mapping (from Table 3), the present set of dynamics and change affecting KSC, as well as an anticipated "slow growth" "prove and grow" environment for utilizing IE expertise at KSC, the following are suggested:

♦Begin now pushing toward placement of the IE group at a center-staff level. This placement provides a view of organizational inefficiencies at a top/integrative-solution level. However, use a matrix or detail-type implementation to keep project work at the in-line level — leveraging resources, solutions and common tools at the staff level.

♦Create successes in the "now-high" potential domains (from Table 2) and grow success through a focus on deliverables. Expand the sphere of impact and influence by first cultivating contractor shop-floor relationships and expanding into KSC, NASA, other government and industry domains. Begin establishing those relationships today.

♦Continue an appropriate role with the SBIR and other technology development vehicles. An appropriate role utilizes the IE resource as project proposal reviewers for technical feasibility, necessity and applicability at KSC as well as in the COTR role for selected projects. A few points of recommendation: maintain a technical versus managerial role, do not allow the process of involvement with these projects to pull resources away from the main goals of the group to any significant level; as COTR insist on a user-focused design from the onset of the project, even requiring end-user input to the technical evaluation stage; and drive these projects toward meaningful deliverables that will enhance the ability of the group to accomplish its goals in support of the center's goals.

4.3 Recommendation #3

Given the impact that can be made by this group at KSC today and the future growth of the group, it is very important to create a *system* for office operations (standard operating procedures) for: considering projects, selecting projects, mapping projects to resources, managing projects, project communication and reporting, and measuring the results of projects. The modified P-D-C-A project process as well as a list of project management questions given previously could serve as a starting point for formulating group-developed systems. Active leadership and management is required to make it a priority and make it happen. Such a system impacts the group's work and its ability to grow and create center-wide successes in the current environment.

3.4 "Forrest Gump" Recommendations

Two "Forrest Gump"-type recommendations are given in the context of the overall observations and recommendations given for the use of the IE resource at KSC.

♦ *"If you don't know where you are going, you will probably not wind up there"* This recommendation concurs with the statement that "for a ship with no destination any harbor will do". It is very important to set the strategic direction and goals for the IE group and develop plans to achieve those end-states. Change is omnipresent at KSC and even the best of plans are affected by these dynamics, but it is important to "plan the work and work the plan". Establish a vision and direction and iterate plans around these as conditions shift. This group has the potential to make a huge impact at KSC — the past was great and the future is very bright!

♦ *"People say that the earth is round but you don't have to believe it if you don't want to"* This recommendation espouses a thought dynamic "to challenge conventional wisdom." As the future role, placement, management, growth and leadership of the IE group is formalized it is important to consider the *possibilities* and not be constrained by historical or organizational thought patterns. From a selection and implementation perspective many of the possibilities for the IE group may be impossible or improbable given today's constraints. However, given the environment of change, management is looking for creative and innovative ways of using resources and creating efficiency across the center (and agency). Also, as project work is taken on, continue with the creative/imaginative, or re-engineering, orientation in providing solutions and processes to produce low cost, highly effective, people friendly solutions to KSC's challenges.

5. CONCLUSION

Today there is a new and changing role for government both in terms of its content and the way in which it operates within that content. This changing role has affected all agencies, and administrative and bureaucratic units, within the government structure. NASA KSC has been affected by this changing role and is engaged in re-defining and re-directing its resources to be aligned with the goals of the agency. The IE resource at KSC has a vast potential to provide value-added tools in the definition and engineering of the organization as it reacts to change requirements.

6. REFERENCES

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ENHANCEMENT OF THE GROUND PROCESSING SCHEDULING SYSTEM (GPSS)

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ABSTRACT

A scheduling process that maintains, repairs and configures a space shuttle orbiter must satisfy temporal, resource and configuration constraints. The GPSS, which stands for ground processing scheduling system, has been successfully used to schedule tasks that prepare an orbiter for its next launch.

The objective of this project is to enhance and to improve the GPSS. The GPSS uses an iterative repair method that starts with a rough schedule, which satisfies only the temporal constraints. Then it repairs the resource and configuration constraint violations one by one until no more violations exist or no further improvements can be made. The conflict resolution, which repairs all the resource and the configuration constraint violations, forms the bulk of the cognitive and computational complexity of the system.

We started with a study of the solution space of the GPSS which will help us to develop algorithms and strategies to improve the efficiency of the deconfliction process. To our knowledge there has been no previous effort to obtain this solution space. We probed the existing GPSS and constructed its solution spaces. The total number of iterations during the deconfliction process depends on the quality of the initial schedule - better the quality the smaller the number of iterations. The quality of the initial schedule can be improved by applying a genetic algorithm on an abstract problem generated from the original problem. We have designed and developed a genetic algorithm and interfaced with the GPSS to generate a feasible schedule that satisfies temporal and resource constraints.

Further, the computational efficiency of the deconfliction portion of the GPSS can be improved by using better heuristic strategies and better cost estimators instead of actually computing the cost for the heuristic table. The heuristic table used in the GPSS is very static, and the normalization process is somewhat arbitrary. We have designed and developed an evolutionary learning technique and interfaced it with the GPSS so as to learn the appropriate ways of combining the heuristic parameters and thereby reduce conflicts faster.

ENHANCEMENT OF THE GROUND PROCESSING SCHEDULING SYSTEM (GPSS)

Rasiah Loganantharaj and Bushrod Thomas

1. INTRODUCTION

The objective of this project is to enhance and to improve the GPSS. The GPSS uses an iterative repair method that starts with a rough schedule, which satisfies only the temporal constraints. Then it repairs the resource and configuration constraint violations one by one until no more violations exist or no further improvements can be made. The conflict resolution, which repairs all the resource and the configuration constraint violations, forms the bulk of the cognitive and computational complexity of the system. We start with an introduction of scheduling, GPSS, and the opportunity to improve the quality and the computational time of a solution.

Scheduling is a process of assigning time slots for activities while satisfying their resource and configuration requirements, and temporal ordering relationships. A typical temporal constraint specifies a successor, a predecessor, and possibly a minimum delay between them. For example, a temporal constraint may have a form such as: task T_2 is a successor of a task T_1, and T_2 can start only after 10 units of time from the completion of T_1. Satisfying all the temporal constraints among the tasks provides a schedule with early and late start time of each task, critical path, etc. There are plenty of sophisticated software algorithms to schedule tasks that are constrained only by temporal relations. Satisfying temporal constraints of this sort will take polynomial time. When we introduce resource requirements for tasks, the problem can no longer be solved optimally in polynomial time. The requirement that a task have two overhead cranes is an example of a resource constraint. A task can be scheduled only after it is assigned all of its requested resources. If we have an unlimited quantity of resources to the extent of satisfying all the resource requirements, the problem reduces to solving only the temporal constraints. However, in many real world problems, resources are limited. Thus, decisions must be made about the order in which requests are satisfied. An optimal schedule maximizes the resource utilization and minimizes the schedule length.

An objective function of a scheduler is to obtain a placement for each activity such that the overall schedule maximizes resource utilization and minimizes schedule length. Except for some trivial cases, obtaining an optimal schedule that satisfies temporal, configuration, and resource constraints is NP-hard. That is, no polynomial-time algorithm is available to solve these optimization problems. The algorithm that solves the problem optimally will take time on the order $O(2^N)$, where N is the number of tasks to be scheduled. When N is in the order of hundreds, it will take thousands of years to solve the problem, even if we run it on the fastest computer available today. Typical flows at KSC involve twelve hundred to eighteen hundred tasks. Therefore, a sub-optimal solution is being sought to solve scheduling problems of this sort.

There are two major approaches to obtaining the sub-optimal solution: the constructive method, and the iterative repair method. In the constructive method, one tries to build a feasible solution satisfying temporal, resource, and configuration constraints incrementally. When there is a failure, the algorithm backtracks and a new choice is made. This approach can further be categorized based on how the

backtracking is done. The backtracking can vary from simple methods, such as chronological backtracking, to very sophisticated methods, such as intelligent backtracking. Heuristic methods are used to decide how to allocate resources among the competing tasks.

On the other hand, the iterative repair method starts with a rough schedule that satisfies only the temporal constraints. Then it repairs the resource and configuration constraint violations one by one until no more violations exist or no further improvements can be made. The iterative repair method is very suitable to tackling over-constrained problem instances because it will iteratively reduce the number of violations even though there may not be any feasible solutions (solutions satisfying all constraints, though not necessarily optimally) for the problem. If the constructive method is used to solve an over-constrained problem, it will consume a substantial amount of time exploring the entire search space before it eventually fails. Many of the ground processing scheduling problems at KSC are over-constrained, and hence, GPSS uses the iterative repair method to solve the scheduling problem.

1.1 GPSS

GPSS has been used successfully at KSC for scheduling orbiter processing facility (OPF) operations. The OPF processing has three phases: (1) making the orbiter safe for processing and gaining access to the orbiter through the installation of access platforms, (2) testing, maintenance and repair operations on the orbiter, (3) close-out and checkout of orbiter. Approximately 40% of OPF processing is routine and very predictable in advance. The remaining 60% of OPF activities is very dynamic, and driven by factors such as payload of the previous and the following missions, test requirements specific to the age of the orbiter, diagnostic in-flight anomalies, and unexpected damage caused to the insulators.

GPSS provides a graphical interface for specifying tasks. Each task has a duration, work calendar, resource requirements, state requirements, and state effects. Temporal constraints between predecessor-successor pairs are specified. The number of resources available for each resource type is specified. A task may require many resource types, and for each resource type the task can specify the number of resources it needs. GPSS assumes that resources are reusable, that is, once the task is completed, the number of resources used by the task is released and can be used by other tasks. Each attribute's initial state is specified. A task may request an attribute to be in a specified state. When a task is scheduled in a time period during which the attribute has a different value than the one it requested, we say *configuration violation* has occurred.

Given an initial specification of tasks that may include resource and configuration requirements along with temporal constraints, GPSS satisfies their temporal constraints first. Resources are allocated, and a *profile* (a.k.a. *history*) is maintained for each resource. A resource profile consists of a sequence of intervals along the time line indicating the *users* and *changers* of each interval. In an interval where the total requests of the users exceed the number of available resources, the resource type is said to be *over-allocated* and it is an indication of a *resource constraint violation*. In a system modeling consumable resources, a changer could allow a task to produce or consume some quantity of the resource, but GPSS is not used in that way at present.

When there is a resource violation, a user can either resolve the conflict manually or use the system to deconflict the violation. A user can select a task from among the tasks in violation for the same resource, and move it to another time interval where the resource request of the task can be satisfied. After each move, the system runs the temporal constraint satisfying algorithm and accepts the move only if there

exists a way to satisfy all temporal constraints. Otherwise the move is rejected and the previous system status is restored.

Similar to the resource profile, a profile is maintained for each configuration attribute. Each interval of an attribute profile maintains its users and changers. Unlike the reusable resource constraints, users and changers need not be the same. The changers affect the attributes value. When there are many changers in an interval, the value of the attribute is determined by the effect of the latest changer. A task is said to be in configuration conflict if the requested attribute does not match with the attribute value in the interval. As with resolving resource conflicts, a user can either resolve the configuration conflict manually or use the system to deconflict the violation.

1.2 Opportunity to improve the solution quality

GPSS is widely used as a conflict report generator and a schedule editor even though it has features such as auto-deconfliction to resolve all the resource and configuration conflicts. The lack of usage of the auto-deconfliction feature can be attributed to the following: (1) the current version of GPSS does not allow a user to specify or to modify available resources, (2) the goal of GPSS is to find a feasible conflict free schedule as opposed to find a better schedule that has maximal usage of resources and minimum schedule length, and (3) the time taken for performing auto-deconfliction in GPSS is not reasonable for an interactive user. The re-engineering group of GPSS is considering to rectify the first problem. We focus on improving the quality of the solution and to reduce the computational time to achieve such solution. Specifically, we investigate the following problems and provide solutions to them: examining the suitability of simulated annealing algorithm, reducing the high degree of conflicts in the initial schedule (it satisfies only the temporal constraints), and developing a systematic and adaptive method for combining heuristics.

1.3 Organization of the report

Following the introduction, we describe the simulated annealing technique and its suitability to GPSS. It is followed by the topic of quality of initial solution and how to obtain it. In the next topic we describe repairing resource conflicts. This is followed by summary and discussion.

2. SUITABILITY OF SIMULATED ANNEALING

Simulated annealing [1,3] is an excellent technique to avoid the local minimum trap that is typical in many hill climbing technique. This technique simulates some aspects of the natural annealing process, and hence got the name simulated annealing. In an annealing process, a metal is heated to a higher temperature and then cooled down gradually to obtain fine grain. When the temperature cools down rapidly, one obtains course grain in the annealing process.

In a typical hill climbing method, heuristics are applied to find the next, most promising move. The algorithm commits itself to that move and continues forward from the new state. Moves with higher cost are rejected as the search progresses through moves that always decrease the cost. Very often the algorithm attains a local minima or plateau. To avoid local minima, moves with higher cost must also be accepted with some controlled probability. This is exactly what is done in simulated annealing. Suppose

delta, Δ, is the increase in cost. A move which normally would be rejected for having higher cost will now be accepted with probability $e^{-\Delta/T}$, where T is the temperature. Initially T is set to a higher temperature and it is decreased gradually. At the higher temperature, or in the initial phase of the solution, the probability of accepting moves with higher cost is high. This probability decreases as the temperature decreases.

2.1. How is Simulated Annealing used in GPSS?

The deconfliction algorithm used in GPSS is a hill climbing algorithm coupled with a weaker version of the simulated annealing algorithm. The temperature is set at 75 and it remains at that temperature until the cost is less than 10 and the number of iterations completed is greater than 5. When these conditions are met, the temperature is reduced to 25.

Setting of initial temperature should be dependent on the problem size, the domain of the problem, and the heuristic strategy being used to solve the problem. In the GPSS implementation, temperature remains fixed for a wide range of solutions. We reject fixing the temperature statically. Instead, we favor setting the temperature for each set of iterations. The initial temperature is based on the initial cost, say init-cost, percentage of allowable increases in cost, say per-incr-cost, with the probability, say p. Then the initial temperature is equal to:

$$\frac{\text{per-incr-cost} \times \text{init-cost}}{100 \times \ln\left(\frac{1}{p}\right)}$$

2.2 Solution Space of GPSS

We probed GPSS and constructed a sample solution landscape for the purpose of validating the usefulness of the simulated annealing technique. We disabled the simulated annealing feature of GPSS and recorded the number of conflicts (the cost) at the end of each iteration. We made sure that the algorithm committed to all the moves. The GPSS has two kinds of conflicts: resource and configuration. We studied the solution space under different conditions: one or both types of conflicts exist. The graph of Figure 2 shows the cost for each iteration under all three conditions. The data set is obtained by running GPSS for 40 iterations with the window size of 10. The cost obtained at the end of each iteration is plotted as shown in Figure 1. We ran a similar experiment for 1000 iterations with the window size of 1. The snapshots of the solution space show that the application of simulated annealing is not very useful to GPSS. We need to do further studies of the solution space with different flow data set to conclude that hill climbing alone will produce the best result.

3. QUALITY OF INITIAL SOLUTION

If a feasible schedule fs_1 has a shorter schedule length than another feasible schedule, say fs_2, then fs_1 is better than fs_2. The quality is a measurement of completion time and resource utilization. Let us briefly look at how GPSS achieves a feasible solution. Given the set of tasks with their temporal, resource and configuration constraints, GPSS satisfies temporal constraints first and then repairs all the conflicts

Solution Space with Window Size 1

Figure 1

Solution Space with Window Size 10
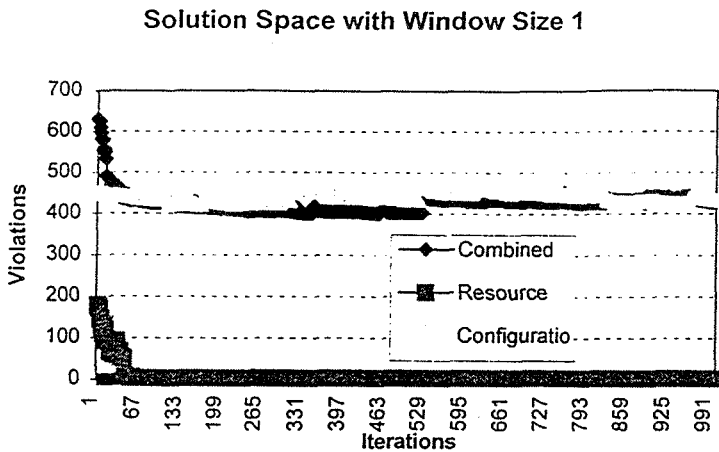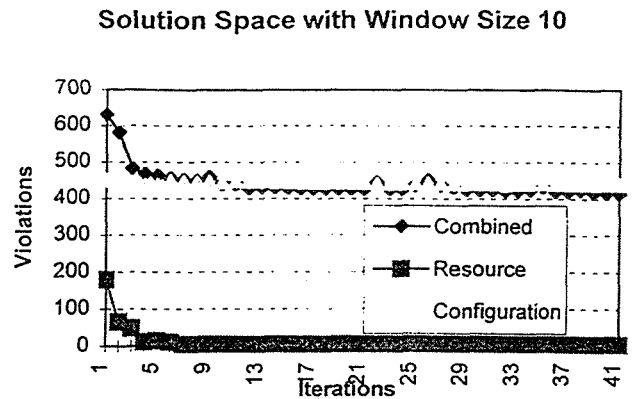
Figure 2

iteratively one at a time. After each repair, it runs Waltz's algorithm [6] to ensures the temporal consistency. This procedure continues until all the constraints are satisfied, or the maximum iteration specified by a user is reached. Suppose we generate a feasible schedule that satisfies the resource and temporal constraint and optimize to have a shorter schedule length. If we use such a partial schedule as the input to GPSS to satisfy the configuration requirements, we expect GPSS to resolve all the conflicts in a shorter time and to achieve a better schedule length than if we start GPSS with all the constraints as is done in the current practice. Let us address how to obtain a partial schedule that satisfies only the temporal and resource constraints.

Finding an optimal schedule to a resource constrained schedule is computationally intractable, hence sub-optimal solutions are sought. A genetic algorithm that borrows features of evolutionary theory is often used successfully for obtaining sub-optimal solutions to computationally intractable problems.

4.1 Genetic Algorithm

A genetic algorithm [1,5] starts with an initial population consisting of a set of chromosomes. Each chromosome in the population corresponds to a feasible solution of a problem that we are trying to solve. Each chromosome consists of a sequence of genes. In the scheduling domain, a chromosome could correspond to a feasible schedule and each gene in a chromosome could correspond to a task in the schedule. Typically a gene is represented by a binary string, though other representations are also possible. New solutions are created from the population by selecting a pair of chromosome and mating them. A mating is performed by a single or a multiple crossover operation. The crossover points are randomly selected. Let us illustrate it with an example. Consider the pair of chromosomes G_{11}, G_{12}, G_{13}, G_{14}, G_{15}, G_{16} and G_{21}, G_{22}, G_{23}, G_{24}, G_{25}, G_{26}. Suppose a single crossover takes place after the second gene. The offspring are G_{11}, G_{12}, G_{23}, G_{24}, G_{25}, G_{26} and G_{21}, G_{22}, G_{13}, G_{14}, G_{15}, G_{16}. This is illustrated in Figure 4.
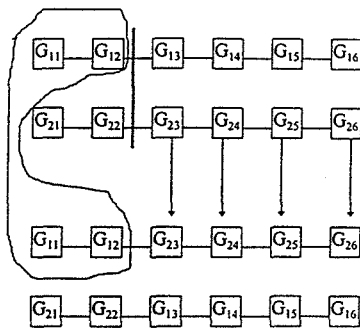
Figure 4
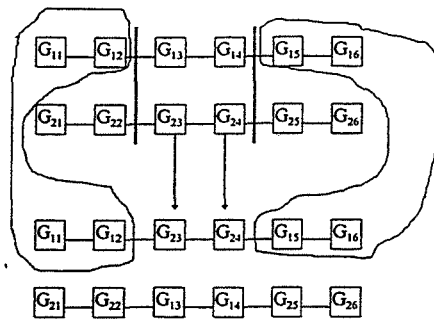
Figure 5

A double crossover operation after genes 2 and 4 on these two chromosome is illustrated in Figure 5.
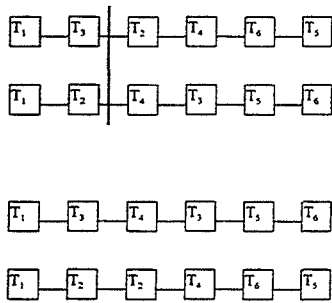
Figure 7
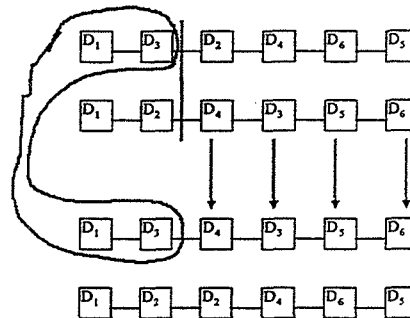
Figure 6

Straightforward encoding of a task into a gene will not work since the crossover operation will not produce a feasible schedule as shown in Figure 7: note the repeated tasks T_3 in the first offspring and T_2 in the second offspring. To circumvent the problem, we apply feature-based encoding in which some feature of a task, say duration, is encoded as a gene. Suppose D_k is a duration of a task T_k. The chromosome corresponding to a schedule T_1, T_3, T_2, T_4, T_6, T_5 will be D_1, D_3, D_2, D_4, D_6, D_5. Similarly, chromosomes are constructed for other schedules. The crossover operation after the second gene and the generation of the offspring are shown in Figure 6. The schedule corresponding to an offspring is obtained by matching the duration to the eligible task after satisfying temporal and resource constraints. Thus the feature based encoding always produces a feasible schedule.

We applied the genetic algorithm to the STS-85 data set to improve the initial schedule. We created a population of eight schedules with the best completion time 329,756 hours from the reference time January 1st of 1970. After applying the genetic algorithm the best schedule has the completion time of 329,172 hours, a saving of 24 days and 8 hours (we considered only the resource constraints).

4. REPAIRING RESOURCE CONFLICTS

GPSS is an iterative repair scheduler which first satisfies all the temporal constraints among the tasks and then repairs all the resource and the configuration violations iteratively. The Waltz algorithm [6], which was originally developed for the purpose of scene analysis, was modified to propagate temporal constraints and to achieve temporal constraint satisfaction. In the process of achieving temporal constraint satisfaction, the Waltz algorithm may move tasks that cause resource or configuration constraint violations. The Waltz algorithm cannot move the tasks that are user-fixed. In such cases when temporal satisfaction cannot be achieved, the algorithm reports failure.

When there is either a resource or a configuration violation, GPSS provides two options to the user: the user can manually resolve the conflicts by moving tasks, or use the auto deconfliction option to resolve the conflicts. When a user resolves conflicts by moving tasks, GPSS allows the user to move one task at a time. Temporal consistency is maintained by running the Waltz algorithm after each movement. When temporal constraints cannot be satisfied, the move made by the user is rejected. In this section we look into how the system deconflicts the violations.

When GPSS deconflicts the violations, a user has limited options: (1) select the relevant resources on which to focus, and (2) control the time taken for deconfliction by setting the number of iterations and the window size. The window size determines how many violated resource constraints and configuration constraints are selected for deconfliction in each iteration. For example, if a user selects window size 5 and iteration 40, 5 resource constraints and 5 configuration constraints are resolved in each iteration, or until all the constraint violations are resolved.

A conflict, either resource or configuration, can be resolved by moving a task involved in the conflict to a new time period where the conflict does not arise. Let us consider how GPSS repairs the constraint violations. During each iteration, a list of tasks called tasks-to-focus is created randomly by selecting tasks of window size from the resource conflicting tasks, or the total of the resource conflicting tasks, whichever is the smaller. For each task in the tasks-to-focus list, find the earliest constraint violation and call a routine called Repair to repair the violation. The Repair routine, knowing the resource and the time period of the violation, determines all the tasks that request the resource during the time period. A heuristics table is constructed to determine which task to move to reduce the conflicts. The heuristics table consists of ten columns to represent (1) fitness, (2) nearest-fix, (3) task-active, (4) temporal dependents, (5) proximity to now, (6) cost, (7) task, (8) start time, (9) weighted sum of scores, and (10) next time to try. Each task is given two rows: one for the forward direction and the other for the backward direction.

When all the computations are done for each row, the table is normalized. The task with the best weighted summation is selected for the actual move. The weighted summation of a task t_i is given by the formula $\sum_k (w_k * v_{ik})$ where w_k is the weight of the heuristic parameter P_k and v_{ik} is the value of P_k for t_i. In GPSS all the heuristic parameters are equally weighted to 1. For a complex constraint satisfaction

problem similar to GPSS there are no expert to judges the appropriateness of weight to each parameter. Therefore, we planned to apply a machine learning technique to study the proper weight combination that will help to resolve the conflicts faster. We have considered two candidate techniques: artificial neural network and genetic algorithm.

4.1 Artificial Neural network

An artificial neural network (ANN) has been successfully used for solving different problems including classification and prediction problems. The learning of the weight combination can be easily modeled as a classification problem. The success of applying ANN to solve a problem is dependent on a "noise free" training set, but in our case we do not have any possible training set. Even if we can train the ANN, it is not guaranteed to be very effective in reducing the overall conflicts on the schedule because of complex temporal dependencies and the chain reaction of further conflicts after moving a task.

4.2 Evolutionary learning

We are faced with a situation where there is no expert available to judge the effectiveness of a task movement towards reducing the overall conflicts on resources. Suppose R_i is the resource selected for deconfliction, and let there be k tasks using the resource. After applying a set of heuristics, a task, say t_n, is selected for backward movement. The effectiveness of moving the task t_n should not be judged with the current reduction of conflicts alone. We have to look at the subsequent reduction of conflicts too. The learning mechanism must take a sequence of the conflict reduction into account.

An evolutionary learning algorithm such as the genetic algorithm [1,5] will help to evolve the heuristic weights to improve the convergence and to reduce the overall resource conflicts. We will start the learning with randomly generated weights. To learn the heuristic weights of 9 parameters, the size of the chromosome is set to 9 and each gene will take a random number between 0 to 1. With the weight given by the chromosome, we deconflict some fixed number of times, say 10, and sum up the total conflicts over 10 moves. The summation of conflicts becomes the fitness value of the chromosome (the chromosome with a lower fitness value is better). Similarly, we generate new chromosomes and obtain their fitness values to fill the population. For each chromosome we start the deconfliction process of GPSS for the same data set at the same conflict status.

After generating the initial population, we evolve the new weights using single and double crossover

Comparison of Conflicts w/wo Training
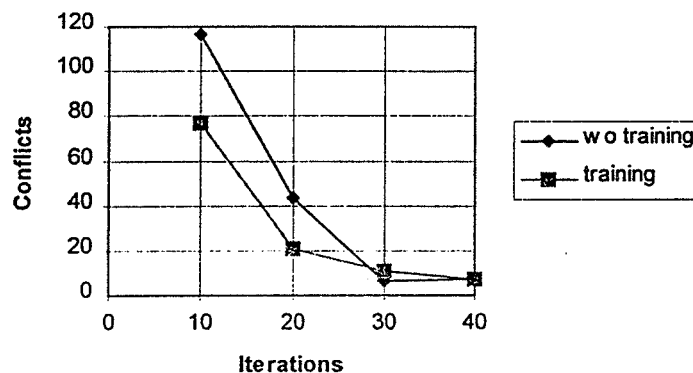
Figure 8

operations. We compute the fitness value for each offspring using the method described above. After generating enough offspring, we form a new generation and thereafter start evolving the new weights. The repetition of evolution continues until no more significant improvement is obtained. Our evolutionary learning algorithm incorporates an "anytime good results" strategy, that is, the algorithm always remembers the best combination of heuristic weights. We summarize the result with a graph of Figure 8.

5. SUMMARY AND DISCUSSION

We have successfully completed the following overall objectives of the summer research sponsored by NASA/ASEE. We have successfully investigated some important computational bottlenecks of the GPSS. We probed the GPSS and constructed some samples of solution space. A simulated annealing technique works fine to overcome the local minimum if the solution space forms lots of dips and humps. Our preliminary results shows that the number of conflicts reduces rapidly and it does not need the simulated annealing technique. We, however, caution that further studies need to be done over several flows to conclude that simulated annealing is useless for GPSS. Our examination of the GPSS code reveals that the simulated annealing has not been used properly. We have shown how to set the initial temperature and how to reduce it gradually to achieve the annealing effect. In this research we have designed and developed simulated annealing modules that will help to fine tune parameters to properly implement simulated annealing technique in the GPSS.

The computational bottleneck lies in the deconfliction process. We can improve the computational time by generating a partial schedule that satisfies the temporal and resource constraints. Further, the quality of the overall schedule can be improved by finding a sub-optimal solution to the resource constrained schedule. We have designed and developed a genetic algorithm and its interface to GPSS so that off-line preprocessing can be done to reduce the schedule length. We have applied our approach to the STS-85 flow data and have shown the possibility of reducing the schedule length by 24 days (we have considered only the resource conflicts).

The GPSS uses a set of heuristics to select a task to move so as to resolve the conflicts on resources. The heuristic parameters are uniformly weighted to 1. We have investigated the resource deconfliction process and developed machine learning techniques that will help to determine the correct weight combination. We have designed and developed an evolutionary learning method in C++, interfacing to the LISP GPSS scheduling engine using socket mechanisms. Our preliminary results seems to be very promising to improve the resource deconfliction process.

We have discovered several important areas to investigate in the future. We need to investigate the deconfliction of configuration conflicts. The GPSS selects the resource or configuration requirement to deconflict randomly. We need to develop a set of heuristics that will help in determining the resource and configuration to be deconflicted. We than need to apply the learning techniques to determine the appropriate weighting mechanism for these heuristics.

ACKNOWLEDGMENTS:

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Management and Executive Development Programs
NASA/ASEE Summer Faculty
Fellowship Program
Final Report

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Abstract

Quality leadership is perhaps the most significant factor in organizational success. The focus of this project was to create a holistic professional development program for current and future leadership at Kennedy Space Center (KSC). The project involved an extensive review of existing methods for professional development at KSC and an analysis of professional development techniques used throughout other NASA centers and private corporations. A needs assessment was done to determine the management and leadership qualities required of managers and executives. Upon completion of the needs analysis an evaluation of the resources available to meet these needs was conducted. Two modular programs were designed: (1) Management Development Program and (2) Executive Development Program. The professional development programs are designed to produce world-class managers, highly skilled in addressing the unique problems of Kennedy Space Center while demonstrating the executive competencies required of all federal executives by the Office of Personnel Management (OPM). Program evaluation methodologies and steps to implementation are included.

1.0 Introduction

The President's National Performance Review (NPR) concluded that executives are the keys to creating a corporate culture within Government's executive branch. (Guide to Senior Executive Service Qualifications, 1994). The capability and perceived competence of this corporate culture will have a direct impact on management effectiveness and organizational success. The responsibilities of those at the helm of an organization include supporting and perpetuating organizational vision, reaching and empowering individuals as well as establishing a positive, productive work environment. Though individuals may be highly educated in specific areas, this does not imply an innate understanding of how to manage people or meet the previous responsibilities. Managers are often grown within an organization and in technical environments there may not be an opportunity for the breadth of management skills to develop in route to supervisory, management or executive positions. This is even more of an issue when the professional workforce is comprised of approximately 75% engineers, as is the case at KSC. Thus the managerial capabilities of the individuals in a technical environment are often underdeveloped as these high potential candidates ascend within the organization. For many of these future managers, a professional development program will be the only resource sought to establish and nurture critical leadership skills.

Understanding the importance of professional development, the objectives of the project were:

- To produce a development program(s) to offer relevant training and experiences to address a holistic body of management and leadership issues.
- Create professional development activities that produce world class leaders.
- Offer a program that promotes concurrent development and synergy among participants while permitting individual growth and reasonable flexibility.

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The first action in the project consisted of interaction and knowledge acquisition with an array of individuals within NASA. These individuals include, but are not limited to, current management personnel, senior executives, training personnel, and human resource professionals. The objective of this interaction was to obtain a holistic representation of the kind of knowledge and skills that a "successful" management team member should possess. The curriculum has been designed to reflect experiences and training necessary for one to demonstrate the core competencies for an executive as outlined by the Office of Personnel Management (OPM). The methodology serves as a tool to prepare managers for executive positions, given the resources and constraints of KSC. The following outlines the activities in the project:

- Evaluation of existing KSC development activities
      Interviewed individuals at KSC, NASA Headquarters
- Identification of specific management needs
- Identification of resources available to meet the management needs
      Review of rankings for business education
      Evaluation of Executive Development Programs
      Comparison of costs for development programs
      Availability of courses
      People/Organizations taking the courses
- Program outline

   Module 1: Introduction and orientation to the program; First course is taken and program participants are introduced to potential mentors.
   Module 2: Common training and experiences are obtained to address the LEF competencies. Competencies addressed vary from management program to executive program.
   Module 3: Common training and experiences will continue in this module. By this point a quarterly presentation to senior management will have taken place.
   Module 4: Training and experiences will continue but at this point in the program participants may incorporate a unique training program or experience that has relevance to their area of specialty or personal interest.
   Module 5: Training and experiences will continue and at this point a profile should be done by program participants and mentees to be certain that they have addressed all competencies through a training exercise and experience. At least one additional quarterly presentation to management should have taken place by this time.
   Module 6: This module begins the off-site work experience. An environment will be sought where the program participant will utilize the learned skills and have the flexibility to   actually   participate   in   management/executive   responsibilities.

