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2003 RESEARCH REPORTS

NASA/ASEE FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
AND
UNIVERSITY OF CENTRAL FLORIDA

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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 2003 NASA/ASEE Faculty Fellowship Program at the John F. Kennedy Space Center (KSC). This was the nineteenth year that a NASA/ASEE program has been conducted at KSC. The 2003 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 2003.

The basic common objectives of the NASA/ASEE 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 19 through July 25, 2003) 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 research areas of current interest to NASA/KSC. A separate document reports on the administrative aspects of the 2003 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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2003 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

DEVELOPMENT OF HYDRAZINE/NITROGEN DIOXIDE FIBER OPTIC SENSOR

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ABSTRACT

Bromothymol Blue (BT)/Bromocresol Green (BG) mixture (1/1) in hydrogel (1/1), produces a blue-green indicator for HZ and/or NO_2. The stability over a two months period of this BT/BG (1/1) indicator solution was tested and no evidence of performance deterioration was detected. A dual HZ/NO_2 prototype sensor utilizing an acid-base indicator was previously constructed. A monitor and control circuit are also designed, built and tested during the course of this project. The circuit is controlled with Motorola MC68HC11 microcontroller evaluation board to monitor the voltage level out of the photodetector. Low-pass filter and amplifier are used to interface the sensor's small voltage with the microcontroller's A/D input. The sensor, interface circuit and the microcontroller board are then all placed in one unit and powered with a single power supply. The unit is then tested several times and the response was consistent and proved the feasibility of dual HZ/NO_2 leak detection. Other sensor types, suitable for silica glass fiber, smaller in size, more rugged and suitable for use on board of the Space Shuttle and missile canisters, are then proposed.

DEVELOPMENT OF HYDRAZINE/NITROGEN DIOXIDE FIBER OPTIC SENSOR

Alfred S. Andrawis &
Josephine Santiago

1. INTRODUCTION

Gases formed by rocket propellants (hydrazine and nitrogen tetroxide), used in the Space Shuttle and other civilian and military applications, are very toxic to humans at low concentrations as well as flammable and explosive at high concentrations. The American conference of governmental industrial hygienists (ACGIH) has recommended that the exposure limits are 10 ppb for hydrazine (HZ) and 3 ppm for nitrogen dioxide (NO_2) [1]. The explosion limit for HZ in atmospheric pressure is 2.9% [2]. Accidental leak detection is of a great concern to protect personnel, wild life and the environment.
A fiber optic sensor is an ideal and inherently safe propellant leak detector due to the following advantages:

- Spark hazard free, which is an obvious requirement for propellant leak detection.
- Immunity to electromagnetic interference making it suitable for use in the closed environment of missile canister, spacecrafts and on board of the Space Shuttle.
- Distance to the measuring point can be great (several kilometers) due to small attenuation of optical fiber.
- Possibility of multiplexing several sensing elements to one remote data acquisition station.
- Low cost, lightweight, small size and low power component enables densely multiplexing sensor arrays for precise leak localization.
- Can withstand relatively extreme temperatures, which further justifies their suitability for aerospace and military applications.

Previous work was focused on the development of dual HZ/NO_2 prototype sensor utilizing an acid-base indicator that undergoes color changes depending on which gas is present [2]. The indicator is imbedded in a hydrogel matrix to aid long-term stability. This hydrogel is applied to a mirror that in turn is placed in front of two plastic fibers. One of the two plastic fibers is connected to a 630 μm LED while the other is connected to a photodetector. Light emitted from the first fiber is reflected and collected by the second fiber. The amount of the reflected light is a function of the hydrogel color i.e. dependent on detected gas. The purpose of this project is to further the development of the sensor to produce a unit with alarm to indicate either a fuel or an oxidizer leak is detected. Hence, the main objective of this project is to design and build an electronic interrogator board to monitor propellant gas leaks (utilizing existing prototype sensor) and to determine indicator solution stability over time. Another objective of the project is to propose a plan for the development of other fiber optic sensors more suitable for aerospace and military applications.
This report outlines an introduction of gas leak detection and two of the most common methods for detection, it then describes the hardware and the software of the electronic interrogator board designed during this summer, (the control code written in assembly language is attached as an Appendix). Finally, several other fiber optic sensor configurations are also recommended which may be lighter in weight, cheaper and more rugged than the present one in the laboratory.

2. WAVE PROPAGATION IN OPTICAL FIBERS

Optical fibers for communication systems are commodity items easily obtainable and competitively priced. The attenuation characteristics of these fibers, which are the important features in the context of remote chemical sensing, are well known and basically comprise a transparent window over the range 0.6

– 1.6 μm. Attenuation in this window varies from as high as 1 dB/km to as low as 0.2 dB/km. These fibers are obviously excellent transmission media and are supported by an infrastructure of optical components such as connectors, light sources, detectors, wavelength selective filters and numerous other components. An optical fiber is produced by forming concentric layers of low-refractive-index cladding material around a high-refractive-index core region. Light energy is contained within the higher-index core due to the reflection at the interface of the two materials [3]. Figure 1 illustrates the mechanism of the simplest class of fiber design, the step-index, where

η is the refractive index of air,
η_1 is the core refractive index,
η_2 is the cladding refractive index,
θ is the critical angle, and
θ_o is the acceptance angle, also called acceptance cone half angle [4].

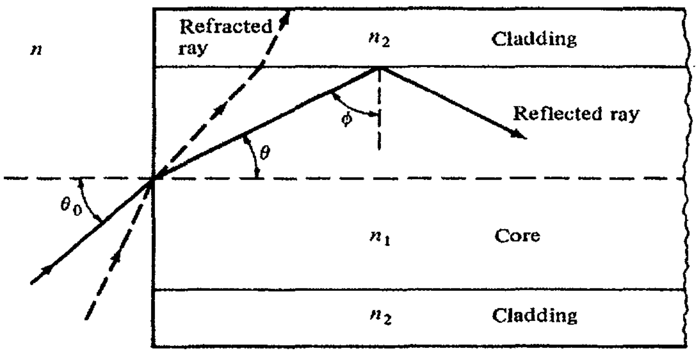


Figure 1. Structure of a step-index optical fiber.

As a light ray strikes the surface of the fiber, it is refracted slightly toward the center of the core with an angle that is a function of the glass/air interface refractive-index difference. Once the ray enters the core, it propagates and strikes the core/cladding interface. If the angle at which the ray strikes the core/clad interface is less than the critical angle defined by the core/cladding refractive-index difference, it reflects back into the core and continues to propagate in the same manner. Although the light energies are totally reflected, the electromagnetic fields still penetrate into the cladding as evanescent fields (Section 3.*b*). If the ray strikes the core/clad interface at an angle greater than the critical angle, it passes into the cladding and is eventually lost.

The critical angle within the fiber translates to an acceptance angle at the fiber surface. The sine of this angle defines the numerical aperture of the fiber. Numerical aperture is a parameter that defines the cone of optical-energy acceptance of the fiber and is critical to the coupling efficiency and propagation properties of the fiber.

3. SENSING TECHNIQUES

There are numerous gas sensing techniques, two of the most common methods are outlined in this Section.

a. Coupling Technique

Transducers in which the light exits from an optical waveguide and is coupled to the same or other waveguide/s are called coupling based transducers [5]. The light must be extracted from the waveguide in order to interact with the sensing material. This principle has led to a range of gas sensor designs: single or multiple fibers, either single-mode or multimode, in transmissive or reflective configurations. The existing HZ/NO_2 leak sensor utilizes the reflective configuration as shown in Figure 2, and the sensing material is a pH indicator solution. The coupled power collected by the receiver fiber changes according to color change in the sensing material upon exposure to acidic and basic gases.

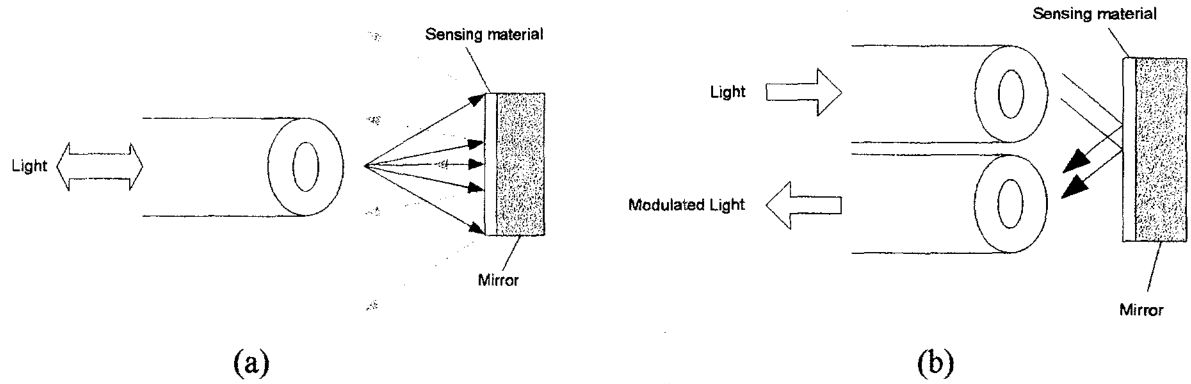


Figure 2. Reflective configuration of coupling-based HZ/NO_2 leak sensor using: (a) a single fiber acting as both emitter and receiver, (b) one fiber acting as emitter, another fiber acting as receiver.

One of the major drawbacks of the use of coupling based transducers, especially with single-mode fibers, is the poor coupling efficiency between the fibers, which greatly affects the resolution of the sensor system. Intensity modulated optical sensors were developed to utilize volume or GRIN optics or fiber bundles to compensate for the limited displacement range of measurement with bare optical fibers. Other designs have been proposed: a single fiber acting as both emitter and receiver, or two or more receiver fibers as an alternate form of compensation.

b. Evanescent Field Technique

The evanescent field or wave is a well-known effect experienced by light at boundaries with a refractive index change: although the light can be totally reflected by the boundary, part of the electromagnetic field 'enters' the other side, occupying the two media [5]. This is the case for optical waveguides. As shown in Figure 3.a, light is guided by the core (inner medium of higher refractive index), but a small percentage of the field, called the evanescent field, travels in the cladding. If the cladding is removed, or its properties modified, the evanescent wave, and thus the guided light, is able to interact with the sensing material, providing the basis for many sensing schemes (see Figure 3.b).

The simplest evanescent transducer is made of a segment of optical fiber with the cladding removed or side-polished. Many chemical species in gas form can be directly detected through the absorption of the evanescent wave. An indirect measurement can be performed by substituting the cladding with a material, layer or film whose optical properties can be changed by the substance to be detected, usually indicator dyes immobilized by a sol-gel film deposited on the core's surface. Sensitivity and the long-term reliability due to the surface contamination as well as the degradation of the indicator are major concerns in this design.

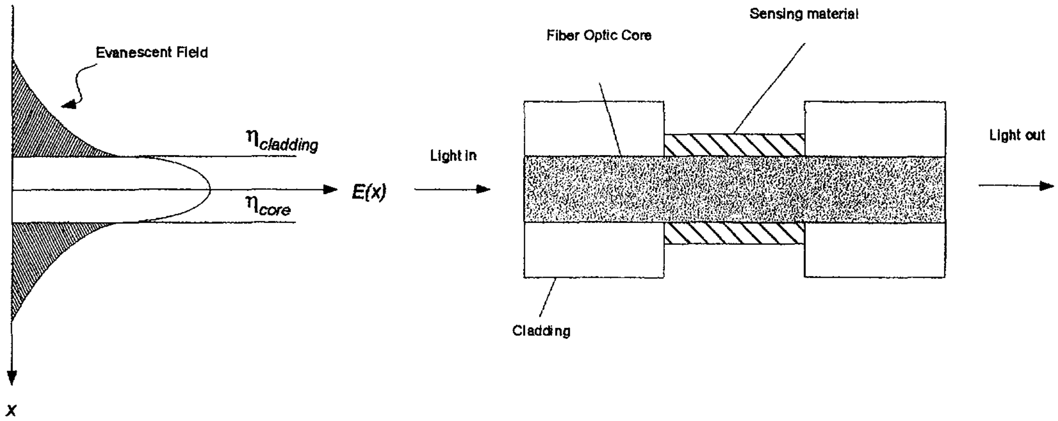
One of the drawbacks of evanescent field sensors based on conventional waveguides is the weak interaction with the sensing material due to the small excursion of the field into the cladding. In order to improve the weak interaction of the evanescent field with the sensing material, tapered segments of optical fibers have been proposed as shown in Figure 4. The field strength decreases exponentially outside the core regardless of the waveguide shape or modal distribution. The evanescent field penetration depth into the cladding is inversely proportional to the normalized frequency number, V, defined as:

$$V = \frac{2\pi a}{\lambda}\sqrt{\eta_1^2 - \eta_2^2}$$

where: a is the radius of the core, and

λ is the wavelength of the light ray.

The evanescent field penetration depth into the cladding is inversely proportional to the normalized frequency number V. The lower the value of V, the greater the evanescent field penetration into the cladding. The ratio of optical power through the cladding to the total optical power (P_{clad}/P) is controlled by several factors such as core diameter, operating wavelength and several other factors.



(a) (b)

Figure 3. (a) Evanescent field in a guided optical medium;
(b) Scheme of a transducer based on this principle (modified cladding).

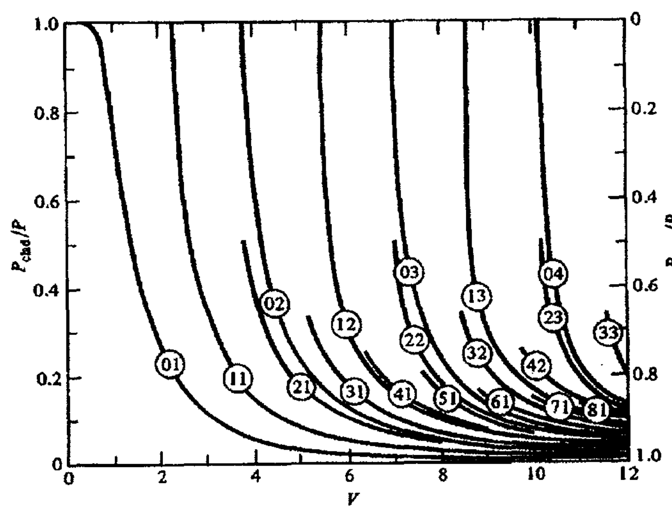


Figure 4. Fractional power flow of a step-index fiber as a function of V. [3].

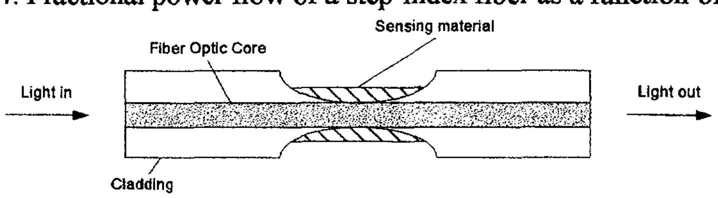


Figure 5. Optical fiber with a new proposed tapered segment.

As the sensing film changes its color P_{clad} will change accordingly. Manipulating the ratio P_{clad}/P could control sensor's sensitivity and insertion loss.

4. PROTOTYPE FIBER OPTIC SENSING SYSTEM

This section explains the hardware and the software designed to interrogate the prototype HZ/NO_2 leak sensor designed and built by Ms. Rebecca Young (KSC colleague). The sensor is a reflective configuration type with two plastic fibers: one fiber acting as emitter, and another acting as receiver as shown in Figure 2. Sensor's interrogator circuit is controlled with Motorola MC68HC11 microcontroller. The MC68HC11 microcontroller has built in 8-channels/8-bits analog-to-digital (A/D) converters. A/D channel #2 (pin # PE-1 connected to the amplifier output) is to monitor the voltage level out of the photodetector. The following two sections explain the hardware of the circuit needed to condition the output signal of the sensor to interface with the A/D input.

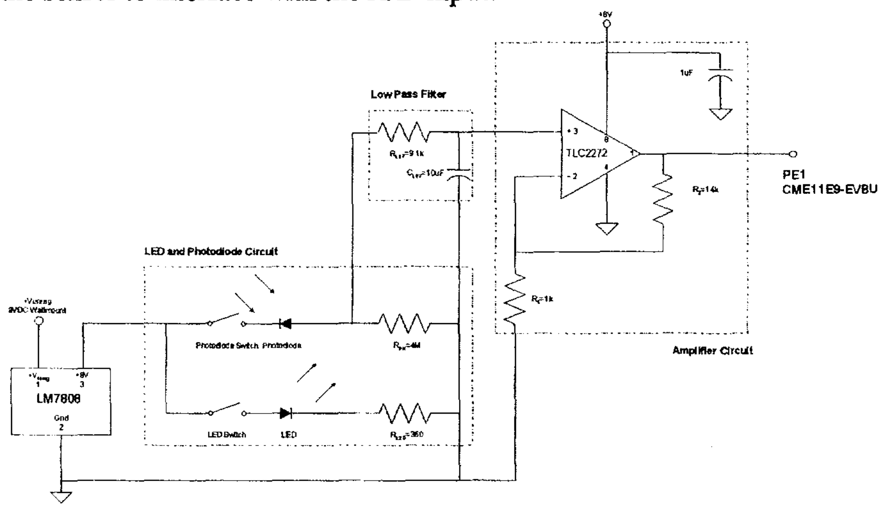


Figure 6. Leak sensor control circuit.

a. Interrogator Circuit Hardware

The minuscule voltage from the photodiode circuit needed to pass through a low pass filter to remove unwanted higher frequency components, and a non-inverting amplifier with a gain of 15 for the voltage to fall within the 2-5V input range of the microcontroller (input pin PE1). The voltage resolution is calculated using the equation $\frac{(V_{rH} - V_{rL})}{G \times 2^n}$, where $V_{rH} = 5V$ (reference voltage high), $V_{rL} = 2V$ (reference voltage low), G is the amplifier's voltage gain, and n is the number of bits per sample of the A/D (8 bits/sample for the HC11). The calculated resolution is found to be 0.78 mV/division. Circuit schematic diagram is shown in Figure 6.

b. Interrogator Circuit Software

Due to the fact that the output voltage drifts slowly, the output voltage per minute is allowed to drift within certain tolerance. Therefore, three tolerances are imbedded in the code: one is when no gas leak is suspected (TOL) and the other two are when gas leak is suspected (HZTOL for hydrazine and NO2TOL for NO_2). A flow chart of code flow is shown in Figure 7. The microcontroller software would be able to effectively detect the presence of Hydrazine (52 ppm) in one minute and Nitrogen Dioxide (400 ppm) in two minutes. However, for convenience detection time is set to be two minutes for both gasses. More detailed flowcharts for the code are included in Appendix A. The control code, written in assembly language, is included in Appendix B.

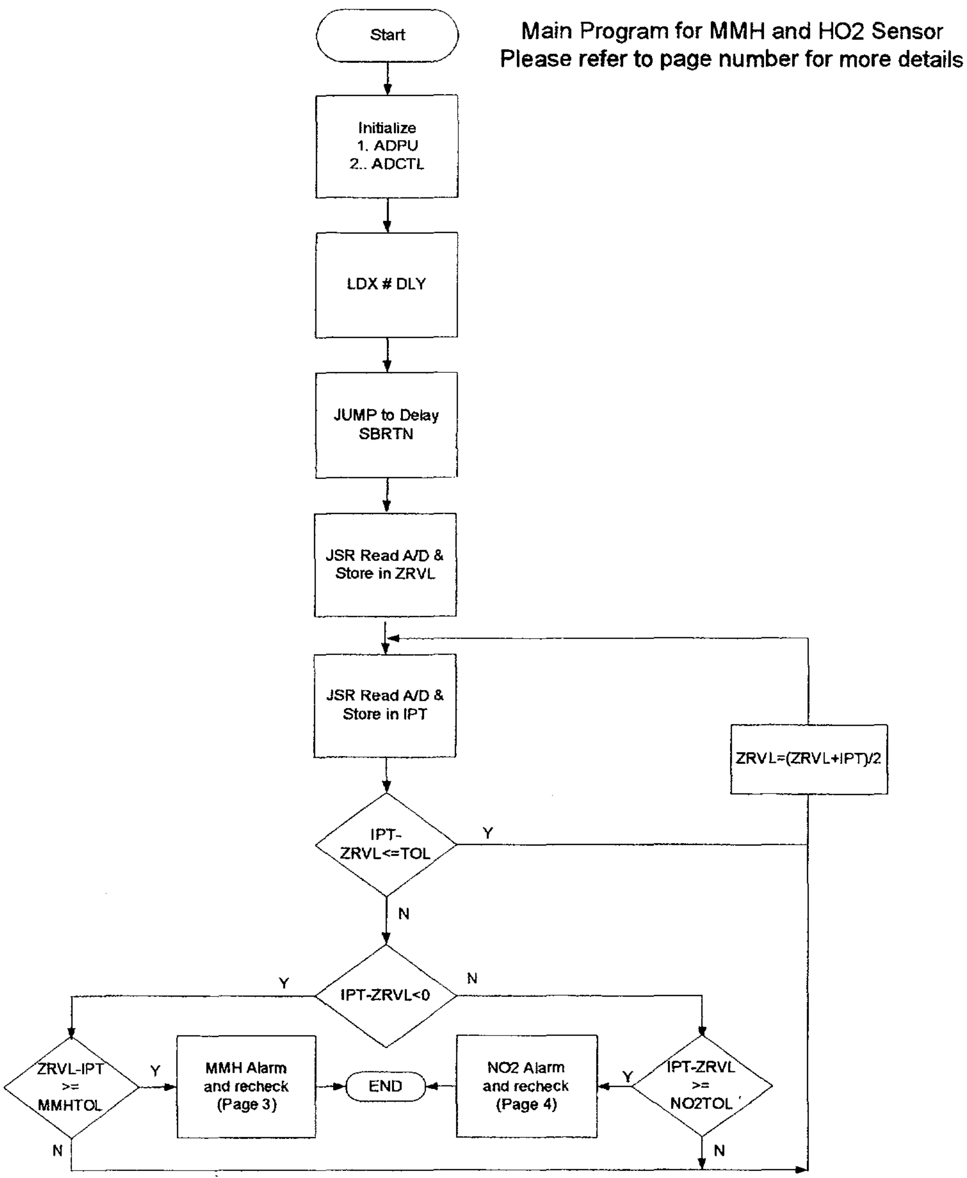
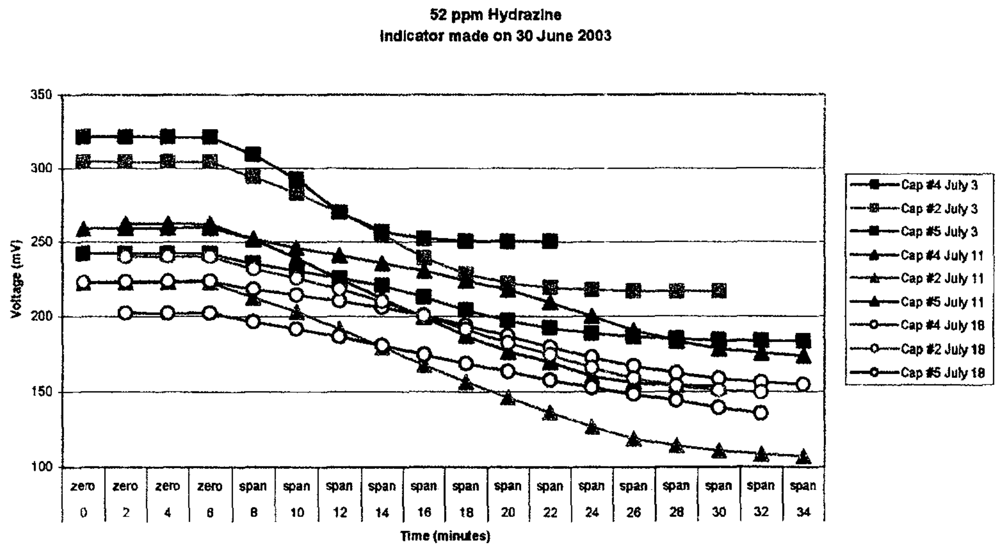


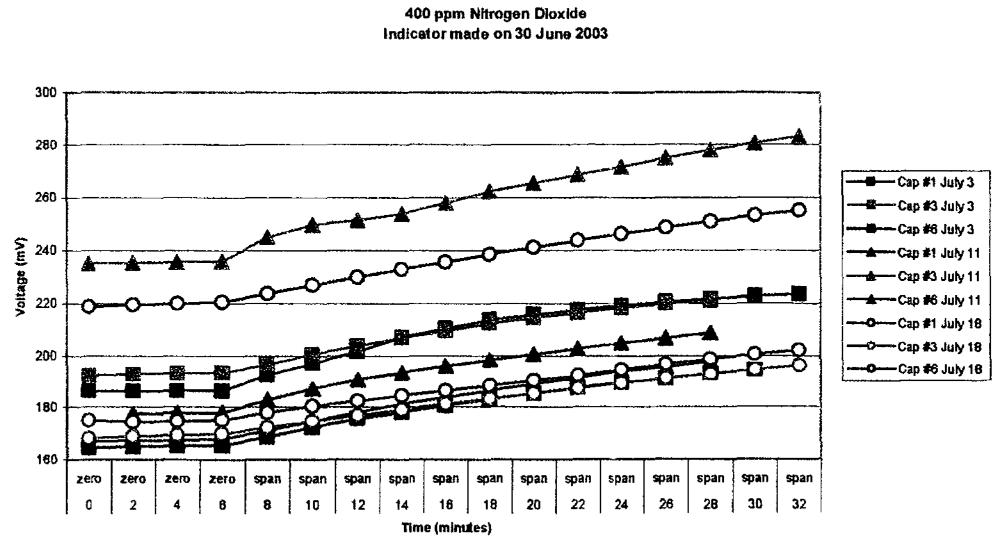
Figure 7. Control code flow chart.

5. SUMMARY OF RESULTS

The six sensor caps had different baseline values for each trial. This could be due to inconsistencies in the fiber distance to the mirror, inconsistencies of the thickness of the indicator solution on the mirror, and/or instability of the power supply (first set of trials were done on 9V batteries while the rest were done using a wall pack power supply). Overall, the performance curves of the sensor caps were consistent over the two months period, as shown in Figure 8.



(a)



(b)

Figure 8. Sensor response using indicator solution made on 30 June 2003. Test conducted on 3, 11 and 18 of July 2003 for the detection of (a) 52 ppm Hydrazine and (b) 400 ppm Nitrogen Dioxide.

6. RECOMMENDED DEVELOPMENT PLAN

The objective of this plan is to design, fabricate and test a more advanced, dual HZ/NO_2, leak detector. The ultimate goal is to detect concentrations as low as ACGIH recommended exposure limits. The research will be conducted in phases, vapor's concentration will be decreased in later phases.
Rather than fabricating just a fiber optic sensor, the final outcome of this proposed project includes a fiber

optic sensor, signal conditioning circuit, microcontroller system and alarm system.

a. Sensor

As indicated in Section 3, two types of sensors could be used for this application; coupling type and modified cladding (evanescent field) type. The coupling type is the one experimented with in the previous section. In this section, suggestions are given to, fabricate the coupling-type sensor using silica fiber and to fabricate cladding type sensor using the same sensing chemical as the one used in this experiment.

Coupling Type: To facilitate using silica fiber in a coupling type sensor, collimators could be attached to the emitting and the collecting fibers as shown in Figure 9. However, in this configuration the two collimators have to be placed at equal angles with respect to the reflecting mirror. While this configuration could be hard to align, the success of the preliminary work guarantees its validity.

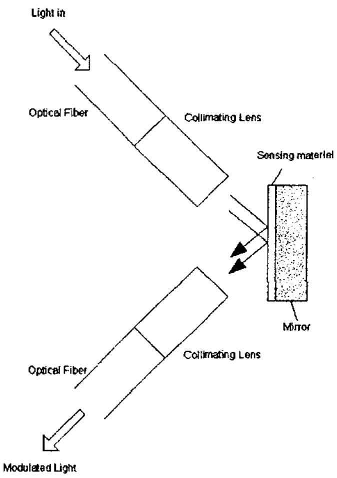


Figure 9. Silica fiber coupling type sensor using collimators.

Modified Cladding Type: Based upon the success of this preliminary work, the following conclusion could be drawn; the red light (λ= 633 nm) reflected off a mirror covered with a sensor film is a function of the gas applied to the film. The same concept is applicable for the second type of sensors: evanescent wave type. The basic modified cladding type sensor configuration as the one shown in Figure 2b should be fabricated and the following parameters should then be evaluated with HZ as well as NO_2:

- Percentage change of received optical power per unit time vs. chemical exposure run.
- Percentage change of received optical power per unit time vs. wavelength.
- Percentage change of received optical power per unit time vs. gas concentration.

b. Electronic Interrogator

An amplifier is a suitable electronic circuit to interface the photodetector to the A/D input. Amplifier gain could be determined to adjust sensor's output voltage to match A/D input allowable range.
To increase the resolution of the detector system, 16 bits - 10-bit A/D microcontroller is suggested to monitor the sensor (Motorola MC68HC12 is suggested).

7. CONCLUSIONS

The stability of the BT/BG mixture in hydrogel was tested over a period of two months and no evidence of performance deterioration was detected. However, there was no permanent baseline value for the start of each trial. The six sensor caps had different baseline values that fell in the range from 150 mV to

350 mV. The differences could be due to inconsistencies in the fiber distance to the mirror, the thickness of the indicator solution on the mirror, and/or impurities (in the form of bubbles or dust particles) in the indicator solution or on the surface of the mirror. The experiment was repeatable with consistent response.

An alarm unit, to monitor sensor's output voltage based on the MC68HC11 microcontroller, was successfully built and tested. This alarm unit successfully detected the presence of HZ (52 ppm) and the presence of NO_2 (400 ppm) in two minutes time. Detection time could be smaller, however the system may be more prone to false alarms.

Recommended development plan includes the development of other sensor types, such as the modified cladding sensor. Several parameters to be tested are suggested such as response vs. chemical exposure run, response vs. wavelength, and response vs. gas concentration. Future development plans also include a 16 bits - 10-bit A/D microcontroller to monitor the sensor.

Acknowledgements

We would like to thank Rebecca Young of YA-C3 for initiating the project and giving us the opportunity to contribute to it. Also, we would like to thank Teresa Lawhorn, Carol Moore and Bill Larson of YA-C3 for their much valued support, as well as Eduardo Lopez of NASA/KSC Organization XA-D1, Cassandra Spears and Tim Kotnour of UCF for facilitating and organizing the Faculty Fellowship Program, under which this project was managed.

We wish to thank Po Tien Huang (YA-D5) for sharing his valued expertise in the Fiber Optic area, Pedro Medelius (EDL) for being instrumental in our circuit design, Jeffrey Rees, Barry Slack and Bob Youngquist for providing the needed electronics for our project, Liliana Fitzpatrick and Steve Parks for the use of the CIP chemical lab and electrical/mechanical lab respectively.

We would also like to thank Marie Reed for providing workspace in YA-E2, and Dan Keenan, Lon Piotrowski, Chaz Wendling, and Charles Ensign for their hospitality during this summer experience.

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APPENDIX A

Hydrazine Detection and Recheck
Page 3

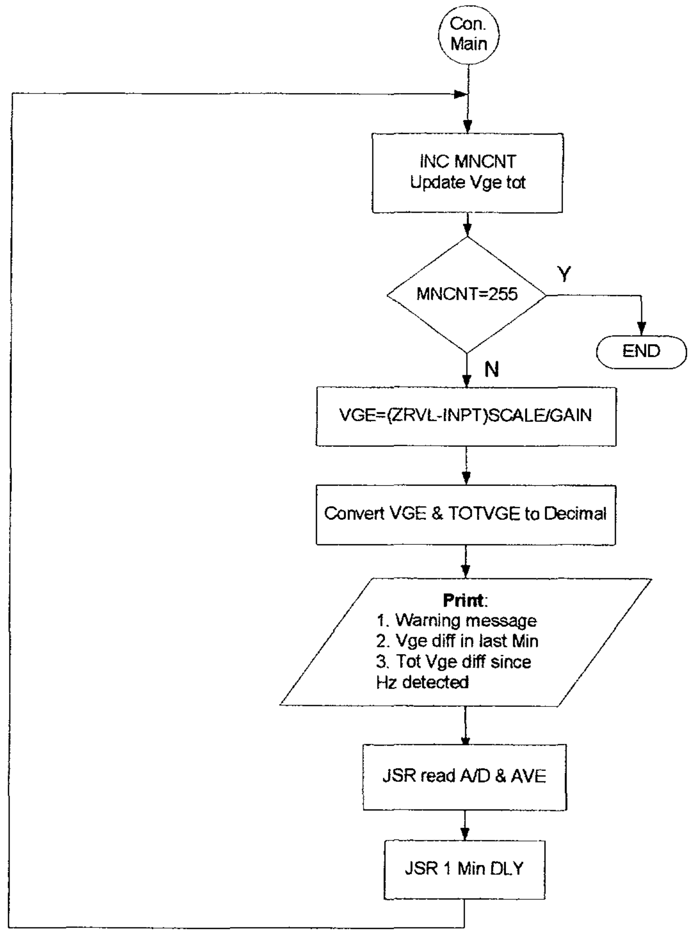

Figure a. Code segment for HZ detection routine (NO_2 routine i.e. Page 4 is very similar)

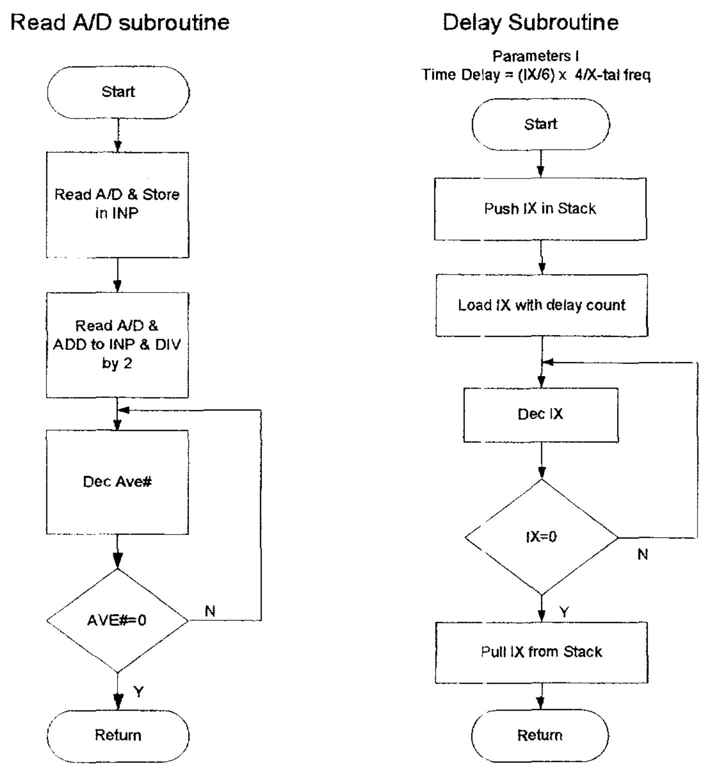

Figure b. A/D Read and Average and Delay subroutines

2003 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

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Development of Charge to Mass Ratio Microdetector For Future Mars Mission

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ABSTRACT

The Mars environment comprises a dry, cold and low air pressure atmosphere with low gravity (0.38g) and high resistivity soil. The global dust storms that cover a large portion of Mars are observed often from Earth. This environment provides an ideal condition for triboelectric charging. The extremely dry conditions on the Martian surface have raised concerns that electrostatic charge buildup will not be dissipated easily. If triboelectrically generated charge cannot be dissipated or avoided, then dust will accumulate on charged surfaces and electrostatic discharge may cause hazards for future exploration missions. The low surface temperature on Mars helps to prolong the charge decay on the dust particles and soil. To better understanding the physics of Martian charged dust particles is essential to future Mars missions. We research and design two sensors, velocity/charge sensor and PZT momentum sensors, to measure the velocity distribution, charge distribution and mass distribution of Martian charged dust particles. These sensors are fabricated at NASA Kenney Space Center, Electrostatic and Surface Physics Laboratory. The sensors are calibrated. The momentum sensor is capable to measure 45 μm size particles. The designed detector is very simple, robust, without moving parts, and does not require a high voltage power supply. Two sensors are combined to form the Dust Microdetector - CHAL.

Development of Charge to Mass Ratio Microdetector for Future Mars Mission

Chen, Yuan-Liang Albert

1. INTRODUCTION

To date, there have been no direct measurements on the surface of Mars that characterize the concentration or distribution of the aerodynamic size, mass, shape, or charge deposited on suspended dust [1]. The dust is of great importance on Mars. Dust appears to have both long-term effects on the surface geologic evolution as well as on the aeolian processes in the present climate conditions. Early spacecraft missions confirmed that changes observed in the planet's surface markings are caused by wind-driven redistribution of dust [2][3][4]. Suspended dust is known to alter the atmospheric thermal structure and circulation. Large, planet-encircling dust storms occur on average once every three Martian years [5][6].

There are three sources by which the dust particles can be charged: (1) Saltation, the process by which small grains of dust are lifted off the surface due to impact of a dust-laden flow; (2) Photoionization, [7][8] soil and dust particles acquire a charge due to incident UV radiation; (3) Triboelectrification. The high frequency of dust devil activity in some regions and seasons and the presence of local and global dust storms produce a favorable environment for inter-particle contact charging. This charging is exacerbated by the low humidity in the dry Martian atmosphere. The wind mixes the dry dust and could produce bipolarly charged dust clouds as happens for both terrestrial dust devils [9][10]. Since grain electrification is easier to obtain in the low-pressure dry atmosphere of Mars [11], there is a good possibility that dust raised during storms would undergo intense electrification. Experimental studies conducted at KSC show that simulant dust is highly resistive and has a long charge decay constant at very low temperature.

The primary objective of this project is to develop the Dust Particle Analyzer (DPA), a microdetector that is capable of performing real time, simultaneous measurements of the mass, the velocity and the electrostatic charge distributions of dust particles in the Martian aeolian process. This objective will be achieved by: (a) the design and development of a low cost, simple, and robust detector; (b) calibrating, breadboard testing and design concept improving; (c) testing and evaluation of the detector in simulated Martian atmospheric conditions with respect to temperature and pressure for the measurement of mass, electrostatic charge, and velocity distributions. This detector is named - CHAL.

2. CHAL DETECTOR DESIGN

. The CHAL detector consists of two major components. They are: (1) velocity/charge sensor; (2) mass/momentum sensor. These two sensors, each serving different purposes, combined to form the detector as shown in Figure 1. The velocity/charge sensor measures the charge of particle and TOF (time of flight) as the particle passed through two identical capacitors at a pre-determined distance.

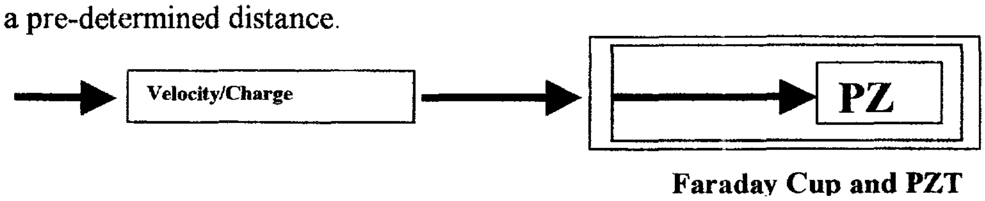

Figure 1. Charged dust particles pass through velocity/charge sensor impacts on the momentum-PZT sensor.

The mass/momentum sensor utilizes a piezoelectric ceramic (PZT) to measure the impact momentum delivered to the PZT. Obtaining the velocity from the first sensor, we can calculate the particle's mass.

2.1 Momentum Sensor

Momentum sensor uses the property of Piezoelectric Transducer (PZT) that changes the mechanical energy (crystal distortion due to stress applied – impacted particle's momentum) into electrical voltage. By calibrating the momentum/voltage relationship the voltage output is translated into the impact momentum of the incident particle as depicted in Figure 2.

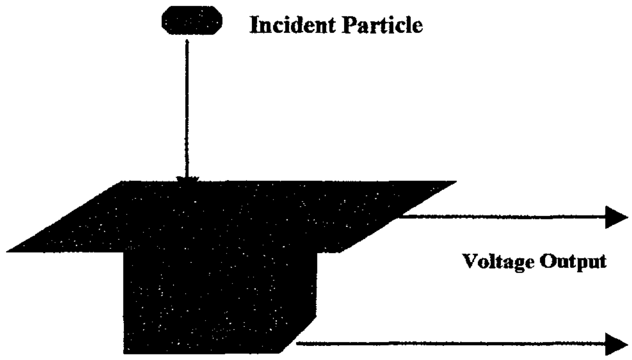

Figure 2. The top plate of PZT Transducer received the momentum from incident particle causes a voltage change at the output

The PZT sensor is calibrated by using "bead dropping" procedure. Different spherical masses (beads) are dropped from different heights to induce a voltage at the PZT output leads. We use 1.4 mg, 2.0 mg and 7 mg iron beads and drop these beads from .1 cm to 3 cm. The results are presented in figure 3. The equation from the curve fitting shows a 0.4377 power factor, which is very close to the 0.5 factor calculated value. Figure 3 presents the relationship between impact momentum and PZT voltage response.

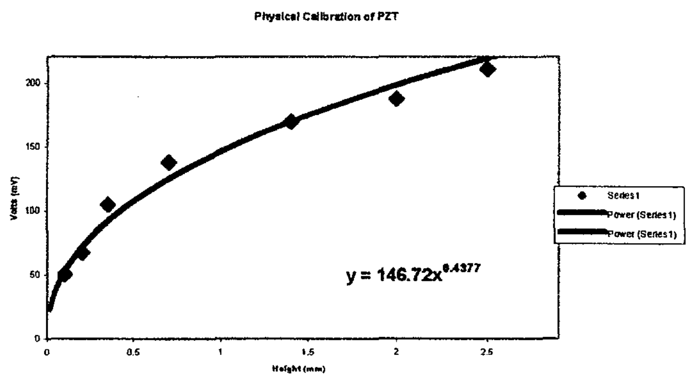

Figure 3. Beads Dropping Results for 2mg iron sphere.

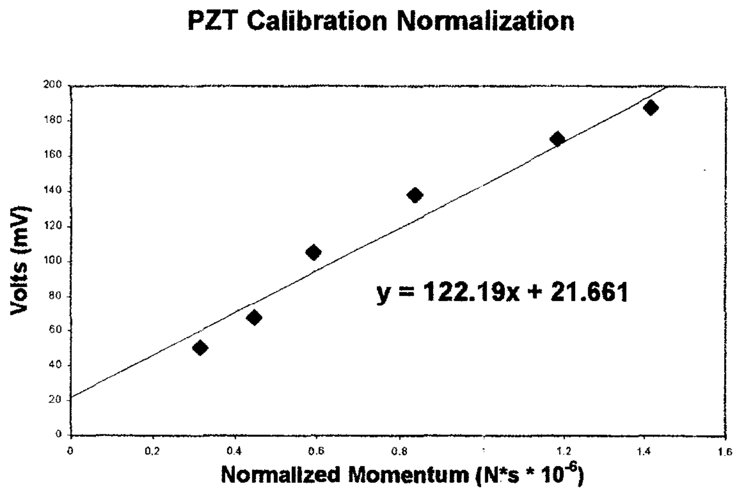

Figure 4. Normalized PZT Bead Dropping of 2 mg iron sphere at different Height. The minimum voltage at x = 0 is 21.661 mV.

The PZT used has a noise level of 10 mV. Including the minimum voltage 21.661 mV from PZT gives the low threshold of 30 mV as shown in Figure 4. The 30 mV is at 0.68 * 10^{-6} Ns, the lowest impact momentum that is detectable by our disc PZT. For a particle with 2.4 m/s. the smallest size that can be detected is 45 μm at a density of 2 g/cm^3 (JSC-Mars-1 simulant).

Advantages of the piezoelectric sensor, PZT, are: (1) low cost of producing and processing; there are many different type sensors for a wide range applications readily available commercially; (2) can be form a different shapes and sizes so it is very adaptive to the instrumentation need; (3) momentum-to-voltage sensitivity can be very high. In this project, we selected a thin disc form PZT. A stack form PZT, instead of disc form, can be selected for higher momentum-to-voltage response to measure smaller particles. The drawbacks of PZT are: (1) temperature dependence - at Mars temperature condition, a temperature calibration parameter will be needed to measure accurately the momentum from the PZT voltage output: (2) PZT is pyroelectric, which means that it is sensitive to sudden temperature. The pyroelectric signal can not be distinguished from the piezoelectric signal. A special caution has to be taken to decide the unwanted signals.

2.2 Velocity/Charge Sensor

When a charged particle passes through the center of a cylindrical capacitor, an equal amount of opposite charge will be induced on the capacitor. By measuring the induced voltage on this capacitor and knowing the capacitance of the cylinder, we can compute the original charge of the passing particle. Setting two cylindrical capacitors at a predetermined distance and measuring the time (TOF) that takes the charged particle to pass through, the particle speed can be calculated. Figure 5 shows a two cylindrical capacitors system that was constructed to perform the experiments. The cylinder is a brass tubing of 0.1875 cm OD, 0.1595 cm ID and 1.0 cm in length. Each cylinder is supported by a 0.5 cm long Teflon spacer and housed inside a 0.347 cm ID brass tube. Two cylindrical capacitors are mounted inside a 0.96 cm ID grounded metal cylinder. The cylinders and amplifiers form the center component of the velocity/charge sensor. Two cylinders are separated by 2.0 cm in the housing tube. The effective separation distance "d" is 3.0 cm. In front of the first cylindrical capacitor, there are three collimator disks to filter and align the dust particles. The collimator has a small hole, diameter 0.033 cm, at the center of the disk. The charged dust particles must pass through three collimator plates to reach the capacitor sensors.

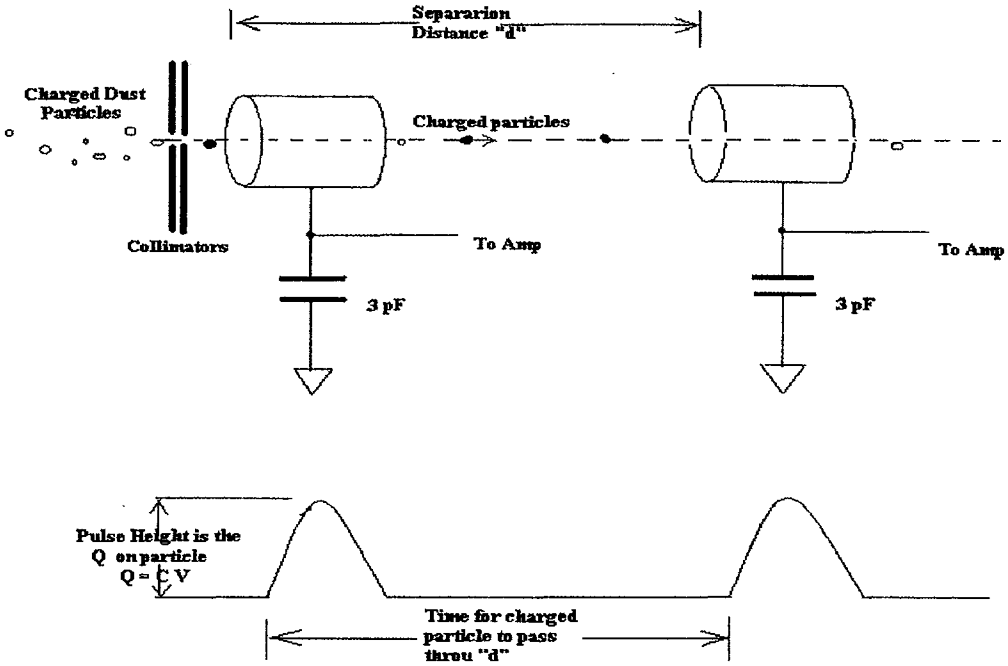

Figure 5. Velocity Sensor Design

The capacitance of the sensing tubing is 49.2 pF [12]. This capacitor in series with a fixed external capacitor, 3.3 pF, forms a voltage divider. The induced voltage is measured through an amplifier with a gain of 21. Figure 6 shows the basic electronics of the amplifier. The amplifier is using a LMC6042 chip, which has two identical OP-Amps. This is a non-inverting amplifier. The total gain of the amplifier is determined by the ratio of two external resisters R_1, R_2, and the voltage divider.

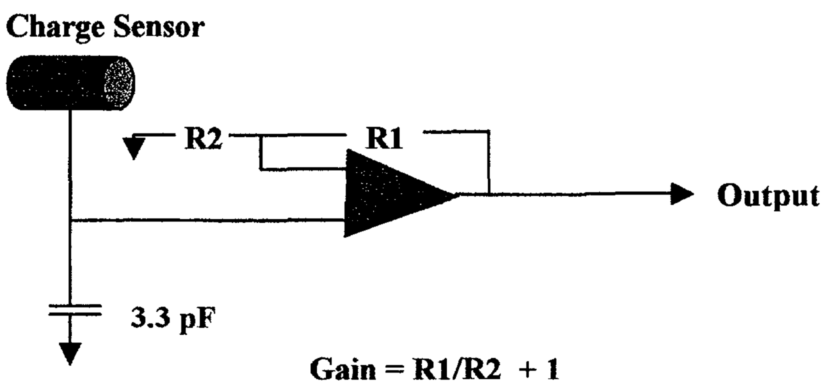

Figure 6. Velocity Sensor Amplifier Circuit

The amplifier circuitry is derived from the MECA electrometer, a proven flight instrument designed and developed by NASA KSC Electrostatic and Surface Physics Laboratory Team and NASA JPL scientists [13][14][15]. We use this circuit to simplify the design and to cut down the hardware cost. A Tektronix Digital Phosphor Oscilloscope (DPO) model DPO3052 (500MHz, 5GS/sec, 2 channels) was used to collect the data. A DPO probe type P6139A (10 Mohm, 8 pF, 500 MHz, 10:1) was used to pick up the output voltage coming from the sensor amplifiers.

The circuit gain is calibrated by sending a calibrated AC signal through a known external capacitor, 160 pF, which replaces the cylindrical capacitor. The output is measured and compared with the input signal. Figure 7 illustrates the calibration procedures.

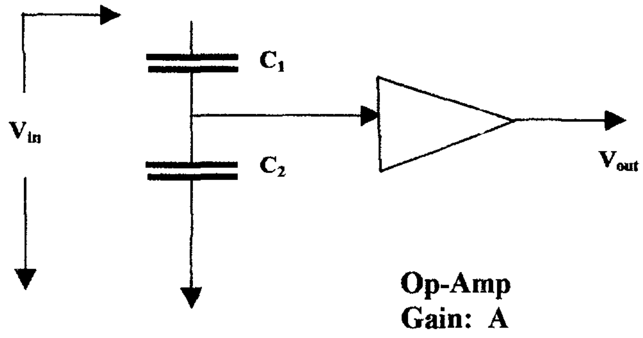

Figure 7. Velocity/Charge Sensor Calibration

The total gain of the sensor **G** is related to circuit components as

$$G = \frac{V_{out}}{V_{in}} = A \cdot \frac{C_1}{C_1 + C_2} \cdot V_{in} \cdot$$

The calibrated G is then used to obtain the charge on the cylinder capacitor by

$$Q_{cyl} = C_{cyl} \cdot V_{cyl} = \frac{V_{out}}{G} \cdot \frac{C_2}{C_{cyl} + C_2} \cdot C_{cyl} \cdot$$

The G value has to be determined by experiment. A signal generator supplies a 200 mV input voltage with variable frequency was used. The data are recorded for V_{out}/V_{in} with respect to frequency.

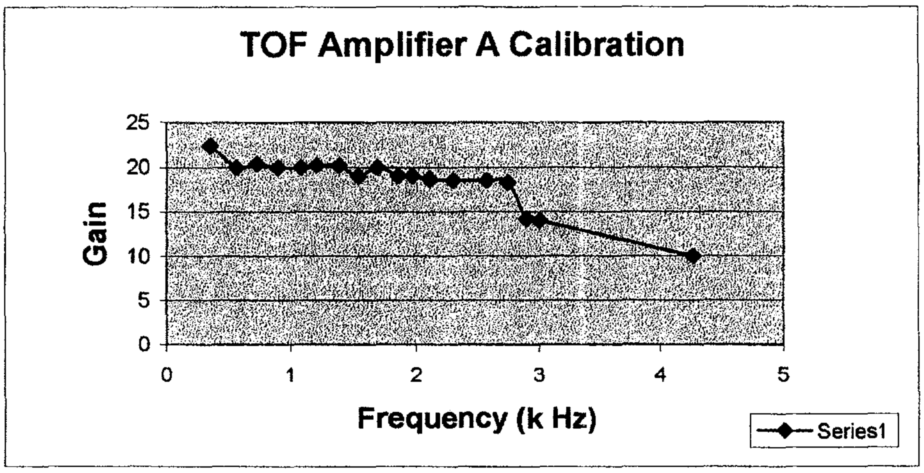

Figure 8. Calibration Results for Amplifier A, the amplifier applies to the first cylindrical sensor. It has a constant total gain between 450 Hz to 2.8 KHz.

Figure 8 shows the calibration results for the first of two cylindrical velocity/charge sensor. The total gain has a fairly flat area at 450 Hz to 2.8 KHz. This means that the amplification within this region is frequency independent. The lower limit of particle speed detectable is around 2 m/s; the upper end is at 12.4 m/s for this constant amplification region. For higher particle speed, the gain factor in the calibration curve has to be taken into consideration.

Delivering dust to the CHAL microdetector testing is the most difficult task. One of the methods is using the Dust Impeller in a vacuum chamber to test the system. The impeller fan propels dust particles to the velocity sensor. We are currently working on different dust delivering schemes.

3. DISCUSSION

The velocity/charge sensor is very simple, inexpensive to build, and can be fabricated into a very small instrument to measure the velocity vector as well as charge of dust particles on Mars. The small cylindrical capacitor configuration with the amplifier has high input impedance. It is necessary to take extra care for noise reduction. We find that by packaging the sensors in a conducting enclosure reduces the noise a great deal. A single dust particle source is needed to test the velocity/charge sensor.

In Martian atmosphere conditions, due to a 0.38 g Martian gravity, the lower limit of particle speed is approximately 1.5 m/s to 2.0 m/s. Slower particle detection can be achieved by shorting the distance between the cylindrical capacitors, and/or increasing the diameter of the cylinders. The upper limit of the particle velocity is controlled by the speed of the electronics.

The Quartz Crystal Microbalance (QCM) has been widely used for micro-scale mass detection. The QCM is reliable and able to detect very small mass. However the electrostatic adhesions of dust particles require an extra effort to clean the detector. The PZT can be made very small. It has a fast response, simple design, and is very inexpensive. The PZT needs calibration for temperature and momentum/voltage sensitivity. We selected the PZT over the QCM for the reasons that PZT handles the dust adhesion with better single response for single dust particle, and smaller physical size. The PZT sensor is capable of measuring the individual particle mass to collect the mass distribution of Martian dust particles and total charges over a given period of time.

4. CONCLUSIONS AND FUTURE WORK

We designed the velocity/charge sensor with a few targets in mind: (1) simple, (2) inexpensive to build, (3) small size, and (4) fewer problems of dust cleaning and maintenance. The current research efforts at NASA KSC Electrostatic and Surface Physics Laboratory are also concentrating on the development of miniaturize the Electronic Single Particle Aerodynamic Relaxation Time (E-SPART) analyzer that is capable of performing real time, simultaneous measurements of the aerodynamic diameter and the electrostatic charge distributions of dust particles in the Martian aeolian process. The E-SPART analyzer requires a high voltage power supply and offers a fast response for possible multi-particles analysis. The E-SPART is quite expensive. The detector developed in this project is a complementary instrument to the NASA KSC E-SPART analyzer to cover the area that requires a quick measurement and works under a more restrained environment. We are also developing the CHAL automation to make this sensor more adaptable to those applications require charge measurement over small particles.

ACKNOWLEDGMENTS

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UNIVERSITY OF CENTRAL FLORIDA

LIGHTNING INSTRUMENTATION AT KSC

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ABSTRACT

This report summarizes lightning phenomena with a brief explanation of lightning generation and lightning activity as related to KSC. An analysis of the instrumentation used at launching Pads 39 A&B for measurements of lightning effects is included with alternatives and recommendations to improve the protection system and up-grade the actual instrumentation system. An architecture for a new data collection system to replace the present one is also included. A novel architecture to obtain lightning current information from several sensors using only one high speed recording channel while monitoring all sensors to replace the actual manual lightning current recorders and a novel device for the protection system are described.

LIGHTNING INSTRUMENTATION AT KSC

Jose L. Colon

1. INTRODUCTION

Lightning is a natural phenomenon, but can be dangerous. Kennedy Space Center is located near the maximum lightning activity and lightning represents a hazard for all phases of space lift operations. Prevention of lightning is a physical impossibility and total protection requires compromises on costs and effects, therefore prediction and measurements of the effects that might be produced by lightning is a most. The Air Force Weather Squadron provides prediction of lightning at KSC using several ground-based instruments and it is well attended. Protecting the launching pads from lightning effects cannot be absolute, but some critical sections are now exposed to possible lightning strikes. Adding more protecting wires can reduce the probability. Adding and inexpensive corona device to the actual protection wires might also help to reduce this probability, but further analysis and investigation is needed on this subject.

