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CASE WESTERN RESERVE UNIVERSITY

2003 NASA FACULTY FELLOWSHIP PROGRAM AT GLENN RESEARCH CENTER

FINAL REPORT

NASA FACULTY FELLOWSHIP

PROGRAM

AT

NASA GLENN RESEARCH CENTER

AT LEWIS FIELD

CLEVELAND, OHIO

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INTRODUCTION

The Office of Education at NASA Headquarters provides overall policy and direction for the NASA Faculty Fellowship Program (NFFP). The American Society for Engineering Education (ASEE) and the Universities Space Research Association (USRA) have joined in partnership to recruit participants, accept applications from a broad range of participants, and provide overall evaluation of the NFFP. The NASA Centers, through their University Affairs Officers, develop and operate the experiential part of the program. In concert with co-directing universities and the Centers, Fellows are selected and provided the actual research experiences. This report summarizes the 2003 session conducted at the Glenn Research Center (GRC). Including all prior years of the ASEE Summer Faculty Fellowship Program this was the 40th consecutive session of the program a GRC. GRC has conducted the program since 1964, the year the program was instituted a NASA, originally involving only a few centers.

At each center, management of the program is shared between one or more educational institutions. At GRC, two institutions, the Ohio Aerospace Institute (OAI) and Case Western Reserve University (CWRU), a member of OAI, serve as concurrent partners – thereby involving the NASA co-director and two university co-directors each year.

The primary objectives of the NASA Faculty Fellowship Program are:
- To provide university faculty with unique research experiences to enrich and refresh the research and teaching activities of the participants' institutions.
- To further the professional knowledge of qualified engineering and science faculty members.
- To stimulate an exchange of ideas between participants and employees of NASA.
- To contribute to the research objectives of the NASA Center.
- To provide faculty insight to NASA's future human resources needs and education program opportunities for student engagement in NASA.

From a broader perspective NASA sees the NASA Faculty Fellowship Program as a vehicle for initiating lasting partnerships in the academic community. While research assignments result in immediate contributions to host organizations, the development of longer-term collaborations has far greater potential for NASA programs. Such developments are welcome. Opportunities to move from fellowships to funded grants, which fuel lasting collaborations, are always a matter of interest to fellows and NASA colleagues alike though they never can be assured. At all centers, fellows spend 10 weeks in residence working on research assignments in collaboration with designated NASA colleagues and generally participating in other organized professional activities. Appropriate social activities are also arranged for the fellows, and their families. All fellows receive a stipend, which was $1200 per week in 2003. The program is open only to U.S. citizens, and participation is limited to two consecutive residencies. Implementation of the program varies at each center within broad guidelines established by the NASA Headquarters Education Division in partnership with ASEE.

THE GLENN RESEARCH CENTER PROGRAM

At GRC, the program focus is primarily on the intensity and quality of the individual participant's research experience in collaboration with the NASA colleague and less on structured group activities. The latter are considered ancillary activities. The focus has been determined by the co-directors from many years of experience to produce the greatest benefits and satisfaction, programmatically and educationally, to NASA and the program participants.

After initial administrative screening, applications are reviewed by the NASA co-director for its technical interests and qualifications. The applications are then circulated to appropriate research organizations for review in consideration of the organizations' immediate technical needs. Selection of the applicants is made by the research organizations. If an organization desires to host a fellow, it prepares a written statement of the proposed assignment that is sent to the applicant along with an offer of award. The assignment is designed to match the interests and qualifications of the applicant, to be professionally challenging, and to enable meaningful results to be accomplished in 10 weeks. This process assures good matches between the interests of the faculty and the programmatic needs of NASA.

GRC also offers an Accompanying Student Option whereby faculty may be accompanied by one of their students for the full duration of their fellowship. In this arrangement, the student is not formally given a NASA mentor. Instead, the on-campus professor/student relationship is intended to be sustained in the center research setting. Nomination and selection of the students is accomplished on an *ad hoc* basis in consultation with the NASA co-director.

In response to 115 applications received, offer letters were sent to 29 faculty, and 26 accepted. In addition, 2 students were admitted to the program to accompany their professors, for a total of 28 participants in the program.

Participants are encouraged to devote their best efforts to their research. Attendance at ancillary activities offered by the program to promote a group identity and facilitate professional interaction is always optional. While less emphasis is placed on this activity, considerable care is taken to insure that the quality of the activity is a strong motivator for attendance. This approach has proven successful over many years.

The primary ancillary activity offered at GRC is a weekly lecture series organized by the university co-directors. The lecture series features invited speakers, usually from outside organizations, on a variety of carefully selected subjects. All students who are at GRC concurrently in a variety of programs are also invited to the lecture series, and an opportunity is provided before each lecture for the faculty and students to interact informally and to socialize. The lectures offered in 2003 are listed in Appendix A.

In addition to the lecture series, the participants and their families were invited to a reception at the GRC Conference Center in the second week of the program to meet with other program participants and with the center officials, a mid-program picnic at the GRC recreation area, and a closing banquet. On the first day of the program,

participants attended a kickoff orientation at which they were provided with a variety of printed material describing amenities of the Cleveland metropolitan area for their private pursuits. The program began officially with the orientation meeting on June 2, 2003 and concluded on August 8, 2003. However, the actual dates of participation of some faculty deviated from these.

RESEARCH SUMMARIES

While several objectives are served with this program, the central mechanism involved is the conduct of research assignments by faculty in direct support of NASA programs. In general, the results of the research will be assimilated by NASA program managers into an overall effort and will ultimately find their way into the literature. Occasionally, specific assignments result directly in reports for publication or conference presentation. Taken as a body, the assignments represent a large intellectual contribution by the academic community to NASA programs. It is appropriate therefore to summarize the research that was accomplished.

The remainder of this report consists of research summaries arranged alphabetically by participant name. For each summary, the faculty fellow is briefly identified and the assignment prepared by the GRC host organization is given. This is followed by a brief narrative, prepared by the fellow, of the research performed. Narratives provided by the accompanying students immediately follow the narratives of their professors.

SPECIAL ACKNOWLEDGEMENT

The participants in the NASA Faculty Fellowship Program sincerely express their recognition of service of Dr. Francis J. Montegani who retired as Chief, Office of University Programs at NASA Glenn Research Center, and Dr. Joseph Prahl of Case Western Reserve University, former Co-Director of the Program. We wish them well in their future endeavors.

Name: **Rupak Banerjee**
Education: Ph.D., Mechanical Engineering
Drexel University

Permanent Position: Assistant Professor, Mechanical Engineering
University of Cincinnati

Host Organization: Microgravity Science Division
Colleague: 6712/John Sankovic

Assignment:

Modeling of Biological Fluid Systems

In support of NASA's Office of Biological and Physical Research the applicant will conduct research to improve space flight crew health, safety, and performance and to increase reliability and efficiency. The applicant has a thorough understanding of the use of numerical tools to model biological cardiovascular systems. His recent research in the development of a pulsatile flow model of coronary arterial flow is of direct interest to astronaut health. He has extended the numerical model to include stenosed vessels, repesented in an axisymmetric fashion. NASA GRC is currently collaborating with the Cleveland Clinic to understand the effects of pulsatility on stenosed vessels. Current efforts have included the development of an experimental flow model and initial experimental measurements of the flow field. It is believed that coupling the experimental results with continued work by Professor Banerjee to develop a numerical simulation, will lead to synergistic results toward the understanding of diseased coronary flow.

Research Summary Submitted by Fellow:

Fluid Flow Validation in a Realistic Reconstructed Domain

This study presents a detailed methodology for modeling and validating three-dimensional fluid flow in realistic reconstructed vasculature geometry. Optical scanned data from a sectioned stenotic lumen having ~65% area constriction within an arterial vessel of 9 mm diameter is processed and converted into a finite-element mesh. Mass and momentum transfer equations within the reconstructed stenotic vessel with a flow rate of 200 ml/min is solved using the Galarkin Finite Element formulation. The calculated velocities at several axial locations along the length of the vessel are compared with the Particle Image Velocimetry (PIV) measurements. The computation results are in agreement with the initial steady state PIV measurements. In addition, initial results from pulsatile flow computations at different time points of a pulse cycle will be presented.

METHODOLGY

The conservation of mass within the vessel is expressed by the continuity relation:

$\nabla . u = 0$, where u is the fluid velocity. The momentum equation is expressed by the Navier-Stokes equation: $\rho u_j \dfrac{\partial u_i}{\partial x_j} = \dfrac{\partial \sigma_{ij}}{\partial x_j} + \rho f_i$, where $i, j =$ 1,2,3 for three dimensional flows, $\dfrac{\partial \sigma_{ij}}{\partial x_j}$ is the stress tensor, and f_i is the body force per unit mass. The present study considered isotropic fluid properties at 37C. The density of the fluid $\rho = 1690$ kg/m^3 and $\mu = 0.005408$ N-s/m^2. The inlet flow is 200 ml/min. The equations governing fluid flow were solved using the Galerkin finite element (FE) method (Fidap, 2002). The partial differential equations and boundary conditions were transformed to a system of algebraic equations that were solved to yield velocity, pressure, and temperature:

$M \dot{V} + K(U,T)V = F(U,T)$, where $K(U)$ is the global system matrix developed from the conservation of flow and energy, M is the mass matrix, and F is the forcing function (including the body forces e.g. sources, sinks etc.).