Each of the previous modules is presented in more detail in the body of this document. Finally, this report suggests an approach to initiate implementation. This simply offers suggestions for the program coordinator including project coordinator training, program evaluation, and accountability issues.

2.0 Methodology

The methodology stage in the project includes an examination of existing professional development techniques, a determination of professional development needs, and identification of resources to meet the determined needs. Given the limited time to accomplish the goals of the project, the methods utilized were designed to obtain results in a timely manner. For example, the use of an evaluation with follow-up and feedback after managers work for a given quarter might enhance the research results but would have taken considerably longer than general knowledge acquisition. However, these approaches will be utilized in the evaluation of the program and incorporated in future refinements. The primary actions within the methodology include:

1. Knowledge Acquisition: evaluation of existing KSC development activities
2. Identification of specific management and executive needs
3. Identification of resources available to meet the management needs
    Review of rankings for business education
    Evaluation of Executive Development Programs
    Availability of courses
    People/Organizations taking the courses

Each of these activities is presented in more detail in the following section.

Knowledge Acquisition

The project began by meeting with the Deputy Center Director, Mr. James Jennings, Loretta Drier, Training coordinator and Ms. Kim Cochrane. Ms. Cochrane has the responsibility of assisting senior executive service (SES) candidate in preparing their packages for presentation to the Office of Personnel Management (OPM). This meeting laid the foundation for program expectations. According to Mr. Jennings the program should be designed to holistically address the competencies as listed by OPM but should reflect the skills required of any leader in a world-class organization. The criticality of the international collaboration and corporate alliances requires effective management at all levels throughout KSC.

To further understand the current approaches additional knowledge acquisition was performed with managers and individuals responsible for professional development activities. Those interviewed included Mr. Ken Aguilar, Mr. Frank Nesbitt, Mr. Jim Norman and Mr. John Pennington @ NASA Headquarters. Mr. Saul Barton was also interviewed to obtain a strategic view of how this program will most effectively complement senior management and KSC long term goals. Finally, Ms. Shannon Roberts was briefed on program objectives and provided further insight and details about program expectations.

Identification of Management Needs

The knowledge acquisition provided a wealth of information about the perceived issues of importance for leaders at KSC. The characteristics are not unlike those expected of leaders in other organizations. One of the primary differences that individuals interviewed mentioned is that the managers at KSC must often operate in uncertain

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environments with tremendous scheduling constraints, thus making formal professional development activities difficult to schedule. There was also a sense that many of the new executives and managers, while technically competent, lack basic managerial skills. The ability to implement strategies and empower a work force was also listed as a needed skill for the KSC leadership.

The most prominent factor in assessing the specific, required management needs was the Guide to Senior Executive Service qualifications. In order to move toward a corporate culture within the Government's executive branch, executive core qualifications (ECQ's) have been established. The ECQ's are to help agencies develop and identify those individuals that will support and promote the vision of the NPR. The ECQ's include the following:

Strategic Vision (ECQ1): The ability to ensure that key national and organizational goals, priorities, values, and other issues are considered in making program decisions, and exercising leadership to implement and to ensure that the organization's mission and strategic vision are reflected in the management of its people.

Human Resource Management (ECQ2): The ability to design human resource strategies to meet the organization's mission, strategic vision, and goals and to achieve maximum potential of all employees in a fair and equitable manner.

Program Development and Evaluation (ECQ3): The ability to establish program/policy goals and the structure and processes necessary to implement the organization's mission and strategic vision. Inherent in this process is ensuring that programs and policies are being implemented and adjusted as necessary, that the appropriate results are being achieved, and that a process for continually examining the quality of program activities is in place.

Resources Planning and Management (ECQ4): The ability to acquire and administer financial, material, and information resources. It also involves the ability to accomplish the organization's mission, support program policy objectives, and promote strategic vision.

Organizational Representation and Liaison (ECQ5): The ability to explain, advocate, and negotiate with individuals and groups internally and externally. It also involves the ability to develop an expansive professional network with other organizations and organizational units.

The ECQ's have key characteristics and competencies that should be demonstrated by a leader possessing the previously listed qualities. The Leadership Effectiveness Framework (LEF) Competencies are those specific attributes or characteristics contained with the ECQ's. The LEF Competencies are considered essential as they represent the criteria that executive candidates must demonstrate a knowledge of to be confirmed as qualified for Senior Executive Service (SES) within the federal government. The competencies and their relationship to the ECQ's are listed in Table 1.

Table 1. LEF Competencies	ECQ1	ECQ2	ECQ3	ECQ4	ECQ4
Conflict Management		x		x	x
Creative Thinking	x		x		
Customer Orientation	x	x	x		x
Decisiveness		x	x	x	
External Awareness	x		x	x	x
Financial Management				x	
Flexibility		x	x	x	x
Human Resource Management		x	x	x	
Influencing/Negotiation		x	x	x	x
Leadership	x	x	x	x	
Management/Controls			x	x	
Interpersonal Skills		x			x
Managing a Diverse Workforce		x			
Oral Communication	x	x	x	x	x
Planning & Evaluating	x	x	x	x	
Problem Solving		x	x	x	
Self-Direction	x	x	x		x
Team Building	x	x	x		
Technical Competence					
Technology Management			x	x	
Vision	x	x	x		
Written Communication			x	x	x

Upon examination of the literature and qualities associated with developmental activities the OPM competencies appear to be consistent with what other organizations expect in their leadership. Finally, "Key Characteristics" are described for each ECQ. These Key Characteristics outline specific tasks or functions that a person skilled in the required competencies should be capable of performing. The purpose of three levels for describing leadership qualities, ECQ, LEF Competencies and Key Characteristics, is to provide as much explanation and expectation for agencies in preparing individuals to compete for SES positions.

Identification of Resources
Existing Developmental Activities
The existing approaches to professional development were initially examined and revealed an array of tools to support KSC personnel. The Training Leadership Program and Kennedy Management Education Program are likely the most utilized courses for program candidates. Additional developmental opportunities exist through the Human Resources and Development Branch bringing requested short-courses to KSC as well as funding

limited opportunities for attendance at off-site courses. Also, there exist a very helpful resource titled "Guide to Career Development - Kennedy Space Center" (KSC1, 1997). This document provides an overview of the career paths possible for individuals in various specialties and with varying degrees of education. In the discussion of routes to SES positions, the guide also list the required competencies for attaining these positions. The final page of this document lists an outstanding overview of Development Activities available through KSC (see Appendix). These Development activities are listed by career level and this can be extremely useful as an individual is preparing to construct his/her own Individual Development Plan (IDP). It is clear that a number of outstanding activities are available however, the problem is that there is not a coordinated and cohesive approach to utilization of these courses and experiences for professional development.

Among the developmental activities, a limited number of fellowships exist to pursue academic degree programs. While, this is a tremendous commitment on the part of NASA and KSC to invest in an individual at this level of funding, these fellowships are generally, very competitive and accommodate one to two persons/NASA center.

The program that most closely represents what is being proposed through this effort is the NASA SES Candidate Development Program. The NASA SESCDP offers individuals a structure approach to prepare for application to SES positions (NASA1, 1997). This program focuses on the competency development and demonstration. Again, the problem with this program is accessibility. Only one to two participants from KSC are admitted thereby making this resource unavailable for many candidates that need this type of knowledge.

Academic-Based Professional Development Courses

Thousands of executive and management development courses exist and to minize the list for selecting relevant offerings, those programs that were consistent with KSC philosophies and leadership style were considered. An equally important criteria was the quality of the institutions or organizations offering the course(s). An evaluation was done of the rankings of business schools that offer professional development programs by obtaining the Marr and Kirkwood Official Guide to Business Schools (Marr and Kirkwood, 1997). This guide provided the ranking of six organizations that rate business schools. The ranking organizations include Business Week (1996), U.S. News & World Report (1997), T & W (1995), Gourman Report (1995), Asia, Inc. (1994), and Asian Business (1995) (see appendix). To narrow down the schools those business schools appearing in six of the seven ranking lists' for the top ten schools were considered to be the primary candidates for professional development training. These schools included:

- Wharton, University of Pennsylvania
- Kellogg, Northwestern University
- Harvard University
- Stanford University
- Sloan School of Business, MIT

An additional ranking on professional development programs/institutions list the executive development programs by dollars received. In this ranking, the schools indicated as primary in the previous ranking appeared as having receipts among the highest for professional development. However, caution must be taken with this list as the amount of receipts does not necessarily correlate with number of individuals participating in the developmental activities. For example, Harvard Business School was number one in this list. Harvard is clearly an outstanding business school but courses offered at Harvard may cost twice as much (approximately $8,900) as a comparable course at Wharton, Penn State (approximately, $4,950). Nonetheless this information was used to get a pulse on some of the most utilized business schools. The principal difference in this second list was the surfacing of the Center for Creative Leadership (CCL) as the organization, following Harvard, with the second highest receipts for Management/Executive Development Training. CCL was stated to be "hands down, the best training available through a non-academic environment." It appears that not only does CCL do a considerable amount of training between their four sites, but they also offer courses off-site and many universities utilize CCL resources. This implies that the activities, research, and development programs offered through CCL are highly respected and useful.

3.0 Results

The result of the literature review and knowledge acquisition suggested that two separate programs should be developed, one to address middle to upper level mangers and the second, to address the needs of senior managers and executives. The literature suggest that there is a difference in concerns and responsibilities for functional managers and executives. Thus, the programs should separate these two groups to be more effective in addressing the group needs. The result is a six-module management development program and as six-module executive development program. The following sections provide the details of each program.

Management Development Program

The program has been designed in a modular format with each module having a training objective and experiences recommend or encouraged experience. The specific experiences have not been included because knowledge acquisition was not fully successful in identifying a body of common-experiences that would be available to all program participants throughout KSC. The identification of these common experiences will be one of the first task to be accomplished by program mentors. The mentors will collectively identify experiences that are relevant to the LEF competencies and occurring regularly enough for all participants to have an opportunity to take part in the activity.

The structure host six modules, each with training and experience components. The modules are expected to last from 4 to 12 weeks. The duration of the module will depend on the accessibility of the management trainee (MT) to an experience that complements the current modular training. Table 2 provides an overview of the modules and associated activities for the management development program.

Table 2. Management Program

Module	Professional Development Activity	Demonstration	Evaluation
1	Orientation; Introduction to Mentor; TLP and KMEP (if not already taken) OPM Course	Related Experience	Modular Evaluation of Activity Mentor/Mentee Evaluation
2	Avraham Goldratt's Management Skills Workshop Facilitated Peer-Group Meeting	Related Experience Presentation to Senior Management	Modular Evaluation of Activity Mentor/Mentee Evaluation
3	Creating and Managing Strategic Alliances, Northwestern University or Strategic Alliances, Wharton School of Business	Related Experience Management of a Service Activity/Program within KSC Presentation to Senior Management	Modular Evaluation of Activity Mentor/Mentee Evaluation
4	Developing the Strategic Leader, Thinking, Acting, Influence - Center for Creative Leadership	Related Experience Presentation to professional society, school, or other community/service based organization.	Modular Evaluation of Activity Mentor/Mentee Evaluation
5	Management of Change in Complex Organizations, Sloan School of Management, MIT and Individual Course of Choice (i.e. Management of an Accident Investigation ; Women in Management; African American Leadership Training Course - CCL)	Related Experience Presentation to Senior Management	Modular Evaluation of Activity Mentor/Mentee Evaluation
6	Off-site Assignment	A culmination of the training and experiences for application to a given environment	Program Evaluation Evaluation by Manager in off-site Mentor/Mentee Evaluation

Quarterly meetings are schedule with senior management where each MT, with mentor present, will provide the KSC senior management with a status on their experiences. These status presentations will be high quality presentations highlighting the MT's training and experiences for the previous quarter. A detailed discussion of the experience should be provided to allow the senior management to fully understand the knowledge that the MT's are acquiring and/or to utilize the lessons learned in their organizations. The presentation will also include an overview of upcoming training and proposed experiences.

After the program overview is provided, the individual management trainees will meet with the training organization to determine who will be their mentor (SES) and whether or not placement in a temporary position would be beneficial to their development activities.

Orientation:

Orientation provided by training department where individuals are introduced to the Management Trainee Program and the participating SES personnel. A member of senior management within HM will welcome the participants to the program and provide an overview of the program. The importance of their active involvement and feedback to enhance program quality will be stressed.

Module 1:

The objective of module one will be to provide an orientation to the program and introduce the new management trainees to program and anticipated results.

Activity 1.1: All management trainees will be sent to an OPM Seminar "Seminar for New Managers"

This seminar is designed to provide the MT's with a foundational understanding of management within the federal government. All participants are to attend the same session.

Competencies addressed: Conflict management, creative thinking, external awareness, flexibility, human resources management, interpersonal skills, leadership, management controls integrity, managing diverse workforce, problem solving, self-direction, team building

Suggested Experiences: To be determined (TBD)

Cost: $2,775/person (Tuition, meals, and lodging)

Module 2:

Activity 2.1: This training activity will be attendance at the Avraham Goldratt Course: A five-day on-site course is available. The desire is to bring this course to KSC so other individuals will have an opportunity to attend. Further, this makes the course more cost effective if several KSC managers can attend to fill the course to capacity.

The objective of this module will be to provide MT's and ET's with a detailed of management skills and workshops that apply across a variety of private and public organizations.

Competencies addressed: Creative thinking, Decisiveness, Human Resources Management, Influencing/Negotiating, Interpersonal skills, Leadership, Oral Communication, Problem solving, Team Building; oral communication (through presentation to Senior Management)

Experiences suggested: TBD

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Cost: $1,200/person on site + expenses/travel for instructor; $1,500/person off site (course fee)

Module 3:

Activity 3.1 This module is designed to enhance the MT's ability to interact with individuals outside of the KSC and NASA organization. This is critical for KSC, because basically every organization interfaces with contractors for a variety of task. This will become even more important as the climate of NASA continually moves toward privatization of developed projects.

Activity 4.1 The course *"Creating and Managing Strategic Alliances"* is offered at Kellogg School of Business, Northwestern University, Evanston, Ill. or

"Strategic Alliances" offered through Wharton, Penn State

Competencies addressed: Customer orientation, external awareness, planning and evaluating, technology management, oral communication (through presentation to Senior Management)

Costs: Kellogg Course - approximately, $4,000; Wharton Course - approximately

$4, 900.

Experiences suggested: MT's should be given the task of initiating a project and managing it to a certain, measurable level of completion with an outside contractor or other NASA center. Other experiences TBD.

Module 4

Activity 4.1: The course "Leadership Development Program" will be the primary activity in Module 4. The Center for Creative Leadership is clearly the leader in non-academic management and executive training. All participants will attend the one week course together.

Competencies addressed: Creative Thinking, Decisiveness, Influencing/Negotiation, Leadership, Interpersonal skills, Problem solving, Team Building, oral communication (through presentation to Senior Management)

Experiences suggested: Participate in the development of a strategic plan others TBD

Costs: $4,950/person off-site (course fee only). This course is offered through Eckerd College, St. Petersburg, Florida. Jessica Harwell of Eckerd College has indicated that for classes of 15 or more, the fee may be reduced by 15%.

Module 5:

Understanding how to manage change in complex situation and a participants area of choice will be the focus of this module.

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Activity 5.1
Training: Management of Change in Complex Organizations, Sloan School of Management, MIT
and/or
Individual Course of Choice for participant (mentor should be consulted to discuss possible courses)

Competencies addressed: creative thinking, leadership, planning and evaluating, problem solving, self-direction, oral communication

Experiences desired: TBD

Costs: $4,650/person, includes tuition, room and meals, and all program materials

Module 6

Off-site assignment.   The off-site assignment is the capstone activity and should be performed in an environment where the MT will have the opportunity to utilize as many of the newly acquired skills as possible. The activities associated with the position should be of significant benefit to whomever the MT reports to throughout the project period.

Executive Development Program

The program has been designed in a modular format with each module having a training objective and experiences recommend or encouraged experience. The executive training program also has a structure with six modules, each with training and experience components. The modules are expected to last from 4 to 12 weeks. The duration of the module will depend on the accessibility of the MT to an experience that complements the current modular training. Table 3. lists the modules and associated activities for the Executive Development Trainees (EDT's).

Table 3. Executive Development Program

Module	Professional Development Activity	Demonstration	Evaluation
1	Orientation; Introduction to Mentor; TLP and KMEP (if not already taken) OPM Course: Workshop in Executive Leadership	Related Experience Presentation to Senior Management	Modular Evaluation of Activity Mentor/Mentee Evaluation
2	Avraham Goldratt's Management Skills Workshop and Executive Leadership p in a Changing Policy Environment, The Brookings Institute	Related Experience	Modular Evaluation of Activity Mentor/Mentee Evaluation
3	Developing the Strategic Leader: CCL and/or Liberating leadership: Creating Unity through	Related Experience Presentation to professional society, school, or other community/service based	Modular Evaluation of Activity Mentor/Mentee Evaluation

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	Diversity: Wharton, Penn State	organization. Presentation to Senior Management	
4	"Executive Team Dynamics: When all members are leaders" : Wharton, Penn State	Related Experience Management of a Service Activity/Program within KSC	Modular Evaluation of Activity Mentor/Mentee Evaluation
5	Strategic Planning Under Uncertainty and Individual Course of Choice (i.e. Management of an Accident Investigation ; Women in Management; African American Leadership Training Course - CCL)	Related Experience Presentation to Senior Management	Modular Evaluation of Activity Mentor/Mentee Evaluation
6	Off-site Assignment	A culmination of the training and experiences for application to a given environment	Program Evaluation Evaluation by Manager in off-site Mentor/Mentee Evaluation

Quarterly meetings are schedule with senior management where each MT, with mentor present, will provide the KSC senior management with a status on their experiences. These status presentations will be high quality presentations highlighting the MT's training and experiences for the previous quarter. A detailed discussion of the experience should be provided to allow the senior management to fully understand the knowledge that the MT's are acquiring and/or to utilize the lessons learned in their organizations. The presentation will also include an overview of upcoming training and proposed experiences.

After the program overview is provided, the individual management trainees will meet with the training organization to determine who will be their mentor (SES) and whether or not placement in a temporary position would be beneficial to their development activities.

Orientation:

Orientation provided by training department where individuals are introduced to the Management Trainee Program and the participating SES personnel. A member of senior management within HM will welcome the participants to the program and provide an overview of the program. The importance of their active involvement and feedback to enhance program quality will be stressed.

Module 1:

The objective of module one will be to provide an orientation to the program and introduce the new management trainees to program and anticipated results.

Activity 1.1: All executive trainees will be sent to an OPM Seminar "Workshop in Executive Leadership"

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This seminar is designed to provide the program participants with a foundational understanding of executive leadership within the federal government. All participants are to attend the same session.

Competencies addressed: Leadership, Vision, oral communication, written communication, external awareness

Suggested Experiences: TBD

Cost: $2,775/person (Tuition, meals, and lodging)

Module 2:

Activity 2.1: This training activity will be attendance at the Avraham Goldratt "Management Skills Workshop". This will be a five-day on-site or remote course. The desire is to bring this course to KSC so other individuals will have an opportunity to attend. Further, this makes the course more cost effective if several KSC managers can attend to fill the course to capacity. The objective of this module will be to provide MT's and ET's with a detailed of management skills and workshops that apply across a variety of private and public organizations.

Competencies addressed: Creative thinking, Decisiveness, Human Resources Management, Influencing/Negotiating, Interpersonal skills, Leadership, Oral Communication, Problem solving, Team Building; oral communication (through presentation to Senior Management)

Experiences suggested: TBD

Cost: $1,200/person on site + expenses/travel for instructor; $1,500/person off site (course fee)

Module 3:

Activity 3.1: The course "Leadership Development Program" will be the primary activity in Module 3. The Center for Creative Leadership is clearly the leader in non-academic management and executive training. All participants will attend the one week course together.

and

Executive Leadership in a Changing Policy Environment, The Brookings Institution

Competencies addressed: Human Resources Management, Leadership, Management/Controls Integrity, Self-Direction, Team Building, Oral Communication (through presentation to senior management)

Experiences suggested: Participate in the development of a strategic plan

Costs: CCL Course: $4,950/person off-site (course fee only). This course is offered through Eckerd College, St. Petersburg, Florida. Jessica Harwell of Eckerd College has indicated that for classes of 15 or more, the fee may be reduced by 15%.

Brookings Institution Course: $3,500/person, includes lodging, meals, reading materials, and related educational costs.

Module 4

Understanding the specifics, purpose, and approach to management and motivation of other managers within one's organization will be the focus of this module.

4.1 Training Activity. The course offered through the Pennsylvania State, Wharton School of Business "Executive Team Dynamics" is suggested for this module.

Competencies addressed: Team Building, Problem solving, Human Resources Management, Influencing/Negotiating

Experiences suggested: EDT's should be given the task of initiating a project to be conducted with other managers and managing it to a certain, measurable level of completion. Other experiences TBD

Costs: $4,950/ person

Module 5:

This module will provide an workshop in Strategic Planning under Uncertainty, Berkeley Center for Executive Development, University of California, Berkeley.

Activity 5.1 This module will consist of participation in the course

Management of Change in Complex Organizations, Sloan School of Management, MIT

and/or

Individual Course of Choice for participant (mentor should be consulted to discuss possible courses)

Competencies addressed: Sloan Course - creative thinking, leadership, planning and evaluating, problem solving, self-direction, oral communication; Berkeley Course: creative thinking, planning and evaluating, flexibility, external awareness, vision.

Costs: Sloan Course "Management of Change in Complex Organizations": $4,650/person, includes tuition, room and meals, and all program materials

Berkeley Course "Strategic Planning Under Uncertainty": $2,850 includes instruction and class materials, continental breakfast, luncheons, and all customary breaks

Experiences desired: TBD

Module 6

Off-site assignment. The off-site assignment is the capstone activity and should be performed in an environment where the EDT will have the opportunity to utilize as many of the newly acquired skills as possible. The EDT should have specific tasks that he/she is

responsible for carrying out and room to be creative in the position. The activities associated with the position should be of significant benefit to whomever the EDT reports to throughout the project period.

Mentor/Mentee Relationship Development

Formal mentoring training should be offered to mentors and mentors at the beginning of the program. This training will help all mentors know what it means to be a mentor and provide useful insights about experiences and best approaches to being a mentor. It is very important for mentors to have an interest in seeing their mentees succeed. The mentees will also gain a clear understanding of the type of support they can expect from the mentor. At this point, it will also be important to discuss suggested rate of mentor/mentee interaction (i.e. weekly meetings) as many participants will not know how often to meet. Effective initiation of the mentor/mentee relationship is critical because the program evaluation will be largely dependent on the mentors perception of the development rate of the mentee. Likewise, the mentee will have an opportunity to evaluate the mentor. This training can be facilitated by Dr. Howard Adams of the National Institute on Mentoring, Georgia Tech Institute (see appendix for details).

Executive Coaching

A growing number of companies are utilizing executive coaches as a means to nurture executives. Executive Coaching is suggested for the EDT. Presently a positive example of executive coaching exist at KSC. Mr. Joel Reynolds has been receiving executive coaching from Right Associates, Orlando, FL. The experience has been very positive and noticeably beneficial results are already evident. The suggestion is that the Executive Coaching aspect of the Executive Development Program be carried out by Right Associates.

Facilitated Peer-Groups

In order to build a collaborative, class-mate environment among MT's "Facilitated Peer Groups" are suggested bi-monthly. The purpose of these facilitated sessions will be to allow an organized exchange of information among MT's without intimidation of a senior manager or other KSC personnel. The information obtained from the facilitated session will be organized by one of the MT's and distributed to other members. This information will also be given to the program administrator in the Human Resources Development Branch to improve the program. At this time, a specific facilitator has not been identified.

Program Evaluation

Program Evaluation has been discussed throughout the document and will primarily consist of the following:

Modular evaluation of training program by MT's and EDT's

Quarterly or modular evaluations (be consistent for all) by Mentors/Mentees

Quarterly presentations to senior management

End of program evaluation by MT's and EDT's

End of program evaluation of Mentees by Mentors

Other evaluation techniques may prove useful and should be incorporated as they are developed for continual program improvement.

4. Implementation

The primary concern in the development of any new program is successful strategies to implementation. The program clearly has upper management support, but this support must translate into support for implementation through training for program administrators and making those program participants (MT's and EDT's) accept responsibility for helping the program to be a success through active participation and providing constructive feedback. For the program administrator or facilitator a course offered through CCL designed to guide individuals responsible for developing or maintaining professional development programs may prove to be invaluable. This course should be taken by the program facilitator prior to the offering of the first class. The developmental period of a program are the ideal time to train program facilitators. Any useful information obtained from the course at CCL can be applied to improve the program before it's inaugural offering.

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Note: All guides to programs are listed in the full report see full report for details

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1997 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

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Design and Evaluation of the Human-Computer Interface of the Portable Data Collection System

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ABSTRACT

The purpose of this research was to apply the concept of user-centered design to the design and evaluation of the human-computer interface of the Portable Data Collection System (PDC). The Portable Data Collection System allows work procedures to be created and executed in a paperless environment. Presently, the system is in the prototype stage and is being developed to support Space Station processing. A usability evaluation was conducted of an early version of the system. Results from the formative evaluation revealed several areas within the system which should be redesigned. Both quantitative and qualitative data were collected which provided justification for design changes. The design and evaluation of a new subsystem of the PDC system was also conducted. A WAD creation tool was designed which eliminates the need for document conversion within the PDC system. Results revealed that the concept is feasible, and early evaluation with end-users provided important design input.

Design and Evaluation of the Human-Computer Interface of the Portable Data Collection System

Loretta A. Moore

1. INTRODUCTION

The Portable Data Collection (PDC) project is a development effort aimed at creating a paperless Work Procedure system. It is a joint effort between the Quality Assurance and the Payload Processing Directorates at the NASA Kennedy Space Center. A prototype was developed which implements several features of the PDC system. The main components of the PDC system are the Central Data Server (CDS) and the Portable Data Terminals (PDTs). The CDS is the main computer that serves as network host and database server. The PDTs display the procedure steps and enable users to collect test data and stamps. A pilot study was conducted to assess the PDC system in an actual work environment. This study compared the PDC electronic system with the paper system and provided an overall assessment of the PDC project. A detailed flow analysis was conducted which compared the process flows of the electronic and manual procedures. The results of the study verified that PDC is viable. Several improvements were identified based upon direct observation and post test interviews.

The research presented in this paper describes 1) the introduction of the concept of usability evaluation to the PDC project and 2) the use of a user-centered software life-cycle to develop a third component of the portable data collection system. To introduce the concept of usability evaluation a formative evaluation of the human-computer interface of the Portable Data Terminal was conducted. The method and results of the formative evaluation are discussed in section 3.

The process of user-centered design was next applied to the design of a Work Authorization Document (WAD) creation tool. The objective being to develop a graphical based tool to allow users to create WADs for electronic execution within the Portable Data Collection (PDC) system. WADs are procedures used at Kennedy Space Center for processing and integration of space flight systems. Word processing templates are currently used for creating WADs used in the PDC system. The design of this tool is presented in section 4.

2. BACKGROUND

Currently work procedures for Payload processing and checkout operations at the Kennedy Space Center are 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 Innovative Research Contract (SBIR) 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 the Kennedy Space Center.

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 that is connected to the serial communication port of the computer. The system provides protection mechanisms to assure data and stamp integrity. Once the procedure has been worked to completion, it is converted to Portable Document Format (PDF) and stored electronically in a documentation 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.

- The time to gather information for incident investigations and management reporting is decreased.

- Information availability is improved. Test data can be searched and retrieved, through standard database queries.

- The time to process a procedure is decreased (i.e., printing and distributing a procedure prior to a test, and scanning the procedure for storage).

- The completed document requires less computer storage space than the present method.

- Emergency procedures can be accessed immediately.

- Paper is reduced.

Presently, the system is in the prototype stage and is being developed to support Space Station processing. During a pilot study of the system, several areas for improvement were identified through observation. After a review of the results of the pilot study, a need for a more objective way to identify

areas for improvement was recognized. A usability evaluation of the system was suggested. The next section describes the method and results of the usability evaluation. The most significant area of improvement from a system standpoint was the need to eliminate the conversion step. As stated earlier, in the current version of the software, the document is created in MS Word and converted into a database. A WAD creation tool was designed and evaluated. The results are presented in section 4.

3. USABILITY EVALUATION

A usability evaluation measures the usability of the human-computer interface of a system. The steps which were conducted include: Needs Analysis; User Analysis; Task Analysis; Development of Usability Specifications, Benchmarks, and Questionnaires; and Formative Evaluation. The steps performed for formative evaluation included: selecting participants to perform tasks, choosing benchmarks and representative tasks for participants to perform, determining protocol and procedures for the evaluation session, pilot testing the experiment, conducting the evaluation session, generating and collecting the data, analyzing the data, drawing conclusions to form a resolution for each design problem.

3.1   Method

3.1.1   Participants

The goal in participant selection was to obtain a subset of the target population of end-users. An email message was sent requesting volunteers for the experiment. In order to get samples from each category of end user, recruiting was also necessary. There were seventeen participants, fifteen were male and two were female. Most participants had a Bachelor's or Master's degree. There were nine engineers, three quality, three technicians, one manager, and one other. Most of the participants felt confident about using computers. All used computers at work, and fourteen had computers at home. In a self-rating of their computer experience on a scale of 1 to 5, most participants rating their experience as a 4 or intermediate to expert level. Sixteen of the seventeen participants used word processing packages, and ten of them had programming experience. Twelve of the participants had heard of the Portable Data Collection System; however, only one participant had used it.

3.1.2   Procedures

From the task analysis of the Portable Data Collection system, the set of representative tasks were chosen. Below is a sample of the benchmarks which were chosen:

> Review step 02-003
> Clear the back stamp on step 02-008 and say, "PL2 is ready"
> Review the note on step 02-004
> Without going to step 01-005, show proof that a deviation was written
> Incorporate the deviations to steps 01-005 and 02-002
> View a picture (Choose Figure 1 with 50% zoom power)
> Go to step 02-002 and review the deviation
> Find a list of all the pages which have not been bought off

The benchmarks are designed so that they tell the user what to do, but not how to accomplish a task. A note taking sheet was developed to facilitate the collection of data. A portion of this form is shown in Figure 3-1. After the experiment was developed, it was pilot tested with several volunteers who were not familiar with the system.

Participant ID: Session Date: Session Start Time: Session End Time:

Task description:	Number of Errors:	Elapsed Time:	Participants Actions and Comments:	Evaluator's Evaluations
Start the CDS application (A.)				
Convert TAP P8337b~1.doc (B.)				
Start TAP P8337b~1 (C.)				
Start the PDT (F.)				
Enter a page Buy on step 01-009 (G.)				
Add a constraint to step number 02-004 saying, "Remove and replace LED" (I.)				
Enter a Backstamp on step 02-008 and say, "PL2 is not ready" (J.)				

Figure 3-1 Note Taking Sheet

At the beginning of the evaluation session, each participant was greeted by the test monitor and the purpose for performing the evaluation was explained. They were next asked to sign consent forms and a user information questionnaire was given. The participants received a short, verbal, scripted introduction to the test. They were reminded that the product was the center of the evaluation and not themselves, and they should perform naturally. They were informed that notes were being collected. The "think aloud" protocol was used to elicit information during the completion of tasks. The performance test consisted of a series of tasks that the participants were asked to carry out. During the test, time and errors were noted for each task. The test monitor also made notes about relevant participant behavior, comments, and all critical incidents which occurred. After all the tasks were completed participant debriefing occurred. Participants were asked to fill out a brief questionnaire pertaining to subjective perceptions of usability and aesthetics of the design. Participants were also encouraged to make overall comments about the system. After the debriefing session, participants were thanked for their efforts.

3.2   Results

A set of specifications were developed to ascertain the usability of the system. For each task that would be performed with the system, a usability attribute must be chosen. Various usability attributes include initial performance, learnability, and retainability. Also an expert level of performance must be measured. The value to be measured can be error rate or time to perform a task. The expert level is doubled to obtain the planned target level, and tripled to obtain the minimum acceptable level. The minimum acceptable represents the minimum level at which users can perform and the system still be considered usable. If the mean of the user times are greater than this level, this particular component of the system should be redesigned. Figure 3-2 shows a subset of the usability specification table for this experiment. The mean values are shown in the observed results column. A system questionnaire was also given. This questionnaire asked for information about the layout of screens and the overall usability and functionality of the system. The average score for most questions was 3.5.

There were twenty-five tasks, the minimum acceptable level was met for all but eight of the tasks. A summary was created which addressed each task which did not meet the minimum acceptable levels. Shown below is a subset of the summary data:

- Closing the PDT Viewer
  Quantitative Data: The minimum acceptable level was 21 seconds and the average user time was 31 seconds.
  Critical Incident(s): The words "Exit the QAPDC System" confused the participants. Many were reluctant to say yes to the question because they felt that it implied leaving the entire system.
  Solution: Those words should be changed to "Exit the PDT Viewer"

- Entering a Pagebuy
  Quantitative Data: The minimum acceptable level was 51 seconds and the average user time was 69 seconds.
  Critical Incidents(s): The participants preferred to look for items in the menus. The pagebuy option was located down below in the 'stamp' button. Often participants would use the 'bulk pagebuy' option because it was under a menu.
  Solution: The 'stamp' button should be removed and a 'stamp' menu should be added at the top.