Measurements on several electrical parameters are needed to evaluate possible effects on sensitive electronic equipment and most of them are been measured. But the electric and magnetic fields induced by lightning currents in the Payload Changeout Room (magnitudes and rate of change) are not been monitored. This data is needed to determine possible damaging effects into payload. The system in use to determine the lightning effect in the slide wires is a manual reading system, which is time consuming and requires a complex calibration process and does not provide all the needed data. This system can be replaced with a novel one that can provide the needed data in electronic format for integrated processing using only one high-speed channel recorder.

2. LIGHTNING PHENOMENA

The atmosphere is an electrical insulator or not a good conductor. Due to sun energy or radiation, moisture is always present and accumulates forming clouds. Since the atmosphere with the clouds is a gas with particles in continuous movement, due to the same sun activity, there are collisions continuously, and an ionization process is present that produces a huge amount of positive and negative charges. These charged particles tend to separate under the influences of upper drafts and gravity and same type of charges accumulates in large sections of the cloud [1]. This will produce an enormous electric potential (voltage that can amount to millions of volts) within the cloud, between clouds, between clouds and ground, and also between cloud and upper atmosphere or stratosphere.[1]

When an insulator; any insulator (solid, liquid, or gaseous) or a semiconductor, is subject to a high voltage across it, the covalent bonds of the molecules, will "breakdown"(as it is named) producing a large amount of conducting electrons and the material becomes a good conductor. (This effect is known as the Zener breakdown in solid semiconductors and Plasma for gasses.) The total voltage will be distributed between the charged regions and, since it is a gas with moisture in a continuous movement, density is not uniform and the ionization will take place in sections called step leaders. Once a section is ionized will affect the voltage distribution and higher voltages will be present at other sections still not ionized. This sequence is like a domino effect, and will occur real fast. It has been estimated to occur in microseconds[2]. When the steps meet, a conducting channel is available for charges to move or discharge, and lightning begins.

Since the effect will occur between high voltage regions, lightning can occur within the cloud, between clouds, between clouds and ground, and between clouds and upper atmosphere.
Since the process is produced by a high intensity electric field, the field can be measured and it is used to predict lightning occurrence.
Once the path is available, which happens to be a good conducting path between two charged regions with millions of volts, it will produced a sudden current flow up to hundreds thousands amps. Peak power has been estimated in gigawatts. The current flow will start fast with rise time measured in the range of 2 to 10 microseconds. The length and duration of each lightning stroke vary, but typically average about 30 microseconds [3].
This high current, changing at such a fast rate, will produce magnetic fields in the area that will induce voltages and currents on other nearby conductors due to magnetic coupling. The induced voltages or currents can affect and damage sensitive electronic equipment. Another effect, that produces high voltages nearby, is also present in a lightning strike. Due to the high and fast changing electrical field, any nearby exposed conductive (or semi-conductive) and electrically insulated section will be charged by capacitive coupling that can also produce ionization and an electrical path between that section and grounded areas generating sparks between them. This effect can also damage sensitive equipment and will be very dangerous if combustible materials are present. Notwithstanding, this capacitive coupling effect can be eliminated with good grounding techniques.
The magnetic field produced by the lightning current can be measured and it is used to detect that lightning has occurred and how strong was it.
Since lightning is a high voltage discharge, the generation of high energy particles like X rays and Gamma rays had been predicted. A recently research at the University of Central Florida by Dr. Joseph Dwyer obtained data indicating that X rays are present in lightning strikes.
Since the lightning flash occur in microseconds, the lightning channel will be heated to the order of 20,000 degrees C or more (3 times the temperature of the surface of the sun!), and the air expansion will produce a shock wave (for approximately the first 10 meters), then decay to a sonic wave or thunder as it propagates away from the channel.[1]
This sonic wave can be measured and is to be used to accurate locate the strike point. [4]
The cloud to ground lightning strikes is not the most common type, but it is the most damaging, and dangerous form of lightning. The event can start with a corona effect from sharp pointed conductive objects at ground level. (This is a basic concept for lightning rods)
The lightning flash is composed of a series of strokes with an average of about three to four per strike. The initial stroke usually produces the strongest current and successive strokes will be less than half the previous stroke current. Fifty percent of all strikes will have a first strike of at least 18KAmps, ten percent will exceed 65KAmps level and only one percent will have over 200KAmps. The largest strike ever recorder was almost 400KAmps. [3]

3. LIGHTNING PREVENTION

Since Benjamin Franklin, the use of lightning rods in preventing or reducing the damage from direct lightning strikes has been demonstrated. But, many attempts have been done to market other types of lightning protection systems claiming prevention properties. The Charge Transfer Systems and the Early Streamer Emission are two examples. Other researchers have analyzed this subject and their conclusion is that these systems do not work. [5a, 5b] One of those systems was tested at KSC and results confirmed that conclusion.

4. LIGHTNING PREDICTION

Lightning and weather has a direct relationship; weather data is used to predict lightning and lightning data is used for weather prediction. Investigations using rockets, high-altitude airplanes and spacecrafts had been carried out and there are other lightning related research projects in progress focusing on the relationships between global and regional lightning activity and rainfall, linking electrical development to the environments of surrounding storms.

Researchers to determine the relationship between the quasi-static ground electric field and the occurrence of lightning have done studies, but none are conclusive. Further research is needed. Several experimental spacecraft systems are available with weather data that also provide lightning data: the Lightning Image Sensor on Tropical Rainfall Measuring Mission with circular orbit that can locate and detect lightning with storm scale resolution, the Optical Transient Detector, that detects momentary changes in an optical scene which indicates occurrence of lightning and the Lightning Mapper Sensor in a geostationary orbit that detects all forms of lightning, determine flash rates, storm motion and evolution.[6]

There are also Ground Based Lightning Detection Networks with magnetic direction finders that cover the entire USA and determine direction toward a detected electromagnetic discharge [1]

5. LIGHTNING HAZARD AT KSC

Lightning presents a significant hazard to all phases of space lift operations. These activities, which often occur outdoors, can involve propellants, ordnance, and sensitive electronic systems, all at risk from nearby or direct lightning strikes. During the actual launch, the vehicle and its payload are even more at risk because of the threat of a triggered strike. [7]

KSC is located near the center of maximum lightning activity. The avoidance of lightning strikes to a spacecraft during launch relies heavily on the ability of meteorologists to accurately forecast and interpret lightning hazards to NASA vehicles under varying weather situations. [1]

Severe hazards for NASA due to lightning have been well documented. One major incident occurred during the 1969 launch of the Apollo 12 mission when lightning briefly knocked out vital spacecraft electronics. Fortunately, the astronauts regained control.

The unmanned Atlas Centaur 67, which carried a Naval communication satellite, was determined to have been struck by a triggered cloud-to-ground lightning flash on March 26, 1987. The lightning current apparently altered memory in the digital flight control computer. This glitch resulted in the generation of a hard-over yaw command, which caused an excessive angle of attack, large dynamic loads, and ultimately the breakup of the vehicle. [1]

On a smaller scale, two sounding rockets being prepared for launch from NASA's Wallops Island in 1987 were prematurely launched as a direct result of lightning. [1]

6. KSC LIGHTNING FORECAST

To assess the triggered lightning threat, the United States Air Force and NASA jointly developed a complex set of weather launch commit criteria (LCC) [8]. Air Force 45th Weather Squadron evaluates these LCCs (and detects and forecasts natural lightning), using an extensive suite of instrumentation deployed throughout the ER and KSC. Five independent ground based systems are in used for this purpose with closer spaced detectors to provide real time location of lightning in a 6 to 10 Kilometers range with 5% resolution. [9,10]

7. LIGHTNING PROTECTION

Traditional lightning protection has proven to be the best solution. The principle is simple: provide a Faraday cage type of structure or equivalent by placing preferential strike points using electrical conductors higher than the object to be protected and connected to a good grounding system to carry the damaging currents. It is also needed to provide appropriate transient protection on power and signal wires entering the structure. [3] Lightning rods, or sharp pointed electrical conductors at the highest points in an area, connected to a good ground plane has proven to provide protection from lightning strikes.

8. KSC LIGHTNING PROTECTION AT LAUNCH PADS

The launching pad is a massive conductive structure with a good grounding system. It also has appropriate transient protection on power and signal wires. But, the Space Shuttle, when in place before launch, is exposed to lightning. A catenary steel wire is installed on top of the structure on an electrical insulator (fiber glass mast, 70 feet tall on top of the metal structure), extending 1,100 feet north and 1,100 feet south, well grounded at both ends, to provide a preferential strike point for lightning. (Good grounding is a critical condition for this purpose and it is required to be tested periodically.)

There are also seven slide wires to provide an escape route for personnel. Another catenary wire is installed on top of the slide wires to reduce the probability of a strike to the slide wires.

9. LIGHTNING MEASUREMENTS AT KSC LAUNCH PADS A&B

Lightning strikes produce a high magnetic field with a fast rate of change that will induce high voltages on conductors in the nearby surrounding area. Electric resonant effects of the protecting wires and the structure can also contribute to high-induced voltages. Since the payload is typically sensitive electronic equipment that can be damaged by transient induced overvoltages; existing launch procedures require that, in the event of nearby or direct lightning strike, launch procedures be suspended and system level tests be performed to confirm that damage or upset has not occurred.

The catenary wire on top of the structure provides a means to measure the magnitude and duration of the strike current. A recorder is always monitoring the current at both ends of the wire. (CWLIS equipment)

The Vent Line is a critical system that requires electric signals for operation and the current waveform on this line is also monitored with the same CWLIS recorder.

AC power lines (AC and Neutral), DC Power Supply lines (Positive and Negative), and a system ground line are monitored continuously to detect transient overvoltages and both T/0 cables are monitored for induced currents. (LIVIS equipment).

Each slide wire and the catenary wire on top of them are monitored with current recording devices (LCR equipment). This is a very simple, passive, and low cost device that can record the peak value of the lightning current. Each catenary wire current is also monitored with this type of current recorder as a back-up provision.

The Operational Television System (OTV) is a video recording system to provide video images for location of the strike. Three images need to be visually analyzed to locate the strike point. Another instrument; the Sonic Lightning Location system, is to be installed at the launching pads. This equipment determines the time of sound arrival and, by triangulation techniques, can locate the strike point. This equipment promises to measure electronically the location of the lightning strike with an accuracy of better than 5 meters in a 500 meters radius. [11]

10. KSC LIGHTNING PROTECTION SYSTEM LIMITATIONS

The Catenary Wire, used to provide lightning protection, is a long steel wire electrically isolated from the structure (approx. total length of 2,500 feet) that should have an equivalent inductance in the order of several hundreds microHenries. [12] The wire needs to be grounded at both sides forming a conductive loop with the ground plane. This loop will be charged with current from the lightning strike. This arrangement can produce higher induced voltages than without it, but the wire is needed as a protective means from a direct strike! (Its natural response will be part of the effects. See Appendix B for oscillatory response of the wire.)

The catenary wire will receive most of the strikes, but cannot provide total protection to all the slide wires nor the Vent Arm, the External Tank, nor Orbiter. These critical sections are under the so called "cone-of-protection" or "zone of protection" concept, but his concept is used to explain lightning protection on ordinary structures that are not too tall. The "Rolling Sphere" concept, incorporated into lightning codes, is a better concept and it has become the standard practice for design. Applying this concept to the Pads, the catenary wires are not protecting these critical sections. (The Orbiter will be protected when the Rotary Service Structure is in the mate position.) Data available (without the Orbiter) indicates lightning strikes at the pad but not on the catenary wires.

The slide wires are not all protected by the catenary wires. Lightning can strike the outer ones and it has already happened. If lightning strikes a slide wire, it can produce metal spots and/or may weaken the wire affecting its performance as a fast escape mechanism, therefore it is required to be tested after a direct strike onto it.

11. INSTRUMENTATION SYSTEM LIMITATIONS

A. Lightning Current Recorders (LCR)

Testing each slide wire is a time consuming process and often unnecessary. If data of the lightning event is available indicating which wire was stricken and if the strike was strong enough to cause any damage to the wire, it will avoid unnecessary testing and delays.

Although the testing process of the slide wire has been greatly improved with robot TV cameras, the data provided by the LCRs for each slide wire indicates peak current only, and does not indicate time duration of the current or waveform, which is an important factor to determine potential damages.

Furthermore, the maintenance and reading of the LCRs, is a manual process, the device requires a complex calibration procedure, and spare parts needed are no longer commercially available.

B. Lightning strike location

The resolution of magnetic field lighting detection system used to predict lightning occurrence is not enough to determine location of the strike. (Resolution of that system is in the order of 350 meters.) Data from the television camera system not always provide an accurate location of strike. It has happened that only one or two cameras have provided needed pictures of the strike. The new Sonic Lightning Location system can overcome this limitation.

C. Electromagnetic field

Power lines (AC and DC), and control lines are monitored in the Mobile Launch Platform, but the electromagnetic field inside the Payload Changeout Room (PCR) is not been measured. The electromagnetic field intensity can indicate the possibility of damage to sensitive components. The rubber seals around the mating surface of the PCR fitting against the orbiter or Payload Canister are electrically open spaces where the magnetic field can penetrate. The study, "Induced Lightning Effects inside Payload Changeout Room" [12], demonstrates the presence of magnetic induced fields inside the room due to lightning currents on the catenary wires.

D. Vent Line Pic Cable current sensor

Vent Line Pic Cable is been monitored for induced current, but waveforms show too high noise present in the signal and signal seems to be an induced voltage from the magnetic field, not real current in the cable.

12. CAPE CANAVERAL AIR FORCE STATION

At Cape Canaveral Air Force Station launching pads (SLC-17B: Delta, SLC-36B: Atlas, SLC-40: Titan) a Faraday Cage type of structure is used with 28 wires electrically interconnected providing a good protection system.

A measuring instrumentation system called On-Line Monitoring System (OLMS) with 16 high speed data channels that can measure and record the magnetic field, electric field, transient voltages and induced currents is in used. (The catenary wires current are not all measured, only two of them, because it will require too many channels for that purpose) The OLMS system was developed by SRI International to support spacecraft launches at a number of launch sites in the United States. OLMS is installed on SLC-17B (Delta), SLC-36B (Atlas), and SLC-40 (Titan) at Cape Canaveral, and SLC-3E (Atlas) and SLC-4E (Titan) at Vandenberg Air Force Base. [13]

13. ALTERNATIVES AND RECOMMENDATIONS

A) Protection

Protection from lightning strikes is a safety issue. Although absolute protection is not possible, any reasonable measure that can reduce the probability of a lightning strike to critical areas shall be seriously considered.

_Adding more catenary wires, closer to the vehicle (in the horizontal projection, further in the vertical projection) and electrically interconnected will reduced that probability providing a better protection system and will reduce the electrical parameters of the array also reducing induced voltages. (The optimum location and the strength of the actual supporting mast for the additional load will need evaluation.)

_Reinstall the original wire used for lightning protection at the center of the lightning mast and electrically interconnect to the main catenary wires, this will reduce the electrical characteristics of the array. A sensor connected to one recorder channel will be needed for this wire

_Adding lightning rods on top and upper sections of the catenary wires to stimulate possible corona effect for a better preferential strike area, instead of nearby sections, shall provide better protection. The idea can be accomplished with sharp pointed lightning capturing rods arranged in a star or crown shape form for better effect and easy installation. This inexpensive corona device (CD) should be mechanically and electrically connected to the catenary wires. This is a novel device based on the same old principle of the lightning rods that can make the catenary wires more attractive for lightning strikes than its surrounding structures. Several CDs spaced apart at the top and upper section of the catenary wires should provide a better preferential area for lightning strokes. This idea is based on data from two studies to protect photovoltaic (PV) panels [14,15], and will require investigation and analysis Furthermore, the weight that can be added to the catenary wire needs to be analyzed to decide material to be used in the construction of the CDs and how many can be safely added. A robot mechanism, similar to the one used for testing the slide wires, can be developed to simplify the installation of the CDs without taking the wires down. These CDs, properly designed, will also dampen or reduce the mechanical vibrations of the wire, thus reducing the mechanical stress. A sample drawing for these CDs is included in Appendix C of this report.

_Evaluate cost of installing one or two more wires on top or slide wires to protect them from direct strokes versus cost of testing and possible replacement of the wires due to lightning effects. (If the actual wire on top of the slide wires is relocated, only one additional wire will then be needed for this purpose.)
_Eliminate the insulated section of the wire on top of the slide wires and electrically interconnect with the main catenary wire. This wire does not have to be insulated from the main catenary wire if current is measured on each wire, including this wire. The interconnection will contribute to reduce the electrical parameters of the array. (The insulation in used will not really "insulate" because, if a stroke hits that wire, the inherent inductance of the wire will maintain the current flowing, shorting it to the main catenary wire if the lightning path tends to open.)

B) Measurements

a) Modify or Replace Lightning Current Recorder System

-**Modifications**: Five possible set-ups for this system

1.Install current transformers connected (wired) to the recorder used for catenary wires with a multiplexer

2. Same as one above, but with new multiple channel measuring and recording system (one channel for each slide wire)

3.Develop a new detector circuit with local AC Powered and using same AC power lines for communication

4. Develop a new detector circuit with battery power and storage of data for wireless retrieval.

5. Develop a new detector circuit with battery power and wireless communication.

-Replacement

Develop a new system with one current sensor for each slide wire, interconnected to one recording channel and a monitoring circuit with slave current sensors for each sensor line. This is a novel architecture that will require only one high-speed recording channel while providing needed data for each wire. The monitoring circuit will detect and store the peak level and time of arrival. The arrangement can also be used to monitor several catenary wires, but the "latch" circuit should select the first signal (above a defined threshold level) for waveform storage. A block diagram or architecture for this recorder system is included in Appendix A.

b) Accurate Lightning Locator System
The new SOLLO System should be finally installed and tested.

c) Electromagnetic Field Recorders
Install Electromagnetic Field Recorders or sensors at Payload Changeout Room
Or provide portable temporary magnetic field recorders that can be placed near sensitive equipment. (If at least three sensors are installed at the PCR, this portable recorder will not be needed.)

d) Power and Communication Lines
If power and communication lines are to be connected to payload equipment, provide temporary transient voltage recorders or sensors for each line.

d) Vent Line current sensor
Add a current sensor placed parallel to the Vent Line current sensor but without the inner cable, and measure the differential signal between them to cancel the magnetic field induction signal.

e) Previous recommendations for PCR
Implement the recommendations indicated in report: "Lightning Effects in the Payload Changeout Room"[12]. All these recommendations will contribute to reduce hazards and to reduce induced magnetic fields inside Payload Changeout Room.

C. System Integration
The recommended systems above provide the collected data from sensors in a format that can be analyzed and displayed with proper algorithms (except for the TV images, if used). This will allow generation of the needed information: magnitude, rate of change, and time duration of the electromagnetic fields, voltage, and current signals and location of lightning strikes in an integrated format for easy access and displaying even on the Web. The actual LIVIS system can be up-graded adding another four channels recorder for the new electric and magnetic sensors but it will require a program to integrate the data for proper display.
The OLMS system does include the integration program. Both systems will need the new current recorders and the SOLLO system. Block diagrams for both systems are included in Appendix A.

14. CONCLUSIONS

The Lightning Protection System and the Lightning Instrumentation System installed at KSC Launching Pads 39A&B can be up-graded to provide a safer system that will reduce risks, re-testing and delays. Two more catenary wires on the vehicle side of the Pads with the corona devices installed, reinstallation of the original center wire, and another wire and relocation of the actual catenary over the slide wires, will provide a better protection system. The actual instrumentation system can be up-graded by adding another four channels recorder with electric and magnetic sensors and the needed program, or installing the OLMS system. Both systems will need the new current recording system and SOLLO system to obtain an integrated lightning instrumentation system.

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2003 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

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Development of Algorithms for Control of Humidity in Plant Growth Chambers

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ABSTRACT

Algorithms were developed to control humidity in plant growth chambers used for research on bio-regenerative life support at Kennedy Space Center. The algorithms used the computed water vapor pressure (based on measured air temperature and relative humidity) as the process variable, with time-proportioned outputs to operate the humidifier and de-humidifier. Algorithms were based upon proportional-integral-differential (PID) and Fuzzy Logic schemes and were implemented using I/O Control software (OPTO-22) to define and download the control logic to an autonomous programmable logic controller (PLC, 'Ultimate' ethernet brain and assorted input-output modules, OPTO-22), which performed the monitoring and control logic processing, as well the physical control of the devices that effected the targeted environment in the chamber. During limited testing, the PLC's successfully implemented the intended control schemes and attained a control resolution for humidity of less than 1%. The algorithms have potential to be used not only with autonomous PLC's but could also be implemented within network-based supervisory control programs. This report documents unique control features that were implemented within the OPTO-22 framework and makes recommendations regarding future uses of the hardware and software for biological research by NASA.

Development of Algorithms for Control of Humidity in Plant Growth Chambers

Thomas A. Costello

1. INTRODUCTION

Considerable plant growth chamber infrastructure has been maintained by NASA within the Biological Sciences Office at Kennedy Space Center (KSC). The systems were used to study response of crop plants to changes in artificial light regimes, controlled gaseous composition, temperature, atmospheric pressure, and nutrient/water delivery. The intent of the research was to optimize systems to grow food, regenerate oxygen, remove carbon dioxide, recycle nutrients, stabilize wastes and purify water for long-term space missions. At present, this infrastructure for advanced life support research, including 6 plant growth chambers, is being moved from Hangar L (and Little L) at the Cape Canaveral Air Force Station to a new NASA/KSC facility owned by the State of Florida (known as 'SERPL'). With the move, there will be installation of 9 additional plant growth chambers, along with the associated environmental systems, controls and software.

Although commercial environmental controllers were typically included with each chamber, researchers have preferred to use these only as a backup, and have relied principally upon custom data acquisition and control hardware/software. In the past, custom NASA-developed software (i.e., UNDACE, Universal Networked Data Acquisition and Control Engine) operated on a Unix workstation, and was interfaced via serial communications to input/output modules that provided connection to sensors and actuators. The UNDACE scheme was successful not only in providing real-time control and automatic data acquisition but it also provided a visual interface for researchers to easily review growth chamber conditions during an on-going experiment. Despite its past functionality, UNDACE will not be implemented in SERPL because of the inability to transfer and maintain the code to a newer web-based platform.

In the new facilities, the function of UNDACE will be performed either by autonomous control algorithms residing in local programmable logic controllers (PLC's, i.e., 'Ultimate' ethernet brain with associated input/output modules, OPTO-22, Temecula, CA) or by supervisory control programs residing on a network server. In either case, researchers should have the ability to select/design specialized control algorithms to optimize the control of lights, carbon dioxide, heating-cooling equipment, humidifying-dehumidifying equipment and other devices which impact the life support experiments.

In growth chambers, humidity is a relatively difficult parameter to control because of its interactions with the heating-cooling equipment. For example, the process of cooling air often removes water via condensation at the cooling coil. This impact depends upon the dynamic energy balance of the chamber, which can be affected not only by the selected inside temperature setpoint and the ambient temperature external to the chamber, but also by changes in heat introduced by artificial light fixtures/lamps. Moreover, variations in chamber temperature (T) necessarily impose concurrent fluctuations in relative humidity (RH) because RH depends upon saturation vapor pressure, which is a direct function of T. Control is further complicated by the use of two devices, a humidifier (HUM) and de-humidifier (DEH), to independently effect increases and decreases in humidity in an attempt to achieve the targeted humidity setpoint.

A simple approach to humidity control has been previously tested using autonomous PLC's at KSC. The algorithm used an RH setpoint (with specified deadband) as thresholds to activate timed on/off control of the HUM and DEH. Whenever HUM or DEH was triggered, the specified on-time was followed by a required, fixed wait (off) time. The disadvantage of this type control was that the fixed on-times and off-times do not allow the controller response to be sensitive to the magnitude of the deviation between the current RH and the setpoint; thus, the devices may respond too slowly or they may overshoot. Overshoot causes the two devices to operate alternately in sequence with one device counteracting the overshoot of the other. Although this control scheme provided approximate control resolution of 5% of the RH setpoint, excessive HUM and DEH activation was inherent.

Because of the interaction between T (and temperature control) and RH, it was hypothesized that a more stable control might be obtained if *absolute* humidity (e.g., vapor pressure, VP) were used as the process variable. To accomplish this, the VP would need to be computed in real time based on measured values of T and RH. This would necessitate the use of a controller that is able to perform real-time digital computations. Given that such a controller is used, then the flexibility would also exist to implement a variety of control algorithms, including those using PID (proportional-integral-differential) or Fuzzy Logic.

Objective

The objective of this project was to develop and test humidity control algorithms that operate with the following desired characteristics: a) deviations from a VP setpoint will be minimized to achieve the desired humidity conditions, b) activation times of the HUM and DEH will be minimized to extend the life of the devices, and c) frequency of cycling of the HUM and DEH will be minimized to extend the life of control relays, valves, and motors.

2. DESCRIPTION OF THE ALGORITHMS

Control algorithms were designed to use the computed water vapor pressure (VP) as the process variable, with time-proportion outputs (TPO) to operate the HUM and DEH. Multiple algorithms were developed, including those based upon a proportional-integral-differential (PID) scheme and others using a Fuzzy Logic scheme. The algorithms were implemented using I/O Control software (OPTO-22) to generate and download the algorithms to the autonomous Ultimate PLC, which performed the monitoring and control logic processing, as well the physical control of the devices, which effected the targeted environment in the chamber.

With the I/O Control package, logic could be defined using a limited set of instructions represented in flow-chart form, or the control engineer could define a control program using a script language similar to Visual BASIC or C, with real-time access to sensor readings and the ability to manipulate digital and analog outputs. Use of the script language was preferred for this project due to the prevalence of detailed conditional logic that is tedious to define using the flow-charting facility. The actual script text for the algorithms can be obtained by contacting the senior author. A summary of algorithm features is presented here.

PID Algorithm

Control of a process using a PID algorithm is a form of feedback control in which a device/actuator is fed a control output that is intended to effect changes in the selected process variable toward some targeted setpoint value. The control output is computed as a function of the dynamic trend in the process variable, given by the classic PID equation (e.g., Harrison and Bollinger [1]):

$$O = P * E + I\int E dt - D \frac{dE}{dt} \quad \text{Eq. [1]}$$

where, O = the control output,
P = proportional gain parameter,
E = error = (set point – process variable),
I = integral gain parameter,
t = time, and
D = derivative gain parameter.

Historically, the PID control was used with analog controllers. The algorithm can operate on a digital controller by computing the output at some arbitrary time interval called the scan time (t_{scan}). During each scan, the error, the accumulated error (a numeric integration) and the derivative of the error (the numeric approximation) are updated and then used to compute the contributions to the output based on P, I, and D, respectively. The P-gain is the primary control component that provides increased output as the process variable deviates from the setpoint (note that it can be positive or negative depending upon the sign of the error). The I-gain provides an adjustment to the output to avoid fixed offsets (persistent error) that are often associated with proportional controllers. The D-gain provides an adjustment that tends to decrease the rate of approach toward the setpoint or decrease the rate of divergence away from the setpoint, in an effort to attain control at the setpoint in minimal time with minimal overshoot.

Modern implementation of a PID in a digital controller provides the opportunity to modify the classic PID output using conditional logic to optimize system response. A number of modifications to the classic PID were implemented using the script language in I/O Control to operate the HUM and DEH, as described below. The computed VP was the process variable, computed using the method of ASAE [2], based on measurements of T and RH.

The PID algorithm output was defined in the range from –10 to 10, with negative values (-10 to 0) referring to DEH duty cycle from 100% (steady ON) to 0% (steady OFF), and positive numbers (0 to +10) referring to HUM duty cycle from 0% (steady OFF) to 100% (steady ON), respectively. This scheme did not allow both devices to be ON at the same time and included a center position (0) with both devices OFF. At regular time intervals, the output from the PID algorithm was interpreted as the duty cycle to control the ON/OFF sequence of either the HUM or DEH. This regular updating of the duty cycle of a discrete device (that has only two states, ON and OFF) is known as 'time proportioned output' (TPO).

A TPO period parameter, t_{TPO}, was specified to control the rate at which the PID output was sampled and interpreted. The ON-time for each cycle was computed as (PID_Output/10 multiplied by t_{TPO}), with the OFF-time computed as (t_{TPO} minus the ON-time). The I/O Control script code was written to execute the TPO-sequence (turn ON device, delay, turn OFF device, delay) for the needed device depending upon current readings of the VP relative to the VP setpoint, as processed by the PID algorithm. The overall scheme is shown in Figure 1. The PID calculations repeated every t_{scan} and called the appropriate TPO sequence every t_{TPO}.

The P-gain component of the PID algorithm was adjusted by inclusion of a multiplicative factor that was proportional to E, scaled to vary linearly between 1 and 5, with scaling based on a specified tuning parameter. This factor produced a non-linear response that was intended to offset observed behavior in which VP seemed to be especially sensitive to changes in HUM and DEH duty cycle near the setpoint.

Other non-linear functions could also be investigated to provide an alternative to standard proportional output that might better match system dynamics. Separate parameters for proportional gain were defined for the HUM and DEH.

The I-gain component was ignored when the VP process variable was considered to be 'out of control'. This method avoided the build-up of accumulated error (that would later need to be offset by forcing errors of opposite sign) during transient periods (following setpoint change or large disturbances such as opening the chamber door, turning off the lights, etc.). The 'out of control' condition was detected when VP was outside an arbitrary zone near the setpoint, defined by a tuning parameter, $VP_{ControlZone}$ (a specified fraction of the VP set point). The process was also considered 'out of control' when the derivative of the VP exceeded some arbitrary limit defined by the tuning parameter, $VP_{SmoothZone}$ (a specified fraction of the VP setpoint, per unit time). Thus, the I-gain only operated when the error was small and the VP was fairly steady.

Early versions of the PID algorithm for VP computed the D-gain component by estimating the derivative using a simple finite-difference approximation, namely $(VP_{now} - VP_{previous})/(t_{scan})$. Based on observations in real time, the resulting derivative did not appear to be a smooth function due to noise (apparent random time variations) in the VP input readings. The noise created D-gain adjustments that did not correspond to the intended effect, which was to decrease the control output when the VP was converging toward the setpoint (to avoid overshoot) or to boost the control when VP was drifting away from the setpoint (to increase responsivity). Hence, alternative methods of derivative calculation were tried, including simply using finite difference over multiples of t_{scan} with corresponding VP values taken from a stack from previous scans. Linear regression was also used to estimate the slope of the VP trend over the last few scans (using up to 16 previous values).

Based upon trial and error experimentation, the D-gain component was eventually modified using the concept of 'anticipated error' in which the VP trend was extrapolated to the next $(t = t_{TPO})$ to provide a quantitative measure of where the VP was headed. The predicted deviation (rather than the derivative itself) was multiplied by an anticipated error gain parameter (different for HUM and DEH) to get D-gain. The anticipated error was extrapolated by fitting a second-order polynomial to the VP stack using multiple linear regression techniques. The script language did not support matrix algebra; hence, the regression parameters were estimated based upon the solution of a system of 3 simultaneous equations (the so-called 'Normal' equations, Draper and Smith [3]) using Cramer's Rule (i.e., finding ratios of 3X3 determinants algebraically). This scheme allowed the D-gain to detect and respond to curved trends in VP.

Observations of VP trends in real time indicated that the 'braking' and 'boosting' instances of derivative control needed to be detected and scaled according to the magnitude of the error. The braking control was augmented as VP approached the setpoint, and the boost control was augmented as VP diverged from the setpoint. This adjustment was accomplished using a multiplicative factor that was computed as a linear function of error and a specified tuning parameter.

Nominal PID output (sum of P, I and D components) was conditioned according to an additional set of tuning parameters. For HUM and DEH, the maximum and minimum values of the duty cycle were specified as well as the maximum output change per scan time. After conditioning the nominal output, the final output value was used to specify the duty cycle for either the HUM or DEH for the next TPO cycle.

Fuzzy Logic Algorithm

Fuzzy Logic provides a framework to compute a control output for many complex processes for which human operators seem to develop an intuitive feel for successful manual control that cannot be duplicated by traditional automatic feedback loops (such as PID). The basis for a Fuzzy controller is a set of rules developed in consultation with experienced operators. The rules represent the knowledge of the operator and capture the manual control response to various input scenarios, converting that knowledge to code that can run automatically.

To implement a Fuzzy controller for VP, a Fuzzy algorithm was defined that provided a real time estimate of the VP-output. This code was substituted for the PID code within the OPTO-script program. The Fuzzy controller used the same code for actuating the HUM and DEH on a TPO basis. The steps in obtaining the Fuzzy output included: 1) classifying the inputs (VP and its derivative, VP') as: ('very dry', 'dry', 'VP-OK', 'humid', 'very humid') and ('rapid drying', 'slow drying', 'steady VP', 'slow wetting', 'rapid wetting'), 2) processing the rules that defined HUM/DEH-output for given combinations of the classified VP and VP', and 3) combining results of the rules to obtain a quantitative output.

The classification of the inputs, the so-called fuzzification (e.g., Paraskevopoulos [4]) was implemented using linear interpolation for each input class (or membership function) based on pre-defined function shapes and breakpoints. Breakpoints were coded as multiples of specified error or derivative values (with tuning parameters $VP_{ControlZone}$ and $VP_{SteadyZone}$), respectively. Tuning was performed by changing the zone parameter to simultaneously narrow or widen the class definitions. The membership function shapes were defined as overlapping 'Z', 'pi' and 'S' patterns, with function values at the breakpoints specified as 0 or 1 (see [4]).

Various sets of rules were tried, including the use of additional input variables (such as T, T' and the temperature control output, O_T, and O_T', O_T'') in an attempt to anticipate and adjust for characteristic VP trends and their interaction with T. Many rules represented action analogous to the P and D of PID control, that is, outputs were increased for large error, and boosting and braking functions were coded into the rules based on VP'. Eventually, a simple set of 25 rules was defined, consisting of one rule for each combination of the 5 classes for VP and VP', see Table 1.

Rules were sorted to collect all rules that applied to each classification of the VP control output ('high dehumidify', 'medium dehumidify', 'low dehumidify', 'HUM/DEH off', 'low humidify', 'medium humidify', 'high humidify'), respectively. Rules within each group were tested individually, with the result of each rule being the minimum membership value among the antecedents (in the 'if' part of the rule). The output classification was then assigned the maximum value among the results for all rules in that group. The script language had MAX and MIN functions that were used in this process. Since the script language did not allow for multiple-dimension subscripted variables (only single dimension arrays), the rule processing could not be coded within a loop but was repeated explicitly for each group of rules. Single dimension arrays were used to represent membership function values for each input (VP and VP').

The so-called 'crisp' output from the Fuzzy algorithm was computed using the Center of Area method [4] in which the values for each output classification (from rule processing) were used to compute a weighted average for the output. This was done using a set of HUM and DEH duty cycles that were specified to correspond to the 7 classes of the output. These values were specified as parameters that could be altered in the tuning process.

3. PRELIMINARY TESTING

Testing of the control algorithms was performed in CEC-4 in Hangar L at KSC during July 2003. The chamber was a reach-in chamber (1 m x 1 m x 1 m) equipped with a commercial controller (model TC2, Environmental Growth Chambers, Chagrin Falls, OH) that actuated a 'Barber-Coleman' temperature control valve. No plants were grown in the chamber during the tests but water was added to the hydroponic trays (providing a free water surface for evaporation over approximately 75% of the bottom surface area). Two, 400-W high-pressure sodium lights were energized continuously during the tests.

Before testing to compare algorithm performance, each algorithm was tuned by a trial and error process in which dynamic trends in VP were monitored in real time and then adjustments were made to tuning parameters to improve the control response. Some delay in finding an acceptable set of tuned parameters for both the PID and Fuzzy controls was due to an interaction between the tested VP controls and the PID algorithm defined within I/O Control to control the air temperature in the chamber. This problem was overcome by re-wiring the control relays to allow the TC2 to control the Barber-Coleman valve while the PLC controlled the HUM and DEH.

After tuning was completed, the performance of both the PID and Fuzzy algorithms was tested. For each test, the chamber was initially controlled using the TC2 controller and was then sequenced to the selected I/O Control algorithm to control the HUM and DEH. Device activation states, as well as sensor (T, RH and computed VP) readings, were recorded every 1 s during each 30-min. test period.

4. RESULTS AND DISCUSSION

During limited testing, the PLC's successfully implemented the intended control schemes with acceptable resolution of humidity control after limited tuning. Compared to the commercial controller, the PID for temperature control implemented with I/O Control (not described here) introduced periods of accelerated drying and wetting that the VP controls could not overcome (see Figure 2). Eventually, the VP controllers were tested with the temperature controlled by the commercial controller. Modifications to the PID algorithm for temperature control need to be developed to avoid this behavior. It is possible that this anomaly might not be exhibited for larger growth chambers or for chambers with different temperature control valves. Testing is needed to verify this. The commercial controller output for the temperature control valve exhibited a technique called 'dithering' (visible in Figure 2) in which an arbitrary boost voltage is superimposed upon the PID output at some regular interval. This may have prevented the excessive condensation/re-evaporation that apparently occurred with the PLC control.

Examples of steady control of the VP using the PLC algorithms--PID (with a 5-s TPO period), PID (with an 8-s TPO period) and Fuzzy—along with the commercial control algorithm, are shown in Figures 3-6. The PID control (5-s TPO) provided the least VP variations around the setpoint. Additional verification of the control stability under other combinations of temperature and humidity is still needed. Formal testing of each algorithm's response to disturbances such as setpoint changes, door opening, lights on/off, etc. has not been done although abbreviated testing has indicated that the algorithms seem to be able to respond to disturbances adequately (within 1 min.).

Based upon this limited testing, the different algorithms seem to vary in their ability to maintain the targeted VP setpoint and their impact upon the HUM and DEH device utilizations, see Table 2. The mean VP measured over the 30-min. test with PID (5-s TPO) was nearly identical to the VP setpoint (deviation was much less than 1%), with the other controllers achieving accuracy of 1% or less. The PID (5-s TPO) also performed best in terms of maintaining a steady VP with standard deviation of less than 1% of the mean. The commercial control operated the humidifier and dehumidifier 36% and 19% of the time, respectively, while the PLC-based controls operated them less than 10% and 4%, respectively. The cycle times for the commercial controller were longer than the other controls, which may affect the life of relays and actuating valves/motors.

5. CONCLUSIONS

The humidity inside plant growth chambers can be controlled using a PLC-based controller ("Ultimate" ethernet brain, OPTO-22) with computed vapor pressure as the process variable. The PLC script language provided adequate memory and process speed to implement PID and Fuzzy Logic controllers. The programming package ('I/O Control', OPTO-22) had a few operational quirks (mostly unexpected, intermittent results when real-time processing may have exceeded the CPU capacity) but these were overcome by streamlining the code. Otherwise, the package was easy to learn and easy to use. The combination of the Ultimate brain and I/O Control makes an efficient tool with adequate flexibility and power to perform virtually all anticipated control functions for growth chambers, bioreactors and apparatus for other life support experiments.

The PID and Fuzzy controllers reduced the required activation time for the humidifier and dehumidifier to 10% to 30% of that required by the commercial controller, due to the derivative control components and the TPO activation scheme. The PID algorithm exhibited the best performance in these tests; however, more testing is needed to confirm that the control is stable under many other test conditions. The Fuzzy control had the advantage of being intuitively simple and should prove to be very robust across many control scenarios. Since I/O Control does not support a Fuzzy tool set, tuning the Fuzzy algorithm is quite tedious. Tuning the PID algorithm could be facilitated with a simple operator interface that would allow on-line adjustments to setpoints and parameters. Once tested and tuned, either the PID or Fuzzy algorithms should provide acceptable humidity control, whether implemented autonomously on the PLC brain or operated by a supervisory control program on a web-server.

Further improvements to the performance of algorithms presented here might be accomplished by implementing a relay 'anti-clicking' routine (that was coded but not tested) to skip relay activation or deactivation when the duty cycle is nearly 100% or 0%, respectively. Tuning processes should include exploration of the impact of TPO period on VP control. The concept of 'dithering' also needs further exploration as a method to improve system response time.

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Table 1. Visualization of Fuzzy Rule Space.

	rapid drying	slow drying	steady VP	slow wetting	rapid wetting
very humid	off	low deh	med deh	high deh	high deh
humid	low hum	off	low deh	med deh	med deh
VP OK	med hum	low hum	off	low deh	med deh
dry	high hum	med hum	low hum	off	low deh
very dry	high hum	high hum	med hum	low hum	off

Table 2. Summary of VP Control Algorithm Testing.

Test Result	Control Algorithm: Commercial Control	PID (5-s TPO)	PID (8-s TPO)	Fuzzy
Ave. Dev. from VP Setpoint (Pa)	-	-0.8	-7.5	-15.4
% of Mean VP	-	0.05%	0.49%	0.96%
Standard Deviation of VP (Pa)	21.9	9.46	11.1	16.9
% of Mean VP	1.44%	0.61%	0.72%	1.05%
Ave. HUM Duty Cycle	35.9%	4.1%	8.0%	9.7%
Ave. HUM Cycle Time, s	78.3	38.3	30	32.7
Ave. DEH Duty Cycle	19.5%	2.8%	3.9%	2.3%
Ave. DEH Cycle Time, s	85.7	47.4	40.9	58.1

Note: VP setpoint deviation could not be determined for the commercial controller because the control was based on output from a different RH sensor that may have significant offset compared to the sensor used to record VP.

Figure 1. Schematic of the PID control scheme implemented using I/O Control software to control vapor pressure.

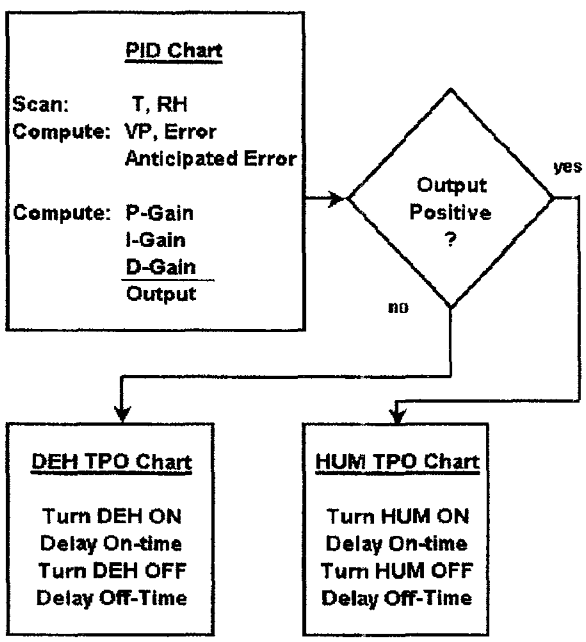


Figure 2. Center section shows humidity control using Fuzzy algorithm and temperature control using PID algorithm.. Control prior to and after the center section--bounded by the dotted lines--was obtained using the commercial controller. The associated output to the temperature control valve is shown with scale 9 V = 900 Pa, read from the right hand axis.

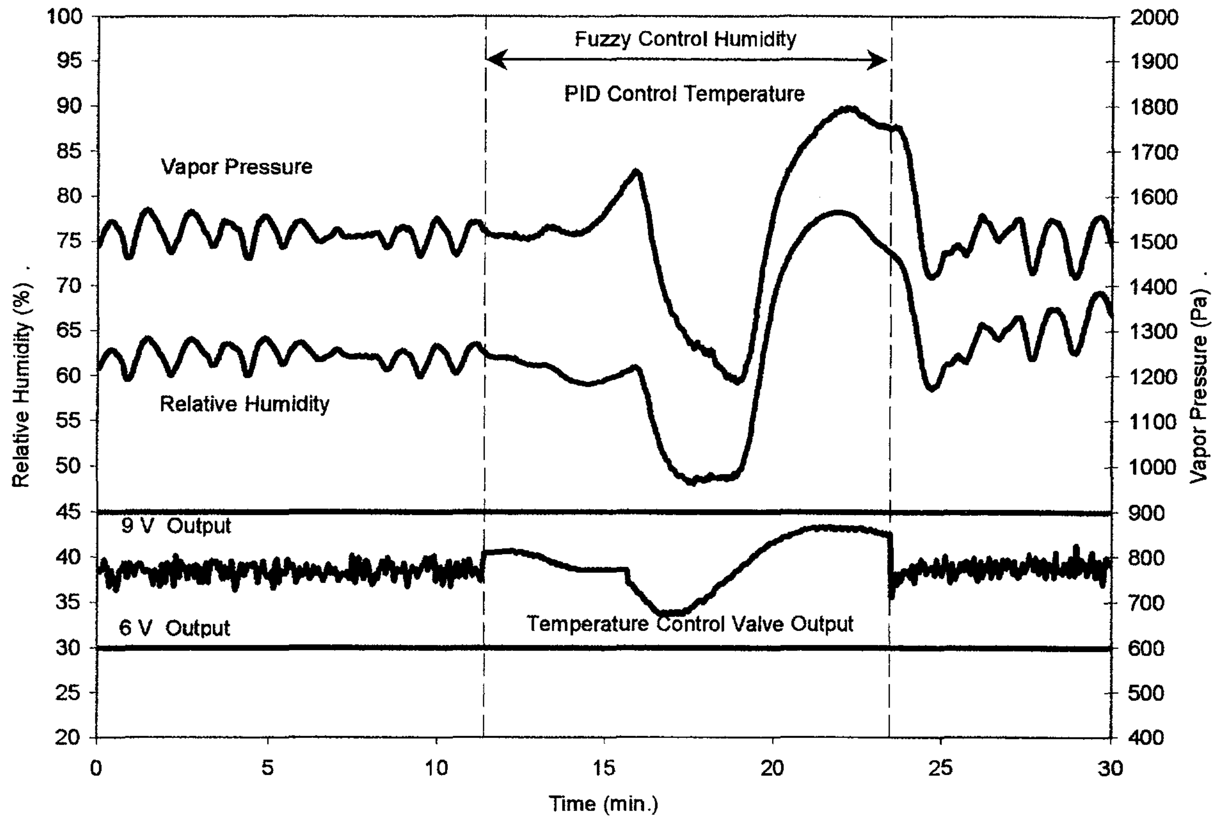


Figure 3. Humidity control with commercial controller. The pulse train for the humidifier and de-humidifier are also shown.

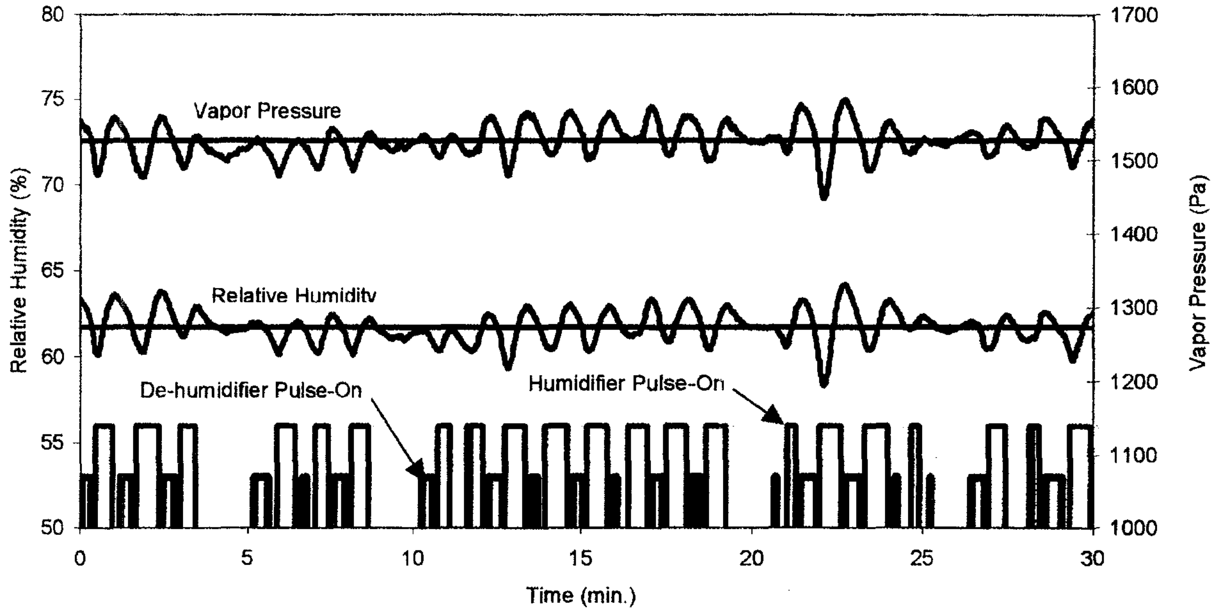


Figure 4. Humidity control with the PID algorithm (with 5-s TPO period). Temperature was controlled using the commercial controller.

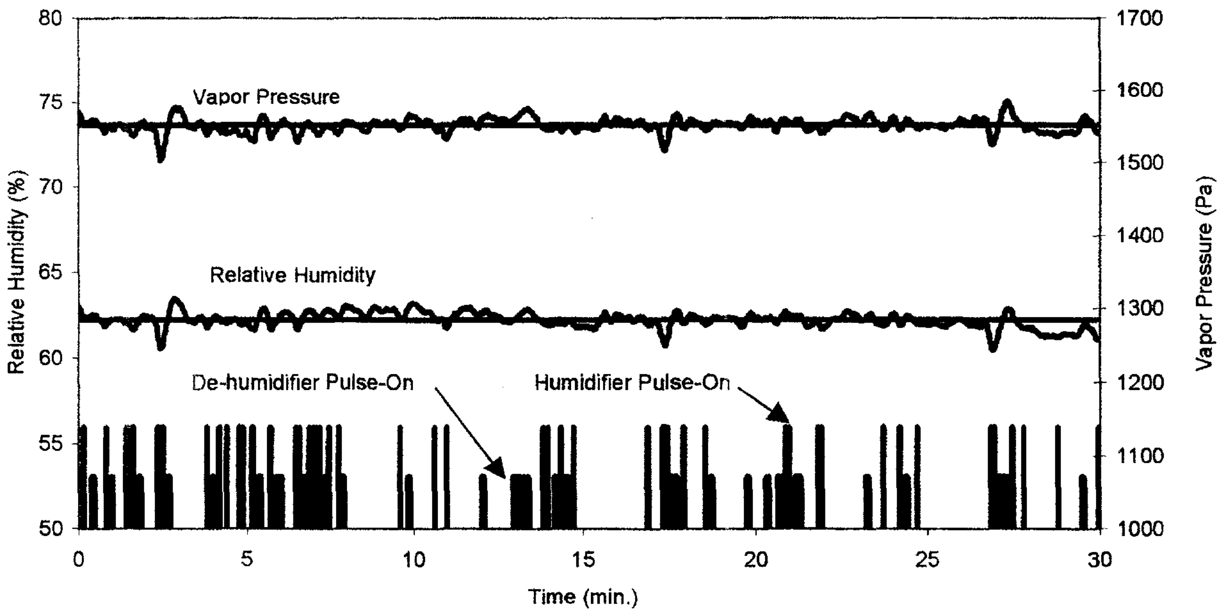


Figure 5. Humidity control using PID algorithm (with 8-s TPO period). Temperature was controlled using the commercial controller.

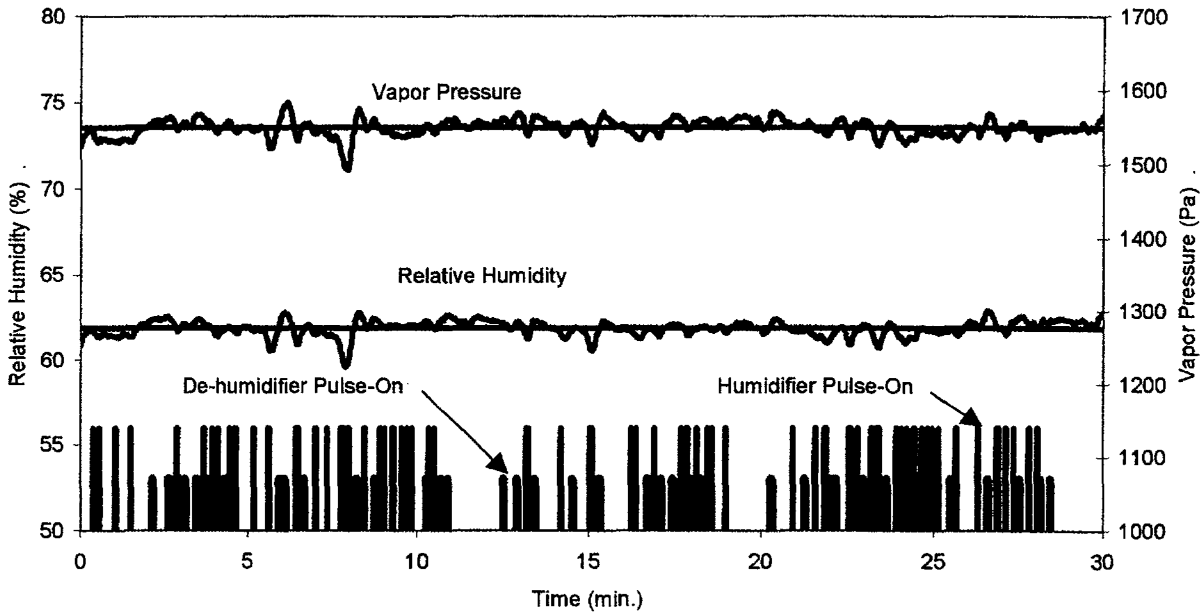
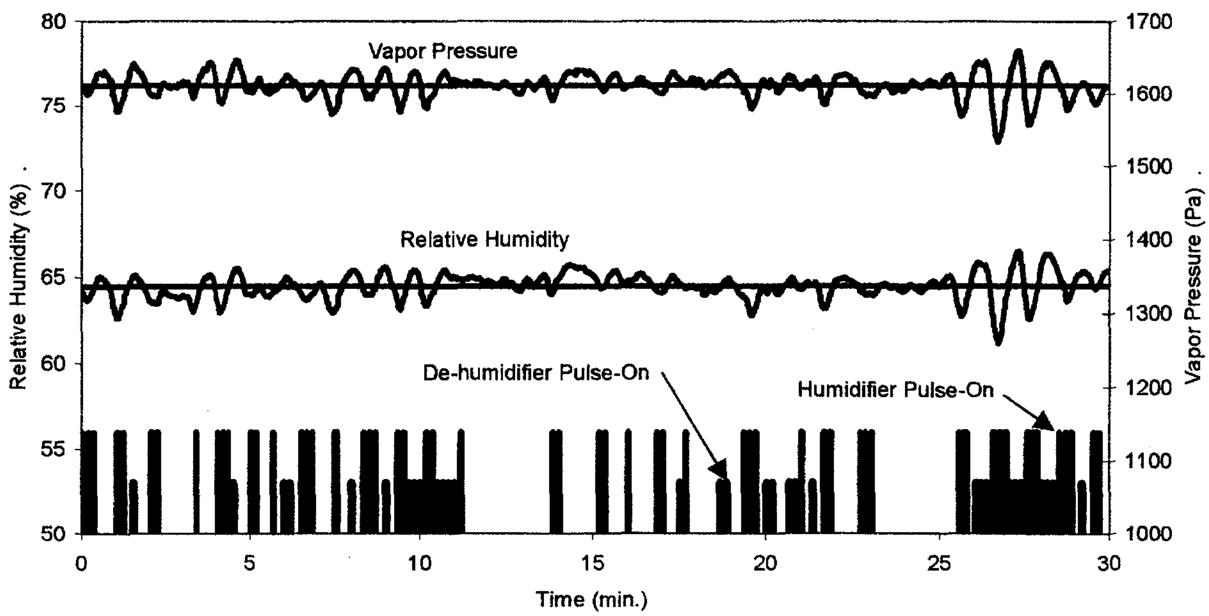


Figure 6. Humidity control using Fuzzy Logic. Temperature was controlled using the commercial controller.



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HYDROGEN PURIFICATION USING NATURAL ZEOLITE MEMBRANES

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ABSTRACT

The School of Science at Universidad del Turabo (UT) have a long-lasting investigation plan to study the hydrogen cleaning and purification technologies. We proposed a research project for the synthesis, phase analysis and porosity characterization of zeolite based ceramic perm-selective membranes for hydrogen cleaning to support NASA's commitment to achieving a broad-based research capability focusing on aerospace-related issues. The present study will focus on technology transfer by utilizing inorganic membranes for production of ultra-clean hydrogen for application in combustion. We tested 3 different natural zeolite membranes(different particle size at different temperatures and time of exposure). Our results show that the membranes exposured at 900°C for 1Hr has the most higher permeation capacity, indicated that our zeolite membranes has the capacity to permeate hydrogen.

HYDROGEN PURIFICATION USING NATURAL ZEOLITE MEMBRANES

William Del Valle, M.S.

1. INTRODUCTION

The School of Science at Universidad del Turabo (UT), as part of a long-lasting investigation plan to study the viability of applying the plasma torch technology for hydrogen production from solid waste and also the development of integrated hydrogen cleaning technologies, proposes to develop a research project for the synthesis, phase analysis and porosity characterization of zeolite based ceramic perm-selective membranes for hydrogen cleaning to support NASA's commitment to achieving a broad-based research capability focusing on aerospace-related issues. The present study will focus on technology transfer by utilizing inorganic membranes for production of ultra-clean hydrogen for application in combustion. KSC will eventually be required to manufacture the hydrogen they use locally for reasons that include economics, transportation safety, and quantity requirements. The KSC spaceport hydrogen requirements will vary in the future, as they have in the past, due to fluctuations in launch activities, program changes, and other technical and weather-related factors. The development of perm-selective membranes for ultra-pure hydrogen production will, for example, result in increased efficiency of on-board fuel cells, thus reducing payload costs. NASA is interested in fuel cells that are light-weight, robust, and provide 2-20X more power density than the current state of art. Fuel cells can readily use pure hydrogen as a fuel source. Hydrogen has three main advantages relative to existing hydrocarbon fuels, i.e., no local air pollution, reduced oil consumption, and no greenhouse gas emissions.