RESULTS

Optical scanned data from a sectioned stenotic lumen (Figure 1) having ~65% area constriction within an arterial vessel of 9 mm diameter is processed and converted into a finite-element mesh. The reconstructed image and mesh is shown in Figure 2. The calculated velocities at several axial locations, shown in Figure 3, along the length of the vessel are compared with the Particle Image Velocimetry (PIV) measurements. The computation results are in agreement with the initial steady state PIV measurements.
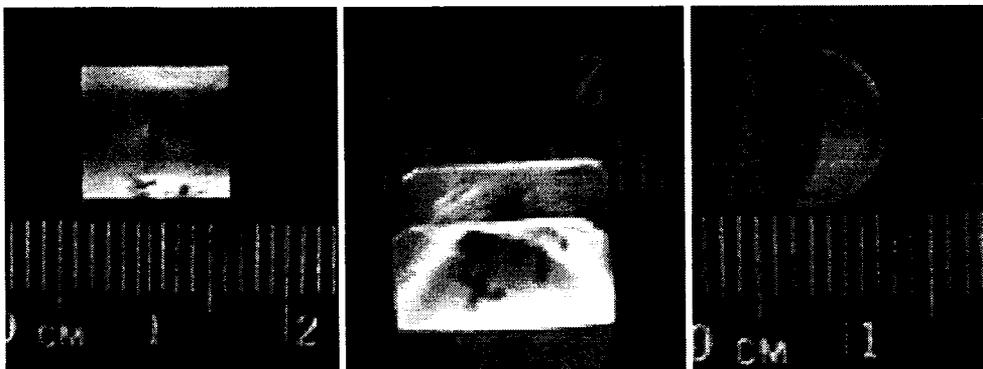
Figure 1: Three views of stenotic lumen
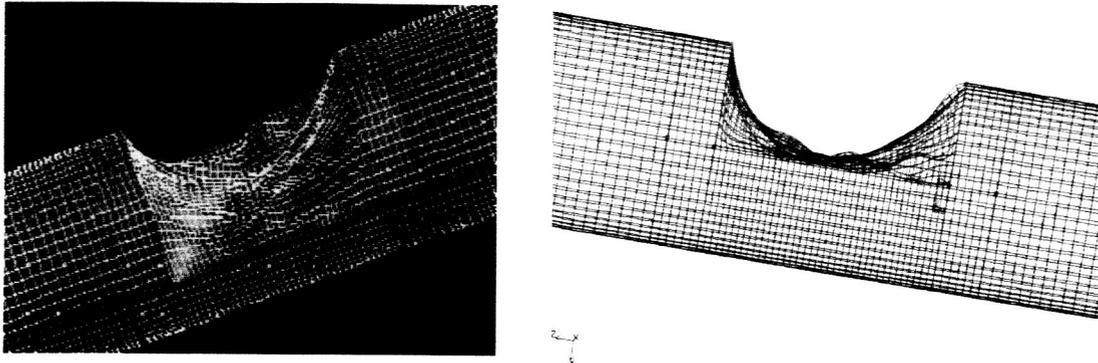
Figure 2: Reconstructed image and mesh
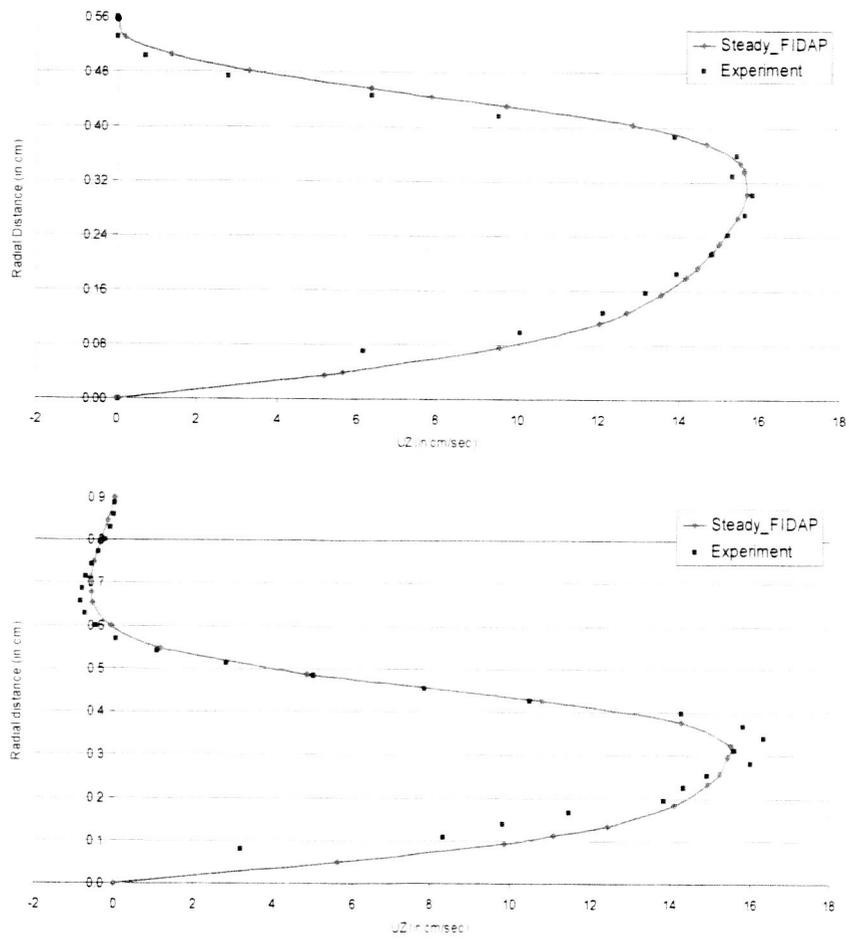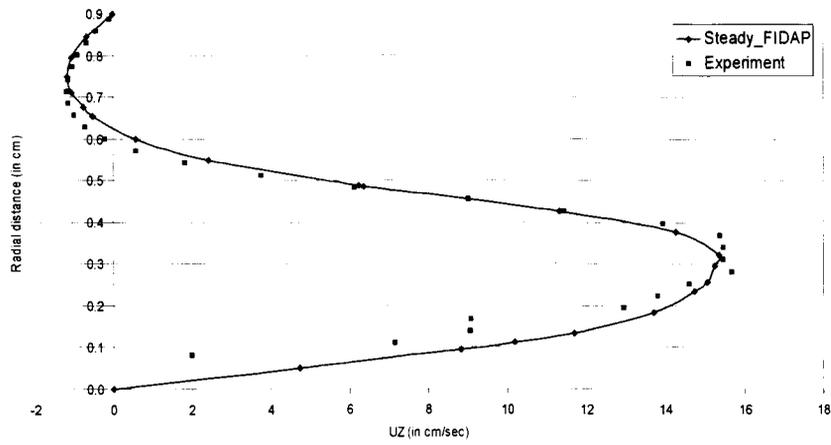
Figure 3: The calculated velocities at several axial locations (top: 0.057 cm before trailing edge; middle: 0.576 cm from trailing edge; bottom: 0.5202 cm from trailing edge) along the length of the vessel are compared with the Particle Image Velocimetry (PIV) measurements.

Name: **Joseph J. Christie**
Education: Ph.D., Organic Chemistry
University of Southern Mississippi

Permanent Position: Visiting Assistant Professor, Chemistry
Muskingum College

Host Organization: Materials Division
Colleague: 5150/Michael A. Meador

Assignment:

Synthesis of Charge Transfer Dyes for Use as Molecular Sensors in Biological Systems

This is a continuation of last year's project to synthesize tetraaryl substituted benzodifurans for use as molecular probes in biological systems. The project will involve the synthesis and chemical characterization of dyes and precursor molecules.

Research Summary Submitted by Fellow:

New Synthetic Approaches to Benzodifuran CT Dyes

The non-photochemical synthetic approach to obtain consistently good yields of CT dyes or benzodifuran dyes involved the two important changes below to the currently employed method:

1. The Friedel-Crafts diaroylation (or dibezoylation in the simplest case) of 1.3-dimethoxybenzene is a time-consuming procedure and yields of the product are inconsistent and often poor. This step is eliminated in the modified approach.
2. The bis-O-benzylation of the diaroylated resorcinol under PTC conditions to obtain the precursor to the photochemical reaction is again fraught with limitations and uncertainties resulting in low to moderate yields.

To circumvent these problems, the proposed synthetic involves the preparation of:
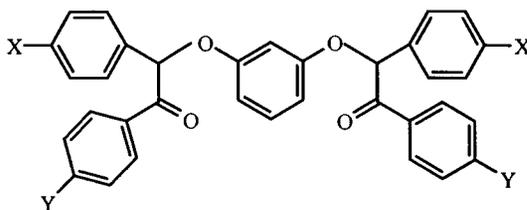
Where X = H, -OCH₃, Br, CN etc. and Y = H, -OCH₃, Br, CN etc

as the key intermediate in a convergent strategy. It is a dibenzylated resorcinol in which the appendages on the two phenolic oxygens are functionalized as to contain a benzyl moiety on to which the pendant aroyl groups are appropriately substituted. Acid- promoted dicyclization (using methanesulfonic acid or triflic acid as catalysts) of this compound, presumably, will give the target molecule, namely, the benzodifuran dye. Two convergent approaches to the above compound were followed.