Usability Attribute	Measuring Instrument	Value to be measured	Current Level	Minimum Acceptable Level	Planned Target Level	Expert	Observed Results
Initial Performance	Enter a page Buy on step 01-009 (G.)	Length of time to successfully enter a page buy	minutes (on paper)	51 seconds	34 seconds	17 seconds	69 seconds and .88 errors
Initial Performance	Enter a perm dev to step 02-002 saying, "Use sensors 4,5,and 6"(without incorp it) (H.)	Length of time to successfully enter a permanent deviation	minutes (on paper)	255 seconds	170 seconds	85 seconds	258 seconds and 2 errors
Initial Performance	Add a constraint to step number 02-004 saying, "Remove and replace LED" (I.)	Length of time to successfully add a constraint	minutes (on paper)	75 seconds	50 seconds	25 seconds	72 seconds and .76 errors
Initial Performance	Enter a Backstamp on step 02-008 and say, "PL2 is not ready" (J.)	Length of time to successfully enter a backstamp	minutes (on paper)	45 seconds	30 seconds	15 seconds	53 seconds and .82 errors
Initial Performance	Add a note to step 02-004 saying, "The constraint has been closed" (K.)	Length of time to successfully add a note to a step	minutes (on paper)	82 seconds	54 seconds	28 seconds	94 seconds and 1.53 errors
Learnability	Enter a permanent dev to step 01-005 saying ,"Support Rack 4 instead of Rack 3" (L.)	Length of time to successfully enter a permanent dev	minutes (on paper)	180 seconds	120 seconds	1 minute	150 seconds and .94 errors

Figure 3-2 Usability Specifications Table

4. DOCUMENT GENERATION

Documents are currently created for the Portable Data Collection system using MS Word. The document is then converted and stored in a database. During a pilot study of the system several areas for improvement were identified. The most significant area was the need to eliminate the conversion step. The means by which the document is created allows the user to enter data inconsistently, which creates problems when converting. These inconsistencies are not identified until the document is loaded and converted to be run. The clean up process is time consuming, and it introduces the possibility of errors. If a document is edited at this point, it would not typically be by the creator of the document. The conversion process itself may possibly introduce errors. Even if the document is converted 99% successfully, and there is one error, the PDC system loses credibility, which is crucial for acceptance. These are all usability issues which need to be addressed in the new design. A needs analysis was conducted to verify the conversion problem. It was determined that the most efficient and effective way of addressing this problem would be to create a tool which deposits components of the Work Authorization Document directly into the database system. This direct interface between the tool and the database allows various integrity constraints to be checked at creation time. This tool would also reduce the possibility of errors that might be produced during the conversion process.

An initial design was developed. A Visual Basic front end was created which allows users to create a new WAD. The contents of the WAD are deposited directly into the database. An early evaluation of the WAD creation tool was conducted and several recommendations for redesign were proposed. The initial design only addressed the creation and storage of a WAD. There are several other requirements which need to be implemented to make this a fully functional tool.

In addition to the system requirements, the usability issues must be addressed. This is especially important since it will change the way users create WADs. The existing system has been in place for many years. The use of the new system will be a culture change, so the new system must meet the capabilities of the old system and provide incentive for users to want to change. Usability will be a critical issue. Results from the initial design and evaluation indicate that further research is needed.

5. CONCLUSIONS

The process of usability evaluation is a valuable tool in the design of systems. Members of the PDC team were at first hesitant about the impact of allowing users to evaluate software in a prototype stage. The results from the evaluation were very encouraging, and members of the design team are excited about evaluating the next version of the Portable Data Collection System.

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1997 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER

UNIVERSITY OF CENTRAL FLORIDA

IMPLEMENTATION OF INSIGHT RESPONSIBILITIES IN PROCESS ENGINEERING

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ABSTRACT

This report describes an approach for evaluating flight readiness (CoFR) and contractor performance evaluation (award fee) as part of the insight role of NASA Process Engineering at Kennedy Space Center. Several evaluation methods are presented, including systems engineering evaluations and use of systems performance data. The transition from an oversight function to the insight function is described. The types of analytical tools appropriate for achieving the flight readiness and contractor performance evaluation goals are described and examples are provided. Special emphasis is placed upon short and small run statistical quality control techniques. Training requirements for system engineers are delineated. The approach described herein would be equally appropriate in other directorates at Kennedy Space Center.

1. Introduction

This report will describe an approach developed to assist Process Engineering in the transition from the historical systems engineering position requirements to the future surveillance position requirements. Initially, a description of the current approach used by systems engineers is presented, followed by a description of the new role. A flowchart of the steps that systems engineers will follow to implement insight responsibilities is provided.

Approaches for collecting data before and after transition are included. Types of data are considered, yielding statistical quality control (SQC) tools appropriate for the types of data and subsequent use of the analyses. SQC tools recommended for insight activities include Pareto charts, specialized control charts, scatterplots, and capability analysis. Thus, detailed guidance is provided for collecting, analyzing, and interpreting systems performance data as part of the insight responsibility.

Training requirements for implementing the proposed insight approach are detailed, and a timeline for implementing the various insight responsibilities is provided. To evaluate the success of the implementation, measures of performance are provided.

2. Transition

Within the Process Engineering Directorate (PK), the role of the systems engineer has focused primarily upon Work Instruction Generation, Requirements Control, and Processing Task Execution associated with the Space Shuttle Program. However, the responsibilities of systems engineers are expanding to include new initiatives, as depicted below.

Figure 1. Responsibilities of Systems Engineers

Before   After

Shuttle
Processing

Shuttle
Processing

New Launch Systems & Adv Tech
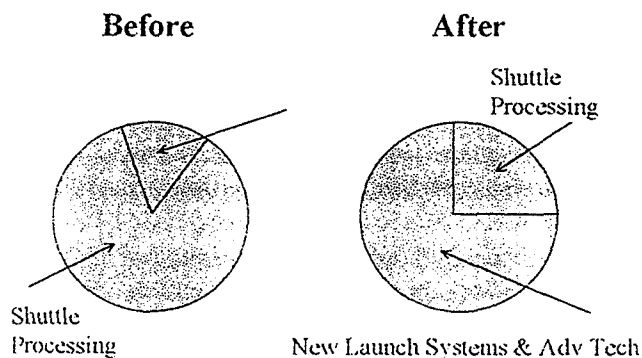
The historical approach used to fulfill the shuttle processing responsibilities has focused upon personal interaction between the NASA systems engineers and the contractor personnel assigned responsibility for the corresponding system in the space shuttle. At each step in the process, the signature of the appropriate NASA systems engineer has been required to release the work requirement. This signature signified that the systems engineer reviewed and approved the work instructions. Typically, the NASA and contractor personnel work cooperatively, with the systems engineer directly involved in all three responsibilities: work instruction generation, requirements control, and processing task execution. While this approach has demonstrated its effectiveness in assuring shuttle safety, it is resource intensive and the role of the systems engineer has been redefined to minimize direct involvement in the shuttle processing. Instead, the shuttle processing role of the systems engineer will be focused upon surveillance activities necessary to achieve three primary objectives: certification of flight readiness (CoFR), performance evaluation of the contractor, and shuttle upgrades.

Recognizing the unique requirements of transitioning from one role to another, the Process Engineering directorate has developed criteria sheets that are currently used by the systems engineers to formalize and document the steps employed to evaluate the contractor. Additionally, a limited quantity of systems performance data and contractor MIS data are collected. Thus, the current approach for certifying flight readiness and evaluating contractor performance utilize three primary approaches, as follows:

Figure 2. CoFR and Award Fee Evaluation: Before Transition
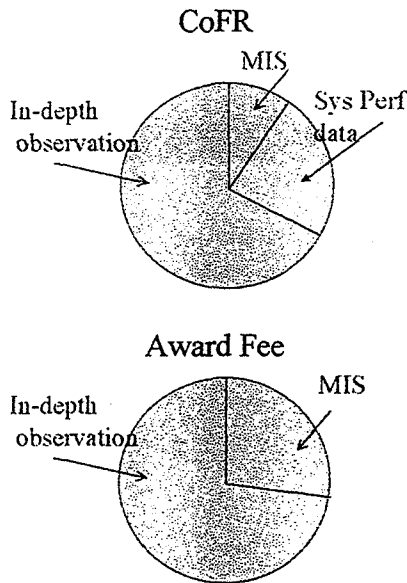
Unfortunately, the in-depth observations required to complete criteria sheets are labor intensive and the personnel resources necessary to support this level of involvement are already diminishing. With redirection of resources into new projects, this trend will certainly continue. Thus, the methods for certifying flight readiness and evaluating the contractor must be modified. Systems engineers have identified critical tasks that must be closely monitored to certify flight readiness. For these tasks, some level of direct observation will still be required. However, two levels of involvement are possible: technical and insight, where a technical review requires a high level of involvement in examining paper or monitoring task execution and an insight review targets only key aspects of the paper or the task. Especially in those cases where an insight level

of review is used, system performance data should be used to ensure the stability and capability of the associated process. For noncritical tasks, systems performance data can be sampled occasionally to ensure process stability and capability. In these cases, direct observation may not be necessary unless process instability is identified through the analysis of system performance data. The following charts depict the approaches to certification of flight readiness and contractor evaluation that should be used after transition to the new role.

Figure 3. CoFR and Award Fee Evaluation: After Transition

CoFR

Award Fee
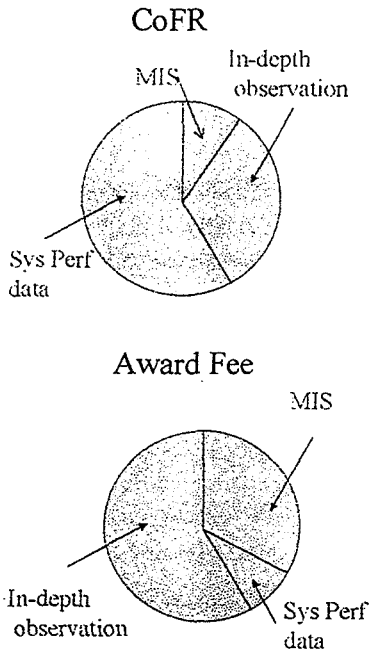
Thus, the use of system performance data for certification of flight readiness will increase considerably. The number of critical tasks will continue to diminish as systems engineers determine that tasks initially identified as critical are stable and capable and do not require direct observation. The following chart depicts the evolution of critical tasks.

Figure 4. Evolution of Critical Tasks
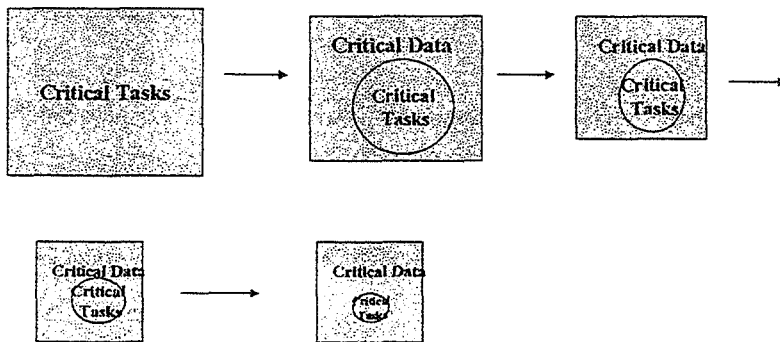
While critical tasks will decrease in number over time, system performance data associated with former critical tasks will continue to be analyzed to ensure that the processes are stable and

capable. In those cases where instability occurs, the systems engineers will become involved in monitoring process improvement to ensure the certification of flight readiness.

3. Insight Role of Systems Engineers

The role of the systems engineers must support the two primary goals of certifying flight readiness and contractor evaluation. However, this must be accomplished efficiently and effectively. Thus, the activities of systems engineers will be focused upon tasks that support critical and out-of-family processes. With a strong emphasis upon certifying flight readiness, systems performance data are essential. However, monitoring of those critical tasks that do not have systems performance data available necessitates the application of technical reviews of the tasks and/or the work authorization documents. Technical reviews involve in-depth, detailed observation of work instructions or execution of tasks with special emphasis upon engineering orders, specifications, requirements, and troubleshooting.

The following flowcharts provide a description of the role of the systems engineers in certifying flight readiness, where each supporting flowchart provides guidance for those situations where out-of-family tasks, critical tasks, or no observation of the tasks are encountered.

Figure 5. Flowcharts for CoFR

A

Add Technical Content
to Work Instruction

Complete Checksheet
for WAD Generation

Observe Task
Execution? — No

Yes

Complete Task
Execution Checksheet

Identify Process
Improvement
Opportunity to
Contractor ← No — All Areas
Satisfactory?

Yes

A

B

Identify Data that
will Indicate
Process Stability
and Capability

Possible to
Identify
Mechanism for
Data
Collection? ← No — Data
Available?

No

Yes

In-Depth
Observation of
Task

Yes

Determine
Appropriate SQC
Tool

Complete Criteria
Sheet

Apply SQC to
Data

Identify Process
Improvement to
Contractor ← No — All Areas
Satisfactory?

Yes

B

Identify Process
Improvement
Opportunity to
Contractor ← No — Is Process
Stable and
Capable?

Yes

Insight
Observation of
Task and
Complete Criteria
Sheet

B

4. Implementation of Systems Engineering Insight Role

Implementation of the insight role began with the development and subsequent application of criteria sheets, with six criteria sheets currently used by systems engineers for subjective measurement of products/results. There are two criteria sheets for each area of responsibility: hardware and software criteria sheets for PRACA Review, Task Execution, and the Work Instruction Generation. Each criteria sheet includes the requirement of documenting the criticality of the process, the flow number, and whether the systems engineer influenced the process. The body of each criteria sheet requires information regarding technical accuracy, conformance to standards, safety, and workmanship. Whenever a problem is identified, the criteria sheet includes choices of problem categories. Additional space is provided for remarks and explanatory narrative. The criteria sheets have been modified several times over the last several months to improve the usefulness of the data collected. The latest revision requires the systems engineer to indicate whether a technical review or an insight review was conducted, where the insight review involved examining only a portion of the paper or the task. Typically, an insight level review is accompanied by the analysis of critical systems performance data associated with the task. While the criteria sheets have been used for several months, additional training for systems engineers is required to ensure a consistent use of the fields on the criteria sheets. Particular attention to the definitions of several of the terms listed on the criteria sheets is necessary. Appendix 1 provides a list of definitions.

Each branch has been charged with the responsibility of examining all tasks within its purview to determine those tasks that are critical. At this point, all branches have completed this analysis, and the initial determination of critical tasks is available. While many tasks that are labeled as critical may eventually be reconsidered and labeled as noncritical, any tasks labeled as critical have concomitant responsibilities for systems engineers (see Figure 5). Use of systems performance data will provide the opportunity to monitor process stability and capability without the necessity for technical or insight reviews for many tasks. However, the current instructions require either a technical or insight review for all critical tasks. To enable a reduction in the number of technical or insight reviews, systems engineers require training in the identification and use of systems performance data. Additionally, analysis of systems performance data is a

MIS, etc.) yields binary attribute data (in spec/out of spec). System performance data can be collected during in-depth observation, or by examining paper, survey results, or contractor/NASA MIS databases. System performance data is measurement data that may be variable or attribute data. A few examples of system performance data are pressure, temperature, volume, current, and number of defects.

While many tools are available for analyzing attribute and variable data, several tools have a broad range of application for the types of data that are and/or will be collected as part of the surveillance activities in Process Engineering.

A tool designed to help distinguish between the significant few and the insignificant many problems or causes of problems is the Pareto Chart. The Pareto Chart has already been applied to several fields in the Metrics database used by Process Engineering to store the criteria sheet data. An example of the use of a Pareto Chart for examining the problems observed by systems engineers in the areas tracked on the criteria sheets follows.

Figure 7. Pareto Chart of Errors for Process Engineering
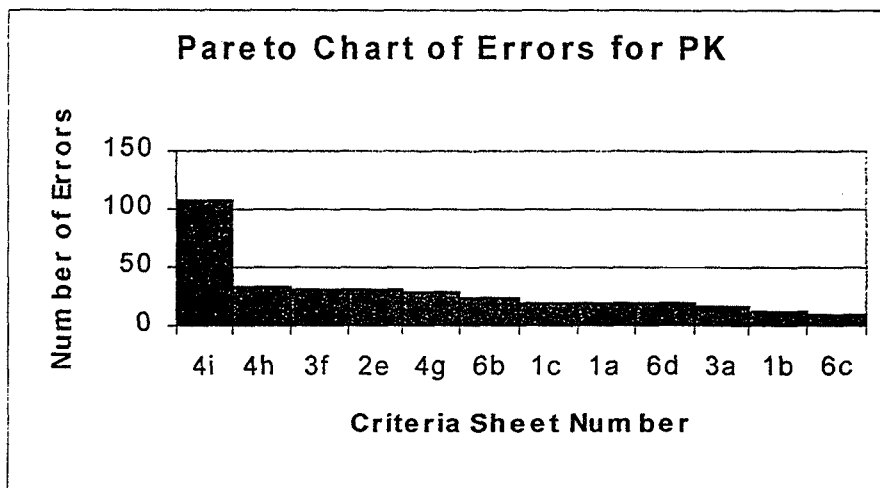
When systems performance data or MIS data must be analyzed to determine process stability, control charts provide the most valuable analytical tool. Unfortunately, the standard X-bar and R chart is not appropriate for many of the variable data collected in Process Engineering because the data represent tasks that are more similar to short run and low volume processes. Hence the use of individual X and Moving Range Charts, Exponentially Weighted Moving Average (EWMA) Charts, and Difference Charts are important tools for determining process stability. Attribute data can be analyzed using p charts, c charts, np charts, or u charts, depending upon the type of attribute data. Statistical Quality Control (SQC) software will be made available to assist systems engineers in using these tools. Two examples of control charts that have been developed using process engineering systems performance data follow.

prerequisite for identifying those tasks where the use of systems performance data can supplant a technical or insight level review of the task.
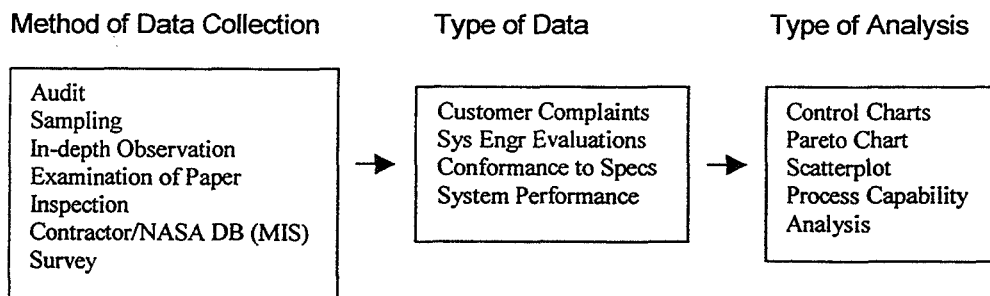
Another component of the insight role for both certification of flight readiness and contractor evaluation is the use of contractor- and NASA-managed data housed in Management Information System (MIS) databases. Systems engineers will require access to these data to assist in tracking RCNs, waivers/exceptions, flight hardware modifications, and OMRSD closed loop tracking, as well as monitoring PRs, IPRs, DRs, etc. Additionally, several configuration management databases are available, including Configuration Verification Accountability System (CVAS), MRCS, Baseline Accounting Reporting System (BARS), and Engineering Drawing System/Shuttle Drawing System (EDS/SDS). The Shop Floor Data Collection (SFDC) may also house information that is valuable to perform insight functions. These data will be especially useful for evaluating contractor performance. [NASA Process Engineering Directorate Implementation Plan]

All three approaches for certifying flight readiness and evaluating contractor performance: in-depth observation (criteria sheets), systems performance data, and MIS data, will yield data that must be analyzed to enable the CoFR and Award Fee decisions to be made.

5. Data Analysis Techniques

While several methods of data collection are used in shuttle operations, the primary methods that are used by systems engineers include in-depth observation, examination of paper, and contractor/NASA MIS databases. In-depth observation may include examination of the entire work instructions or only a portion (sampling). When in-depth observations are used, subjective systems engineering evaluations are performed, yielding data recorded on criteria sheets. In those cases involving examination of paper, systems performance data may be identified that can be used to monitor process stability and capability. However, examination of paper may yield only conformance to specifications' data. In some areas (especially payload processing), it may be possible to survey the customer to collect customer complaints and system performance data. The figure below briefly lists all data collection methods to be used for insight activities as part of surveillance.

Figure 6. Data Collection, Type of Resulting Data, and Types of Analysis

Method of Data Collection	Type of Data	Type of Analysis
Audit Sampling In-depth Observation Examination of Paper Inspection Contractor/NASA DB (MIS) Survey	Customer Complaints Sys Engr Evaluations Conformance to Specs System Performance	Control Charts Pareto Chart Scatterplot Process Capability Analysis

Customer complaints provide subjective information indicating areas of concern for the customer. This information is useful for contractor performance evaluation and certification of flight readiness. System engineering evaluations are recorded on criteria sheets, resulting in a subjective determination of contractor performance for a particular task. This information typically results in attribute data indicating the number and types of errors occurring during paper generation or task execution. Conformance data, frequently collected by examining paper (OMIs,

Figure 8. Control Charts for Process Engineering

MSBLS: XMR Chart for OV103
S/N 006 Power Msmt

X-Bar and R Chart for Flow Pressure Secondary
A-Leg and B-Leg Fuel Reg. and A-Leg and B-Leg Oxidizers
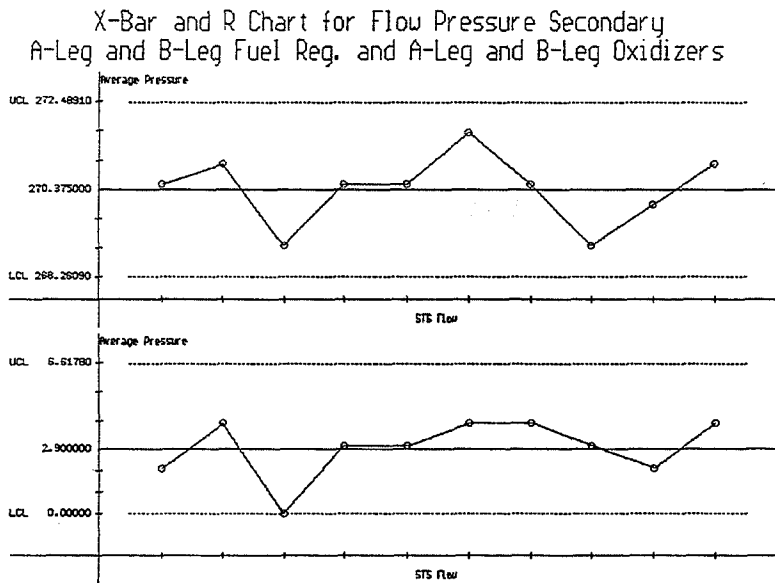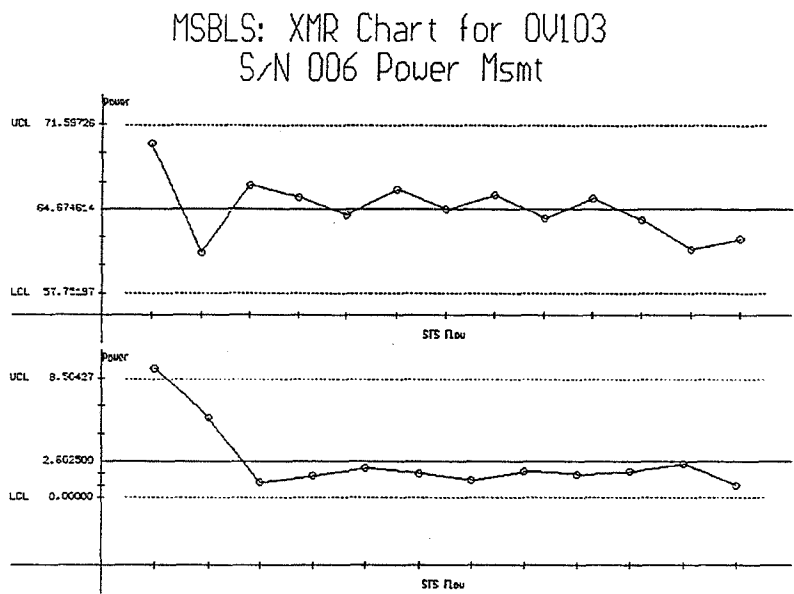
Once the systems engineer determines that the process is stable, the ability of the process to consistently yield results that are within the process specifications can be ascertained using process capability analysis. Once again, this analysis can be completed using the SQC software.

When identifying the systems performance data to utilize for determining process stability and capability, it is frequently desirable to use one variable that is easy to measure rather than another measure that may be difficult to obtain. In these cases, if the process outcome is the measure that is difficult to obtain, it is necessary to know the relationship between the two variables, and as long as there is a strong linear relationship between the two variables, the easy to measure variable can be used to indicate process stability and capability. To determine the relationship between the two variables, a scatterplot can be used.

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While there are many other tools that would be useful for certifying flight readiness and contractor performance evaluation, these fundamental tools provide the most valuable beginning tool kit for systems engineers. A training program has been developed to assist the systems engineers in the transition. Workshop #1 provides overall guidance to systems engineers regarding implementation of the insight role for certifying flight readiness and evaluating contractor performance. Within this workshop training for the consistent application of criteria sheets and definitions of insight-related terms is included. This is followed by a workshop that provides guidance in the application of SQC tools appropriate for the types of data collected at KSC. Workshop #3 focuses upon application of insight responsibilities, including application of the SQC tools for systems performance data, criteria sheet data, and MIS data in each branch in Process Engineering. Each workshop has associated activities and an assignment to be completed. The first of three workshops has been conducted for several of the branches within Process Engineering. Examples of the slides used during the workshop follow.

Figure 9. Insight Workshop #1 for Process Engineering
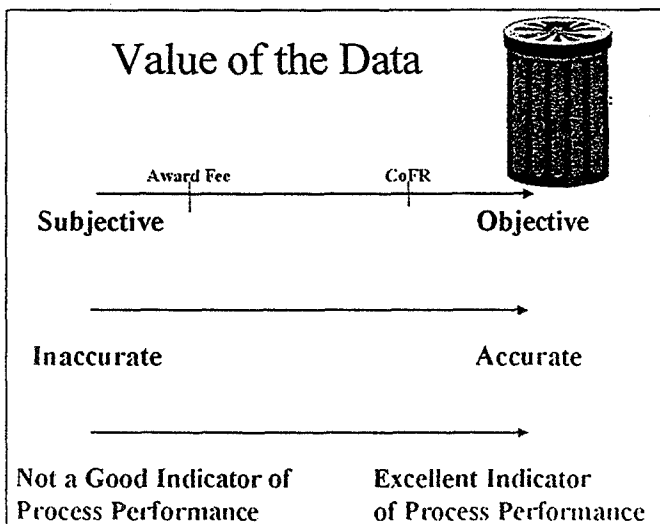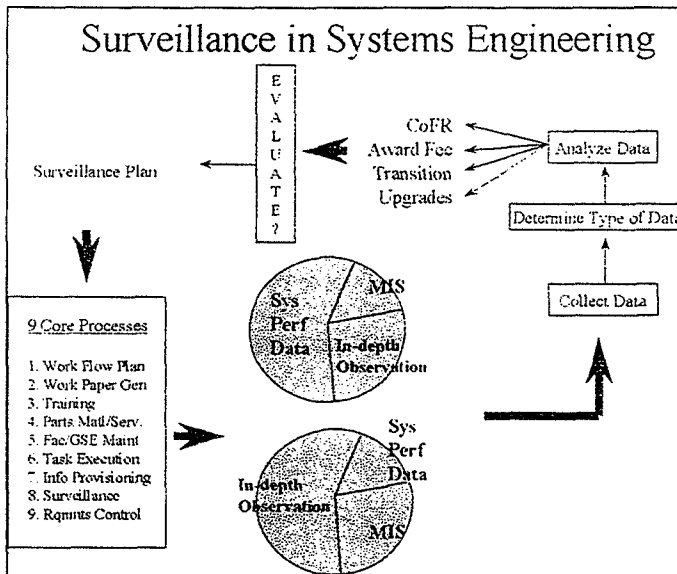
6. Measures of Performance

To ascertain the value of this approach, the systems engineers should be surveyed to determine their level of satisfaction with the techniques used for certifying flight readiness and contractor performance evaluation after transition. A baseline survey should be administered immediately to determine perceptions currently, and the follow up survey should be administered after several months to determine the change in perception, once the new tools are understood and have been applied to most tasks.

Additionally, several high level indicators of performance should be monitored to determine whether significant improvement results using the approach outlined in this report. Examples of these indicators include key system performance data collected to monitor overall system stability and capability (fluids, electrical, mechanical, etc.).

7. Conclusion and Recommendations

Process Engineering has begun the transition to the new insight role for shuttle processing. The tools used for this role will serve the systems engineers well in the expanded role involving new launch systems and advanced technology. Thus, the skills necessary for applying the insight responsibilities must be developed throughout the directorate. While a transition of this magnitude poses great challenges for personnel at all levels, the benefits will impact the future of the space program in many ways, including increased efficiency and effectiveness in shuttle operations. The use of SQC tools for analyzing systems performance data, criteria sheet data, and MIS data will facilitate appropriate decisions regarding certification of flight safety and contractor performance evaluation. However, the training and subsequent applications of the tools are a crucial part of the eventual success of the transition.

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1997 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
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APPLICATION OF MATHEMATICAL STATISTICS IN STATISTICAL QUALITY CONTROL

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ABSTRACT

This project, operating from the Office of Safety & Mission Assurance, will address some basic statistical concerns. The first concern will be to develop a survey course in mathematical statistics. This course will focus on the basic statistical/probabilistic principles (without too much detail) that are used in some of the statistical analysis carried on by the Safety & Mission Assurance Directorate. Discrete and continuous probability distributions will be derived from a heuristic and a mathematical point of view using the above principles. Finally, two proposals are presented that speak to the concept of advance training. The first proposal is concerned with training personnel at S&MA in mathematical statistics and statistical quality control. The second proposal deals with the concept of a "University of S&MA" which is a natural progression of the first proposal.

1. INTRODUCTION

With the advent of "performance based contracts" which involves the review of contractor provided data, the S&MA directorate is the logical directorate to provide a "data validation " service to the various directorates that have direct responsibility for the evaluation of performance based contracts. The S&MA directorate routinely samples data and performs statistical analysis in the fulfillment of its mission to insure safety and quality assurance.

While, the S&MA directorate has a history of performing data analysis, there is crucial need for the directorate to focus on "why" a certain statistical analysis is performed as opposed to "how" it is performed. In short, it is not enough for a task to be performed correctly. The person responsible for the analysis should be able to justify the analysis using sound and correct statistical principles.

A survey course in mathematical statistics attempts to provide justification for the statistical analysis of data. In many textbook on statistical quality control, the prerequisite is generally a basic course in statistical methods. A careful perusal of some of the textbook on statistical quality control reveals the listing of probability density functions along with the mean and variance of the corresponding distribution; acceptance plans / rejection schemes are listed without associated probabilities. In short, the computation of mean and variance involve the concept of expectation and the calculation of probabilities associated with acceptance plans involve an understanding of combinatorics. Since these concepts are not traditionally proven in a basic statistical methods course, most authors of statistical quality control texts do not require the student to understand the mathematical derivation of certain statistical concepts. The result is that the typical student will probably be unable to develop new methods of statistical analysis and consequently will be limited to those methods that presented in the text.

To quote Grant and Leavenworth, the authors of <u>Statistical Quality Control</u>, *"There are four different levels of understanding statistical quality control. One is the level of understanding the mathematics on which are based the control charts and sampling tables and their relationship to the many other tools for the analysis of data that have been developed by mathematical*

statisticians ...The second level is that of a general understanding of the principles underlying the various types of control charts and sampling tables. It calls for understanding why these methods work, how to interpret their results, and how to decide which methods to use in any particular case..."

The survey mathematical statistical course and basic statistical quality control course would certainly satisfy the second level of statistical understanding and some portions of the first level of statistical understanding. To accomplish some of the goals mentioned in the previous paragraphs, the following prerequisites are strongly urged:

1. Differential and integral calculus
2. Some familiarity with a statistical software package (JMP)
3. Some familiarity with MATLAB or similar package.

The intent of the above course will be to deal most of the prerequisites.

2. RESULTS

In this section, the course outlines of the survey mathematical statistics and basic statistical quality control course will be presented. A description of the topics in the mathematical statistics course with examples and illustrations will be presented. Finally, a proposal for the instituting of a "University of S&MA" will be given.

2.1 Course Outlines

Mathematical Statistics Survey Course Outline

1. Counting
2. Discrete Probability Distributions
3. Continuous Probability Distributions
4. Expectation
5. Estimation
6. Special Distributions and the Central Limit Theorem
7. Sample Designs

Counting or combinatorics is used to determine the outcomes of a sample space given a particular experiment. Consider the experiment of tossing two die. There are six ways that the first die can be toss and there are six ways that the second die can be tossed. The total number of ways in which both die can be tossed is 6•6 = 36 ways.

Discrete Probability Distributions are represented by random variables (a real-valued function defined over the elements of a sample space) whose range is finite or countably infinite. Examples include the binomial, hypergeometric, and Poisson distributions.

Continuous Probability Distributions are represented by random variable whose range is a continuum or a line segment. Examples include the normal, gamma , Weibull, continuous uniform, and chi-square distributions.

Expectation The expectation of a discrete random variable X with probability distribution function $f(x)$ is given by

$$E(X) = \sum_x x \cdot f(x) \tag{1}$$

If X is a continuous random variable , then its expectation is given by

$$E(X) = \int_{-\infty}^{\infty} x \cdot f(x)\, dx \tag{2}$$

The mean and variance of a distribution is defined in terms of mathematical expectation.