Many industrial activities and other endeavors, such as combustion and fuel cells, require clean gases. Consequently, any effort to develop effective processes for gas cleanup is very useful. For example, an emerging new source of hydrogen gas comes from the pyrolysis of organic waste materials using a plasma arc torch [1-8], however, the hydrogen produced with this method is impure. Inorganic membranes are potentially very useful for gas separation and cleaning [9]. Microporous inorganic membranes are made of amorphous silica, carbon, and zeolites [10] and are potentially useful in gas separation for cleaning processes and in other areas, such as catalytic reactors, gasification of coal, water decomposition, and solid electrolyte fuel cells [10]. [11]. We used a combination of ceramic and sol-gel techniques to produce (synthetize) our natural zeolite membranes, it was characterized by Electronic Microscopy, X-Ray Diffraction, Elementary Analysis (EDAX) and Atomic Source Microscopy. Techniques.

Zeolites have been shown to be good adsorbents [18-27]. When a molecule diffuses inside a zeolite channel, it becomes attracted to and repelled by different interactions, such as the dispersion energy, repulsion energy, polarization energy, field dipole energy, field gradient quadrupole, sorbate-sorbate interactions [10, 23, 27-29] and the acid-base interaction with the active site if the zeolite contains hydroxyl bridge groups [27]. For the application of zeolites, the migration or diffusion of sorbed molecules through the pores and cages within the zeolite crystal plays a dominant role, *configurational diffusion* is the term coined to describe diffusion in zeolites

[20,22,23-25,30-33]. Free molecular transport generally occurs by ordinary diffusion such that Fick's laws are considered valid [30], however, single-file diffusion is also possible and very promising in membrane applications [34-38].

The diffusion of guest molecules through zeolite cavities and channels determines the molecular sieving properties of these materials [25,30,31,34,39,40]. Consequently it is possible to use zeolites based membranes for gas cleaning, since it is feasible, with the help of synthesis procedures, to control the pore size distribution of the obtained nano-structured materials in order to use it's molecular sieving properties to selectively separate gases and as a result purify it. The most striking results in this field will be obtained in hydrogen cleaning, because of the small kinetic molecular diameter of the hydrogen molecule in comparison with the kinetic molecular diameters of the impurities [9-15,39].

Ceramic Technique:

If the zeolite temperature is increased to more than 500°C, after the dehydration, a phase transformation of the zeolite to a siliceous phase and a compact aluminosilicate phase occurs [41]. Moreover, if zeolite is ground and the powders obtained are sieved to obtain particles of grain size less than 100 μm, and if wafers are prepared with these fine particles by pressing at 100 MPa, after first agglomerating the powders with polyvinyl alcohol, and the wafers are thermally treated at 600, 700, 900, 1000, and 1150°C, an increase is observed in the density of the wafers from 1 g/cm3 at room temperature to 2.3 g/cm3 at 1150°C. As a result of a decrease of wafer porosity, ceramic materials are obtained that possess excellent mechanical properties [41] and also have a developed mesoporous structure [42]. Using the ceramic methodology, we has produced mesoporous ceramic membranes [42], these materials will be further transformed with the help of other methods, such as the sol-gel methodology, to obtain materials with micropores, that is, a pore distribution appropriate for hydrogen cleanup.

Sol-gel Method:

The hydrothermal synthesis of zeolites is carried out with highly reactive aluminosilicate gels under autogenous conditions [22]. The hydrothermal treatment of natural zeolites with highly basic sodium or potassium hydroxide solutions causes its amorphization and change in a chemical composition [29]. From our previous experience we know that it is possible to grow zeolite crystals over the surface of expanded clays [43,44], consequently we expect also to grow zeolite crystals over the produced mesoporous ceramic membranes in order to generate the microporous membrane. Thus, it is also proposed within the framework of the present project, to synthesize inorganic membranes with the help of the sol-gel method using the previously described zeolite-based mesoporous porous membranes [41-44] as support. The concrete sol-gel methodology that will be used for the hydrothermal treatment with a highly basic sodium solution [45] has been previously used by us for different purposes [29,45,46]

Porosity Characterization:

The analysis of isotherms of physical adsorption of gases and vapors represent a standard and conventional method for obtaining information about the pore structure of porous materials [18, 21, 28, 47-51]. During adsorption in complex systems, such as zeolites and related materials, the adsorption process occurs as follows: initially, micropore filling (this means adsorption in the primary porosity, to be exact, pores with widths not exceeding about 2 nm) and afterward, at higher pressures, external surface coverage, consisting of monolayer and multilayer adsorption on the walls of mesopores (pores of width between 2 to 50 nm) and open macropores (pores of widths exceeding about 50 nm) and capillary condensation taking place on the walls of mesopores [18,21,38,47-49]. Adsorption in the primary porosity of zeolites is considered as a volume filling of the zeolite microporous adsorption space and not as a layer-by-layer surface coverage [51]. As is very well known, adsorption in the micropores is the principal method for the measurement of the microporous volume using the Dubinin adsorption isotherm [51], the t-plot method [18,21,47] and other adsorption isotherms [27]. On the other hand, capillary condensation of vapors is the primary method of assessment of the Pore Size Distribution (PSD) in the range of mesopores [18,21,28,48]. Capillary condensation is associated with a shift of the vapor-liquid coexistence in pores compared to bulk fluid, that is, a confined fluid in a pore condense at a pressure lower that the saturation pressure at a given temperature [48-50]. The condensation pressure depends on the pore size and shape an also on the strength of the interaction between the fluid and pore walls, consequently the adsorption isotherm allows to determine the PSD in the range of 2 to 50 nm [18, 21, 47-50]. During the last years the standard method for the determination of the PSD in the mesoporous range with the help of adsorption isotherms was the Barret-Joyner-Hallenda (BJH) method [18,48,50], however this methodology do not estimate properly the PSD [48,49]. Recently a new methodology of adsorption isotherm calculation based on the Non-Local Density Function Theory [48,49,52-54] which was originated in the Density Functional Theory applied to inhomogeneus fluids [55-57] have revolutionized the methodology of PSD calculation in microporous (less than 2 nm) and mesoporous materials (2 to 50 nm) [58]. This methodology is implemented in the Quantachrome Autosorb-1 Automated Surface Area and Pore Size Analyzer [58].

2. Methods and procedures

Clinoptilolite homoionization: A very well characterized natural zeolite [29] from the Sweetwater, Wyoming deposit [42,46] were refluxed five times for 1-3 hr. each in a 2M NaCl solution (liquid solid ratio = 2) at 373 K. The obtained samples were carefully washed with distilled water to produce the homoionized Na-clinoptilolte The degree of Na exchange in the Na-clinoptilolite will be around 80-90 % [29,46].

Mesoporous zeolites based ceramics membranes synthesis: *The homoionized sample were grounded, the sample obtained were sieved to obtain particles of grain sizes of 40<ø<30, 50< ø<40 and 100< ø<50. With these grains we prepared cylindrical wafers (10 mm x 0.5-1 mm) by pressing at 100 Mpa. The wafers were thermally treated at 700, 800 and 900°C during 1 and 2 hours.*

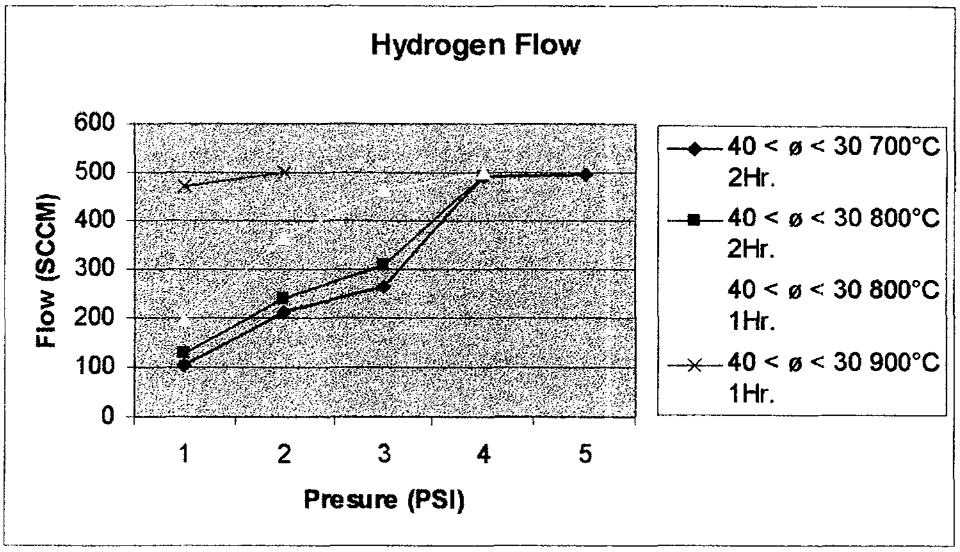
Phase analysis by XRD: The phase analysis of the transformation products and as-synthesized samples were determined using powder X-ray diffraction [61,62] in a Siemens powder diffractometer at the Materials Characterization Center at University of Puerto Rico-Rio Piedras Campus.

Electronic Scanning Microscopy: The synthesized samples was studied by SEM technique using a Scanning Microscope Model GOEL 5800LV and an elementary analysis by EDAX (DX4).

Pore size characterization by adsorption methods: We used the Quantachrome Autosorb-1 equipment to carry out the characterization of the pore structure of the produced membranes with the confidence that this is possibly the most reliable equipment in use worldwide among the research community for the characterization of the porous structure of porous materials [48,49,52-54,58]. Nevertheless, we will use also other methodologies, such as the t-plot method [18, 21,59] the Dubinin equation [51] and Langmuir and Fowler-Guggenheim Types Volume Filling Adsorption Isotherms [27] to test the validity of the new method used by the Autosorb-1 equipment employing the Ar and N_2 adsorption isotherms measured by the Autosorb-1 Surface Area and Pore Size Analyzer [58].

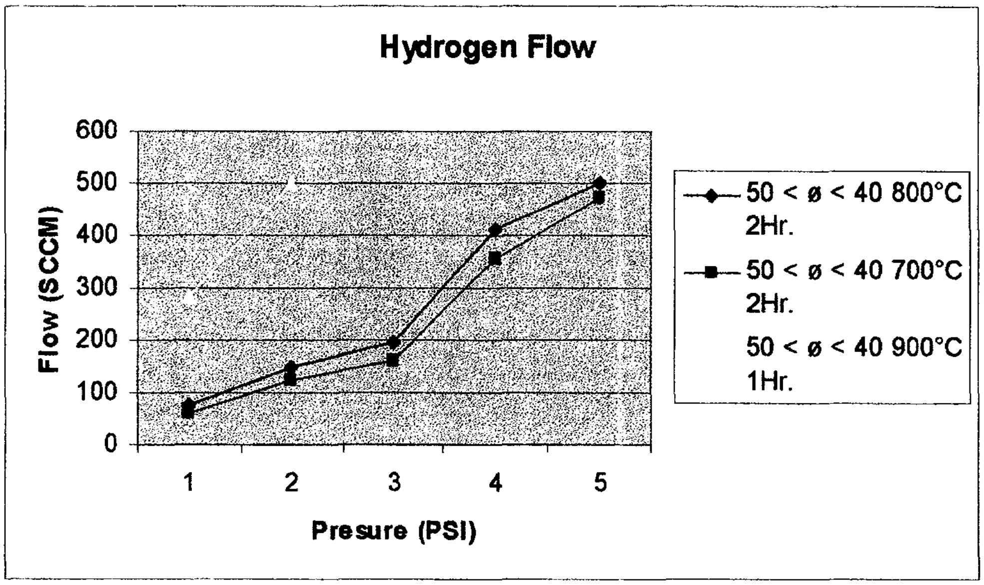
3. **Results**:

The zeolite membranes was placed into the gas system, the hydrogen(H_2) gas inlet pressures was 64.60, 79.60, 88.00, 127.60, 146.40, 197.20 and 208.80 PSI. The zeolite membranes of 40< ø <30, 50< ø <40 & 100< ø <50 700, 800 & 900°C 1 & 2Hr results are showed in graphs 1,2 & 3. In graph 1, as you can see the most permeable membrane was 40< ø <30 900°C 1Hr, were at 64.60 PSI the flow throught the membrane was 473.00 SCCM(Standard Cubic Centimeter per Minute) and the lowest permeation membrane was 40< ø <30 700°C 2 Hr(at 64.60 PSI the flow was 104.00 SCCM). We found the same results with the 50< ø <40 900 °C and 100< ø<50 900 °C 1Hr(the highest permeability) and 50< ø <40 700°C 2 Hr and 100< ø <50 700°C 2 Hr (the lowest permeability)(see graphs 2 & 3). We also test the carbon dioxide(CO_2) permeability and we found that the membranes permit the CO_2 flow throught them and we found the same order, the most high permeability is on the membranes that was exposed at 900°C for 1Hr and the lowest permeability is on the membranes that was exposed at 700°C for 2 Hr. You can see in graphs 4, 5 & 6, the differences between the most high permeable membranes for hydrogen and carbon dioxide. The difference between them is around 2.00. The CO_2 permeation in this case is insignificant, that mean that the membranes have the capacity to permeate the Hydrogen.



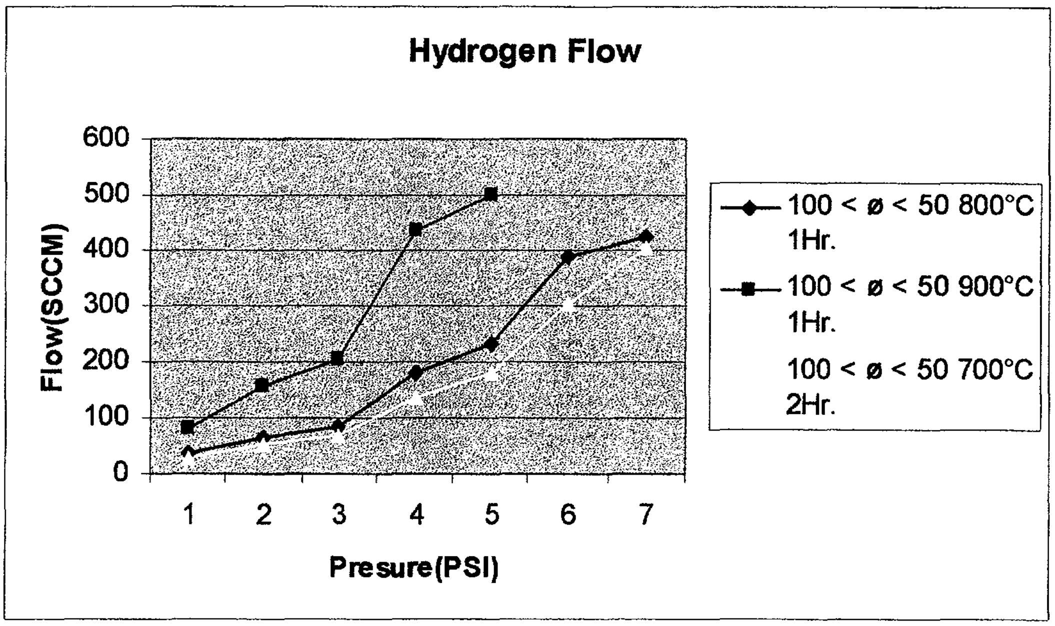
1 = 64.60 PSI, 2 = 79.60 PSI, 3 = 88.00 PSI, 4 = 127.60 PSI, 5 = 146.40 PSI

Graph 1: 40< ø >30 Membranes



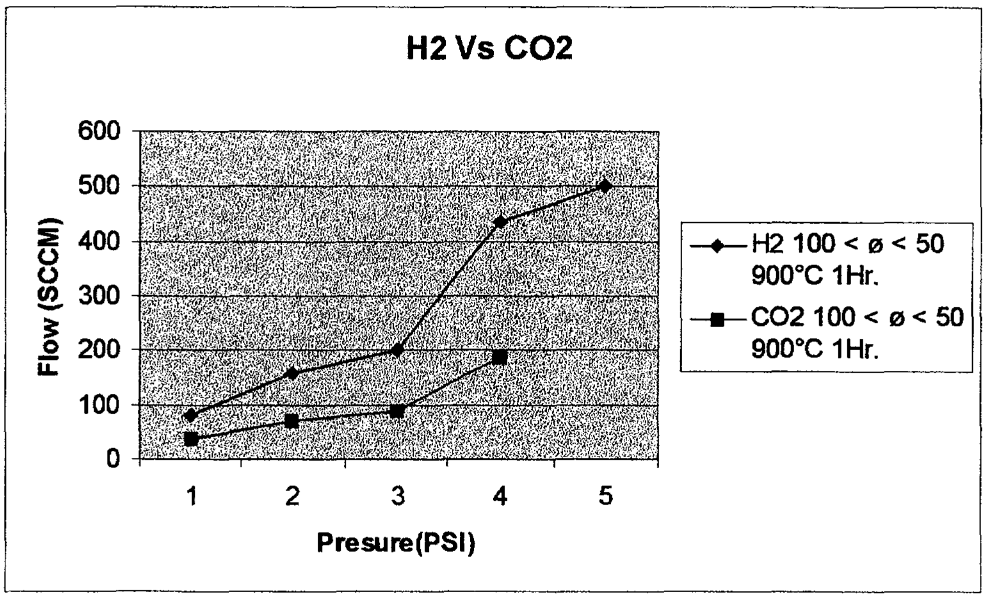
1 = 64.60 PSI, 2 = 79.60 PSI, 3 = 88.00 PSI, 4 = 127.60 PSI, 5 = 146.40 PSI

Graph 2: 50< ø <40 Membranes



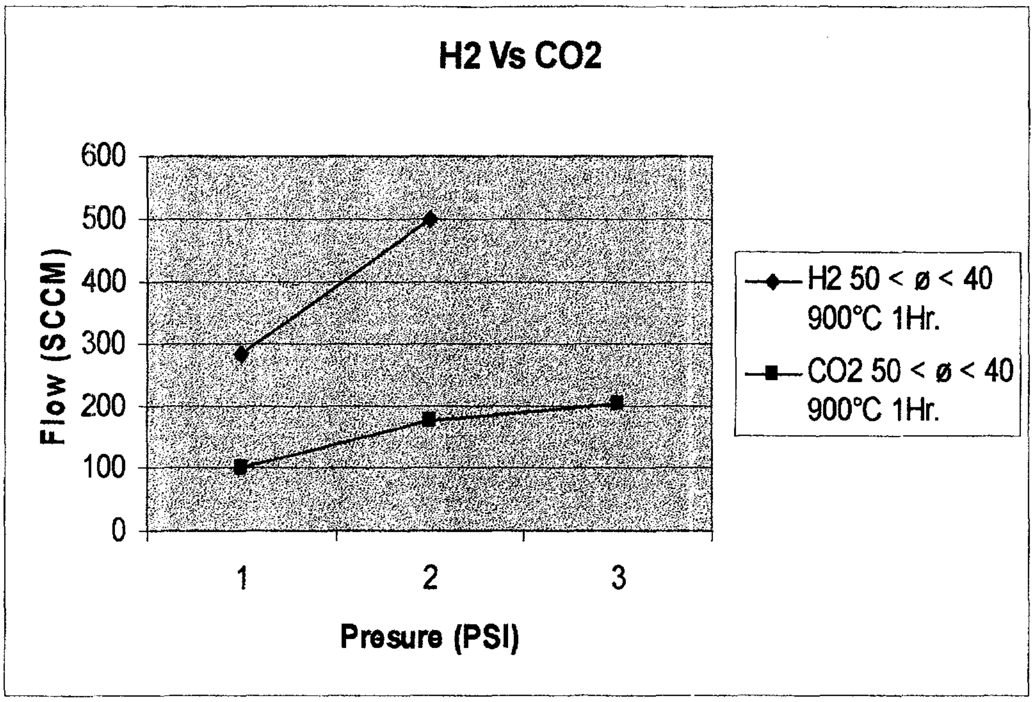
1 = 64.60 PSI, 2 = 79.60 PSI, 3 = 88.00 PSI, 4 = 127.60 PSI, 5 = 146.40 PSI, 6 = 197.20 PSI, 7 = 208.80 PSI

Graph 3: 100< ø <50 Membranes



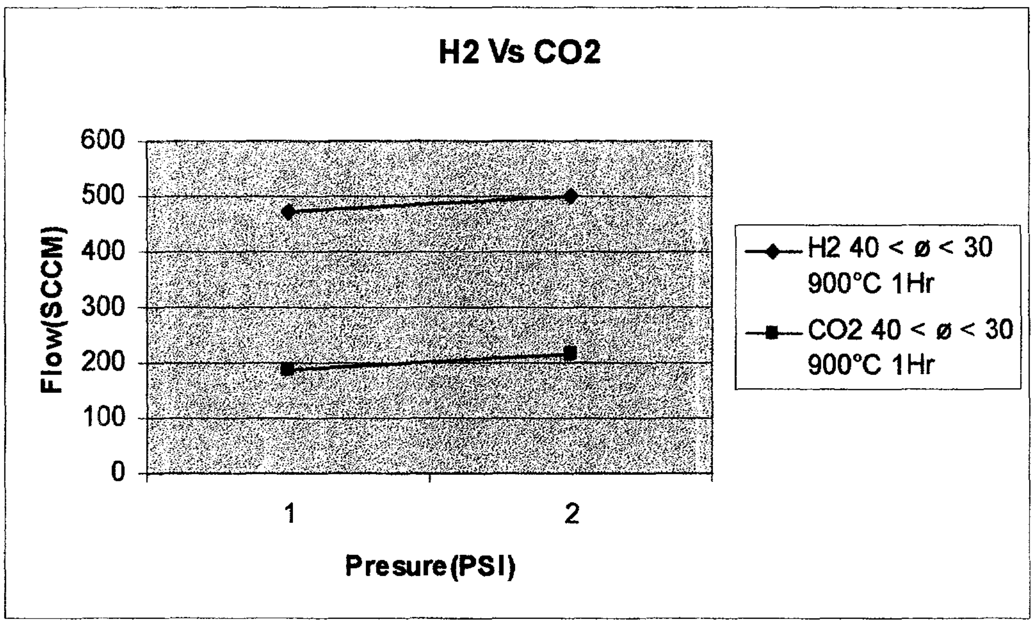
1 = 64.60 PSI, 2 = 79.60 PSI, 3 = 88.00 PSI, 4 = 127.60 PSI, 5 = 146.40 PSI

Graph 4: 100< ø<50 900 °C 1Hr Membranes Comparation



1 = 64.60 PSI, 2 = 79.60 PSI, 3 = 88.00 PSI

Graph 5: 50< ø <40 900 °C 1Hr Membranes Comparation



1 = 64.60 PSI, 2 = 79.60 PSI

Graph 6: 40< ø <30 900°C 1Hr Membranes Comparation

CONCLUSIONS

Our results show that our Natural Zeolite Membranes have the capacity to permeate hydrogen, in addition can permeate Carbon Dioxide in a small ratio. This proposed, that we have to improve the zeolite synthesis and treatment to increase the hydrogen permeability and decrease the carbon dioxide permeability. One of our future plans, is to test other gases like nitrogen, helium, methane, etc. and use the combination of other material to produce good cleaning and purifier materials.

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2003 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

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Corrosion Study Using Electrochemical Impedance Spectroscopy

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ABSTRACT

Corrosion is a common phenomenon. It is the destructive result of chemical reaction between a metal or metal alloy and its environment. Stainless steel tubing is used at Kennedy Space Center for various supply lines which service the orbiter (2). The launch pads are also made of stainless steel. The environment at the launch site has very high chloride content due to the proximity to the Atlantic Ocean. Also, during a launch, the exhaust products in the solid rocket boosters include concentrated hydrogen chloride

The purpose of this project was to study various alloys by Electrochemical Impedance Spectroscopy in corrosive environments similar to the launch sites. This report includes data and analysis of the measurements for 304L, 254SMO and AL-6XN in primarily neutral 3.55% NaCl. One set of data for 304L in neutral 3.55%NaCl + 0.1N HCl is also included

Corrosion Study Using Electrochemical Impedance Spectroscopy

Muhammad Umar Farooq

1. INTRODUCTION

Stainless steel tubing is used at Kennedy Space Center for various supply lines which service the orbiter (2). The environment at the launch site has very high chloride content due to the proximity to the Atlantic Ocean. Also, during a launch, the exhaust products in the solid rocket boosters include concentrated hydrogen chloride. The acidic environment is aggressive to most metals and cause pitting in some of the common stainless steel alloys. Pitting corrosion can cause cracking and rupture of both high-pressure gas and fluid systems, which can result in the safety of shuttle launches.

The purpose of this project was to study various tubing alloys by Electrochemical Impedance Spectroscopy in corrosive environments similar to the launch sites. This report includes data and analysis of the measurements for 304L, 254SMO and AL-6XN in primarily neutral 3.55% NaCl. One set of data for 304L in neutral 3.55%NaCl + 0.1N HCl is also included. Three more alloys in similar environments are to going to be studied.3.55% NaCl +1N HCl is also going to be studied.

2. NEXT SECTION

Electrochemical Impedance Spectroscopy

EIS. A low voltage 5 – 10mV (to keep it non-destructive) of varying frequency (100K to 10mHZ) is applied between the working electrode and the counter electrode, of course in the presence of the electrolyte. The data provided by the measuring equipment is in two forms. Impedance modulus |Z| and phase angle phi-vs-frequency, Bode plots. Real part of Z vs imaginary part of Z, Nyquist plots.
Bode plots points to a single time constant, hence the data is analyzed using a simple model, $R_S + R_P||C_P$, where R_S is the resistance of the solution (electrolyte), R_{EDL}, resistance of the electrical double layer and C_{EDL}, capacitance of the electrical double layer.
Software package PowerSuite was used to analyze the data. It regresses the appropriate equation around experimental data, by iteratively adjusting parameters, such as R_P and C_P, until the closest fit of the equation to experimental data is obtained.

Three alloys 304L, 254SMO and AL-6XN are currently being studied. Eletrolytes used/to be used are, 3.55% neutral NaCl solution, 3.55% NaCl + 0.1N HCl and 3.55% NaCl + 1N HCl.

3. RESULTS AND DISCUSSION

1. Alloys in 3.55% neutral NaCl.
   As is expected, corrosion is a random process and reproducibility is not very good. Figure 3 shows a plot of R_p –VS- Time for the second run of 304L. For this particular reason, a particular alloy is being studied three times under similar conditions.The resistance increases with time pointing to an increase in the thickness of the corrosive film.

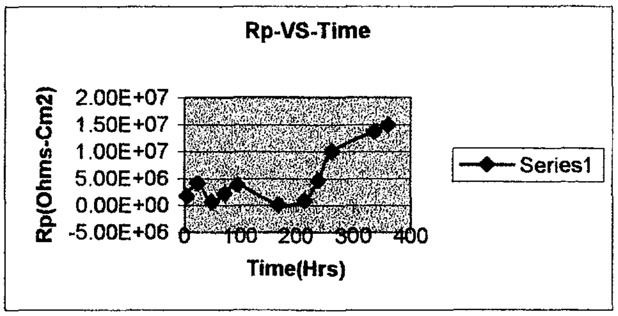

Figure 3. Change of resistance of the corrosive film with time

Figure 4 shows its capacitative behavior. As expected the capacitance goes down with time but not in a well behaved manner.

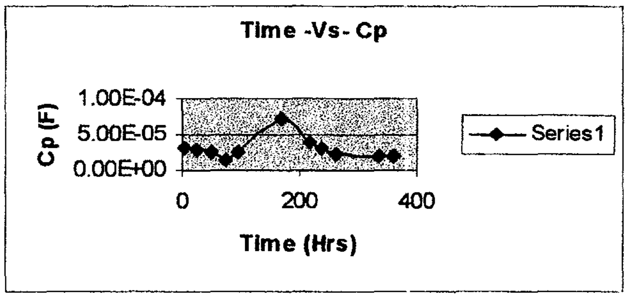

Figure 4. Change of capacitance of the corrosive film with time

Figure 5 shows change of open circuit potential (OCP) with time. OCP becomes more and more positive becoming less and less prone to corrosion.

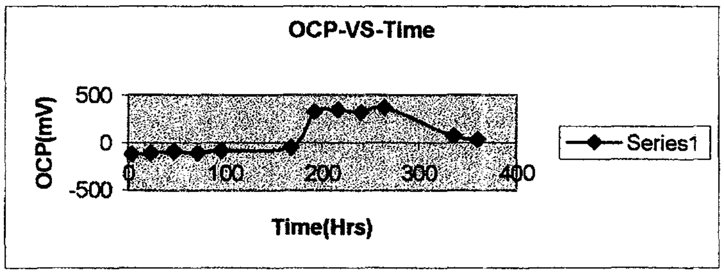

Figure 5. Change of open circuit voltage of the corrosive film with time

Figure 6 shows Rp –VS- Time for another run for 304L and shows that initially its resistance hence the thickness of the corrosive layer goes up but then the thickness decreases due to etching of the layer and it increases again etc.

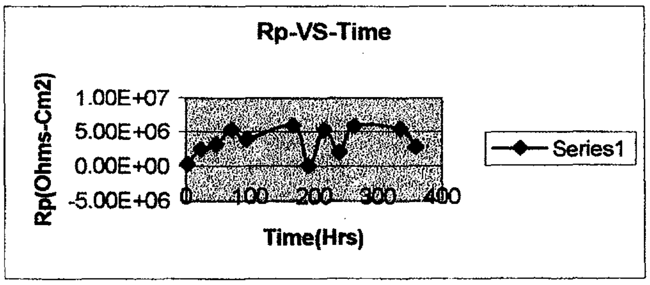

Figure 6. Change of resistance of the corrosive film with time

Alloys in 3.55%NaCl in 0.1N HCl

So far only 304L has been studied and it shows an interesting behavior. Figure 7 shows how the resistance with time changes. It appears that in the first 24 hours the passive film grows but then it gets etched away with time.

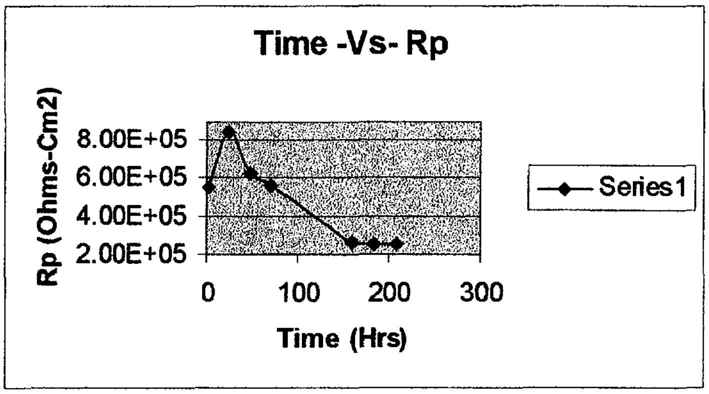

Figure 7. Change of resistance of the corrosive film with time

4. CONCLUSIONS

1. With time the thickness of the passive film grows initially but this trend does not continue for longer times. Even different coupons of the same alloy do not show consistent behavior.
2. Alloys show a different behavior in 3.55%NaCl+0.1NHCl.

Recommendations for future work

1. The behavior of alloys in 3.55% NaCl + 0.1N HCl should be looked at more closely between the time it is immersed in the electrolyte and 24 hours. Time interval for EIS data collection is too long.
2. 0.05N HCl should also be studied.
3. If a visible passive film appears then it should not only be photographed but also analyzed for its composition.
4. Find the concentration of the active ion (chloride) in the electrolyte at the end of a run.
5. Analyze the electrolyte to determine which of the element/elements from the alloy are being attacked. This should help to determine which alloy tubing to use in the launch pads.

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2003 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

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Parameter Estimation of Spacecraft Nutation Growth Model

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ABSTRACT

Modeling fuel slosh effects accurately and completely on spinning spacecraft has been a long standing concern within the aerospace community. Gyroscopic stiffness is obtained by spinning spacecraft as it is launched from one of the upper stages before it is placed in orbit. Unbalances in the spacecraft causes it to precess (wobble). The oscillatory motions are caused in the fuel due to this precession. This phenomenon is called "fuel slosh" and the dynamic forces induced could adversely affect the stability and control of a spacecraft that spins about one of its minor moments of inertia axes. An equivalent mechanical model of fuel slosh is developed using springs and dampers that are connected to the rigid fuel tank. The stiffness and damping coefficients are the parameters that need to be identified in the fuel slosh mechanical model. This in turn is used in the spacecraft model to estimate the Nutation Time Constant (NTC) for the spacecraft. The experimental values needed for the identification of the model parameters are obtained from experiments conducted at Southwest Research Institute using the Spinning Slosh Test Rig (SSTR). The research focus is on developing models of different complexity and estimating the model parameters that will ultimately provide a more realistic Nutation Time Constant obtained through simulation.

Parameter Estimation of Spacecraft Nutation Growth Model

Sathya N. Gangadharan

1. INTRODUCTION

Fuel slosh in spacecrafts has been a long standing concern within the aerospace community and has been a source of dynamics and control problems [1]. Quantifying the fuel slosh effects using equations is not feasible during the initial phases of design. Simplified models will greatly help to reduce computational time and design costs [2].

Liquid oscillations in spinning tanks have been studied in the past. Liquid oscillations in spinning fuel tanks produce very different response characteristics compared to those of non-spinning fuel tanks [3].

An energy sink model was originally developed by Thomson [4] to include the effects of small, passive sources of energy dissipation. This model does not work well for spacecraft fuel slosh energy dissipation due to the fact that fuel mass is a large fraction of the total mass of the spacecraft.

A homogeneous vortex model of liquid motions in spinning tanks and an equivalent mechanical model was developed by Dodge et al., [5]. An approximate theory of oscillations that predicts the characteristics of the dominant inertial wave oscillation and the forces and moments on the tank are described. According to Dodge et al., the pendulum model simulates a motion that does not involve an oscillation of the center of mass, it is not a valid model of inertial wave oscillations. Weihs and Dodge [6] illustrate that the free surface effects can be ignored when the liquid depth is small.

A 3-D pendulum model was proposed by Green et al., [7]. There was evidence of liquid resonance from the experimental data. The resonance closely was tied to the tangential torque and to a lesser degree to the radial torque, and little or no resonance in the force measurements. Green at al., proposed a rotary oscillator concept to simulate the torque resonance in tangential and radial directions. This rotary oscillator model was superimposed on the pendulum model to provide the overall response of liquid oscillation in the tank.

Hence, there is a need to develop a model that is capable of accounting for all motions of the liquid within the tank. In this research, a more generalized 3-D Rotor Model is proposed that will account for all the liquid oscillation effects through springs and dampers.

2. SCOPE OF RESEARCH

The scope of this research is to provide an alternate approach to obtain the Nutation Time Constant (NTC) by developing mechanical models of various complexity through springs and dampers that simulate the fuel motion inside the spinning spacecraft fuel tank. The model parameters will be identified using the experimental values for forces and torques obtained by conducting experiments using the Spinning Slosh Test Rig. The "goodness of fit" will be assessed for the identified parameters.

3. PROBLEM DEFINITION

The experimental set-up of the Spinning Slosh Test Rig (SSTR) is shown in Figure 1. The SSTR can subject a test tank to a realistic nutation motion, in which the spin rate and the nutation frequency can be varied independently, with the spin creating a centrifugal acceleration large enough to ensure that the configuration of the bladder and liquid in the tank is nearly identical to zero-g configuration. A complete description of the actual tests, data acquisition and analyses of data is provided by Green, et al., [7]. The fuel motion is simulated using models with various parameters (inertia, springs, dampers, etc.,) and the problem reduces to a parameter estimation problem to match the experimental results obtained from SSTR.

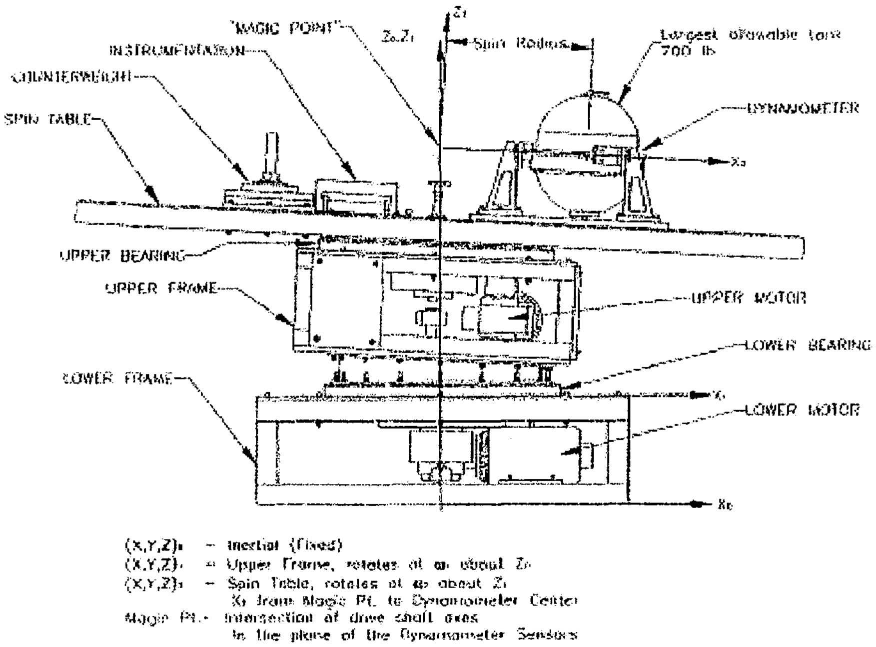

Figure 1. Schematic diagram of Spinning Slosh Test Rig (SSTR)

4. METHOD OF APPROACH

A 3-D Rotor Model of SSTR is developed using SimMechanics software [8,9] and shown in Figure 2. This model has flexibility to include different parameters (inertia of rotor, translational and rotational stiffnesses and dampers in the three mutually perpendicular directions, offsets, etc.,) in the parametric estimation process. The complexity of the Rotor Model depends on the parameters included in the estimation process. It is imperative that more parameters will provide better response characteristics closer to reality. The block diagram of the system identification procedure is illustrated in Figure 3. The identified parameters are input into the spacecraft model to obtain the Nutation Time Constant.

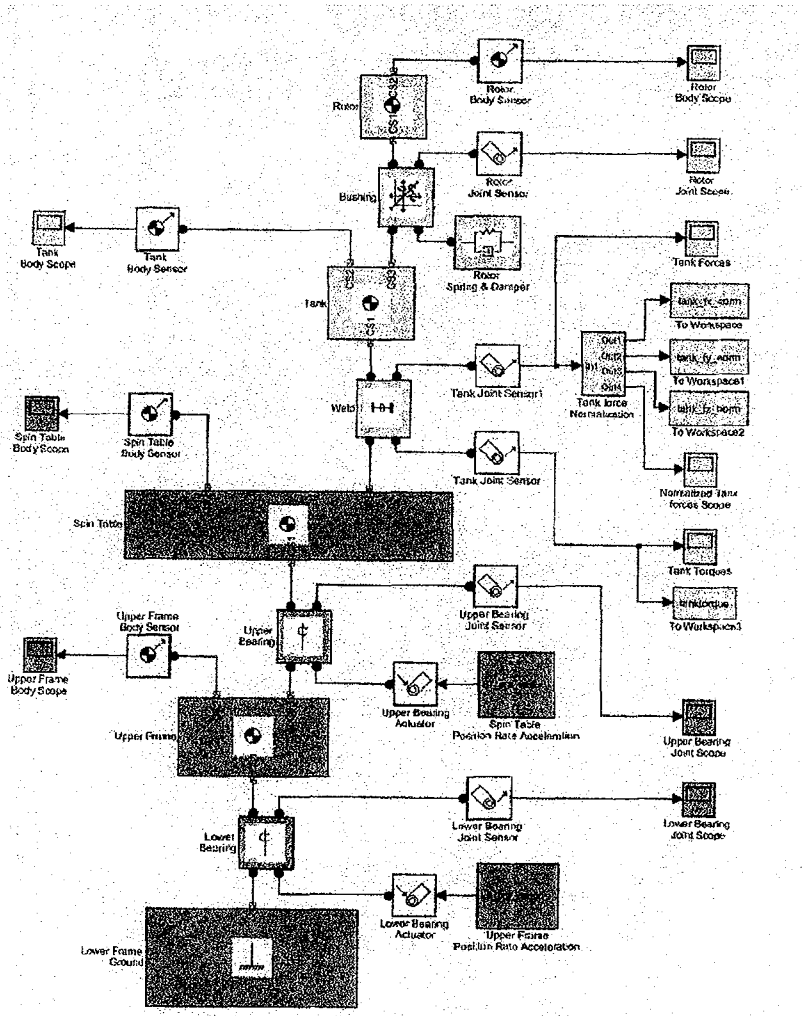

Figure 2. 3-D Rotor Model developed using SimMechanics software

5. OPTIMIZATION CONCEPT

The parametric estimation problem reduces to an optimization problem of minimizing the residual which is the sum of the squares of the difference between the experimental and model response. This can be put in the mathematical form as:

Minimize

$$\text{Residual } R = \Sigma\ (\text{Experimental Response} - \text{Model Response})^2$$

This minimization of residual is performed using a nonlinear least squares algorithm "LSQNONLIN" available in Optimization Tool Box.

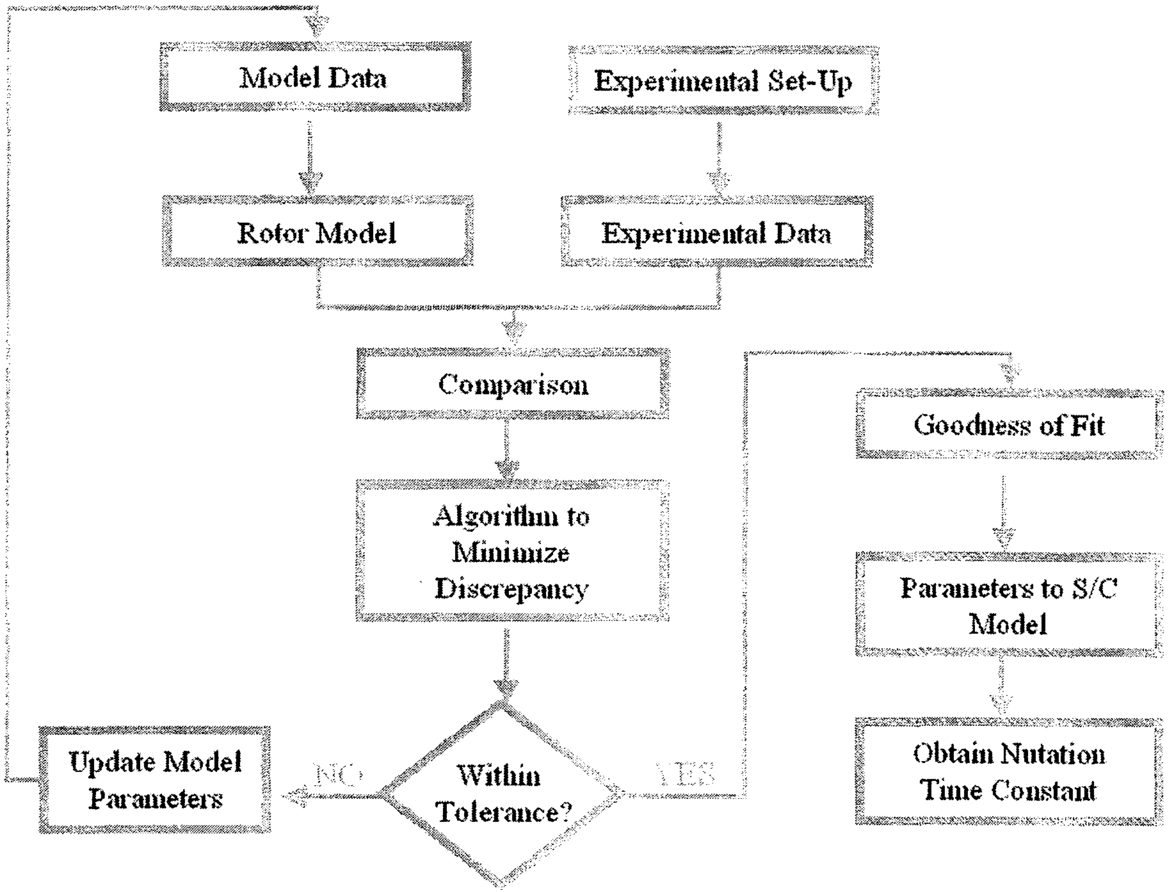

Figure 3. Block diagram of the parametric estimation process

6. ILLUSTRATIVE EXAMPLE

A simple model of a mass-spring-damper was used to illustrate the concept (Figure 4). The parameters chosen are the stiffness of the spring (k) and the damping coefficient (b). In the "Experimental" model parameters are fixed while in the "SimMechanics" model, the initial values of the parameters are assumed and then estimated using LSQNONLIN algorithm. Table 1 shows the estimated parameters. The results indicate that the stiffness has a dominating effect on the response compared to damping.

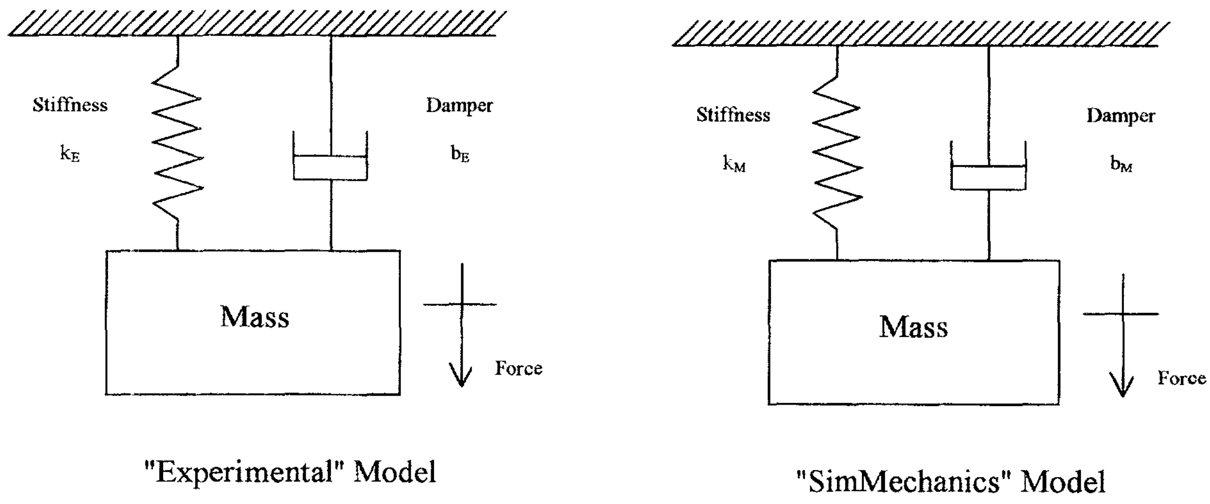

Figure 4: Simple model of a mass-spring-damper

"Experimental" Model	k = 150 N/m	b=100 N-s/m
"SimMechanics" Model	k=149.8 N/m (Dominant)	b=75.8 N-s/m

Table 1. Estimated parameters for the simple model of a mass-spring-damper

7. ROTOR MODEL

The Rotor Model of spacecraft fuel tank is shown in Figure 5. The response of the model with and without the rotor is compared to determine the effect of fuel slosh on the overall response. It is found that the maximum percentage difference of 107.7% for torque M_y and the minimum percentage difference of 0.0078% for force F_y.

The experimental data needs to be converted to a format that will serve as an input into the estimation process. The SwRI LabView data is converted to "csv" format using Forced Motion Data Acquisition System. The converted data is then organized and imported into MATLAB for use in simulations.

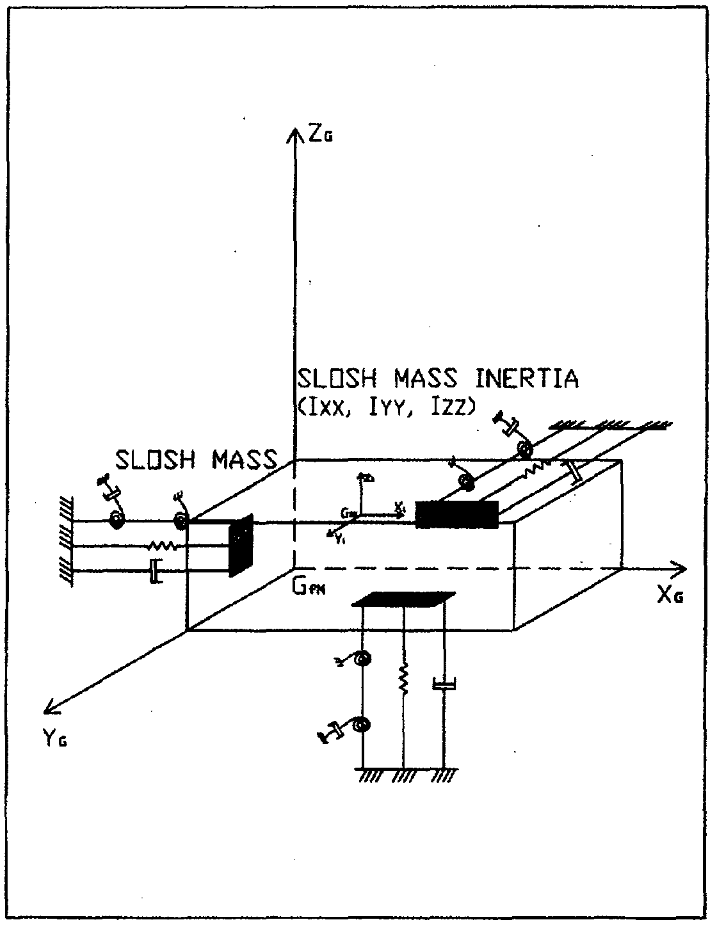

Figure 5. Schematic diagram of Rotor Model with modeling parameters

In the study, the experimental data is simulated using the SimMechanics model with different parameter values. Dominant parameters that impact the response are assessed. The effect of inertia, stiffness, and damping elements are explored. There are various levels of complexity in the Rotor Model based on the number of parameters chosen. The first estimate is obtained with three inertia elements as parameters. The next level involves using the translational and rotational stiffness and damping elements as 12 parameters. Furthermore, offset distances and cross-coupling effects can be added to improve the model response. Overall, the various combinations lead to a total of 31 possible parameters. The validation of the models using the antioptimization concept developed by Gangadharan et al., [10] will be explored. The automation of the process is illustrated in Figure 6.

LSQNONLIN file

Simulate experimental data with fixed parameters
"function Exp"

Calculate difference function

Simulate model data with initial values of parameters
"function Model"

Run **LSQNONLIN** algorithm

Update parameter values

Convergence ?

***Estimated parameters**

Figure 6. Automation flowchart for the parametric estimation process

8. LESSONS LEARNED

Throughout the course of this research work, the following lessons were learned:

- The "Black box" approach to the parametric estimation process made it difficult to understand the construction of the code within the nonlinear least squares algorithm (LSQNONLIN). The problem encountered was updating the information required to run the simulations to estimate the parameters.
- Conversion of experimental data posed a problem because the SwRI Forced Motion Data Acquisition System did not allow access to the LabView data files.
- The outputs needed to be scaled so that the average values are of the same order of magnitude.
- The optimization tolerances (TolFun and TolX) needed to be modified to allow for better convergence. This is necessary because the norm of the error between the model response and the experiment is very small.

- The impact of magnitude of response was analyzed. It was concluded that the amplitude of the response was much smaller than the actual mean values of the response.
- Sensitivity of parameters: Certain parameters that are sensitive to the response are studied. The parameters that do not cause significant change in the response are not considered in the estimation process.
- Improved computational efficiency was achieved by vectorizing and by use of special MATLAB commands.

9. CONCLUSIONS

The following are some of the conclusions of this research work:

- A parameter estimation process is developed using optimization toolbox
- The Rotor Model is studied to understand the effect of various parameters in the response
- The entire process is automated

10. FUTURE MODEL DEVELOPMENTS

The future improvements to the current Rotor Model are as follows:

- Consider coupling between rotational springs and dampers
- Better understanding of energy dissipation in fuel slosh phenomenon
- Consider additional masses, springs, and dampers

11. OUTCOMES OF THE PROJECT

The following are the benefits to NASA-KSC and the Faculty Fellow:

NASA-KSC

- An alternate approach to estimation of Nutation Time Constant (NTC) for various spacecraft models
- Compare the NTC with those provided by SwRI
- Beneficial to both Mission Analysis Branch and NASA/KSC.

Faculty Fellow

- Helps to acquire "real-world" experience that will highly compliment classroom teaching
- Introduce "SimMechanics" in System Dynamics course in Fall semester
- Build long-term relationship between Embry-Riddle and NASA (through grant proposals, graduate student research, co-op opportunities, and publications)

12. ACKNOWLEDGEMENTS

This research was conducted as a part of the NASA Summer Faculty Fellowship at NASA Kennedy Space Center. The authors would like to thank NASA-KSC ELV Mission Analysis Branch, in particular, James Sudermann, Charles Walker, Michael Carney, Amy Duffy, David Nardino, and Jonathan Whitney. Special thanks goes to Bora Eryilmaz (The MathWorks, Inc.) and Raphael T. Haftka (University Distinguished Professor at University of Florida) for all their guidance and help on this project. The authors wish to acknowledge the Southwest Research Institute for providing information on the experiment and the experimental results used for identifying the model parameters.

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IN SITU REMEDIATION OF POLYCHLORINATED BIPHENYLS USING PALLADIUM COATED IRON OR MAGNESIUM

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ABSTRACT

The remediation of polychlorinated biphenyls (PCBs) and other chlorinated synthetic aromatic compounds are of great concern due to their toxicity and persistence in the environment. When released into the environment, PCBs are sorbed to particulate matter that can then disperse over large areas. Although the US Environmental Protection Agency (EPA) has banned the manufacture of PCBs since 1979, they are still present in the environment posing possible adverse health affects to both humans and animals. Thus, it is of utmost importance to develop a method that remediates PCB-contaminated soil, sediments, and water.

The objective of our research was to develop an in-situ PCB remediation technique that is applicable for the treatment of soils and sediments. Previous research conducted at the University of Central Florida (UCF) proved the feasibility of using an emulsified system to dehalogenate a dense non-aqueous phase liquid (DNAPL) source, such as TCE, in the subsurface by means of an *in-situ* injection. The generation of a hydrophobic emulsion system drew the DNAPL TCE, through the oil membrane where it diffused to the iron particle and underwent degradation. TCE continued to enter, diffuse, degrade and exit the droplet maintaining a concentration gradient across the membrane, thus maintaining the driving force of the reaction.

The use of iron as a reductant has proven useful for treating chlorinated aliphatics but not

chlorinated aromatics. Studies have shown that a light palladium coating on the surface of iron or magnesium will dechlorinate these compounds. While the Pd/Fe and Pd/Mg bimetallic particles have been shown to effectively remove dissolved phase PCBs, the use of the Pd/Fe and Pd/Mg particles to treat sorbed phase hydrophobic PCBs is expected to be minimized by the hydrophilic nature of the Pd/Fe and Pd/Mg bimetallic particle. The emulsion technology developed by UCF to remediate TCE DNAPL pools in the subsurface could also be used to remediate PCB-contaminated soil and sediments. The generation of a hydrophobic emulsion system draws the PCBs through the hydrophobic membrane where it can diffuse to the Pd/Fe or Pd/Mg particle and undergo degradation. The PCBs, like the DNAPL TCE will continue to enter, diffuse, degrade, and biphenyl will exit the particle maintaining a concentration gradient across the membrane and thus maintaining a driving force of the reaction.

IN SITU REMEDIATION OF POLYCHLORINATED BIPHENYLS USING PALLADIUM COATED IRON OR MAGNESIUM

Cherie L. Geiger, Ph.D.

1. INTRODUCTION

Polychlorinated biphenyls (PCBs) are a group of synthetic aromatic compounds with the general formula $C_{12}H_{10-x}Cl_x$ that have been widely used because of their excellent dielectric properties and their resistance to heat and chemical degradation (1). PCBs have been introduced into the environment via improper disposal and accidental leaks from transformers, heat exchangers, and hydraulic systems. PCBs in the environment are transported primarily by particulate matter containing the adsorbed compounds and as a consequence are dispersed worldwide. The uptake of PCB-contaminated sediments by biota at the water-sediment interface can introduce PCBs into the food chain and may cause serious health problems in humans. It is of utmost importance, therefore, to seek effective methods to remove PCBs from the environment. This work demonstrates a simple method for the rapid and complete dechlorination of PCBs that are present in contaminated soils. The PCBs that were tested in this project are those that are present in commercially available mixtures Aroclor 1260 and Aroclor 1254.

The methodology that we tested consists of micometer size iron and magnesium particles that have been surface doped with elemental palladium. These bimetallic micro-particles are then incorporated into an emulsion in which the nano particles are contained within the aqueous zone of a droplet while the outer skin of the droplet is hydrophobic. When the droplet comes into contact with a PCB molecule it passes through the droplet wall and then is adsorbed onto the bimetallic micro particle where it is dechlorinated and reduced to biphenyl and chloride ions. The elemental iron and magnesium serves as the reducing agent and is oxidized to ferrous and ferric ions. The palladium on the surface of the iron and magnesium particle serves as a catalyst for the dechlorination reaction.