Approach I:

A. Bis-O-alkylation of resorcinol with an α-haloketone of the type PhCOCHXAr, in which the aromatic rings Ph and Ar are appropriately substituted. (X = Cl, Br, OTs).
B. The simplest case is desyl bromide the bromoderivative of benzoin, $C_6H_5COCHBrC_6H_5$.
C. The product can, presumably, be dicyclized as described as shown below.

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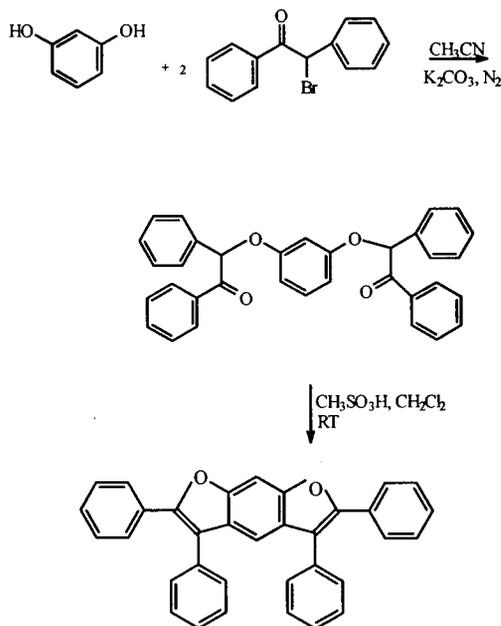
Approach II:

A. Bis-O-benzylation of resorcinol using K_2CO_3 as base in refluxing acetonitrile or DMF under nitrogen (or Argon) by a Williamson-type reaction.

B. The bis-benzylayed aryl ether is di-brominated (NBS in carbon tetrachloride in presence of peroxide and UV light).

C. The dibromo ether is then treated with an appropriate lithio-dithiane at -73°C after which the product is deprotected to unmask the two keto groups.

D. Final step involves mild di-cyclization using methanesulfonic acid in methylene chloride at room temperature to obtain the benzodifurans.

The essence of the two approaches is the Reaction, namely, bis-O-benzylation of resorcinol using K_2CO_3 as the base in boiling aprotic solvents such as acetonitrile or DMF under nitrogen (or Argon). The electrophilc substrate is:

or
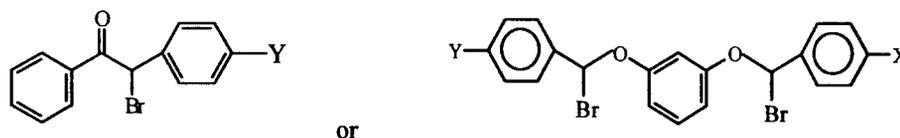
where x and y are H, Br, CN, -OCH₃, CH₃ , etc.

Conclusions:

1. During summer 2003, Approach I was studied with desyl bromide and chloride as substrates. The PTC reaction conditions have to be optimized using desyl bromide in order to improve the yields of the key intermediate. In future work, the pure compound has to be prepared and the final cyclization step carried out before the methodology can be extended to more complicated molecules.

2. Regarding Approach II, while synthesis of bis-benzylated resorcinols, gave good yields; NBS bromination to obtain the dibromo derivative gave low yields. Perhaps, changing the solvent from CCl₄ to benzene or other such alterations to standard procedures might resolve the problems.

Name: **Stephen Ekwaro-Osire**
Education: Ph.D., Mechanical Engineering
                     Texas Technical University

Permanent Position: Assistant Professor, Mechanical Engineering
                     Texas Technical University, Lubbock

Host Organization: Structures and Acoustics Division
Colleague: 5920/Noel N. Nemeth

Assignment:

Development of Testing Methodologies for the Mechanical Properties of MEMS

This effort is to investigate and design testing strategies to determine the mechanical properties of MicroElectroMechanical Sytems (MEMS) as well as investigate the development of a MEMS Probabilistic Design Methodology (PDM). One item of potential interest is the design of a test for the Weibull size effect in pressure membranes. The Weibull size effect is a consequence of a stochastic strength response predicted from the Weibull distribution. Confirming that MEMS strength is controlled by the Weibull distribution will enable the development of a probabilistic design methodology for MEMS - similar to the GRC developed CARES/Life program for bulk ceramics. However, the primary area of investigation will most likely be analysis and modeling of material interfaces for strength as well as developing a strategy to handle stress singularities at sharp corners, filets, and material interfaces. This will be a continuation of the previous years work. The ultimate objective of this effort is to further develop and verify the ability of the Ceramics Analysis and Reliability Evaluation of Structures Life (CARES/Life) code to predict the time-dependent reliability of MEMS structures subjected to multiple transient loads.

Research Summary Submitted by Fellow:

Weibull Failure Criterion for Components with Stress Singularity

Introduction
This summer, the topic of research was "Weibull Failure Criterion for Components with Stress Singularity" and was conducted with researchers at the Life Prediction Branch (Structures & Acoustics Division). The main accomplishments were a journal paper written and a grant proposal submitted to a federal funding agency.

Journal Paper
A paper entitled "Weibull Failure Criterion for Interface Stress Singularity" will be submitted to the Journal of Engineering Materials and Technology. Next is a brief summary of the paper.

There are many applications in engineering where two dissimilar materials are adhesively bonded resulting in a bimaterial interface. Initiation and growth of cracks often occur at bonded bimaterial interface corners and at the sharp notches that may result from the manufacturing process. In these situations, the initiation and growth of cracks is often attributed to stress singularities. Engineering applications, for which the initiation and growth of cracks occur in the vicinity of the bonded material interface or at sharp notches include: thin-film coatings; microelectromechanical systems (MEMS) structures; laminated microelectronics packaging; ceramic thermal barrier coatings for metallic substrates; and composite patch repairs to damaged aircraft skins. An analytical method that is often used to characterize interfacial stresses is the asymptotic solution approach [1].

There are several engineering applications with brittle materials, where singularities do occur. In such applications if a probabilistic analysis is desired the Weibull theory may be used [2]. It has been observed though, that in the presence of singularity the conventional Weibull theory tends to overestimate the failure probability, particularly for higher Weibull moduli [3]. This has been attributed to the fact that, in the vicinity of the singularity point, the critical flaw size is underestimated by conventional Weibull theory. Thus, there is a need to develop a more useable approach anchored in the Weibull theory to address singularity issues since there is a whole class of engineering problems needing to be addressed. The motivation of this paper is to review practical approaches to predict the probability failure of such situations using the Weibull failure theory.

The objective of this paper is to review the theoretical basis concerning the Weibull failure theory in order to address singularity in MEMS materials interfaces. The study will comprehend the review of the current literature and present analyses to show the suitability of such approaches in addressing the application of Weibull failure criterion (for brittle materials) to situations where a stress singularity occurs. Results on a notched strip and a bimaterial strip under far-field stresses are presented.

Grant Proposal
A proposal entitled "Weibull Failure Criterion for MEMS Component with Stress Singularity" was submitted to the National Science Foundation. This proposal is concerned with the probabilistic analysis and design of MEMS, specifically with the application of the Weibull failure criterion to components with stress singularities or high stress gradients. The proposed research addresses a critical

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aspect of MEMS reliability. This is an important issue since MEMS are finding extensive use in the critical areas where reliability is paramount: the medical field and homeland security. MEMS materials have been shown to behave in a brittle manner and to exhibit the size effect – thus the choice of the Weibull theory, which is based on the size effect of brittle materials. Additionally, the etching process and the nature of MEMS materials often result in sharp notches in the manufactured components. Furthermore, many MEMS components consist of multi-layers. Both the sharp notches and material interfaces create stress singularities – thus the singularity problem. Separately, each of these Mechanics problems has been researched extensively, but sparse work has been conducted on the combined problem of Weibull theory and singularity. In fact, it has been noted that applying the traditional Weibull theory in situations of high stress gradients can lead to erroneous probabilities of failure. Thus, the motivation of the proposed research is the need for a useable approach anchored in the Weibull theory to address singularity that occurs in a whole class of engineering problems. To complement the proposed analytical work, testing of the MEMS materials will be conducted on a novel testing apparatus. Thus the objective of the proposed work is twofold; namely, develop a robust Weibull failure criterion for brittle MEMS components with stress singularities and to perform experimental testing to verify the theory, using a novel testing apparatus.

References
[1]Akisanya, A. R. and Meng, C. S., 2003, "Initiation of Fracture at the Interface Corner of Bi-Material Joints," J. Mech. Phys. Solids, 51(1), pp. 27-46.
[2]Nemeth, N. N., Powers, L. M., Janosik, L. A., and Gyekenyesi, J. P., 2003, "CARES/LIFE Ceramics and Reliability Evaluation of Structures Life Prediction Program," NASA/TM-2003-106316, NASA Glenn Research Center, Cleveland.
[3]Brückner-Foit, A., Hülsmeier, P., Sckuhr, M., and Riesch-Oppermann, H., 2000, "Limitations of the Weibull Theory in Stress Fields with Pronounced Stress Gradients," Proc. ASME TURBO EXPO, ASME, Munich, pp. 1-5.