Estimation involves point and interval estimation. This section also talks about consistent, sufficient and efficient estimators. The sample mean

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n} \tag{3}$$

is a consistent and sufficient estimator of the population mean μ.

<u>Special Distributions and the Central Limit Theorem</u> The two special
distributions mentioned in the survey mathematical statistics course is the
"Student" t - distribution and the F - distribution. In simple terms, the
central limits theorems states that the distribution of the sample mean from
a sample of size n from a population with mean μ and standard deviation σ
is approximately normal with mean μ and standard deviation $\sigma/\sqrt{n}$
(provided n is sufficiently large). Symmetric distributions such as the
continuous uniform distribution, require a small sample size to achieve
approximate normality. Heavily skewed distribution, such as the
exponential distribution, require larger sample sizes to achieve approximate
normality. Consider the histogram of the exponential distribution presented
below. It is clearly heavily skewed to the left.
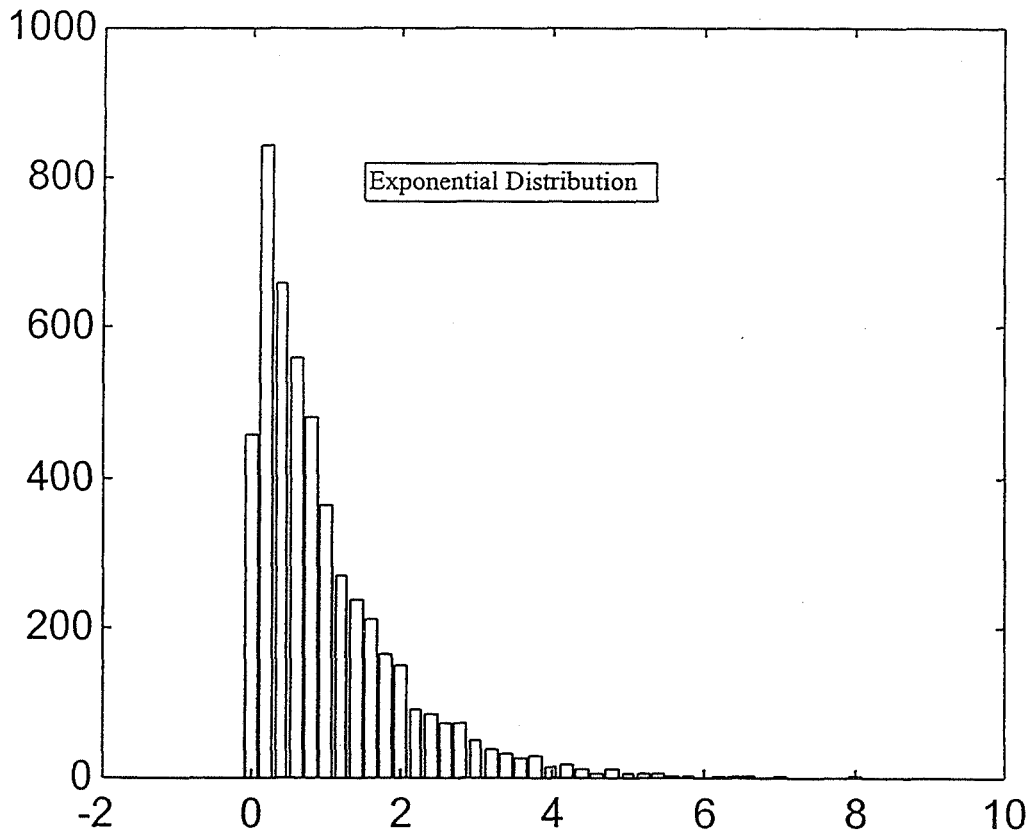
The next graph displays the distribution of the sample mean from a sample
of size 20 from the above exponential distribution. It is evident that a
sample size of at least 20 gives a distribution that is approximately normal.

Note that the spread or variation is very small in comparison to the original distribution. This is not surprising since the variance of the sample mean is the variance of the original distribution divided by n.
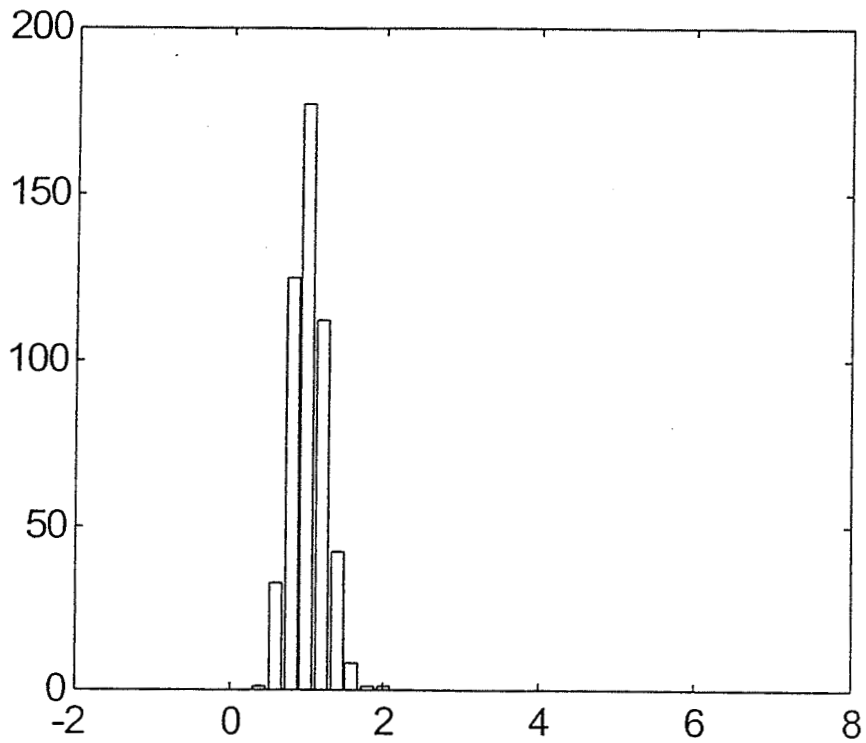
The next distribution is the continuous uniform distribution which is given below. The uniform distribution is symmetric about its mean of $\mu = .5$.
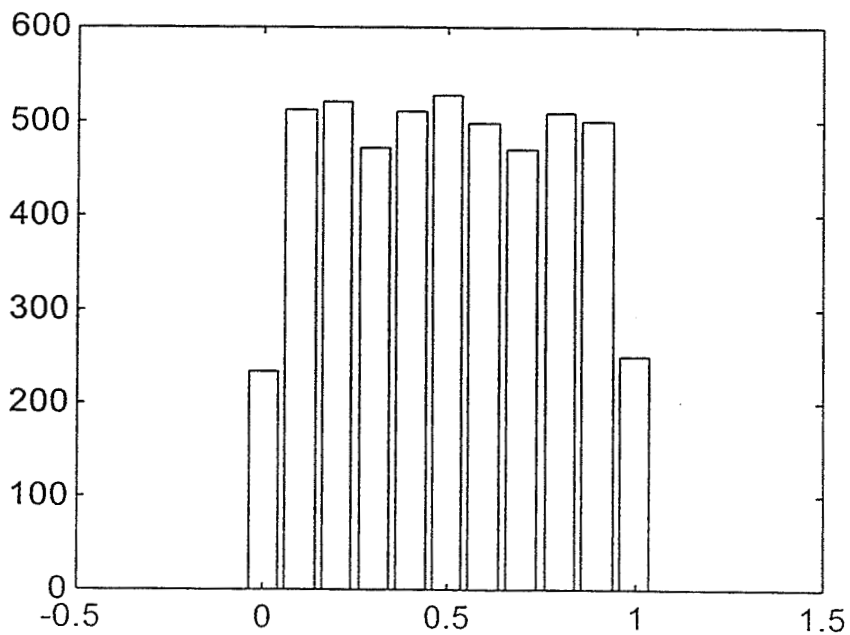
The next graph displays the distribution of the sample mean from a sample of size 2 from the above continuous uniform distribution. It is evident that a sample size of at least 2 gives a distribution that is approximately normal. The initial symmetry of the original continuous uniform distribution is the reason why a significantly smaller sample size was required in comparison to the exponential distribution to achieve approximate normality.
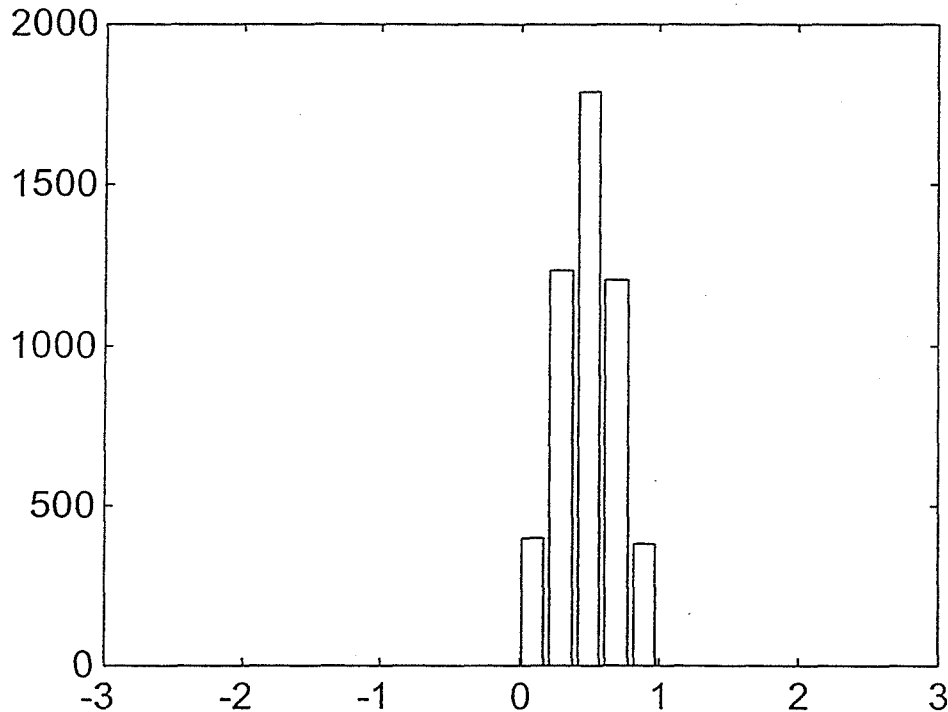
The **Sample Designs** mentioned in the survey course in mathematical statistics include the *simple random sample, the stratified sample design* and the *multi-stage sampling plan* .

Basic Statistical Quality Control Course Outline

1. General Principles and Tools of Statistical Process Control
   a. Choice of control limits
   b. Sampling size and frequency
   c. Rational subgroupings and cost considerations
   d. Analyses of Patterns
   e. Check sheets and scatter diagrams
   f. Pareto charts and control charts
   g. Cause and effect diagrams

2. Control Charts

   a. Fraction nonconforming
   b. Number of defects
   c. Sample mean
   d. Sample range & standard deviation
   e. Sequential individual measurements
   f. Cumulative sum charts
   g. Exponentially weighted charts
   h. Economic design considerations

3. Acceptance Sampling and Data Validation Procedures

   a. Types of sampling plans
   b. Operating characteristic (OC) curves
   c. Rectifying inspection plans
   d. Double & multiple stage sampling plans
   e. Military Standard 105D
   f. Lot tolerance percent defective (LTPD) plans
   g. Average outgoing quality limit (AOQL) plans

2.2　The University of S&MA

For an advance training and education program to be successful, the various levels of management in the S&MA Directorate must see a need for the program. Also, the engineers, technicians and pertinent staff must see and appreciate the necessity of advance training and education as a means of self-improvement and as an ultimate vehicle for the overall advancement and improvement of the Directorate. To achieve this goal, the participants in advance training & education could do the following:

1. Attend and participate in the regional, national, and international meetings in the appropriate discipline or related disciplines. Usually, these meetings offer short courses which may be of benefit to a person. Finally, a person attending these meetings should attend the talks that relate to their discipline.

2. Enroll in an advance degree program taking the thesis option. The KSC environment contains a host of research items that can be developed into a thesis or dissertation.
3. Attend seminars with industry and the university community to look at current problems and developments that impact on the various disciplines.
4. Subscribe to the appropriate refereed journals. The benchmark of a successful advance training program is that people will submit papers to journals and present talks at conferences & meetings in their discipline.

The chart below give sufficient conditions for a person to do research in statistics. These conditions need not be necessary, if a person has an adequate theoretical background in statistics to perform scholarly research. The research topics are suggestive only. There are probably many research topics that can spin off of the ones listed in the chart below. **Finally, management must set the example by participating in the research effort**.

College of Quality

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              ┌─────────────────────────┐
              │ Department of Statistics │
              └─────────────────────────┘
                          │
                 ┌──────────────────┐
                 │    MS or PhD     │
                 │    Statistics    │
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                 │  Research Areas  │
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│Statistical Quality Control│ │ Sampling Theory │ │ Experimental Design │
└──────────────────────┘ └──────────────────┘ └─────────────────────┘
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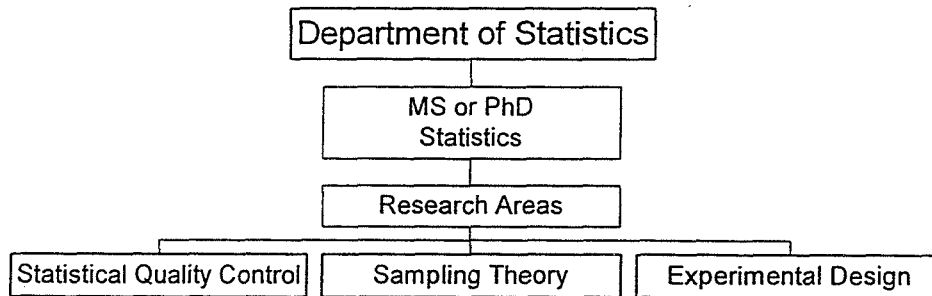
3. CONCLUSION

In this paper, course outlines for two statistics courses were given along with some explanations of statistical concepts. The mathematical statistics course commence within the time frame of the Summer Faculty program. This author will teach a course in statistical quality control during the spring of 1998 at the University of Georgia. The intent of this effort is to teach the basic quality control course at KSC, go to the Joint Statistical Meetings in August of 1998 and attend in the sessions on statistical quality control.

4. ACKNOWLEDGMENTS

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Modeling Nutrient Mineral Transport in Advanced Life Support Systems

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ABSTRACT

Mass transfer of plant and human nutritional minerals in a Biological Advanced Life Support (BALS) was simulated in a dynamic simulation computer program to determine if deficiencies or toxic levels of minerals would develop in plant or human diets in a BALS. The physical system modeled included one crew member, a biologically active nutrient recovery unit, sufficient plants and hydroponics growing equipment to meet the sustained food requirements of the crew, external resupply of nutrients and an external sink for unrecovered minerals. Crops grown were soybeans, potatoes, wheat, rice and a mixture of green leaf vegetables. Percentages of each crop in the diet were similar to the crop mixture proposed for BIO-Plex, a BALS testbed. Enough of the edible portion of crop mixture to meet the crew's energy needs was ingested daily. Crew waste and inedible plant tissue were decomposed in the nutrient recovery unit, where a portion of the minerals in the waste stream were leached and transferred to the plant nutrient system. As plants grew, they removed minerals essential for plant growth from the solution, leaving nonessential minerals to accumulate in the solution. Unrecovered minerals were removed from the BALS, and mineral deficiencies in the crew diet or plant nutrient solution were made up from external resupply.

Three scenarios of mineral recovery were simulated (full recovery, no recovery and partial recovery) to determine if harmful levels of minerals develop in the human diet and in the nutrient solution, how long the nutrient solution could be used before toxic concentrations exist in the solution, and the level of mineral resupplied needed to support a BALS. Simulation results indicated that the human diet is (without supplementation) deficient in some mineral levels, and contains excess, but not harmful, levels of many minerals. Plant deficiency levels and the accumulation of toxic concentrations of minerals in the nutrient system was dependent on the recovery of minerals in the bioreactor. Under partial recovery conditions, 11 grams/(person * day) of human and plant nutrient minerals from external sources will be needed, and fluoride will build up to toxic levels the nutrient solution in 1.25 years.

The simulation was verified for correctness with the databases used, but these results should be used with caution because the databases used were incomplete, and required a number of simplifying assumptions for use in the simulation. Improving the nutritional databases and transfer data is needed before this simulation's results are used with confidence.

Modeling Nutrient Mineral Transport in Advanced Life Support Systems

Marvin Pitts, PhD. PE

1. INTRODUCTION

Scientists and engineers within NASA are conducting research which will lead to the development of advanced life-support systems that use plants and microbes to solve long term life-support problems in space (1). The Biological Advanced Life Support (BALS) is a complex, extensively-controlled, bioengineered system for human life support. It relies on plants and microbes to perform gas exchange, food and potable water reclamation to supply principal elements needed for human existence.

Advanced life support systems which are based on bioregenative systems depend on maintaining a balance between humans, plants and microbe populations. Plants perform many functions in maintaining the environment for human life including production of oxygen, consumption of carbon dioxide, production of potable water and food. Microbes in a bioreactor waste recovery unit reclaim carbon, nitrogen and essential minerals. Balancing nutritional needs is particularly important. Improper diets will reduce the health and performance of both plants and crew. In particular, plants which are not vigorously growing will not provide the needed oxygen and water, or remove carbon dioxide from the environment.

Mass and energy balances within the BALS are essential to long term sustainability. Plant and microbe populations must be sized to meet the gas exchange, water, waste removal and nutrient needs of the crew and each other. Extensive research into these needs has lead to the development of BIO-Plex, a large scale ($940m^3$) test chamber to develop ALS data for projected operational missions in space (2). An initial mixture of crops and growing area has been proposed (Table 1) that will meet human protein and carbohydrate nutrition needs.

Providing an adequate supply of minerals was not a major criterion for the selection or growing area partitioning of BIO-Plex crops. An important question to raise is how well the BIO-Plex mix of crops meet both the energy and mineral needs of a crew. Table 2 lists the energy, proimate (proteins, carbohydrate and lipid or fat) and mineral composition of the crops proposed for BIO-Plex (4). Assuming that a person will consume enough of the BIO-Plex crops to meet their energy needs, the amount of minerals consumed can be determined. Using the percent of diet column from Table 1 and the mineral composition column from Table 2, the daily consumption of minerals was computed (Table 3).

Table 1: BIO-Plex Crops and yield proportions. (3)

Crop	BIO-Plex growing area m²	edible yield density kg/m²	edible yield kg	% of diet by mass
Mix	5.1	0.15	0.745	0.5
Peanut	10.2	0.60	6.120	4.2
Potato	16.4	4.35	71.373	48.6
Rice	14.0	1.22	17.080	11.6
Soybean	28.0	0.38	10.612	7.2
Wheat	19.1	2.14	40.874	27.8
Total	92.8		146.803	100.0

From comparison of RDA (5) mineral requirements (Table 4) and the minerals in the BIO-Plex diet (Table 3) one can determine that the BIO-Plex diet provides excess, but not toxic amounts of the following minerals specified in the RDA; Cu, Mg, Mn, P, K, and Zn. The diet does not provide enough Cl, F, I, and Na, because these minerals are not needed by plants, and insufficient amounts of Ca. Regardless of the amount in the food, two essential elements, Cr and Fe, must be provided via animal protein in the human diet for proper absorption. A source of these elements from outside of the BALS will be needed to maintain human health (6).

Table 2. Proximates and Mineral % for Edible portions of BIO-Plex Crops. All values except Energy are in percentage by dry weight. (4)

Nutrient	Soybean[1]	Wheat[2]	Rice[3]	Potato[4]	Peanuts[5]	Mix of Greens[6]
Energy (kJ/g)	17.42	13.7	15.48	3.31	23.74	0.5
Moisture	8.54	13.1	10.37	79.96	6.5	95.89
Protein	36.49	12.61	7.94	2.07	25.8	1.01
Lipids	19.94	1.54	2.92	0.1	49.24	0.19
Carbohydrates	30.16	71.18	77.24	17.98	16.14	2.09
Fiber	9.3	12.2	3.5	1.6	8.5	1.4
Ash	4.87	1.57	1.53	0.89	2.33	0.48
Ca	0.277	0.029	0.023	0.007	0.092	0.019
Fe	0.0157	0.00319	0.00147	0.00076	0.00458	0.0005
Mg	0.28	0.126	0.143	0.021	0.168	0.009
P	0.704	0.288	0.333	0.046	0.376	0.02
K	1.797	0.363	0.223	0.543	0.705	0.158
Na	0.002	0.002	0.007	0.006	0.018	0.009
Zn	0.00489	0.00265	0.00202	0.00039	0.00327	0.00022
Cu	0.001658	0.000434	0.000277	0.000259	0.001144	0.000028
Mn	0.002517	0.003985	0.003743	0.000263	0.001934	0.000151

[1]mature seeds, raw NDB No. 16108   [4]raw, flesh and skin NDB No. 11352
[2]hard red winter NDB No. 20072   [5]all types, raw NDB No. 16087
[3]brown, long grain, raw NDB No. 20036 [6]iceberg (includes crisphead types), raw NDB No.11252

The mineral needs of the plants within an operating BALS were also considered. The edible portion of plants in general contain excess essential plant nutrient minerals for human needs, which the human digestive system will pass as long as the amount of any particular mineral remains below its human toxicity level. Assuming that the bioreactor recoveres most of the minerals in the human waste and in the inedible plant biomass, toxicity is more of a concern in plant mineral nutrition that is maintaining an adequate mineral supply. Plant toxicity is a concern because the human diet requires minerals (Cl, F, I, and Na) that are not needed by the plants and which over time could become toxic to the plants if the concentration of these minerals in the plants' nutrient solution increase.

Further complicating the problem of toxic mineral levels in the nutrient solution is that the plants may or may not absorb nonessential minerals (13). Unless these minerals are removed from the nutrient solution, their concentrations will increase with time. Understanding the impact of increasing mineral concentration in the plant nutrient solution, and the impact of failing to recover essential plant nutritional minerals in a bioreactor process is critical in determining cost effective nutrient recovery methods.

Bacteria are critical to the recovery of minerals from human waste and inedible biomass produced by the plants. Within a bioreactor such as a composter, the bacteria will breakdown organic matter, releasing nitrogen, carbon dioxide and nutrient minerals from the biomass. Minerals which are not released will not return to the nutrient solution, and are likely to be removed from all BALS material flows via incineration. Minerals thus lost to the BALS will have to be replaced from external sources.

Simulation of mineral movement in a BALS is a good starting point. No test bed facilities exist that integrate human, plant and bioreactor environments in a nearly closed system. BIO-Plex, when operational, will have the capability of mapping mineral flows, but the amount of closure needed to identify the dynamics of mineral flows is not within the proposed mission parameters for BIO-Plex. Even if a testbed was available, a preliminary simulation would help identify critical mineral flows and scenarios to test.

Table 3. Nutrient balance using BIO-Plex proportion of crops; sized to meet the energy needs for one person. Energy in KJ, other values in grams. (5, 6, 12, 13, 14)

Edible Portion of Crops	
Energy	11800
Protein	99.4
Fat	34.24
Carbohydrates	556.0
Fiber	66.4
Ash	23.8
Ca	0.402
Fe	0.0318
Mg	0.980
P	2.24
K	11.5
Na	0.127
Zn	0.0182
Cu	0.00689
Mn	0.0189
Inedible Portion of Crops	
Ca	6.04
Fe	0.303
Mg	2.78
P	2.10
K	44.9
Na	0.0976
Zn	0.0116
Cu	0.0127
Mn	0.0631
B	0.0258
Mo	0.00219

Table 4. Adult human and Plant Mineral requirements and toxicity levels. Plant mineral consumption based on providing 11.8 MJ nutritional energy / (person * day)

Mineral	RDA mg / day	Human Toxicity Level mg / day	Plant Nutrient Consumption g / day	Plant Toxicity Levels ppm
B	0	.7	.0258	1
Ca	800	2500	6.446	400000
Cl	3400	30000	0	10000
Cr	0.125	10	0	1
Cu	2.5	100	.0196	1
F	2	4	0	2
Fe	14	100	.3347	75
I	0.15	2	0	1
K	3020	30000	56.487	10000
Mg	300	6000	3.763	10000
Mn	3.125	700	.0820	10
Mo	0.32	10	.0022	70
Na	1800	30000	.2243	10000
P	800	2500	4.347	20000
S	15	100	0	50000
Zn	15	19	.0299	1

2. OBJECTIVES

The objective of this project was to determine if toxic levels of nutrient minerals will accumulate in the human diet or in the plant nutrient solution of a closed bio–regenerative life support system, and to estimate the mineral resupply needs for an extended mission. To address the project objectives, the simulation must provide insight to three questions:

Will any of the mineral concentrations increase to levels toxic to the plants being grown? A first approximation to this question is that minerals not essential to plant nutrition will accumulate to toxic levels, given enough simulation time. More detailed examination of plant mineral uptake dynamics indicate that plants may not be able to selectively reject some nonessential minerals. If a plant absorbs a nonessential mineral and lowers the mineral's concentration in the nutrient solution, then the mineral concentration may not build up to toxic levels.

If a mineral concentration is increasing, how long before the concentration becomes toxic? The time until a toxic concentration accumulates is important to determining the useful life of the nutrient solution, or if a process to remove particular minerals is justified for a particular mission.

How much of any mineral must be supplied from external sources? Achieving complete recovery of minerals from human waste and inedible plant biomass is likely to involve an uneconomic combination of biological, physical and chemical systems. A key criterion in selecting a waste recovery system is to compare the cost of such a system to the cost of external resupply.

3. SIMULATION

The computer simulation package, STELLA™ (15), was used to model the flows of twenty five minerals and elements in a BALS consisting of a single person crew, bioreactor–based waste recovery unit, plants and external resupply (Figure 1). Recovery rates for each mineral were a simulation variable. Warning messages were displayed if toxic levels of minerals were consumed by the crew, or if mineral concentrations toxic to plants were present in the nutrient solution. The simulation computed the mass of each mineral supplied from an external source.

Figure 1. STELLA diagram of mineral flows in a bioregenerative BALS

Crop production was sized to meet the energy needs for one person. Crop area and production matched the BIO-Plex crop mixture. A nutrient solution mass of 400kg was used to compute nutrient solution concentrations (16). This amount of water was sufficient for a growing area large enough to support one. External supplies of plant and crew nutritional minerals were provided to correct for deficiencies in plant nutrient concentrations and crew nutritional mineral consumption.

In the simulation, plants provided most of the human nutritional minerals in the edible food for the crew. For many minerals, crew mineral consumption was in excess of RDA values, but for all minerals the consumption rate was below toxic levels. Mineral supplements from the external supply were provided as needed to ensure the crew

received at least the RDA of each mineral. The crew eliminated minerals in order to maintain a typical body concentration of each mineral.

Crew waste and the plant inedible biomass were fed into the bioreactor. As the microbes in the bioreactor consumed organic matter, nutrient minerals were released from the organic matter, and added to the plant nutrient solution. The recovery rate of each mineral was a variable in the simulation. Minerals not recovered were carried with undigested organic matter and lost to the system.

Plant nutritional minerals were removed from the nutrient solution to support edible and inedible plant growth. External supplies supplemented the mineral flow from the bioreactor as needed to maintain nutrient mineral concentrations. Nonessential plant nutritional minerals were not removed from the nutrient solution, and concentrations of the nonessential minerals increased. Depending on the flow rate from the bioreactor and the toxicity levels of each mineral, mineral concentrations could reach toxic levels.

Three mineral bioreactor recovery scenarios were developed to address the project objectives. The first scenario was that all of the minerals were recovered in the bioreactor. This scenario was developed to identify potentially toxic (to plants) mineral concentrations, and to provide a conservative estimate of the nutrient solution life.

The second scenario was that none of the minerals were recovered in the bioreactor. This scenario was developed to determine a baseline cost of resupply that can be compared to the cost of prospective mineral recovery processes. Because the scenario opened the mineral flows, the results of this scenario could be compared to independent estimates of plant mineral resupply needs as a verification check.

The third scenario used experimental estimates of mineral recovery rates in the bioreactor. While this scenario is only a first order estimate based on incomplete data, it was designed to provide the most realistic (of the three scenarios) estimate of nutrient life and the mass of minerals required from external sources.

Table 5. Estimate of mineral recovery rates in bioreactor. (17)

Mineral	Decimal Recovery			Weighted Recovery	Source
	Soybean	Potato	Wheat		
B				0.80	Estimated[1]
Ca	0.44	0.23	0.72	0.46	Garland[2]
Cl				0.99	Estimated
Cr				0.30	Estimated
Cu	0.91	0.82	0.8	0.82	Garland
F				0.99	Estimated
Fe	0.25	0.37	0.3	0.32	Garland
I				0.80	Estimated
K	0.99	0.99	0.99	0.99	Garland
Mg	0.81	0.8	0.92	0.85	Garland
Mn	0.55	0.69	0.62	0.64	Garland
Mo				0.30	Estimated
Na				0.99	Estimated
P	0.55	0.8	0.6	0.68	Garland
S				0.80	Estimated
Zn	0.99	0.91	0.9	0.92	Garland

[1] Value estimated from mineral recovery rates in Garland (17) and the relative position of the mineral to minerals measured by Garland in the Periodic Table.

[2] Weighted mean of the recovery rates reported in Garland (17) using the BIO-Plex crop mix masses (Table 1).

There are few references to plant nutrient mineral recovery rates in bioreactors. Garland (17) determined the recovery fraction of eight plant nutrient minerals after leaching inedible biomass. Recovery rates varied by crop, with potato biomass producing the best recovery rate, followed by wheat and soybean. A weighted average (based on BIO-Plex mix) mineral recovery rate for the minerals studied by Garland is presented in Table 5. Recovery rates of chemically similar (same valence, same grouping within the periodic table) nutrients of interest to this study, were estimated where they were not measured by Garland (Table 5).

4. RESULTS

Table 6 summarizes the results of the three scenarios. In the full recovery scenario, all of the minerals from the crew and inedible plant biomass was returned to the plant nutrient solution. The crew did not consume lethal amounts of any mineral. The edible plant matter consumed by the crew did not contain sufficient amounts of the following

Table 6. Mineral nutrient concentrations and daily resupply of minerals for crew and plants

Mineral	Full Recovery			No–Recovery			Partial Recovery				
	Day 450 Nutrient Concen	Daily Crew Resupply	Days to Plant Toxicity	Day 450 Nutrient Concen	Daily Crew Resupply	Daily Plant Resupply	Day 450 Recovery Ratio	Nutrient Concen	Daily Crew Resupply	Daily Plant Resupply	Days to Plant Toxicity
	ppm	g/p*d	days	ppm	g/p*d	g/p*d		ppm	g/p*d	g/p*d	days
B	0.0645	0		0.0530	0	0.0464	0.80	0.0623	0	0.00926	
Ca	65.5	0.439		14.7	0.439	5.8	0.46	15.4	0.439	2.93	
Cl	383.	3.4	11450	0	3.4	0	0.99	377.	3.4	0	11600
Cr	0.0141	0	9250	0	0	0	0.30	0.00423	0	0.00317	30850
Cu	0.0490	0		0.0445	0	0.0176	0.82	0.0483	0	0	
F	0.225	0.002	450	0	0.002	0	0.99	0.223	0.002	0	450
Fe	2.37	0.014		0.763	0.014	0.301	0.32	0.787	0.0142	0.002	
I	0.0169	0.00015	18850	0	0.00015	0	0.80	0.0135	0.00015	0	23550
K	141.3	0		129.	0	50.8	0.99	141.	0	0.506	
Mg	9.40	0		8.55	0	3.39	0.85	9.28	0	0.506	
Mn	0.205	0		0.187	0	0.0738	0.64	0.198	0	0.0266	
Mo	0.0055	0		0.00453	0	0.00394	0.30	0.00480	0	0.00276	
Na	190.	1.69	2900	0.510	1.69	0.202	0.99	188.	1.69	0	2950
P	10.9	0		9.90	0	3.91	0.68	10.6	0	1.25	
S	1.69	0.015		0	0.015	0	0.80	1.35	0.015	0	
Zn	0.0748	0		0.068	0	0.0269	0.92	0.0743	0	0.00215	
Total		5.56		0	5.56	64.6			5.56	5.44	

human nutritional minerals; Ca, Cl, Cr, F, I, Na and S. Although there is a sufficient amount of iron in the edible biomass to meet RDA levels, external supply of iron (from animal protein sources) is needed because humans poorly absorb iron from vegetative sources. These eight elements are the only mineral nutrients added to the system. Over time, each of these elements would accumulate in the nutrient solution to toxic levels, as indicated in Table 6. Fluorine was the first element to build to toxic levels (450 days), followed by sodium at day 2900 (about 8 years).

In the no–recovery scenario all of the inedible biomass and minerals from the crew were diverted out of the system in the bioreactor. In this scenario, external supplies of minerals for both the crew and the plants were needed. The amount of human nutrients remained the same as in the first scenario. About 65g / (person * day) was required to meet the plant needs. This is the maximum amount of mineral that would need to be transported to the system. Because none of the supplemental human nutrient minerals were deposited in the nutrient solution, no toxic nutrient concentrations built up in the nutrient solution.

The last scenario, partial recovery of minerals in the bioreactor, is the most realistic scenario of the three. The more soluble nutrients are more likely to disassociate from the biomass, and have larger recovery rates. Using the recovery rates in Table 5, crew and plant external supply rates were computed (Table 6). The grind and soak procedure used by Garland (17) resulted in a 92% decrease in the mass of externally supplied plant nutrient minerals. In the simulation, potassium accounted for 85% of the decrease in the external supply of plant nutrient minerals. For a 10 person, ten year mission, this level of recovery would save the transport of 2,200kg over the life of the mission (not including packaging).