The uniqueness of the technique is that it can be applied in situ directly into the PCB zone where remediation can take place with a minimal disruption in surface related activities. This methodology also poses no threat of accelerating the spread of PCB contamination in the vadose or saturated soil zones. The UCF research team, with support from NASA-KSC, has demonstrated that zero-valent nanometer-size and micron iron particles can be stabilized in an emulsion that possesses a hydrophobic interior. These emulsion system has been shown to rapidly dechlorinate trichloroethylene (TCE) to ethene in a soil matrix (2). It has been documented that this emulsion system can be pumped through a soil column and it remains intact when pumping pressures are removed. The emulsion has been shown to capture free-phase TCE and 'pull' it into the droplet where dehalogenation occurs. While this emulsion system has been demonstrated to very actively dehalogenate chlorinated aliphatic hydrocarbons it does not completely dehalogenate PCBs.

However, several studies have documented that palladized iron and magnesium particles will very rapidly completely dehalogenate PCBs (3, 4). Thus, the primary objective of this project was to combine our metallic emulsion system with the palladized iron and magnesium particles for the purpose of developing a methodology for the in situ remediation of soils contaminated with PCBs.

2. EXPERIMENTAL SECTION

Primary experiments conducted included:

1. Develop analytical techniques for measuring the concentration of PCBs and byproducts within a soil matrix, a water-methanol solution and an emulsion.
2. Prepare palladized microiron and magnesium particles
3. Incorporate palladized iron or magnesium particles into emulsion that is built from corn oil or limonene, a nonionic surfactant (i.e. SPAN 85) and water.
4. Study the PCB degradation rates in vials containing soil-water and palladized iron or magnesium emulsion.

3. RESULTS

Over forty batches of palladized iron were made and the consistency of the palladium coating process remained a problem. Some of the batches were highly active while others were not as reactive or not active at all with respect to PCB degradation. We used two different plating processes. One used potassium hexachloropalladate and the second used a commercially available coating mix that is used for industrial plating processes. Pallamerse ™(Technic, Inc., Cranston, R.I.), a solution containing Pd^{2+}, was added to a vial containing acid-washed microscale iron particles and stirred for 2 minutes. The bimetal was then filtered and dried and tested for reactivity with PCBs. The results indicate that not only does Pallamerse coat the iron consistently (based on degradation efficiency) but also PCB dechlorination proceeds at a faster rate. However, a recurring problem with both methods is the sensitivity of the Pd/Fe system to oxygen exposure. Under careful conditions in a nitrogen atmosphere, the Pd/Fe emulsion system will dechlorinate 5% of Aroclor 1260 to biphenyl in 14-days.

The emulsion formulation that has been found to be the most active with the Pd/Fe system used limonene and food-grade surfactant (Span 85) in the hydrophobic exterior of the emulsion. This change was made in an effort to enhance the mass transport of PCBs across the membrane of the emulsion droplet. We found that in terms of reactivity, this formulation provided the most active emulsion, however, previous emulsions had been stable for several months while this formulation began to dissociate into its components after only three weeks. Because this emulsion is not structurally stable for as long as the vegetable oil/surfactant emulsion, more work is necessary to alter the formulation to provide for an emulsion that can remain stable for the time necessary for field injection.

The Pd/Mg system has thus far proven to be a more rigorous system that doesn't show the sensitivity to oxygen that was a problem with the Pd/Fe system. Reactivity is very fast with 20% conversion to biphenyl (using Aroclor 1260) in only 19-hours. Further experiments are underway to verify that the Pd/Mg system will work as effectively in the emulsified system.

Since the terminal product of the dehalogenation of all PCBs is biphenyl, the rate of PCB degradation can be determined by monitoring the rate of biphenyl production. The appearance of biphenyl proves that the PCBs have sorbed into the emulsion droplet where dehalogenation reactions take place.

Several emulsions were tested for their reactivity by extracting the aqueous sample with a solvent followed by acid clean up. The emulsions that were tested were all stable and flowable. An emulsion formulation made with the addition of limonene to the oil phase (micrographs shown in Figure 1) was able to dehalogenate the PCBs to their final product, biphenyl. These studies indicate that PCBs enter the emulsion droplet and degradation occurs. Any lesser-chlorinated PCB congeners produced during the dehalogenation process remain in the emulsion and are eventually converted to biphenyl.

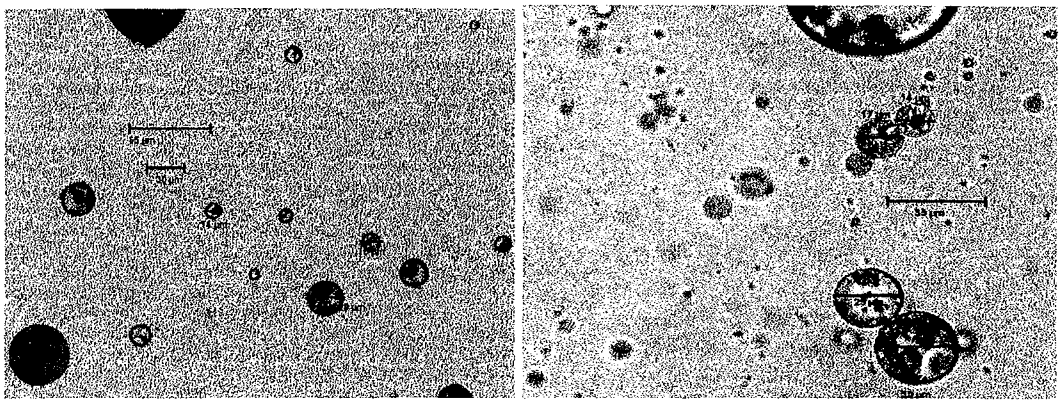

Figure 1. Micrographs of palladized, microscale zero valent iron emulsion (limonene formulation) droplets.

4. CONCLUSIONS

Many experiments were performed in an attempt to find a consistent plating technique that would produce consistent destruction efficiencies with regard to the bimetal alone with PCB mixtures Aroclor 1254 and Aroclor 1260 in an aqueous environment. The problems associated with the technique caused inconsistent rates of degradation to biphenyl. A new plating process using a commercially available liquid plating solution (Pallamerse) containing palladium (II) has been used and the degradation rates are fairly consistent (under nitrogen atmosphere) and faster than found in even the successfully plated iron using the potassium hexachloropalladate.

The use of limonene in the hydrophobic membrane improved the transport of PCBs across the membrane. This emulsion was effective at removing PCBs and degrading them to biphenyl. The stability of this emulsion was not at the same level of earlier emulsions so further work on the formulation is necessary. All emulsions that were prepared showed good physical properties with respect to density and viscosity indicating that the ability to inject the emulsions into soil or sediments can be accomplished.

The use of magnesium instead of iron shows great promise. The fact that this bimetallic system is active even when exposed to oxygen will mean a much easier transition to field scale use. The rates on initial experiments were fast with biphenyl production in as little as 10-minutes. Further experiments with this bimetal in an emulsified system are currently under way.

With the successful formulation of an emulsion and in light of the stability and viscosity of early emulsion formulations, this technology shows promise for widespread use for remediation of contaminated soils, sediments and water.

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ANALYSIS OF RETURN AND FORWARD LINKS FROM STARS' FLIGHT DEMONSTRATION 1

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ABSTRACT

Space-based Telemetry And Range Safety (STARS) is a Kennedy Space Center (KSC) led proof-of-concept demonstration, which utilizes NASA's space network of Tracking and Data Relay Satellites (TDRS) as a pathway for launch and mission related information streams. Flight Demonstration 1 concluded on July 15, 2003 with the seventh flight of a Low Power Transmitter (LPT) a Command and Data Handler (C&DH), a twelve channel GPS receiver and associated power supplies and amplifiers. The equipment flew on NASA's F-15 aircraft at the Dryden Flight Research Center located at Edwards Air Force Base in California. During this NASA-ASEE Faculty Fellowship, the author participated in the collection and analysis of data from the seven flights comprising Flight Demonstration 1. Specifically, the author examined the forward and return links' bit energy E_B (in Watt-seconds) divided by the ambient radio frequency noise N_0 (in Watts / Hertz). E_b/N_0 is commonly thought of as a signal-to-noise parameter, which characterizes a particular received radio frequency (RF) link. Outputs from the data analysis include the construction of time lines for all flights, production of graphs of range safety E_b/N_0 values for all seven flights, histograms of range safety E_b/N_0 values in five dB increments, calculation of associated averages and standard deviations, production of graphs of range user E_b/N_0 values for the all flights, production of graphs of AGC's and E_b/N_0 estimates for flight 1, recorded onboard, transmitted directly to the launch head and transmitted through TDRS. The data and graphs are being used to draw conclusions related to a lower than expected signal strength seen in the range safety return link.

ANALYSIS OF RETURN AND FORWARD LINKS FROM STARS' FLIGHT DEMONSTRATION 1

James A. Gering

1. INTRODUCTION

Space-based Telemetry And Range Safety (STARS) is a Kennedy Space Center (KSC) led proof-of-concept demonstration, which utilizes NASA's space network of orbiting communication satellites as a pathway for launch and mission related information streams. NASA's space network (SN) consists of seven Tracking and Data Relay Satellites (TDRS) in geosynchronous Earth orbit. The project also makes use of another group of orbiting satellites, the Global Positioning System, (GPS) to determine the position and velocity of the flight vehicle. The long-term expectation is for STARS to demonstrate and develop the technology needed to replace much of the extensive, down-range, land-based infrastructure currently used to launch spacecraft and support space missions.

Originally, STARS began as a combination of two Space Launch Initiative proposals: the Space Network Range Safety project proposed by KSC and Goddard Space Flight Center (GSFC) and the Range Safety and Telemetry proposal made by Dryden Flight Research Center (DRFC). Today, STARS receives its continuing funding via the Next Generation Launch Technology (NGLT) program. Today, STARS includes personnel from seven NASA centers. The STARS project management is also in communication with elements of the U.S. Air Force and that organization's effort to modernize its telemetry path through the use of assets in space.

Before each launch of an American rocket (civilian or military) or the space shuttle, the U.S. Air Force and the Federal Aviation Administration opens and clears a volume of air space over either the Atlantic or Pacific oceans. These volumes of air space constitute the Eastern and Western Test Ranges (ER and WR). Each range utilizes a unique assembly of tracking radar antennas, optical tracking telescopes, two-way communication antennas and one-way Flight Termination Signal (FTS) antennas. These facilities must maintain a radar and optical lock on the ascending space vehicle for the first 8.5 minutes of flight. The facilities of the ER are distributed down the length of the Florida coast, on islands in the Atlantic and on U.S. Navy ships in the eastern Atlantic. This extensive infrastructure is complicated, aging and increasingly expensive to maintain. It is estimated each launch in the ER periodically occupies the efforts of 700 people in several civilian and military government agencies. It is further estimated that a space-based replacement of much of this infrastructure would cost on the order of $6 million per year as compared to today's $15 million. [1].

Furthermore, STARS represents a paradigm shift from reliance on personnel, ground-based facilities and analog communications to reliance on significantly fewer personnel, space-based assets and digital communications technologies. At some point in the future, it is expected that numerous spaceports will be distributed across the United States and many countries around the world. Given the large geographic coverage provided by constellations of satellites, STARS can be viewed as one step toward enabling the eventual development of a network of spaceports for more routine and frequent access to space.

2. FLIGHT DEMONSTRATION 1

The STARS project is divided into three chronological phases: Flight Demonstrations 1, 2 and 3. Each phase of the project involves several flights of a set of GPS and TDRS transceivers. Flight Demonstration 1 concluded on July 15, 2003 with the seventh flight of a Low Power Transmitter (LPT) a Command and Data Handler (C&DH), a twelve channel GPS receiver and associated power supplies and amplifiers. The equipment flew on NASA's F-15 aircraft at the Dryden Flight Research Center located at Edwards Air Force Base in California. Flight Demonstration 2 is anticipated to again fly on NASA's F-15 while Flight Demonstration 3 will utilize an expendable launch vehicle to test the system through orbital insertion.

The purpose of this NASA-ASEE Faculty Fellowship was to assist in analyzing a portion of the data gathered through Flight Demonstration 1 and to gain increased knowledge and experience in digital satellite communications and other space launch and range technologies. Due to the size and complexity of the project, the remainder of this report will focus on

- A qualitative description of the data streams
- Examination of a parameter to characterize one data stream for all seven flights
- Examination the same parameter for the Flight Termination System (FTS) signals.
- A summary of notable events which marked the seven flights

3. THE DATA STREAMS

The data streams acquired during Flight Demonstration 1 are typically characterized by the terms 'forward' and 'return' link with the LPT and C&DH on the aircraft as the reference point for these two terms. The LPT terminates in two patch antennas, which are 4-inch by 4-inch plates mounted on the top and bottom of the F-15 fuselage, forward of the pilot's canopy. Each patch antenna receives flight termination commands (sent via TDRS) on two S-band frequency channels. Thus, in the forward link, four data streams are received by the LPT. The forward link to the aircraft consists of the monitor, arm and terminate commands of the FTS. This information is transmitted in 64 bit words. The same two antennas transmit a return link consisting of

- range safety information: x, y, z position and velocity components derived from signals received by the GPS antenna
- vehicle orientation information derived from the F-15's inertial measurement unit
- timing information
- a variety of digital frame synch information
- calculated values which correspond to the signal-to-noise ratio of the forward link information.

The return link consists of frames of 62 words, each word contains 16 bits and it is transmitted at 10,000 bits per second (bps). This contrasts with the FTS rate of 400 bps. The difference in data rate owes to an inherent trade-off, which occurs in any digital spread spectrum radio frequency transmission. Essentially, there is an inverse relationship between data rate and signal strength-to-noise. Since flight termination commands occupy the highest priority signal within the range safety community, they are transmitted at the lowest bit rate to maximize the probability of reception.

This project examined the forward and return links' bit energy E_B (in Watt-seconds) divided by the ambient radio frequency noise N_0 (in Watts / Hertz). For the return link, personnel at the White Sands Complex (WSC) in New Mexico calculate this ratio, E_b/N_0. For the forward link, values for E_b/N_0 are estimated from the automatic gain control on the LPT. Eb/N_0 is commonly thought of as a signal-to-noise parameter, which characterizes a particular received RF link. [2] Eb/N_0 is indicative of the received strength of the signal carrying the information. It is not the information itself. Hence the forward link Eb/N_0 characterizes the FTS data stream (i.e. the forward link). These values are recorded on a magnetic tape cartridge onboard the aircraft, they are also transmitted directly to the launch head at Dryden and also transmitted through TDRS as part of the 10 Kbps return link. The significance of a high value of E_b/N_0 can be seen in Figure 1 where a precipitous drop in the bit error rate occurs when E_b/N_0 decreases by a relatively small amount. [3]

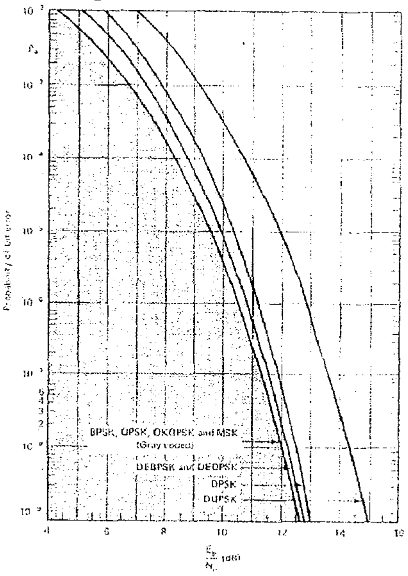

Figure 1. Theoretical probability of bit error vs. E_b/N_0 for several types of phase modulation.

4. OUTPUTS FROM THE DATA ANALYSIS

- Construct timelines for all flights from summaries and flight cards provided by DRFC
- Return Link Analysis:
  - 37 graphs of range safety E_b/N_0 for all seven flights
  - Histograms of range safety E_b/N_0 in five dB increments
  - Calculated averages and associated averages and standard deviations

- 30 graphs of range user E_b/N_0 for all seven flights
- Correlate all graphs with timelines
- Forward Link Analysis:
  - 50 graphs of AGC's and E_b/N_0 estimates for flight 1, recorded onboard, transmitted directly to the launch head and transmitted through TDRS

The STARS range safety experiment hypothesis is the anticipation that both forward and return links will exhibit sufficient signal strength, information quality and incidence of confirmed signal reception. An important secondary test is to characterize yet another group of data streams termed the 'range user' information. These signals consist of only a TDRS return link and are generated onboard the aircraft. The data rate for the range user signals is significantly higher, 125 Kbps, and (in the future) would contain information generated by the launch vehicle's payload and/or video cameras.

The return link E_b/N_0 values are calculated once every second by NASA-JSC personnel at WSC. [4] This value accounts for various energy losses that occur while the digital RF signal is travels from the aircraft through TDRS and then to the ground station in White Sands, New Mexico. Examples of ways in which power can be lost include atmospheric moisture, thermal background RF noise, and interference from reflected microwave frequency signals, antenna inefficiencies. Figures 2 displays the approximately 10,000 E_b/N_0s calculated for the first flight as a function of universal coordinated time (UTC) and Figures 3-4 display expanded segments of the flight with vertical markers indicated when the aircraft executed a particular maneuver. The F-15 flew several compass headings, 360° loops, push-over / pull-ups (i.e. dives) and 360° rolls. The rolls were executed at three differing angular rates of change and are labeled quarter, half and full stick, which is a reference to how far the pilot moves the flight control stick to rotate the aircraft about it's long body axis. One maneuver was designed to mimic (in reverse) the climb and rotation the space shuttle executes immediately after launch.

The forward link E_b/N_0 values are calculated ten times every second in the C&DH and then transmitted through TDRS to WSC. This higher data rate made generation and manipulation of the plots more time consuming and cumbersome, as did certain limitations in Microsoft Excel. [5] Four Visual BASIC scripts where developed to automate portions of the task. Nevertheless, since each flight had its own unique timeline of maneuvers, it was necessary to repeatedly handle the data and the graphs manually. Also it was of interest to compare the forward link values from the onboard data recorder and the same values transmitted to the launch head and through TDRS. Since the forward link is received on two channels for each of two antennas and is recorded at three locations, the multiplicity of the task for the forward link grew. For the first flight 60 plots were generated for the forward link and over 60 for the return link for all flights.

Figures 3 and 4 depict the drops in received power suffered after takeoff, push-over / pull-ups (POPUs) and rolls. The stepped 5 dB decline seen late in Fig. 4 is a typical example of the performance obtained in other flights when the aircraft flew level at a particular compass heading. Ostensibly, these portions of the flight should provide the most constant value of E_b/N_0. However, in many instances this was not the case.

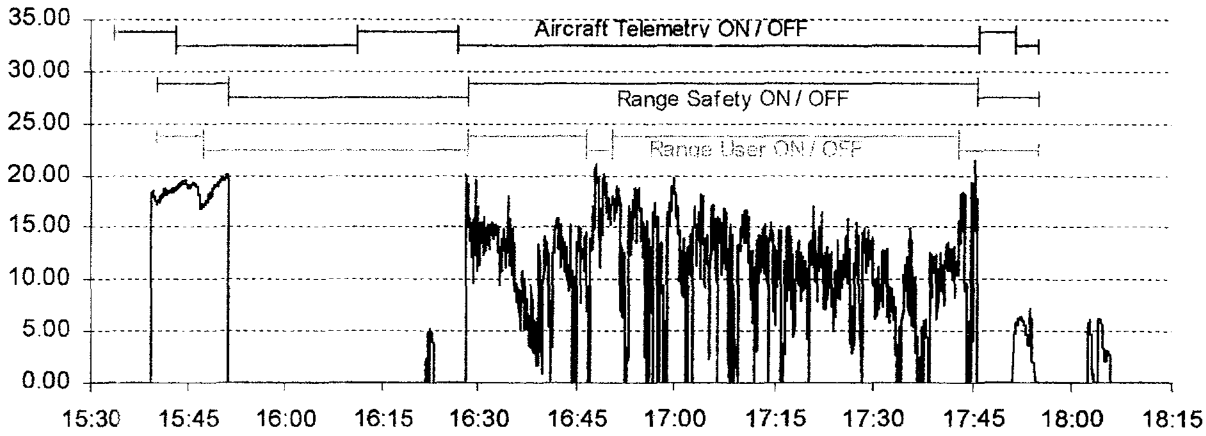

Figure 2. E_b/N_0 for flight 1's return link

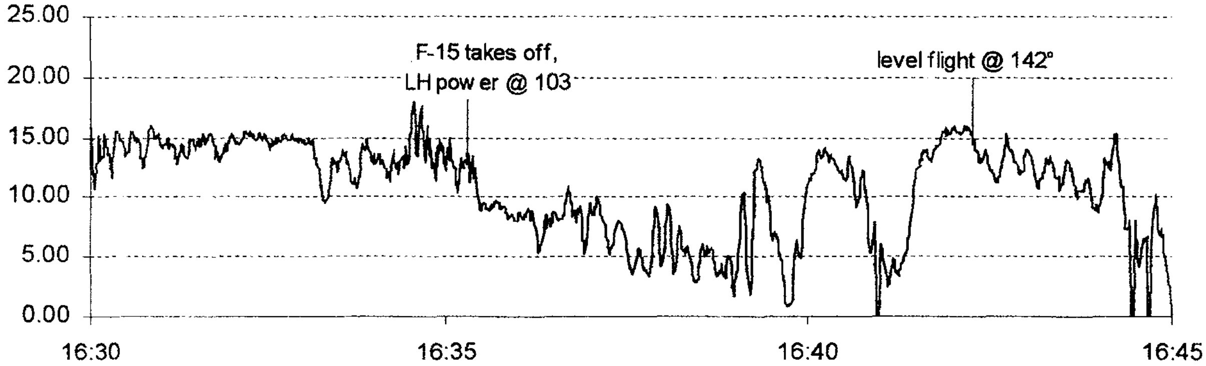

Figure 3. Expanded and labeled E_b/N_0 for flight 1

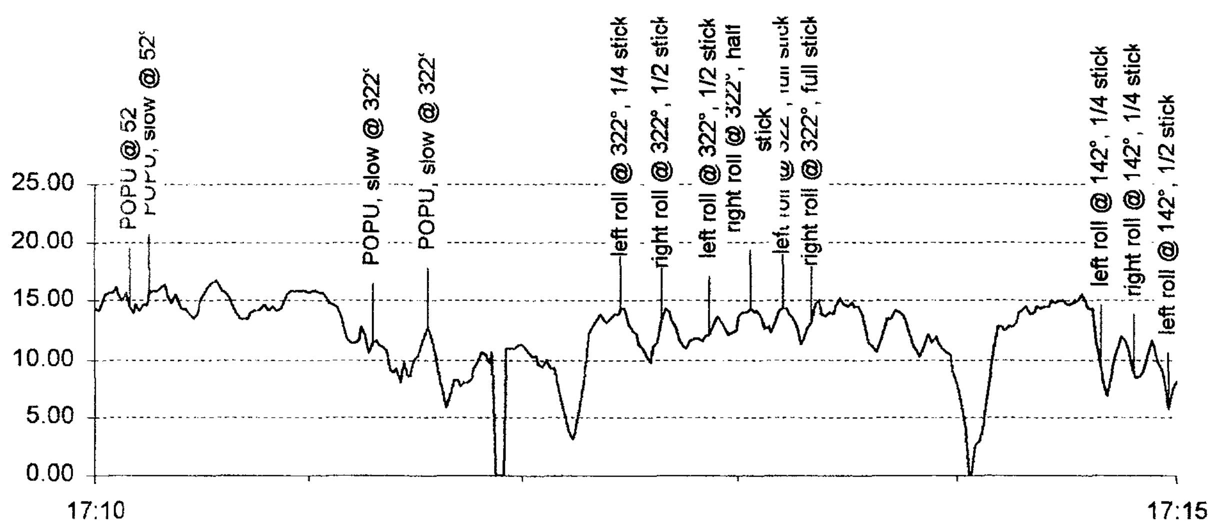

Figure 4. Expanded and labeled E_b/N_0 for flight 1

5. EVENTS DURING THE FLIGHTS

As the flights and data analysis progressed, the low average values of E_b/N_0 for the return link caused concerns among the STARS team. Competing hypotheses developed to explain the low values. One was possible interference between the range safety and range user transmissions. Another was that the voltage generated onboard the aircraft contained sufficient ripple to compromise the performance of the LPT's high power amplifiers. After the fourth flight, the decision was made to temporarily suspend further flights. A plan developed to install a power filter on the F-15 to address the second hypothesis. Also there was insufficient time between flights 4 and 5 to implement this change so flight 5 was conducted on schedule. Perhaps as an omen, an electronic problem onboard the aircraft made it impossible to transmit range safety information during flight 5. Additionally, the range user transmission was turned off during all of flight six to address the first hypothesis.

As the reader may note, two changes to the system were implemented for flight 6 rather than making one change at a time and addressing its impact. To further complicate matters, flight 6 had a very different character than all other flights. During flight 6 the aircraft flew aa level box pattern around the perimeter of the Dryden Flight Research Center to test the system beyond the reach of the launch head radars. Thus flight 6 contained none of the high dynamic maneuvers of flights 1 through 5. The values of the return link E_b/N_0 for flight 6 did show an average increase of 2 dB over earlier flights. Flight 7 contained a smorgasbord of maneuvers from all previous flights and the range user transmitter was on for the entire flight. The E_b/N_0 values again dropped to previous levels. A histogram of the values of E_b/N_0 in 5 dB increments is seen in Figure 5. Table 1 gives the average and sample standard deviations of this parameter for the return link's range safety transmissions.

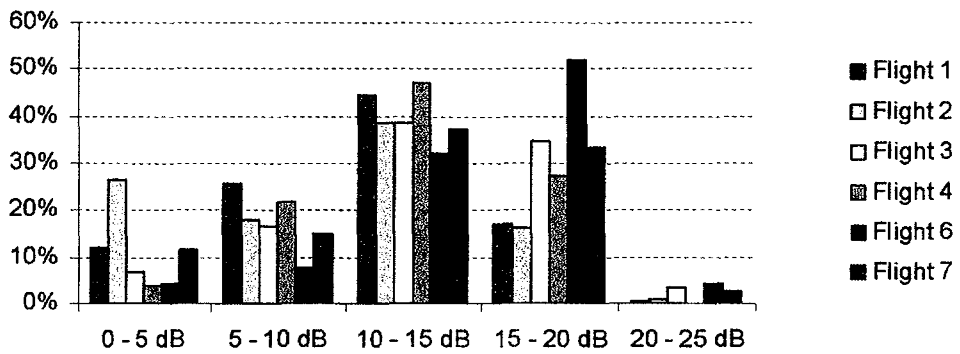

Figure 5. Histogram of range safety, return link E_b/N_0 values for all flights

Flight No.	1	2	3	4	6	7
Average	10.9	9.9	12.9	12.2	14.5	12.1
Stnd. Dev.	4.5	5.1	4.9	3.3	4.3	5.3

Table 1. Return link, range safety averages and standard deviations of E_b/N_0 values

In order to terminate the flight of an errant launch vehicle, the vehicle must receive a sequence of Monitor, Arm and Terminate commands. Again, this relies upon a low bit error rate and sufficient signal strength to noise. Flight 1's forward link E_b/N_0 values indeed demonstrate some fluctuations due to the high dynamic flight maneuvers. However, overall signal strength appears to be sufficient. Figures 6 and 7 compare one channel from the forward link as recorded onboard the aircraft and relayed through the TDRS to WSC. The numerous drops to zero are indicative of the signal's path through the ionosphere (twice) and inherent losses in passing through the TDRS.

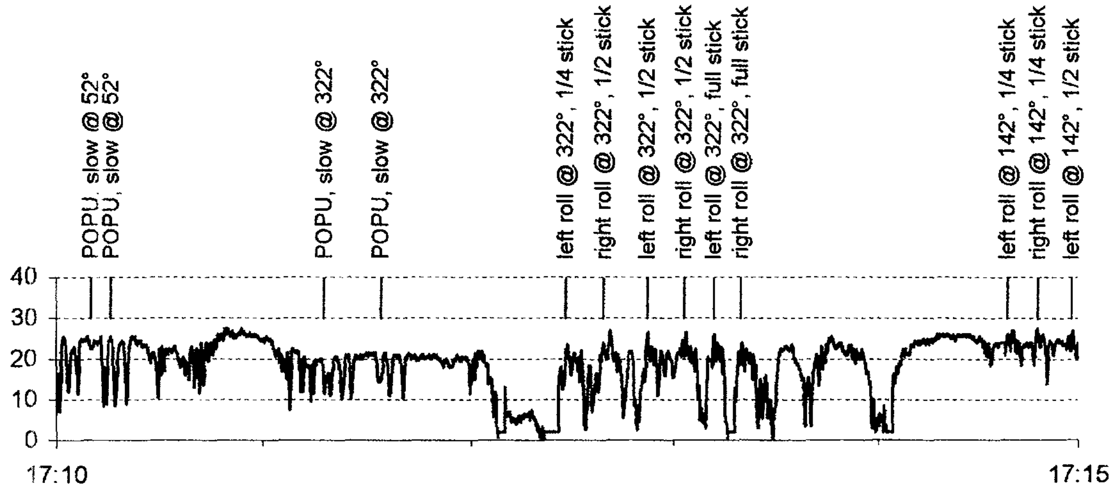

Figure 6. Forward link values of E_b/N_0 recorded onboard the aircraft

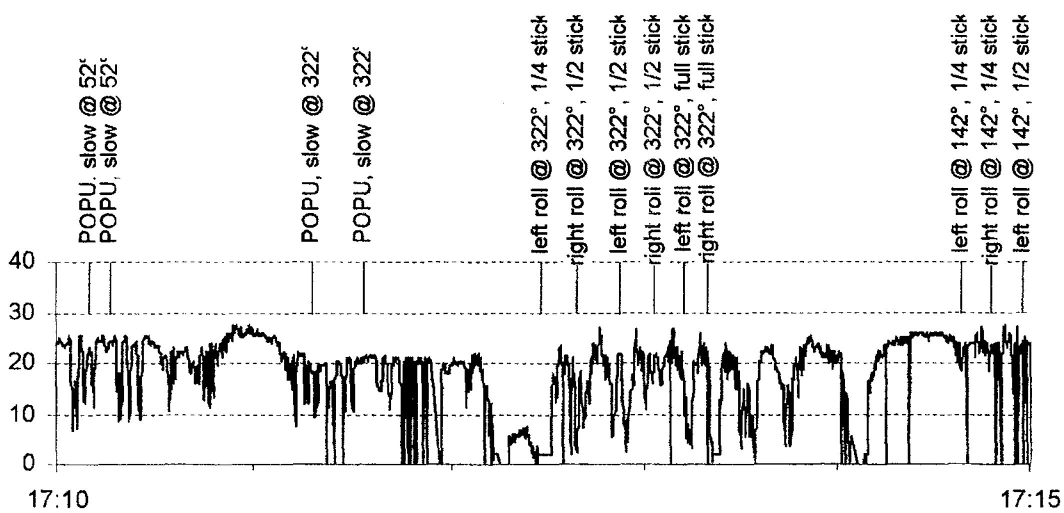

Figure 7. Forward link values of E_b/N_0 transmitted through the TDRS

6. CONCLUSIONS

During flight 7, transmitted power from the launch head was decreased by 7dB to challenge the system to receive the signals. Nevertheless, the range safety forward link through the launch head and through TDRSS appeared to be strong as determined by real-time indicators on the control consoles during the flight. The range user system also appeared to perform well based upon this first assessment and post-flight graphs of E_b/N_0 as prepared by the author. At this point in the post-flight analysis, the increase in the return link's signal strength seen in flight 6 was likely due to the level flight pattern. The patch antennas nominally radiate power in a hemisphere. However, they do have null regions and these likely give rise to the dips seen in Figs. 3 and 4. An open question remains as to the impact of interference caused by signals reflecting off of the aircraft's fuselage, wings and tail fins during high dynamic maneuvers. This issue must await a more detailed RF interference analysis of the F-15. Overall, the seven test flights comprising Flight Demonstration 1 were extremely successful. A tremendous amount of data was collected and is being analyzed. This NASA-ASEE fellowship evolved into a project in data management and visualization, which is necessary for further analysis by the STARS team.

The author would like to acknowledge and sincerely thank all the members of the STARS team and the NASA-KSC Faculty Fellowship team. In particular, Dr. Jim Simpson devoted significant time and energy in support of this work. I greatly enjoyed and benefited from the opportunity to attend the ASTWG/ARTWG conference in May and travel to Dryden for the first flight. I look forward to a continued relationship with the Range Systems Design & Development Branch of Kennedy Space Center.

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2003 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

SHUTTLE SYSTEMS 3-D APPLICATIONS

Application of 3-D Graphics in Engineering Training for Shuttle Ground Processing

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ABSTRACT

This project illustrates an animation of the orbiter mate to the external tank, an animation of the OMS POD installation to the orbiter, and a simulation of the landing gear mechanism at the Kennedy Space Center. A detailed storyboard was created to reflect each animation or simulation. Solid models were collected and translated into Pro/Engineer's prt and asm formats. These solid models included computer files of the: orbiter, external tank, solid rocket booster, mobile launch platform, transporter, vehicle assembly building, OMS POD fixture, and landing gear. A depository of the above solid models was established. These solid models were translated into several formats. This depository contained the following files: stl for sterolithography, stp for neutral file work, shrinkwrap for compression, tiff for photoshop work, jpeg for Internet use, and prt and asm for Pro/Engineer use. Solid models were created of the material handling sling, bay 3 platforms, and orbiter contact points. Animations were developed using mechanisms to reflect each storyboard. Every effort was made to build all models technically correct for engineering use. The result was an animated routine that could be used by NASA for training material handlers and uncovering engineering safety issues.

SHUTTLE SYSTEMS 3-D APPLICATIONS

Application of 3-D Graphics in Engineering Training for Shuttle Ground Processing

Dr. Gary S. Godfrey

1. INTRODUCTION

The following assignments reflect application of 3-D models to the education of Kennedy Space Center workers. These assignments include: Orbiter Mate to the External Tank (S0004), OMS Pod Installation to Orbiter (V5011.1 & 2), and Landing Gear Operation (Graphics to Kinetic). An animated simulation of each assignment was to be created. Pro/Engineer's mechanisms module was to be used to kenetically control motion or degrees of freedom.

2. ASSIGNMENTS

The initial project was to develop and animate the Orbiter Mate to the External Tank. To accomplish this duty, several tasks had to be completed. These tasks included: collecting 3-D models, drawing 3-D models, translating 3-D models into a common language, securing engineering drawings, collecting operational manual documents, and using motion simulation techniques. Compression techniques were incorporated to handle large file sizes. The animation of assembly routines required an analysis that was accomplished by development of a detailed storyboard. Storyboard routines were refined to reflect operational procedure. The scope of the problem grew to include the creation of a Model Depository, animation of OMS Pod Installation to the Orbiter, and Orbiter Landing Gear Operation. Sterolithographic techniques were used to create scaled models. The result of this project will be a set of training aids for the education of Kennedy Space Center workers. A secondary benefit will be the creation of a 3-D solid model depository that engineers may use in their design and analysis activities.

3. STATUS OF ASSIGNMENTS

The status of the Orbiter Mate to the External Tank (S0004) follows. This project is approximately 50% complete. Sling parts have been drawn, A storyboard has been completed, Orbiter/Transporter attach points have been drawn, The bi-pod, salad bowl, platforms for bay 3, and crane hook need to be drawn. There is a need for a better orbiter model. Assembly Models will have to be created to include combinations of the following: transporter, orbiter, and contact points; orbiter, sling, and crane; and orbiter, external tank, sling, SRB, and MLP. Each of the assembly models will be confined within platforms of Bay 3 and/or the VAB. Figure 1 shows a South View of VAB and Figure 2 shows the Forward Spreader Beam Model. See Figure 1 and Figure 2.

South View of VAB Model

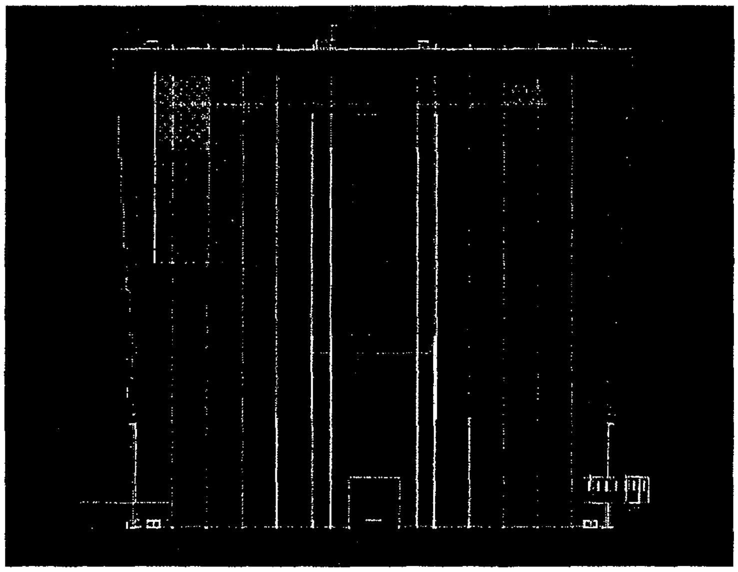

Figure 1: SOUTH VIEW OF VAB MODEL

Forward Spreader Beam Model

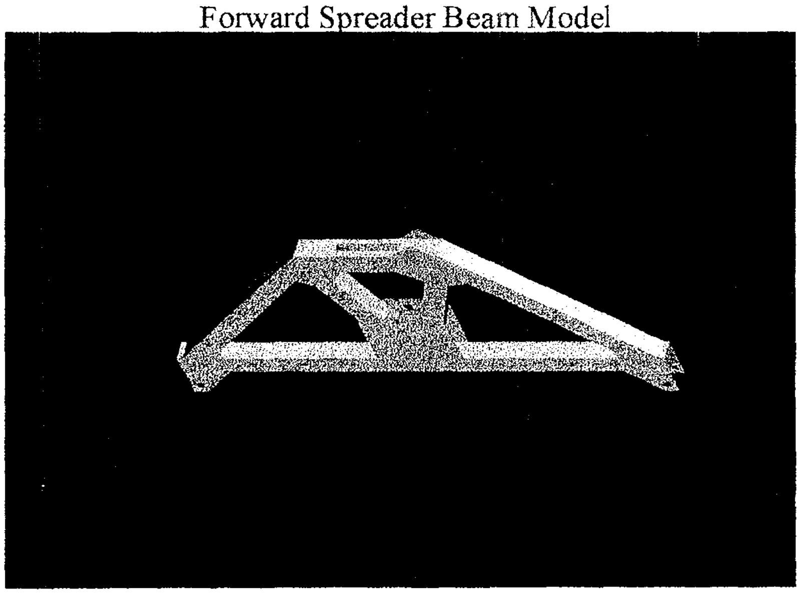

Figure 2: FORWARD SPREADER BEAM MODEL

The status of the OMS Pod Installation to Orbiter (V5011.001 & 2) follows. This project is 10%

complete. OHM's pod fixtures have been drawn. The storyboard is incomplete. The OPF model, OPF assembly platforms, and orbiter model sub assemblies need to be drawn. A better orbiter model needs to be drawn. Assembly models of the orbiter, OHM's POD fixtures, and OHM's POD will have to be created. Each of the assembly models will be confined within the OPF.

The status of the Landing Gear Operation (Graphics to Kinetic) follows. This project is 30% complete. The landing gear parts have been drawn. A storyboard needs to be created. Some parts have been modeled using sterolithography techniques. The cam displacement charts and wheel well need to be drawn. Movements have to be analyzed. Each of the assembly models will be confined within the left wing of the orbiter.

4. 3-D MODEL FILE DEPOSITORY

A 3-D Model File Depository is available for engineering use. 3-D models were collected in the following formats: (CATIA, CADAM, Intergraph, Pro/Engineer, etc.) Files were translated into a single model format (Pro/Engineer .prt & .asm). Information was translated into a manner that can be used by NASA employees. Models were translated into formats that may be used for multiple purposes (shrinkwrap, STEP, stl, TIFF, JPEG, etc).

The 3-D Model File Depository contains the following files. See Table 1.

File Format	Type	Number
.prt	Pro/E Part	2487
.asm	Pro/E Assembly	555
Shrinkwrap	Pro/E Compressed	40
Step (.stp)	Neutral File	37
.stl	Sterolithography	37
JPEG (.jpg)	Internet	41
TIFF (.tif)	Photo Shop	34

Table 1: 3-D MODEL FILE DEPOSITORY TYPES

The initial approach was to obtain all solid models required to complete animations. Solid models of the vehicle assembly building, mobile launch platform, transporter, orbiter, external tank, solid rocket boosters, OHMS POD fixture, landing gear, and bay 3 platforms were collected. Many solid models were missing. These were mainly of the material handling sling, and orbiter attach points. All files were translated into stl, stp, shrinkwrap, jpeg, and tiff formats. This provides a tessellation file for sterolithography, a neutral file that other programs could read, a compressed solid model file for handling large file size, an internet picture file, and a print shop picture file. This resulted in a model depository that engineers could use in making analytical decisions. This model depository is almost complete and is available for NASA engineers to use.

Table 2 details the sub-directories created as part of the 3-D Model Depository. See Table 2.

Directory:	3-D MODEL DEPOSITORY		
Sub-Directories:	**Orbiter ET Mate**	**OMS POD Install**	**Orbiter Landing Gear**
Sub-Directories:	ET Bipod Aft connect	OMS2	Door retract mechanism
	High bay 3	OMS Handling	MLG clean
	MLP SRB hdp Rainbird	SSV Elements	MLG Up-lock mechanism
	Orbiter ET SRB	Integrated OMS	OV 102-052103
	Orbiter Sling		OV102 left wing
	SRB		OV102 MADS stick
	Transporter		OV107 Wing Feb
	VAB		Up-stop assembly
	Integrated S0004		Integrated V5011

Table 2: 3-D MODEL FILE DEPOSITORY SUBDIRECTORIES

Pro/Engineer Wildfire has proven to be a top choice for data exchange input and output data exchange. Using Wildfire data exchange is quite possible between Catia, Unigraphics, Solidworks, and AutoCAD [1]. These data exchanges may be made using STEP, IGES, ACIS, Parasolid, STL, VRML, and DXF. Wildfire will import STL, VRML, STEP, IGES, faceted, Catia SOLM, CGM, CADAM, Medusa, DXF, and DWG. Export formats include: STEP, SET, IGES, Medusa, CGM, DXF, DWG, ProductView, and Shrinkwrap. Direct translation is possible to Catia, PDGS, CADAM, Medusa, Stheno, AutoCAD, DFX, DWG, Parasolids, and ACIS. Other translations possible are IGES, STEP, SET, VDA, ECAD, CGM, Cosmos/M, Patras, Supertab, SLA, CGM, JPEG, TIFF, Render, VRML, and Inventor. Wildfire data exchange capabilities make it a good software for handling files from many different sources.

Point Clouds are typically a series of points with (x, y, z) coordinates. These points lie on a digitized surface. These points are produced by scanners or digitizers. Point Clouds need to be surface reconstructed. This may be done by meshing which creates a triangular polygonal mesh and a resulting STL file; or by segmentation which corresponds to faces, planes, cylinders, etc, and results in IGES or STEP files. The use of Point Clouds is becoming increasingly popular in re-engineering activity and for adding detail to more primitive features. Point Cloud data should be used to detail primitive solid models.

5. COOPERATIVE ANIMATIONS

There was an effort to initiate a cooperative animation simulation with (Boeing/NASA). The project was to be a joint Boeing/NASA modeling simulation of Orbiter Mate to the External Tank (S0004). DELMIA, a custom built interface, and Ensight were to be used to enact motion and simulate the material handling activities of S0004..

There was an effort to initiate a cooperative Digital Shuttle animation with (USA/NASA). This project was to be a joint USA/NASA modeling animation of Orbiter Mate to the External Tank

(S0004). Alias was to be used to enact motion. Digital imaging techniques were to be incorporated to enhance primitive parts. This project was to be created in VRML format.

6. MECHANISM ANIMATION SIMULATION

Mechanism animation simulation was to be developed using the following methods. They include the Design Animation Option of Pro/Engineer (Image driven), and the Motion Simulation Option of Pro/Mechanica (kinetic driven), Shrinkwrap files were to be used to manage file size. Custom storyboard routines were created to time frame each routine. Mechanisms were to be created. The process includes: configuring joint axis settings, defining drivers and motion, reviewing mechanisms, reviewing motion analysis, optimizing mechanism designs, calculating degrees of freedom, and setting range of motion. The language of mechanisms included terms such as fix, welded, and translate. See Table 3 for a mechanism joint example.

	MECHANISM JOINT EXAMPLE
A.	The VAB is positioned using Fix.
B.	The Orbiter is welded to the transporter.
C.	Move to translate the orbiter and transporter from outside the VAB to the inside of the VAB and in align with Bay #3.

Table 3: MECHANISM JOINT EXAMPLE

Sterolithography is an instant prototyping process. This process produces plastic replicas of an object. The replicas may be produced scaled. Sterolithography lets the designer complete the full design process from initial concept to replica of a product. A Pro/Engineer part file is tessellation file is processed and used to create a M & G code for prototype production. Plastic is placed to build-up the part shape and size description. Wax is used for support. The wax is cleaned from the part by using an ultrasonic cleaning process. The resulting part is quite accurate in dimension.
Assembly modeling involves the combination of a number of parts. Using assembly methods sub-assemblies and final assemblies may be created [2], [3], and [4]. Assembly components are put together using assembly constraints. When a component becomes part of an assembly, it is considered placed [5] and [6]. This means that it is fully constrained. Mate, align, and insert are the main constraint methods. Assembly methods are used in animation.

Pro/Engineer's Design Animation option lets you organize parts and assemblies in an animation [7] and [8]. After routines have been coordinated, the animation may be played back. This module lets you run, create, and manage an animation. When using this option, animation may be created by linking a series of snapshots. A timeline is used to control motion.

It is claimed that motion is a virtual prototyping tool used for mechanism analysis and design [0], [10], and [11]. Motion is a module of Pro/Mechanism. Its use is in the finalization of a design. After a mechanism has been designed, it may be tested using forces. Loads generated may be measured. Use of these mechanisms give engineers an analysis tool.

7. STORYBOARDS

Storyboards were created or are being developed to detail material handling routines for the Orbiter Mate to the External Tank and OMS POD Installation. Another storyboard is being developed for the kinetic movement of the Landing Gear Operation. Each storyboard slide contains three types of information. Appendix B gives an example of a slide. See Appendix B. This slide is titled Attach Sling to Orbiter. It shows an animation of the Attachment of the Left/Right Aft Adapter in the window. The installation is attained by rotating the Inner Hand Wheel Adapter a minimum of 13 turns clockwise. The installation animation may be repeated for training purposes.

8. CONCLUSION

The use of digital imaging must be researched since there is a large amount of 3-D modeling building that must be completed. This use of digital imaging should allow for the quick creation of 3-D models.

Translation between various software platforms appears to be a problem. This is especially true when dealing with older 3-D models. Translation workstations should be identified. There file input and output capabilities should be identified. Procedures for preparing files before output should be adopted. Procedures for correcting input files should be adopted.

There must be an assigned responsibility for maintaining a master model depository. This responsibility includes 3-D creation and revision. This group should have the duty of writing files. Their distribution should be in a read-only format. This read-only format file can then be used by manufacturing for post-processing, engineering for material analysis, or drafting for 2-D drawing creation.

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APPENDIX A

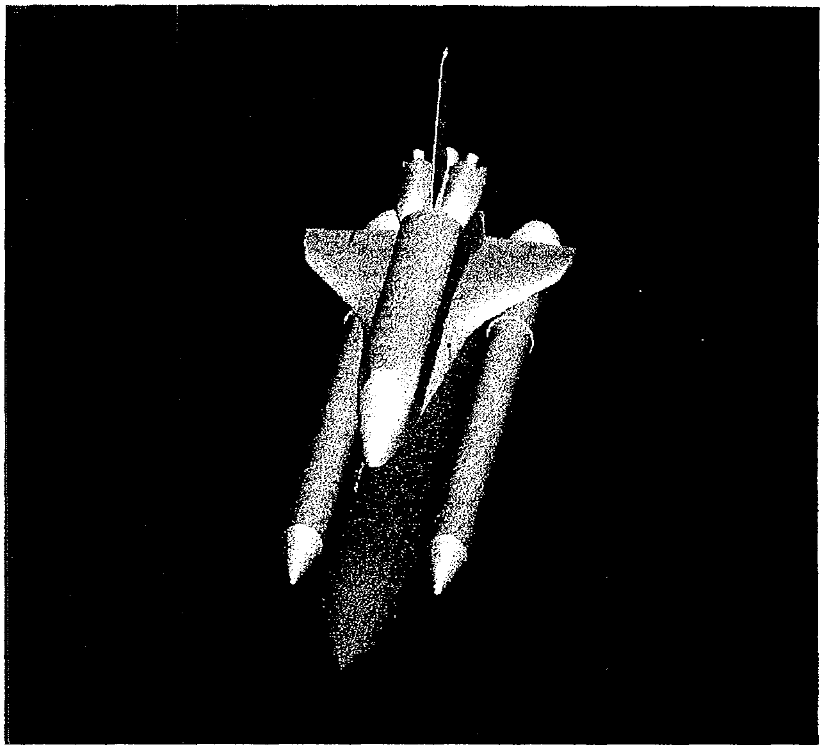
ACRONYMS

ASEE	American Society of Engineering Education
ET	External Tank
KSC	Kennedy Space Center
MADS	
MLB	
MLG	
MLP	Mobile Launch Platform
NASA	National Aeronautics and Space Administration
OHM	
OMS	Orbital Maneuvering System
OPF	
OV	
POD	
SRB	Solid Rocket Booster
SSV	
USA	United Space Alliance
VAB	Vehicle Assembly Building

Attach Sling to Orbiter

Attach Left/Right Aft Adapter

- Installation is attained by rotating the Inner Hand Wheel Adapter a minimum of 13 turns CW.



2003 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

Web Audio/Video Streaming Tool

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ABSTRACT

In order to promote NASA-wide educational outreach program to educate and inform the public of space exploration, NASA, at Kennedy Space Center, is seeking efficient ways to add more contents to the web by streaming audio/video files. This project proposes a high level overview of a framework for the creation, management, and scheduling of audio/video assets over the web. To support short-term goals, the prototype of a web-based tool is designed and demonstrated to automate the process of streaming audio/video files. The tool provides web-enabled user interfaces to manage video assets, create publishable schedules of video assets for streaming, and schedule the streaming events. These operations are performed on user-defined and system-derived metadata of audio/video assets stored in a relational database while the assets reside on separate repository. The prototype tool is designed using ColdFusion 5.0.

Web Audio/Video Streaming Tool

Eranna K. Guruvadoo

1. INTRODUCTION

In an effort to promote NASA-wide educational outreach program to educate and inform the public of space exploration, the web is emerging as powerful medium, in addition to existing NASA TV Channel. With rapid advances in audio and video technologies, NASA at Kennedy Space Center (KSC) is actively seeking efficient ways to add more contents to the web by encoding and streaming audio/video files. Currently, the process of Web audio/video streaming at KSC is done manually. Audio/video files are selected and copied to a folder. A scripted program, executing at every fifteen minutes interval, migrate the files to the edge servers for streaming. There is no capability to manage, browse and query the audio/video assets repository, and to produce reports of streamed items. Live feeds of special events from encoders have to be setup manually for web streaming. A framework to support NASA outreach program via the web is highly desirable. A web-based tool to manage the audio/video asset, to create and schedule publishable streaming program is necessary to meet the short-term goals.

The purpose of this project is to design a framework to support audio/video content creation, content management, content schedule and delivery via web streaming, and to demonstrate a prototype web-based tool to audio/video streaming. This tool will automate the audio/video streaming process at KSC. And establish a capability similar to NASA TV to deliver content via the web. The proposed framework, when fully established, will provide NASA with the capability to create and deliver content via the web at an enterprise level. The scope of this project is limited to a high-level overview of a proposed framework, and the design and implementation details of the web-based tool without any consideration of storage or video streaming technology.

This paper is organized as follows: KSC current web architecture is described briefly. A high level architecture of a proposed system is described, followed by a description of the system and functional requirements of the web-based tool to meet the short term need for content management, scheduling and delivery. Some implementation details are presented, followed by some concluding remarks

2. KSC Current Web Technologies

Figure 1, on page 3, shows an overview of current KSC technologies supporting its web services. Several web servers, ColdFusion Application Servers, video streaming servers, and a cluster of MS SQL servers are connected to a RAID repository system. All servers are connected in clustering mode with load balancing hardware. Currently, KSC supports video streaming only in Real Player format.

3. Proposed Framework

In order to meet KSC goal of utilizing the web to promote NASA-wide educational and public outreach content, a framework is proposed. A high level architecture of a proposed framework is shown in Figure 1. The model is derived from InfoSpaces [1], which describes a prototype for a large-scale content classification and dissemination network. The models are similar in terms of their abstractions but with different purposes. The challenges in [1] is the design of the scheduling algorithm for competing data-

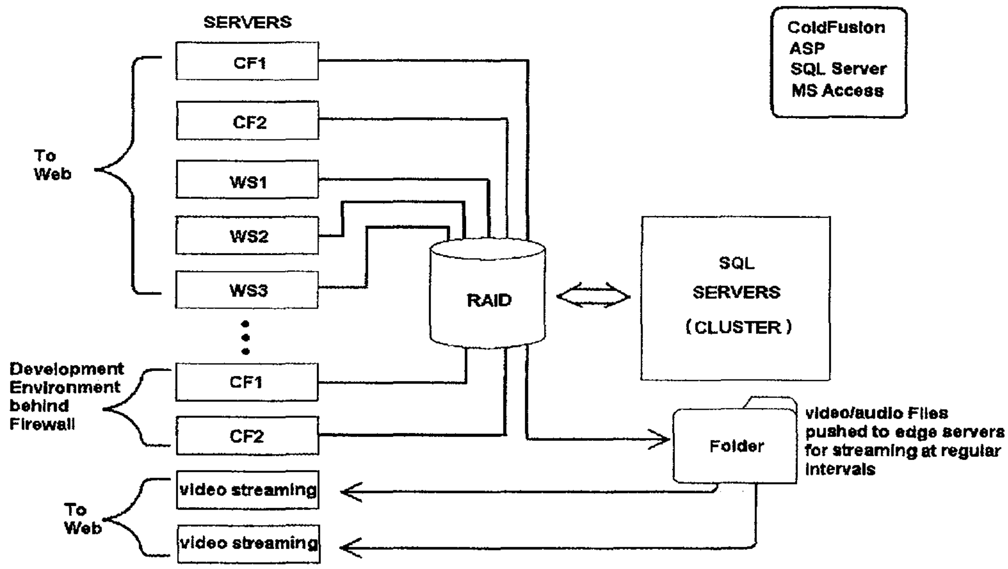

Figure 1. KSC Current Web Technologies

items over a limited number of heterogeneous delivery points. Like InfoSpaces, the proposed framework consists of three abstractions, which interact with each other through well-defined interfaces to provide the following capabilities over the Web:

1. Content Creation.
    - Web-based form interface to allow users to create and input content directly.
    - Information aggregator that uses pull mechanism to extract content from the Internet.
    - All application extensions to support content creation and extraction from the Internet have to operate within some form of security context

2. Content Management
    - Add/edit/delete "items" to content repository
    - Classify and queue "items" for approval
    - Maintain active "item set" for scheduling and delivery
    - Query content repository for report generations
    - Select items to create publishable schedules for streaming

3. Content Scheduling and Delivery
    - Time/Event triggered streaming of "items" of publishable schedules

4 Compatibility
- Support multiple streaming format – MPEG –1, MPEG –2, MPEG –4, Real Media, Quick Time, Windows Media.
- Support multiple delivery networks & protocols
- Accommodate streaming of live feeds from encoders

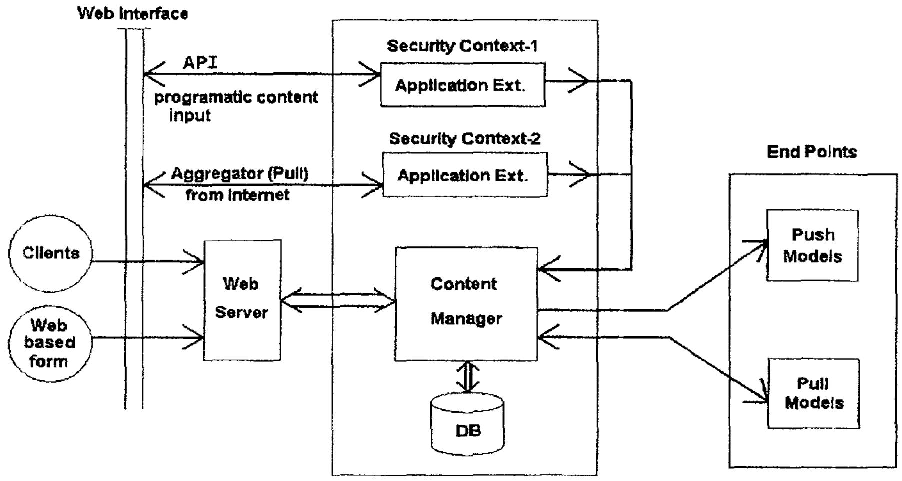

Figure 2. High Level Architecture of Proposed Framework

4. Database Server Support

Video files tend to be very large. Performing content management with the files directly would require costly storage requirements. Instead, metadata is used to describe, locate, fetch, and cache video objects for streaming. Metadata are user-defined and system-generated attributes, such as the name of a video object, physical characteristics (formats, size, bit-rate, etc.), rights associated with it, and the locations of the actual video object in the network. Using metadata provides several advantages in addition to reducing storage costs. All video attributes and URLs, regardless of their media format, can be mapped into a standard format of a database, rendering tracking, reporting, scheduling for streaming of video assets much easier. It can also help for caching items at edge servers for streaming.