Name: **Malik E. Elbuluk**
Education: Ph.D., Electrical Engineering
Massachusetts Institute of Technology

Permanent Position: Professor, Electrical Engineering
The University of Akron

Host Organization: Power & On-Board Propulsion Technology Division
Colleague: 5480/Richard Patterson

Assignment:

Development of Low Temperature Electronic Circuits

Professor Elbuluk will develop circuits for operation at extremely low temperatures down to -230°C. As a part of his work, he will evaluate (at low temperatures) devices to be used in the circuits.

Research Summary Submitted by Fellow:

A Stepper Motor Control Electronics for Ultra-Low Temperature Environments

At present, most manufacturers specify –40°C as the lowest temperature for operation of their commercial-off-the-shelf electronic components. Even the military-grade devices are rated for operation down to only –55°C. These low temperature boundaries are due to limitations in the materials being used in the manufacture of the devices or due to the inherent design and processes techniques. Many missions, such as James Webb Space Telescope (JWST), require electronics that will operate below today's specification limits. In addition to surviving the hostile environment, low temperature electronics are expected to result in more efficient systems than those at room temperatures. This improvement results from superior electronic, electrical, and thermal properties of materials at low temperatures. In particular, the performance of certain semiconductor devices improves with decreasing temperature down to liquid nitrogen temperature (-196°C). At low temperatures, majority carrier devices demonstrate reduced leakage current and reduced latch-up susceptibility. In addition, these devices show higher speed resulting from increased carrier mobility and saturation velocity. An example is the power MOSFET that has lower conduction losses at low temperature due to the reduction in the drain-to-source resistance $R_{DS (on)}$ resulting from increased carrier mobility. Such devices, which are typically used for switching or control, must certainly be considered in the design of a motor drive system for use in deep space `missions.

The operational environment for some of the electronics planned for use in the JWST mission requires devices and components capable of surviving and

working efficiently under cryogenic temperature conditions. This particularly applies to stepper and other motors and their associated control and logic drives. These motors, which are designed to drive filter wheels and provide steering and alignment for other camera assemblies, are expected to encounter temperatures as low as 30 K. In addition, some of the electronics will be required to operate near infrared where thermal noise need to be avoided or kept to a minimum. In order to meet these challenges, the electronics should be able to operate reliably at cryogenic temperatures, simplified circuit configurations with minimum device count in the cold region need to be implemented, and interface wiring between the cold and hot temperature regions of the electrical system must be kept to a minimum.

The work included investigations of motor controllers geared for the cryogenic environment of the JWST mission. The initial circuitry was drawn up keeping in mind that the four phases of the motor must be controlled and timed, and that the motor to be driven had to be electrically selected. Most uni-polar motor drives are low-side drives, that is, the switching transistors that drive each of the four phases of the motor are located between the motor winding and ground. For a low-side control, the emitter of each npn bipolar switching transistor (or the source of each n-channel FET) is held at ground. High-side switching, on the other hand, requires the placement of the switching element between the positive side of the power supply and the motor winding. As a result, the emitter of a high-side npn switching transistor (or the source of an n-channel FET) can change voltage, and this can make control of the switch more complicated.

Candidate commercial off-the-shelf motor controllers, that would be located (in major part) on the hot side of the sun shield near room temperature, were identified and acquired for evaluation. The four-phase switching transistors, which are driven by the outputs of the controller, and some logic devices, could be located on cold side of the sun shield (if necessary). Studies were performed in this work to address current state-of-the-art technology with regard to electronic components and circuit topologies that might contribute to meeting these requirements. An extensive search was performed on commercially available and recently developed devices and controller boards. A vast array of semiconductor transistors was evaluated, and a database on the effect of temperature on their switching characteristics was generated. Limited testing of logic devices was also performed at cryogenic temperatures. A simple but typical control circuit was constructed and evaluated at low temperature under power cycling. The preliminary results of this activity indicate that while some types of the transistors functioned properly under the extreme temperatures, others did not fare as well. CMOS-based logic gates and other integrated circuits looked promising for their good behavior at cryogenic temperatures. More comprehensive testing, however, is needed to fully characterize these devices and circuits under long-term electrical bias and thermal cycling so that reliability and efficiency can be established.

The performance of the controllers was examined by driving the motor with the controller phasing switches (warm silicon MOSFETs on the low-side of the motor) and by using ultra-cold high-side switches to represent ultra-cold motor selection switches. The prime area of interest was on the ultra-cold motor selection switches. In the early phase of the work, two different types of transistors were utilized as the ultra-cold switching elements. These comprised of a germanium-type (Ge) npn transistor and a heterostructure bipolar silicon-germanium (HBT SiGe) transistor. Phase controller boards were constructed with a motor control integrated circuit, some passive components, and the silicon MOSFET phase-control switches. The motor selection switching transistors were mounted on separate boards so that they could be evaluated under cryogenic temperatures. Due to complexity of the Simple Step controller, which was a triple axis controller and required programming and special connector fixtures, it was excluded from this preliminary evaluation. The two other controllers were evaluated in combination with the motor-select transistors (which were held at room temperature (20°C) and also at liquid nitrogen (-196°C) temperature).
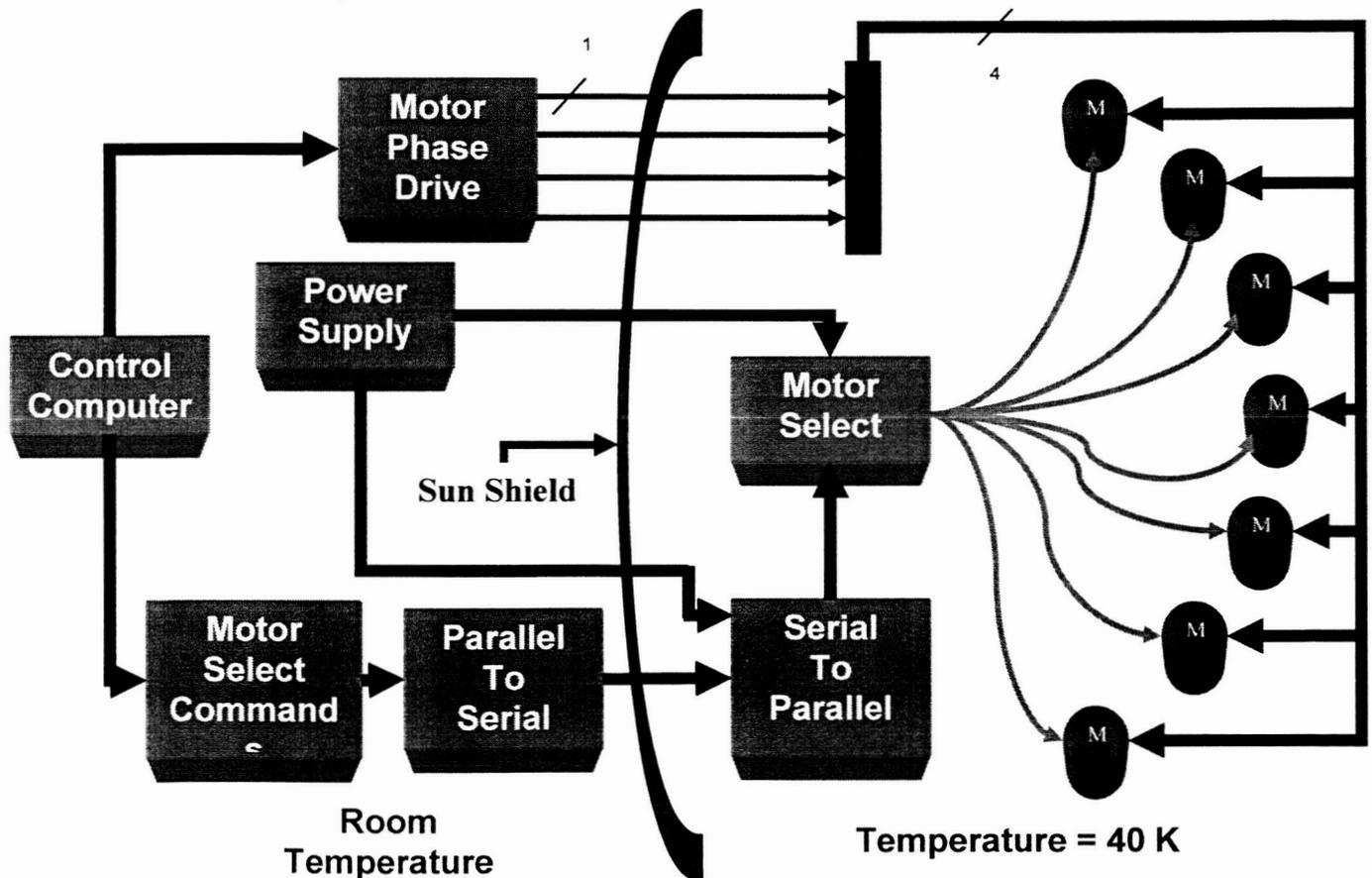
Figure 1 Top Level Diagram of a Multi-Motor Control

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Name: **Maryam Eslamloo-Grami**
Education: Ph.D., Materials Science and Engineering
University of California, Davis

Permanent Position: Professor, Composite Materials Engineering
Winona State University

Host Organization: Materials Division
Colleague: 5130/Narottam P. Bansal

Assignment:

Development of Ceramic Systems for High Temperature Coatings

Professor Eslamloo-Grami will synthesize ceramic powders of various compositions based on pyrochlore, perovskite, and magnetoplumbite structures by doping with various oxides. Sol-gel and combustion synthesis routes will be used for powder syntheses. The powders will be characterized for particle size, surface area, microstructure, sintering etc. Thermal conductivity of the hot pressed specimens will also be measured at various temperatures. At the end, a project report will be prepared describing in details the experimental methods, results, discussion, and future research.