Using the results from the partial recovery scenario, about 11g/(person * day) of minerals (both crew and plant) would be needed. Full recovery of minerals in the bioreactor would reduce this external mineral supply by about half. Crew needs will still require 5.56 g/(person * day) of external mineral supply.

5. SIMULATION LIMITATIONS

The data which was used in the simulation came from a number of sources, and was not uniform in its applicability to a hydroponics growing system within a BALS. Because some of the data has significant impact on the scenario results, it is important to understand the limitations in the data set used. Incorporated in the simulation are a number of simplifying assumptions about the various processes and expected BALS missions. Many of these assumptions were made because not enough was known about the underlying chemical and biological processes. Better understanding of the biological and chemical processes, and a more complete database of mineral movement in hydroponics growth systems will result in more accurate simulation results.

Database Limitations: Human toxicity levels of the minerals in the simulation were collected from a number of references that discussed nutritional mineral levels in the human diet. Many of these levels were identified from medical cases of short exposure to a high level of a mineral. Only a few references considered long term exposure to high levels, and most of these cases dealt with exposure to heavy industrial metals such as lead. Because most of the minerals needed by plants are in the human diet at levels twice or three times the RDA, there is a need to determine if long term exposure to these elevated mineral levels present a health threat to the crew.

Mineral recovery ratios for organic matter treated in the bioreactor was incomplete. Garland (17) measured eight elements, and the recovery rates for the remainder of the minerals in the simulation were estimated based on the chemical similarity of a mineral to those measured by Garland. There was no data or knowledge available which would provide a biological perspective on recovery rates. Inedible biomass was the organic matter used by Garland. In a BALS, the organic matter will include human waste, inedible and edible plant biomass, and possibly other materials such as trash. This different composition of carbon sources may support a different range of bacteria, which may result in different mineral recovery rates.

Plant toxicity levels had a significant effect on the life of the nutrient system. Data on toxic nutrient solution concentrations of the eight minerals in the human RDA, but not essential to plant growth in hydroponics systems was not available. A first approximation of toxic levels were gleaned from references on solid waste disposal on agricultural fields, and from plant mineral nutrition texts. These approximations were then refined by ALS Breadboard Project researchers experienced in the operation of the Biomass Production Chamber. There remains a degree of uncertainty about the quantitative values for the toxic concentrations of these minerals in the nutrient solution.

Numerous references have observed that plant tissue mineral concentrations are dependent on mineral concentrations in the nutrient solution, both in plant absorption of nonessential minerals and in higher plant tissue concentrations of minerals in plants grown in nutrient solutions containing high concentrations of the minerals (for example, 13 & 18). However, there is no quantitative data on these effects. Plant absorption of nonessential minerals would remove these minerals from the nutrient solution, and lengthen the life of the solution. Higher plant tissue concentration of minerals luxuriant in the nutrient solution may have health implications in the human diet, and may affect mineral recovery in the inedible biomass.

Finally, the data on mineral composition of the edible and inedible plant biomass is not complete. Sources reporting the mineral composition of the edible plant portions emphasize minerals in the RDA while sources reporting on the mineral composition of inedible plant biomass emphasize minerals important to plant growth. Because different sources were used to gather mineral composition data for inedible and edible biomass, and for the different crops in the BIO-Plex crop mixture, the data may contain minor inconsistencies such as reporting mineral compositions of the edible portion of one wheat variety, and the mineral composition of the inedible portion of a different wheat variety. Consistency in this data, as well as the other data used in the simulation is needed.

Simulation Limitations: The biological and chemical relationships in the simulation were modeled as first order, single variable relationships. Simple relationships were used because there is insufficient quantitative data on higher order relationships in the literature. These relationships govern mineral transport through the BALS. In plant and human mineral absorption, interactions between two or more minerals and absorption mechanisms are present, but not considered in this model. The bioreactor module did not consider the effects of population dynamics between plant matter and human waste digesters, and estimated mineral recovery on chemical solubility rather than a combination of biological degradation and chemical solubility.

The mass of nutrient solution had a direct effect on the rate toxic concentrations increased, and on the useable life of the solution. The mass of water used in the simulation was based on 400kg to support 100 days of food per person. Because the amount of water has such a direct effect on the simulation results, the amount of water was programmed as a variable which can be adjusted for other hydroponics systems.

Mineral solubility in the nutrient solution is essential for plant absorption. The simulation did not determine if the minerals would remain soluble in the complex cation–anion mixture that was in the nutrient solution. Instead, the

simulation kept the plant mineral concentrations at one half Hoagland's concentration (19), and allowed the human minerals to accumulate in the nutrient solution to toxic levels. Because the minerals that were of concern (F, Na, I) are very soluble, it is likely they would stay in solution, but their effect on the solubility of the plant minerals and vice versa was not considered.

In the simulation, external mineral additions to the nutrient solution were accounted for in molecular or atomic forms rather than as part of compounds. In practice, many of the minerals are added to nutrient solutions as part of a compound that contains a nitrogen source (NO_3^- or NH^+). The simulation did not consider how these compounds would affect mineral solubility.

In most biological and chemical processes, concentrations of nutrients or feedstocks have a limiting effect on the rate of the process. In the simulation, the rates mineral absorption by plants and crew were kept constant. In the scenarios used in this report, mineral deficiencies were made up via external supplies. If this simulation were used to predict effects of mineral depletions, the concentration of remaining minerals in the crew or nutrient solution would become important.

In determining the mineral composition of the crew diet, all of the edible food was consumed by the crew. Because some waste is present in all food preparation processes, a more accurate model of the mineral supplied to the crew would include a waste stream from a food preparation unit to the bioreactor. The amount of edible food waste is highly dependent on the food preparation process. For example, a baked potato with skin has almost no waste, but production of potato flour results in a loss of about half the potato mass (20). This module was not included in this simulation because there is no standardized set of food preparations for BALS simulations, and assuming a particular set of food preparation steps may lead to results with unrealized assumptions.

Finally, the simulation does not consider consumption of minerals by the microbe community in the bioreactor. Mineral recovery from dead microbe mass depends on bioreactor sludge treatments (including incineration) prior to disposal of the residue in an external mass repository.

6. CONCLUSIONS AND RECOMMENDATIONS

The computer simulation developed in this project provided insight to the questions posed in the objectives. From the simulation results, it is apparent that humans in a BALS will not be at risk of ingesting toxic levels of minerals from the BIO-Plex mixture of crops. The results also indicated that fluorine concentrations will build to toxic levels after about 1.25 years of nutrient solution use. Expected mineral re-supply for both plants and crew was 11 grams/(person * day) using a bioreactor for resource recovery. Plant toxicity levels and resupply needs were based on incomplete databases and should be viewed as a first approximation only.

The previous section outlined areas for improvement in the simulation and associated databases. Key recommendations for the ALS Breadboard Project are to expand plant tissue mineral assays to include minerals essential in human diets, to study the effect of mineral concentrations on absorption into edible and inedible plant tissues, and to include low concentrations of potentially toxic minerals into the nutrient solution to measure the effects of these minerals on plants grown in hydroponics systems, and to measure plant uptake of nonessential minerals into plant tissues.

Additional research is needed to quantify the interaction of minerals in the mineral absorption processes in humans and plants, and in mineral recovery in bioreactor systems. Qualitative observations of mineral interactions are noted in both human and plant nutrition literature, and inclusion of the interactions into simulations such as this one is critical to gaining acceptance in mineral mass transport simulation results.

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DENSE WDM ANALYSIS AND APPLICABILITY TO NASA-KSC REQUIREMENTS

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ABSTRACT

Basic concept of Dense Wavelength Division Multiplexing (DWDM) is presented and various techniques have been analyzed. The laser optical amplifier and LED to be used as sources in such techniques are characterized and compared especially with respect to their bandwidths suitable for multiplexing range for KSC applications. The 8 channel Dicon Multiplexer /Demultiplexer with center wavelengths from 1535.04 to 1557.37 nm and inter-channel spacing of 3.2 nm has been thoroughly characterized. The DWDM technique may be particularly suitable for high speed digital video transmission of camera inputs from shuttle launch pad to launch control center (LCC).

DENSE WDM ANALYSIS AND APPLICABILITY TO NASA-KSC REQUIREMENTS

Banmali S. Rawat

1. INTRODUCTION

The advantages of optical fiber communication technology like large bandwidth, very high speed, secure communication, no EMI effects, reliability etc. are well established by now. In order to utilize the large bandwidth available in optical fibers the time division multiplexing (TDM) and frequency division multiplexing (FDM) concepts borrowed from microwave communication have been in use during early part of optical fiber communication. However due to extremely large bandwidth availability it has been found that the wavelength division multiplexing (WDM) is more appropriate for optical fiber communication. In wavelength division multiplexing (WDM) several optical signals at different wavelengths are multiplexed and transmitted simultaneously over a single optical fiber. The optical source can be laser or LED depending on the channel spacing and distance. Similarly the fiber can be single -or multi-mode for large and short distances respectively. Generally in WDM the optical signals around two wavelengths viz. 1310 nm and 1550 nm are multiplexed to increase the capacity. Recently communications industries have further increased the capacity by multiplexing very closely spaced optical wavelengths within the same window [1]. This new multiplexing technique has become popular by the name of dense wavelength division multiplexing (DWDM). The DWDM technique is being investigated for NASA- KSC requirements particularly for uncompressed digital video transmission of camera inputs from shuttle launch pad to launch control center (LCC). The main focus of this report is the analysis of DWDM techniques, comparison of laser optical amplifier and LED sources to be used and characterization of Dicon 8 channel multiplexer/demultiplexer being investigated for KSC applications.

2. BASIC CONCEPT OF DWDM AND ANALYSIS OF VARIOUS TECHNIQUES

In dense WDM , all optical carriers to be multiplexed are within the same window i.e. either 1310 nm or 1550 nm and are spaced within few nanometer or less. Generally, for long haul communication the 1550 nm window is preferred as the optical amplifier, the erbium doped fiber amplifiers (EDFA) are available at this wavelength. However for short haul optical links either of the windows can be used. A simple analogy of DWDM can be drawn with RF carriers in cable TV system as shown in Fig. 1. Similar to a WDM system, DWDM system also consists of a transmitter for electrical to optical conversion of signals, optical fiber link with amplifiers depending on the link length and optical receiver for optical to electrical conversion of signals. Due to increased number of carriers the DWDM is the highly cost effective system especially for long haul communications. It has increased flexibility and is easy to manage due to channels being within the same wavelength window. Three main types of multiplexing technique: (1) multidielectric filters (2) diffraction grating and (3) integrated waveguide couplers are in use today. Some variations of these basic types are also available in the market.
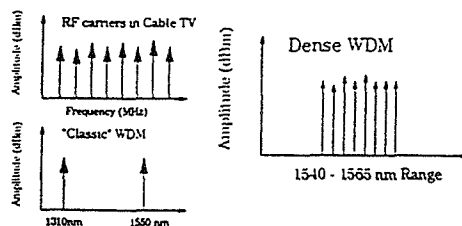
Fig. 1. Comparison of DWDM with RF carriers in cable TV

2.1 MULTIDIELECTRIC FILTER MULTIPLEXER

As the name suggests this type of multiplexer uses multidielectric filters to reflect and transmit the light beams depending on the refractive index of the material and wavelength of the beam. The filter consists of stacks of alternately high (H) and low (L) index layers on a substrate (S). The optical thickness of each layer is made in such a way that $n_e = \lambda_0/4$ for order '0' filters and $n_e = 3\lambda_0/4$ for order '1' filters [2]. The stack structure is given in a particular format as: $(H/2\ L\ H/2\ )^K$, where K is the number of times the structure is repeated. The main objective of this stacked structure is to obtain sharp edges and high reflectivity, generally greater than 99%, for the given spectral range and very high transmission for the complementary spectral range. Based on this structure, the long wavelength pass filters (LWPF) and short wavelength pass filters (SWPF) are obtained. Again these multidielectric filters or dichroic filters can be built in different ways. Two commonly used structures are shown in Figs. 2 and 3. In Fig. 2 the fibers are directly connected to the integrated interface of the dichroic filters and the horizontal fiber This is a four-channel multiplexer/demultiplexer and uses three filters of order '1'. All the filters transmit λ_1 and reflect λ_2, λ_3, λ_4 in order. In Fig. 3 the coupling between the fibers is obtained by using focusing optics [3]. The multidielectric filters are attached to two parallel planes. The light beam is separated in two spectral ranges and the desired optical wavelengths are obtained by using proper band pass filters attached to optical plane. These multidielectric filter type multiplexers/demutliplexers are particularly useful when the channel spacing is not very close and the number of channels is not very high. The insertion loss for these filters are in the range of 0.5 to 2.2 dB and the cross-talk in the range of - 15 to -40 dB depending on the wavelength and the source used.
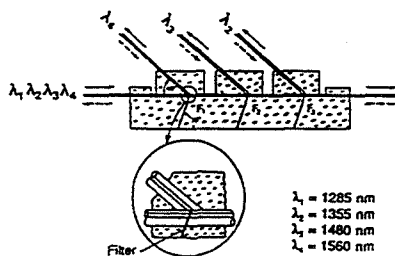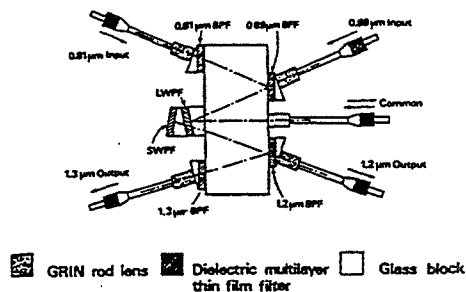

Fig. 2. Multidielectric filter with direct fiber coupling

Fig. 3. Multidielectric filter with focusing optics

2.2 DIFFRACTION GRATING MULTIPLEXER

The diffraction grating multiplexers are becoming common for the applications where the number of channels are very large. A grating consists of large number of grooves on an optical surface which can transmit or reflect light. It can diffract light in a direction related to its wavelengths as shown in Fig. 4 (a). Thus an incident beam with several wavelengths is angularly separated in different directions. Similarly several wavelengths $\lambda_1, \lambda_2, \ldots\ldots \lambda_n$ coming from different directions can be combined in the same direction. The diffraction angle depends on the groove spacing and incident angle. Light diffraction can also be obtained by a transparent and

(a) Optical grating diffraction

(b) Array of slits diffraction
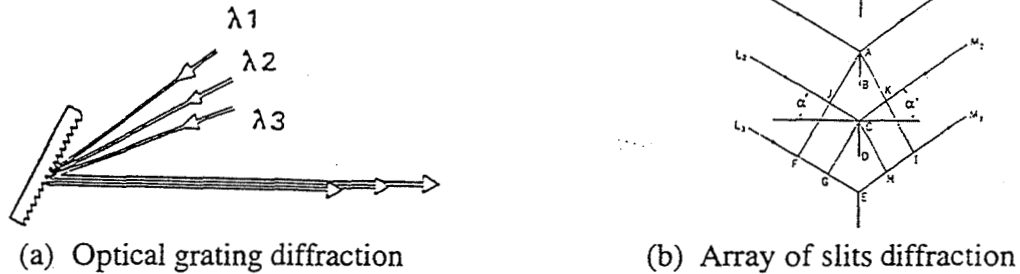
Fig. 4. Diffraction grating multiplexer

equidistant slit array shown in Fig. 4 (b). In this case the waves coming from different slits are in phase in the direction of angle α' under the condition that the path difference between successive paths $L_1 M_1$ and $L_2 M_2$ satisfies the following equation:

$$\Delta_0 = d (\sin \alpha + \sin \alpha') = k \lambda \qquad (1)$$

where k is an integer, λ is the wavelength and d is distance between the successive slits. The value of k indicates the order of diffraction. The angular dispersion with respect to any wavelength is obtained from

$$d\alpha' / d\lambda = k / d \cos \alpha' \qquad (2)$$
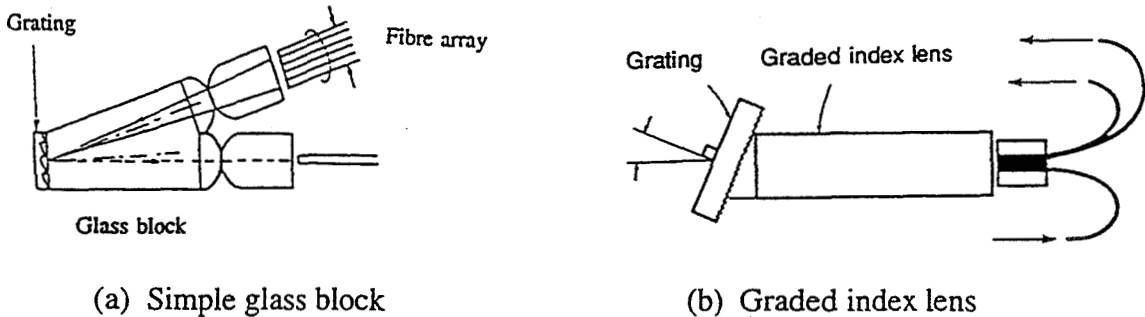

(a) Simple glass block

(b) Graded index lens

Fig.5. Multiplexers with plane grating

Actually there are several variations of diffraction and reflection grating multiplexers and demultiplexers available in the literature [4]. Two simple plane grating structures are shown in Fig. 5. These days several of the diffraction grating type multiplexers are being fabricated in integrated optics form. The phasar and arrayed waveguide grating structure is one such multiplexer available in the integrated optics form. The main feature of this mulitplexer is the distribution or routing of wavelengths in such way that the cross-talk is minimum possible. Due to large volume production potential ,the cost of this type of multiplexers is very low.

2.3 PLANAR OPTICAL WAVEGUIDE COUPLER TYPE MULTIPLEXER

The optical power can be coupled from one waveguide to another if placed very close to each other as shown in Fig. 6. [5-6]. The coupling coefficient between two single mode fibers separated by a distance h is given by

$$c\,(h) = \lambda\,u^2\,K_0\,(v\,h\,/\,a\,)\,/\,2\pi\,n_1\,a^2\,V^2\,K_1^{\,2}\,(\,v\,) \qquad (3)$$

where a is the fiber core radius, λ is the wavelength, n_1 is the core refractive index, K_0, K_1; u and v are modified Bessel functions and transverse mode propagation parameters, respectively, and V is the normalized frequency. The coupled and transmitted powers are also function of the coupling length as given by

$$P_{coupled} = \sin^2 \int_{-\infty}^{+\infty} c(z)dz \qquad (4a) ; \qquad P_{transmitted} = \cos^2 \int_{-\infty}^{+\infty} c(z)dz \qquad (4b)$$
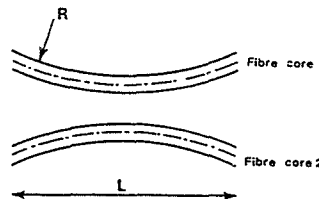

Fig. 6. Coupling between two fiber cores

For proper coupling of optical power it is necessary that the cores of the coupled fibers are very close to each other. This is generally obtained by either fusing two fibers or removing the cladding of the coupled portion of the fibers by polishing. In fused structure better coupling is achieved without affecting the strength of the fiber while in the cladding removed fiber coupling it is an important consideration. In actual practice the fibers are placed in a fused quartz slot. It is expected that the integrated waveguide coupler are going to get more attention in the near future, especially as demultiplexers due to less cross-talk . The coupling is further improved by cascading this type of couplers.

3. VARIOUS MULTIPLEXERS UNDER INVESTIGATION AT KSC

For KSC requirements three different types of multiplexers/demultiplexers are currently being investigated . These are: dielectric filters from two different sources, arrayed waveguide grating and diffraction grating type. The main focus of this study is the dielectric filter (Dicon) type

multiplexer and demultiplexer. Fig. 7 shows the block diagram of a DWDM system under investigation for digital video transmission. This system is expected to multiplex 8 channels with inter-channel separation of 3.2 nm and bit rate up to 360 Mbps. The center wavelengths of the channels are designated as: 1557.36, 1554.14, 1550.92, 1547.72, 1544.53, 1541.35, 1538.19, and 1535.04 nm. The expected characteristics of the filter are:

pass band at 0.5 dB : 1.0 nm MIN and 1.5 nm TYPICAL
pass band ripple   : < 0.5 dB
isolation   : 28 dB TYP, 24 dB MIN (single drop)
directivity   : 60 dB MIN
insertion loss   : 1 dB for the channel # 1 and goes up to 10 dB for channel # 8
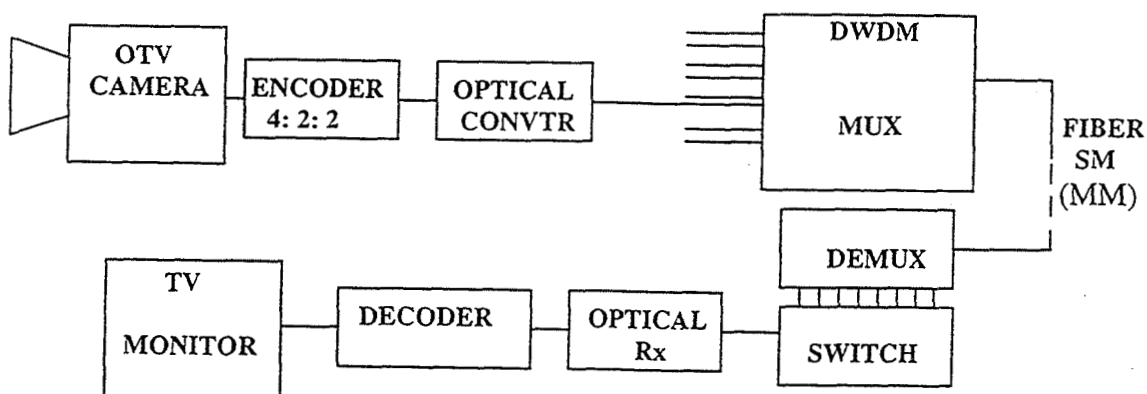
Fig. 7. 8-Channel DWDM system

3.1 OPTICAL SOURCE CHARACTERIZATION AND COMPARISON

Three optical sources viz. EDFA Pump Laser, LED and wide band white light source available in the fiber optics laboratory have been characterized for power and wavelength range of the filter multiplexer for 100, 200, 500, 1000 and 1500 nm wavelength spans. All these comparisons have been made using Anritsu optical spectrum analyzer consisting of MS 9701 optical unit and MS 9030 display unit. For laser source the bias current is fixed at 356 mA and the output power at 53 mW. For LED source the bias current is fixed at 50.1 mA and for white light source the voltage and current are fixed at 11.91 V and 8.00 A to obtain source output power of - 46. 40 dBm. The center wavelength of the spectrum analyzer display unit is fixed at 1550 nm. A simple block diagram of the measurement system is shown in Fig. 8.

3.2 DIELECTRIC MULTIPLEXER/ DEMULTIPLEXER CHARACTERIZATION

The measurements system of Fig. 8 is slightly modified for characterization of multplexer. In this case the source is connected to the common terminal of the multiplexer and the outputs are connected to the spectrum analyzer. The source in this case is the EDFA pump laser source as the output of this source is fairly high. The measurements have been conducted for multiplexer
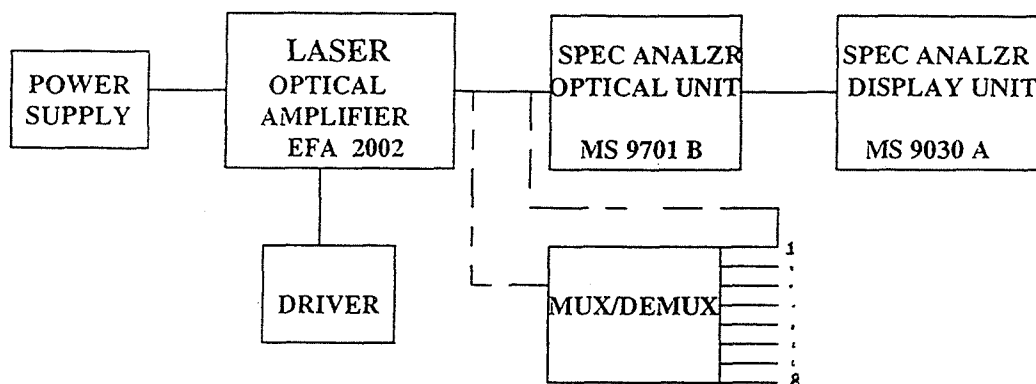
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Fig. 8. Experimental set-up for source and multiplexer characterization

and demultiplexer both. However the demultiplexer measurements have more severe constraints as the channels are to be separated with minimum possible cross-talk. The measurements are focused in four areas: comparison of each channel output to the source, insertion loss, cross-over points and center wavelengths of the channels. The output from each channel of the demultiplexer is compared with the source output to get an idea of the required output power and wavelength span to cover all the channels. The center point of the wavelength scale on the spectrum analyzer is adjusted to bring each channel output center wavelength within well measurable and visible range of the screen. The center wavelength of the screen is set at 1550 nm or very close to it. Most of these experiments have been conducted using LED also which has smoother output compared to laser source but lower power. The center wavelengths have been measured on the basis of 3 dB bandwidth where most of the channel bandwidth is covered.

4. RESULTS AND DISCUSSION

The output power and wavelength characteristics of EDFA pump laser (EFA 2002), LED (MRV-MRED 145005 M) and white light source with external fan are shown in Fig. 9 . These characteristics are measured for 500 nm span with 1550 nm display screen center wavelength as the bandwidth of LED and white light source are very large compared to laser source. Though the measurements are done from 100 nm to 1500 nm span but only the representative data are included in this report due to page limitation. But this certainly provides good idea about the performance of these sources. It is evident from Fig. 9a for this particular laser source that the output is not smooth in this wavelength range and has two peaks separated by 55.56 nm. It means in this particular wavelength range this source may not provide correct measurements for demultiplexer characterization. The main peak power is - 1.2 dBm and 3- dB BW is not the true laser source bandwidth. For the LED characteristic in Fig. 9b, the peak power is - 35.25 dBm with 3- dB BW as 75 nm. It means the power is low and the bandwidth is quite large, indicating that it is not a suitable source for such a narrow band demultiplexer channels. Fig. 9c is the power wavelength characteristic of a white source where the power is lost in the noise which is
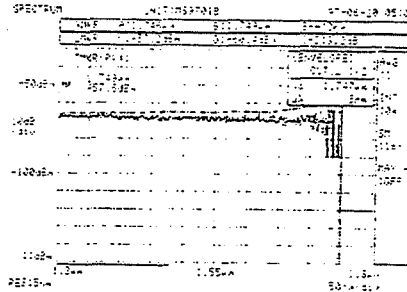
-57.6 dBm. It is also noticed that the characteristic of LED is smoother compared to laser for the entire span from 100 nm to 1500 nm.
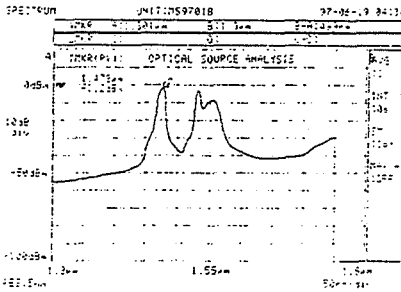
(a) Laser source
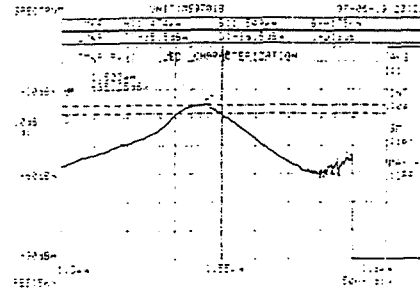
(b) LED

(c) White light source

Fig. 9. Power and wavelength characteristics of optical sources

Table 1 shows the comparison of source and demultiplexer output and 3-dB bandwidths for all 8 channels. As expected the LED output power is quite low compared to laser source but the 3-dB bandwidth for all the channels is very close to 5 nm. The peak powers for all the channels with LED as source are within close range but there is substantial variation with laser source. This is because the laser output in this range is not smooth and has two distinct peaks. This is evident

Table 1- Comparison of source and demultiplexer output   .

CH #	LASER			LED		
	source peak power, dBm	channel peak power dBm	3-dB BW nm	source peak power, dBm	channel peak power, dBm	3-dB BW nm
1	5.250	-4.000	5.10	-37.375	-41.125	5.00
2	5.250	-5.750	4.90	-37.375	-43.500	5.12
3	5.250	-5.125	5.10	-37.375	-44.375	5.00
4	5.250	-7.250	4.80	-35.125	-43.375	4.80
5	5.250	-10.000	4.90	-35.125	-42.375	4.92
6	5.250	-14.000	5.10	-35.125	-46.175	4.96
7	5.250	-13.000	5.20	-33.250	-46.250	5.08
8	5.250	- 5.250	5.20	-33.250	-46.000	5.04

from channel 8 output which is quite high compared to channel 7 as it falls under higher peak of the laser source. A representative comparison of channel 2 demultiplexer outputs for laser and LED sources is shown in Fig. 10.

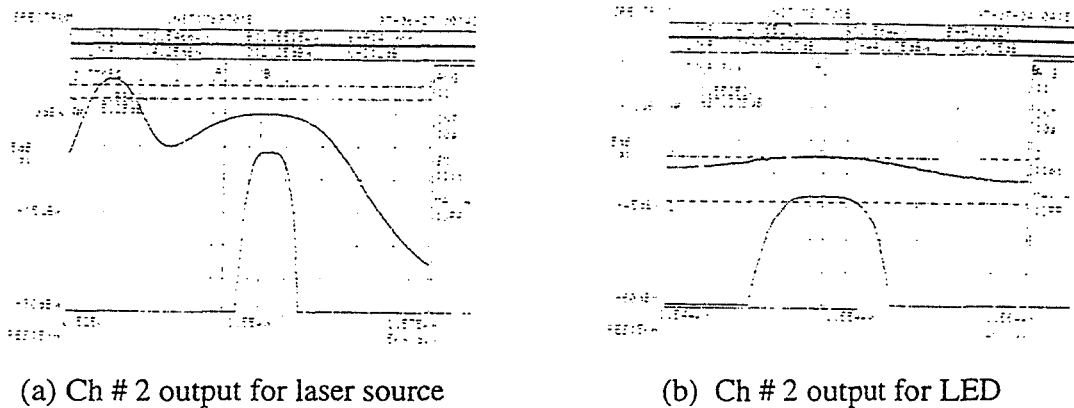(a) Ch # 2 output for laser source   (b) Ch # 2 output for LED

Fig. 10. Comparison of source and demultiplexer outputs for channel 2

Some other important characteristics of the demultiplexer like insertion loss, cross-over points and channel center wavelengths (λc)are presented in Table 2. It is to be noted that the cross-over points have been determined for LED only because it has a smoother output characteristic compared to laser in this wavelength range. However every channel output is compared with channel 1 output in the case of laser source. The insertion loss for channel 1 and 2 seems to be

Table 2- Insertion loss, cross-over points and center wavelengths for demultiplexer

CH #	LASER			LED		
	insertion loss, dB	cross-over point, ch#1, dB	λ_c nm	insertion loss, dB	cross-over point, dB	λ_c nm
1 (1-2)	2.750	-	1555.93	2.500	2.875	1555.78
2 (2-3)	5.375	2.000	1552.66	4.000	1.125	1552.72
3 (3-4)	4.750	7.375	1549.38	7.000	2.875	1549.38
4 (4-5)	5.750	> 25.000	1546.21	8.375	2.000	1546.26
5 (5-6)	7.250	> 25.000	1543.10	5.125	1.625	1542.86
6 (6-7)	9.250	> 25.000	1539.82	4.125	1.500	1539.72
7 (7-8)	10.875	> 25.000	1536.39	9.250	1.125	1536.62
8 (8-1)	9.750	> 25.000	1532.90	9.000	>30.000	1533.04

higher. The main reason is the correct determination of center wavelengths. The manufacturer's center wavelength is determined at 0.5 dB point which is not possible with the laser and LED sources considered in the experiment due to high ripples in this region. In order to avoid this ripple problem , the center wavelengths are determined at 3.00 dB point. This shows slight

variation in the values which may be due to some error with the spectrum analyzer also. However the channel spacing is very close to desired value of 3.2 nm. The cross-over points related to inter-channel cross-talk , seem to be very close suggesting that some other method of measurement is necessary.

5. CONCLUSION

Basic concept of DWDM and analysis of various techniques has been presented in a simple manner. The laser optical amplifier, LED and white light source have been characterized to determine their suitability for multiplexer/demultiplexer characterization. Dicon 8 channel demultiplexer has been characterized which is going to be very helpful for complete system characterization with very narrow band laser sources. For improved system performance, it is necessary to investigate the temperature and humidity effects, loss analysis of each channel, non-linearity effects and polarization effects (if any). It is also recommended that DWDM technique should be investigated for entire communication network of the Kennedy Space Center.

ACKNOWLEDGEMENTS

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Integrating Task-Based Evaluation into the CLCS Design Process

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1.0   Introduction

1.1 Introduction to CLCS

The CLCS project is a significant attempt by KSC to fundamentally reengineer the way it does business, specifically the business of launching orbiters in the Space Shuttle program. The CLCS project will improve every facet of launch processing, including the facility layouts, the hardware, and software used by system engineers, support personnel and test conductors, and others. The philosophy of CLCS conforms with NASA's overall objective to do things better, faster, cheaper and safer.