Figure 3 shows the database schema, in MS SQL Server 7.0, for mapping metadata of video assets for content management. The Auth_users table holds user attributes to support a user authentication scheme with different user-level privilege. The Category table holds the different group of video asset and the Collections holds the attributes of the each asset in the repository. The Schedule table holds a record for each item set (scheduled list of item for time triggered streaming). The Schedule_Details table contains the itemized listing of each item set. The shows table is a log of all items that have been successfully streamed.

5. Requirements of Web-based Tool (short-term)

In order to meet the short-term requirement of KSC for automating the video streaming process, a web-based tool is proposed to facilitate the process. The tool should allow a nontechnical user to manage the video assets; select and schedule the activation of streaming files (in multiple formats), and to create publishable schedule for the web. All operations should be performed through web-enable user interfaces that are driven by the back-end database holding the metadata of video assets. The set of permissive operations should depends on user-level privilege (ranging from administrator to user and guest). The functional requirements are:

1. Content Management:
   Add/Delete/Edit items
   Browse/Query items for reporting purposes

2. Schedule Management
   Create Schedules of item set for streaming
   Schedule publication of item set over the web
   Update schedules
   Schedule streaming of item set
   Provide status report to administrator of any malfunction

3. Administrative Tasks
   Add/Delete/Edit User Accounts & Privileges
   Access to Log Files

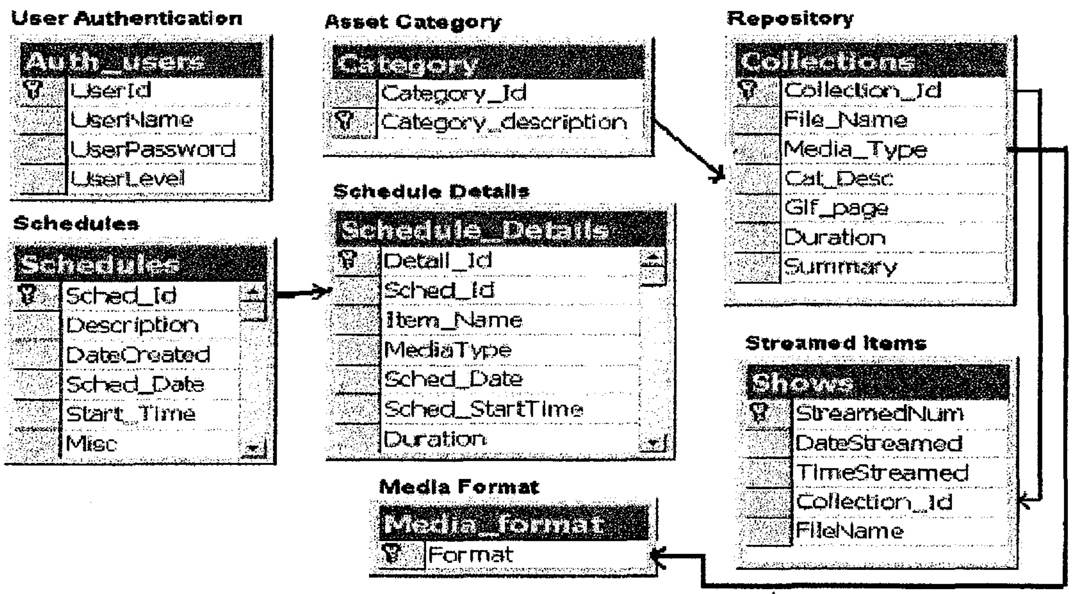

Figure 3. Database Schema of Metadata of Video Assets

6. Web Application Framework

The web application framework for the tool is designed using the features presented in ColdFusion 5.0 (KSC current web application servers) to logically group the CFML templates into a cohesive application capable of maintaining states, utilizing constants, handling exception and errors, and enforcing security. The Application.cfm and OnRequestEnd.cfm templates to provide these features [2], [3].

7. Development Technologies

The following technologies have been used to develop the prototype tool:

Operating Systems: Windows 2000 Advanced Server,
running MS-Internet Information Server 5.0, MS SQL Server 7.0, and ColdFusion MX.
Development Environment: Macromedia Dreamweaver MX.

8.CONCLUSIONS

A high-level framework to support the creation and management of video/audio assets is presented. A prototype for a web-based tool to automate the creation of publishable schedules, and the scheduling of the streaming process of audio/video files has been designed and demonstrated. A fully operational tool would require more robust user interfaces with additional functionalities, such as error handling and user-level customization. The problem of accommodating live feeds from encoders has yet to be solved. One solution would be to use Java threads with different priorities to handle scheduled streaming and live feed separately. However, this would require migration to ColdFusion MX. While the tool would support content management, scheduling and delivery of streaming video files, content creation within the proposed framework would require the development of application programming interface to input content directly into the system, and to support content integration from the Internet. Both should be operated within some security context. ColdFusion provides the necessary security framework for such development.

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2003 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

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Management Systems Simulation Model of the Mission Management Workflow

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ABSTRACT

The Mission Management Office (MMO) is a key element in the Launch Services and Expendable Launch Vehicle Program. The responsibility of this group is to assure proper integration of spacecraft/payload activities to the Launch Services provider (launch vehicle) and all ground support activities (launch support and global telemetry needs). The office was consolidated at Kennedy Space Center from a number of different NASA centers and at this time is reviewing its work processes and workflow. A Management System simulation model was developed for work being performed by the Mission Integration Managers (MIM) to determine the workforce requirements for core activities. A dynamic model was developed to allow for variations and uncertainty in the resource expenditures required for each activity and to allow for potential what-if analyses for future workloads. The model while only an early revision predicted workforce requirements that were consistent with a previous static model. Future activities and modeling approaches are identified.

Management Systems Simulation Model of the Mission Management Workflow

James R. Hemsath, P.E., PMP

1. INTRODUCTION

"It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow".
Robert Goddard

These words of Dr. Robert Goddard spoken in 1904 set the stage for space exploration in the past century as well as this new millennium. The business of space exploration is complex; to be able to master this complexity requires not only sophisticated technology but sophisticated management approaches. The successful management of programs and properties is a key requirement for achieving NASA's mission.

To understand and protect our home planet,
To explore the universe and search for life,
To inspire the next generation of explorers … as only NASA can.

Two of NASA's implementing strategies as described in the *National Aeronautics and Space Administration 2003 Strategic Plan* relate directly to management excellence:

IS-1: Achieve management and institutional excellence comparable to NASA's technical excellence.
IS-3: Enhance NASA's core engineering, *management,* and scientific capabilities and processes to ensure safety and mission success, increase performance and reduce cost.

There are three space flight programs at NASA, the Space Shuttle program, the International Space Station and the Expendable Launch Vehicle (ELV) program. The ELV program is responsible for all non-manned missions for NASA; customers include the Human Exploration and Development of Space (HEDS), Earth Sciences (OES) and Space Science (OSS) enterprises. Mission have included the Mars Exploration probes, the National Oceanic and Atmospheric Administration (NOAA) weather satellites, the Space Observatory satellites (GALEX and SIRTF), among others. The ELV program was consolidated at the John F. Kennedy Space Center (KSC) from a number of centers in October 1998 to provide a single focus for the acquisition and management of ELV launch services. One of the core offices of the ELV program is the Mission Management Office (MMO).

The MMO provides the primary customer and launch service provider technical interface for each mission, responsible for the overall management of the integration effort between the payload or spacecraft (science), the launch vehicle and all ground support. This work is performed by Mission Integration Managers (MIM) who lead the Mission Integration Teams (MIT) and are responsible for the schedule (spacecraft, integration, and launch site), budget and contract technical requirements (mission unique and launch site), and the technical requirements of the mission. There are a large variety of missions in terms of science or payload customers (JPL, other NASA centers, Universities), launching a large variety of vehicles (Boeing, Delta, Lockheed Atlas and Titan, Orbital Pegasus), from a variety of launch locations (KSC, Vandenberg AFB, Kodiak Alaska, Kwajelein Island). Figure 1 is a recent NASA Launch Services Manifest showing the plan for missions over the next 7 years and is prime example of the kinds of missions, launch vehicles and launch locations the MMO and the MIM's are responsible for.

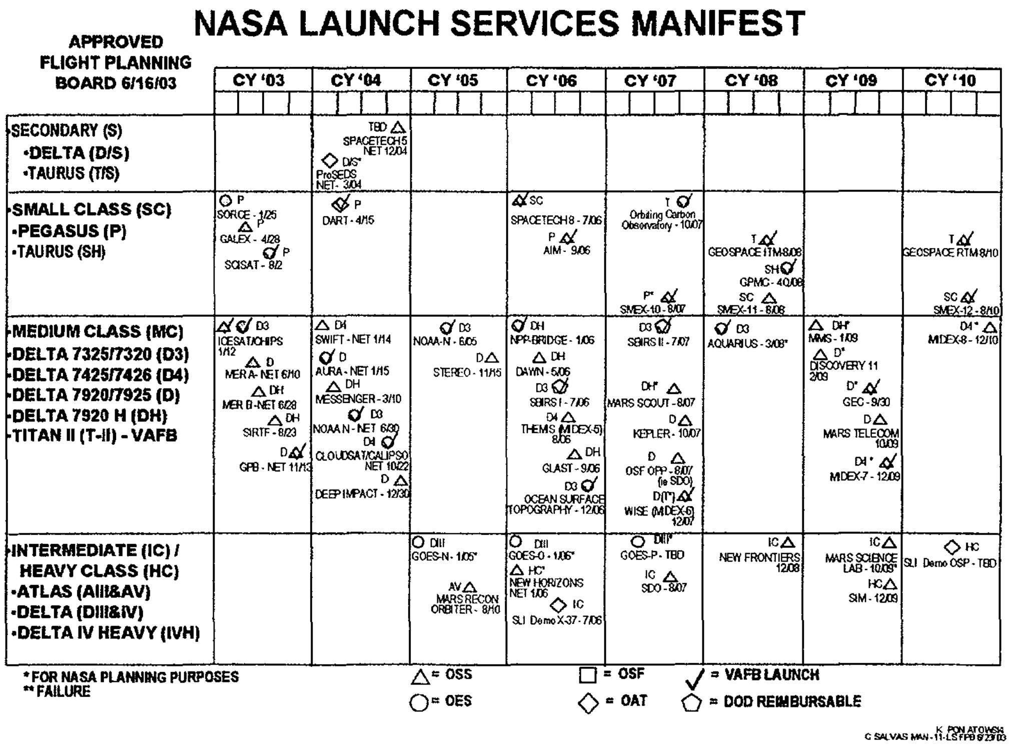

Figure 1. Example of Launch Services Manifest

This study will focus on the core activities of the Mission Management Office, specifically the core activities of the Mission Integration Managers. The MIM is the single role that follows mission from early conception through to launch. A key role is the leading of the Mission Integration Team, which is responsible for the execution of the Launch Services plan. The members of this team come from four key areas – the MIM, the interface between payload and the launch vehicle; the Integration Engineer representing Engineering; the Launch Site Integration Manager representing the local ground based activities (vehicle assembly and pad activities); and the Launch Service Manager responsible for the execution of the Launch Service contract. This group and a number of their interfaces are represented in Figure 2.

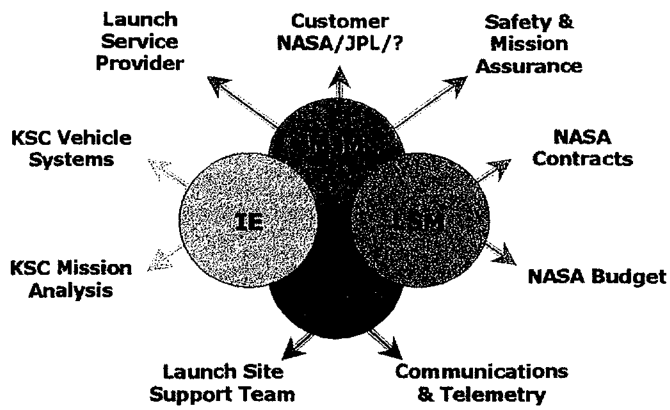

Figure 2. Mission Integration Team

The activities of the MIM are unique and in determining the manpower requirements the following characteristics must be considered. First the MIM is working with and through multiple organizations, there are multiple interfaces that must be managed and influenced. The amount of effort that is expended by a MIM can be related to the type and kind of organization that are involved in any given mission. Secondly, the missions (spacecraft and science) that are being conducted are true research projects with spacecraft component and instrumentation being developed for the very first time to achieve a one-time objective. Again, the amount of effort that a MIM will expend in managing a combined effort will vary greatly from mission to mission with no historical database to rely on. These two characteristics result in projects that are truly unique and have a high degree of management complexity. The result is to make the prediction of manpower loading under a given manifest (Figure 1.) difficult to predict.

2. THE PROBLEM

As described in Section 1, the ELV organization is a relatively new organization having been consolidated at the Kennedy Space Center in 1998. The organization and subsequent size of the organization was determined using the information and mission requirements at the time. The current concern from a management perspective is that large amounts of overtime and travel time are being expended now as compared to when the group was put together. This concern was the primary driver for an internal analysis and estimate of necessary workforce to be able to meet the needs of the most current Launch Services manifest performed in April 2003.

This bottom up workforce analysis was developed using an extensive spreadsheet model. A microanalysis approach was taken to create a work breakdown structure for every identifiable activity being done by the ELV program with the effort (in Full Time Equivalents or FTE) and assigned a time slot consistent the most current manifest. An excerpt from the work breakdown structure is shown in Figure 3.

Launch Services Program - CY03 Mission Support WBS Summary

						Engineering					MMO	
WBS1	WBS2	WBS3	Task	Time Line	Admn Off	ELE SYS	MA	MEC SYS	Res Off	SE&I	MIM	LSM
01.00.00	01.00.00	01.00.00	**Mission Support**	L-8 Y to L-5 Y								
01.00.00	01.01.00	01.01.00	**Pre-Mission Planning**			0.05	10.63	0.05	0.01	0.35	0.42	
01.00.00	01.01.00	01.01.01	AO Preparation & Approval			x	x	x	x	x		
01.00.00	01.01.00	01.01.02	Bidder Question Responses			x	x	x	x	x		
01.00.00	01.01.00	01.01.03	Proposal Evaluations			x	x	x	x	x	0.42	
01.00.00	01.01.00	01.01.04	Answer early S/C questions			x	x	x	x	x		
01.00.00	01.01.00	01.01.05	Perform vehicle trade studies			x	x	x	x	x		
01.00.00	01.01.00	01.01.06	Pre-Proposal Conferences			x	x	x	x	x		
01.00.00	01.02.00	01.02.00	**Mission Planning**	L-5 Y to L-30 M		0.71	12.72	0.71	0.09	1.61	3.01	
01.00.00	01.02.00	01.02.01	Answer early S/C questions			x	x	x	x	x	1.33	
01.00.00	01.02.00	01.02.02	Perform vehicle trade studies			x	x	x	x	x		
01.00.00	01.02.00	01.02.03	Participate in S/C Reviews (SRR, PDR, MCR)			x	x	x	x	x	0.63	
01.00.00	01.02.00	01.02.04	Prepare IRD			x	x	x	x	x	0.36	
01.00.00	01.02.00	01.02.05	Initiate TA's with LSPs for studies			x	x	x	x	x	0.31	
01.00.00	01.02.00	01.02.06	Early Planning meetings/TIMs/telecons			x	x	x	x	x	0.37	
01.00.00	01.03.00	01.03.00	**Baseline & Procure Launch Service**	L-30 M to L-27 M		0.52	0.21	0.52	0.08	0.40	1.29	0.32
01.00.00	01.03.00	01.03.01	Requirement Review / IRD			x	x	x	x	x	0.13	
01.00.00	01.03.00	01.03.02	FPB Preparation			x	x	x	x	x	0.09	
01.00.00	01.03.00	01.03.03	Prepare Mission Plan			x	x	x	x	x	0.11	0.01
01.00.00	01.03.00	01.03.04	Prepare PRCB mission pkg for approval			x	x	x	x	x	0.11	0.14
01.00.00	01.03.00	01.03.05	Place Mission on Contract			x	x	x	x	x	0.08	
01.00.00	01.03.00	01.03.06	Customer Survey			x	x	x	x	x	0.08	
01.00.00	01.03.00	01.03.07	Lessons Learned			x	x	x	x	x	0.09	0.01
01.00.00	01.03.00	01.03.08	S/C CDR			x	x	x	x	x	0.23	
01.00.00	01.03.00	01.03.09	KOM MIWG			x	x	x	x	x	0.25	0.14
01.00.00	01.03.00	01.03.10	Early Planning meetings/TIMs/telecons			x	x	x	x	x	0.13	0.01
01.00.00	01.04.00	01.04.00	**Launch Site Integration**	L-30 M to L-3 M		0.25	0.29	0.25	0.06	0.44	0.32	0.02

Figure 3. Workforce Planning Analysis

For each of these activities a Full Time Equivalent fraction was identified and then this template was applied to each mission on the manifest with the manpower expenditure taking place at a given month or timeline related to Launch occurring at L-0. Mission multipliers were used to accommodate project type, complexity and location. A manpower plot for MIM activity is shown in Figure 4 for this 7-year period.

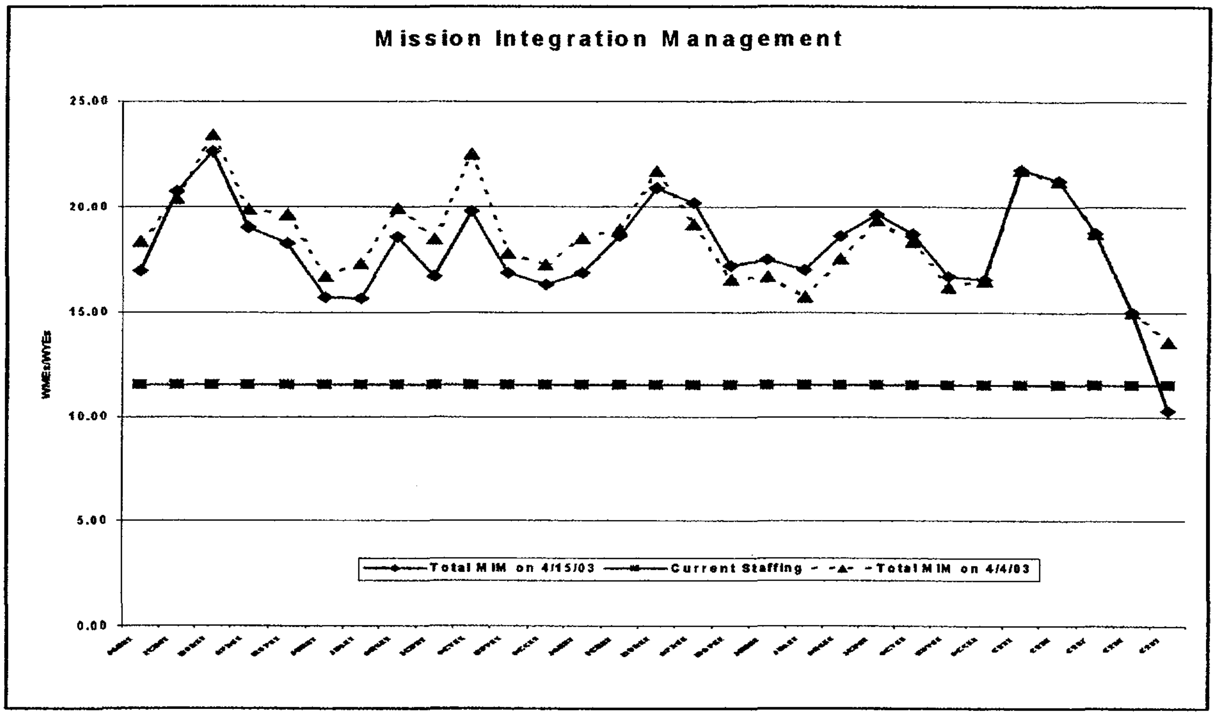

Figure 4. Workforce Requirements – MIM

This spreadsheet was used to develop an augmented manpower budget for the ELV Launch Services program.

There are a number of concerns about this model – the first and foremost is that it is a static model built on a prescribed schedule or manifest and does not represent future work or variations in the time frame. In Figure 4, the manpower requirements fall away at the end of the time period – this is a result of looking at only one project manifest. As time proceeds new missions currently not on the manifest will be added and a new 7-year cycle will begin. The question then becomes are these requirements accurate? The micro approach applies specific resource expenditures at a specific time. As discussed in Section 1, the uniqueness and complexity of the work would prevent an accurate estimate of the time required for a project as well as when that expenditure would take place. The micro model does not allow for variations or the impact of these variations.

As a result of these concerns a new problem statement was created - " Develop a system dynamics model to allow for the development and prediction of staff workload under multiple mission scenarios". This work was conducted as part of the NASA Faculty Fellowship Program.

3. MODEL DEVELOPMENT

A *system* is defined as a collection of elements that interact over time to form a unified whole and operate towards a common purpose. The term *dynamic* refers to change over time. A dynamic system is therefore a system in which the components interact to simulate change over time, and system dynamics is an approach used to understand how those systems change over time. A system dynamics model is the representation of the structure of that system. System dynamics is an outgrowth of traditional control theory. Control theory (or more accurately, feedback control theory) was developed to explain and design mechanical operating control systems (such as speed control on turbines).

This approach has since been developed to model nature, neural networks and organizations. A feedback control system has a controlled variable (output), a reference variable (input), a measurement device (allows for the generation of an error signal) and a controller (some way to send a correcting signal back to the input). The simplest example of a feedback control system is the thermostat in a house as depicted in Figure 5.

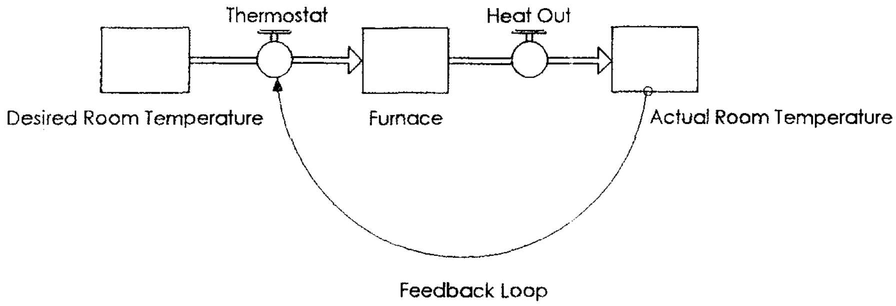

Figure 5. Simple Feedback Loop

The input (desired temperature) is set at the thermostat. The thermostat sends a signal to the furnace for heat, the house heats (with external temperature generating a disturbance to the house temperature) and the actual room temperature is measured (output). Feedback is sent back to the thermostat allowing the thermostat to turn off (temperature reaches the input setting) or to turn on (temperature is below the input setting). This basic feedback loop is what gives rise to the entire field of system dynamics. This process has been used to model large population groups, natural resources and other significant systems.

An extension of system dynamics is system thinking. It is a much more general approach to the field, rooted in the philosophy of cause and effect, versus the control loop feedback theory of system dynamics. System thinking is a way of thinking about, and a language for describing and understanding, the forces and interrelationships that shape the behavior of a system.

The advantage of this approach is that it allows for the 10,000-foot view of a problem. Instead of worrying about whether the time expenditure occurs in month 10 vs. month 11 or is equal to .43 FTE vs. .51 FTE, the model allows for a variation in the expenditure and when it occurs. The model is developed looking at the structure and relations between different activities so the points of leverage can be identified – which component or activity has the greatest impact on the workforce requirements? Most importantly the system dynamics model allows for variation in the activities independent of other activities so that the combined impact of the natural variations in the work activities can be seen.

In approaching the model we were guided by Edward Deming's view on models – "All models are wrong, some models are useful". The situation that is being modeled is extremely complex, takes place over a large time span and has a high degree of uncertainty. The approach taken was to take a large view focusing on the accumulation of Full Time Equivalents for an annual period rather than attempt to determine an exact time for an exact activity. From a management perspective, identifying the number of missions that are planned for any given year provides them the flexibility to plan for a variety of different missions.

To provide organizational consistency the model was organized by sectors around the five project phases that are used for all NASA projects and missions. Figure 6 shows these project phases overlaid on the ELV process flow.

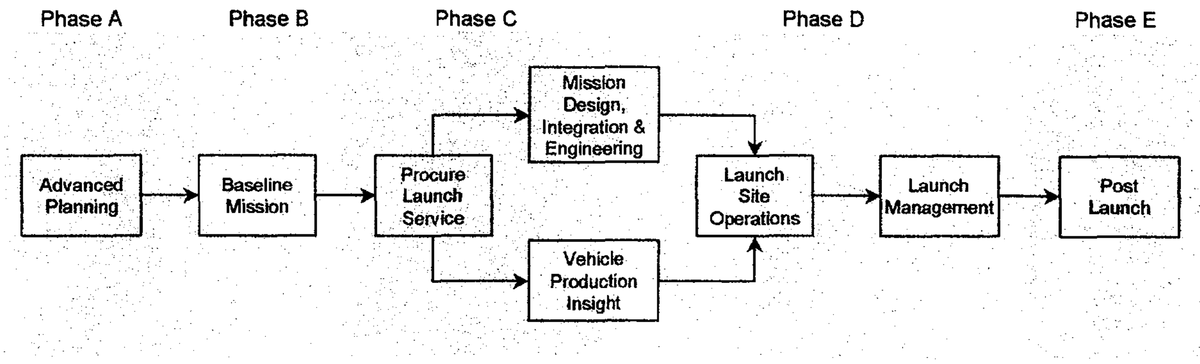

Figure 6. Project Phases

In the development of the simulation model, we concentrated on the core MIM activities and did not try to address any supporting activities or special studies. In reviewing the supporting activity expeditures from the static study, there was general consistency that this work was steady and accounted for approximately 15% of the total manhours.

To determine manpower requirements for the core activities interviews were held with the MIM's to determine their key activities and milestones. This work verified the data that had been used in the static study and a decision was made to use the estimates for Full Time Equivalents adjusted to fit the model paramters. The key to the simulation model is allowing for random variations to take place. The time that the MIM's have identified as normal for a given activity is really an average of some given distribution. A normal distribution was used to simulate the different times each activity takes for different missions or projects. Table 1 is a portion of the data set used in this model, including the standard deviation that was applied to each mean FTE.

Task	Total FTE	FTE Used	Standard Deviation
Proposal Evaluations	1.20	0.01	0.0067
Answer early S/C questions	1.92	0.60	0.4020
Participate in S/C Reviews (SRR, PDR, MCR)	0.88	0.40	0.2680
Prepare IRD	0.48	0.28	0.1876
Initiate TA's with LSPs for studies	0.43	0.25	0.1675
Early Planning meetings/TIMs/telecons	0.59	0.28	0.1876
Requirement Review / IRD	0.21	0.21	0.1429
Early Planning meetings/TIMs/telecons	0.19	0.19	0.1251
Launch Site Support Plan	0.05	0.05	0.0480
GOWGs / GORs	0.07	0.07	0.0600
MIWGs / Telecons / TIMs	3.48	1.32	1.1880
ICD approval, implementation, verification	0.98	0.51	0.4590

Table 1. Data Set for Simulation Model

4. MODEL RESULTS

The *ithink* simulation program developed by High Performance Systems, Inc. was used to create the MIM Core work process model. Forty-four key activities were identified and organized into the five project phases; Phase B of the model is shown in Figure 7.

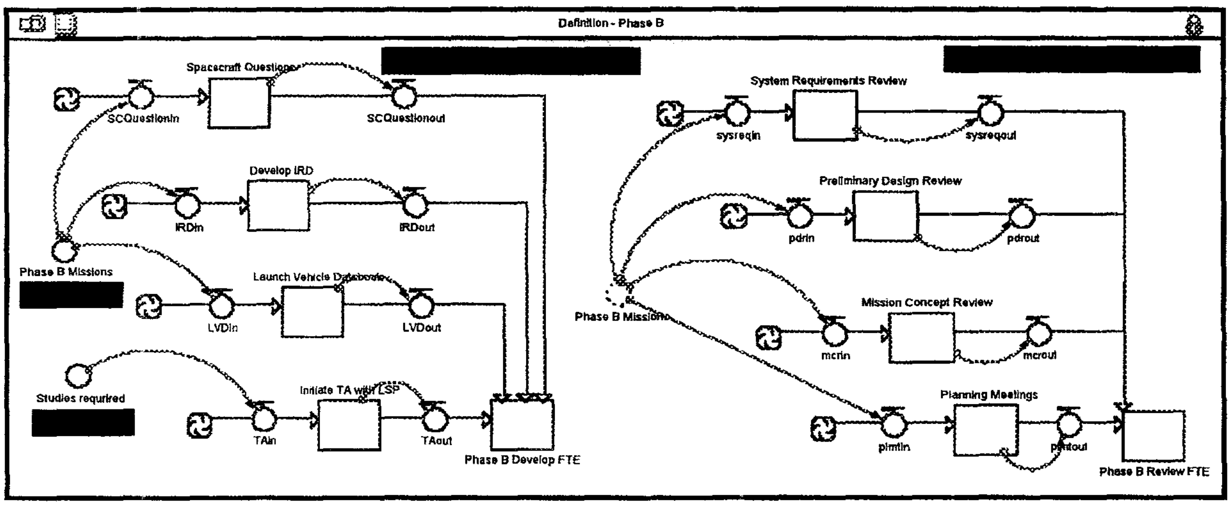

Figure 7. Phase B Simulation

The logic shown in this phase was replicated in the other four phases. The intent of this model is to accumulate FTE's for each phase, the variables are the number of missions that are expected to be completed in a given project phase in a given year and the FTE constant/mission for each activity (see Table 1.) The model generates a "mission" and for each mission a random number for each activity based on the mean FTE and the standard deviation is applied. These FTE's are then accumulated for each phase. Each activity and each project phase are independent of each other resulting in an annual core manpower loading in Full Time Equivalents. Table 2 summarizes the results of this model based on 25 simulation runs.

Project Phase	Input	Phase FTE	Minimum FTE	Maximum FTE
Pre A	30 proposal	0.02	0.01	0.02
A	15 proposal	0.07	0.07	0.07
B Development	5 missions	3.69	3.53	3.87
	10 studies			
B Reviews	5 missions	2.04	1.92	2.12
C through Contract	5 missions	1.83	1.67	1.95
C Activities	5 missions	2.17	1.98	2.33
D Mission Management	6 missions	7.05	6.49	7.40
D Mission Costs	6 missions	5.00	4.69	5.48
D Mission Support	6 missions	2.66	2.50	2.78
D through launch	6 missions	3.62	3.30	3.77
E	4 missions	0.14	0.12	0.15
Total		**25.94**	**25.28**	**26.72**

Table 2. Simulation Results

The 25 – 26 FTE required for this particular set of inputs is consistent with the 20 FTE predicted by the spreadsheet model although the number is consistently higher. There can be many reasons for this including that the 6 missions being executed in Phase D is high. Additionally, forcing workflow into an annual basis does not fully represent the partial year carry over on missions. Another area of concern is the narrowness of variation between highs and low manpower numbers. The expectations were that this variation would be larger. This will have to be studied in further detail and a simple answer may be that there are many different activities that are varying with the net effect that one variation cancels out another giving a relatively small spread in the total numbers.

However, the use of variations does seem to accommodate mission-to-mission variation without having to identify specific variations and the model easily accommodates changes in mission numbers and duration of activities allowing for what-if analyses.

5. CONCLUSIONS

This is truly a first revision model. At this point we know that the model logic is valid, that the work activities have been identified and that simulation does in fact work. However there are a number of limitations. The first is that each sector is independent, precedence of the activities is not established and the constraints that may impact activity duration may not be represented. Secondly, as mentioned above, the statistical variations do not seem to be as significant as expected. Understanding what the distributions mean and how each activity's individual variation impact another is necessary. Thirdly, the model simulation seems high and it is thought that the forcing of an annual manpower summation may be distorting the final numbers. One additional refinement of the model will be to allow the four manpower areas modeled in Phase D to have separate active missions. Currently, the same number of active missions is used for all activities in Phase D. Phase D drives the total FTE requirement, a reduction of the Phase D missions from 6 to 5 reduced the total FTE to 25.3, a reduction of approximately 2 FTE. This project phase covers a long calendar time period and refining this input could have significant impact.

There are some immediate benefits that can be drawn from even this simple model. The first is it will be very easy to see the impact of launch delays can have on annual FTE requirements. The delay of a launch will recycle some of the activities, with the refinement mentioned above it will be easy to adjust the mission needs to be able to model the additional manpower needs. Secondly, the model does provide the opportunity to examine baseline MMO department sizes under differing workload conditions. A third benefit is the ability to run different what-if analyses to study the workforce requirements for differing mission manifests. And perhaps most importantly, the model provides a tool to assist in the articulation of the variety of activities currently being performed by the MIM's and ask the question - are we doing the right activities, are we focused on the activities of highest value? The fact that it is organized around the NASA project phases allows more effective communication with other NASA centers as "apples can be compared to apples".

This is just the first iteration in the modeling process. Some of the next steps that need to be addressed include identifying linkage parts in the model. Which activity has an impact on other activities? Some of these leverage points include:

- The choice of launch vehicle type
- The science package and the experience of the customer (spacecraft designer)
- Schedule – especially as it relates to inter-planetary missions
- Maturity of the launch vehicle – launch vehicle certification requirements
- Telemetry needs and the impact a schedule change could have on the availability on telemetry
- Nuclear permitting requirements for long-term space missions
- Workload – how does the group workload impact the available resources?

The model itself can be enhanced to include a simple flight simulator interface allowing quick changes to the number of missions in each phase, the standard deviation on the distributions and the FTE constant for each activity. In this enhanced mode many different contingency studies can be performed. For example possible solutions to the root causes of historical launch delays, at least those that relate to the amount of effort performed by the MMO, can be run on this simulation allowing a cost/benefit analysis from a manpower basis.

The management of space mission activities is a complex endeavor. The work performed by the Mission Management Office is truly unique – these are research projects with no mission being the duplicate of another. New tools are needed to assist in managing these critical projects and it is hoped that this simulation model will provide a vehicle to assist management in determining what their manpower needs may be. The goal of these models is to be useful and assist in the successful execution of NASA's mission, to build good ships and successfully explore space – as only NASA can.

" We shall build good ships here: at a profit if we can, at a loss if we must, but always good ships"

Collis P. Huntington

2003 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

LEARNING NEW TECHNIQUES FOR REMEDIATION OF CONTAMINATED SITES

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ABSTRACT

The project emphasizes NASA's Missions of understanding and protecting our home planet as well as of inspiring the next generation of explorers. The project fellow worked as part of a team on the development of new emulsion-based technologies for the removal of contaminants from soil, sediment, and groundwater media with the scientists in charge of the emulsion-based technologies. Hands-on chemistry formulation and analyses using a GC/MS, as well as field sampling was done. The fellow was fully immersed in lab and fieldwork, as well as, training sessions to qualify her to do the required work. The principal outcome of the project is the motivation to create collaboration links between major research university (UCF) and an emerging research university (UT).

LEARNING NEW TECHNIQUES FOR REMEDIATION OF CONTAMINATED SITES

Teresa Lipsett-Ruiz

1. INTRODUCTION

The Strategic Plan proposed by NASA in 2003 establishes three missions with its respective goals and objectives. The first and third missions are related with this project. The first mission in the plan is to understand and protect our home planet. One of the goals to reach that mission is to create a more secure world and improve the quality of life by investing in technologies and collaborating with other agencies, industry, and the academia. At the same time an objective to reach the goal is to eliminate environmental incidents, toxic chemical use, hazardous waste, and environmental liability at all NASA sites.

The third NASA mission is to inspire the next generations of explorers. The education component might be considered if our younger generations are to be motivated to pursue careers in science and technology. Education was added as a new NASA Enterprise in 2002 with the goal of inspire more students to pursue the study of science and engineering (Strategic Plan, 2003). One of it objectives is to improve higher education capacity to provide for NASA's and the Nations future science and technology workforce requirements. Students and educators will be able to work with NASA and university scientists to use real data to study the Earth, explore Mars, and conduct other scientific investigations. The Education enterprise will permeate and be embedded within all Agency activities.

This summer project involved the two missions. First it covered research related to the development and use of new technologies for the removal of contaminants to soil, sediment, and groundwater. The new emulsified-palladized-iron (EPI) technology is in an experimental phase. Emphasis had been put in hands-on chemistry formulation and analyses using GC-MS, as well as field sampling. In terms of the third mission it models collaboration between a research university and an emerging research university, Universidad del Turabo (UT). In accordance with NASA's missions this project has as main goals to:

- Understand science solutions to environmental problems
- Immerse science students at the fellow institution, graduate and undergraduate, in different research projects related to the environment
- Attract students to pursue careers in Science
- Work at the fellow institution to achieve and sustain national competitiveness in determined areas of science and/or engineering.

Universidad del Turabo is a private, non - profit institution in Puerto Rico with more than 10,000 regular Hispanic students. The Institution offers Baccalaureate degrees in Biology, Chemistry and Environmental Chemistry with 500 regular students. UT also offers a Masters degree in Environmental Science and recently submitted a proposal for a Ph D degree in Environmental Science to the Council of Higher Education in Puerto Rico. Students admitted to the Program will be involved in research related to: Innovative Clean-up Technologies, Environmental Chemical Analyses, Environmental Biology Analyses, and Environmental Management.

Over the last 6 years, UT has been building a research infrastructure in Science. The School has been working towards the establishment of Biology, Chemistry, Materials, and Environmental Science research niches. The creation of a masters' degree in environmental science was the first step. The next step is to build and improve the institution's research infrastructure. Collaborations and partnerships between agencies, industry, and well-known research institutions have been encouraged.

NASA and University of Central Florida (Geiger et al, 2001) have been working in the development of new emulsified technologies for environmental clean up of TCE, VOC, and PCBs. The fellow was interested in learning and understanding the techniques with the goal of motivating graduate students in UT to apply those remediation techniques in contaminated sites in Puerto Rico. Introducing students to these new methodologies will enhance their research capabilities. Also this is a way of developing new research and determining how successful can be the emulsion-based technologies to treat different kind of soils. Also graduate students will obtain clean up data that will be valuable to treat different polluted sites in Puerto Rico. At the moment the Emulsified Zero Valent Iron (EZVI) had been used at Launch Complex 34 (LC34) mostly in sandy soil.

2. DESCRIPTION OF PREVIOUS WORK

Trichloroethylene (TCE), Volatile Organic Compounds (VOC), and Polychlorinated biphenyls (PCBs) are among toxic compounds that have high persistence in the body and the environment. Most have been proven to be carcinogenic, teratogenic, or mutagenic. Removal of these man-made pollutants is a significant problem. Once the heavy metals have been introduced to a body of water, they are extremely difficult to remove. When they mix with sediment in the bottom of a river, lake, or ocean it becomes even more difficult to remove them from the contaminated site. PCBs high toxicity results from their resistance to degradation and their propensity to bioaccumulation in living organisms. Numerous treatment technologies have been considered for soils and contaminated groundwater remediation.

Incineration is the recommended technology for destruction of PCBs. Incineration requires up to 1200°C achieving 99.999% destruction and removal efficiency necessary for discharging products into the air (De Filippis, P. et al, 1999). However this is an expensive process, unpopular with the public because of the potential for emissions of dioxins and other products of incomplete combustion. This technology is limited to pure PCBs mixtures.

Other technologies are emerging. Biological and chemical treatments are in experimental phases. The biological treatment requires conditions to be controlled over a four weeks or longer period and in some cases this is still ineffective. Chemical treatments such as Base-catalyzed decomposition - hydrogen transfer agents and catalysts improve the base-catalyzed decomposition of PCBs (Kawahara & Michalakos, 1997). It had been applied *ex situ*.

TCE degradation is increased by deliberately treat iron with chloride ions (Gotpagar J, 1999). Chloride ions are responsible for the crevice corrosion observed. Gotpagar hypothesized that increasing that kind of corrosion; TCE degradation rates should increase too. He found that TCE degradation is most prominent in the reaction at early times. At later times, the effect of chloride pre-treatment provides little improvement.

In situ techniques would be much simpler to implement and more cost effective than many of the techniques in use today. A methodology for groundwater *in situ* remediation is the use of permeable iron barriers. These have become a popular choice as a passive, cost-effective *in situ* remediation. Economic considerations and the concern about effective long-term disposal are contributing to a shift towards methods that specifically enhanced biodegradation or abiotic transformation (Ruiz et al, 2000). In biotic environments, microorganisms attach to metal surfaces and change the surface chemistry via biofilm formation. Such metals present a unique opportunity to provide passive *in situ* treatment to degrade chlorinated organics. Iron provides an opportunity to degrade chlorinated organics under reducing conditions, rather than simply transfer them to the subsurface to another medium. Loss of reactivity over time, due to corrosion products on the iron surface is a great concern. As a result of their study, Ruiz et al concluded that acid washed iron presents more reactive surface, with a high first-order rate constant in TCE disappearance.

Treatment of the source of contamination in the subsurface is essential to lowering the overall cost and time required for complete remediation of affected aquifers. Emulsified zero-valent iron (EZVI) has been shown to be a useful technique in the *in situ* remediation of Dense Non-Aqueous Phase Liquids (DNAPL) such as TCE. EZVI is composed of surfactant, biodegradable oil, water and zero-valent iron particles (either nano or micro-scale iron), which form emulsion particles that contain the iron particles in water surrounded by an oil-liquid membrane. It has been demonstrated in laboratory experiments conducted at UCF that DNAPL compounds diffuse through the oil membrane of the emulsion particle and undergo reductive dechlorination facilitated by the zero-valent iron particles in the interior aqueous phase.

3. NEW EMULSIFIED TECHNOLOGIES

A field-scale technology demonstration of the use of EZVI to degrade TCE DNAPL was conducted in the summer of 2002 at the LC34 Site at Cape Canaveral Air Force Station, FL. DNAPL, consisting primarily of TCE, is present in the subsurface at the Site as a result of historical releases from operations at the Site. The technology demonstration involved the injection of EZVI, an emulsion containing nano-scale zero-valent iron, vegetable oil and surfactant. Significant reductions in TCE concentrations were observed at all soil boring locations with the exception of two locations where the EZVI migrated up from the injection interval. For those two locations the observations suggested that most if not all of the EZVI migrated up above the target treatment depth. There was a significant reduction in the concentrations of TCE in groundwater samples following treatment with EZVI. The significant reduction in concentrations of TCE in samples following treatment demonstrates that a significant change has occurred in the treatment zone. It is believed that the reduction in dissolved phase concentrations is due to the destruction/degradation of residual and pooled TCE DNAPL by the EZVI. EZVI is a very promising technique for removal of DNAPL in subsurface environments. Soil coring from the LC 34 demonstration confirmed that where EZVI reached, the soil was cleaned.

In Puerto Rico as in all parts of the world exists contamination of soil, water, and air. USEPA has identified eleven superfund sites. Among the sampled chemicals and other contaminants found in them are TCE, VOC, and PCBs. Vega Alta Public Supply Wells Site is an example of groundwater and soil contamination with TCE and VOC. After different studies it was found that groundwater poses an unacceptable carcinogenic risk to human health for the ingestion and inhalation routes of exposure for sites residents and workers. Two long-term remedial phases were designed and approved by USEPA. Soil Vapor Extraction System was selected as the remedial alternative for the cleanup of the contaminated soil to avoid further migration of contaminants to the groundwater. To treat groundwater they constructed a Source Area Wells System. *In situ* treatment like injecting the EZVI to the soil could be tried as a cleanup alternative in this case. EZVI is cost effective, takes less time to decontaminate, and no residue goes to the air.

The Island-town of Vieques is part of the Commonwealth of Puerto Rico. It is located about seven miles southeast of the main island of Puerto Rico. The United States Navy owns approximately one-third of the island and conducts military training exercises that, until recently, included live bombing. The Agency for Toxic Substances and Disease Registry (ATSDR), USEPA, Puerto Rico Department of Health

(PRDOH), USGS and a Navy contractor conducted sampling studies of the different wells at Vieques from 1995 to 2000. No action has been taken at the moment. Vieques represent another possibility to use the EZVI injection *in situ* remediation.

4. EXPERIMENTAL METHODS

During this summer the team (colleague, two fellows and two students) have been experimenting with a matrix for emulsion formulation for PCBs cleanup. First the emulsions were prepared using the designated formulation. The emulsion was prepared in the following way: first iron and d-water were mixed together in a blender. Oil, d-limonene and surfactant were mixed together in a beaker and added slowly to the aqueous mixture in the blender during two minutes. After two days volume of d-limonene and/or oil that crashed out of the emulsion was measured using a graduate cylinder to see what emulsion configuration was the most stable. Then the top layer was decanted off and the emulsions were re-emulsified in the blenders. Later studies and comparison with lab results at UCF suggested that iron had to be acid washed.

Figure 1: MATRIX FOR EMULSION FORMULATION EXPERIMENTS

Formulation designation (ml-ml-g-g)w/o d-limonene (ml-ml-ml-g-g) w/ d-limonene	d-limonene as % of oil mass	Oil in g (ml)	d-limonene g(ml)	Water (ml)	Metal (g)	Surfactant-Spam 85(g)
80-100-20-3	0	73.44(80)	0	100	20	3
64-17.5-100-20-3	20	58.75(64)	14.69 (17.5)	100	20	3
60-100-20-3	0	55.08(60)	0	100	20	3
48-13-100-20-3	20	44 (47.9)	11 (13)	100	20	3
16-70-100-20-3	80	14.69 (16)	58.75 (69.9)	100	20	3
12-35-100-20-3	80	11 (12)	44 (52)	100	20	3
48-35-100-20-3	40	44 (47.9)	29.4 (35)	100	20	3
32-52.4-100-20-3	60	29.4 (32)	44 (52.4)	100	20	3
56-26-100-20-3	30	51.4 (56)	22 (26.2)	100	20	3
42.4-19.6-100-20-3	30	38.6 (42.4)	16.5 (19.6)	100	20	3
24-61.2-100-20-3	70	22 (24)	51.4 (61.2)	100	20	3
18-46-100-20-3	70	16.5 (18)	38.6 (46)	100	20	3
40.3-43.7-100-20-3	50	36.7 (40.3)	36.7 (43.7)	100	20	3
30-32.7-100-20-3	50	27.5 (30)	27.5 (32.7)	100	20	3

The emulsion matrix was prepared in the glove box using bimetal (Pd/Fe). A total of 80 ml of PCB was added and six vials were prepared. After three days, biphenyl extraction in two samples was done. For the extraction a Dismembrator and EPA SW 846 Method 3550 was followed. The aqueous layer was decanted off and the remaining Methylene chloride and nanoiron were passed through a column of granular anhydrous sodium sulfate. The dried Methylene chloride extract was exchanged into hexane prior to Florisil cleanup and reduced it volume using EPA SW 846 Method 3620 reduced version for cleanup of PCBs and organochlorine pesticides. After reduction to a volume of 5 ml, the mix was ready GC/MS analysis. The final emulsion has not been found yet. Replications of the experiment, during the summer are taking place and will keep until the right emulsion is found. Changing the percent of palladized iron had been one way of experiment with the emulsion. Also new studies using magnesium instead of iron had begun.

5. RESULTS AND DISCUSSION

The experimental results for the emulsion at the moment are not final. The main focus during this summer was on attaining a stable emulsion containing both d-limonene and oil. Stability of the emulsion was achieved with the percent of d-limonene being about twenty percent by mass. Readings from the GC/MS reveal that the production of biphenyl is rather low and that the production is not mass dependent. The importance of Pd on iron for best results is evident. It seems that for a fixed total PCB concentration, the rate of the reaction depends on the amount of Pd/Fe used. For about 40ppm of PCBs, only 1ppm of biphenyl is recovered through the extraction process (16ppm is expected), regardless of the amount of iron or emulsion that is being extracted. Stability and transport are limitations to be considered in the experimental phase. The transport limitation is caused by the inability of PCBs to dissolve fast enough in the water. PCBs may be getting trapped in the oil layer and not transferred over to the water and bimetal layer where dechlorination takes place. Presently, the use of methanol is being tested to see if the solubility of the PCBs can be increased. New experiments with magnesium are being tried.

Soil coring from the LC34 demonstration confirmed that where EZVI reached, the soil was cleaned of TCE. Demonstrations of the EZVI should be replicated at other sites. Puerto Rico has contaminated sites with urgent needs of remediation. The EZVI represents an alternative. For NASA-KSC this implies assessment of the technology. Finding a funding source for field demonstration in Puerto Rico is an expected outcome.

6. EDUCATIONAL OPPORTUNITY

Academic institutions of higher education play a vital role in conducting research that contributes to our knowledge base in all disciplines, and in educating students who go on to careers in fields of science, technology, engineering and mathematics. A way of building and improving research infrastructure in academic institutions of higher education is by encouraging science and/or engineering faculty in general to compete and participate in fellowships and internships programs so they learn new technologies that could be demonstrated and teach to their undergraduate and graduate students. Hands on activities, learning by doing, are invaluable.

Faculty participation in this program contributes to build the research infrastructure of the faculty Institution by bringing students the tools and motivation necessary to be involved in research. This involvement will represent an increase of minority, graduate and undergraduate students participating in the national pool of scientists. Once the student learns and understands new research technologies the next step is to obtain data that could be use as a research basis to solve environmental problems.

Compromise with the education enterprise is outstanding. Networking between colleagues and faculty is strongly supported. The fellow participation is a form of encouraging the establishment of collaborations between recognized research universities, the agency, and emerging research universities: minority and non-minority. These collaborations will help in achieve and sustain national competitiveness in determined areas of science or engineering research.

For future selection of participating faculty it is suggested to invite science or engineering fellows from minority institutions along with a scientist from primarily researching universities. In doing so more students will be touched. The science fellow from the minority institution, especially those who attend freshmen and sophomore population, is in charge of maintaining the student motivation to keep in the science/math/ engineering fields. If this person has the knowledge about what is new, she/he will teach with a different view and conceptualization.

Funding fellow participation through other agencies, not NASA, have a positive impact in the Fellowship Program. This year few fellows were supported by other agencies. Puerto Rico Space Grant Consortium (PRSGC)was one of those agencies. This gave the opportunity to more faculty members to participate of a unique experience.

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2003 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

KSC HISTORY PROJECT

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ABSTRACT

The 2003 NASA/ASEE KSC History Project focused on a series of six history initiatives designed to acquire, preserve, and interpret the history of Kennedy Space Center. These six projects included the completion of *Voices From the Cape,* historical work co-authored with NASA historian Roger Launius, the completion of a series of oral histories with key KSC personnel, expansion of monograph on Public Affairs into two comprehensive pieces on KSC press operations and KSC visitor operations, the expansion of KSC Historical Concept Maps (Cmap) for history knowledge preservation, the expansion of the KSC oral history program through the administration of an oral history workshop for KSC-based practitioners, and the continued collaborative relationships between Kennedy Space Center, the University of West Florida, the University of Central Florida and other institutions including the University of Louisiana at Lafayette.]

KSC HISTORY PROJECT

Patrick K. Moore

1. INTRODUCTION

Since July 24, 1950, with the launch of a modified German V-2 rocket called Bumper 8, the focus of the United States space program centered on the areas of Cape Canaveral and what would later become the Kennedy Space Center. In 1958, faced with a growing Cold War military threat, the United States Congress created the National Aeronautics and Space Administration to oversee the development of the nation's civilian space program. By the nature of that Act, Congress designed the agency to cultivate new avenues for space exploration and, in contrast to the Soviet Union, to keep the developments of the operations "open to public inspection." In keeping with that mission, NASA proceeded to face the challenges of exploring not only the earth's outer atmosphere, but also the other planets of the solar system and the cosmos beyond. In time, the obstacles facing NASA evolved from a Cold War mission to one of technical and scientific exploration. For KSC, despite the national and international issues surrounding the agency, they remained dedicated and have proactively evolved into a viable Spaceport Technology Center that cultivates safe and successful Spaceport operations. As part of that process, the American public, as well as much of the global population, focused their attention on the evolving activities and took ownership of the NASA program and the Kennedy Space Center in both its triumphs and its tragedies.

While the NASA operations encompass Centers and field operations across the country, for many people, Kennedy Space Center became the focal point of the space program because of the highly visible launch and landing operations. Despite this international attention directed at the Center, the process of collecting and preserving its rich history was occasionally lost between the transition of programs and amidst the excitement of launches. Because of this, the KSC Public Relations Office and the KSC Archives actively set out to create a formal history preservation program that would enable the Center to acquire, preserve, and interpret its history before the institution loses the pioneers of the many important programs and their personal papers and collection. As part of this endeavor, Public Relations secured funding for a visiting faculty fellow to assist in the accomplishment of this monumental task. During the summer of 2002, the collaboration between Kennedy Space Center and the University of West Florida resulted in a series of history initiatives for the ongoing mission of the KSC History Project. Building on the successes of the 2002 program, during the summer of 2003, this process continued with the expansion of activities and programs through six specific initiatives:

1. Complete editing of *Voices From the Cape* oral-history based work.

2. Complete 4 additional oral histories of key KSC officials.

3. Expand historical monograph on KSC public relations into two works on press relations and visitor operations.

4. Expand and cultivate Concept Map prototypes using UWF's Institute of Human and Machine Cognition's Cmap technology.

5. Conduct oral history workshop for Kennedy Space Center civil servants, contractors, and retired alumni to expand Center's oral history acquisition capability.

6. Expand collaborative efforts for history-related activities between KSC, the UWF Public History Program and Institute of Human and Machine Cognition, the University of Central Florida, and other universities and colleges.

Voices From the Cape

In 1999, the NASA History office published Glen Swanson's *"Before This Decade Is Out. . .": Personal Reflections on the Apollo Program.*[O1] This work incorporates edited oral histories of fourteen prominent participants in the Apollo program including Center Directors, engineers, astronauts, and others. While the work was quite successful with readers, both NASA employees and the general public, its focus was strictly on the early lunar programs and the residual Skylab and Apollo Soyuz Test Project between 1961 and 1975. Although important, the Space Shuttle and International Space Station programs during the following twenty-five years offered an equally important aspect of the NASA story. Based on this, historians conducted a series of interviews between 2000 and 2002 that highlighted the entire scope of Kennedy Space Center History. Started in 2002, the project has now resolved its remaining legal constraints dealing with copyright issues and is in the final editing stages prior to press submission for review.

Following is the tentative "chapter" outline for *Voices From the Cape*. These 24 interviews (23 individual interviews and 1 group interview) comprise the basis for the specific chapters in the work. Progressing chronologically, the work begins with the advent of the Bumper 8 launch and the subsequent vision of Center Director Dr. Kurt Debus. It then continues through the various Human Spaceflight and Expendable Launch Vehicle programs to the present. Opening the work, the text will begin with the Foreword, expectantly written by Mr. Walter Cronkite, as his offices have given a tentative acceptance for the project.

While most of the interviews cover several programs and time periods, the arrangement of the work provides a breadth of information that progresses through the history of the Center and its people. In the *Introduction* chapter and the beginning of each subsequent chapter, the editors provided a brief narrative on the subject(s) and their background(s). Also within the introductory sections, the editors included a brief synopsis that provides the analytical framework for the reader to understand the historical context of each section. Between individual chapters, the authors are selecting a series of topical vignettes of additional KSC subjects. Comprising only a few brief paragraphs, these pieces will serve to provide significant insights to the center while providing a reader with a sample of other materials available at the KSC Archives.

In order to craft a representative presentation of the "voices" of Kennedy Space Center and Cape Canaveral Air Force Station, the authors have extended considerable effort to encompass a diverse set of subjects that reflect the scope of NASA and KSC programs, gender, ethnicity, age, leadership levels, as well as external "voices" who played a pivotal role in communicating space history. Certainly there are dozens if not hundreds of valuable stories that could have been included. The editors contend that the collection of these specific interviews provide a complementary balance in presenting and interpreting the history of Kennedy Space Center. Although time considerations and pending deadlines prevented the use of any unprocessed new interviews for this work, we conducted a number of follow-up interviews to incorporate the tragic loss of the orbiter *Columbia* and her crew into the work.

While there are a total of 24 interviews selected, as a result of the limited focus of the topic, or because of limited available resources, many of these are brief in nature, comprising only a few pages. In order to create a clear and concise presentation, all interviews were re-arranged to organize information "flow" and edited for readability. However, in order to assure the intellectual and academic integrity of the work, specific points, arguments, and insights remain as stated by the subjects.

For *Voices From the Cape*, the chapter and chronological outline is as follows:

Foreword – By Mr. Walter Cronkite (or other designate if necessary).

Introduction – By Patrick Moore and Roger Launius

1. *Bumper 8 Group Interview*—Bumper 8—first launch and foundation of program
Reasons behind move to Cape, environmental conditions, first launch.