Research Summary Submitted by Fellow:

Synthesis and Characterization of Multi-Component Ceramic Compounds

Samarium zirconate of composition $Sm_2Zr_2O_7$ is found to be a promising high temperature ceramic because of its very low thermal conductivity and good thermal shock resistance. The thermal properties of this material are expected to improve by addition of doping elements that reduce thermal conductivity and change the thermal expansion coefficient. Reduction of thermal expansion mismatch can be achieved by fabrication of graded materials. This study is focused on the citrate based sol-gel synthesis, processing, and characterization of $Sm_2Zr_2O_7$ and its Gd, Yb, and Er doped compounds. The compounds are:
$Sm_2Zr_2O_7$, $Sm_{1.7}Gd_{0.3}Zr_2O_7$, $Sm_{1.7}Yb_{0.3}Zr_2O_7$, $Sm_{1.7}Er_{0.3}Zr_2O_7$,
$Sm_{1.7}Gd_{0.15}Yb_{0.15}Zr_2O_7$, $Sm_{1.7}Gd_{0.15}Er_{0.15}Zr_2O_7$, $Sm_{1.7}Er_{0.15}Yb_{0.15}Zr_2O_7$,
and $Sm_{1.7}Er_{0.1}Gd_{0.1}Yb_{0.1}Zr_2O_7$

The study was also included the citrate based sol-gel synthesis and characterization of the magnetoplumbite structure of the Sm, Gd, La, Mg, and Al compounds and their doped structures with Er and Yb. The compounds are:
$LaMgAl_{11}O_{19}$, $SmMgAl_{11}O_{19}$, $GdMgAl_{11}O_{19}$, $Gd_{0.7}Yb_{0.3}MgAl_{11}O_{19}$,
$Gd_{0.7}Er_{0.3}MgAl_{11}O_{19}$, and $Gd_{0.7}Er_{0.15}Yb_{0.15}MgAl_{11}O_{19}$

Experiments and Results:

Samarium Zirconate System:

For preparation of Samarium zirconates stoichiometric amounts of Sm, Er, Gd, and Yb nitrates, and zirconium oxide dinitrate $ZrO(NO_3)_2$ were dissolved in water. Citric acid ($HOC(CH_2COOH)_2COOH$) of about 1.2 to 3 mole per mole of metals in the nitrate solution, was separately dissolved in water. The nitrate solutions were gradually added to the boiling citric acid solution. Depending on the composition of the nitrate mixtures a clear yellowish or pink color solution resulted. The resulting solutions were heated in a 110°C oven for about 48 hours to evaporate water and form condensed clear orange color gels. The gels turned to yellowish foams by further heating in the oven.

The resulting concentrated yellowish foams were slowly heated (1°C/minute) to 350°C and held for 5-8 hours to remove volatile organic compounds. The resulting brown porous materials were amorphous zirconates and some charred organic material. The foams were grinded into powder for further calcination at higher temperature. Depending on the quantity of the gel prepared, 5-8 hours of additional heat treatment of the crushed powder at 800°C was required to burn off carbon residue. The resulting white or light pink colored powders were partially crystalline zirconates. Additional heat-treatments at 1000, 1200, 1400, 1600°C, for two hours converted the powder to the corresponding crystalline zirconate and some minor phases of related oxides.

For preparation of dense specimens, 10 grams of the 800°C partially amorphous calcined powder were unidirectionally hot-pressed in 25.4 mm diameter dies at 1600°C and 4 KSI pressure for 4 hours in vacuum to produce translucent pink or beige colored disks of 2-3 mm thickness. The samples were heated for 8 hours at 800°C for burning the carbon layer deposited from the graphite die on the samples.

The composition and structural analysis of zirconate samples produced by sol-gel method were performed by X-ray diffraction method.

The effect of heat treatment on the chemical composition and crystallinity of the reaction products were also evaluated by the X-ray diffraction method. It was noticed that the sol-gel derived oxides with and without dopant were amorphous after being calcined at 350°C for burning the extra organic compound. They turned to partially crystalline oxides after heat treatment at 800°C. The percent crystallinity and composition of the phases changed with heat treatment temperature, resulted pure crystalline oxides at 1600°.

Scanning electron micrograph of the samples loose powder heat-treated at 800 and 1600°C, revealed very porous structures. At higher magnification of 20,000 times the highly crystalline structure indicate the grain growth for the sample heated at 1600°C with an average grain size of about 0.7 μm. The 800°C heated

treated specimen had a very smooth surface even at 20,000 magnification, which is an indication of amorphous structure and/or very fine grain size. The average grain size for the sample measured from the X-ray peak width results 60 nm.

Effect of heat treatment was also evaluated by thermal analysis methods of combined differential scanning calorimetry and thermogravimetry (DSC/TGA). The DSC/TGA graph was obtained for $Sm_{1.7}Yb_{0.3}Zr_2O_7$ sample heated at the rate of 10°C/min to 1000°C in air. The TGA curve reveals three weight losses during heating process, a minor weight loss at around 160°C, a major one around 225°C, and another at 350°C. The corresponding DSC curve illustrates two endothermic peaks around 160°C and 225°C, and a major exothermic peak at 350°C. The two endothermic peaks are related to evaporation of water and volatile organic compounds. The exothermic peak is for combustion of extra citric acid and other possible organic compounds.

BET surface analysis of the $Sm_2Zr_2O_7$ sol-gel derived samples calcined at 800°C, showed that the surface area for the powder is about 4.62 m^2/gr.

Magnetoplumbite System:
For citrate base sol-gel preparation of $MMg\ Al_{11}O_{19}$, where M = Gd, La, and Sm; and $Gd_{0.7}X_{0.3}MgAl_{11}O_{19}$, where X = Er, Yb or 0.15 mole of each, stoichiometric amounts of Er, Gd, La, and Yb nitrates, and zirconium oxide dinitrate $(ZrO(NO_3)_2$ were dissolved in water. Citric acid $(HOC(CH_2COOH)_2COOH)$ of about 1.2 mole per mole of metal ions in the nitrate solution, was separately dissolved in water. The nitrate solutions were gradually added to the heated citric acid solution. Depending on the composition of the nitrate mixtures a clear yellowish or pink color solution resulted. The resulting solutions were heated in a 115°C oven for about 48 hours to evaporate water and form condense clear orange color gels. The gels turned to yellowish foams by further heating in the oven.

Similar to the samarium system, the resulting concentrated yellowish foams were heated and converted to their corresponding solid compounds. Additional heat-treatments at 1000, 1200, 1400, 1600°C, for two hours converted the powder to the corresponding crystalline structures.

For preparation of dense specimens, 10 grams of the 1000°C partially amorphous calcined powder were unidirectionally hot-pressed in 25.0 mm diameter dies at 1600°C and 4 KSI pressure for 4 hours in vacuum to produce disks of about 4.5 mm thickness.

The as synthesized reaction products and the heat-treated samples had been characterized by X-ray diffraction, scanning electron microscope, and thermal analysis methods. It was noticed that the reaction products for the undoped compounds had the magnetoplumbite structures of $MMgAl_{11}O_{19}$. However, the doped compounds contained some extra oxides of the corresponding elements. Further investigation is needed to conclude this work.

Name: **Frederick Ferguson**
Education: Ph.D., Aerospace Engineering
                       University of Maryland

Permanent Position: Associate Professor, Mechanical Engineering
                       North Carolina A&T State University

Host Organization: Research and Technology Directorate
Colleague: 5000/Isaiah M. Blankson

Assignment:

The objective of this work is to establish the feasibility and demonstrability of kinetic energy bypass from the inlet air stream of a jet engine, using weak ionization of the inlet stream by an external means. MHD interaction with the ionized gas then leads to energy bypass. The engine consists of an existing commercial or military jet engine preceded by an MHD power generator. The jet engine may be a turbojet (Allison J-102) or a ramjet, individually, or in various combined configurations. The resulting engine is a revolutionary power plant capable of Mach 7.

(i)   Setting up of a model and calculation scheme on a parametric basis for the interaction between a weakly ionized air stream and an applied magnetic field, when the ionization is undertaken with different means (e.g. High – energy microwaves, ion beam, etc.). Modeling of MHD interaction will be based on a GRC MHD code.

(ii)   Considering MHD conversion of kinetic energy, outline a design for the scheme, and the resulting engine thrust-to-weight ratio and thermodynamic efficiency, using electrical conductivity, magnet mass, and power factor as some of the parameters. Extend the analysis to a ramjet and also a turboramjet.

(iii)   Determine and outline an experimental (supersonic wind-tunnel) method of conducting a test on a jet engine for demonstrating and assessing the performance of a MHD energy bypass system incorporated into the jet engine flowpath.