The current launch processing system (LPS) has 12 sets of equipment in 8 control rooms at 3 locations, requires 77,600 sq. ft of floor space and is operated 24 hours per day, 5-7 days per week. It is built on custom hardware and software and about 25% of the components are no longer supported by vendors. Operations and maintenance (O&M) costs are currently at $50 million per year and rising. Training is increasingly difficult because of the outdated systems. The CLCS will be a state-of-the-art replacement for LPS with a large percentage of commercial off-the-shelf (COTS) products. O&M costs, paper documentation, and personnel requirements should be reduced 50% from current levels. CLCS should provide the building blocks for potential shuttle upgrades and future orbiter technology.

The project is organized functionally, with separate divisions for system software, application software, subsystem engineering (hardware), and system integration. For issues which span multiple division content, integrated teams have been created. Chartered panels have been assembled to deal with strategic issues in the areas of software and hardware architecture and fundamental design modifications. As the project nears the end of its first year, the organization is still evolving and the final structure has not yet been determined. The maturation process should continue throughout the project, although at a progressively moderating rate as the addition of personnel slows. This evolution has created unique challenges for the design process within CLCS because of midcourse changes in development processes, personnel, and requirements.

The project combines personnel from NASA, Lockheed Martin and United Space Alliance (USA). The allocation of responsibility commingles staff from each organization with the goal of maximizing the utilization of individual talents as well as streamlining the eventual transition from a NASA design and development project to a functioning USA operation. This organization also creates challenges for CLCS because of slightly discrepant

objectives, backgrounds and procedures among the groups, however the diverse backgrounds of each individual also creates many advantages.

1.3 Objectives of this report

This report will describe the integration of task-based evaluation (TBE) into the design process at CLCS. Two projects will be used to highlight this integration, the design of the console enclosure and the development of facility layouts. Both of these projects are nearing the stage at which TBE can be initiated. The specific benefits of TBE for these projects and for NASA projects in general will be discussed.

2.0 The CLCS Design Process

2.1 Interaction with users

CLCS has recognized the importance of including input from users from each system engineering group in the design process. The structure for this inclusion is the user liaison committee, a group of system engineering personnel composed of representatives from each user category. The user liaison committee is responsible for sending information both downstream from CLCS to the users and upstream from the users back to CLCS. Specifically, the lead of the user liaison committee is responsible for bringing relevant issues from CLCS to the attention of critical members of the committee. These members are responsible for disseminating this information among their user group. Then, the user groups convey their input back to CLCS through the user liaison committee. The creation of this committee is an effective way to organize the user contributions and feedback in terms of requirements definition, project operations and other important issues. The use of independent channels would create logistical problems in managing the information flow and would be much more difficult to manage. The effectiveness of the user liaison committee depends on its ability to control information in both directions and channel it to the right contact personnel.

2.2 Design Panels

The current design process revolves around a series of design panel meetings. The first design panel meeting establishes the requirements of each design thread. This meeting is attended by relevant members of CLCS, the user community, and other interested parties. Requirements can be derived from the needs of user groups, system level specifications and the concept of operations. The second design panel meeting allows the CLCS design team to present an initial design in order to elicit feedback on the appropriateness of the design and any consequences for other design threads. The design panel verifies that all requirements have been considered. The third design panel meeting is a presentation of a detailed design for final approval of CLCS and the users. Small issues may still need to be addressed at this point, but major issues should be resolved. This process is currently being modified, and the final structure has not been determined. The basic steps will remain the same, but will likely be consolidated into two panel meetings.

2.3 Review Panels

In order to deal with design issues that cannot be resolved at the design panel, an Engineering Review Panel (ERP) has been created as a higher court. The ERP is composed of CLCS personnel who have detailed knowledge of the implications of design decisions. The panel insures that designs fit within the strategic needs of CLCS. Similar panels have been created to deal with software architecture issues and hardware architecture issues.

2.4 Task-Based Evaluation

TBE is a process that focuses design improvements on those aspects that truly affect task performance. The premise is that unless a design is tested under the actual conditions of its use, unpredictable emergent properties may decrease the effectiveness of a design. It depends on at least five main factors:

1. The environment of use must be accurately simulated. The physical environment such as lighting and sound and the mental environment such as the time pressure under which users are working must be considered.

2. The activities performed by the users must be accurately simulated. These activities should include a sample of all tasks that the users perform. This will insure that the activities that would have caused performance problems are identified and modified. It is often difficult to predict which activities will fit into this category.

3. A sample of actual users should be tested. The users should represent the range of knowledge, experience and ability of the set of users for which the design is being developed. If users at only one extreme of these ranges are used (such as only experienced users), the design may not be appropriate for the rest of the user group.

4. The critical parameters that define acceptable task performance should be used to evaluate the designs. Some examples of these parameters are performance speed, number of errors, and procedural efficiency. Many studies have shown that the designs that users prefer are not always those on which they perform best. Evaluating designs using critical performance parameters insures that the design maximizes performance in a way that is best for the system.

5. Valid statistical techniques must be used to evaluate the results of the test. Using non-significant differences between user performance to drive design can be a significant waste of resources and may result in a non-optimal design.

Task based evaluation can be incorporated into the existing design process for relevant design threads. After user requirements have been identified and initial design concepts have been generated, these designs can be tested using TBE. TBE can be used to insure that the performance level requirements have been met and to identify any additional requirements that were originally missed.

3.0   Consoles

3.1 Purpose

Three consoles are being developed to support CLCS operation. A systems engineering (SE) console with command and control (C&C) capability and access to an on-line business information network (BIN) and supporting documentation will be developed as the primary workstation for launch engineers. A test conductor (TC) console with limited C&C capability and BIN access will be developed for test conductors to supervise and direct launch operations. A support module (SM) console with as yet undetermined C&C capability and BIN access will be developed for support personnel to assist systems engineers with their launch responsibilities. These consoles will be placed in clusters to promote the collaboration of user groups within each facility. Clusters will be composed of varying numbers of consoles depending on the needs of the system engineering groups. One goal of CLCS is to generate a set of universal designs so that all consoles of one type are standardized. In this way, a user can sit down at any console to perform his/her job.

3.2 Requirements

Assessment of user requirements for the three consoles has been a very complicated process because of the variability in the users' needs and has been a challenge for the CLCS project. The channel for requirements solicitation has been directed through the user liaison group. Additional requirements were discovered during demonstrations of console prototypes to hundreds of individual users via a conceptual survey. The inventory of user requirements will be continually updated until the final delivery of the console design.

3.2.1 *SE Console*

The requirements can be separated into two categories: features that are necessary for acceptable functioning of the console and features that are desirable for user preference but may not add to productivity. The basic systems that must be incorporated in the SE console include two C&C monitors and CPUs, two BIN monitors and CPUs, legacy equipment including an OIS-D communication panel and OTV controls and monitors, a hardwired safing panel and a telephone. The current programmable function panels (PFP) may be included as is, redesigned, or incorporated into the new C&C software. Storage space is an important consideration because of current paper documentation needs, although an objective of CLCS is to eventually reduce the dependence on paper documentation.

Ergonomic considerations are also essential for productive and safe operation of the console. Ergonomic considerations include the height and depth of the worksurface, the height, depth and angle of the monitors, reach distances to the legacy equipment, input device selection and function, and accessibility issues for compliance with the Americans with Disabilities Act (ADA). Task lighting to maximize visibility of paper documentation and to reduce screen glare is also necessary. Color schemes for the console and surrounding environment, shape, the curve of the console clusters and other personal variables will also be considered.

3.2.2 *TC Console*

For the TC console, the same ergonomic and personal factors must be considered. The equipment requirements are somewhat different however. Two monitors and CPUs will be housed at the TC console, although the distribution between C&C and BIN is still to be determined. A rack of legacy equipment is also required. Housing for two telephones are needed somewhere at the console. Storage space for several binders and other paper documentation is also required.

3.2.3 *SM Console*

The SM console requires space for two monitors and CPUs, the allocation still to be determined. Of the legacy equipment, only the OIS-D and power units are required. One telephone is also needed. The same ergonomic and personal criteria must be included. Sufficient desk and storage space is a critical requirement for the initial implementation.

2.3 Console Design Process - Existing Milestones

The console design is following a three stage process. Two stages have been completed. The first stage was the creation of a set of two preliminary design concepts to identify and elaborate user needs. These basic design concepts were created using initial requirements derived informally from the user liaison group. These design concepts were created as demonstration models in the LCC-X (the bubble of Firing Room 2). A conceptual survey was conducted on the two design concepts using a large group of users who were given a demonstration and explanation of the designs and were provided with an opportunity to view prototype displays within the design concepts. This experience lasted up to two hours. As part of the conceptual survey, users also evaluated peripheral aspects of the console system such as chairs and color schemes. The results of this survey were used to drive the second design stage. Additional requirements that were identified from users in the conceptual survey and ergonomic general practices were used in the creation of a final set of requirements. These requirements were provided to a pair of console vendors to construct prototype console designs. In addition, one in-house prototype will be constructed. Two examples of these prototype designs are depicted in Figure 1.

2.4 Console Design Process - Task Based Evaluation

The third stage of the console design process will be a formal task-based evaluation (TBE) of the console prototypes. This TBE will be conducted using a rigorous human factors methodology that was developed for CLCS. The results of the TBE will be used to drive the final stage of the design process, specifying the final design that will be provided to the console vendors for full-scale production.

A general model for TBE was created specifically to fit within NASA's procedural environment. This effort can be used for future design activities. The model focuses on the framework for implementing TBE and includes the selection of users/subjects, the evaluation environment, test preparation, test procedures, performance criteria, and statistical concerns in the evaluation of results.
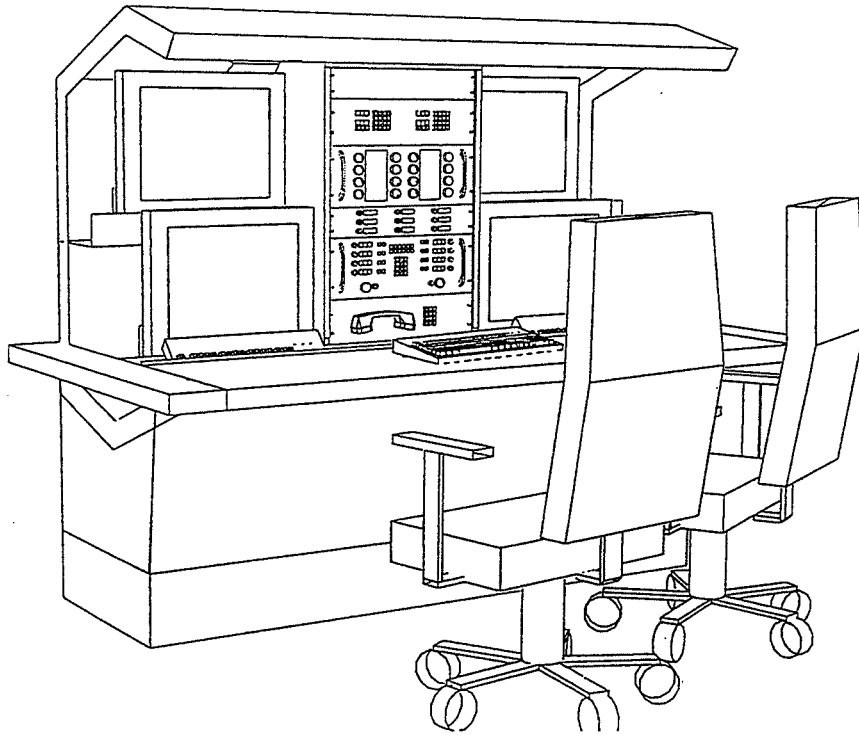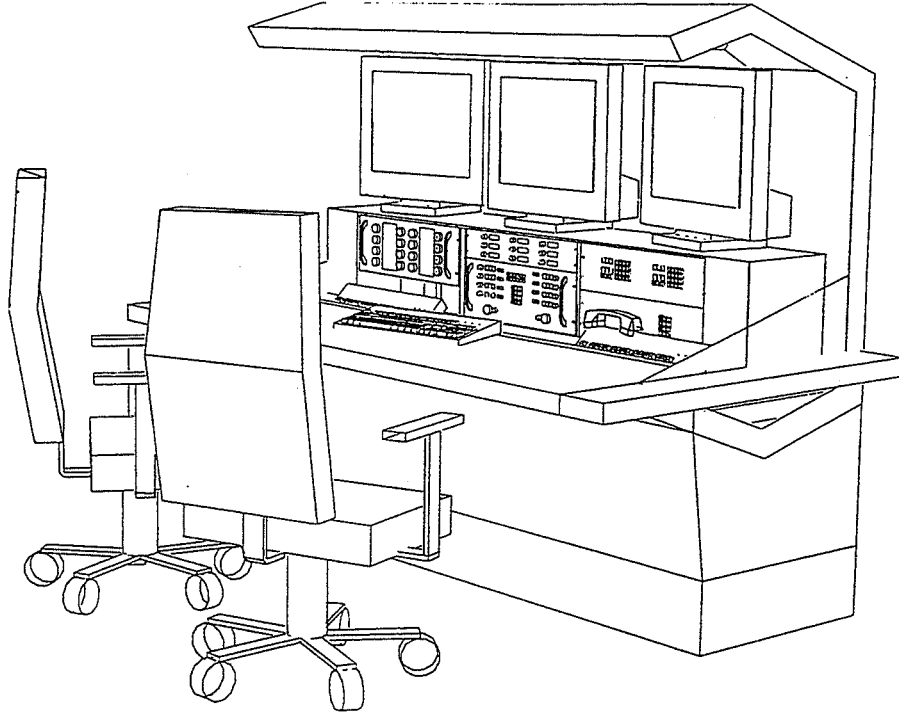
Figure 1. SE Console Design Concepts

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The first step in the TBE process is to develop a procedure which is representative of all user activities. Because of the diversity of users in launch processing, four separate procedures are under development, corresponding to user groups dealing with fluids, electrical systems, data processing and ground systems. Users from each of these groups are being interviewed to investigate all of the details of these users' activities from a console-centered perspective. These interviews concentrate on the users' interactions with data display, data entry, legacy equipment use, telephone needs, hardcopy documentation and peripheral systems around the launch facility such as printers. The goal of the interviews is to develop common procedures which incorporate the activities of each user within the user group. Once the interviews are complete, the data will be aggregated into a set of four procedures modeled on the Operations and Maintenance Instructions (OMI) that are the basis for existing user activities. Representative users will perform this 'test OMI' for approximately two hours on one of three prototype consoles. The 'test OMI' will include situations where users work alone, in pairs and in large groups to represent real conditions. The results will be used to select the attributes of these prototype consoles which best support the users in their tasks. A final console design will be specified using these results.

2.6 Console Design Process - Long Term Evaluation

After the consoles have been installed, there are long term evaluations that can be used to improve the console through periodic incremental changes in the design. These evaluations involve measuring the actual performance of users on the critical performance criteria during use of the installed consoles. Any deficiencies in performance that can be linked to specific design features of the console may be eliminated by tweaking the console layout. Also, cumulative postural discomfort, which may not appear during the TBE but may still affect performance and user safety in the long term, can be alleviated. In order for this to be feasible, the original console design must include some degree of adjustability. The cost effectiveness of these adjustments can be determined as problems are identified.

4.0   Layouts

4.1 Purpose

In order to support the effective flow of personnel and information within the control and development facilities, proper facility layout is essential. CLCS is responsible for the layouts of several development environments and control rooms, including the hypergolic maintenance facility (HMF), integrated development environment (IDE), software development environment (SDE) and operations control rooms (OCR). Important criteria for these layouts include spacing between consoles within a console cluster, size and location of walkways, entrance and egress points, and the locations of common-use peripherals such as fax machines, printers and copiers. Accommodating the requirements of the Americans with Disabilities Act is also necessary.

4.2 Requirements

Each of the facilities has a unique set of requirements. These include the number of each console type which must be included in the room, a set of additional equipment such as fire control, power units, and air handlers,

other computer workstations that are not console-based, Gateway and server hardware, and storage space. The requirements for each facility are at different stages of specification. Requirements for the HMF and IDE facilities are complete, whereas the firing rooms have many variables still to be determined. OCR-1 will require forty-one SE console positions, about half as many SM console positions and eighteen TC console positions. The layout is still pending the final footprint of each console type. There are also some significant decisions to be made, such as the potential expansion of the test conductor and systems engineering areas. These requirements will be driven by input from upper management, user groups and the current room layout.

4.3 Layout Design Process - Existing Milestones

Design of the layouts for the control rooms and development environments has proceeded in a highly iterative way. As requirements are determined, new layout concepts are developed. However, these concepts are initially limited because key parameters have not been set, such as the overall footprint of the console, the number of console positions needed for each control room, and the number of consoles needed in each cluster. As more requirements are specified, layout concepts are more fully developed. These concepts must remain flexible at first because of future changes in requirements. There are often parallel efforts to develop layout concepts to maximize the variety of potential solutions. Currently, there are 90% complete layouts for the IDE and HMF, and preliminary designs for OCR-1 (see Figure 2).

4.4 Layout Design Process - Proposed Future Steps

The facilities are being designed using basic layout techniques to optimize flow and provide for sufficient space for each component. Due to the high costs of construction, task-based evaluation is not feasible for testing the layout concepts. Long term evaluation, however, can be used to drive future incremental changes. As with the console design, this evaluation measures the actual performance of users on critical performance criteria during use of the facilities. Any deficiencies in performance that can be linked to specific aspects of the facility design may be eliminated by adjusting the layout. Aspects such as information flow, walking distances, and aisle space can be evaluated. Data collection techniques such as empirical relationship diagrams and movement flow analysis can identify inefficiencies. The cost effectiveness of any resulting adjustments can be determined as problems are identified.

5.0 Status Summary

5.1 Completed Tasks

- *Console Design*

    Evolution of the console has made significant progress. The LCC-X survey identified many user-defined needs and preferences. Ergonomic evaluation of design alternatives identified several more. These requirements have been included in the new prototypes which are currently being constructed by console vendors.

Preliminary Integrated Development Environment Layout
6/11/97
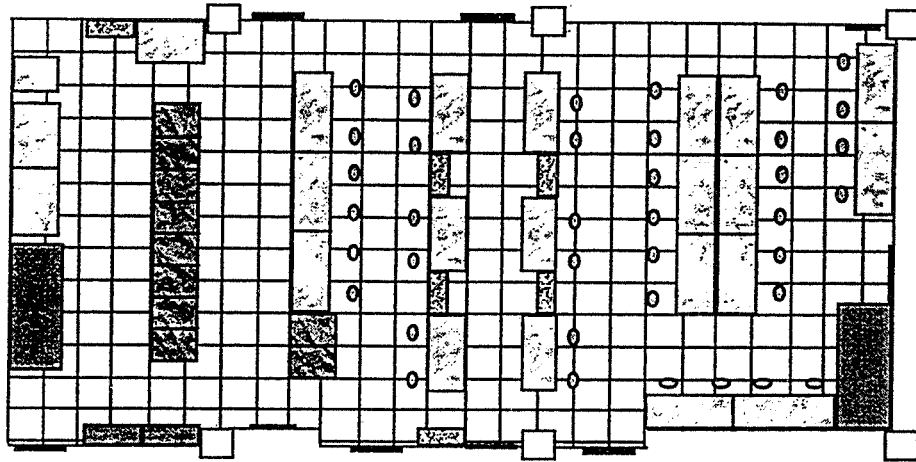
KEY	☐ Desk	⊞ Air Handler	⊠ Equipment Rack
	⊞ Bookcase	☉ Chair	■ Door
	⊞ Storage Cabinet	▣ Existing Panel	☐ Column

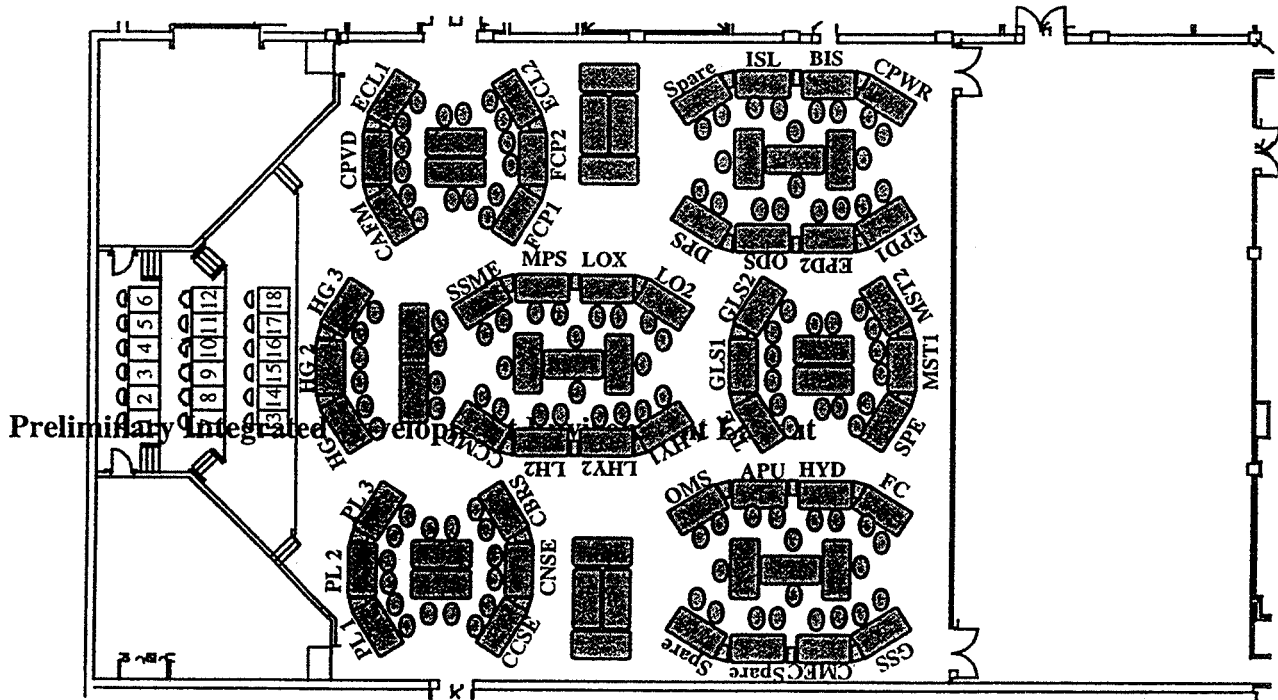**Preliminary Operations Control Room - 1 Layout**
7/10/97

Figure 2. Preliminary Layouts of IDE and OCR-1 Facilities

- *Layout Design*

    Layouts for the HMF and IDE have been accepted at the 90% level. Concepts for the layout of OCR-1 have met with general approval from the user community. Initial layouts for the 60% approval are currently under development. These layouts will be revised to conform with future requirements as they arise.

5.2 Future Tasks

- *Task Based Evaluation for SE consoles*

    TBE for specifying the final SE console design is under development. The evaluation will be conducted in September, 1997. Final specification will be complete by November, 1997.

- *Long Term Evaluation of consoles*

    A general process for implementing long term evaluation of the consoles is under consideration. If implemented, this evaluation will span the entire duration of the CLCS project.

- *Layout Evaluation Methodology*

    An evaluation methodology for assessing the effectiveness of facility layouts from a work flow perspective is currently under development. This methodology can be used to measure and evaluate the flow of personnel and information throughout a work area. This evaluation will span the entire duration of the CLCS project and beyond.

1997 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
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ANALYSIS AND CONTROL OF A PARALLEL MECHANISM
FOR INSPECTING THE ORBITER RADIATOR PANELS

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ABSTRACT

This report summarizes the author's work as a 1997 NASA/ASEE Summer Faculty Fellow at Kennedy Space Center. The project was a continuation of the author's work during the previous summer. The goal of the project was to analyze a cable-suspended robot concept for inspecting the Space Shuttle orbiter's payload bay radiator panels. Important issues considered were the inverse kinematics, inverse velocity kinematics, statics, and stiffness. The analysis was performed using programs written in Matlab.

ACKNOWLEDGMENTS

1. INTRODUCTION

The Space Shuttle orbiter's payload bay radiators are inspected before and after each mission in the Orbiter Processing Facility (OPF). These inspections are labor intensive and require access to overhead bridge crane buckets. The buckets are platforms that are attached to a telescoping tube which is attached to the overhead bridge crane trolley. Technicians ride in the buckets and visually inspect the radiator panels for defects. When defects are found, they need to be quantified and their location logged.

The inspection of the orbiter's radiators is an ideal candidate for automation. The use of robotics for the inspection of payload bay radiators will eliminate the use of the buckets, reduce coordination effort and paper work required, reduce inspection time, and increase personnel and equipment safety. Furthermore, a robotic system can prepare electronic maps of the radiator's surface and automate the generation of problem reports. Robotic concepts have been developed; however, these concepts need to be rigorously evaluated for technical feasibility.

McDonnell Douglas Aerospace has developed a series of unique tendon suspended robots under the trademark CHARLOTTE™ [1,2]. The robot translates and rotates on and about three axes by synchronously modulating the length of the suspending tendons. Charlotte™ was originally designed for attending Space Shuttle experiments and has flown on two Space Shuttle missions. Another version of Charlotte™ supports virtual reality simulations of extra-vehicular activities at the robotics laboratories of NASA's Johnson Space Center.

Last summer, the author derived mathematical models for the inverse kinematics, statics, and stiffness of a general cable-suspended robot. He also developed mathematical tools to analyze the robot. Several programs written in Matlab were developed. This summer, the programs were completely revised and made more user friendly. These programs were then used to perform a detailed analysis of the robot using data for the Space Shuttle orbiter's payload bay radiators.

2. MATHEMATICAL MODEL OF THE ROBOT

The geometry of the robot model is very simple. It is basically modeled as a box with cables attaching its eight vertices to external cable connectors. The robot's position will be denoted by the vector **x** and its orientation is given by a rotation matrix

$$Q = R_z(\phi)R_x(\theta)R_y(\psi) = \begin{bmatrix} c\phi c\psi - s\phi s\theta s\psi & -s\phi c\theta & c\phi s\psi + s\phi s\theta c\psi \\ s\phi c\psi + c\phi s\theta s\psi & c\phi c\theta & s\phi s\psi - c\phi s\theta c\psi \\ -c\theta s\psi & s\theta & c\theta c\psi \end{bmatrix}.$$

There are different formulations for describing the orientation of an object. The most famous formulation is the Euler representation. The representation used here was chosen to follow [3]. The position and orientation will be assumed to be given by the user. This section will briefly

describe the inverse kinematics, inverse velocity kinematics, the statics, and the stiffness analysis of the robot.

INVERSE KINEMATICS

The location of the robot's i-th onboard cable connector relative to the robot's coordinate frame will be denoted by $\mathbf{v}_i$. The location of this connector relative to the world coordinate frame is given by

$$\mathbf{q}_i = \mathbf{x} + Q\mathbf{v}_i.$$

The corresponding external cable connector will be denoted by $\mathbf{p}_i$. The external cable connector is a design parameter that can be chosen to maximize the robot's workspace and performance. The vector representing the i-th cable is

$$\mathbf{l}_i = \mathbf{p}_i - \mathbf{q}_i = \mathbf{p}_i - \mathbf{x} - Q\mathbf{v}_i.$$

The norm of a cable vector is equal to the length of the cable, and the direction of a cable vector is the direction of the force exerted on the robot by that cable.

The vector of cable lengths be will denoted by

$$\mathbf{l} = \begin{bmatrix} l_1 \\ l_2 \\ \vdots \\ l_8 \end{bmatrix}$$

where l_i is the length of the i-th cable. The problem of finding the cable lengths corresponding to the robot's position and orientation is known as an inverse kinematics problem and is relatively straight forward for parallel mechanism's such as Charlotte™

INVERSE VELOCITY KINEMATICS

The inverse velocity kinematics relates the linear and angular velocities of the robot to the required rate of change in the cable lengths using the manipulator Jacobian L and is given by the equation

$$\dot{\mathbf{l}} = L \begin{bmatrix} \dot{\mathbf{x}} \\ \omega \end{bmatrix}.$$

The manipulator Jacobian for Charlotte™ is an 8×6 matrix whose components are functions of the robot's position and orientation. More specifically, L is given by

$$L = \begin{bmatrix} -\hat{\mathbf{l}}_1^T & (\hat{\mathbf{l}}_1 \times Q\mathbf{v}_1)^T \\ -\hat{\mathbf{l}}_2^T & (\hat{\mathbf{l}}_2 \times Q\mathbf{v}_2)^T \\ \vdots & \vdots \\ -\hat{\mathbf{l}}_8^T & (\hat{\mathbf{l}}_8 \times Q\mathbf{v}_8)^T \end{bmatrix}$$

where $\hat{\mathbf{l}}_i = \mathbf{l}_i / \|\mathbf{l}_i\|$ is the i-th normalized cable vector. The manipulator Jacobian $L = \begin{bmatrix} L_1 & L_2 \end{bmatrix}$ naturally breaks up into two components with L_1 corresponding to the linear velocity of the robot and L_2 corresponding to the rotational velocity.

STATICS

The statics is very related to the inverse velocity kinematics. The force and moment on the robot due to the cable tensions is

$$\begin{bmatrix} \mathbf{f} \\ \tau \end{bmatrix} = L^T \mathbf{F} .$$

For static equilibrium to be achieved, the cable tensions must cancel out the force and moment on the robot due to gravity. This is given by the equation

$$\begin{bmatrix} \mathbf{f}_g \\ \tau_g \end{bmatrix} + L^T \mathbf{F} = \mathbf{0} .$$

Note that because cables are being used, $\mathbf{F}$ must have nonnegative components. When no nonnegative vector $\mathbf{F}$ satisfying the statics equation exists, the configuration cannot be held in static equilibrium.

The set of equality and inequality constraints corresponding to the statics of Charlotte™ is similar to what is found in Linear Programming. Using the some of the fundamental results of Linear Programming, one can determine if a feasible tension vector exists for a given robot configuration. One can also use the left null space of L to determine the existence of a feasible tension vector.

STIFFNESS

The stiffness matrix K maps the change in the robot's position and orientation to the corresponding force and torque on the robot. The stiffness matrix is a symmetric positive semi-definite matrix of the form

$$K = L^T K_D L$$

where $K_D = \operatorname{diag}(k_1, k_2, \ldots, k_8)$ is a diagonal matrix whose diagonal elements equal the stiffness of the corresponding cable. The cables are assumed to be under sufficient tension to be modeled as a spring. The stiffness for the i-th cable is then given by

$$k_i = \frac{EA}{l_i}$$

where E is Young's modulus of elasticity, A is the cross sectional area of the cable, and l_i is the cable length. The stiffness matrix naturally partitions into four submatrices:

$$K = \begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix}.$$

The submatrix K_{11} relates forces exerted on the robot with the corresponding change in position while K_{22} relates torques exerted on the robot with the corresponding change in orientation. An interesting discussion of the stiffness of a cable-suspended system can be found in [4].

3. SOME RESULTS

This section presents some sample results of the analysis. Carey Cooper of the Intergraph Corporation provided data for the Space Shuttle orbiter's radiator panels. The robot was commanded to stay a distance of 18 inches from the panels and oriented so that its camera points in the direction of the surface normal of the panels.

The stiffness matrix with respect to linear translation at the center of the radiator data is

$$K_{11} = EA \begin{bmatrix} 0.7269 & -0.0002 & -0.0008 \\ -0.0002 & 0.0397 & 0.0025 \\ -0.0008 & 0.0025 & 0.0223 \end{bmatrix}.$$

The singular value decomposition of K_{11} is

$$K_{11} = USU^T$$

where

$$U = \begin{bmatrix} 1.0000 & -0.0004 & -0.0010 \\ -0.0003 & -0.9905 & 0.1378 \\ -0.0011 & -0.1378 & -0.9905 \end{bmatrix}$$

is an orthogonal matrix and $S = EA$ diag(0.7269,0.0401,0.0220) is a diagonal matrix. From the columns of U it follows that the robot is relatively stiff in the x-direction and is not very stiff in the y and z-directions as physical intuition would suggest.

The stiffness matrix with respect to rotations at the center of the radiator data is

$$K_{22} = EA \begin{bmatrix} 0.0023 & 0.0000 & 0.0000 \\ 0.0000 & 0.0164 & 0.0006 \\ 0.0000 & 0.0006 & 0.0177 \end{bmatrix}.$$

The singular value decomposition of K_{22} is

$$K_{22} = USU^T$$

where

$$U = \begin{bmatrix} 0.0007 & -0.0001 & 1.0000 \\ 0.3556 & -0.9346 & 0.0003 \\ 0.9346 & 0.3556 & -0.0006 \end{bmatrix}$$

and $S = EA \operatorname{diag}(0.0180, 0.0161, 0.0023)$. This shows that the robot is relatively stiff to rotations about the z-axis and is not very stiff to rotations about the x and y-axes. This is unfortunate as the robot's rotation about the x-axis must be carefully controlled to follow the curvature of the panels. A major difficulty with stiffness is due to the length of the cables. The orbiter's payload bay doors are 60 feet long. One option would be to break up the workspace into half; however, this would require additional external cable connections, which would be nontrivial to add to the OPF.

The minimum singular value of L_1 is $\sigma_{\min}(L_1) = 0.4750$ and the minimum singular value of L_2 is $\sigma_{\min}(L_2) = 0.1536$ m. This means that a Δx change in the robot's position results in at least a $0.4750\ \Delta x$ change in the cable lengths. A similar result holds for changes in orientations.