2. *Col. Kenneth Grine, Ret.*—Air Force Public Affairs Officer—(1957-1962)
Early Public Affairs, naming early rockets, launch issues, working with press.

3. *Dr. Kurt H. Debus*— Center Director (1962-1975).
Early foundations of operations from 1952, views on spaceflight, mission of center.

4. *Ike Rigell* – Retired NASA engineer. (1953-1981).
Redstone program, origins of ELV and human spaceflight.

5. *Sue Butler*—AP Reporter, (1957-Present).
Early press issues, Bird Watch Hill, Mercury, Gemini, Apollo 1 fire, Apollo Program, Shuttle—retired from AP in 2001 at 79. Challenges facing females in reporting.

6. *Lee Solid* – NASA engineer. (1960-present).
Contractor with Rocketdyne and U.S. Air Force.
Covers Atlas, Mercury programs through to the present Shuttle program.

7. *Howard Benedict* – AP Reporter at KSC (1958-1990)
Changing relationship between NASA and press, Mercury, Gemini, Apollo, ASTP, and Shuttle.
Sputnik, Cold War issues, value of ASTP, issues of Military shuttle flights.

8. *Raul (Ernie) Reyes* – Engineer, Quality Assurance Directorate. (1964-1990s)
Gemini, Apollo, Shuttle programs. Details Apollo 1 fire and responses in subsequent missions.
Transition of KSC from Gemini through Space Shuttle programs.

9. *JoAnn Morgan* – Engineer, Director, External Relations. (1958-Present)
Began as one of first female engineers that paved the way for future women at the Center.
Changing role of center and programs, gender challenges, leadership perspectives.

10. *Lee R. Scherer* -- KSC Center Director (1975-1979)
ASTP Program, Bicentennial, transition of Center between end of Apollo and beginning of Shuttle Program.

11. *Robert (Bobby) Bruckner* –Engineer. Gemini, Apollo, Shuttle, ELV, Mars Pathfinder (1966-2001)
Came to KSC in 1966 out of college and discusses end of Gemini through the present.
Relationship of the US with the USSR/Russia, MIR, ISS.

12. *James A. (Gene) Thomas* – Engineer, Shuttle Program, Former Deputy Director (1962-1990)
To Cape in 1962. Following work on Human Spaceflight programs, 1977-1983 Lead Orbiter Flight Project Engineer, 1985-1986 Director of Shuttle Launch and Landing Operations, 1987-1990 Safety, Reliability and Quality Assurance at KSC.

13. ***Hugh Harris*** – Public Affairs Directorate Positions, (1975-1998).
Media relations, KSC's relationship with the press and public after Apollo and during Shuttle programs. *Challenger* accident, return to flight, ISS.

14. ***Bill Harwood*** – CBS KSC Correspondent, (1984-Present).
Press perspective, Shuttle years from STS-2 to present. Insights as to *Challenger* accident, return to flight, ISS, future goals, and *Columbia*.

15. ***Richard (Dick) Smith*** – Engineer, KSC Center Director (1979-1986).
Redstone project, Von Braun and Debus memories (not KSC-CC focused, Marshall) Director during early Space Shuttle program through *Challenger*.

16. ***Gen. Forrest McCartney Ret.*** –KSC Center Director, (1986-1991).
U.S. Air Force. Came to Patrick AFB in 1971 and to KSC in 1986. Military and NASA connections, recovery from *Challenger* accident, return to flight.

17. ***Robert (Bob) Sieck***- Shuttle Directorate Positions, Launch Director, (1984-1999).
Aerospace Engineer, Gemini, Apollo, Shuttle Orbiter test team engineer. Approach and Landing Tests at Dryden. Returned in 1978 for Shuttle Program.

18. ***Robert (Bob) L. Crippen***—Astronaut, STS-1, Center Director (1992-1995).
USAF Manned Orbiting Laboratory (MOL), Skylab, Shuttle Program, STS-1 and three others. *Challenger* investigation, reflections on loss of orbiter *Columbia*.

19. ***John Straiton*** – NASA engineer. Shuttle Program, ISS, (1968-Present).
Covers the changing nature of the Shuttle program from inception to changing demands and the International Space Station.

20. ***Jay Barbree*** – NBC Correspondent (1959-Present).
Attended every human spaceflight launch from CC and KSC. Recollections on early launches and gathering information. Selected for "Journalist in Space" program pool originally scheduled for STS-51L, *Challenger* insights.

21. ***James L. Jennings*** –KSC Deputy Director, Business Operations (1997-2002)
Recent insights as to Shuttle Program, International Space Station, ELV, challenges and opportunities facing African-Americans in NASA environment.

22. ***Manny Virata*** – Public Affairs Official (1974-Present).
Discusses experience from ASTP to the present. Issues of press, public, VIPs, film production, September 11th, and communicating the NASA mission. Central insights as to the people, events, and experiences that created the Center's "personality" and importance to the public.

23. ***Roy Bridges*** – Astronaut, KSC Center Director, (1997-Present).
Previous commander of Patrick Air Force Base, astronaut aboard STS-51 F, transition of KSC into a Space Technology Center, views on *Columbia* loss (tentative), and vision for the future.

Bibliographic Essay

Index

The topical vignettes between chapters of *Voices From the Cape* will coincide with the final content and physical layout of the work. Selected potential subjects include:

Jack King, "Voice of Apollo"
George English, KSC Executive Officer
Guenter Wendt, Apollo Pad Leader
Virginia Whitehead, Bumper Project, Payloads, Hubble
David Fraine, Master, M/V *Freedom Star*
Richard (Dick) Beck, Crawler Operator
Andrew (Andy) Allen, Astronaut, Associate Program Manager for Ground Operations, USA

The tentative timeline for completion of the draft manuscript was/is as follows:

June 10, 2003	Acquisition of remaining four missing oral-history releases (Sieck, Smith, McCartney, Solid)
June 20, 2003	Meeting with Bob Crippen for release and follow-up
June 30, 2003	Meeting with co-editors to make final content selection
June 30, 2003	Completion of follow-up interviews reflecting *Columbia* accident
July 20, 2003	Completion of photograph selections for product
Aug. 15, 2003	Return of edited materials from Dr. Launius
Aug. 30, 2003	Circulation of draft interview text to designated content readers
Sept. 15, 2003	Return of draft interview text from designated content readers
Sept. 30, 2003	Completion of editorial changes on interviews
Oct. 1, 2003	Submission of Foreword from Mr. Walter Cronkite
Oct. 15, 2003	Completion of draft manuscript for submission

KSC Oral Histories

The NASA/ASEE project agreement stipulated the completion of four (4) oral histories during the 2002 summer program. However, as a result of the demands for the historic monographs and *Voices From the Cape*, Dr. Moore conducted ten (10) oral history interviews. Primarily focusing on Public Relations media and visitor operations, completed interviews, with transcripts pending from KSC contractor, include the following:

Roy Bridges, Astronaut, KSC Center Director

JoAnn Morgan, Director, External Relations and Business Development Directorate

Lisa Malone, Associate Director, External Relations and Business Development Directorate

Bill Harwood, CBS News

Dan LeBlanc, Delaware North Parks Services, Inc.

Bruce Buckingham, KSC News Chief

Virginia Whitehead, Bumper Project, Payloads, ISS

Robert Crippen, Astronaut, Former Center Director

David Fraine, Master M/V *Freedom Star*

Andrew Allen, Astronaut, United Space Alliance

Historic Monographs on Press Relations and Visitor Operations:
Fueling the Fascination: Kennedy Space Center and the World's Spaceport Romance

During the summer, 2002, Dr. Moore built upon his research specialization in Cold War Culture, in writing a monograph which addressed the changing patterns in which Kennedy Space Center and its Public Relations operations. The work addressed how Public Relations the population's intrinsic interest and connection with the institution and worked, at varying levels, to cultivate their intrigue, communicate the intricacies of the operation, and capitalize upon this interest in furthering both the Center's and NASA's spaceflight mission between the Cold War Years from 1957 to 1975 and then for the shuttle years between 1986 and 2002.

As a central component of the KSC operations, *Fueling the Fascination* marked the first scholarly evaluation on the subject of Public Relations operations. While under review, however, new events—one devastating and one exultant--occurred at Kennedy Space Center that provided new and compelling insights to the Public Relations evaluation. The first came with the tragic loss of the orbiter *Columbia* on February 1st, 2003 as she was returning to the Shuttle Landing Facility at Kennedy Space Center after concluding the flight of STS-107. Facing this loss, the Public Relations efforts by NASA as an agency and at KSC responded in an entirely different fashion than they had thirteen years prior with the *Challenger* accident. Demonstrating the practice of what many officials had suggested during the previous investigation, both the agency and KSC reflected "lessons" learned from the past in their response and behavior. The second issue, in a more jubilant vein, occurred when the visitor operations assumed control of the Astronaut Hall of Fame located immediately beyond the KSC property near Gate 3 on SR-405. Saving the operations from cessation after financial difficulties, the new collaboration between KSC, Delaware North Park Services, and the Astronaut Scholarship Foundation forms an invaluable resource for interpretation and preservation of the "human" components of the KSC story. Further, in facing the ongoing challenge of remaining competitive in the central Florida tourism market, this provides Public Relations with an important new mechanism for that endeavor. Because of these two events that essentially created another set of "chapters" for the Public Relations story, the author split the original monograph into two individual, yet complementary pieces. Upon completion after the return to flight, the work will be reviewed and should be published as part of the NASA *Monographs in Aerospace History.*

Historical Concept Mapping (CMap) and the History Database

In 2002, working with the University of West Florida's Institute of Human and Machine Cognition (IHMC), Dr. Moore and the UWF Public History Program crafted a series of important research tools for preserving, organizing, and arranging KSC history. Called Concept Mapping, these tools are based upon IHMC computer-driven models for acquiring, organizing, presenting, and preserving institutional knowledge. Unlike a book or report that reads from start to finish, these "cognitive prostheses" allow both researchers and audiences to identify and address materials through significant interrelating concepts rather than through the rigid, and often inflexible, framework of conventional publications.[02] As part of the history initiatives at Kennedy Space Center, Dr. Moore expanded upon the 2002 Cmap prototypes to address the Center's history and create a cognitive tool for working with the various aspects of its development. The Cmapping software and maps are now being used by the KSC Archives and will serve as a template for expanding Cmap activities. The following maps represent a sample of this undertaking that relate to the momentous task of recording and preserving the history of the STS-107 flight of *Columbia* and its context within the history of Kennedy Space Center.

Starting with the "KSC Master Map" (Figure 1) the structure provides key current and historic activities, or "concepts" connected by linking phrases. Fully "populated" (containing icons below each "concept" for access to secondary maps and supporting materials), each of the concepts on the Master

Map contain specific key materials and maps. Users can either click on documents, graphic resources, photographs, video clips, interviews, and other materials to explain the specifics of the concept. To explore the concept at a deeper level, users can then click on the secondary maps icon to open a new map.

Opening the secondary map under "Columbia" users find themselves at the "Orbiter Columbia Map" (Figure 2). In this map, users can explore the history of the orbiter as well as the purpose behind the vehicle and specific missions. For this discussion, the user would select from a series of maps under on the "STS-107" concept. These maps include "Pre-Flight Processing (Figure 3)," "Pre-Launch Preparations," "Launch (Figure 4.)," "Mission," "Return," etc. At this level, program participants, researchers and others can address various mission-specific concepts. By working through the maps and the associated support materials, users can both incorporate new information as necessary and/or work through the maps to garner information from various sources relating to specific topics. Unlike a conventional report, this allows the investigation to reflect the needs and focus of the user rather than the interpretation of the creator.

By incorporating the existing KSC History Database into the Cmap framework, the tools will provide all interested parties, including senior management, policy planners, engineers, researchers, historians, and many others, with a conceptual framework for understanding all aspects of Kennedy Space Center. Further, by applying these tools to the existing Kennedy Space Center Website, Internet users all over the globe can access and understand the depth of the Center, its history, and its personnel.

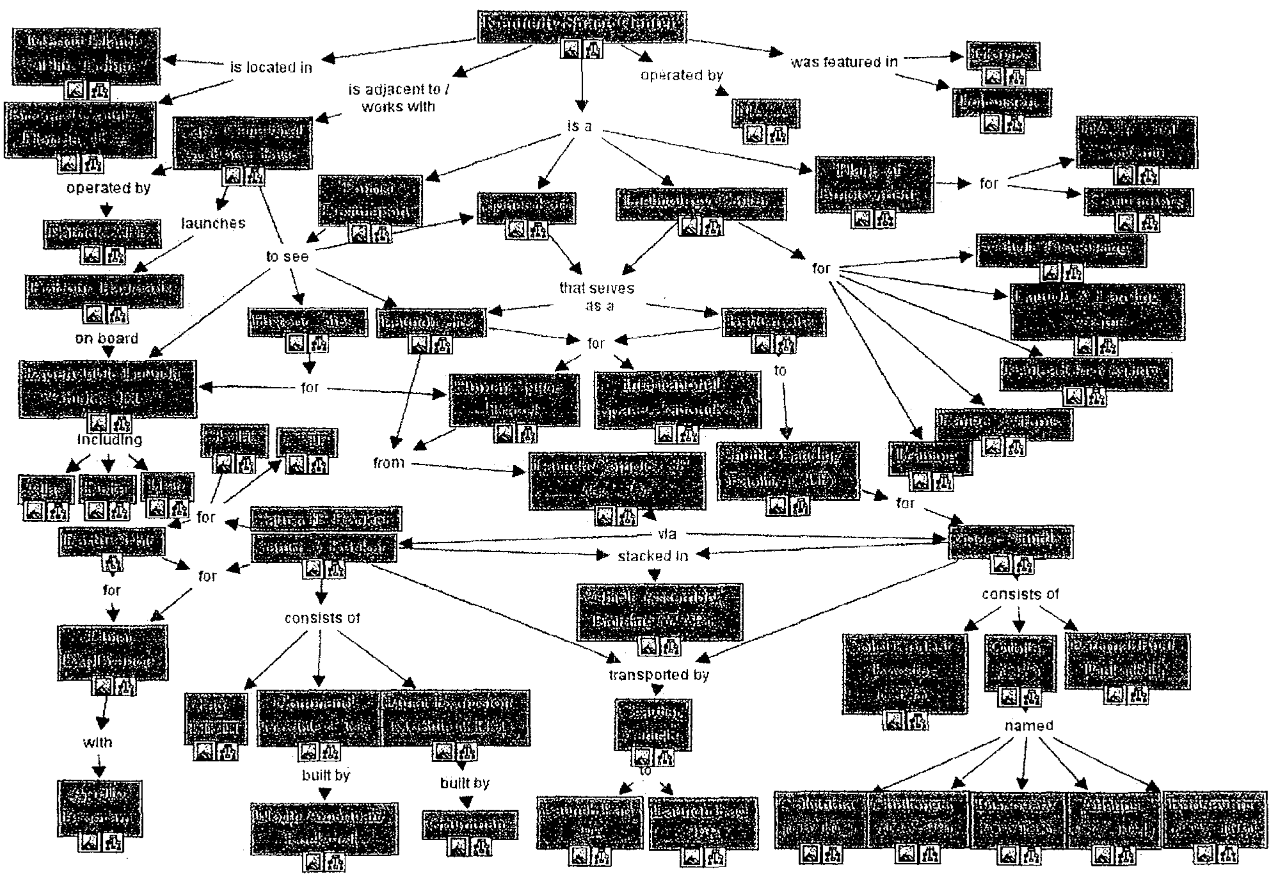

Figure 1.

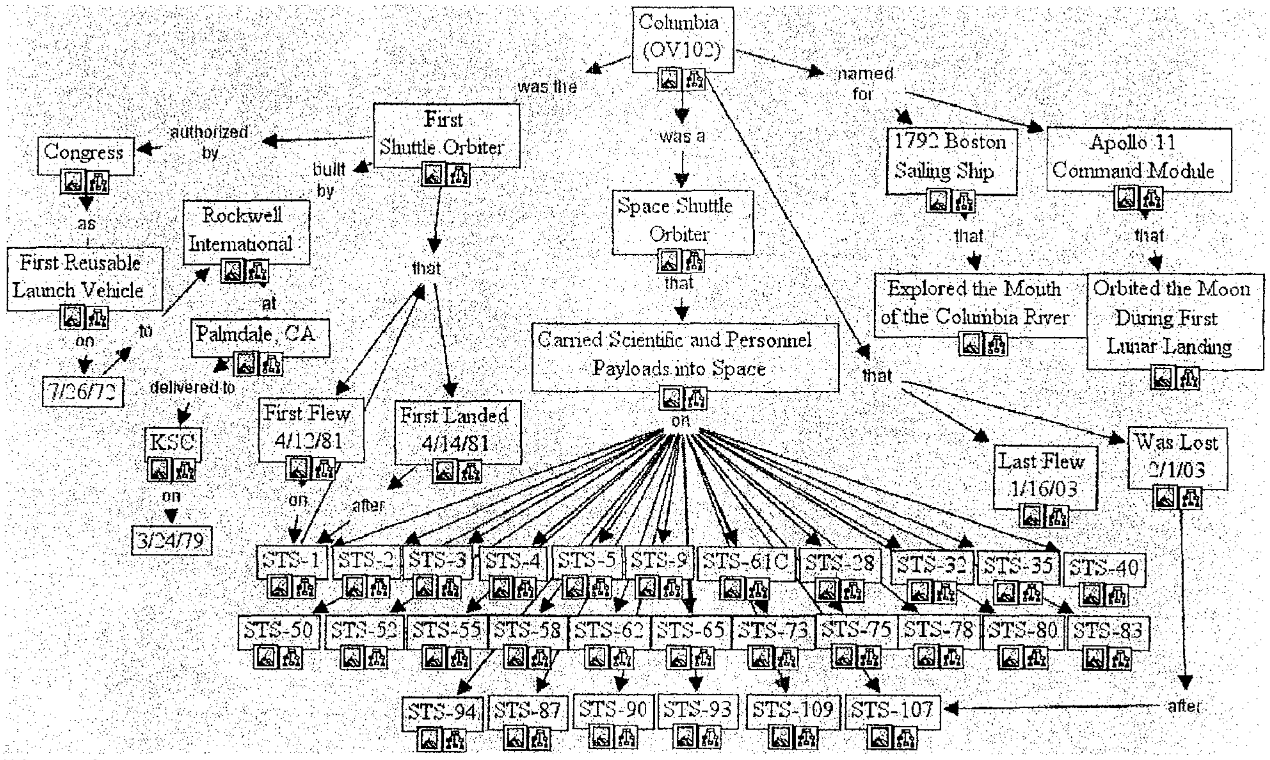

Figure 2.

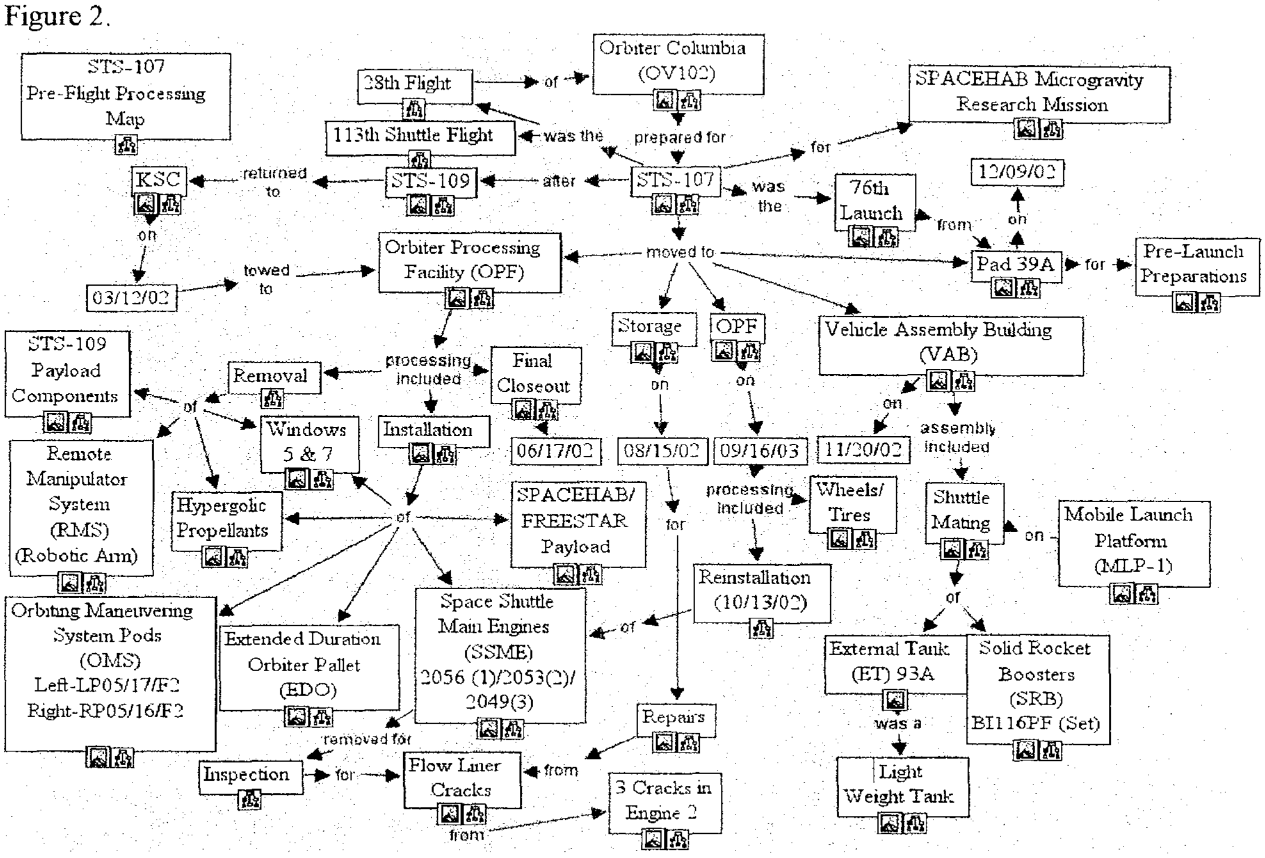

Figure 3.

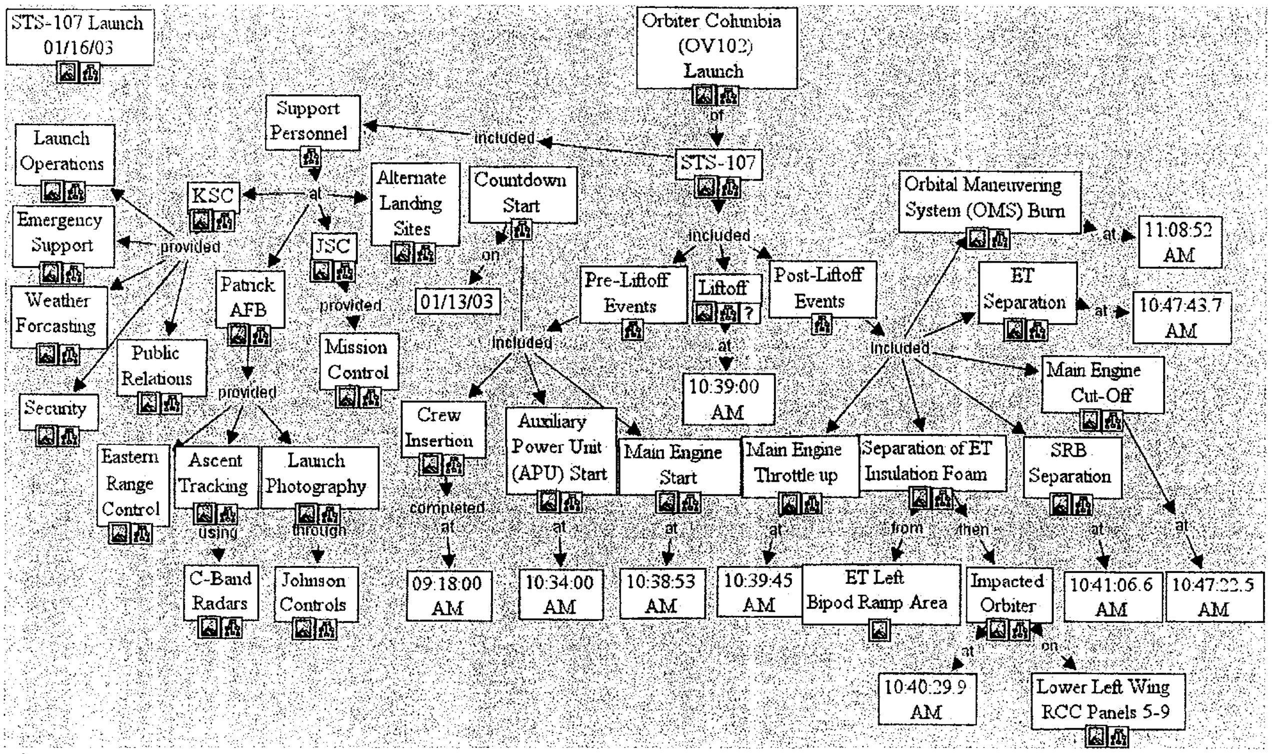

Figure 4.

KSC Oral History Workshop

As one of the most valuable and informative resources for collecting history, Kennedy Space Center began the task of collecting oral histories during previous programs and with the assistance of the NASA History Office. During the summer 2002, Dr. Moore developed a framework for the proposed mission, focus, policies, procedures, and pertinent forms and documents associated with the National Aeronautics and Space Administration, Kennedy Space Center Oral History Program.

Building on this initial foundation, on July 17, 2003, Dr. Moore conducted the first Kennedy Space Center Oral History Workshop. Attended by twenty individuals representing various KSC directorates, civil servants, contractors, and KSC retired alumni, the workshop provided the attendees with the history of the oral history discipline, insights as to the legal aspects of conducting oral histories, and the basic skills to research, prepare, conduct, and process an oral history interview. Through this workshop, KSC can begin the process of actively collecting its history from within so as to preserve its knowledge for both current and future generations.

Collaborative Framework

As the final initiative of the summer KSC History Project, Dr. Moore expanded on the opportunities for future collaboration between Kennedy Space Center, the University of West Florida, and the University of Central Florida. As part of the 2002 efforts, Dr. Moore identified a series of opportunities for the placement of interns with the UWF Public History graduate program. The first is within the KSC Archives where students can complete a variety of archival-management and history-focused projects as well as Cmap development. The second is with Delaware North Park Services where students concentrating in museology (museum studies) can help develop exhibits, interpretive presentations, and other projects. The final area is working with the Webcast studio (KSC Direct!) where students specializing in media and documentary production can develop historic pieces on KSC and program histories for broadcast over the Internet. Stemming from these efforts, during the 2002-2003 academic year, Dr. Moore brought seven graduate students to Kennedy Space Center to provide assistance in various areas including the ongoing KSC Archives Photograph Project.

The resources from this internship capability provide a wealth of opportunities to Public History graduate students at the University of West Florida and ultimately the University of Central Florida (once its new Public History program begins). To enhance this resource for Kennedy Space Center, however, the program needed to extend to other institutions as well. As a result, Dr. Moore extended the "reach" of this program throughout the region and brought Dr. Robert Carriker, Public History Program Director from the University of Louisiana at Lafayette to Kennedy Space Center. In this, KSC cultivated a greater collaboration between institutions and developed a greater breadth of opportunities for history practitioners across the country.

By expanding these relationships, the collaboration between KSC, UWF, UCF, and ULL creates the unique opportunity for grant submissions to numerous humanities, history, and space related funding operations. Although as a federal agency guidelines prohibit NASA from applying for grants, the university relationship enables UWF and the other institutions to obtain funds for the completion of various projects. From this, the benefits extend to both the graduate students in the completion of their projects and to Kennedy Space Center for the furthering of their History preservation and interpretation goals.

Conclusion

As a result of the 2003 Summer KSC History Project through the NASA/ASEE Summer Faculty Fellowship Program, the Kennedy Space Center has expanded its history capabilities. From expanding structure, KSC has an enhanced history collection, preservation and interpretation through the further development of the Cmap technologies, the KSC Oral History Program Policies and Procedures with trained oral history practitioners, and the collaboration between Kennedy Space Center, the University of West Florida and other partner institutions. Second, the Center now has the expansion of the first significant work into two histories on KSC press and visitor operations and a completed series of ten new oral history interviews. Finally, with the completion of *Voices From the Cape*, Kennedy Space Center will have a significant publication that truly presents the invaluable and untold story of the center and its distinctive technological and human history.

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[O2] Novak, J. D. and Gowin, D. B. (1984). *Learning how to learn.* New York, Cambridge University Press; Novak, J. D. (1990). "Concept maps and Vee diagrams: Two metacognitive tools for science and mathematics education." *Instructional Science* 19: 29-52; Novak, J. D. and Wandersee, J. H., Eds. (1991). *Special Issue on Concept Mapping.* Journal of Research in Science Teaching; Novak, J. D. (1998). *Learning, creating, and using knowledge: Concept maps(R) as facilitative tools in schools and corporations.* Mahweh, NJ, Lawrence Erlbaum Associates. Cañas, A. (1998). *Concept maps: New Uses and the Underlying Technology.* Mountain View, CA, NASA Ames Research Center.

2003 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

INTEGRATED HUMAN FACTORS TOOLKIT

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ABSTRACT

This study is focused on developing an assessment methodology for use in selecting appropriate human factors tools to support task processing at Kennedy Space Center. Processes at ELV, Shuttle, and Station are used to validate the need for human factors tool integration. The problem is analyzed from three complementary theoretical backgrounds: process abstraction, workflow analysis, and requirement analysis. The approach presented departs from the traditional workflow analysis in the sense that process abstraction inquiry and ontology are used to incrementally compile process information along the continua of abstraction hierarchy. Also, unlike the classical task analysis that is often advocated for process modeling, we use work domain analysis because it is robust to capture unanticipated events in time and space, typically, along the boundaries of task processing. It is argued that by combining process abstraction inquiry and ontology, the building blocks for task processes can be developed to contain dense information required to mimics the realism of task behaviors, including, for example, actor-activity interactions, task state predictions, and the tools required to perform the tasks.

INTEGRATED HUMAN FACTORS TOOLKIT

Celestine A. Ntuen

1. INTRODUCTION

The understanding of the role of process in technical activities has matured since the seminal works of Taylor [14] and many other industrial and human factors engineers [8]. The desire of organizations to achieve repeatability in well-understood processes is gaining some momentum and many organizations such as NASA [6] are emphasizing this focus. Also the move to use automated tools in complex systems has also necessitated the need for greater understanding of processes involved in task processing.

There is a growing interest in process modeling as computer simulation and agent technologies become more dependent on task processes. The necessity of this interest arises primarily from the need to package compiled process knowledge to computer agents. NASA's Human Factors group is considering the use of analytic decision aids for selecting from a set of competing human factors tools, the ones needed to support task processing with bias toward improving human performance and safety. In addition, NASA likes to integrate the processes used by the contractors so that a common and pseudo standardized process can evolve. This will allow for easy identification of process bottlenecks, understand constraints, and predict the likely sources of errors in a complete or a partially designed system, both during simulation test and actual operational functionality. Equally important is the development of a legacy process knowledge base that can be used to support new product line developments. Such a legacy process knowledge base would in general be useful for:

- shortening the time to accomplish tasks,
- reducing the number of mistakes made,
- reducing learning time, and,
- integrating NASA and contractor processes to optimize "best practices".

To our knowledge, there are no existing methodologies designed to aid the human operators recognize a suit of software tools that support common human factors enabled processes. If this assertion holds, then it is logical that methods for defining, abstracting, and analyzing process information are needed to classify these tools according to their applications. This information can be used by human factors and system engineers to formalize, assess, evaluate, and /or develop appropriate computer-based human factors tools to support human operators on when and how software tools should be applied to a given task processing. With this in mind, it is posited that as processes are being automated, and as system engineering tools are becoming more ubiquitous in work organizations, then it is possible, and equally meaningful to develop common process standards to support software tool developments and applications across task or project domains. This leads to our concept of Common Process and Tool Support Environment (CPTSE), the basis of, and the focus of this project. The paper is organized to portray both theoretical and application knowledge relevant to process abstraction development required to support generalized human factors tool selection and applications, and, consequently, leading to efforts in developing process standards for workflow or task management.

2. NEXT SECTION

The research was accomplished through three complementary tasks: requirement analysis, process abstraction and tool assessment methodology. A summary is provided below.

2.1 Requirement Analysis

Requirement is a statement of need. It can be expressed in terms of expectations, goals, and procedures. It is also a statement of constraint used to define the conditions required to satisfy the user, task and system functionality. Requirement Engineering (RE) is a document of the process flow of required information and constraints inherent in a process. It also involves the translation of the user's concept of tasks into user's concept of tools, or decision aids.

Requirements Analysis is one aspect of RE which addresses the development and validation of methods for eliciting, representing, analyzing, and confirming system requirements. RA is further concerned with methods for transforming requirements into specification for design and implementation. Usually, information process flow of the system or task is used to realize the product of RA.

By following the same reasoning by Davis [4], five performance components of RA was identified for KSC process abstraction. The technique is currently used to derive process flow information from Space Station Processing Facility (SSPF). The five RA performance components are:

1. Cognitive coupling- does the intended process model represents the mental model of the system as perceived by the user?
2. Representation adequacy- does the knowledge representation represent the diverse procedures and strategies?
3. Efficiency- can the developed process deal with large and complex task processing?
4. Economy of scale- is the process knowledge organized to minimize cost of tool application?
5. Cooperative problem solving- can the developed processes support the use of collaborative problem solving tools?

2.2 Process Abstraction In Work Domain Analysis

Abstraction is generally defined as the process of formulating generalized concepts by extracting common qualities from specific examples [1]. The goal of abstraction is to isolate those aspects that are important for some purpose and suppress those aspects that are unimportant. One point of confusion regarding abstraction is its use as both a process and an entity. Abstraction, as a process, denotes the extracting of the essential details about an item, or a group of items, while ignoring the inessential details. Abstraction, as an entity, denotes a model, a view, or some other focused representation for an actual item. Both abstraction viewpoints are important for process modeling of task information processing. They correspond to Piaget's [11] distinctions between simple knowledge abstraction and reflection abstraction, respectively. According to Piaget, simple abstractions are directed by causality while reflective abstractions are defined by the nature of task operations. An example of application of both viewpoints is the experimental and modeling stages in discrete event simulation languages, see, e.g. Microsaint simulation language [9].

The concept of abstraction hierarchy advocated by Rasmussen [13] is applied for process abstraction in this project. According to Rasmussen [13], a system can be decomposed into two generic or abstract entities—form and function. The form abstraction represents the physical structures and interconnected relations. A functional abstraction is an attempt to describe a system behavior. At the functional abstraction, four basic functions are identified as physical function, general function, abstract function, and functional purpose. The explanation of process abstraction using abstraction hierarchy model complements those explanations given in human activity theory advocated by Russian psychologists [3][5]. In human activity theory, the basic unit of analysis is human (work) activity.

By using process abstraction inquiry, information obtained from a work domain analysis offers a comprehensive combination of functions for modeling, enacting and monitoring modeling processes. Also, it is an environment that supports different process management roles: the organization, the participant (individual or team of human operators), and anecdotal concept of prescribing properties to task entities in the work system. For example, in the classical task analysis techniques, events are not considered to be task characteristics [2]. However, a work domain analysis allows knowledge engineers to prescribe through low fidelity anticipation, the effects of events. Such events may be procedural errors that can lead to task failures. This is one particular instant in which a human factor toolkit may be needed to provide support relevant to error tracing and causal analysis of error impact on the task performance [12].

2.3 Tool Assessment Criteria

Assessment is the process of appraising the worth or capability of a system or device through a method of systemic evaluation of value indicator variables. Most often, usability of software tools or devices has been confused with assessment. Usability is a subset of assessment that is used to determine how users interact with the device of interest. When there is no direct interaction, usability can be measured by hermeneutic evaluation of user's expectation of the device. With this in mind, the assessment of human factors tools for process support takes different set of criteria that must consider the work domain, human operators, task, organizational policies, and the capability of the tool itself. Figure 1 shows this interaction.

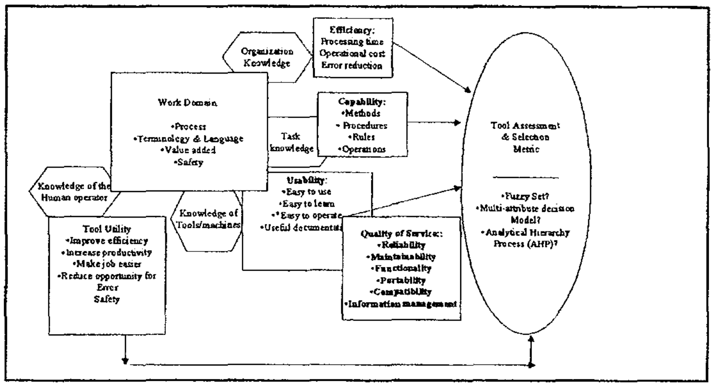

Figure 1. Criteria knowledge for assessing human factors process tools

The human factors tool assessment questionnaire was developed to include work domain, task, human operators, and the tool itself.

A. Work domain:

At the work domain analysis, the tool must contain salient knowledge about the process, terminology or language of the work place, measures of value added, and safety measures.

B. Organization:

At the organizational level, assessment criteria must deal with overall processing times, cost, and error reduction that translate to increase safety.

C. Human operator:

Human operators generally seek tools that can help them to improve efficiency, productivity, make job easier, reduce opportunity for error, and increase work safety.

D. Task knowledge:

A software tool selected for a domain specific task must, in general, have the capability to understand the task processes, methods, procedures, rules, and operations used.

F. Characteristics of the Tool:

The tool, as perceived by the organization and the operators, should possess at least two fundamental characteristics: usability and good quality of service (QoS). Usability implies many things to different people. For tool assessment, the criteria of interest are: ease of use, ease of operation, ease of learning and understandability, and availability of useful documentation and help. Quality of service considers an aggregate measure of such values as reliability, maintainability, portability, functionality, and information management capability.

2.3 Tool Assessment Metric

There are several methods to analyze subjective assessment data [7]. The first data aggregation method considered in this prototype stage of tool selection study is fuzzy set theory (FST). We use FST to model the operators perception of tool need in their work domain because human subjects are more effective in describing situations with verbal expressions than with numerical expressions, even if they are engaged in numerical measurement tasks [10]. This kind of data is often affected by imprecision and incomplete description on the part of the human judge. Generally, a membership function is formed by converting a linguistic scale to a numeric scale with strength of membership. This is defined as U: Ω -> X/μ.; where Ω is the set of elements in the empirical domain. For example, if the fuzzy set is "unsafe", then Ω = {unsafe work conditions}. U is a linguistic function, X is the numerical assignment interval, X ε [-∞, ∞], for example, X can be the interval[1, 7]. μ -> [0, 1] is an implicit strength of perceived numerical assignment. In the TAM model, a Likert scale that captures the rater's opinion from "Extremely not important (1)" to "Extremely important (7)" is used.

Consider a set of assessment issues defined as the university of discourse X, where $X = \{ \mu_1(x_1)| x_1, \mu_2(x_2)| x_2, \mu_3(x_3)| x_3, \mu_4(x_4)| x_4, \mu_5(x_5)| x_5, \mu_6(x_6)| x_6, \mu_7(x_7)| x_7\}$, where, set x_k (k=1,2,...,7) is used to evaluate the opinions of the raters on a set of attributes, such as, usability, utility, functionality, reliability, and so on. These are denoted by R_j. Let R be a set { $R_1, R_2, \ldots, R_M$} of assessment attributes, M is the number of attributes evaluated. Each R_j (j = 1, 2,...,M) has sub attributes, r_{ji}, where i=1, 2,...,m(j), m(j) is the number of attributes observed under R_j. Thus, each R_j is mapped into the fuzzy set X. For each r_{ij}, we obtain a total observation $V^i_j(k)$ for each x_k rating such that $\Sigma V^i_j(k) = n_{ij}$. Let the maximum rating in the Likert scale be N (in this case, N=7). For each R_j, we have a weight assignment W_j such that $\sum_j W_j = 1$. For each r_{ij}, we calculate the preference incident weight a_{ij}. Define $d_{jk}(k = 1,2,\ldots N)$ as inter-rater distance rating and D_{jk} as the average observation of k under j attribute; f_{ij} is the total observed frequency of sub-factors i under j. The calculation followsthe fuzzy aggregation method of Ntuen & Ntuen [10], and is applied to derive the fuzzy linguistic assessment weight (FLAW) for each "tool" attribute criteria:

Step I:

Let $a_{ij} = n_{ij} / N^2$

$\mu_{ij}(r) = 1 - e^{-a_{ij}}$

$R_j = \{f_{ij} / \mu_{ij}(r)\}$

Step II:

Define $\hat{\mu}_j(r) = \dfrac{\sum_i a_{ij}\mu_{ij}(r)}{\sum_i a_{ij}}$

$$f_{R(j)} = \frac{\sum_i a_{ij}\, f_{ij}}{\sum_i a_{ij}}$$

$$\beta_j(R) = \{f_R / \hat{\mu}_j(R)\}$$

Step III: Calculate fuzzy membership for each category of university of discourse (UOD):

$$d_{jk} = \frac{1}{m(j)} \left[\sum_i^{m(j)-1} \sum_{\ell=i+1}^{m(j)-1} \left(V^i_{j(k)} - V^e_{j(k)} \right)^2 \right]^{1/m(j)}$$

$$D_{jk} = \frac{\sum_i V^i_{j(k)}}{m(j)}; \quad \lambda^j_k = 1 - d_{jk} / D_{jk}; \quad \beta^*_j = \{X_k / \lambda^j_k\}$$

Note that β^*_j denote the membership function of each criteria used in the assessment. For example, for usability criterion, β_1 can be derived as = {U_1/0.6, U_2/0.8, U_3/0.03,U_4/0.54}, where, for this example, U_1= "Easy to learn", U_2 = "Easy to use", U_3 = "Easy to operate", and U_4 = "Easy to browse". The FLAW algorithm above is easy to program with desktop computers. By creating a database, several rater data can be stored, and used in the FLAW model for on-line tool selection based on decision criteria to be determined later.

3. CONCLUSIONS

The availability of human factors and system engineering tools are ubiquitous. However, in order for these tools to be used by human operators for task processing, knowledge of the task processes and the relevance to the available tools need to be understood and standardized. We argue that the use of process abstraction will support such effort. Given the rich and ubiquitous human factors principles and theories, it would be beneficial to develop a common framework to support the applications of these tools across multifunctional settings. In addition, the use of robust quantitative analysis to identify and evaluate the available tools required to support KSC processes remains equally important. For this purpose, a fuzzy linguistic assessment weight (FLAW) has been developed as one approach to assist in human factors tool assessment and selection decision-making. This effort is continuing and future research will be focused on the followings:

(a) Develop tool kit assessment, evaluation, and comparison matrix for supporting the choice of a tool for human factors task integration. Comparative models essentially deal with the differences in process data sets with the same schema, for example, "how is aircraft preventive maintenance different from space shuttle preventive maintenance? What tools are used for each task?

(b) Develop a decision support system to help task operators with the analysis of how to better use human factors tools in their tasks. This situation deals with sharing process knowledge across similar tasks. To accomplish this, for example, the user specifies the task domain and the CPSE system will recommend "common" processes that are usually used in the system. For example consider NASA's pre-launch task, say for expendable launch vehicle versus space shuttle pre-launch activities. The CPSE should recommend the available tools within NASA pre-launch system for task processing.

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2003 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

KSC Education Technology Research and Development Plan

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ABSTRACT

Educational technology is facilitating new approaches to teaching and learning science, technology, engineering, and mathematics (STEM) education. Cognitive research is beginning to inform educators about how students learn providing a basis for design of more effective learning environments incorporating technology. At the same time, access to computers, the Internet and other technology tools are becoming common features in K-20 classrooms. Encouraged by these developments, STEM educators are transforming traditional STEM education into active learning environments that hold the promise of enhancing learning. This document illustrates the use of technology in STEM education today, identifies possible areas of development, links this development to the NASA Strategic Plan, and makes recommendations for the Kennedy Space Center (KSC) Education Office for consideration in the research, development, and design of new educational technologies and applications.

KSC Education Technology Research and Development Plan

Michael R. L. Odell, Ph.D.

1. INTRODUCTION

Educational technology is facilitating new approaches to teaching and learning science, technology, engineering, and mathematics (STEM) education. Cognitive research is beginning to inform educators about how students learn [1] providing a basis for design of more effective learning environments incorporating technology. At the same time, access to computers, the Internet and other technology tools are becoming common features in K-20 classrooms. Encouraged by these developments, STEM educators are transforming traditional STEM education into active learning environments that hold the promise of enhancing learning.

Educational technology can facilitate meeting the education goals of the NASA Strategic Plan [2] and the draft NASA Education Enterprise Strategy [3]. To achieve the education goals outlined in the strategic plan, Kennedy Space Center (KSC) should utilize existing and develop new educational technologies to improve STEM education and enhance public awareness. The availability of the Internet in schools and homes provides a unique opportunity to reach more customers than ever before.

The Internet provides an access point for educators and the general public to access programs and products developed at KSC. The NASA Education Enterprise has set a number of metrics for increasing participation of students, educators and the general public by 20% by the year 2008. Educational technologies and the Internet can facilitate this target growth. Utilizing the Internet, KSC can provide programs, access to resources and products (downloads), and e-learning opportunities at all levels.

2. CURRENT EDUCATIONAL TECHNOLOGY PRACTICES

Many states have adopted or integrated the National Educational Technology Standards [4] (NETS) developed by the International Society for Technology in Education (ISTE) into state and local standards. By examining the NETS, stem educators and designers can gain an insight into how technology is being utilized in the K-12 and teacher preparation arenas. A second organization, the International Technology Education Association (ITEA) has also developed technology standards focusing on developing a technology literate populace [5]. ITEA is focusing on the ability to use, manage, and understand technology.

The National Science Teachers Association (NSTA) has addressed the role of computers and developed a set of guidelines for use in science education. The National Science Education Standards (NSES) [6] and American Association for the Advancement of Science (AAAS) Benchmarks [7] also address technology as it relates to science. The National Council of Teachers of Mathematics also addresses the teaching of mathematics utilizing technologies such as calculators and mathematical software. NCTM [8,9] recognizes that technology is an essential component of the future mathematics-learning environment. In contrast to the NETS standards, the STEM standards provide a focus for future development of tools and applications that may enhance STEM learning.

In addition to the standards and reform documents, cognitive science is providing insights into how people learn. These insights should be taken into consideration as KSC develops new educational technologies and applications to enhance STEM learning. In the book, "How People Learn" [1], evidence is presented to demonstrate that technology can play an effective role in supporting six practices that can improve STEM learning. These six practices are: 1) visualization, 2) simulation, 3) problem solving, 4) collaboration, 5) inquiry and 6) design. The following sections will describe specific uses of educational technology and the Internet.

3. COMMON USES OF EDUCATIONAL TECHNOLOGIES

As part of this project a survey was prepared in July to poll teachers about their current use of educational technology and the Internet. The participants were attending an educational technology conference in Washington, D.C. Twenty-six teachers participated in the survey. The teachers were from 7 states and the average experience of the teachers was 17 years in the classroom. All of the teachers who participated in the survey and follow-up focus group discussions were actively involved in a US Department of Education (US Ed) Technology Challenge Grant.

Teachers reported that they primarily utilize productivity (word-processing) and presentation (PowerPoint) software to support instruction in their classes. During follow-up focus groups, teachers reported that these tools came with the computers and their students were more likely to have access to these at home. Multimedia was primarily used to support teacher presentations and student research projects. Over 35% of the teachers utilized GIS and GPS in their classrooms. At first this may seem to be a significant number, however all of the teachers were trained in the use of GIS and GPS technologies and were required to use it as part of the TICG grant. 40% of the teachers utilized cognitive programs in their classroom. These programs allow students to illustrate their thinking by creating cognitive maps or concept webs. These programs were demonstrated in year one of the grant and a significant number of teachers were using them four years later. Teachers informed the researcher that they found these programs easy to use and beneficial to students.

Surveyed teachers use of the Internet supports conclusions in the research literature. In spite of their involvement in an educational technology project, teachers primarily utilized the Internet as a resource to support student research projects. Its other major use was for communication, primarily email. All of the teachers had been required to participate in online courses (e-learning) for professional development. 100% of the teachers found e-learning to be beneficial due to its flexibility and availability. Discussion during the focus group supports the development of online strategies to train and provide professional development to teachers. As a result of participation in project related online classes, over 50% of the teachers involved in this survey, enrolled in and are completing a Master of Education degree online. The pursuit of the degree is not funded by the grant.

Teachers were also surveyed regarding barriers to using technology in the classroom. Barriers primarily included cost of equipment and software, lack of high speed Internet access, lack of training, and lack of time. Teachers were very interested in educational technology that would allow them to teach concepts in a time effective manner. Teachers were particularly interested in having experts; such as NASA scientists connect with their classroom via email, chat or video conferencing. Teachers were also very interested (70%) in participating in online virtual tours and professional development programs available through NASA.

Based on the literature and supported by the study above, it appears the most common use of computer technology and the Internet is accessing educational resources. These resources can be online or on CD-ROM/DVD. The Internet has made available a broad range of information resources and these resources are helping equalize access to quality materials.

The e-learning medium is one of the fastest growing arenas in education. Universities and K-12 systems are using e-learning to deliver courses and programs, provide information to stakeholders, and create opportunities for greater collaboration. Many e-learning strategies focus on more administrative functions, access to course materials, and online discussions. E-learning technology can allow teaching and learning to be transformed in new ways. Many instructors choose to use e-learning tools to post lectures, homework, and quizzes. E-learning can be enhanced to expand the boundaries of the classroom. Strategies such as web-casting, e-mentoring and tutoring, and virtual field trips can allow students to communicate with experts and go into the field. E-learning products can also be enhanced with visualization and simulation tools. NASA, in its Strategic Plan, recognizes the potential of e-learning and has defined objectives that will lead to the creation of a NASA E Learning Infrastructure. This type of learning is already being implemented in the NASA Explorer Schools, NOVA and by NASA's Classroom of the Future.

4. EMERGING USES OF EDUCATIONAL TECHNOLOGIES

Visualizations

The ability to visualize has been linked to increased student achievement in mathematics and science [10]. Visualization tools are vehicles for helping students understand difficult abstract concepts. For example, students who have difficulty in visualization of science concepts often have difficulty in learning the content. Educational technology can provide three-dimensional visualizations to overcome these problems. Computers provide a way to move beyond static two-dimensional representations of three-dimensional phenomena and provide platforms that simulate reality. Current molecular modeling software can alternate images of a given object at rates approaching thousands of times per second, creating a realistic three-dimensional effect [11, 12].

As computers get faster, software developers can now produce pedagogical software that was not possible 5 years ago. This is an opportunity for NASA to sponsor and create new STEM visualization tools. NASA's Learning Technology Program (LTP) has developed a number of visualization tools for STEM education. Many other visualization tools are finding a place in the curriculum. Spreadsheets and graphing calculators are now widely used for mathematical modeling. NASA makes available large databases of all types to educators. These include image databases, media databases, and raw data archives from NASA missions.

Other visualization techniques include video-based laboratories. Video-based labs can help students understand concepts in physics. KSC public affairs has an archive of video that could be utilized. For example students can use the pause and frame-by-frame features on a CD or DVD to examine motion involved in transportation (a space shuttle take-off or landing) [13].

Simulations

Simulations allow students to examine complex systems by looking at the parts simultaneously or sequentially. In the case of Earth systems, output data can be displayed graphically and on maps at the same time. The map and the graph can be linked so that as the user manipulates variables, changes on the graph and map occur simultaneously. NASA has funded STEM education simulations. One of the most recognized is the BioBLAST CD created by NASA's Classroom of the Future. BioBLAST is a multimedia supplemental curriculum for high school biology classes. Students conduct scientific research, based on actual research now being conducted by NASA's Advanced Life Support Research program. Simulations can also replace experiments that may be too costly or risky to perform. Simulations can also save time over live experiments that require more time than is available in a class period. Simulations are a reasonable alternative.

Problem Solving

NASA is currently exploring many questions that will only be answered over long periods of time. Is our planet experiencing global warming? The answer to this and other problems are complex. Providing opportunities for students to develop their problem-solving skills is becoming a high priority for STEM educators. Many new curricula are being created around real-world problems. For example, NASA's classroom of the future has created an interdisciplinary program, *Exploring the Environment,* to provide educators with real-world problems for students to study. The curriculum uses a problem-based learning (PBL) approach. Students explore real-world problems and utilize NASA data to look for patterns and pose solutions. As students explore real-world problems, they can communicate with one another, with their instructors, and with professionals (i.e. NASA Scientists and Engineers).

Collaboration

Today STEM research usually involves collaboration among colleagues. Educators need to provide students the opportunity to participate in collaborative projects. Students can develop teamwork skills using modern information technology as a tool. Projects can be done via the web with participants from all over the world. An example of this is the NASA funded GLOBE program. GLOBE is an Internet-based program that promotes collaboration between schools and scientists researching the environment. Through a web interface, GLOBE provides communication and research tools online for students and faculty. Other forms of collaboration include interactive web-casts, online mentoring and tutoring.

Inquiry

The *National Science Education Standards* emphasize inquiry as a means of learning fundamental scientific concepts. Technology can provide opportunities for learners to conduct their own investigations of real problems. In addition to working with data generated or collected by others, technology enables students to collect and analyze their own scientific data. Many science programs use computer-interfaced sensors to measure different phenomenon. Many of these can be used with handheld calculators, battery-operated computer-based laboratory interfaces, and personal data assistants, making them opportune for fieldwork. The NASA Explorer Schools Program is utilizing PDA's to collect data in middle school science classrooms. Students can also use calculators and software to manipulate and analyze large data sets with statistical tests, simulate models, and draw conclusions based on the outcomes of these actions.

Design

Computer-aided design (CAD) allows students to design objects for the real world. CAD instruction provides important workplace skills. As distance education and collaboration between individuals at different sites become more common, the use of design tools that can be transmitted over the Internet will likely increase [11]. Designers can build a sequence of visual images into web settings, while users can view, move and rotate those images. The work at KSC involves many engineering design activities.

5. THE FUTURE ROLE OF TECHNOLOGY IN EDUCATION

It is important to take into account the current educational environment before proposing the development of any new technologies or applications. Educators are under increasing scrutiny and pressure to produce positive results. The U.S. government is now interested in the research base for programs, strategies and products that schools adopt. The emphasis is on evaluations that use experimental or quasi-experimental designs, preferably with random assignment. Schools, districts, and states must justify the programs that they expect to implement under federal funding. KSC needs to consider the accountability issue when developing products and programs.

Unfortunately, there is currently a lack of valid and reliable instruments for measuring the effectiveness of new teaching and learning approaches that incorporate technology. This poses a barrier to the diffusion of these new approaches and products. New product development will require developers to assess learning by students utilizing new products. Data should be used for formative purposes as well as summative. Development of new educational technologies and programs need to consider how to improve alignment between instructional goals and assessment. Assessment mechanisms should be built in wherever possible to provide feedback to teachers and students.

Future educational technology development should also focus on the learner and be based on current cognitive research. Increased research and development are required to develop the potential of educational technologies to improve pedagogy and enhance STEM learning.

The report, Visions 2020 [14], provides a vision of e-learning in the year 2020 illustrating education technologies such as ubiquitous computing, global access, rich communication (visual), and highly interactive 3-D environments. This proposed future aligns well with NASA's objectives for e-learning. The biggest future leap appears to be the emergence of immersive 3-dimensional environments, where students will be able to explore any place or object. Students will be able to walk through and rearrange atomic structures, travel to far away places, or explore virtual worlds.

What should be developed?

Technology and reform initiatives are rapidly changing education. It is not possible to accurately predict the future impact technology will have on STEM education. Future development cannot solely be based on current trends. KSC will need to identify factors influencing development of technologies that: (1) might be useful in STEM education, and (2) might influence implementation of those technologies over the next 5 years. The previous sections of this document outline the 6 areas that KSC should consider developing.

6. RECOMMENDATIONS FOR RESEARCH AND DEVELOPMENT

KSC should adopt a scientific approach to developing educational technology tools and resources. Developers and researchers should formulate a hypothesis about what technologies are most likely to achieve the educational goal, and develop a protocol for evaluating progress toward the goal.

Research and development funding from NASA has been critical in developing the innovative e-learning courses through COTF, ESE, NOVA and e-learning tools through LTP. NASA should build upon the successes of these programs. KSC should consider partnering with private companies, professional organizations and public/private education institutions to forward its efforts in educational technology. Through partnerships, NASA could support individual faculty and education institutions as they take a scientific approach to deploying technology in STEM education. The focus of research, development, and demonstration should be on student learning and quality of instruction rather than on any particular technological tools. There is a need for further research that would examine how best to use this technology for STEM educational purposes. Three general recommendations for KSC are:

- Virtual Classrooms, Virtual and Remote Laboratories, and Distance Education. This area encompasses long-distance collaboration among students, teachers, mentors, and experts; access to classrooms remote from the student; as well as educational resources not locally available. KSC should try to take a lead role in the development of one of the four e-learning technologies described in the strategic plan.

- Innovation in Curriculum Content. This area encompasses scientific and mathematical modeling, support for collaborative projects, access to and use of data sources, and support for modeling large data sets or complex processes, all of which enable learning through real-world experimentation. Where appropriate, measurement tools should be embedded in learning activities; tools for identifying specific content and methodological strengths and weaknesses of the learner; teacher-oriented measurement; and organization tools should be incorporated.