The expected deliverables are the models, cycles, requirements and associated codes, and a report outlining the test set-up for a turbojet engine in a designated supersonic wind tunnel.

Research Summary Submitted by Fellow:

A Mach 7.0 Global Range Hypersonic Vehicle Employing an MHD/Turbojet Bypass Engine

Introduction

NASA is interested in innovative vehicle concepts that utilize novel technologies that mitigate heat load and extend range. Such innovative concepts could enable effective global reach missions and potentially provide the first stage of a two-stage access to space vehicle. However, current limitations in hypersonic technologies, suggest that a much nearer term prompt, global strike capability must first be developed. This near-term operational capability is embodied in the CAV munitions delivery system integrated with a low-cost, operationally responsive, Small Launch Vehicle (SLV). CAV is an unpowered, maneuverable, hypersonic glide vehicle capable of carrying approximately 1,000 pounds in munitions or other payload. SLV, a low-cost, responsive launch system is capable of boosting a CAV to its requisite insertion conditions (e.g. geo-location, altitude, velocity, and attitude). Taken together, the CAV/SLV system will enable this nearer-term global reach capability. The SLV will serve a two-fold function in that it will also provide a low-cost, responsive launch capability for placing small satellites into Sun Synchronous Orbit.

The Mach 7.0 Global Range hypersonic vehicle concept propose herein will satisfy the major goals set fort the joint DARPA/Air Force FALCON program. In addition, this proposal will lead to the development and validation of in-flight technologies that will enable both near-term and far-term capability to execute time-critical, prompt global strike missions. Moreover, this proposal is consistent with the fundamental underpinnings of the technical approach adopted by the FALCON program. It is based on a common set of technologies which can be matured in an evolutionary manner, and which will provide the near-term operational capability for the prompt global strike missions while enabling future development of a reusable HCV in the long-term. The common set of key technologies of interest to this program includes: efficient aerodynamic shaping for high lift to drag, lightweight and durable high temperature materials, thermal management techniques including active cooling and trajectory shaping, target update and weapons separation.

1.2: Research Scope

For any conflicts in the year 2025 and beyond, no matter what model one uses to postulate and describe the world, the US will most likely have one or more of the following roles:

1. Deliver decisive blows at the outset of hostilities, with the goal of destroying the adversary's desire to fight a protracted war.
2. Deliver cost-effective weapons to defeat time-critical targets and to establish in-theater dominance, if a protracted war cannot be avoided.
3. Maintain flexible, readily accomplished access to space.

It is within this context that a hypersonic vehicle model with a Magneto-Aerodynamic bypass turbojet combined cycle jet engine is proposed. The concept is based on an 'educated guess of the Russian Ajax' hypersonic vehicle concept illustrated in Figure 1. However, a major innovation to this concept is the fact that the hypersonic vehicle will be powered by an existing Allison J-102 Turbojet engine with a Magneto-Aerodynamic generator as its forebody. The proposed modification is shown in Figure 2.

Representation of AJAX Vehicle as Appeared In Szames December 2001 Article in Air Et Cosmos
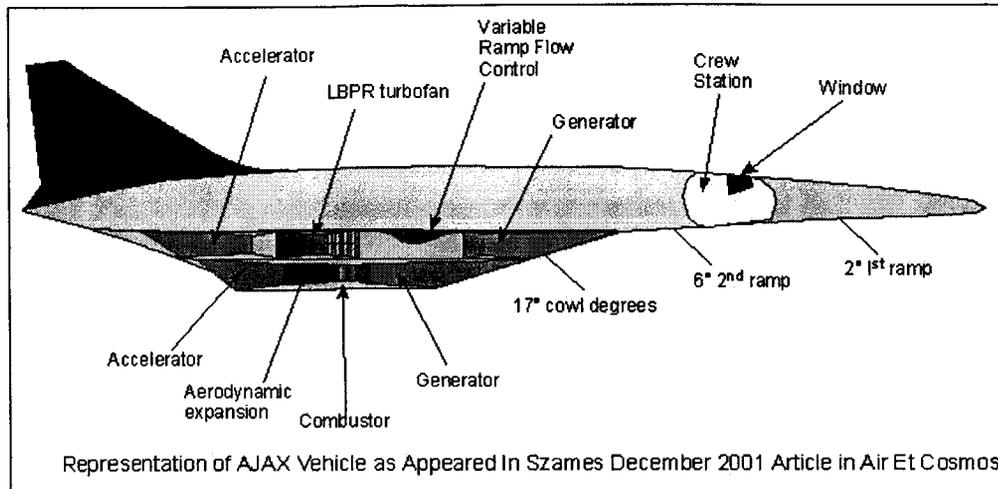
Figure 1: Illustration of the Ajax Hypersonic Vehicle concept.

The proposed vehicle may be used as a deterrent weapons platform, to be used at the onset of hostilities to stop the war before it begins. This technology has the potential to develop hypersonic weapons platform,

i.   which can deliver lethal blows quickly and without a large support infrastructure,

ii.   which is survivable with both the vehicle and the crew returning safely to their base in continental United States, and

iii.   which can provide routine, sustained access to space for a variety of scenarios.
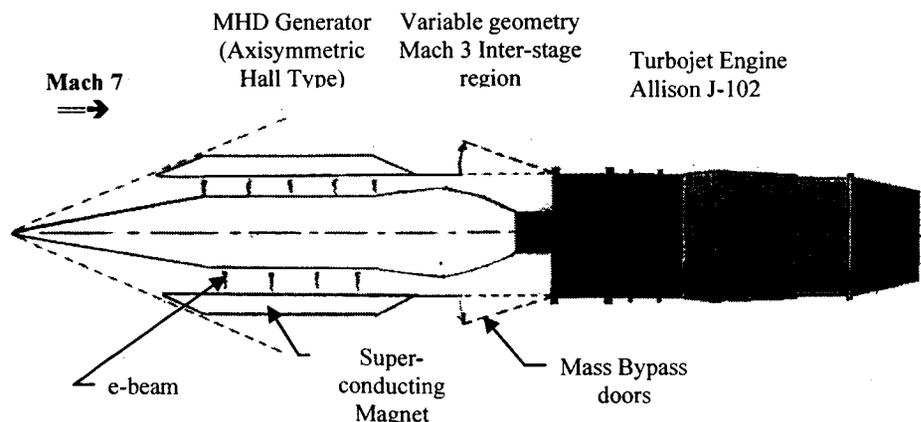
Figure 2: Schematic of MHD bypass inlet to a turbojet engine.

Name: **Michel J. Ghosn**
Education: Ph.D., Civil Engineering
Case Western Reserve University

Permanent Position: Professor, Civil Engineering
City College of New York

Host Organization: Structures and Acoustics Division
Colleague: 5920/Shantaram Pai

Assignment:

Impact of Defect Distributions on the Reliability of Structural Materials

Professor Ghosn will help quantify the reliability debit associated with non-metallic inclusions in powder metallurgy alloys. This work will build on the experimental and modeling efforts in progress in the Life Prediction Branch at NASA GRC.

Research Summary Submitted by Fellow:

**Statistical Analysis and Probabilistic Fatigue Life Estimation of
Seeded Udimet 720 Superalloy Specimens**

The purpose of this study is to develop a probabilistic model to estimate the fatigue life of gas turbine disks made of powder superalloy metals. Such metals are known to have high strength and ductility under extremely high temperatures and known to have high fatigue lives. However, despite the high quality controls instituted during metal processing, sufficiently high numbers of ceramic inclusions materialize within the metal matrix creating weak links that lead to reduced fatigue lives. To study the effect of such ceramic inclusions on the fatigue life of gas turbine disks, an experimental program has been initiated at the NASA Glenn Research. In this phase of the study, a statistical analysis of the test results is undertaken which served as the basis of the probabilistic simulation model. The study is a part of the Crack Resistant Disk Materials task within the Ultra Safe Propulsion Project.

To increase the chances of encountering inclusions within the fatigue test specimens, batches of powder metals had been intentionally seeded with alumina. The specimens were then tested at various fatigue stress ranges and maximum stress amplitudes. The tests were interrupted at various stages of loading and the initiation and propagation of surface cracks was monitored. The test results indicated the following:

- The number of inclusions that intercepted the surface of the specimens can be modeled by a Poisson distribution as a function of the density of inclusions in the metal powder.

- Most surface inclusions initiated cracks that appeared very early in the loading process.
- The number of cracks that were activated during cyclic loading is related to the maximum stress amplitude.
- The relationship between crack growth rate and effective stress intensity factor can be reasonably well represented by an equation of the form:

$$\frac{dc}{dN} = 3.253x10^{-9} \Delta K_{eff}^{2.834}$$

- The analysis of the residuals shows a decrease in the errors between the measured crack growth rates and those estimated using the above equation. Thus, the residuals are providing a quantitative assessment of the large uncertainties observed in the short crack regime as compared to the long crack regime of the fatigue life of powder alloy specimens.

A Monte Carlo simulation is subsequently developed based on the results of the statistical analysis of the experimental results. The simulation provides a histogram of the number of cycles to failure for seeded powder alloy specimens subjected to constant amplitude fatigue cycling.