Figure 1 is a graph of the minimum translational stiffness of the robot during its task as a function of the x and y position of the radiator panel. It is clear from the graph that the stiffness is smaller toward the inside of the door. Figure 2 is a graph of the minimum required tensions as measured by the 2-norm of $\mathbf{F}$.
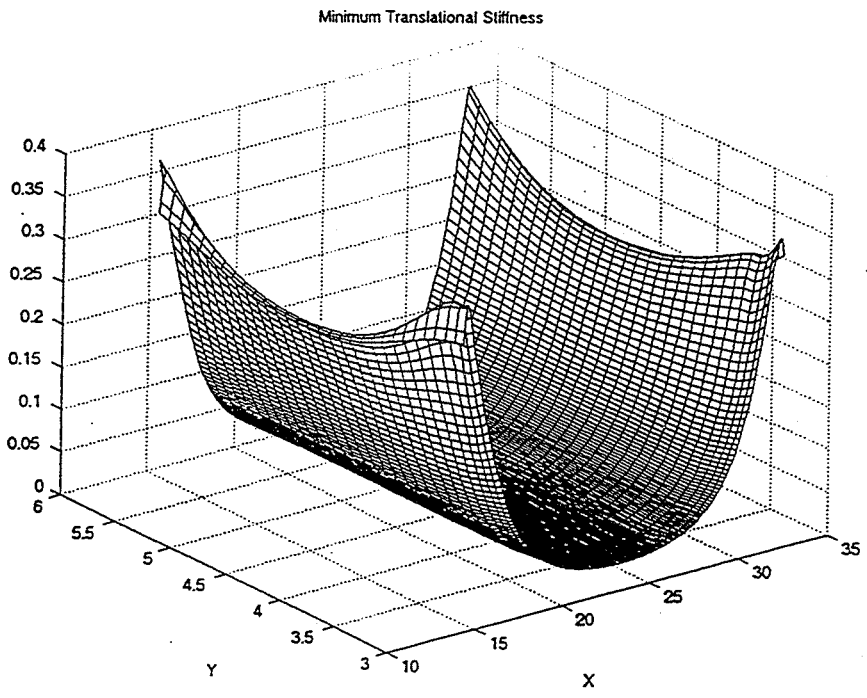
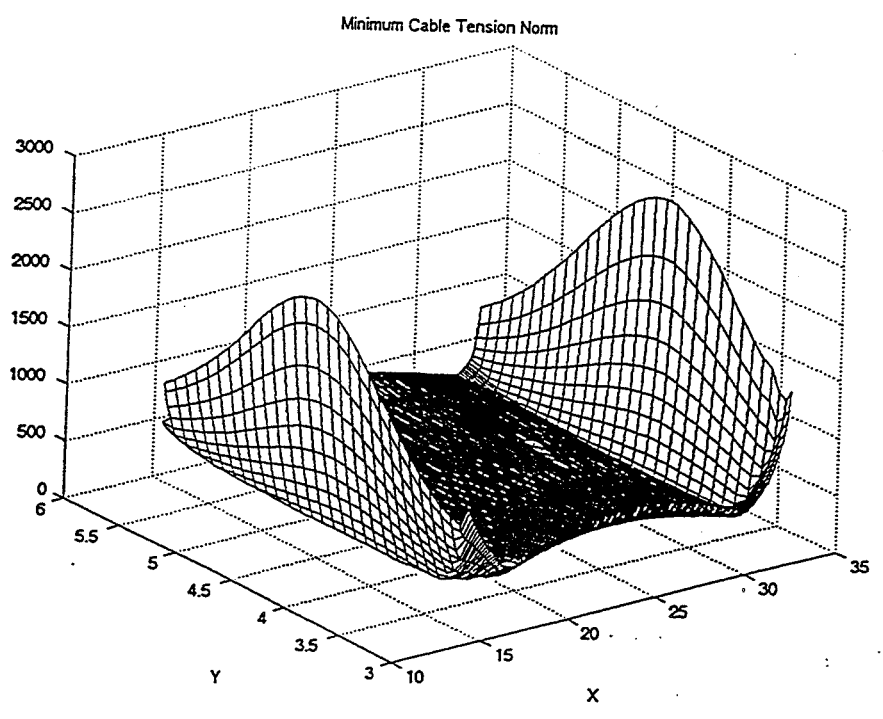Minimum Translational Stiffness

Figure 1

Minimum Cable Tension Norm

Figure 2

Some statistics concerning the task space of the robot are given in Table 1. The minimum values for $\sigma_{min}(L_1)$ and $\sigma_{min}(L_2)$ provide insight into the required resolution for controlling the cable lengths. The minimum values for $min(K_{11})$ and $min(K_{22})$ provide information on cable specifications.

Table 1

	Minimum
$\sigma_{min}(L_1)$	0.4279
$\sigma_{min}(L_2)$	0.0806 m
$min(K_{11})$	0.0180 EA N/m
$min(K_{22})$	6.3822×10^{-4} EA N

4. FAULT TOLERANCE

The vector of cable lengths determines the position and orientation of the robot. For a given set of cable lengths, the robot's position and orientation is a local minimizer of potential energy subject to the set of inequalities determined by the cable lengths. The eight cables of Charlotte™ determine eight inequalities. When a cable is removed, there is one less inequality that must be satisfied. This could result in a new minimum for the potential energy, which may cause the robot to move. If the minimum does not change the robot will stay in the same configuration in which we say the configuration is fault tolerant. Preliminary analysis indicates that the robot is relatively fault tolerant in this sense and when the robot does move to a new local minimum, most of the motion is rotation.

5. CONCLUSIONS

The goal of this project was the analysis and control of a cable-suspended robot for automated radiator inspection of the Space Shuttle orbiter. The analysis was performed using Matlab. Unfortunately, it is unlikely that this concept will be implemented due to the required cost of the project. However, a new robot concept is currently being considered, and the author will be actively involved the analysis and development of this new version of the automated radiator inspection device.

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LEAKAGE OF LIQUID NITROGEN AND GASEOUS NITROGEN

THROUGH A FLAWED PLUG IN A VACUUM HOSE

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This paper presents the results of a ten-week effort to develop a method for measuring the rate of leakage from a flawed plug in vacuum hose under room temperature and cryogenic conditions. The leaked fluid was trapped in a metal bellows vacuum hose during a prescribed time interval and subsequently expanded into a valve manifold, one of whose tubes connects to the inlet to a mass spectrometer residual gas analyzer. If one observes the resulting step change in the ion beam current for Nitrogen, one may calculate the rate of leakage of fluid into the hose. The method requires extensive calibrations (including the measurement of the volumes of the various chambers in the valuve manifold) and the paper includes a description of how these calibrations were carried out. The results show, not surprisingly, that the rate of leakage of the plug under cryogenic conditions is larger by about two orders of magnitude than the rate of leakage of the same plug in room temperature conditions.

LEAKAGE OF LIQUID NITROGEN AND GASEOUS NITROGEN THROUGH A FLAWED PLUG IN A VACUUM HOSE

John M. Russell

1. INTRODUCTION

Kennedy Space Center devotes many man-hours to leak testing. Such leak testing arises in the between-flight testing of the space shuttle orbiter and in the maintenance and upgrading of ground support equipment. Most such leak testing is done with gaseous helium at ambient temperature even if the object under test is meant to transport Oxygen or Hydrogen at cryogenic conditions. The expedient of using gaseous Helium at ambient conditions enables the use of off-the-shelf leak testing equipment and avoids the use of more hazardous test fluids. Of course, the information one gets from a Helium leak test at ambient conditons will be of limited value in the absence of some sort of correlation between the leak rate measured under the test conditions and the leak rate one would expect in service.

Considerations of the above sort led Mr. Irby Moore, (formerly of the Propellants and Gases Branch at KSC) to suggest to me a program of theoretical analysis and, possibly, experimental work in 1989. The aim was to study the general issue of liquid-gas leak rate correlations. In the intervening period, the author has done much theoretical work, a review of which will be found in his NASA/ASEE Final Report from 1996 (Reference [1]). The author devoted much of his 1995 NASA/AAEE work to the development of an experiment for testing liquid-gas leak rate correlations (Reference [2]). The present work describes an implementation of the experiment originally conceived in 1995.

Figure 1.1 provides an overview of leak-test apparatus. For the purpose of this Introduction, the only point the reader needs to notice is that the test object is the plug at the end of the vacuum hose. Figure 1.1 illustrates the plug submerged in a liquid Nitrogen bath.

In the development of the experimental plan, I have given some thought to a convenient method for generating an artificial flaw in the plug. Figure 1.2 illustrates the parts of the plug shown disassembled.
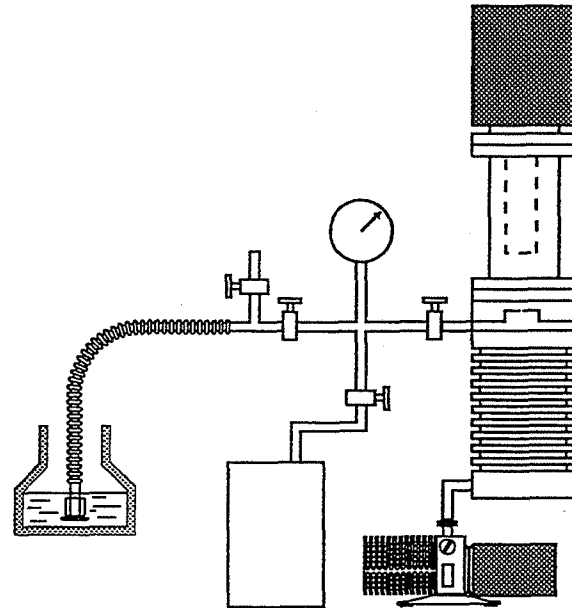

Fig. 1.1 Overview of the apparatus.

Consider a microscopic view of the filament shown in Fig. 1.2 with a line of sight parallel to the filament axis. Figure 1.3 illustrates such a view seen at two different stages of assembly. The main hypothesis here is that the nose seal (made of Teflon) does not completely fill the crevice between the filament and the spud upon which it is pressed. A leak channel (having the form illustrated by the white area in the lower panel of Fig. 1.3) results. One way to model such a leak channel is to approximate it by a *flat bottomed curvilinear triangle*, two sides of which are circular arcs (of arbitrary radius ratio) and the third side of which is a straight line. The main result of my NASA/ASEE work of Summer 1996 (Reference [1]) is a calculation of the contours of constant streamwise velocity in the fully developed laminar flow through a noncircular pipe whose cross section is such a flat bottomed curvilinear triangle.

The foregoing discussion of the history and motivation of the present project suggest three objectives,
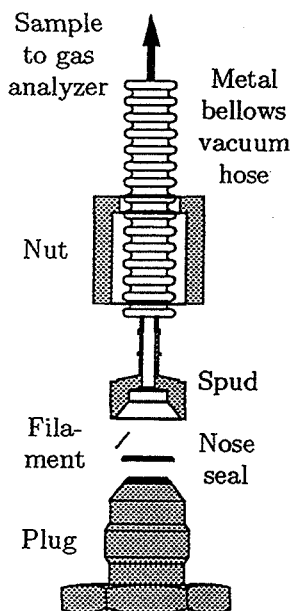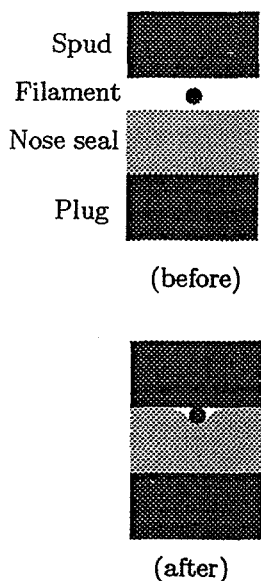
Fig. 1.2 Plug assembly

(before)

(after)

Fig. 1.3 Formation of a leak channel

to wit:

1. *To develop a method for measuring the rate of leakage of Nitgrogen into an evacuated hose through a flaw in a plug;*
2. *To carry out such tests for Nitrogen in air and in cryogenic conditions;*
3. *To compare, when possible, the predictions of the theory of capillary flow through a wire crevice with the measurements.*

Section 2 below describes the proceedure for carrying out leak tests; section 3 describes the methods for calibrating the apparatus; section 4 describes the results; and sections 5 states the one conclusion resulting from the present work.

2. PROCEDURE

Throughput. Before one can discuss any procedure for the measurement of *leak rate*, one must clarify the meaning of the term. To this end, one may state the equation of state for an ideal gas in the form

$$pV = n\mathfrak{R}T , \qquad (2.1)$$

in which p and V are the equilibrium pressure and volume of a sample of gas, T is the absolute temperature, n is the number of moles of gas in the sample, and $\mathfrak{R}$ is the universal gas constant. One may apply (2.1) to a steady stream of moving fluid, in which case one writes $\dot{n}$ for the number of moles of gas per unit time passing a given cross section and $\dot{\Delta}$ for the volumetric flux of gas passing the same cross section. The steady-state form of (2.1) is then

$$p\dot{\Delta} = \dot{n}\mathfrak{R}T . \qquad (2.2)$$

If one uses the subscripts $(.)_1$ and $(.)_2$ to denote two different cross sections of a given steady streamtube, one may write a law of conservation of molecules in the form $\dot{n}_1 = \dot{n}_2$. In view of (2.2), this conservation principle is equivalent to

$$\left(\frac{p\dot{\Delta}}{\mathfrak{R}T}\right)_1 = \left(\frac{p\dot{\Delta}}{\mathfrak{R}T}\right)_2 . \qquad (2.3)$$

If, one restricts attention to the case in which the absolute temperature T does not vary appreciably between these two cross sections, one may cancel the factor $\mathfrak{R}T$ on the two sides of (2.3) to get

$$(p\dot{\Delta})_1 = (p\dot{\Delta})_2 \equiv Q . \qquad (2.4)$$

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The notation Q, thus represents a quantity (with the dimensions of pressure times volume divided by time) which is conserved along a stream tube in isothermal steady flow (even if the individual factors p and $\dot{A}$ vary appreciably along that tube). I will refer to the quantity Q as the *throughput* throughout the rest of this paper and take the throughput of a leak to be the proper measure of the leak rate.

State of the manifold at three reference times. Figures 2.1–2.3 illustrate the state of the inlet manifold at three different times. I will refer to the four valves in these and other figures as follows: The valve that vents to room air is the *vent valve*; the valve that, when closed, obstructs flow between the hose and the cross is the *hose valve*; the valve that, when closed, obstructs flow between the cross and the Tee (the rightmost chamber, with the orifice that feeds into the high vacuum vessal) is the *QMA inlet valve* or *inlet valve* for short; finally, the valve that, when closed, obstructs flow from the cross to the low pressure port of a helium mass spectrometer leak detector is the *cleanup valve*. The arrows indicate the presence of fluid flow.

One may describe the mode of flow illustrated in Fig. 2.1 by the term *split flow mode*, since some of the fluid that enters through the leak in the plug exits through the cleanup valve and the rest exits through the orifice to the high vacuum vessal.

One may describe the mode of flow illustrated in Fig. 2.2 by the term *accumulation mode*, since the hose is slowly filling with gas through the plug leak while the rest of the manifold is effectively empty.

One may describe the mode of flow illustrated in Fig. 2.3 by the term *direct flow mode*, since a single direct path exists between the inlet leak and the orifice that discharges to the high vacuum envelope.

In the sequel I will refer to these three reference times by the names given here.

The basic identity between the leak rate and the rate of pressure rise in a vessel. Fig. 2.4 illustrates two parts of a fluid body, the first internal to a hose and the second external to it. For present purposes, the boundary of the cloud is defined by the condition that all of it is sucked into the hose. Let R_{cloud} be the region enclosed by the cloud of
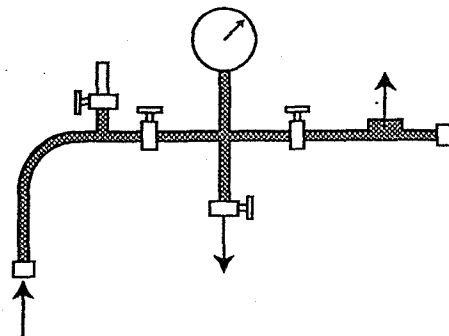

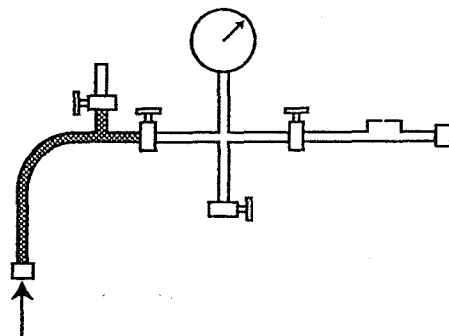**Fig. 2.1 State of the manifold at time** $t = t_s$
(starting time).

Fig. 2.2 State of the manifold at time $t = t_{jbo}$
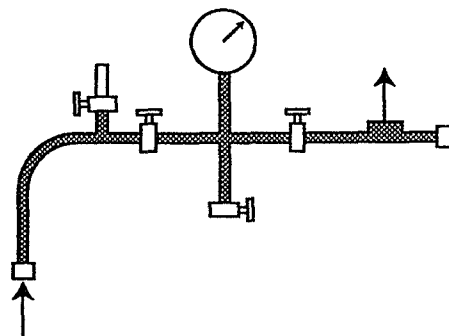**(time just before opening of the hose valve)**

Fig. 2.3 State of the manifold at time $t = t_{jao}$
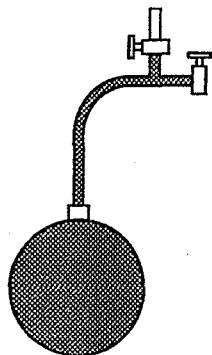**(time just after opening of the hose valve)**

Fig. 2.4 a hose and a cloud of gas
about to be sucked into it

gas. Let n denote the number of moles of gas in a sample with subscripts $(.)_{\text{cl}}$, $(.)_{\text{h}}$, and $(.)_{\text{tot}}$, for *cloud, hose,* and *total,* respectively. By conservation of molecules, we have

$$n_{\text{tot}} = n_{\text{cl}} + n_{\text{h}} . \qquad (2.5)$$

If one multiplies by $\Re T$ (in the notation of equation (2.1) above), one obtains

$$n_{\text{tot}}\Re T = n_{\text{cl}}\Re T + n_{\text{h}}\Re T . \qquad (2.6)$$

Now the left member of the above equation is independent of time (at least as long as the temperature remains fixed). One may, however, rewrite the terms in the right member by means of the equation of state of an ideal gas (*cf.* (2.1)) to obtain

$$n_{\text{tot}}\Re T = \text{const.} = p_{\text{atm}}V_{\text{cl}} + p_{\text{h}}V_{\text{h}} , \qquad (2.7)$$

in which p_{atm} is the atmospheric pressure (the pressure in the cloud, a constant), V_{cl} is the volume of the cloud (a time dependent function), p_{h} is the pressure in the hose (a time dependent function), and V_{h} is the volume of the hose (a constant). If one differentiates (2.7) with respect to time and moves all constants across the derivative sign, one obtains

$$0 = p_{\text{atm}}\frac{dV_{\text{cl}}}{dt} + \frac{dp_{\text{h}}}{dt}V_{\text{h}} . \qquad (2.8)$$

Now $V_{\text{cl}}(t)$ is a decreasing function of time. It follows that its slope, *i.e.* dV_{cl}/dt is negative. The negative of the slope, namely $-dV_{\text{cl}}/dt$, therefore

represents a positive valued quantity, which I will denote by $\dot{\Delta}_{\text{leak}}(t)$. Thus

$$\dot{\Delta}_{\text{leak}}(t) = -\frac{dV_{\text{cl}}}{dt} > 0 , \qquad (2.9)$$

and equation (2.8) is equivalent to

$$0 = -p_{\text{atm}}\dot{\Delta}_{\text{leak}}(t) + \frac{dp_{\text{h}}}{dt}V_{\text{h}} , \qquad (2.10)$$

or

$$p_{\text{atm}}\dot{\Delta}_{\text{leak}}(t) \equiv Q_{\text{leak}}(t) = \frac{dp_{\text{h}}}{dt}V_{\text{h}} , \qquad (2.11)$$

in which, of course, $Q_{\text{leak}}(t)$ is the throughput of the hose leak.

A formula for the leakage into a vacuum in terms of the pressure at two different times. Consider a leak channel whose cross sectional shape and size does not vary in the downstream direction. Let L denote the diameter of the smallest circle into which the cross section may be fit. Let ℓ denote the downstream length of the channel and let μ denote the viscosity of the leaked fluid. According to the theory of the capillary flow of a gas *cf.* equation (22) of Reference [1]), we have

$$Q_{\text{leak}}(t) = \frac{L^4}{\mu}\left(\iint\limits_{S} w \, dx \, dy\right)\frac{p_{\text{atm}}^2 - p_h^2}{2\ell} . \qquad (2.12)$$

The quantity

$$\iint\limits_{S} w \, dx \, dy \qquad (2.13)$$

represents the volumetric transport rate through the channel after expression in terms of nondimensional variables (w is a nondimensional streamwise velocity and (x, y) are nondimensional cartesian coordinates for the cross section). For the purposes of this section, it is sufficient to note that the expression (2.13) changes with changes in the cross sectional shape but not with downstream position along the channel. For a circular cross section, for example, the expression (2.13) take the value $\pi/2^7$.

Let $t = t_{\text{vac}}$ denote a time (possibly hypothetical) at which p_{h} is zero, *i.e.*

$$p_{\text{h}}(t_{\text{vac}}) = 0 . \qquad (2.14)$$

It follows from (2.12) that

$$Q_{\text{leak}}(t_{\text{vac}}) = \frac{L^4}{\mu} \left(\iint\limits_{S} w \, dx \, dy \right) \frac{p_{\text{atm}}^2}{2\ell} \ . \quad (2.15)$$

If one divides (2.12) by (2.15), one obtains, after simplification,

$$\frac{Q_{\text{leak}}(t)}{Q_{\text{leak}}(t_{\text{vac}})} = \frac{p_{\text{atm}}^2 - p_h^2}{p_{\text{atm}}^2} = 1 - \left(\frac{p_h}{p_{\text{atm}}} \right)^2 \ . \quad (2.16)$$

If one eliminates $Q_{\text{leak}}(t)$ from the left member of the above equation by means of equation (2.11), one obtains

$$\frac{dp_h}{dt} \frac{V_h}{Q_{\text{leak}}(t_{\text{vac}})} = \frac{p_{\text{atm}}^2 - p_h^2}{p_{\text{atm}}^2} = 1 - \left(\frac{p_h}{p_{\text{atm}}} \right)^2 ,$$

or

$$\frac{p_{\text{atm}} V_h}{Q_{\text{leak}}(t_{\text{vac}})} \frac{d}{dt} \left(\frac{p_h}{p_{\text{atm}}} \right) = 1 - \left(\frac{p_h}{p_{\text{atm}}} \right)^2 , \quad (2.17)$$

Let

$$\tau \equiv \frac{p_{\text{atm}} V_h}{Q_{\text{leak}}(t_{\text{vac}})} , \quad (2.18)$$

so one may write (2.17) in the more compact form

$$\frac{d}{d(t/\tau)} \left(\frac{p_h}{p_{\text{atm}}} \right) = 1 - \left(\frac{p_h}{p_{\text{atm}}} \right)^2 , \quad (2.19)$$

which has the solution

$$\frac{p_h(t)}{p_{\text{atm}}} = \tanh \left(\frac{t}{\tau} + C \right) , \quad (2.20)$$

in which C is an arbitrary constant. In view of the initial conditon (2.14), we have

$$0 = \tanh \left(\frac{t_{\text{vac}}}{\tau} + C \right) ,$$

which implies that

$$C = -\frac{t_{\text{vac}}}{\tau} . \quad (2.21)$$

Equation (2.20) thus becomes

$$\frac{p_h(t)}{p_{\text{atm}}} = \tanh \left(\frac{t - t_{\text{vac}}}{\tau} \right) . \quad (2.22)$$

Equation (2.22) indicates that the pressure in the hose is initially an increasing function of time, but eventually levels off as the hose becomes full of gas.

It follows from (2.22) that

$$\tanh^{-1} \left(\frac{p_h(t)}{p_{\text{atm}}} \right) = \frac{t - t_{\text{vac}}}{\tau} . \quad (2.23)$$

The particular cases of (2.23) corresponding to times $t = t_s$ and $t = t_{jbo}$ (as illustrated in Figs. 2.1 and 2.2) are

$$\tanh^{-1} \left(\frac{p_h(t_s)}{p_{\text{atm}}} \right) = \frac{t_s - t_{\text{vac}}}{\tau} , \quad (2.24)$$

and

$$\tanh^{-1} \left(\frac{p_h(t_{jbo})}{p_{\text{atm}}} \right) = \frac{t_{jbo} - t_{\text{vac}}}{\tau} . \quad (2.25)$$

If one subtracts (2.24) from (2.25) one obtains

$$\tanh^{-1} \left(\frac{p_h(t_{jbo})}{p_{\text{atm}}} \right) - \tanh^{-1} \left(\frac{p_h(t_s)}{p_{\text{atm}}} \right) = \frac{t_{jbo} - t_s}{\tau}$$

$$= \frac{(t_{jbo} - t_s) Q_{\text{leak}}(t_{\text{vac}})}{p_{\text{atm}} V_h} , \quad (2.26)$$

in which the last equality follows from (2.18). One obtains, upon rearrangement of the outermost equality,

$$Q_{\text{leak}}(t_{\text{vac}}) = \frac{p_{\text{atm}} V_h}{(t_{jbo} - t_s)}$$

$$\times \left[\tanh^{-1} \left(\frac{p_h(t_{jbo})}{p_{\text{atm}}} \right) - \tanh^{-1} \left(\frac{p_h(t_s)}{p_{\text{atm}}} \right) \right] .$$

$$(2.27)$$

Reexpression of the leakage formula in terms of the ion-beam current. Consider the change of state of the gas sample illustrated by the shaded regions in Figs. 2.2 and 2.3. By conservation of molecules, we have $n_{t=t_{jbo}} = n_{t=t_{jao}}$. If, as I have assumed before, the temperature is constant, one may multiply this identity by $\Re T$ to obtain

$$n_{t=t_{jbo}} \Re T = n_{t=t_{jao}} \Re T . \quad (2.28)$$

In view of the equation of state for an ideal gas (cf. (2.1)), (2.28) is equivalent to

$$p_h(t_{jao}) V_h = p_h(t_{jbo})(V_h + V_c + V_T) , \quad (2.29)$$

in which V_h, V_c, and V_T denote the volumes of the hose, the cross, and the Tee, respectively, and p_h denote pressure in the hose.

If one eliminates $p_h(t_{jbo})$ from (2.27) by means of (2.29), one obtains

$$Q_{\text{leak}}(t_{\text{vac}}) = \left[\tanh^{-1}\left(\frac{p_h(t_{jao})}{p_{\text{atm}}} \frac{V_h + V_c + V_T}{V_h} \right) \right.$$
$$\left. - \tanh^{-1}\left(\frac{p_h(t_s)}{p_{\text{atm}}} \right) \right] \times \frac{p_{\text{atm}} V_h}{(t_{jbo} - t_s)} \; . \quad (2.30)$$

In the states illustrated in Figs. 2.1 and 2.3, the gas in the hose (with pressure p_h) communicates with the gas in the Tee (with pressure p_T). In equlibrium, these two pressures must be equal. If one subtsitutes $p_h = p_T$ in (2.30) one obtains

$$Q_{\text{leak}}(t_{\text{vac}}) = \left[\tanh^{-1}\left(\frac{p_T(t_{jao})}{p_{\text{atm}}} \frac{V_h + V_c + V_T}{V_h} \right) \right.$$
$$\left. - \tanh^{-1}\left(\frac{p_T(t_s)}{p_{\text{atm}}} \right) \right] \times \frac{p_{\text{atm}} V_h}{(t_{jbo} - t_s)} \; . \quad (2.31)$$

If one assumes a linear relationship between p_T and the ion-beam current i_{N2} detected by the quadrupole mass analyzer, one concludes that

$$i_{N2}(t) = \frac{di_{N2}}{dp_T} p_T(t) \; , \quad (2.32)$$

in which $di_{N2}(t)/dp_T$—the *sensitivity factor* of the instrument—is a constant.

Equation (2.31) thus becomes

$$Q_{\text{leak}}(t_{\text{vac}}) = \left[\tanh^{-1}\left(\frac{i_{N2}(t_{jao})(V_h + V_c + V_T)}{(di_{N2}(t)/dp_T) p_{\text{atm}} V_h} \right) \right.$$
$$\left. - \tanh^{-1}\left(\frac{i_{N2}(t_s)}{(di_{N2}(t)/dp_T) p_{\text{atm}}} \right) \right] \times \frac{p_{\text{atm}} V_h}{(t_{jbo} - t_s)} \; .$$
$$(2.33)$$

All of the parameters in the right member of (2.33) are measureable. The main obstacle to applying it is the experimental determination of the various machine constants in the right member, namely

$$V_h, V_c, V_T, \frac{di_{N2}(t)}{dp_T} \; . \quad (2.34)$$

Section 3 below is devoted to a discussion of experimental methods for the determination of these constants (and a report of the values I obtained for them for the apparatus I used this summer). With this proviso, equation (2.33) is suitable for the measurement of the throughput of a hose leak as it stands. Be that as it may, one may simplify (2.33) under realistic conditions as follows.

Note that

$$\tanh\left(\frac{t - t_{\text{vac}}}{\tau} \right) \approx \frac{t - t_{\text{vac}}}{\tau} \quad (2.35)$$

whenever $|(t - t_{\text{vac}})/\tau| \ll 1$. If, in (2.18), one puts $V_h = 1.8$ (in)^3, and

$$Q_{\text{leak}} = 1 \times (10)^{-4} \text{ Atm·(cm)}^3/\text{sec} \; ,$$

one obtains $\tau = 82.4$ hours. Thus, if $t_{jao} - t_s$ is on the order of minutes, then the inequality $|(t - t_{\text{vac}})/\tau| \ll 1$ holds to a good approximation indeed and the operators $\tanh(.)$ and $\tanh^{-1}(.)$ in the foregoing equations reduce to the identity operator (*i.e.* equivalent to multiplication by the number one).

With the approximation (2.35) and an analogous approximation for its inverse, equation (2.33) reduces to

$$Q_{\text{leak}}(t_{\text{vac}}) = \left(\frac{i_{N2}(t_{jao})(V_h + V_c + V_T)}{(di_{N2}(t)/dp_T) p_{\text{atm}} V_h} \right.$$
$$\left. - \frac{i_{N2}(t_s)}{(di_{N2}(t)/dp_T) p_{\text{atm}}} \right) \times \frac{p_{\text{atm}} V_h}{(t_{jbo} - t_s)} \; ,$$
$$(2.36)$$

or

$$Q_{\text{leak}}(t_{\text{vac}}) = \left(i_{N2}(t_{jao}) \frac{V_h + V_c + V_T}{V_h} - i_{N2}(t_s) \right)$$
$$\times \frac{V_h}{(di_{N2}(t)/dp_T)(t_{jbo} - t_s)} \; . \quad (2.37)$$

Summary of leak measurement procedure (direct-flow mode). The procedure for determining $Q_{\text{leak}}(t_{\text{vac}})$ belonging to a given hose leak is thus as follows:

1. Determine, by suitable calibrations, the values of the machine constants listed in (2.34) above;

2. For a given hose leak, set up a steady split flow as illustrated in Fig. 2.1 and record the associated ion-beam current $i_{N2}(t_s)$;

3. Close the hose valve (the one at the nine o'clock position relative to the cross in Figs 2.1–2.3) and start a stopwatch at the same time;

4. Let the $i_{N2}(t)$ signal decline to the noise level for the gas analyzer and close the cleanup valve (the one at the six o'clock position relative to the cross in Figs 2.1–2.3);

5. Briefly open the hose valve and reclose it while simultaneously stopping the stopwatch. The $i_{N2}(t)$ signal will undergo a step rise followed by a gradual decline (as fluid drains out of the Tee into the high vacuum envelope). Identify the maximum value of i_{N2} as $i_{N2}(t_{jao})$.

6. Calculate $Q_{leak}(t_{vac})$ from equation (2.37).

Leak measurement in the split-flow mode. In the split-flow mode, the throughput from the hose leak must equal the sum of the throughputs through the cleanup valve and the internal orifice in the Tee, i.e.

$$Q_{leak} = Q_{cleanup} + Q_{orifice} . \qquad (2.38)$$

For moderately large hose leaks,

$$Q_{leak} \gg Q_{orifice} ,$$

so

$$Q_{leak} \approx Q_{cleanup} \qquad (2.39)$$

in (2.38). But

$$Q_{cleanup} = p_T S_{cleanup} , \qquad (2.40)$$

in which $S_{cleanup}$, the volumetric throughput or *pumping speed* of the cleanup pump, is constant under assumptions already introduced. It follows from (2.39) and (2.40) that

$$Q_{leak} \approx p_T S_{cleanup} ,$$

which shows that Q_{leak} is an effectively linear function of p_T, and, hence, of i_{N2}. Thus

$$\frac{Q_{leak}}{i_{N2}} \approx \text{constant.} \qquad (2.41)$$

By carrying out a leak test procedure in the direct flow mode only once, one may determine the numerator and denominator of the fraction in the left

member of (2.41) and, hence, the constant in the right member. In this way, the direct-flow procedure furnishes an *a-priori* method for measurement of leak rate, as well as a *calibration constant* for the split-flow method. Having that constant in hand, one may associate the ion beam current in the split-flow mode with leak rate in a one-to-one fashion.

3. CALIBRATION OF THE APPARATUS

Determination of the ratio V_h/V_c. Consider an expansion of the sort illustrated in Fig. 3.1 nearby.
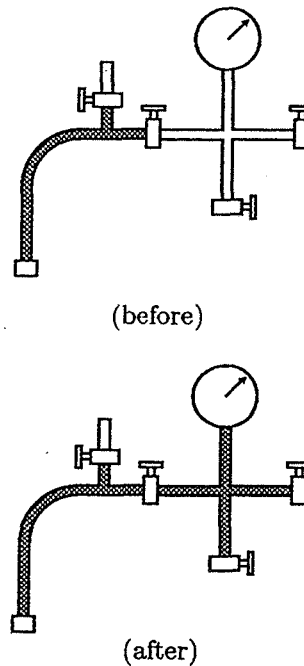

(before)

(after)

Fig. 3.1 Expansion test to determine V_h/V_c.