- Create a research group to develop a scientific approach to the development of educational technology products to support STEM education and their implementation and dissemination. This could include the standardization of learning objects and content so that the greatest number of users can take advantage of KSC developed or sponsored educational technologies.

Before development of any new educational technology products begins, KSC should determine its target grade levels for product/program development based on need. It is recommended that KSC sponsor a symposium of educators (potential users) and developers to discuss classroom needs for teaching STEM disciplines. Too often developers receive their grant funds and the education input comes after the development as part of testing the new product. The end-users need to be included in the planning.

All K-12 products should conform to the standards and a priority should be given to products/programs that can demonstrate a direct connection to the standards and show promise for increasing STEM student achievement if it is to be used in the formal classroom environment. The Third International Mathematics and Science Study (TIMSS) can provide a roadmap for what discipline and content development is needed.

For guidance in content development, AAAS and the National Science Teachers Association have co-published the "Atlas of Science Literacy" [16], a collection of 49 conceptual strand maps that show how students' understanding of the ideas and skills that lead to literacy in science, mathematics, and technology might grow over time. Each map depicts how K–12 learning goals for a particular topic relate to each other and progress from one grade level to the next. These maps can facilitate more meaningful content development connected to the standards.

Development in higher education should revolve around teacher preparation given the interest in improving teacher quality by the current administration. TIMSS [16] data reflect that US students' scores tend to drop following 4th grade as compared to their international counterparts. This trend would support that products focusing on better teacher preparation of grades 5-12 students might produce the greatest return on investment. As students enter these grades, science topics become more abstract and quantitative. Many teachers teaching science at the middle level may have a generalist certification. High school teachers, especially in chemistry and physics may be teaching out of field. Programs and tools that focus on just in time learning and tools to help students visualize concepts would be one area to focus. For example, KSC could partner with NSTA as it builds Science Learning Objects. A learning object as defined by NSTA is one content strand from the Atlas delivered via the Internet. KSC could create the objects related to its mission.

Professional and academic engineers, scientists, mathematicians and STEM educators should convene to discuss development for higher education and preservice. Informal educators should be convened to discuss development for informal education.

7. CONCLUSIONS

Future funding is always a variable in carrying out a production plan. KSC will need to secure funding sources from within NASA and externally by partnering with other agencies, industry, professional organizations, informal education and higher education. The following recommendations are provided.

- KSC and its potential partners need to be aware of the educational environment and policies that could affect the successful implementation of any technologies for a given audience. KSC could sponsor a symposium (live or online) or attend programs sponsored by US Ed and NSF to stay abreast of the changing education environment. There are also several educational technology conferences that could benefit from KSC participation.

- KSC needs to create and maintain a database/inventory of potential learning objects that have already been created. For example, the KSC Public Affairs website has links to a number of ISS videos that could be incorporated into physical science learning applications. KSC should also reexamine its website and consider a redesign to create an educator friendly site. KSC also needs to examine archived sites to determine which sites should be retained or eliminated.

- KSC should conduct a needs assessment in its service area to better facilitate planning. Results should be stored in a database for future reference. In many cases, surveyed educators may be unaware how technologies can assist STEM instruction. If the survey is properly constructed, this information could become apparent. After needs assessments are completed, KSC should base development on scientifically sound research and should plan to embed assessments within proposed products and programs.

- The Education Office at KSC should conduct an assessment of the different KSC research programs to identify potential products or modification of existing ones. Some NASA research programs require a percentage of funds to be spent on education and outreach. KSC Education staff should offer their expertise to assist these researchers in preparing the education and outreach sections of proposals.

- KSC should focus on products that can be delivered or downloaded over the Internet. The Internet offers a cost-effective means to delivering programs and providing products. Many of the elements of these products already exist at KSC. KSC should develop advanced visualizations and simulations based upon the standards and the AAAS "Atlas". These applications could be similar to the Virtual Lab KSC is now developing through NASA LTP.

As KSC builds its research capacity, the education office may want to develop expertise in the area of educational technology research and assessment. Once a product has been developed and tested, KSC should publish the results of the field test and report the effectiveness of the product/program. Effective products should be disseminated via the Internet, NASA Educators Resource Center Network, Space Grant and CORE. Opportunities for training end-users should be available to inservice and preservice teachers live and/or online.

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2003 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

THE VIRTUAL TEST BED PROJECT

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ABSTRACT

This is a report of my activities as a NASA Fellow during the summer of 2003 at the NASA Kennedy Space Center (KSC). The core of these activities is the assigned project: the Virtual Test Bed (VTB) from the Spaceport Engineering and Technology Directorate. The VTB Project has its foundations in the NASA Ames Research Center (ARC) Intelligent Launch & Range Operations program (ILRO). The objective of the VTB project is to develop a unique collaborative computing environment where simulation models can be hosted and integrated in a seamless fashion. This collaborative computing environment will have as emphasis operational models. This report will focus on the decisions about the different simulation modeling environments considered, simulation platform development, technology and operational models assessment, and computing infrastructure implementation.

THE VIRTUAL TEST BED PROJECT

Luis C. Rabelo

1. INTRODUCTION

The contributions to the Virtual Test Bed (VTB) Project during this fellowship are extensive. These contributions can be classified into the following areas: (1) systems architecting activities, (2) evaluations of models and processes, (3) evaluations of technologies, (4) systems design, (5) documentation and technology transfer, and (6) liaison with Academic and Industry groups.

This report is organized in the following sections. Section 2 introduces general concepts about complex systems, spaceports, and virtual test beds. These concepts will be needed to understand the objectives of the project and its implications for the future of NASA. The "preliminary architecture" is the topic of Section 3. The preliminary architecture of the VTB defines the different systems required in order to achieve the objectives of the Intelligent Launch & Range Operations (ILRO) project. Section 4 discusses the selection of the discrete-event simulation platform and the respective model to be hosted. The model to be hosted is the NASA Shuttle Simulation Model built by Mollaghasemi (Industrial Engineering and Management Systems Department – University of Central Florida), and Cates and Steele (NASA KSC). Section 5 discusses the models and process evaluations activities accomplished during this fellowship. Several models are being evaluated to see the opportunities to be integrated in the VTB. Section 6 discusses briefly some of the possible visualization schemes for the VTB.

2. GENERAL CONCEPTS

Spaceports are complex systems. According to Barth [1] "Spaceport technologies must employ a life-cycle "system of systems" concept in which major spaceport systems – launch vehicle processing systems, payload processing systems, landing and recovery systems, and range systems – are designed concurrently with flight vehicle systems and flight crew systems." Therefore, it seems logically to think that a virtual test bed can host the different models that represent different systems and elements of a spaceport. These models in the virtual test bed will work in an integrated fashion synthesizing in a holistic view and becoming together a Virtual Spaceport. This Virtual Spaceport can be utilized to test new technologies, new operational processes, the impact of new space vehicles in the spaceport supply chain, and the introduction of higher schemes of decision-making. A Virtual Spaceport will allow an intelligent visualization of the entire spaceport concept and the implementation of knowledge management strategies.

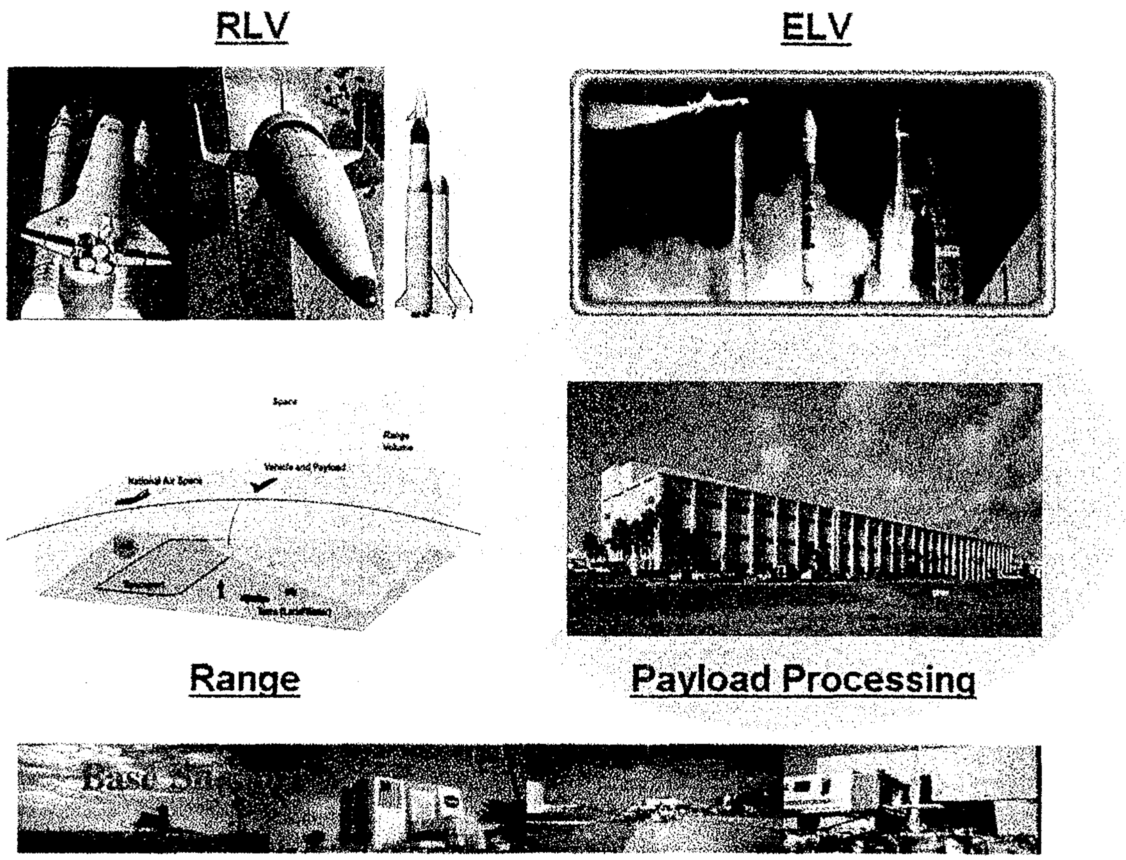

Figure 1. A spaceport is a system of systems

The Intelligent Launch and Range Operations (ILRO) Project at NASA Ames Research Center (ARC) was started to perform initial studies of a test bed with a demonstration. An evolution of the ILRO test bed is the Virtual Test Bed (VTB) Project. The objective of the Virtual Test Bed (VTB) Project is to provide a collaborative computing environment to support simulation scenarios, reuse, and integration of multidisciplinary models that represent elements of operations at spaceports. This VTB will be used

3. PRELIMINARY SYSTEMS ARCHITECTURE

One of the first activities was the development of an architecture. It is very well known that systems architecting integrates systems theory and systems engineering with architecting theory and practice of architecting [2,3]. Conceptualization is the keyword for architecting. System conceptualization involves creativity and the recognition of potential users and perceived needs. System architectures are driven by the function, instead of the form, of the system. Systems engineering is the one that provides the form.

The VTB is composed of the Integration User Interface, Decision-Maker User Interface, Security Component, Integration System, Simulation System, Model Functions Manager, Model Library Manager, Database System, and File Storage System. The Integration User Interface provides the capability to transfer a model to the VTB. The user can integrate an existing model (and create extensions to it) using the different tools and methodologies provided by this interface. The Decision-Maker User Interface is the simulation interface. The Decision-Maker User Interface supports the execution and the development of scenarios with the existing integrated models hosted on the VTB. The Security Component provides different levels of computer security such as password schemes, authentication, firewalls, Secure Socket Layer (SSL) implementations, maintenance and prevention mechanisms (e.g., anti-virus), certificates, and encryption. The Integration System takes the representation and information outlined by the engineer (using the Integration User Interface) and formulates a hierarchical description of entities, activities, and interactions that will be represented in an integrated model. The Simulation System executes the integrated model(s) according to the scenarios submitted by the decision-maker. The Simulation System invokes the integrated model(s) from the VTB Host and the model's operation functions from the Model Functions Manager. The Model Functions Manager provides the business logic for the different transactions to save the different model configurations as specified by the Integration System. The Model Functions Manager also retrieves from the Database System and the File Storage System the simulation models, data, and configuration parameters needed by the Simulation System. The Model Library Manager will support the development and management (retrieval, saving, configuration management) of the libraries. The Database System will store the model and its details. Finally, the File Storage System stores the model and its details in a scheme appropriate for facilitating the operations of the Simulation System and the interface with NASA Ames Research Center Intelligent Launch and Range Operations (ILRO) Virtual Test Bed.

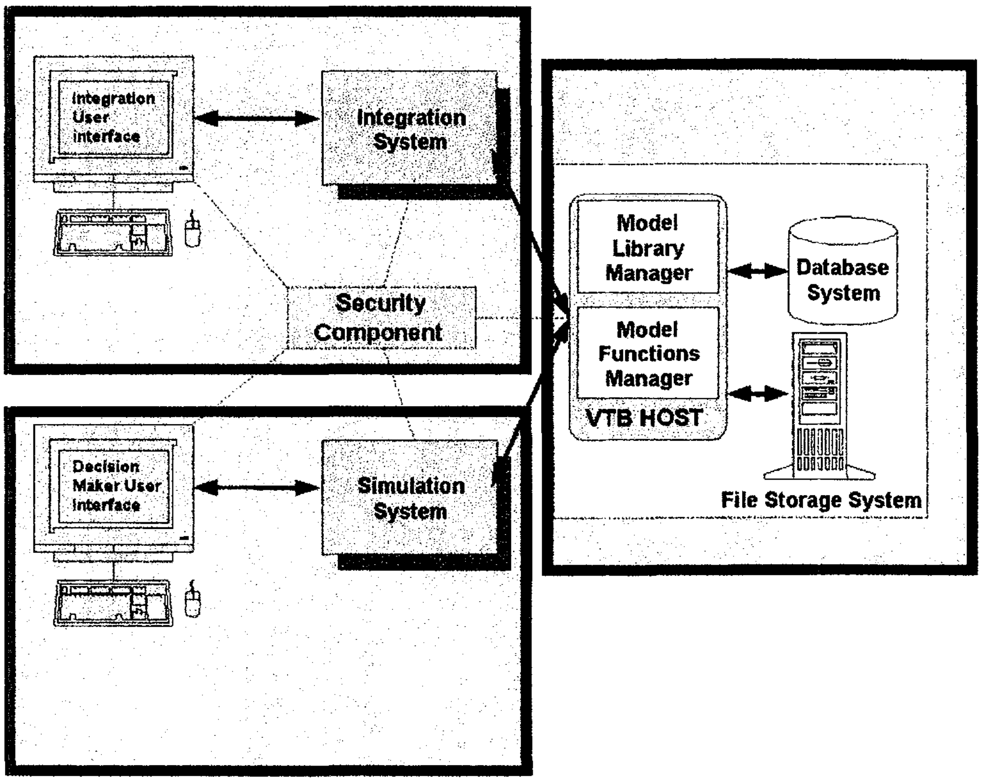

Figure 2. Preliminary systems architecture [4]

The VTB-SM will provide a computing environment capable of hosting in an integrated fashion different models that represent spaceport elements. This integration will allow managers, their staffs, and the aerospace community to examine concepts of operation, techniques, and procedures as an integral part of a spaceport through the use of human-in-control experiments. The VTB is intended to provide a robust, flexible, easy-to-use architecture, which can incorporate current and evolving operational characteristics and scenarios to conduct investigations. Where components-off-the shelf (COTS) software products can meet task requirements safely, the COTS software is utilized instead of developing custom applications. The software to be developed will be written in high-level languages such as Java, C, and C++, which have demonstrated a high degree of portability between platforms. This strategy provides a reliable system that is modular, expandable, and extensible. It is based on open hardware and software standards, easily incorporates new technology and user developed applications, and provides inherent user interface improvements.

The Simulation System will provide an environment to execute integrated simulators/models developed for specific elements of space operations into interactive simulator networks to support a single view of operations. For instance, NASA KSC has existing models that have been developed over time by different sources. These existing models have been developed from different points of view and for different aspects of the operation cycle. Consequently, existing models represent different levels of resolution and have selected different representation methods for internal entities, activities and interactions.

The Simulation System will employ object models and object-oriented methods to exercise a hierarchical description of entities, activities, and interactions represented in the integrated models. Figure 5 depicts a conceptualization of the functionality of the Simulation System using the High Level Architecture (HLA). The Simulation System shall follow the standards of the Department of Defense (DOD) and the Institute of Electrical and Electronic Engineers (IEEE) for the integration of models. The High Level Architecture (HLA) is one of those standards. HLA will be utilized to provide a consistent approach and rules for integrating distributed, heterogeneous, and legacy simulation systems. The HLA has been approved as an IEEE standard (http://standards.ieee.org/) and it has adopted as the facility for distributed simulation systems by the Object Management Group (http://simsig.omg.org/). The Run Time Infrastructure (RTI) software, which implements the rules and specifications of the HLA, provides methods, which can be called and used by individual simulation federates. RTI's interfaces can integrate federates, but implementation is quite complex.

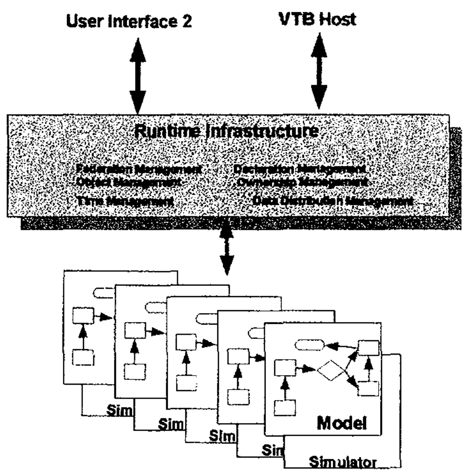

Figure 3. Conceptualization of the simulation system.

4. DISCRETE-EVENT SIMULATION ENVIRONMENT AND MODEL

A spaceport can only be represented using different types of models (sizes and nature). The natures of the models that the Simulation System will execute in an integrated fashion are: (1) Discrete-event models and (2) System Dynamics models. The simulation system will be a subsystem that will evolve over time to meet this important requirement. The scope of the first version to be delivered at the end of FY03 will focus on the hosting of a single discrete-event simulation model [4].

It was decided that the first version of the Simulation System will focus on discrete-event simulation. Therefore, we needed to find a discrete-event simulation environment capable (1) to handle multiple models, (2) compatible with HLA, (3) Open Source (to allow for modifications), (4) cost effective for NASA (to avoid the paying of expensive licenses and maintenance fees), and (5) a proven system being utilized as the backbone of advanced simulation environment. This environment will be demonstrated by the hosting a discrete-event model that represents a comprehensive representation of the NASA Shuttle operations. The NASA Shuttle Simulation Model is being hosted in the first version of the VTB to be delivered by the end of FY03. The NASA Shuttle Simulation Model is a simulation model for the operational life cycle of the Space Shuttle flight hardware elements through their respective ground facilities at KSC developed by NASA (Cates, Steele) and University of Central Florida (Mollaghasemi, Rabadi). The COTS tool used was Arena from Rockwell Software.

We decided to use as the backbone in discrete-event simulation for the HLA implementation the Synchronous Parallel Environment for Emulation and Discrete-Event Simulation (SPEEDES). SPEEDES allocates events over multiple processors to get simulation speed-up (www.speedes.com). This feature enhances runtime, especially when exploiting the very large number of processors and the high-speed internal communications found in high performance computing platforms. SPEEDES is HLA compliant. Another important characteristic of SPEEDES is object-orientation. SPEEDES' object-oriented architecture has a significant impact on the development of simulations. Entities in a system can be represented by individual classes. Such a representation, in turn, facilitates the distribution of the simulation models on different processors and the design of parallel simulation experiments. In addition, SPEEDES supports distributed simulation over the World Wide Web. This provides a very important advantage – a key feature of the World Wide Web for running a distributed simulation is the transparency of network heterogeneity, where interoperability of different networks is achieved through well-defined, standardized protocols such as HTTP and CGI.

A very important challenge for the future is the development of a hybrid simulation environment. Several studies of complex non-linear systems have shown the presence of non-stationary or even chaotic behavior in different operational regions of space vehicles. Discrete-event simulation models allow us to capture the system performance for a specific value of decision variables. However, they do not allow us to capture the dynamics of the system in the region or neighborhood of the control policy or decision variable values being evaluated. Hence, it would be desirable to develop modeling tools that work in conjunction with discrete-event simulation to allow us to evaluate the stability of a complex system in different operational regions. Simulation modeling of hybrid models will be needed to capture discrete and continuous states to accomplish higher levels of simulation fidelity. It is very clear that switching of modes occurs during the reentry transition phase of the NASA Shuttle. This hybrid simulation modeling will have to be studied.

5. ASSESSMENT OF MODELS

During the fellowship, we guided the evaluation of different operational models developed or being developed at KSC. Example of these models and modeling projects are:

- The NASA Shuttle Simulation Model (Current Shuttle Operations/Discrete-Event/COTS)
- GEM-FLO (Generic Environment for Simulation Modeling of Future Launch Operations/Discrete-Event/COTS)
- RPST (Range Process Simulation Tool/Decision Making/Customized Environment)
- ATLAS V (ELV operations by Lockheed/Discrete-Event/COTS)
- AATE (Cost Environment)
- Task Analysis (Project – being defined)
- VAB/OPF (3D Models and future discrete-event simulation environment using QUEST (DELMIA))
- MPLM (Models related to MPLM)
- VisionSpaceport Models (3d Models and Decision-Making Tool)

6.VISUALIZATION

The VTB will need good visualization capabilities. Several technologies such as VRML, X3D, and JAVA 3D were studied too (OpenGL was studied in Summer 2002).

- **Virtual Reality Modeling Language(VRML)**

VRML is a 3D content development language for the Internet. VRML is a high-level language that is used to describe 3D objects and scenes. VRML supports multiple platforms over the Internet.

- **Extensible 3D(X3D)**

X3D is an evolutionary step of VRML. X3D is designed to allow the best capabilities of VRML to be expressed in terms of XML.

- **Java 3D**

Java 3D is a 3D extension to Java. Java 3D allows developers to create comprehensive, platform-independent 3D applications and Web-based applets.

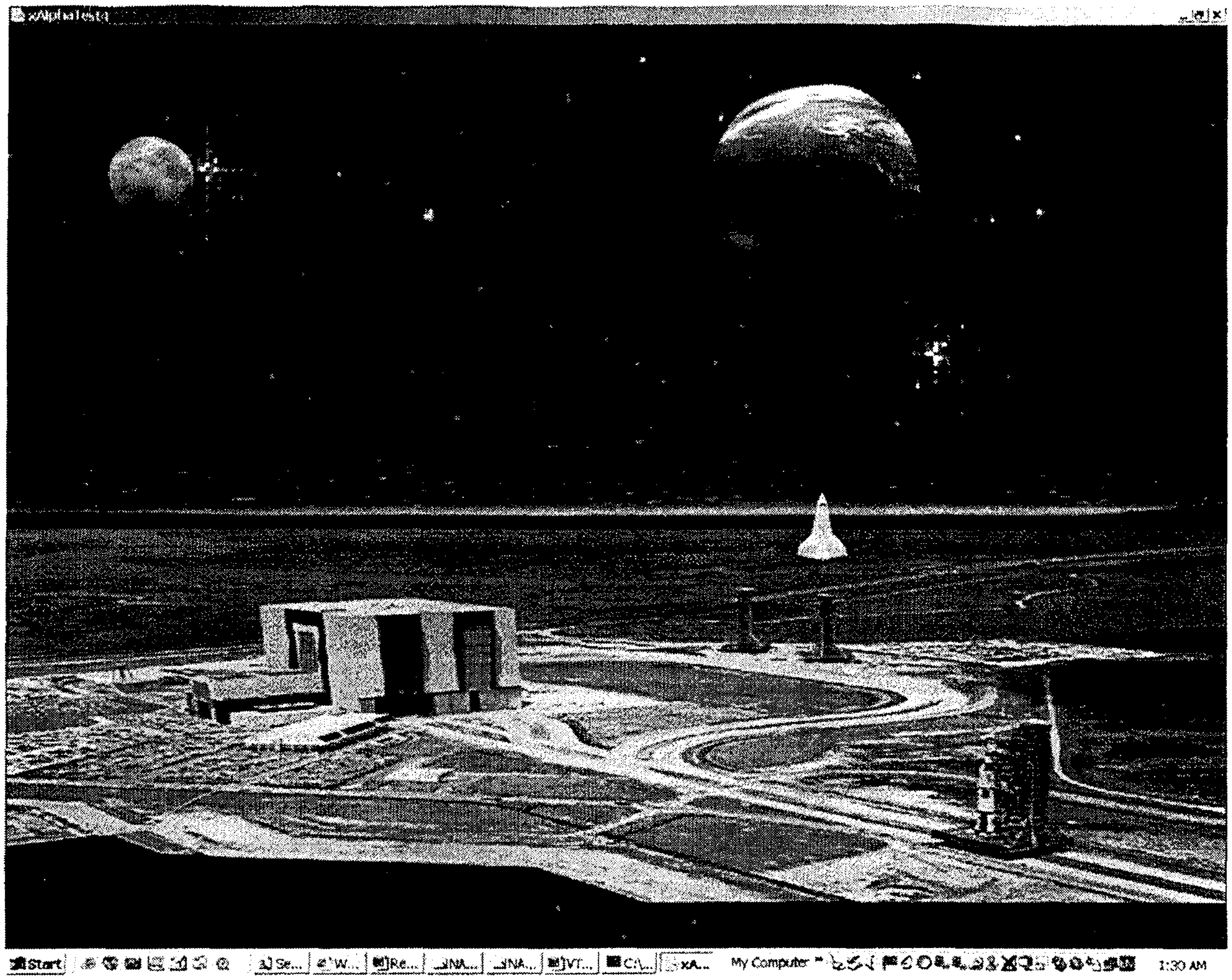

Figure 4. Example of application using JAVA 3D

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Development of an Integrated Human Factors Toolkit

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ABSTRACT

An effective integration of human abilities and limitations is crucial to the success of all NASA missions. The Integrated Human Factors Toolkit facilitates this integration by assisting system designers and analysts to select the human factors tools that are most appropriate for the needs of each project. The HF Toolkit contains information about a broad variety of human factors tools addressing human requirements in the physical, information processing, and human reliability domains. Analysis of each tool includes consideration of the most appropriate design stage, the amount of expertise in human factors that is required, the amount of experience with the tool and the target job tasks that are needed, and other factors that are critical for successful use of the tool. The benefits of the Toolkit include improved safety, reliability and effectiveness of NASA systems throughout the agency. This report outlines the initial stages of development for the Integrated Human Factors Toolkit.

DEVELOPMENT OF AN INTEGRATED HUMAN FACTORS TOOLKIT

Marc L. Resnick, Ph.D.

1. INTRODUCTION

Human Factors is the discipline devoted to optimizing the integration of human abilities and limitations into systems design to achieve safe, reliable, and effective performance. All of these objectives are critical for NASA to achieve its mission. Human factors is thus an integral part of the design and development process of NASA systems. However, in order to achieve successful integration of human factors considerations, they must be integrated throughout the design process. Systems engineers who do not have expertise in human factors must recognize when human factors is needed, how it should be applied, and when specialized expertise in human factors must be recruited.

This report describes the initial stages of development of an Integrated Human Factors Toolkit (IHFT). The IHFT is proposed as a utility to assist systems engineers in the identification of human factors needs in a project, the selection of the most appropriate human factors tool, and the implementation of that tool. Optimal tool selection depends on the:

- requirements of the system under development,
- current stage of system completion,
- resources available, and
- expertise of the project team.

Once a tool is selected, the toolkit also provides advice on how the tool can be implemented to maximize its effectiveness. By facilitating the integration of human factors needs into the project and improving tool use, the IHFT can improve the safety, reliability and effectiveness of the resulting system designs. It also can reduce the amount of time required to implement human factors, thus improving the productivity of the design process.

2. HUMAN REQUIREMENTS

Human performance can be divided into several components, including physical performance, information processing, and human reliability. Physical performance refers to the safety and speed at which physical tasks can be completed. Safety is important for several reasons. Severe injury removes employees from the workforce despite investments in training and experience throughout their years of service [1]. Injury can result from a single case of overexertion [2] or an accumulation of musculoskeletal damage from repeated movements [3]. The development of injury depends on a complicated interaction of multiple workplace, physical, and organizational factors that must be considered in detail to minimize the risk of injury [4]. Models of physical human capabilities have been created and combined with toolkits for biomechanical evaluation to create systems that can predict capabilities such as reach, fit, fatigue, and injury risk [5].

Speed is also critical. Not only does speed have a direct effect on productivity, but it can also have more insidious effects on safety and reliability. Fatigue increases the likelihood of injury [1], in part because of an increased probability of using incorrect postures and in part because of reduced integrity of fatigued muscles. Fatigue can also reduce coordination, increasing the probability of error in tasks requiring accurate manual control, such as interacting with a console interface.

Information Processing refers to the ability of a system user to perceive all of the information needed to complete job-related tasks, interpret and analyze that information, and make appropriate decisions, all while maintaining an acceptable level of mental workload. There are several computational models that have been developed to predict human information processing performance. The Man Machine Integration Design and Analysis System (MIDAS) was created by a joint US Army - NASA Ames team [6]. MIDAS includes models of basic IP processes such as perception, memory, decision making, motor behavior, routine action, and skill, but does not include higher-level processes such as problem solving, learning, language, motivation, emotion, or imagining. The model can be used to predict performance times and levels of mental workload, as well as evaluating competing design alternatives [7]. MIDAS has been validated in many situations such as air traffic control with encouraging results [8]. There are also several commercially available modeling systems, such as the MicroSaint family from Micro Analysis and Design.

Some of the landmark techniques in Human Reliability Assessment (HRA) are described by Kirwan [9]. HRA can be decomposed into several consecutive stages. First, the tasks required to complete a job successfully must be analyzed in sufficient detail to accomplish the project goals. This level of detail depends on the stage of system development and the focus of the analysis. Once the tasks are analyzed, possible errors must be identified, represented, assessed, quantified, and reduced. Techniques for achieving each of these stages have been developed. Many of these are based on a framework developed by Rasmussen [10], which divides human behaviors into three types:

- skill-based: automatic behavior based on well-learned procedures requiring little attention for activation,
- rule-based: procedural behavior that can be followed based on a deterministic set of rules, and
- knowledge-based: event-specific behavior that depends on context and involves problem solving processes.

3. COMPILATION OF THE TOOL LIST

It is essential that a general use Human Factors Toolkit contain all of the tools that should be considered for use by engineers and designers across NASA. This includes both those tools that best satisfy the expected needs of the engineers and designers to efficiently and effectively conduct their analyses as well as those that are preferred because of previous use and training. In order to insure that the tool compilation meets these needs, a comprehensive search for human factors tools from a variety of domains was conducted. Several domains were considered, including a variety of Department of Defense (DOD) collections, academic sources, literature review, surveys of current NASA employees and contractors, and personal communications (see Table 3-1). Several sources provided analysis of the tools in their inventories, either conducted by the tool developer or by independent observers.

3.1 Sources

DoD – The Department of Defense maintains an evolving compilation of human factors tools through the Defense Technical Information Center (DTIC). Originally developed by the Human Factors Engineering Technical Advisory Group in 1994, it continues to be updated as new tools are identified. Tool reviews include basic information on appropriate uses, hardware requirements, processing procedures, output formats, contact information, and validation references.

ONR – The Office of Naval Research Science and Technology Office established a Manning Affordability Initiative to prepare for expected reductions in manpower for naval systems. By encouraging the integration of human factors into the systems engineering process, they hoped to accommodate the reduced manpower without a corresponding reduction in system effectiveness. The tool analyses include descriptions of the tool capabilities, expertise requirements, hardware specifications, and constraints. There are also descriptions of how each tool fits within the Systems Engineering process and suggestions for how each tool complements and is complemented by other human factors and systems engineering tools.

Eurocontrol: Eurocontrol is a European organization dedicated to the safety of air navigation throughout that continent. As part of its mission, it has created a human factors group to investigate human factors issues in future air traffic management systems development (HIFA). HIFA has created an interactive program to assist in the selection of human factors tools throughout the systems engineering design process for managers, designers and human factors practitioners. Brief descriptions and contact information are presented for each tool.

NASA: The National Aeronautics and Space Administration Office of Safety and Mission Assurance has compiled a preliminary list of tools used by human factors practitioners throughout the agency. Tools are added to the list by practitioners, along with references and links to more information from other sources. No analysis of each tool is provided. Additional NASA tools were identified through surveys at Kennedy Space Center of NASA employees and contractors from Boeing, Lockheed, and United Space Alliance.

NAV AIR: The Office of the Navy AIR Training Systems Division maintains a comprehensive list of publications authored by its researchers. Many of these publications describe the use of human factors tools in the areas of decision making and team training.

DISA: The Defense Information Systems Agency manages the Human Systems Information Analysis Center (HSIAC). In addition to providing services, HSIAC also maintains a gateway to resources on human factors methods, tools, and techniques.

FAA: The Federal Aviation Administration Technical Center contains links to many resources used by the FAA to integrate human factors into the design process of air traffic management systems and cockpits. There is considerable overlap between the needs of the FAA and NASA and the tools described in many of the FAA documents are useful sources for the NASA toolkit.

Compendex*Plus: A general search for additional documents was conducted using the digital library resources at KSC and at Florida International University. These sources were used to identify additional tools as well as conduct more in depth analysis of the tools that were identified in the previous sources (see section 4 for more information on the tool analysis).

3.2 Human characteristics addressed by HF Tools

As the tools were compiled, they were differentiated according to the human characteristic(s) that each one addressed. Six major categories were identified. Each major category was further divided into subcategories to isolate the specific target of the tool. Table 3-2 presents the major categories and the subcategories contained within each one.

Table 3-1. SOURCES REVIEWED FOR HUMAN FACTORS TOOLS

Source	Description	Reference
DoD	Compilation of human factors tools by the DoD - Human Factors Engineering Technical Advisory Group (HFE TAG)	http://dtica.dtic.mil/ddsm/
ONR	Compilation of human factors tools by the Office of Naval Research Science and Technology - Manning Affordability Initiative (ONR S&T MAI)	http://www.manningaffordability.com/S&tweb/Index_hse.htm
Eurocontrol	Compilation of human factors tools by Eurocontrol - Human Factors Integration in Future ATM Systems	http://www.eurocontrol.int/eatmp/hifa/index.html
NASA	Compilation of human factors tools by NASA Headquarters - Office of Safety and Mission Assurance	http://humanreliability-pbma-kms.intranets.com
NAV AIR	Publications from the Office of the Navy AIR - Training Systems Division	http://www.ntsc.navy.mil/
DISA	Tools and resources from the Defense Information Systems Agency - Human Systems Information Analysis Center	http://iac.dtic.mil/hsiac/
FAA	Information resources from the FAA Technical Center	http://www.tc.faa.gov
Compendex*Plus	Library database of scholarly engineering publications	http://www.ei.org/eicorp/eicorp

Physical: Tools that address physical requirements and limitations were divided into five categories: overexertion injury, repetitive trauma, fatigue, reach/fit, and toolkits. Overexertion injury refers to a musculoskeletal injury that is sustained as a result of an exertion that exceeds the capacity of the individual. These tools rely on biomechanical models of the musculoskeletal system to determine at what level of exertion users are likely to be injured. Some calculate a risk score indicating an estimate of the injury risk. Others present the quantitative values calculated by the model and rely on the analyst to interpret the data.

Repetitive trauma refers to musculoskeletal injuries that result from the cumulative effects of many small exertions. These tools consider the major risk factors that have been linked to repetitive trauma injuries and assist the analyst in quantifying the degree of risk inherent in a system design. Some of these tools calculate cumulative risk scores that combine the risks identified from each risk factor. Others are checklists that simply highlight the risk factors that are present. Some of these tools provide recommendations based on the results to reduce the risk of repetitive trauma injury.

Fatigue can affect system performance in two ways. Fatigued workers work slower and with reduced quality. This can reduce the efficiency or effectiveness of the system. Fatigue can also increase the likelihood of a user experiencing an injury due to overexertion or motor control error. Tools that address fatigue try to identify fatigue that results from either metabolic energy expenditure or lack of sleep. They can provide a risk score or present the metabolic levels and require the analyst to interpret them.

Reach and fit tools address the anthropometric characteristics of the human components of the system, the physical dimensions of the system layout, and the requirements of the human-system interaction. In general, reach/fit tools evaluate CAD layouts of the system, adding manikin representations of human users using a distribution of population dimensions to insure that any movement requirements are feasible given the physical requirements of the tasks. These tools can include evaluation of cones of vision, collision detection, analysis of clothing requirements for extreme environments, and other considerations.

Toolkits provide a variety of analysis methods, generally assembled from the general literature but with a consistent interface and the ability to share data. The consistency allows multiple analyses to be conducted without repeated data entry and allow analysts to learn a single interface model.

Information Processing: Tools that address information processing were divided into four categories: perception, situation awareness, decision making and mental workload. Perception tools evaluate the ability of the human user to perceive the physical characteristics of the system. Multiple modalities can be addressed, but generally include visibility, audibility, and tactility. Some tools also consider perception between team members for the purpose of coordinating activities and command & control.

Situation awareness (SA) tools evaluate the accuracy of the user's mental model of the important characteristics of the current state of the system and his or her ability to project that model into the future. There are a wide variety of situation awareness tool types. Query insertion tools ask the user relevant questions at periodic intervals to determine how aware of the important characteristics he or she is. Other tools use subjective scales, requiring users to use introspection to rate their awareness of the situation on a variety of dimensions. Some attempt to determine the SA using physiological characteristics. If a critical cue is displayed, responses such as event-related potential can be measured directly to determine if the cue was noticed. Performance-based tools correlate certain aspects of performance with SA. Finally, observer ratings have subject matter experts (SMEs) observe the user's performance and measure the SA based on the appearance of specific behaviors.

Decision making (DM) tools are used to investigate the details of the decision making process applied by users to identify modifications to the system, additional training, or decision support systems that can be applied to improve system performance. In general, a detailed interview must be conducted to identify the cognitive processes that lead to target behaviors.

Mental workload refers to the amount of a user's mental capacity that is occupied during system operation. These tools resemble SA tools in that they can use subjective scales, physiological measures, performance-based measures, or cognitive models. Mental workload tools have been customized to a variety of situations and there is a wide variety of tools available.

Human Reliability and Error: Because of the extreme consequences that can result from human errors, there is a great need to measure human reliability and predict the types and probabilities of errors that may occur. Tools for evaluating human reliability address one or more stages of the analysis process listed in Table 3-2. In order to analyze human reliability, it is useful to analyze the tasks, identify all possible errors that can occur, analyze the consequences of the errors, and predict the likelihood that each error may occur. Error analysis tools can use cognitive models, operator interviews, incident reports, and/or statistical techniques. Some human reliability tools also assist the analyst in identifying ways to reduce the likelihood or magnitude of errors that occur. Usability tools are specifically designed to evaluate error types and probabilities in human-machine interfaces.

Manpower, Personnel, and Training: Manpower, personnel, and training (MPT) tools are used to determine the number of people required to achieve satisfactory performance from a system, what kinds of people are required in terms of skill sets, abilities and authority, and what training would improve system performance or reduce manpower requirements.

Static Resources: There are many handbooks, guidelines, and standards that have been created within the Department of Defense and in general industry to address human factors requirements. Resources were obtained from US DoD, US federal agencies, European organizations, NASA, and private organizations.

Comprehensive Modeling Tools: Comprehensive models attempt to describe all of human behavior. They can be used to predict actual behavior, test theoretical hypotheses, and model populations. For the toolkit, models that attempt to predict actual behavior were considered. Task network models do not explain why behaviors occur, but predict the times that activities require and probabilities of successful mission completion. Cognitive architecture models begin with first principles of human cognition and thus do attempt to explain the mechanisms of behavior. They can predict what behaviors are likely to occur and can be matched with task networks to predict time and reliability as well. Digital human models create simulations of physical aspects of humans to predict the most likely movements and paths taken by humans to accomplish tasks and can be linked with biomechanical models to predict injury risk.

Table 3-2. MAJOR CATEGORIES OF HUMAN CHARACTERISTICS TARGETED BY HF TOOLS AND THE SUBCATEGORIES IDENTIFIED WITHIN EACH

Physical	Information Processing	Human Reliability and Error	Manpower, Personnel, and Training	Static Resources	Comprehensive Modeling Tools
overexertion injury	perception	task analysis	manpower	handbooks	task network models
repetitive trauma	situation awareness	error identification	personnel	standards	cognitive architecture models
fatigue	decision making	error analysis	training	guidelines	digital human models
reach/fit	mental workload	error quantification			
toolkits		usability evaluation			

4. TOOL ANALYSIS

As each tool was identified, a detailed analysis was conducted to determine how it could be applied most effectively within the systems engineering process at NASA. Several factors were determined to be critical components as to whether a particular tool could be applied to a particular design effort.

4.1 Expertise

The expertise required to use the tool is an essential consideration. Tools differed significantly in the amount of knowledge of human factors fundamentals that is necessary to use them effectively. For example, modeling a task using a cognitive architecture model is impossible without considerable expertise in cognitive engineering. On the other side of the spectrum, using a repetitive trauma checklist to evaluate a computer workstation can be accomplished with virtually no knowledge of human factors. Each tool falls along a continuum between these two extremes. Performance-based mental workload tools are easy to implement without human factors expertise, but selecting a performance measure requires a familiarity with the components of mental workload and the types of tasks that draw from each mental resource. Systems engineers should not select tools that require more human factors expertise than is available on the design team.

Another type of expertise that must be considered when selecting a tool involves use of the tool itself. Some tools can be used effectively after a short perusal of the manual. These tools have intuitive interfaces and/or simple processes. Subjective mental workload scales, risk-scoring repeated trauma tools, and many human error tools require little tool expertise. When selecting an unfamiliar tool, it is necessary to select one that does not require past experience to use effectively. Some vendors recommend training classes that can last up to 2 weeks. Projects operating within time constraints may not be able to take advantage of these tools.

A third type of expertise is the familiarity with the requirements of the job being analyzed or designed. In some cases, the analyst can effectively use a tool while observing the end user perform the job without really understanding what is happening. Many of the physical tools fall into this category. However, others require intimate familiarity with how and why each step of the job is performed. Analysts who do not have access to experienced end users and are unfamiliar with the job under study must select a tool that can be implemented without such knowledge.

For each of these types of expertise, the toolkit should provide some insight into how much is needed in order to accomplish the goals for which the tool is intended. In many cases, it depends on details of the project that do not generalize to all uses of a tool. However, the toolkit can provide guidance that helps an analyst determine if he/she has sufficient expertise in order to effectively use the tool for its intended purpose.

4.2 Stage of Development

Tools are generally developed for application at a particular stage of system development. Six phases of human factors application have been integrated into the NASA Systems Lifecycle Stages (see Figure 4-1). While gathering user requirements, tools can assist designers to understand what the needs of the system are, how previous versions have failed to meet expectations, and to identify potential constraints. Tools that address this phase cannot require analysis of specific design components.

During conceptual design, tools can help designers compare alternative design approaches, interaction metaphors, high level architectures, and physical layout schemes. Physical tools that predict injury based only on general task requirments can be implemented here. Mental workload tools that estimate workload based on models of task dynamics and do not require SME interaction can also be useful.

During detailed design, much of the interpersonal communications, interface designs, and workstation layouts are largely determined. Tools that evaluate display legibility, fault trees, and repetitive trauma checklists can be useful here. Tools that use high fidelity simulations to identify design constraints and bottlenecks can be implemented to significantly reduce the costs of redesign once physical mockups are completed.

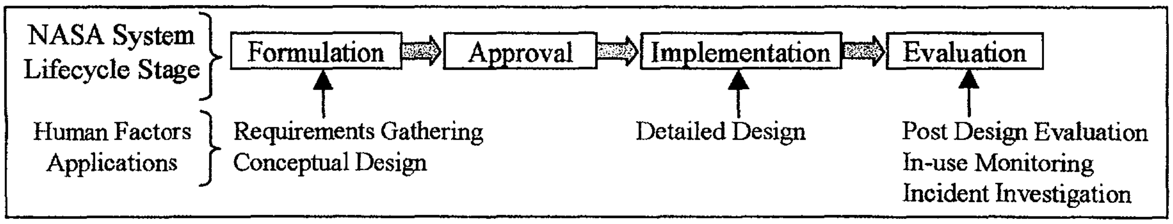

Figure 4-1. INTEGRATION OF HUMAN FACTORS INTO THE NASA SYSTEM LIFECYCLE

After the design is completed and a physical system has been constructed, tools that involve analyzing user performance directly can be used to identify deficiencies before the system is launched. Performance-based workload measures, situation awareness tools, statistical error quantification tools and video-based physical tools are most effective to evaluate completed designs.

Some tools are designed to monitor systems over time during use. At this phase, it is critical that tools are not intrusive so they do not impair user performance. This is critical both because it would invalidate the results and because it could sacrifice the effectiveness of the system during the evaluation. Instantaneous subjective workload scales, continuous safety sampling, and ergonomic workstation checklists are intended for in-use monitoring.

Several tools, particularly those that determine the cause of human errors, are designed to be used during incident investigation. Examples include root cause analysis and cognitive task analysis. During the investigation process, access to users who were involved in the incident is usually required.

4.3 Resources

Selection of an appropriate tool must also consider the resources required to obtain sufficient accuracy and precision in the results. The most basic resource is cost. Tools that are owned by the federal government or are available at no cost should be selected over a tool with similar capability that costs tens of thousands of dollars. The range of tool prices varies considerably. The toolkit lists prices for fixed price tools and facilitates the request for quotes for tools that are flexibly priced.

Time is often a more constrained resource than money. Tools vary in the amount of time required to complete various types of analyses. Often the time requirements are proportional to the scope of the analysis. For example, fault trees that address every aspect and component of a design take considerably longer than an identical fault tree focused on just a partial set of components. However, the toolkit can provide general insight into the time requirements for analysis at various levels and provide comparisons among tools that provide similar analysis.

4.4 Access

The toolkit can also facilitate access to the tool and tool-related support materials. Links to tool vendor contact information, web sites, and training registration can facilitate getting started once a tool has been selected. Links to independent validation studies and tool analyses such as can be found at the ONR Manning Affordability Initiative web site can be very helpful during tool selection. Contact information for experienced users at NASA can help in the selection process as well as during use of the tool.

5. CONCLUSIONS

In order for NASA to design systems that successfully consider human capabilities, it is essential that human factors is integrated into the systems engineering process. The inclusion of human factors can be greatly improved through a utility that assists systems engineers in the selection and application of human factors tools. The IHFT is an effort to provide this assistance. The toolkit allows systems engineers to retrieve a set of human factors tools, along with advice on implementation of each tool. The selection criteria and advice are customized for the project, including its stage of development, resources available, and the expertise of the design team. Use of the IHFT will improve the safety, reliability and performance of systems throughout NASA.

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Treatment of Spacecraft Wastewater Using a Hollow Fiber Membrane Biofilm Redox Control Reactor

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Abstract The purpose of this project was to develop and evaluate design concepts for biological treatment reactors for the purification of spacecraft wastewater prior to reverse osmosis treatment. The motivating factor is that wastewater recovery represents the greatest single potential reduction in the resupply requirements for crewed space missions. Spacecraft wastewater composition was estimated from the characteristics of the three major component streams: urine/flush water, hygiene water, and atmospheric condensate. The key characteristics of composite spacecraft wastewater are a theoretical oxygen demand of 4519 mg/L, of which 65% is nitrogenous oxygen demand, in a volume of 11.5 liters/crew-day. The organic carbon to nitrogen ratio of composite wastewater is 0.86. Urine represents 93% of nitrogen and 49% of the organic carbon in the composite wastestream. Various bioreaction scenarios were evaluated to project stoichiometric oxygen demands and the ability of wastewater carbon to support denitrification. Ammonia nitrification to the nitrite oxidation state reduced the oxygen requirement and enabled wastewater carbon to provide nearly complete denitrification. A conceptual bioreactor design was established using hollow fiber membranes for bubbleless oxygen transfer in a gravity- free environment, in close spatial juxtaposition to a second interspaced hollow fiber array for supplying molecular hydrogen. Highly versatile redox control and an enhanced ability to engineer syntrophic associations are stated advantages. A prototype reactor was constructed using a microporous hollow fiber membrane module for aeration. Maintaining inlet gas pressure within 0.25 psi of the external water pressure resulted in bubble free operation with no water ingress into hollow fiber lumens. Recommendations include the design and operational testing of hollow fiber bioreactors using 1. partial nitrification/nitrite predenitrification, 2. limited aeration for simultaneous nitrification/denitrification or for nitrite reduction/ammonia oxidation, and 3. hydrogenotrophic denitrification.

Treatment of Spacecraft Wastewater Using
Hollow Fiber Membrane Biofilm Redox Control Reactor

Daniel P. Smith, Ph.D., P.E.

1. INTRODUCTION

For long term crewed missions into space, the greatest potential for reducing the resupply requirements for any life support resource is the recovery and reuse of wastewater produced by humans (1). Spacecraft wastewater (i.e., urine, atmospheric humidity condensate, and hygiene water) represents the largest projected wastestream in crewed space systems, with per capita production estimates ranging from 10 to 27 L/day (2,3). Biological treatment can be used to remove organics and nitrogen in the water recovery train, prior to reverse osmosis treatment. Targets of spacecraft biotreatment are physiological organics and nitrogen, hygiene water organics (surfactants), volatile organic chemicals in wastewater or in the supplied spacecraft atmosphere gas, and specific organics such as antibiotics and personal care products. The technical challenge of employing biological treatment as one component within spacecraft water recovery systems is to design bioreactors that are small, reliable, resistant to perturbation, easily maintainable, and safe, while producing an effluent quality suitable for post treatment with reverse osmosis membranes. Supporting feedstocks should be readily available. The Membrane Biofilm Redox Control Reactor is ideally suited to these requirements. Hollow fiber membranes provide a bubbleless gas supply that is suitable for gravity free operation in space, and have a high surface area per reactor volume for gas transfer and biofilm attachment. The corresponding volumetric reaction rates are high, resulting in a small volume and mass requirement. The membrane biofilm reactor is also well suited to space flight application because it is a semi-enclosed system that will minimize operator attention and the exposure of the spacecraft atmosphere to microbial populations within the bioreactor. The reactor can also be designed and operated to provide for varied redox environments to achieve total nitrogen removal. Terrestrial applications are limited but are being actively researched for both oxygenation reactions (4-12), simultaneous nitrification/denitrification (13-14), and hydrogenotrophic reactions (15-18).

2. WASTEWATER COMPOSITION

Spacecraft wastewater production and composition was estimated from wastewater formulations in the Advanced Life Support Baseline Values and Assumptions Document (2), recent stated estimates from Johnson Space Center (3), and estimates of specialty chemicals usage for personal hygiene and the chemical composition hygiene products (19,20). A summary of wastestream volume and composition is presented in Table 2. The three major components are urine with flush water, condensate, and hygiene water. The hygiene water carbon and nitrogen content were estimated based on the chemical composition of a commercial surfactant and a final surfactant concentration of 461 mg/L in the composite wastewater (20). Urine with flush water has the highest nitrogen and organic carbon concentrations, and accounts for 93% of the nitrogen

Table 1 Spacecraft Wastestream Composition

Source	Daily volume per crew	Total nitrogen (mg/L)	Total organic carbon[1] (mg/L)	NOD[2] (mg/L)	COD[3] (mg/L)	ThOD (mg/L)
Urine with flush water	2.0	3423	1556	15643	4512	20156
Condensate	2.3	38	358	174	1038	1212
Hygiene water	7.2	60	330	274	957	1231
Composite: Urine/ condensate/hygiene	11.5	640	549	2927	1592	4519

1 Total organic carbon, not including urea organic carbon in urine
2 Nitrogenous oxygen demand, computed using $Y_{O/N} = 4.14$
3 Chemical oxygen demand, computed using COD/TOC = 2.9
4 Theoretical oxygen demand exerted, computed as the sum of COD and NOD

and 49% of TOC in the composite wastewater. The estimated nitrogenous oxygen demand of the composite wastestream is 2927 mg/L, versus an estimated chemical oxygen demand of 1592 mg/L. Hygiene water and condensate comprise 37% and 13% of organic carbon, respectively. The major fraction of urine nitrogen (81%) is as urea or its hydrolysis product, ammonia nitrogen. Creatinine and hippuric acid comprise 77% of the urine organic carbon. The ratio of organic carbon to nitrogen in the composite wastestream is 0.86, indicating that the composite wastestream is nitrogen rich and organic poor from a classical nitrogen removal perspective.

3. BIOCHEMICAL TRANSFORMATIONS

Aerobic heterotrophic oxidation, aerobic nitrification, and heterotrophic anoxic denitrification are well-characterized processes applied extensively in environmental biotechnology, and experience is increasing in autotrophic denitrification. Recently, microorganisms have been elucidated that catalyze denitrification of nitrite using ammonia as electron donor under anaerobic conditions (21,22). Several microorganisms with anaerobic ammonia oxidation capability are known. Similar to nitrifiers, these microorganisms are autotrophs with low yield coefficients and low growth rates. In general, the ubiquity of metabolic capability for anaerobic ammonia oxidation in the environment is unknown. The bioreactor conditions needed to manifest anaerobic nitrite reduction/ammonia oxidation are long solids retention times, a limited oxygen supply, and appropriate pH. These conditions can be established in a hollow fiber membrane bioreactor, and may be similar to conditions that would promote total nitrogen removal in a single hollow fiber membrane biofilm reactor by nitrification/ denitrification.

To provide an evaluation framework for reactor design, idealized bioreaction scenarios were developed for spacecraft wastewater using stoichiometric relationships between carbon, oxygen, and nitrogen derived from the electron equivalents involved in oxidation and reduction reactions

Table 2. Spacecraft wastewater bioreaction scenarios.

	Bioreactions	O_2 demand, mg/L	Alkalinity, mg/L as $CaCO_3$	Residual NO_3 or NO_2, mg/L
1	Complete organics oxidation and complete nitrification to NO_3	-4133	-4515	640
2	Complete nitrification to NO_3; denitrification with available TOC	-2652	-3209	275
3	Complete nitrification to NO_2; denitrification with available TOC	-1985	-3064	31
4	Complete organics oxidation and balanced nitrification/ anaerobic ammonia oxidation	-2577	-2427	0

and accounting for some degree of net biomass synthesis. Four scenarios are listed in Table 2. In principal, any of these idealized stoichiometries can be established in an appropriate reactor configuration. The first, completely aerobic oxidation of organics and nitrification of ammonia to nitrate, exerts the greatest exerted oxygen demand, consumes the most alkalinity, and has the highest nitrogen residual as nitrate. In scenario 2, ammonia is completely nitrified and nitrate is denitrified with wastewater organics. Denitrification results in a reduction in oxygen demand and in alkalinity consumption. A residual nitrate nitrogen of 275 mg/L is present because there are insufficient electron equivalents of organic carbon in spacecraft wastewater to completely denitrify nitrate. Reaction scenario 3 is similar to scenario 2, except that ammonia is nitrified only to the +III oxidation state (nitrite). The oxygen demand and alkalinity consumption are lowered. Since nitrite denitrification requires less organic carbon than nitrate, the residual nitrogen is reduced to only 31 mg/L (as nitrite), and the requirement for supplemental carbon (or hydrogen) for denitrification is reduced. Reaction scenario 4 combines aerobic organic oxidation, nitrification of 50% of kjeldahl nitrogen to nitrite, and nitrite reduction/ammonia oxidation under anaerobic conditions. This bioreaction scenario is calculated for complete nitrogen removal, and results in a low alkalinity consumption.

Although the reaction scenarios presented in Table 2 will never be totally segregated in an operating bioreactor, the analysis does allow some important conclusions. First, an aerobic first stage treatment would require the highest oxygen transfer capacity and a high dose of electron donor for nitrate denitrification. Predenitrification, simultaneous nitrification/denitrification, or a segregated wastestream feeding approach could be used to exploit wastewater organics for denitrification. The fact that 49% of composite wastewater organics are contained in the urine stream that contains the bulk of wastewater nitrogen suggests that predenitrification or simultaneous nitrification/denitrification should be pursued. Nitrifying ammonia to nitrite, rather than allowing it to proceed to nitrate, can produce lower. Hydrogenotrophic denitrification and nitrite reduction/ammonia oxidation are processes that can be integrated within hollow fiber reactors with limited oxygen supply, or applied as follow up processes in downstream reactor compartments.

4. DESIGN CONCEPTS

Oxygen supply is critical to organic and hydraulic loading. Organic removal rates as high as 27 kg/m^3-day of total chemical oxygen demand have been achieved in hollow fiber membrane bioreactors operated on pure oxygen (11). These high volumetric rates suggest that spacecraft wastewaters in an aerobic only treatment mode (Table 2, scenario 1) require retention times on the order of 4 hours for hollow fiber specific surface areas of 322 m^{-1}. Denitrification using wastewater organic carbon would reduce oxygen demand and proportionally reduce required retention times, although ammonia oxidation (nitrification) would still comprise the major fraction of oxygen demand. Experimental testing using analog spacecraft wastewater is needed to gain confidence in projecting required reactor loadings and retention times.