The results of the simulation show that the model is capable of capturing the overall trend in the fatigue lives of seeded specimens. However, improvements can still be made. In fact, from the limited number of available test data, it appears that the simulation gives a higher average number of cycles to failure for specimens tests at a maximum stress value =159 ksi and a lower average number of cycles to failure for specimens tests at a maximum stress value equal to 109 ksi. These discrepancies may be due to a number of factors, including the accuracy of the linear regression fit and the accuracy of the count of arrested cracks. In fact, the regression analysis performed during the statistical analysis of the test data shows that the Paris law, which assumes a linear relationship on the log-log scale between the crack growth rate and the effective stress intensity factor ΔK_{eff}, may not be very accurate. By looking at the plot, it is presumed that a nonlinear fit would probably provide a better representation of the relationship between the crack growth rate and the stress intensity factor. Future work should develop variations on the Paris Law which would be more appropriate for the particular material being analyzed in this study.

Acknowledgements

members for providing a very rewarding and stimulating research experience and for the warm friendship extended during his stay at NASA Glenn. Thanks also go to Dr. Shantaram Pai for extending the invitation to join the NASA Faculty Fellowship program and providing the financial support.

Name: **Rama S. R. Gorla**
Education: Ph.D., Mechanical Engineering
Hannover University, Germany

Permanent Position: Associate Professor, Manufacturing Engineering
Central State University

Host Organization: Structures and Acoustics Division
Colleague: 5920/Shantaram Pai

Assignment:

Probabilistic Unsteady Aerodynamic Analysis

Professor Rama Gorla will work on the MSU Turbo code and analyze the unsteady aerodynamic characteristics of ERCOFTAC turbine stage. Converged solutions will be obtained for meanline aero-thermodynamic conditions. Independent random variables for the aerodynamic conditions will be identified and converged unsteady solutions will be obtained for perturbations (plus or minus 5 percent) in the random variables. Proper data reduction will be accomplished for the unsteady pressure and temperature fields in the turbine. Comparisons with experimental data may be accomplished to validate the computational predictions.

Research Summary Submitted by Fellow:

Probabilistic Analysis of a Gas Turbine System

Probabilistic CFD design is needed because we are asked to do more with less. To cost effectively accomplish the design task, we need to formally quantify the effect of uncertainties (variables) in the design. Probabilistic design is one effective method to formally quantify the effect of uncertainties. Our objective is to establish a revolutionary new early design process, by developing non-deterministic physics-based probabilistic design tools, which will include all the life cycle processes.

This work was concerned with the usefulness of parametric optimization method coupled with a Navier-Stokes analysis code for the aero-thermodynamic design of turbomachinery combustor liner. The interconnection between the CFD code and NESSUS codes will facilitate the coupling between the thermal profiles and structural design. We have developed new concepts for reducing the computational cost of unsteady, three-dimensional, compressible aerodynamic analyses for multistage turbomachinery flows. The flow was modeled by the three-dimensional Favre-Reynolds-averaged Navier-Stokes equations using the k-ε turbulence closure, which was integrated using an implicit third-order upwind solver. The methodology developed in this work is expected to lead to the design optimization of turbomachinery blades.

Figure 1 shows a comparison of the unsteady aerodynamic computations for pressure coefficient using MSU Turbo code.

Fraction of chord Vs Static Pressure Coefficient
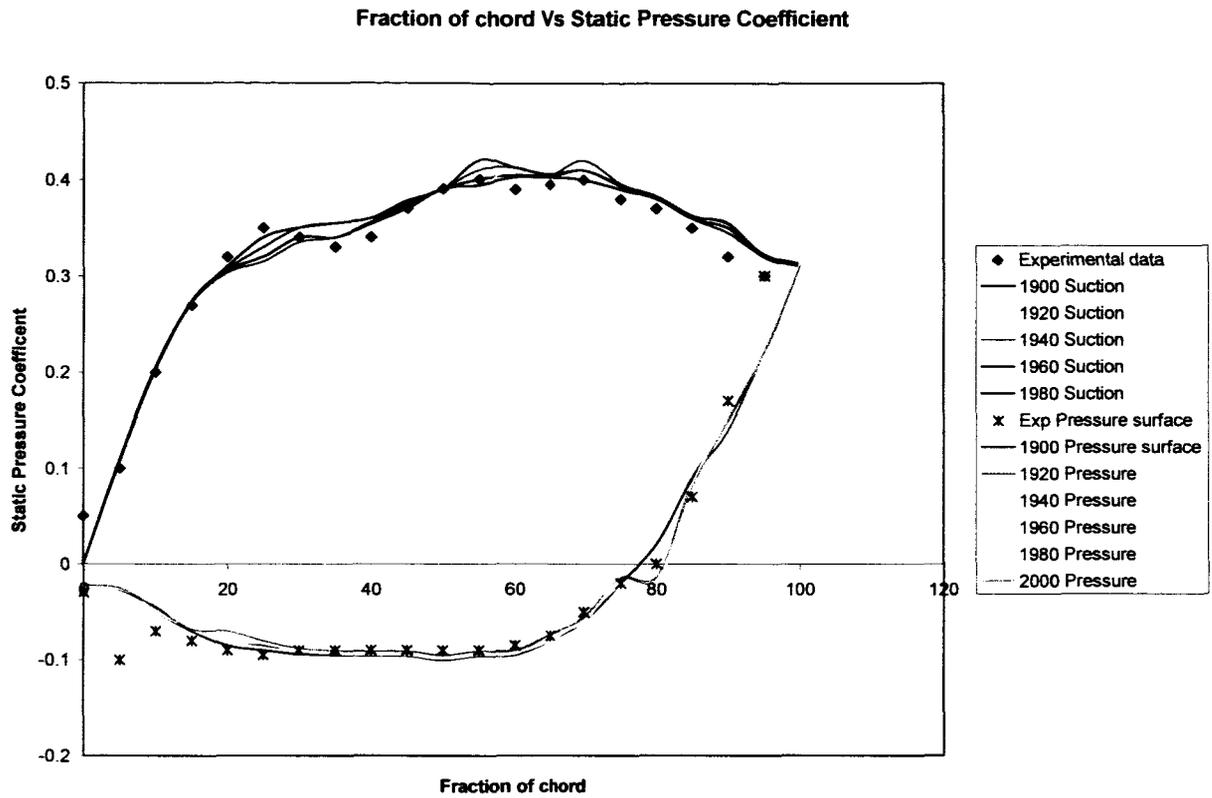
Figure 1. Pressure Coefficient Versus Chord Length

Name: **Marilyn Brown**
Status: Ph.D. Student
Institution: Cleveland State University

Accompanying Student under the direction of Professor Rama S-R. Gorla.

Research Summary Submitted by Student:

Unsteady Probabilistic Analysis of a Gas Turbine System

In this work, we have considered an annular cascade configuration subjected to unsteady inflow conditions. The unsteady response calculation has been implemented into the time marching CFD code, MSUTURBO. The computed steady state results for the pressure distribution demonstrated good agreement with experimental data. We have computed results for the amplitudes of the unsteady pressure over the blade surfaces.

With the increase in gas turbine engine structural complexity and performance over the past 50 years, structural engineers have created an array of safety nets to ensure against component failures in turbine engines. In order to reduce what is now considered to be excessive conservatism and yet maintain the same adequate margins of safety, there is a pressing need to explore methods of incorporating probabilistic design procedures into engine development. Probabilistic methods combine and prioritize the statistical distributions of each design variable, generate an interactive distribution and offer the designer a quantified relationship between robustness, endurance and performance. The designer can therefore iterate between weight reduction, life increase, engine size reduction, speed increase etc.

Figure 1 shows typical unsteady pressure profiles in the turbine system analyzed.

Suction Surface
0 % Chord Length Total Pressure
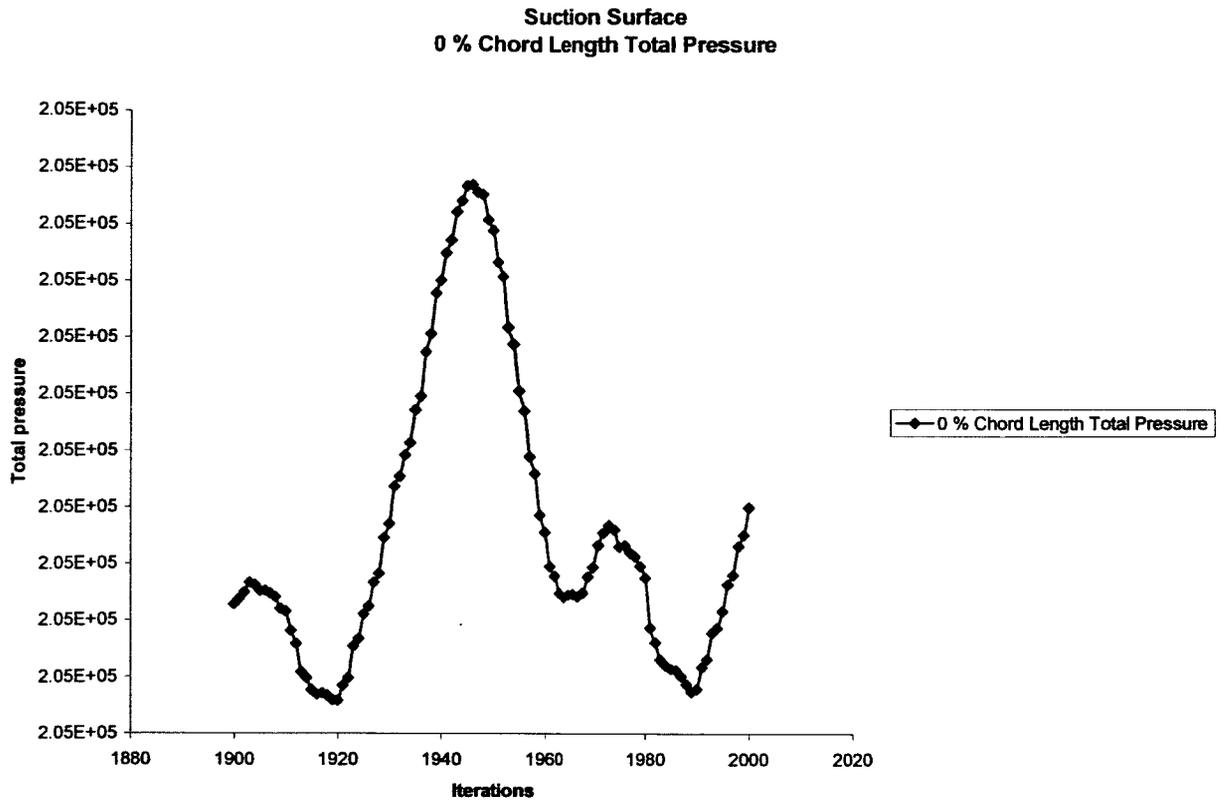
Figure 1. Unsteady Pressure Distribution