Suppose that the states illustrated as *before* and *after* in the figure are after i and $i + 1$ repetitions of the expansion, respectively. Let $p_{h,i}$ and $p_{h,i+1}$ denote the pressures in the hose before and after the expansion, respectively. If n is the number of moles of gas in the shaded region of each figure, we have, from the equation of state of an ideal gas and the assumption of constant absolute temperature,

$$p_{h,i}V_h = (n\mathcal{R}T)_i = (n\mathcal{R}T)_{i+1} = p_{h,i+1}(V_h + V_c) . \qquad (3.1)$$

Define the parameter k by the equation

$$V_h = kV_c . \qquad (3.2)$$

Then the outermost equality in (3.1) becomes

$$p_{h,i} k V_c = p_{h,i+1}(kV_c + V_c) ,$$

or

$$p_{h,i} k = p_{h,i+1}(k+1) ,$$

or

$$p_{h,i+1} = \frac{k}{k+1} p_{h,i} . \qquad (3.3)$$

If $p_{h,0}$ is given (say, atmospheric pressure), then a solution of the difference equation (3.2) for all positive integer i is

$$p_{h,i} = \left(\frac{k}{k+1}\right)^i p_{h,0} . \qquad (3.4)$$

Let $p_{h,u}$ be a *unit pressure*, namely 1 Torr. Then

$$\frac{p_{h,i}}{p_{h,u}} = \left(\frac{k}{k+1}\right)^i \frac{p_{h,0}}{p_{h,u}} , \qquad (3.5)$$

and

$$\ln\left(\frac{p_{h,i}}{p_{h,u}}\right) = i \ln\left(\frac{k}{k+1}\right) + \ln\left(\frac{p_{h,0}}{p_{h,u}}\right) . \qquad (3.6)$$

In equation (3.6), k and $p_{h,0}/p_{h,u}$ are constants. Equation (3.6) therefore predicts a linear relationship between i and $\ln(p_{h,i}/p_{h,u})$. If one takes data in the form of a sequence of values

$$\frac{p_{h,0}}{p_{h,u}}, \frac{p_{h,1}}{p_{h,u}}, \frac{p_{h,2}}{p_{h,u}}, \ldots$$

and fits the sequence of their natural logarithms to a linear function of i, then the slope of that linear function determines the constant

$$\ln\left(\frac{k}{k+1}\right)$$

and, hence, the value of k. Such a least-squares fit led to a value of

$$k = 0.732963 = \frac{V_h}{V_c} \qquad (3.7)$$
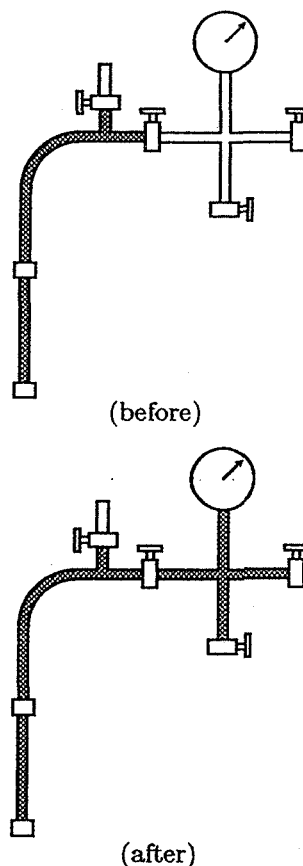
for the apparatus I used this summer.

(before)

(after)

Fig. 3.2 Expansion test to determine $(V_t + V_h)/V_c$.

Determination of the ratio $(V_t + V_h)/V_c$. Consider an expansion of the sort illustrated in Fig. 3.2 nearby.

In this arrangement, an straight rigid extension of volume V_t is attached to the end of the hose. In analogy with (3.2), one defines a new parameter q by

$$V_t + V_h = qV_c \qquad (3.8) .$$

A derivation similar to the one between (3.1) and (3.6) (but with V_h replaced by $V_h + V_t$ and k replaced by q) leads to the equation

$$\ln\left(\frac{p_{h,i}}{p_{h,u}}\right) = i \ln\left(\frac{q}{q+1}\right) + \ln\left(\frac{p_{h,0}}{p_{h,u}}\right) . \qquad (3.9)$$

A least squares fit of a measured sequence of points

$$\frac{p_{h,0}}{p_{h,u}}, \frac{p_{h,1}}{p_{h,u}}, \frac{p_{h,2}}{p_{h,u}}, \ldots$$

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to a straight line of the form (3.9) (on a graph where $\ln(p_{h,i}/p_{h,u})$ is on the vertical axis and i is on the horizontal one) yields a value of the slope of that line, namely

$$\ln\left(\frac{q}{q+1}\right)$$

and, hence, to a value of q. Such a least-squares fit led to a value of

$$q = 2.4639995 = \frac{(V_t + V_h)}{V_c} \qquad (3.10)$$

for the apparatus I used this summer.

Measurement of V_t for a rigid tube extension. For the tube extension used in the determination of q above, I found by direct measurement, that

$$V_t = 4.74088 \text{ (in)}^3 . \qquad (3.11)$$

Deduction of values for V_h and V_c. One may now interpret equations (3.2) and (3.8) as two simultaneious linear equations for the two unknowns V_h and V_c (for *given* V_t). The solution of this system is

$$V_h = \frac{-kV_t}{k-q} \quad , \quad V_c = \frac{-V_t}{k-q} . \qquad (3.12\,a,b)$$

If one substitutes the numerical values of k, q, and V_t given earlier (by (3.7), (3.10), and (3.11)), one obtains

$$V_h = 2.0074 \text{ (in)}^3 \ , \ V_c = 2.73875 \text{ (in)}^3 . \quad (3.13\,a,b)$$

Determination of the ratio $(V_T + V_c)/V_T$. If the QMA-inlet valve (the one at the three o'clock position in Fig. 2.1) is closed while some gas is in the Tee (the chamber with the small orifice leading to the high vacuum vessal), then the gas will leak out through the orifice. Let $n_{\text{stored}}(t)$ be the number of moles of gas in the chamber at any given time. Let $\dot{n}_{\text{outflow}}$ be the number of moles per unit time leaving the chamber at any given time. Then according to an elementary control volumen analysis applied to a chamber with a single orifice, we have

$$\frac{d}{dt}\left(n_{\text{stored}}\right) = -\dot{n}_{\text{outflow}} . \qquad (3.14)$$

Now

$$\dot{n}_{\text{outflow}}\mathcal{R}T = Q_{\text{effusion}} , \qquad (3.15)$$

in which Q_{effusion} is the rate of leakage of gas through the orifice into the high vacuum. If, as usual, T is constant, we have

$$\frac{d}{dt}\left(n_{\text{stored}}\mathcal{R}T\right) = -\dot{n}_{\text{outflow}}\mathcal{R}T . \qquad (3.16)$$

If V is the volume of the control-volume to which (3.14) applies, then one may rewrite the left member by the equation of state of an ideal gas to get

$$\frac{d}{dt}\left(p_T V\right) = -Q_{\text{effusion}} , \qquad (3.17)$$

in which I have also rewritten the right member by means of (3.15).

According to a result from the kinetic theory of gases, *e.g.* JEANS (1940), pp 58–60 [3], when re-expressed in terms of the present notation,

$$Q_{\text{effusion}} = p_T \sqrt{\frac{\mathcal{R}T}{2\pi M}} A , \qquad (3.18)$$

in which p_T is the pressure on the upstream side of the orifice, A is the cross sectional area of the orifice (or cluster of orifices) and M is the molecular mass of the gas species whose throughput one seeks. The equality (3.17) thus implies that

$$\frac{d}{dt}\left(p_T V\right) = -p_T \sqrt{\frac{\mathcal{R}T}{2\pi M}} A , \qquad (3.19)$$

or

$$\frac{1}{p_T}\frac{dp_T}{dt} = -\sqrt{\frac{\mathcal{R}T}{2\pi M}}\frac{A}{V} . \qquad (3.20)$$

If, as in (2.32) above,

$$p_T = Ci_{N2} , \qquad (3.21)$$

where C is an abbreviation for the more cumbersome expression $(di_{N2}/dp_T)^{-1}$, then

$$\frac{1}{p_T}\frac{dp_T}{dt} = \frac{1}{Ci_{N2}}\frac{d}{dt}(Ci_{N2}) = \frac{1}{i_{N2}}\frac{di_{N2}}{dt} , \quad (3.22)$$

so (3.20) becomes

$$\frac{1}{i_{N2}}\frac{di_{N2}}{dt} = -\sqrt{\frac{\mathcal{R}T}{2\pi M}}\frac{A}{V} . \qquad (3.23)$$

Let i_{N2u} denote a *unit current*, say 1 pico Amp. Then

$$\frac{1}{i_{N2}} \frac{di_{N2}}{dt} = \frac{1}{(i_{N2}/i_{N2u})} \frac{d(i_{N2}/i_{N2u})}{dt}$$

$$= \frac{d}{dt} \left[\ln \left(\frac{i_{N2}}{i_{N2u}} \right) \right] . \qquad (3.24)$$

Equation (3.23) therefore becomes

$$\frac{d}{dt} \left[\ln \left(\frac{i_{N2}}{i_{N2u}} \right) \right] = -\sqrt{\frac{\mathcal{R}T}{2\pi M}} \frac{A}{V} . \qquad (3.25)$$

Equation (3.25) states that the slope a plot of the natural logarithm of the ion-beam current versus time is a constant. If one applies (3.25) to two different volumes, namely V_T and $V_T + V_c$, and equates the ratio of the left members of those equations to the ratio of their right members, one obtains, after simplification,

$$\frac{\frac{d}{dt} \left[\ln \left(\frac{i_{N2}}{i_{N2u}} \right) \right] \Big|_{V=V_T}}{\frac{d}{dt} \left[\ln \left(\frac{i_{N2}}{i_{N2u}} \right) \right] \Big|_{V=V_T+V_c}} = \frac{V_T + V_c}{V_T} . \qquad (3.26)$$

For brevity, I will denote the numerator and denominator of the left member of (3.26) by σ_T and $\sigma_{T \cup c}$, respectively. Curve fits to experimental time series in i_{N2} yield the values

$$\sigma_T = -1.06941 \ (\text{min})^{-1} , \qquad (3.27a)$$

$$\sigma_{T \cup c} = -0.237029 \ (\text{min})^{-1} . \qquad (3.27b)$$

If one solves (3.26) for V_T in terms of V_c, σ_T and $\sigma_{T \cup c}$, one obtains

$$V_T = \frac{V_c}{(\sigma_T/\sigma_{T \cup c}) - 1} \qquad (3.28)$$

For the numerical values already given for V_c, σ_T and $\sigma_{T \cup c}$, one obtains

$$V_T = 0.779888 \ (\text{in})^3 . \qquad (3.29)$$

Determination of the sensitivity factor, di_{N2}/dp_T. Knowing the volumes of the various chambers in the valve manifold, there is, in principle, no difficulty in producing a wide variety of
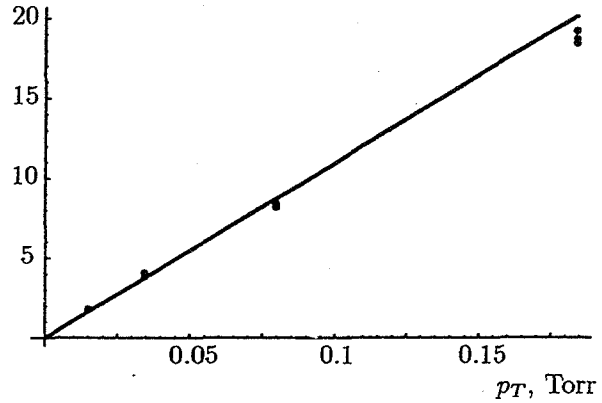
i_{N2}, Pico Amp

p_T, Torr

Fig. 3.3 Ion-beam current versus pressure in Tee.

known pressures in the Tee chamber. The procedure consists merely in producing various fractions of atmospheric pressure by repeated expansions from smaller chambers to larger ones. By comparing the measured i_{N2}-signal with the associated chamber pressure p_T in a variety of cases, one may generate a curve of the form shown in Fig. 3.3.

The average ratio of i_{N2} to p_T over the set of all the points is

$$\frac{di_{N2}}{dp_T} = 109.601 \ \frac{\text{PicoAmp}}{\text{Torr}} . \qquad (3.30)$$

Since all of the parameters in the list (2.34) have now been determined, the parameters needed for the conduct of leak rate measurements are now in hand.

4. RESULTS

Room temperature tests with a nominally flawless nose seal and full torquing. When the nose seal was torqued down to the book value of 200 in-lbs and there were no deliberate flaws, the leak rate was below the noise level (of $i_{N2} = 1 \times (10)^{-13}$ Amp (for the UTI Detec-Torr analyzer operating with the Faraday cup detector).

Room temperature tests with fibers draped over the nose seal and full torquing. When the nose seal was torqued down to the book value of 200 in-lbs and the only flaw was due to the draping of

a fiber across it during assembly, the leak rate was again below the noise level even when the fiber was a human hair.

Room temperature tests with fibers draped over the nose seal and weak torquing. When the nose seal was finger tightened and the flaw was due to the draping of a human hair across it during assembly, the leak rate was typically on the order of $3.0 \times (10)^{-4}$ Atm·(cm)^3/sec.

Cryogenic tests with a nominally flawless nose seal and full torquing. When the nose seal was torqued down to the book value of 200 in-lbs and there were no deliberate flaws, the leak rate was on the order of $1.5 \times (10)^{-4}$ Atm·(cm)^3/sec after the hose had been dipped in liquid Nitrogen an allowed to reach equilibrium for about a half hour.

Cryogenic tests with with a small fiber over the nose seal and full torquing. When the nose seal was torqued down to the book value of 200 in-lbs and the only flaw was a five micron wire draped over the seal during assembly, the leak rate was on the order of $1.6 \times (10)^{-4}$ Atm·(cm)^3/sec after the hose had been dipped in liquid Nitrogen an allowed to reach equilibrium for about a half hour. It is not clear whether the slight rise in leak rate was indeed due to the effect of the wire or normal scatter within a statistically equivalent population.

Cryogenic tests with with a large fiber over the nose seal and weak torquing. When the nose seal was finger tightened and the only flaw was a human hair draped over the seal during assembly, the leak rate was large enough to peg the machine after the hose had been dipped in liquid Nitrogen an allowed to reach equilibrium for about a half hour.

Observed rise in leak rate versus time during cryogenic cooldown. When a nominally flawless seal is torqued to the full book value and immersed in liquid Nitrogen the signal is initially in the noise range of the device, but rises into the measurable range in a minute or so. The slope of $i_{N2}(t)$ curve is initially steep, starts to level off, then becomes steep again, then levels off a second time. The final value of the $i_{N2}(t)$-signal is more than one hundred times that of the signal at ambient temperatures. The nonmonotonic drop of slope of the $i_{N2}(t)$-curve is puzzling and suggests a need for further work.

Contrast between leak rate of cryogenic gas and cryogenic liquid. When a nominally flawless seal is torqued to the full book value and the plug is held above the liquid Nitrogen level before immersing it in the liquid, the rate of leakage in the immersed state is higher but not much higher than it was in the unimmersed state.

5. CONCLUSION

The experimental results obtained thus far seem to support only one definite conclusion, to wit:

> *Cryogenic cooldown of an otherwise flawless KC fitting greatly increases the leak rate of Nitrogen. The ratio of the cold leakage to the room temperature leakage is more than a factor of one hundred.*

ACKNOWLEDGEMENTS

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1997 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
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JAVA SERVER FOR REAL-TIME DATA

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ABSTRACT

In this project we developed a computer program in the Java programming language to display real-time data. The data comes from the numerous systems monitoring the operation of the space shuttle while on the ground and in space. The data can be displayed on any computer platform running a Java-enabled World Wide Web (WWW) browser and connected to the Internet.

We undertook to build a prototype system to demonstrate that the Internet and the Java programming language could be used to present the real-time data conveniently and efficiently. We implemented a Java data server program that communicates with an existing program called the scan server. The scan server is our source of real-time data for all the individual measurement data.

We implemented client programs that communicate with our Java data server and display the desired measurements. Among these clients are ones to

1. simulate any screen of the PC GOAL system,

2. graph over time up to 12 different measurements, and

3. show the position of the space shuttle while on orbit.

Our demonstration project shows the great flexibility of the approach. The unique relation between Java and the Internet makes our system easy to administer, update, and efficient. The good graphical user interface (GUI) library makes it easy produce any sort of visulization of the measurements. Also, it is easy to program any sort of data analysis, e.g., anamoly detection.

1 Introduction

During the operation of the space shuttle, sensors are monitoring many of the subsystems. This data goes to special hardware at the Launch Control Center (LCC) known as the Common Data Buffer (CDBF). Lots of data is collected, approximately 30,000 measurements. These measurements are continually changing—some of them can change rapidly at certain times. The data is used in monitoring the operation of the shuttle and in analyzing subsystems for safety, performance, technological improvements, etc. Each individual measurement is given a short tag called a function designator (FD). The list below is a sampling of the FDs as well as a short description (called the nomenclature), a value during a recent query of the data, and the units.

```
Func Desig   Nomenclature                         Value Units
NSTSNUMBER   STS NUMBER                              85 PDP-N/A
NORBFLIGHT   ORBITER FLIGHT NUMBER                   23 PDP-N/A
NORBTAILNO   ORBITER TAIL NUMBER                    103 PDP-N/A
NFIRINGRM    FIRING ROOM NUMBER                       3 PDP-N/A
NTBISKPADA   TCID BUILD IN SUPPORT FOR KPADA         ON OFF/ON
NTBISKPADB   TCID BUILD IN SUPPORT FOR KPADB        OFF OFF/ON
SOIADATAV    128 OI FEP ACTIVE DATA VALID            ON ON/OFF
KMTHA001A    WIND DIRECTION CAMERA SITE 6      444.95996 DEG
KMTLA001A    WIND SPEED CAMERA SITE 6          6.719999 KT
KMTPA001A    BAROMETRIC PRESSURE CAMERA SITE 3 30.099995 INHG
KMTQA001A    AMBIENT RELATIVE HUMIDITY C SITE 3    72.0 PCT
KMTRA002E    RAIN RATE MEAS CAMERA SITE 6            ON OFF/ON
KMTTA001A    AMBIENT TEMPERATURE CAMERA SITE 3 85.59999 DEGF
N03IS003E    LCC HOLD                               OFF OFF/ON
N03IS006E    LH2 REPLINISH TERM IN PROGRESS         OFF OFF/ON
N03IS078E    ORBITER AT OPF                         OFF OFF/ON
N03IS079E    ORBITER AT VAB                         OFF OFF/ON
N03IS080E    ORBITER AT PAD                          ON OFF/ON
V61Q2551A1   CABIN HUMIDITY                        12.4 PCT
V61P2405A1   CABIN PRESS                      14.719997 PSIA
V61T2552A1   CABIN TEMPERATURE                79.15999 DEGF
V51P0370A1   NLG LH TIRE PRESS 1             364.13986 PSIA
V51P0471A1   MLG RH INBD TIRE PRESS 1       386.47095 PSIA
```

Real-time data is monitored on system engineering consoles of then the Control Checkout and Monitor System (CCMS) in the Launch Control Center (LCC). The command and control software is written in the Ground Operations Aerospace Language (GOAL).

The PC GOAL system presents the same data to a wider audience in a format closely resembling the consoles of the CCMS. The CCP (CDBF Communications Processor) scans the memory of the CDMF every 2 seconds and broadcasts the data on the LPS Operations Net (LON). This data (and other data, e.g., FIFO) is relayed to the PC GOAL stations. The PC GOAL stations are PCs with network hardware running DOS and the PC GOAL software.

The PC GOAL system presents shuttle data on schematic like screens described by character-oriented DSP files. Each shuttle mission requires substantial effort to organize the CDBF, distribute the DSP files, etc.

2 JGOAL

The JGOAL project is motiviated by the PC GOAL system to display real-time shuttle data as conveniently and efficiently as possible. The programming language Java was choosen because of the easy of writing both graphical user interface (GUI) code and distributed programs. The Internet is the obvious mechanism to transport the data. The wide-spread availablity of browsers for the World Wide Web suggests an obvious user interface for any large scale information system.

Java code can be transmitted as part of the WWW protocol, just like pictures, sound and other data. The extreme interest in Java is caused by the ability of browsers to execute the Java code. These Java programs transported across the Internet and executed locally by a WWW browser are called applets. Applets add interaction to otherwise static WWW documents. The JGOAL project uses applets to form a connection to a Java data manager that relays the real-time data to the applet.
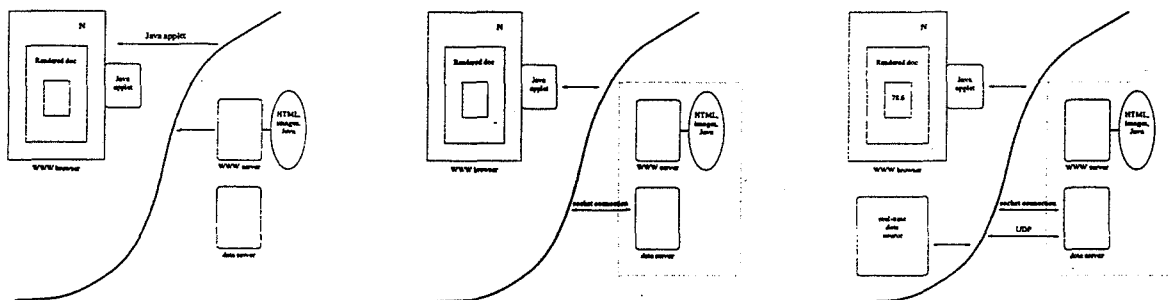
2.1 Java applets

The key advantage with using Java applets is that after the applet makes a connection to a data server only the data is transmitted across the network. The following steps summarize the establishment of a direct connection to the data using the WWW.

1. Get document. Local machine makes a request for a document.

2. Return document. A WWW server finds the document and returns it.

3. Get applet. The WWW browser begins to display the document, requests the Java applet, and leaves space for the applet in the document.
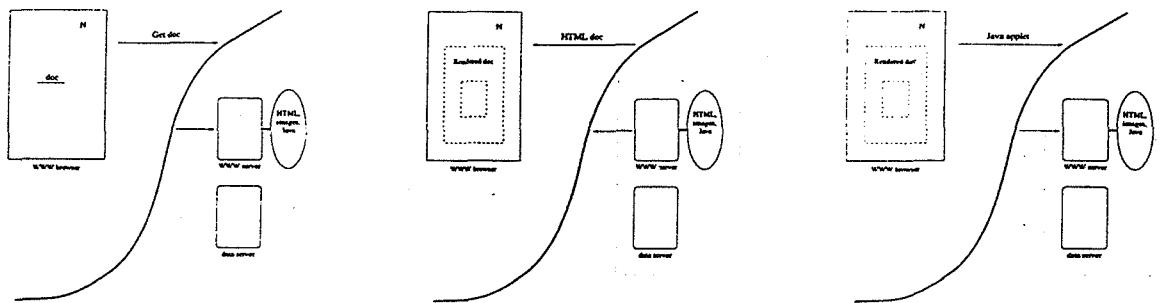
4. Applet running. The WWW server returns the applet, the browser runs the applet which controls the space in the document.

5. Socket connection. The applet makes a socket connection to a data server on the remote machine.

6. Data pipeline. The data server exchanges UDP packets with the real-time data source, and sends the data on to the applet.

The advantages in using Java are even greater than the technical merits suggest. Administratively, the operation of a real-time data service using Java is much better. The Java applet is written once and executed remotely; no porting has to be done. Also, the latest version of the applet is always distributed to the user; there is no version control problem. Finally, the operation of the service is easy as browsers are ubiquitous; no training is required.

2.2 Related Work

There are other mechanisms that can be used to display real-time shuttle data on the Internet.

The Exodus project displays its data on WWW documents using common gateway interface (CGI) programs. Periodically another document is produced with the data on it and

sent to the WWW browser. This requires a lot of redundant network traffic when on a few numbers have changed. Also graphics are hard to produce on an HTML document without resorting to graphic images that would have to be transmitted each time to the browser.

Another direct approach is server-push. In this approach the server periodically resends the HTML document. In the meantime another program can write a new and updated version of the document. An example of this approach is the Shuttle Page. This works best with text, as again an entire HTML document is transported across the Internet with each update.

3   Transport Layer

The Java data manager consists of two halves. One that communicates with the scan server and one that communicates with the clients. Each of these protocols are described below.

The scan server protocol begins by naming the IP address of the scan server in the setHost command. At this time the scan server is interrogated about the available CDB streams. The labels associated with these streams are returned by the getConfigs method. A DataStream object is returned by the chooseConfig method for each possible choice. These choices persist until the end of the session, so if the actual data streams at the LON are reconfigured, then the session must be closed and restarted. Interest in a collection of FDs is expressed the by the addFDs method (per data stream). The FD_Set object is not created until the first data has arrived. So the getValues always will work. Some data, prehaps old data, will be associated with the FDs of the set. The getData tries to get new values for all the FDs and for *all* the data streams. This can fail due to network problems, eventually getData gives up. Finally, the close destroys the connection to the scan server and all the data structures associated with the data streams.

The methods are summarized below.

```
                    ScanServer.setHost ( String )
String [] l       = ScanServer.getConfigs()
DataStream ds     = ScanServer.chooseConfig ( int )

                    ds.getOrbiter()
                    ds.getTCID()

FD_Set set        = ds.addFDs ( String [] )
                    set.removeFDs ( FD_Set )
```

```
String [] n        = set.getNames()
String [] n        = set.getNomen()
FDInfoStruct [] f = set.getFdInfos()

                   ScanServer.getData()

double [] v        = set.getValues()
String [] v        = set.getStringValues()
String             = set.getTOD();

                   ScanServer.close()
```

The following table summarizes the protocol between the Java data server and a client. The left hand side are those objects sent from the client, the right hand side are those sent from the server. All objects are written using the `ObjectOutputStream` in the IO library of Java 1.1.

```
"LOGIN"
String user
String passwd
                             Boolean loginAccepted

"GET_SOURCES"
                             String [] sources

"SELECT_SOURCE"
int sourceNumber

"SELECT_DATA_SET"
String[] FDnames

"GET_INFO"
                             FDinfoStruct[] info
"UPDATE_ALL"
                             String [] data
                             String timeOfDay
                             String countDownTime
"LOGOFF"
```

4 User Interface

The primary application using the data stream is a Java applet that allows the display any of the 300 or so DSP files of the PC GOAL system. Figure 1 shows the Java applet after launching three DSP screens displaying real-time data. The browser is running in the upper left-hand corner. The only thing in the document is the JGOAL applet for display DSP files.

The applet requires the user to pick one of the available data streams. Then a list of all the available DSP files appears on the right. (A particular subsystem can be chosen, then the list of DSP files for that subsystem is displayed on right.) The user selects the DSP file and clicks on a button and a new window comes up with the real-time data displayed. As many windows as the user can tolerate may be started in the same fashion. Notice that these Java window do not appear inside the confines of the browser, but may be placed anywhere on the screen.

5 Conclusions and Future Work

Simulating PC GOAL screens is by no means the only possible applications. We have implemented an extensive graphing application that mimics many of the features of the graphing feature of the PC GOAL system. In addition we have implemented applications with bit-mapped gauges and meters to display the data. One application creates an orthographic projecting of the world showing the position of the shuttle while on orbit. This application requires extensive calculations using 7 FDs simultaneously to compute the necessary information.

Many other enhancements await further development. A GUI interface for managing the server needs to be written. Playback of historical data needs to be considered. A server directly on the LON needs to be written to gain access to all available data.

6 Acknowledgments

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Finally, I wish to thank the summer interns Will Riddle (Duke) and Kevin Gillette (Princeton). Will wrote the DSP display application, the data manager, and the graphing application. Kevin wrote the Java code for interpreting and converting DSP files.

A   Links

The scientific literature is no particular use in understanding the context or methods of this work, so in lieu of traditional references I have listed a number of links to material on the WWW that provides additional information pertaining to the project.

Exodus – The Exodus project

> `http://lpsweb.ksc.nasa.gov/EXODUS/`

LPS – Launch Processing System Home Page

> `http://lpsweb.ksc.nasa.gov/`

JGOAL – JGOAL (Java 1.0) Home Page

> `http://o2.ksc.nasa.gov/tryJGOAL/`

PC GOAL – PC GOAL Home Page

> `http://lpswebksc.nasa.gov/SDC/PCGOAL/homepage.html`

Shuttle Page – Real-Time Data

> `http://shuttle.nasa.gov/ccc/`

Ryan Stansifer – the author

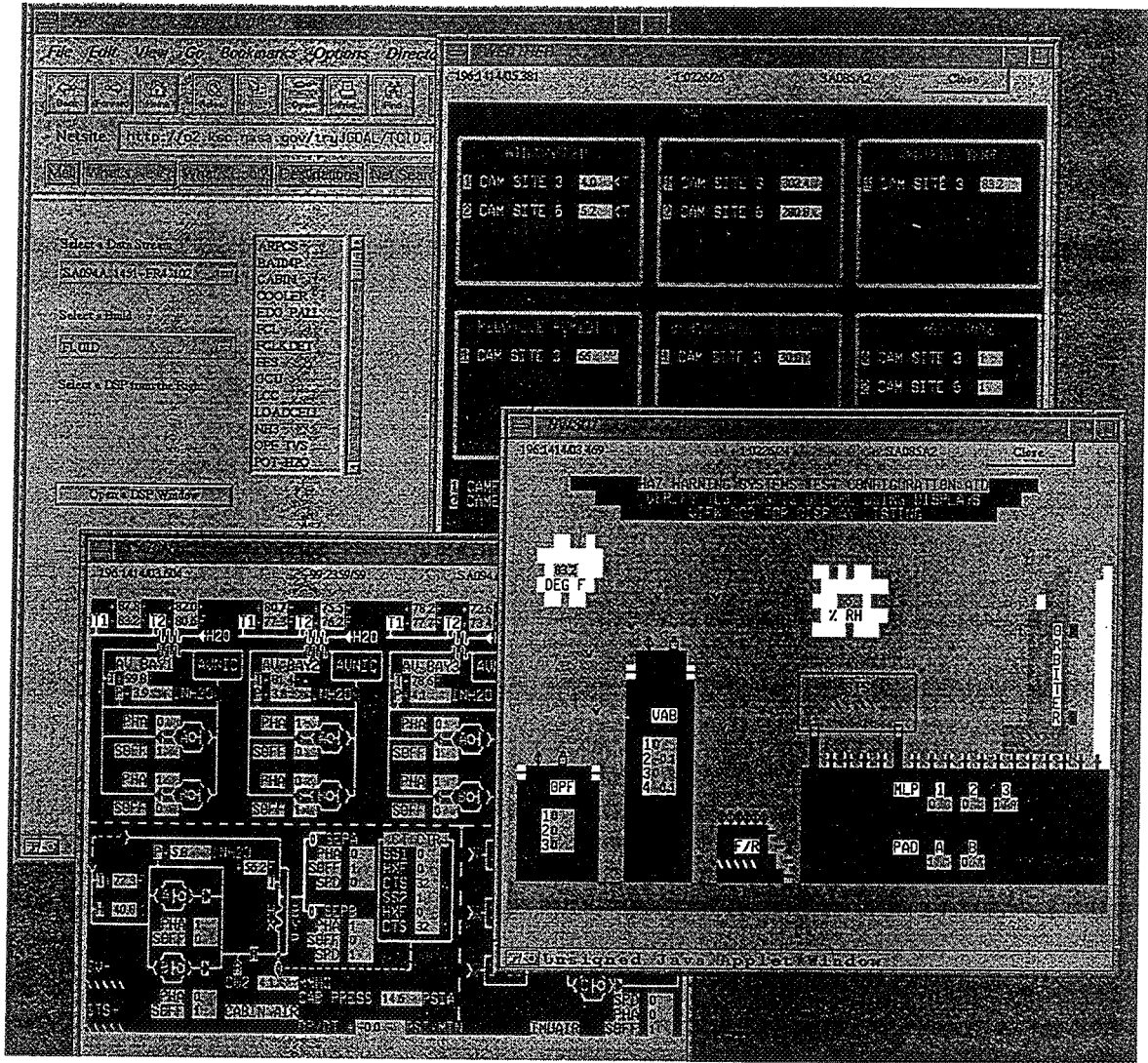> `http://www.cs.fit.edu/~ryan/`

Figure 1: JGOAL

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13. ABSTRACT (Maximum 200 words)

This document is a collection of technical reports on research conducted by the participants in the 1997 NASA/ASEE Summer Faculty Fellowship Program at the Kennedy Space Center (KSC). This was the 13th year that a NASA/ASEE program has been conducted at KSC. The 1997 program was administered by the University of Central Florida in cooperation with KSC. The program was operated under the auspices of the American Society for Engineering Education (ASEE) with sponsorship and funding from the Education Division, NASA Headquarters, Washington, D.C., and KSC. The KSC Program was one of nine such Aeronautics and Space Research Programs funded by NASA in 1997. The NASA/ASEE Program is intended to be a two-year program to allow in-depth research by the university faculty member. The editors of this document were responsible for selecting appropriately qualified faculty to address some of the many problems of current interest to NASA/KSC.

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