Hollow fiber membranes are manufactured down to diameters on the order of 250 um, which provides a high surface area per reactor volume for transfer of gases and for biofilm attachment. Packing densities of 2 to 5% can achieve specific surface areas of 150 to 500 m^2/m^3 reactor volume while maintaining centerline separation distances of 0.5 to 2 mm. These factors can result in very high volumetric reaction rates. Hollow fiber membranes can be manufactured in dense, microporous, or composite configurations (Table 3).

Table 3 Candidate Hollow Fiber Membrane Materials

Material	Advantage	Limitation	Characteristic
Microporous hydrophobic polypropylene	Very high oxygen permeabilities	Must maintain lumen pressure below bubble point or pressurize reactor liquid	Liquid film diffusional resistance to mass transfer
Nonporous silicone rubber	Can be operated at high lumen gas pressures without bubble formation	Not available in small diameters	High membrane resistance to mass transfer
Nonporous composite	Very high oxygen permeabilities Can be operated at high lumen gas pressures without bubble formation Resistant to abrasion Mechanical strength	Limited availability	Thin nonporous membrane layer Liquid film diffusional resistance to mass transfer

For microporous fibers, lumen gas pressure must be maintained below the bubble point for bubbleless operation, and a high lumen pressure can be maintained if the liquid is pressurized so the transmembrane pressure does not exceed 2 to 3 psi or less. Accumulation of water vapor in the fiber lumen has been reported with high shell side pressures (15). Hollow fiber membranes can be operated in a flow through or a dead end mode. Dead end mode can potentially achieve 100% gas transfer efficiency, but may result in the accumulation of water vapor and nitrogen in the lumen; either could reduce oxygen transfer or cause operational problems.

For spacecraft application, nonporous hollow fibers avoid the need to balance lumen and external water pressure. Nonporous silicone membranes are ready available and have the highest intrinsic permeabilities of commercially available dense materials, and are recommended for evaluation. Their oxygen transfer capability can be enhanced with pure oxygen if needed. If silicone membranes prove inadequate, they can be substituted with a composite membrane with higher areal oxygen delivery rates or higher specific surface area.

Liquid recycle serves two functions: diluting the feedstream and maintaining superficial velocity. Recycle results in more uniform solute concentrations across the bioreactor and avoids potential toxicity. A recycle ratio of 10 to 20 can provide substantial reduction of the actual influent concentration entering the reactor. For a wastewater ammonia-N of 640 mg/L and 95% removal, recycle ratios of 10 and 20 reduce the actual reactor influent ammonia-N levels to 87 mg/L and 61mg/L, respectively. Another potentially important benefit of recycle is to even out pH gradients that could occur, for example, from nitrification. In a reactor with no recycle, destruction of alkalinity by nitrification could make it difficult to adjust the feed pH at the influent end in order to achieve a pH all across the length of the reactor within the acceptable range for nitrifying organisms. Recycle would reduce the pH gradient and result in a more uniform concentration profile. The second important effect of recycle flowrate is on the superficial liquid velocity. Superficial velocity produces bulk liquid transport and mixing, mass transfer from bulk liquid to and from attached biofilms, and shearing or sloughing of attached microbial biomass. It may also help to avoid channeling. At long reactor residence times, the need for bulk liquid movement (as assessed by superficial velocity of Reynolds number) may predominate over the need for wastewater dilution, and high effective recycle ratios would produce a reactor liquid phase approaching completely mixed. A wide range of recycle rates have been used in experimental studies of hollow fiber bioreactors, and optimal recycle ratios must be experimentally determined.

Limited oxygen supply operation can be used to achieve simultaneous nitrification and denitrification of terrestrial wastewaters in a single reactor, and deserved evaluation for spacecraft wastewaters. Limited oxygen supply operation can be established by gradually reducing the lumen gas pressures in a nitrifying reactor. Continuous operation with limited oxygen supply could lead to a high oxygen transfer efficiency and reduced oxygen concentrations and denitrification in outer biofilm layers. Denitrification under this scenario requires an adequate supply of electron donor. In limited oxygen supply operation, heterotrophic utilization of organics could exert a strong competition with nitrifiers for oxygen at the membrane surfaces and limit the availability of electron donor for denitrification.

The Membrane Biofilm Redox Control Reactor is a new alternative reactor configuration that contains two separate hollow fiber gas supply systems: one for oxygen and the other for hydrogen gas. Hollow fiber membranes from the two systems are interspaced in close spatial juxtaposition, allowing solute transport to and from biofilms attached to either the oxygen or hydrogen membranes. The Membrane Biofilm Redox Control Reactor is a new treatment concept that has not been attempted for any wastestream, but could provide substantial benefits to spacecraft wastewater recycling. Both O_2 and H_2 will be produced on future spacecraft from the electrolysis of water, so H_2 gas will be an available feedstock. A possible strategy for complete nitrogen removal is an alternating sequence of 1. oxygen on/hydrogen off followed by 2. oxygen off/hydrogen on. Nitrification and organics oxidation would occur during oxygenation period, while denitrification would occur in the hydrogenation period. Based on alkalinity consumption by nitrification and its restoration by denitrification, monitoring of pH and feedback to gas supplies could be developed as a process control strategy. The alternating use of oxygen and hydrogen, as well as the ability to alter the timing and intensity of the supply of these oxidizing and reducing gases, will create a highly flexible and versatile reactor system. The ability to precise engineer desired microbial syntrophic associations will be substantially enhanced over current technology.

Nitrite reduction to N_2 using ammonia as electron donor is a reaction sequence that could become established in bioreactors operated in a limited oxygen regime. Oxidation of about 50% of ammonia to nitrite, followed by nitrite reduction/ammonia oxidation, would result in complete nitrogen removal. To accumulate nitrite in the first step, an oxygenation strategy in needed to decouple nitrite oxidation from ammonia oxidation to nitrite. One potential strategy is pulsed on/off operation of oxygen supply. This could be achieved by relatively rapid step up/step down alternations in lumen gas pressure. Each pressure upstep would result in a nonsteady diffusion pulse of molecular oxygen to biofilm reaction sites. During the pressure-off downstep, oxygen diffusion to catalytic sites will cease, and nitrite from partial nitrification would counterdiffuse with ammonia from the bulk liquid to reach ammonia oxidizing/nitrite reducing bacteria in the anoxic biofilm. Nonsteady oxygenation during a limited duration pressure pulse has a similarity to the surface renewal theory of oxygen mass transfer across open gas liquid interfaces, which hypothesizes non-steady diffusion of oxygen from liquid packets that have temporally limited surface contact intervals.

An approach to optimize the spacecraft wastewater organic carbon for nitrogen removal is predenitrification (Figure 1) with an aerobic, limited oxygenation regime reactor that nitrifies to nitrite. An important feature of this design is the recycle of nitrite in the aerobic reactor effluent to the denitrification reactor, allowing efficient use of influent organic carbon to fuel denitrification. In Figure 1, a hydrogenotrophic denitrifying reactor is shown for follow up removal of the nitrite that is not recycled to the anoxic reactor. Ultrafiltration retentate is partially recycled to the hydrogenotrophic reactor influent.

5. PROTOTYPE

A laboratory scale hollow fiber membrane oxygenation bioreactor (Figure 2) was constructed to evaluate its ability to nitrify and achieve total nitrogen removal from an analog spacecraft wastestream. The reactor consisted of a vertically oriented column with an overall length of 42 cm and an internal diameter of 5.7 cm. The reactor was subdivided by a horizontal ported flow distribution plate into an upper reaction zone (30.5 cm), and a lower mixing zone. Wastewater flow is mixed with recycle flow before entering the reaction zone. A CellGas hollow fiber oxygenation module (Model CG2M-020-01N, Spectrum Labs, Inc., Laguna Hills, CA) was

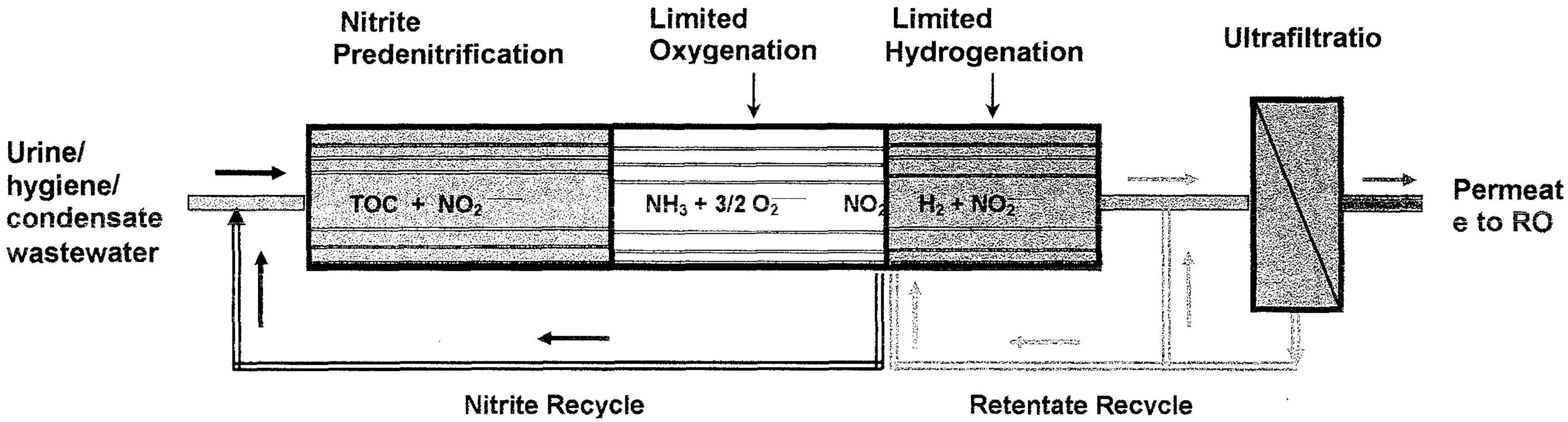

Figure 1. Hollow Fiber Bioreactor Zonation

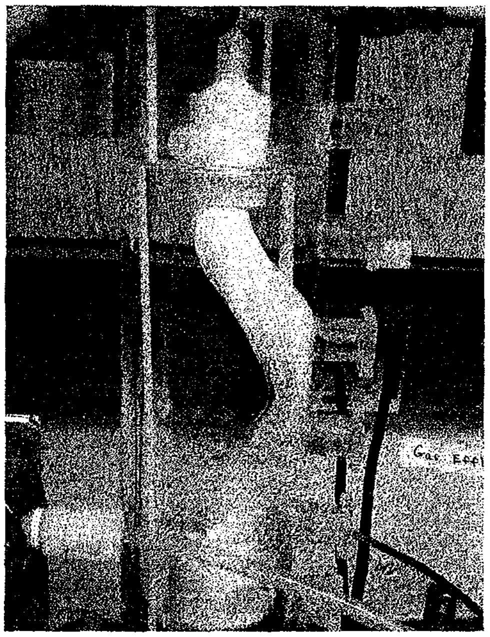

Figure 2. Prototype Hollow Fiber Biofilm Reactor

installed for oxygen transfer. The module consisted of a bundle of approximately 1540 polypropylene hollow microporous membrane fibers potted into a PVC endcap and flow header. The hollow fibers had an active length of 20.7 cm, 0.20 mm inner diameter, 0.25 mm outer diameter, a 250 um wall thickness, and a pore size of 0.05 um. The module had 0.25 m^2 of surface area based on the outer diameter of the hollow fiber, which provided a reactor specific surface area of 322 m^{-1}. The CellGas module was connected to horizontal pipes that were mounted through horizontal ports. The gas was supplied by an air cylinder, flowed through a metering bubble flowmeter (Shorate), into and through the CellGas module, and through an effluent metering valve. Pressure gages were used to measure inlet and outlet gas pressure; both gages were placed on the CellGas module side of the flow meters.

A series of tests were performed to determine the range of pressures and pressure differentials that would result in no bubble formation or water ingress. The pressure drop between module inlet and module outlet remained at approximately 1.5 psi throughout the tests. Across a range of water pressures of 3 to 10 psi, maintaining an inlet gas pressure in the range of 0.25 psi above or below the reactor water pressure resulted in neither bubble formation nor water ingress into the lumen. When inlet gas pressure was 0.75 psi or more greater than water pressure, bubbles were formed at all water pressures. An inlet gas pressure 1 psi or more below water pressure resulted in water ingress in most cases. Operation with an inlet gas pressure within 0.25 psi of water pressure precluded bubble formation and water ingress.

Gas liquid mass transfer capabilities were evaluated by applying the abiotic dynamic method to determine a first order oxygen transfer rat constant K_La. Forward flow was discontinued and the reactor was operated as a closed water system using the recycle pump. Deionized water was deoxygenated with sodium sulfite and spiked with 2.0 mg/L cobalt chloride as catalyst. The water was pumped into the reactor, the recycle pump was turned on, and the airflow was started.

The water temperature was approximately 24C during oxygenation tests. The oxygen transfer rate constant was evaluated at two different liquid flowrates that produced superficial velocities of 0.068 cm/sec and 1.5 cm/sec. The experimental K_La were 0.0013 min^{-1} at the low flowrate and 0.0061 min^{-1}, or 4.7 times higher, at the high flowrate. This indicated that oxygen transfer from the hollow fiber membranes was strongly influenced by liquid film mass transfer resistance.

The design of the bioreactor prototype will be used to evaluate bioreactor features and their effects on biological treatment of spacecraft wastewater, including the use of air versus pure oxygen, operation in gas flow through or dead end mode, low oxygen operation, and temporal variation of gas pressure (on/off operation; pressure fluctuations) to evaluate performance.

6. CONCLUSIONS AND RECOMMENDATIONS

The development of hollow fiber membrane bioreactor systems for spacecraft water recovery is in its infancy, and the Hollow Fiber Membrane Biofilm Redox Control Reactor, with its dual oxygen and hydrogen feed, appears to be highly promising. Experimental evaluations should be conducted to provide performance data upon which to develop process designs for flight testing and to advance to Technology Readiness Level 3. Application of hollow fiber redox control bioreactors requires extensive experimental evaluations on the unique composition of spacecraft wastewaters to develop a confident basis for system design. Ground based testing should be conducted first on simulated spacecraft wastewater containing all three spacecraft wastewater sources, followed by the use of real urine with simulated hygiene and condensate water.

Several system configurations of hollow fiber bioreactor should be evaluated in parallel to delineate the effects of multiple issues of reactor design and operation on the transformations of nitrogen and organic carbon, including: hollow fiber array design, superficial liquid velocity, nitrite recycle from partial nitrification, and oxygenation and hydrogenation regimes. For each reactor configuration, influent, intermediate, and effluent monitoring should be conducted to delineate process performance and allow changes in operation to be monitored for their effect on treatment efficacy. Mass balance analysis and stoichiometric relationships should be applied, and net biomass and process residuals should be quantified. In addition, pH control strategies and fouling and flux decline of hollow fiber membranes should be evaluated.

The hollow fiber membrane biofilm redox control reactor configurations that are recommended for parallel evaluation on the composite spacecraft wastestream are:

1. aeration, phasing into limited oxygen operation for simultaneous nitrification/denitrification, nitrite production, or nitrite reduction/ammonia oxidation
2. predenitrification/aeration phasing into predenitrification/limited oxygen operation,
3. oxygen/hydrogen with varied gas application regimes
4. pulsed oxygenation for 50% ammonia nitrification to nitrite, followed by ammonia oxidation/nitrite reduction

Follow-up experiments could consist of coupling a hydrogenation reactor to the end of the predenitrification/limited oxygen reactor to achieve complete nitrogen removal. Cell retention using microfiltration or ultrafiltration should then be incorporated into the experimental evaluations. Finally, effluent water quality must be evaluated for its suitability as a feedwater to reverse osmosis.

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Intelligent Work Process Engineering System

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ABSTRACT

Optimizing performance on work activities and processes requires metrics of performance for management to monitor and analyze in order to support further improvements in efficiency, effectiveness, safety, reliability and cost. Information systems are therefore required to assist management in making timely, informed decisions regarding these work processes and activities. Currently information systems regarding Space Shuttle maintenance and servicing do not exist to make such timely decisions. The work to be presented details a system which incorporates various automated and intelligent processes and analysis tools to capture organize and analyze work process related data, to make the necessary decisions to meet KSC organizational goals. The advantages and disadvantages of design alternatives to the development of such a system will be discussed including technologies, which would need to bedesigned, prototyped and evaluated.

Intelligent Work Process Engineering System

Kent E. Williams

1. INTRODUCTION

The behavior of an organization is motivated by its goals. The processes, activities and materials required to meet organizational goals, in turn, define organizational behavior. These activities and processes are sometimes referred to as the value chain of an organization. The value chain activities are critical to the successful performance of the organization in meeting their goals and objectives. The goals of the KSC organization are to launch and recover space vehicles in the service of the greater NASA mission. These goals are achieved as a result of the various work processes and activities performed at KSC and other supporting facilities both contractor and government. Consequently, these activities and processes must be performed; safely, reliably, efficiently and effectively while optimizing cost and the predictability of performance of space vehicles. Optimizing performance on these work activities and processes requires metrics of performance for management to monitor and analyze to support further improvements in efficiency, effectiveness, safety, reliability and cost. Being able to monitor and anlyze these metrics will further enhance KSC operations in the service of their mission. Information systems are therefore required to assist management in making timely, informed decisions regarding these work processes and activities. Currently information systems regarding Space Shuttle maintenance and servicing do not exist to make such timely decisions regarding the specific activities, which must be performed to ensure the safety, reliability, efficiency and predictability of Shuttle processing.

As a case in point, a report identifying Root Cause for Space Shuttle Operations and Infrastructure Costs, was recently developed by McCleskey [1]. His analysis found that ~ 25% of Direct Work costs were categorized as Unplanned Troubleshooting and Repair activities and another ~ 24% of Direct Work costs were associated with Vehicle Servicing. However the specific activities making up these servicing and repair tasks could not be readily identified. The magnitude of these unplanned activities relative to the totality of direct labor, reflects uncertainties and risks in the design of the vehicle. This indirectly impacts the cost for Operations Support, Logistics, Sustaining Engineering, Safety Reliability and Quality Assurance, and Flight Certification, all of which are hidden costs. These hidden costs most importantly make up the greatest percentage of recurring operational expenditures.

If data were captured and organized relative to the tasks making up work instructions, one could conduct a deeper analysis of unplanned as well as planned vehicle processing activities. Management could address work process changes and design changes to reduce costs and risk in the future while improving upon the efficiencies of processing the Shuttle. Start-stop time data associated with tasks related to differing Operational Functions and Design Disciplines could be captured and analyzed to pinpoint specific problems. These problems could then be targeted for improvement in process and or design. This data could also be used to develop models of future design alternatives to make predictions concerning budgetary requirements and the reliability of designs.

2.0 BACKGROUND KNOWLEDGE: MANAGEMENT INFORMATION REQUIREMENTS AND TOOLS

Management is decision-making and problem solving. In order for management to make informed decisions about the performance of activities regarding the safety, efficiency, reliability and costs of operations, data must be gathered and translated into information regarding these dependent measures. Numerous methods and technologies (i.e. tools) have been developed for industry to conduct the needed analyses for management to make decisions regarding these measures. One of the classical techniques employed is that of the control chart. There are numerous forms of the control chart [2]. In the abstract, however, the control chart is a data mining tool which plots a measure of performance as a function of time. The chart is segmented into three boundaries called the centerline which represents the mean value of the measure of interest, the upper control limit and the lower control limit. The upper and lower control limits typically represent values which represent some number of standard deviation units above and below the mean value represented by the centerline. As the measure of performance is plotted over time one can see how this measure is varying.

Of specific interest, however, is when the measure starts moving toward either the upper or lower boundary. This means that the process is out of control. A visual inspection of the chart will show a slope deviating from a straight horizontal line moving toward one of these boundaries. One can glance at the chart and judge how quickly the process being measured will go out of control by looking at the magnitude of this slope. Figure 1.0 shows a control chart and a trend developing, which would indicate that the process is going out of control. Exceeding one of these boundaries indicates that there is a failure in the process or in the material being measured. This kind of information can be used to prevent or alert operators to the potential failure of a system. Armed with such information management can then make decisions regarding system operability and can trigger an analysis of the causes for the system going out of control. Hopefully, this will preclude any future problems in the operation of the system.

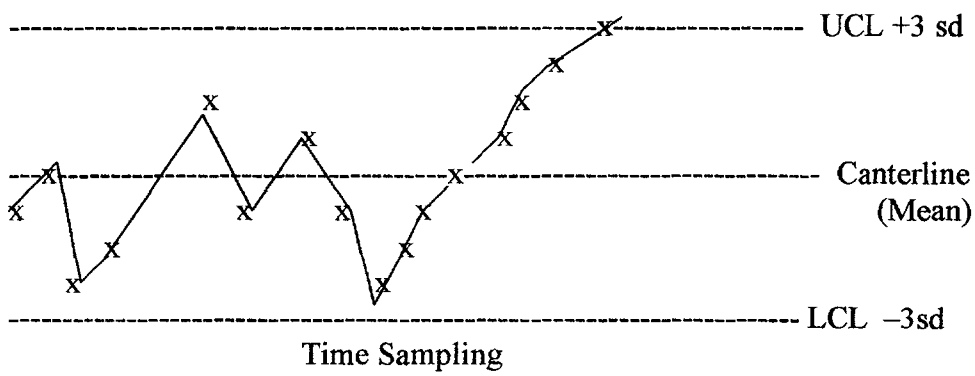

Figure 1.0 Generic depiction of a process control chart showing a trend which is exceeding the

upper control limit of + 3 standard deviations (sd) above the mean.

This type of data analysis can be employed to plot and track the variation of an activity about its expected value in terms of time to complete that activity or to track the performance of a component or system about some expected value indicative of its health. Moreover costs to perform specific activities can be plotted to determine if expected costs are on track, below expectations or exceeding expectations. Other statistical regression analysis techniques can equally well be applied to the types of dependent measures reflective of safety, reliability, efficiency and cost. These techniques can be used to make predictions regarding the time to failure of a component or the time to complete a process given historical data from past records [3]. Madigan and Ridgeway [4] have also described Bayesian analysis techniques for making such predictions and for modeling processes for which prior probability distributions on work metrics are available.

Another type of analysis typically performed by management especially when monitoring organizational performance is that of root cause analysis or drill down. Root cause analysis is a technique for identifying the source or the cause of a specific problem identified. In management information system terms, root cause analysis is performed by drilling down into the various layers of information recorded regarding specific activities of the organization to identify the source of a problem. This is typically a lower level of analysis than that conducted employing control charts of a specific process or system performance. Whereas control charts can indicate that a process or system is about to go out of control, indicating that a special cause for the loss of control is apparent, control charts and trend analyses do not specifically identify the cause or source of the problem. Identifying the source or cause of the problem requires further in depth analysis of the process or system. However with well specified data, recorded at some basic unit of analysis, management can perform root cause analyses on organizational activities employing a drill down capability.

As an example given the analysis performed by McCleskey regarding the apportionment of dollars to direct labor, he found that ~ 50% of the direct labor costs were associated with unplanned activities. However, these unplanned activities could not readily be identified. Consequently, management has still not identified the source or deeper cause for such costs. In essence such costs still remain unaccounted for. However, if data could be captured at a basic, fundamental unit of analysis for work processes, one could identify precisely what tasks are responsible for this large portion of direct labor costs. For example, if data regarding the tasks of a work instruction along with the context with in which the task is performed were captured, such deeper level analyses and ultimate identification of the source of such costs could be specified. Data related to the technical staffing requirements to perform such tasks, the historical safety record on task related work, the time to complete a task, the materials required for the completion of the task, the ground service equipment required for the task, any associated quality assurance support, hazard and safety considerations, as well as, environmental facility requirements and associated costs could be captured and stored in a data warehouse. Armed with this store of data relative to this basic unit of analysis, the task unit and its context, management could readily perform root cause analyses to answer any questions regarding potential deviations from expected operations along with safety and health concerns.

A third class of management tools, which has recently received broad attention and application in industry is that of simulation and modeling of industrial and organizational processes [5]. These modeling tools allow managers to create chains of input-output processes which reflect the underlying activities of the organization. The inputs to the processes and the processes themselves are the independent variables, which can be manipulated by management. The outputs are the effects of the work processes or the transformations imposed upon the inputs. That is, the results of work performed on the inputs. These outputs are typically referred to as the dependent variables and can be measured to reflect the performance of the processes imposed upon the inputs. What is unique about such tools is that management can experiment with different organizations of tasks within a process, can modify specific processes by introducing new technologies or can change the values of input parameters and receive information regarding the likely impact of such changes upon the performance of the organization. Such tools can also demonstrate where the bottlenecks to organizational performance occur and allow for a deeper analysis of the underlying cause and effect relationships inherent in any model of the organization, process or system. Such simulation and modeling tools have effectively been used to make predictions regarding performance. As a relevant case in point, all of the space missions executed by NASA in one form or another were the products of simulation and modeling tools. The Department of Defense has also directed all services that any future defense program procurements will require that competing contractors supply simulations and models of the operation of the engineering systems to be designed and developed along with models of life cycle development processes for the procured system.

Given the basic unit of analysis, the task and its context, along with the associated data which could be captured for the data warehouse, models can be developed and executed to make numerous predictions. For example alternative sequences of tasks can be modeled to determine if any improvement in efficiency and or schedule can be achieved. Information regarding materials required for the conduct of tasks, the location of task performance, the labor and support required and the schedule of tasks can be used to make predictions which can effect the supply chain of operations at KSC. Such process simulations can supply management with an experimentation platform from which to evaluate improvements which may be associated with proposed changes to operations to foster continuous process improvement.

2.1 Data Requirements for Management Decision-Making To Meet Organizational Goals

In order for management to make decisions based upon the categories of analyses discussed above a basic unit of analysis had to be decided upon which could then be subjected to the various analysis methods and tools. That unit of analysis was determined to be the task level or step level unit embodied in a work instruction. This was found to be the lowest unit of analysis about which various data elements could be recorded during the execution of a work instruction. This unit of analysis was associated with the various data relevant to making the kinds of decisions required on the part of management in order to meet organizational goals. Additionally, a scheme for organizing the needed data was developed such that various analyses could be carried out relevant to processing the Shuttle orbiter.

The results of the investigation of data required is presented in Figures 2.0-6.0. The investigation of data requirements found that most if not all data required for the conduct of these various categories of analysis could be found in the Operational and Maintenance Instructions (OMI) and their associated runs as well as in the Problem Reporting and Corrective Action (PRACA) data base. The data required was then placed into a structure characterizing this basic unit of analysis, the work step or task, along with its context. That is, this structure defines the work step and the context in which the step is performed. This structure or instance regarding the basic unit of analysis could then be used to organize the data and yield the needed information for the conduct of various analyses for management decision-making. The analysis yielded the following data structure.

1. OMI ID#
2. Step Name
3. Requirement Addressed
4. Operational Function
5. Design Discipline Required
6. Materials Required Yes/No
7. Special Consideration Yes/No
8. Quality Assurance Requirement Yes/No
9. Environmental Requirement Yes/No
10. Safety Requirement Yes/No

11. Accident Report
12. Deviation to Work Instruction
13. P/FRACA
14. Initial Problem Report
15. Materials Costs
16. Skill Codes
17. Start Time
18. Stop Time
19. Date Performed
20. Location Of Work Performed

The first ten rows represented in this data structure are used to classify an instance or the basic unit of analysis. They define the context in which the work is performed and identify the basic unit as belonging to an Operational and Maintenance Instruction (OMI) ID number, row 1.. Within the OMI the basic unit is also given a Step Name, row 2., describing what task must be performed. The remaining rows, 3-10, of this block characterize the work step to be performed as a set of attributes which can take on a finite set of values either Yes/No or some set of nominal values as in Operational Function and Design Discipline Required. These attributes and their values were designed in a manner consistent with the way in which management analysts typically organize their thinking regarding a work step instruction. This classification scheme was developed as a result of interviews with individual stakeholders who would be the potential end users of this kind of management information.

Rows 11-20 consist of data which is gathered as a result of the actual execution of the work step. This is the data that will be used to perform the various types of analyses discussed for management decision-making. Figures 2.0-4.0 present data flow diagrams specifying how the various data elements within the data structure will be used in the various types of analyses discussed. Additionally, Figure 5.0 indicates how this data may also be used to feedback information regarding Lessons Learned, modifications to Training Requirements and Work Requirements.

2.2 Current Status of Data Generation and Collection Relative to Shuttle Work Processes

Currently, work instructions and their associated data are recorded manually on hard copy paper sheets detailing the work to be performed. This information is then scanned into a document store. No further processing into an electronic format is generated relative to this information. Problem reports on the other hand are first collected on hard copy forms and then transformed into and electronic data base which can be readily accessed for analysis. As a result of this current state, the collection, gathering and organization of the required data to conduct the analyses for management decision-making in large part is none existent. Needed analyses and information organization would have to be conducted with considerable human interaction. A major constraint then is the absence of an electronic format in which the needed data can be captured, organized and analyzed. Therefore although the data exists for such analyses to be conducted it is currently in an inert form. Any analyses to be performed for management decision making is conducted with considerable time and effort on the part of the analyst.

3. PROPOSED ALTERNATIVE TO THE CURRENT SYSTEM

As an alternative to the current lack of information systems to support management decision-making regarding work processes and work process engineering, a paperless work processing system is proposed. Such a system would include a work authoring tool, electronic work control and instruction execution capability, a data warehouse which can filter needed information and automatically organize this information for analysis purposes, process analysis tools for analyzing work results and a feedback loop to incorporate changes that could help reduce cost and improve on work efficiency, scheduling, safety and resource allocation This system could model work processes to make predictions regarding; the costs and schedules associated with alternative vehicle design configurations, the reliability and safety of a work processes, time to execute a work process, utility of a work process, cost of implementing a work process in material, support and labor. In short such a system would allow the various categories of analysis to be conducted for management decision-making.

The benefits of such a systems would allow management to: monitor and set control limits for work related measurements, identify uncertainties in work processes as targets for continuous process improvement, identify excessive costs related to work processes, identify root causes for operational costs and hazards, predict actual time and costs for processing orbiter and for estimating operational budgets, provide needed information for analysis of design inefficiencies, provide feedback for developing and updating work requirements, training requirements, lessons learned, and safety in the performance of work and the integrity of the orbiter.

3.1 Description of Proposed Work Process Engineering System

3.1.1 Work Instruction Authoring

The alternative system proposed to meet the needs of management is graphically depicted in Figure 6.0. This system design presupposes that the current process for recording and storing data relative to work processes, lends the data inaccessible by way of standard electronic processes. Consequently this alternative would begin processing work instructions with the aid of an intelligent work instruction authoring system. This system would place all work instruction information into an electronic format capable of being stored in accordance with the data structure outlined above. Work instructions and their component steps would be uniquely authored or retrieved in whole from existing data sources which store the components of the work instructions. The work instructions could also be subjected to modification if needed by the user. New work instructions could also be developed and designed in accordance with accepted human factors principles by accessing a task analysis system. The task analysis system would guide the user through a task analysis process and then access other tools to assess the human factors issues, which must be addressed in the design of the work instruction. Upon completion of a work instruction all of the information regarding the attributes of the work unit would have been provided for sorting in the Work Unit Warehouse.

Issues which must be addressed regarding the authoring of work instructions would include but not be limited to: the human interface, the structure of the interview process to elicit information from the user, the format and media to be employed relative to differing types of information to be communicated to personnel performing the work process, the human engineering principles which must be accessed and implemented employing the human factors tool kit, the differing types of intelligent search routines required to gather stored information when needed to facilitate the construction of an OMI and other intelligent systems required to store work instructions and their component steps in a data warehouse which is self-organizing and adaptive.

3.1.2 Electronic Work Instruction Distribution

The output from the authoring system would be transmitted electronically to personnel responsible for scheduling the execution of the work process and to a data base of work instructions. The instruction could alternatively be transmitted to an intelligent work scheduling system which could automatically schedule the work activities, the supply of needed materials, ground service equipment, environmental facilities where the work would be performed, the necessary technical crew and support personnel. The information upon which such decisions could be made would be contained in the first block of attributes describing the task step and context for the work unit as well as from data contained in the data warehouse.

The needed personnel, facilities, material requirements and schedule for the work unit along with the work instructions, could then be received via wireless transmission by the appropriate personnel by way of a personal digital assistant (PDA). Personnel could then enter the raw data relative to performance on the task during task execution employing this PDA. Data recorded would consist of that specified in the second block of fields in the data structure designed. Information regarding problem reports could also be entered by this system such that it could be transmitted, received and stored in the existing PRACA data base electronically. Consequently upon completion of the work instruction, the information needed to categorize a work unit or work step and the data associated with the performance of the work step would be available for storage, organization and retrieval in the Work Unit Warehouse of information.

3.1.3 Work Unit Warehouse

The Work Unit Warehouse would provide managers with the needed store of information and data required to conduct the various analyses for management decision-making. The warehouse would consist of an interface for users to create their own organizations of data and information if desired, as well as, machine learning algorithms which would automatically cluster information contained in the basic work unit data structure specified or some other unit of analysis specified by a user. That is, a user could construct their own database organized differently than that specified by the data structure defined. This of course is contingent upon the fact that the information and data is contained in the work instruction database or other databases, which could be accessed by the warehouse routines.

In order to develop such a warehouse an appropriate machine learning algorithm must be provided to automatically retrieve, sort and classify information relative to the basic unit of work, to be subjected to various analyses. One potential algorithm is CLASSIT developed by Fisher [6]. CLASSIT is an incremental concept formation algorithm, which takes instances made up of a set of attributes and their associated values and automatically finds the best clustering or organization of these instances. For the case at hand, CLASSIT would sort and organize work unit information based upon the attributes and their associated values as specified in the basic unit of analysis defined. The categories, which evolve after processing numerous instances, would represent classes of information, which are inherent in the instances fed to the algorithm. What is unique about CLASSIT is that the conceptual clusters that are formed correlate extremely well with those categories, which would have been developed by humans given the same instances. Given this current design each instance, which is fed to CLASSIT would also be associated with a record which identifies all of the data recorded as a result of the execution of a work unit. So for example, if one wanted to determine how many PRACA reports were filled out relative to a specific Design Discipline, one could query CLASSIT and retrieve all of the problem reports associated with that Design Discipline. Any questions regarding the attributes of a work unit or the data associated across work units could be retrieved with this system. All of the analyses specified for management to make their decisions regarding the goals of the organization could be conducted given the data stored in this warehouse and the organization of the data provided by the algorithm. The advantage is that no predefined structure for the database of information in the warehouse is required. This provides the needed flexibility for organizing information in various ways, to meet managers information needs. Information could essentially be sorted and organized based upon any combination of attributes and data stored as defined by the basic unit of analysis.

The features of CLASSIT, which are of importance for organizing information, are presented in the following. CLASSIT differs from other algorithms in that it can not only organize information automatically, but it can modify its organization based upon new instances to be sorted. That is, it is self-organizing. CLASSIT operates in an unsupervised fashion. It does not require any feedback as to the goodness of fit of the categories it forms, unlike many other algorithms, which do require some form of external feedback. Due to the incremental nature of this classification algorithm initial instances may bias the clustering of new or future instances to be processed. However, CLASSIT continuously evaluates a current organization of information such that it can form new classes, merge existing classes and split existing classes to improve upon its ability to discriminate between instances, which do or do not belong together. This is accomplished by way of a category utility measure. The expression for **category utility** is based upon conditional probabilities and is expressed as follows:

Eq [1]

$$\frac{\sum_{k=1}^{K} P(C_k) \sum_i \sum_j P(A_i = V_{ij} \mid C_k)^2 - \sum_i \sum_j P(A_i = V_{ij})^2}{K}$$

If new attributes are to be added to an instance or deleted from an instance, CLASSIT has the capability to modify an existing organization to form a new organization of the information based upon the addition or deletion of attributes and their associated values. CLASSIT is also one of the only algorithms, which was designed to simulate human performance on classification tasks. The resultant classifications therefore would be most compatible with human organizational processing of the information. This algorithm can handle missing data and missing attribute values since it is stochastic in nature. It can accommodate nominal as well as quantitative values.

CLASSIT forms categories of instances in a hierarchical fashion with the most general classes of information toward the top of the hierarchy and the more specialized categories toward the bottom of the hierarchy. Each specific instance would be stored as a singleton class under its parent category. An instance may also belong to more than one different category at any given level of organization if the instance cannot be clearly discriminated. This is called clumping and has also been observed in human information processing.

The category utility function of equation [1] is used to classify a new instance into an existing class, to create a new class (i.e. a singleton) to combine two classes into a single class (i.e. merging) or to divide a class into several classes (i.e. splitting). When a new instance is to be sorted it is first placed in the root node. At this node as in all other nodes, the system computes the probability of an instance occurring at that node. This probability yields the $P(C_k)$ value, which represents the probability that an instance would belong to any given node, which has been created. CLASSIT also computes a conditional probability for each attribute and its associated value. This is represented as

$$\sum_i \sum_j P(A_i = V_{ij} \mid C_k)^2 \ .$$

This is the sum of the probabilities of the attributes having specific values given that they belong to a specific class. It is referred to as the predictability of attribute values belonging to a given class. If an instance and its associated attribute values match the probabilities associated with attribute values of an existing class then there is a high probability of that instance belongs to that class.

However this conditional probability should be adjusted by the probability of the attribute and its value occurring independent of any specific class. This is called predictiveness and is represented as

$$\sum_i \sum_j P(A_i = V_{ij})^2.$$

That is if an attribute and its value has a high probability of occurrence independent of membership to any specific class, then it is not providing much information regarding class membership since it is highly likely to occur independent of class membership. The number of classes, which the category utility function is evaluating is represented as **K.**

Once an instance is placed in the root node it is then passed to each child of that root node and the measure of category utility is applied to each child to determine to which node the new instance most likely belongs. If there is a match to any of these children which ever has the highest score will retain the new instance. If none of the children match closely, then CLASSIT will consider forming a new singleton class based upon the category utility measure. If two or more of the children match the instance closely, then CLASSIT will consider merging the instances together into a single class. CLASSIT also considers the inverse operation of splitting nodes. If CLASSIT decides to classify an instance with an existing category it also considers removing the category and making the instances in that category children of that categories parent. That is the category is removed and the instances, which belong to that category are elevated to become directly linked to that categories parent. In essence they now become candidates for new categories if the category utility function indicates an improved clustering. This entire process is iterated for each node that CLASSIT visits during its attempt to sort a new instance. In this way CLASSIT is continuously modifying its organization based upon the probabilities calculated with the introduction of a new instance into the system.

3.1.4 Search Agents

The Work Unit Warehouse could also contain search agents, which would search the Work Instruction Data Base and retrieve the information required by the basic unit of analysis. This would then create the instances required for sorting by ClASSIT in the Work Unit Warehouse organizing the information for analysis by managers. If the data regarding the basic unit of analysis is captured and stored employing an Intelligent Work Instruction Authoring system and an electronic mode for capturing data relative to the execution of the work instruction, these agents could be easily designed. Since the data regarding a work instruction and its execution is captured in an electronic format with a known structure, simple If-Then rules could be created to retrieve the necessary data for insertion into the slots of the basic unit of analysis. This would require that someone knowledgeable about the structure of the Work Instruction Data Base and the information needed for insertion into the basic unit of analysis, create the simple If-Then rules. Rules could be developed for the retrieval of any element of information in the Work Instruction Data Base. Data elements could then automatically be retrieved and inserted in their appropriate slots in the basic work unit data structure. Again this scheme presupposes that data regarding the basic unit of analysis be captured and recorded electronically and placed into a structured database.

3.1.5 Advantages of Design

The advantages of this design is that the cost to generate work instructions would be reduced due to the facilities provided in the authoring tool which would automatically search and retrieve the needed information for the user. A paperless format would also eliminate the costs for archiving and distributing multiple hardcopies of work instructions to the appropriate recipients for management and execution of the work instructions. The system would also supply the user with the flexibility to organize data and information in accordance with the users conceptualizations, dynamically, in real time.

In the absence of a data warehouse requests for alternative organizations of information would require that information systems personnel specialized in the interfaces of various data bases write routines to gather and organize the data in accordance with a request. This could take days if not weeks to achieve dependent upon the personnel resources available. Moreover, the self-organizing properties of CLASSIT would reduce the costs accrued in developing a model for database storage and retrieval. The traditional approach to database design can be an expensive process requiring considerable analyses of user needs and information storage and retrieval requirements. Once a structure for a database model is settled upon the structure of the database is fixed. Any modifications would require considerable effort. This would all be eliminated employing CLASSIT.

3.1.6 Disadvantages of Design

The disadvantages of this proposed design would include the cost to develop an intelligent work authoring instruction system, the costs to implement wireless communications, PDA hardware and software, the cost of a data base management system for the Work Instruction Data Base, and the costs to integrate the CLASSIT algorithm and associated agents with the Work Instruction Data Base. A user interface for the Work Unit Warehouse would have to be designed and developed. Interfaces connecting The Work Unit Warehouse with the various analysis packages for management decision-making would need to be developed. Lastly any modifications as to the way in which work is performed relative to the status quo would probably result in change order requests on the part of the contractor associated with increased costs.

3.2 An Alternative Approach

An alternative effort to that proposed in the above would make use of the current system for processing work instruction documents and executing work instructions. This alternative would also use existing document and data stores to capture the needed information required for constructing the basic work unit data structure. The development of the work unit warehouse would consist of the same effort as that described in the above with the exception that research would need to be conducted in the development of semantic search agents to identify and retrieve information regarding the attributes of the data structure and the raw data associated with the execution of the work unit.

3.2.1 Semantic Search Agents

Current search agents employ a simple key word search for information stored in various databases. These key words can form conjunctions of terms as well as disjunctions of terms. They are simple Boolean Logic expressions. The number of terms is also typically constrained to two or three terms making up an expression. The search simply consists of recognizing the words making up the expressions and retrieving information which matches the key word expressions. The underlying meaning of the expression used for the search is not sought. In order to conduct such meaningful searches the technology currently employed is natural language processing (NLP). This technology takes as an input a grammatical sentence, which represents the meaning of the information which is the target of the search. In order to establish the meaning of the expressions, the system must first parse the sentence grammatically and then interpret the meaning of the words making up the sentence to understand the query. Once the target of the query is understood the system can conduct a search and retrieve the desired information. The problem is that the words used in the query must be represented by the system in advance such that an understanding of the expressions can be identified. Considerable knowledge engineering is required to develop such systems. For general purpose applications such systems are cost prohibitive if they can even be developed to work.

On the other hand a system could be designed which interviews the user and elicits from the user, his/her semantic representation of the target of the search. This approach would not require any form of natural language processing and would place the burden of establishing the meaningful representation of the query upon the user interacting with the system. The challenge then would be to design an interface, which could elicit such meaningful representations from users. If this can be achieved then, general purpose searches can be made of existing data sources to retrieve the needed information. This is necessary since in many cases users searching for information would not know the contents of the many legacy data bases which exist. The user could engineer his/her understanding of the meaning of the information, which is the target of the search, launch an agent with this representation and receive responses which identify sources of data consistent with the users meaningful representation. It would then be up to the user to decide if a particular data store would be of interest. The user could browse through data store retrieved to determine if specific elements of information are located there. If so then the site would be flagged to indicate that the user request is associated with the specific data store and a rule would be coded which points to that site given the representation provided by the user.

This would not require the creation of new data capture technologies and a new data base management system as would be the case with the original proposal. The needed data could be retrieved, encoded and stored to conduct the analyses of concern employing the data warehouse. Such a capability is a compromise between a keyword system and a natural language processing system. Keyword searches are limited in that they consist of simple Boolean expressions and do not have associations to equivalent forms of these expressions. Natural language processing on the other hand, requires considerable engineering of the complete vocabulary of the domain of interest along with complex parsing mechanisms. Such systems are still limited in terms of their ability to resolve ambiguous expressions entered by the user. Consequently, a system, which elicits from a user the representation of the users meaningful representation of a search topic, would limit the necessity for engineering an entire domain vocabulary. Also the need for complex understanding and generation of English sentence expressions as is the case with NLP, would be eliminated. In time various search agents would be developed by differing users within the organization and made available to other users in a library of search agents.

3.2.2 The Representation of Meaning

In order to design such a system however, one must understand the nature of human associative memory, which is the seat of meaningfulness. Since the meaningfulness of something is the product of an individuals stored experiences in memory, in order to understand meaning one must examine the structure of information in human memory. The approach taken herein was first to collect the works of the foremost researchers and theorists with respect to human memory and the representation of meaning, second, to examine their thinking regarding the representation of meaning in memory, third, to find some common ground amongst these theorists and fourth to come up with a set of guidelines or principles which could guide the design of an interface for eliciting meaning from a user.

The primary sources for theoretical and empirical research were Anderson [7],[8] and [9], Anderson and Bower [10], Quillian [11] and [12] , Kintsch [13] and [14] and Ausubel [15]. These investigators are considered to be the most prominent in the field of human memory. In common to all is their agreement on the obvious fact that memory is associative and therefore meaning is represented by a variety of associations in memory. Therefore to understand meaning one must examine the types of associations, which can be formed in human memory.

Of particular importance in defining how meaning is represented is the classification scheme for meaningful representations espoused by Ausubel [15]. True of all disciplines, either arts, sciences or engineering, in order to understand a subject matter classification comes first. Ausubel [15] has proposed a threefold classification of types of meaning. The first and most basic form of meaning within this classification is that of representational meaning. Representational meaning is defined as words or symbols which represent corresponding objects. This is typically what takes place when one is learning a vocabulary. It involves rote learning, that is the simple assignment of a name to an object. Representational meaning must come first in that the individual must have a name for something that s/he is referring to. Representational meaning involves supplying that name for something. It establishes an equivalence between a verbal symbol and a referent. There may also be different verbal symbols which establish the same equivalence relations. That is different words referring to the same thing. Representational meaning however is not flexible or general in that it has a very specific referent.

The next type of meaning is that of concept meaning. Concept meanings are generic or categorical in nature. They are general and they are flexible. They are ideas, which like representational meaning have verbal symbols, but the symbols have no specific referent. That is, the meaning of the symbols represents an entire class of instances or things, which share some common attributes. These attributes provide distinguishing characteristics, that provide the meaning for the concept. Concept meaning is typically abstracted by experiencing many instances of something and recognizing similar features between these instances. The human information processing system performs this kind of function naturally. For example a child who first experiences a ball object may assign the representational meaning of ball to that specific object. That meaning however only refers to that specific ball and no other types of balls. With further experience, the child sees other round like objects, of differing colors and sizes which can be manipulated in the same way as the first ball experienced and abstracts common criterial features. The word ball no longer represents a specific object called a ball but represents a whole class of specific objects which can be referred to as ball. Given this evolution of experiences, representational meaning come first, followed by the formation of a concept. As we gain more experience with objects most words take on meanings, which are conceptual in nature. That is the names assigned to represent objects or ideas in our experiential base are typically conceptual in nature. As concepts are formed other exceptional features can be taken on to modify our notion of the concept. Hence they are flexible and generalizable. For example a football can take on many of the same characteristics as a ball since it shares similar properties with respect to how it is used and manipulated although its shape is a not round but elliptical.

The elliptical shape is an exception but can easily be taken on to further specify the instances which can be classified as ball.

The third type of meaning employing Ausubel's scheme is called propositional meaning. Propositional meaning expresses a relationship. The relationship is a comment about something. Propositional meaning is formed by a combination of concepts that are combined to each other such that a new idea is formed. This new idea is more than the sum of its component concepts. For example the proposition "semantic network", is made up of two concepts which means something more than the concept "semantic" and "network" on their own. When these concepts are combined they refer to a web of associations between words, that defines the meaning of the words relative to other words in the neighborhood of words to which they are associated. Other examples of propositional meaning may define the relationship between mass and energy or between heat and volume etc. Most English sentential expressions yield prepositional representations in order to establish meaning.

Anderson and Bower [10], Quillian [11] and [12] and Kintsch [13] and [14] all support the notion of the propositional representation and the concept for establishing meaning in memory, although they may use different verbal referents. For example, Quillian [12] refers to "property information" as the basic building block for meaning. This property information is essentially a labeled association or a relation, a proposition. Examples of such property information would consist of; verb phrases, relative clauses, adjectival or adverbial modifiers or any verb and its object. The other fundamental units are referred to as types and tokens, a token being a member of a type. That is types represent classes or concepts and tokens represent characteristics or modifiers of a type. Tokens themselves may serve as types subsuming other tokens, which in turn modify them.

The other theorists reviewed also propose that propositions and concepts can be nested within other concepts or propositions forming a heterarchical network representing all of the potential associations of concepts and relations. All agree on some form of subset-superset structuring of concepts, which forms a hierarchy of meaning typically in a top down fashion moving from general to specific. That is with experience meaning becomes organized moving from high level concepts or propositions to low level instances or instantiations of the concepts or propositions. Quillian additionally proposes that the attributes or tokens of a type can take on different weights which indicate how indicative that attribute is of identifying membership to a type. Highly weighted tokens are more predictive of a type's membership than low weighted tokens. This allows for considerable flexibility in making predictions regarding membership to a class or type. Anderson [7] and Kintsch [13] also support this notion of strength of association or activation between attributes and their respective associations.

With respect to differing types of meaningful representations, then all of the theorists are in agreement as to prepositional and conceptual classes of meaning although they have not explicitly identified them as classes as has Ausubel. Most, if not all, agree that the most prevalent forms of memory for meaning consist of concepts and propositions idealized as a network of associations made up of concepts and the myriad of relationships they can form dependent upon the context in which they are used. The context of textual information therefore is also an important component in establishing the meaning of a target of search. This context forms the neighborhood of words, which provide meaning for the target under search and would govern what gets visited.

3.2.3 Contextual Relations

These propositional relations and subset-superset hierarchies forming concepts defines what is referred to as the context of relations or associations between the words. It is this context of relations and associations, which forms the meaning of an expression. The search for information consistent with a users understanding of the meaning of the target must then incorporate those word units and their associations making up this context of relations. All of the theorists reviewed agree that such associations are what provides for meaning in human memory. Therefore, the context of relations or associations must be defined by a user to represent the users meaning for the target of search. Identifying the kinds of associations and relations would then define this context and represent the meaning of the information targeted for search by the user.

First of all as indicated by these theorists the meanings of concepts are represented as a hierarchy of associations between the concept name and the attributes which define the meaning of the concept. In turn the names of attributes and the name of the concept may have representational equivalents. That is they may be known by different names. The structure for representing a concept would then look like a tree. The concept name would be the top level node of the tree and the attribute names would serve as the first layer of nodes linked by downstream arches from the concept name node as in Figure 7.0

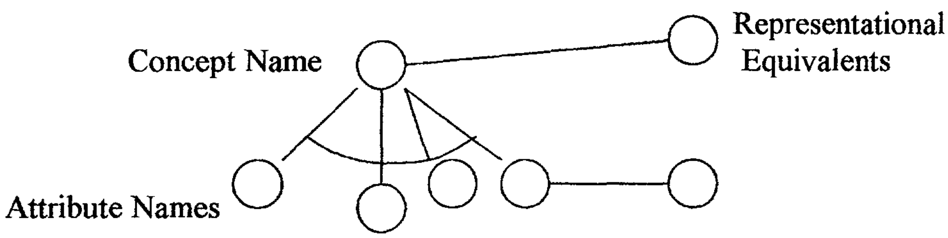

Figure 7.0 Nodes and links representing a concept and its defining attributes along with representational equivalents.

The nodes of Figure 7.0 would represent word units which represent the verbal names assigned as the concept name, the names of attributes and the representational equivalents to the concept name and attribute names. The attributes are ANDed together representing a conjunction of terms which are the defining characteristics of the concept. A concept name and or the names of its defining attributes may also have equivalent representations. These would be different words that could be used to define the same characteristics or the same concept name. They would be represented as a disjunction of terms or they would be ORed. These names for the concept and the names for the attributes would be elicited from the user along with any of their representational equivalents. If the user can not recall representational equivalents then the system can make use of Word Net. Word Net is an ontology of English words which provides alternative representations for English language terms and currently consists of over 100,000 words and growing. It can be downloaded free from the DARPA web site or from Princeton University. Equivalent terms for the names provided by the user can be retrieved and examined by the user for their appropriateness as representational equivalents. It may be that the concept name and its equivalents along with the attributes of that concept and their equivalents can be automatically retrieved and inserted from Word Net into the users representation of the meaning of the target. The user could then inspect this representation and edit it if desired.

During the process of building this concept tree, the attributes may also represent concepts, which in turn must be decomposed into their associated attributes. The process would be continued until the user makes a judgment that no further decomposition is required. In addition to specifying the concept names and attribute names the user would also be required to indicate the strength of the relation between the attributes and their associated concept. This feature is borrowed from the concepts of associative strength or activation from Anderson [8] and [9] from Kintsch [13] and [14] and from Quillian [11] and [12]. In many cases a search which is being conducted comes across documentation which does not explicitly mention the concept name or its equivalents but does mention some number or all of the attributes. This would imply that the document is associated with the concept dependent upon the amount of evidence found related to the attributes mentioned. The weights or strength of association between the attributes and the concept name could then be used to determine if the document is truly concerned with the concept in question. If attributes with high valued weights relative to their association with the concept are found then the evidence is in favor of recognition of the concept. If not then the concepts relation to the document would be questionable. The amount of evidence in favor of a concept would be specified by the user.

If the subject of a users search is a propositional expression or a combination of concepts, then the user would be requested to enter the expression into the system which best represents the users understanding of the target for search. This would more than likely not consist of more then three or four words, which is the limitation of most phrases. Any articles or prepositions would be ignored by the system and the concepts making up the expression would become the topic for decomposition. Again the user would be requested to supply alternative expression equivalent to that originally specified. For example, one may want to conduct a search for the proposition "semantic representation". This could equivalently be expressed as the "structure of declarative memory", or the "representation of meaning in memory", or "cognitive models of meaning", etc. Each of these propositions equally (in my mind anyway) represent the meaning of what I am searching for. These propositions are made up of a combination of concepts each of which independently does not refer to the target of the search. However their conjunction would more then likely get me to the specific information I am looking for. However, the combination of words used in different documents may not be the same as any one combination or expression listed. Therefore one would need to decompose each concept in each proposition in a similar fashion as that described for a single concept term. If any conjunction of terms representing the various representational equivalents of the concepts making up these equivalent expressions is found then this would indicate that the meaning of what I am looking for is contained in the document or database.

Again the process for representing the meaning of a proposition could be aided by retrieval of individual concepts and attribute names from Word Net. If this is the case then the task becomes less difficult for the user. However in many technical domains the terms used would probably not be represented in Word Net and the user would have to be guided through a process of defining referential equivalents to their expressions and to decomposing each into their component parts. The component parts must then further be decomposed as singular concepts and weights would be applied to their links as before. The search process then amounts to a search for evidence in support of a specific meaning. The meaning is inferred from this evidence regarding the conjunction of disjunctive terms. That is several trees would be constructed to represent each concept and its associated disjunctive equivalents. If any of the attribute names or their equivalent representations are true then the attribute is true. Likewise if any of the concept terms or their equivalent representations are true then the concept term is true. If the concept terms are all true then the proposition is true. The conjunction of these concepts would represent the prepositional relationship of choice. Partial truth may also be represented by propagating forward the weights assigned to any attributes strength of association with any given concept. The user can set the degree of truth which is acceptable during a search for meaning. Thus even partial truth in satisfying the meaningfulness of a target can be retrieved and examined by the user. Any documents which are found as a result of conducting these multiple searches on the conjoint terms and their representational equivalents, could then be compared for their intersection. These would most likely be the documents which would most closely match the meaning of the target of interest.

This type of search bears similarity to the use of Bayesian equations to classify text documents. The equations are made up of expressions representing the probability of a specific class of document being found in general and the cross product of the probabilities of some number of words being conjointly found within a given document. This type of algorithm has been found to be capable of reading documents on news group pages and correctly classifying them into one of twenty different categories of news Mitchell (1999). The Bayesian equation for classifying such documents is as follows:

Eq. [2] $$P\,(D_{\mathrm{i}} \mid A_{\mathrm{i}} = \mathrm{V}_{\mathrm{ij}}, \ldots\ldots\ldots, A_n = \mathrm{V}_{nj}\,) = \underset{\mathrm{i}}{P(D_{\mathrm{i}})}\ \Pi\, P\,(A_{\mathrm{i}} = \mathrm{V}_{\mathrm{ij}})$$

This simply states that the probability of a document belonging to a specific class given that specific words are evidenced is equal to, the probability that the class of document would occur in your experience, in general, times the cross product of the probability of the words occurring. This assumes that words can occur independent of the occurrence of other words in a document.

Although this is obviously false it works very well. It is referred to as a Naïve Bayes Assumption.

Consequently, meaningful search is likened to classifying documents, which belong to certain categories of information, very much like the type of meaningful search, which is being proposed herein. Consequently there is conceptual evidence due to the similarity to the Bayesian classification scheme that such a process would work to successfully retrieve meaningful information.

4. CONCLUSIONS/FUTURE RESEARCH

Future research can focus upon the first alternative specified as defined in the scheme presented in Figure 2.0. Another alternative is to develop the semantic search capability, evaluating it empirically with users to determine agreement between the searched for target and the users confirmation or disconfirmation of information retrieved. If the empirical evidence supports the validity of the semantic search capability then it would be developed and integrated with the Work Unit Warehouse and its classification algorithm. A third option would be to develop the first alternative and also conduct research to develop the semantic search capability. The semantic search capability would have widespread use across the various divisions of NASA as well as having considerable commercialization potential.

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