Name:	**Heath Hofmann**
Education:	Ph.D., Electrical Engineering
	University of California, Berkeley

Permanent Position:	Assistant Professor, Electrical Engineering
	Pennsylvania State University

Host Organization:	Power and On-Board Propulsion Technology Division
Colleague:	5450/Barbara Kenny

Assignment:

Investigation of Combined Motor/Magnetic Bearings for Flywheel Energy Storage Systems

There are two thrusts of activities for Professor Hofmann this summer, both related to improving future motor designs for flywheel energy storage systems. The first is related to the losses of a high speed PM machine of the type presently used in the flywheel system. Professor Hofmann will develop a tutorial type presentation to be given to interested Branch personnel regarding the sources of losses in the machine and possible design techniques to minimize these losses. Due to the difficulty of removing heat from the rotor during operation, the rotor losses are of particular interest.

The second thrust of Professor Hofmann's work will be in the area of a combined motor/magnetic bearing. Professor Hofmann will review existing literature and develop a summary of present approaches to the problem with brief descriptions of each. The literature survey should focus on permanent magnet machine types predominately although other promising machine types could be considered. Professor Hofmann will present pro's and con's of the different approaches and make recommendations for future NASA efforts based on consultations with NASA personnel and the literature review.

Research Summary Submitted by Fellow:

Dr. Hofmann's work in the summer of 2003 consisted of two separate projects. In the first part of the summer, Dr. Hofmann prepared and collected information regarding rotor losses in synchronous machines; in particular, machines with low rotor losses operating in vacuum and supported by magnetic bearings, such as the motor/generator for flywheel energy storage systems. This work culminated in a presentation at NASA Glenn Research Center on this topic. In the second part, Dr. Hofmann investigated an approach to flywheel energy storage where the phases of the flywheel motor/generator are connected in parallel with the phases of an induction machine driving a mechanical actuator. With this approach, additional power electronics for driving the flywheel unit are not required. Simulations of the connection of a flywheel energy storage system to a

model of an electromechanical actuator testbed at NASA Glenn were performed that validated the proposed approach. A proof-of-concept experiment using the D1 flywheel unit at NASA Glenn and a Sundstrand induction machine connected to a dynamometer was successfully conducted.

Name: **Osama Jadaan**
Education: Ph.D., Engineering Mechanics
                    Pennsylvania State University

Permanent Position: Professor, General Engineering
                    University of Wisconsin, Plattville

Host Organization: Structures and Acoustics Division
Colleague: 5920/Noel N. Nemeth

Assignment:

Development of Probabilistic Life Prediction Methodologies and Testing Strategies for MEMS and CMC's

This effort is to investigate probabilistic life prediction methodologies for ceramic matrix composites and MicroElectroMechanical Sytems (MEMS) and to analyze designs that determine stochastic properties of MEMS. For CMC's this includes a brief literature survey regarding lifing methodologies. Also of interest for MEMS is the design of a proper test for the Weibull size effect in thin film (bulge test) specimens. The Weibull size effect is a consequence of a stochastic strength response predicted from the Weibull distribution. Confirming that MEMS strength is controlled by the Weibull distribution will enable the development of a probabilistic design methodology for MEMS - similar to the GRC developed CARES/Life program for bulk ceramics. A main objective of this effort is to further develop and verify the ability of the Ceramics Analysis and Reliability Evaluation of Structures/Life (CARES/Life) code to predict the time-dependent reliability of MEMS structures subjected to multiple transient loads. A second set of objectives is to determine the applicability/suitability of the CARES/Life methodology for CMC analysis, what changes would be needed to the methodology and software, and if feasible, run a demonstration problem. Also important is an evaluation of CARES/Life coupled to the ANSYS Probabilistic Design System (PDS) and the potential of coupling transient reliability analysis to the ANSYS PDS.

Research Summary Submitted by Fellow:

My efforts during this summer at NASA Glenn focused on predicting the reliability of SiC MEMS notched specimens and pressure membranes, a literature review on theoretical strategy for predicting probabilistically the rupture life of ceramic matrix composites (CMC), and finite element analysis and reliability evaluation of specimens with stress singularity.

Two papers on MEMS were written and are in the process of being submitted for publication. The abstracts for these two papers follow below.

Probabilistic Failure Prediction and Size Effect in SiC MEMS

For bulk ceramics, the term Weibull effect means that significant scatter in fracture strength exists, hence requiring probabilistic rather than deterministic treatment. Also it means that a size effect exists where the strength decreases with increasing size, and vice versa. Since many MEMS devices are fabricated from ceramic materials, then it would be very beneficial to determine if the Weibull theory extrapolates down to the microstructure scale. Therefore, the objective of this paper is to examine whether the Weibull probabilistic theory can predict the strength behavior of different specimen configurations at the MEMS scale by investigating whether a Weibull size effect exists for these different coupon specimens. Three tensile specimens, straight, curved, and notched were specifically designed to display a Weibull size effect. Straight, curved, and notched specimens were then fabricated from poly SiC wafers and fracture tested. Finite Element Analysis (FEA) and the NASA CARES/life integrated probabilistic design code were used to perform the reliability analyses for the curved and notched specimens. Unfortunately, useful strength data were only obtained for the straight and curved specimens. Results for the straight and curved specimen configurations indicated that a size effect existed and that the Weibull theory was successful in predicting their probabilistic strength behavior.

Design of Experiment for Effective Size and Fracture Strength Analysis of Brittle MEMS Pressure Membranes

Review of brittle MEMS literature shows that a probabilistic Weibull effect exists at the structural microscale. Since many MEMS devices are fabricated from brittle materials, the question becomes whether these miniature structures behave similar to bulk ceramics. For bulk ceramics, the term Weibull effect is used to indicate that significant scatter in fracture strength exists, hence requiring probabilistic rather than deterministic treatment. Also it means that the material's strength behavior can be described in terms of the Weakest Link Theory (WLT) leading to strength dependence on the component's size (average strength decreases as size increases), and geometry/loading configuration (stress distribution). Hence, the objective of this paper is to design and analyze various microscale pressure membrane test geometries with maximum effective size and strength difference among them. This is done in order to examine the Weibull size effect at the MEMS scale. This study is conducted as a prelude to fabricating pressure films (by NASA) appropriate for testing the Weibull size effect hypothesis in MEMS devices. The analysis will also be used to determine the pressure capacity needed for a pressure rig required to cause membrane rupture. The NASA CARES/Life probabilistic code in combination with nonlinear finite element analysis was used to calculate the effective areas and volumes for a variety of pressurized films as a function of Weibull modulus. Four pressure membrane geometries were considered: circular, square, rectangular, and butterfly (notched square).

In addition, I coauthored a third paper titled "Weibull Failure Criterion for Interface Stress Singularity," with Professor Stephen Ekwaro-Osire (who is also a summer faculty at NASA Glenn this year) and Noel Nemeth.

A 27 page report summarizing the state of probabilistic strength and life prediction for CMC's was prepared and submitted to Noel Nemeth and other NASA personnel. The report included a study on whether size effect exists in composites, as well as a reliability analysis of turbine vane.

Name: **Baha Jassemnejad**
Education: Ph.D., Solid State Physics
                 Oklahoma State University

Permanent Position: Professor, Physics & Engineering
                      University of Central Oklahoma

Host Organization: Instrumentation and Control Division
Colleague: 5520/Arthur J. Decker

Assignment:

Photonic Interrogation and Control of Nano Processes

Professor Jassemnejad will continue investigating approaches for using optical-tweezers-controlled micro tools to detect and measure nano processes. This work will continue research begun in 2002.

Research Summary Submitted by Fellow:

Nanostructures and Angular Momentum of Light

My research activities for the summer of 2003 consisted of two projects: One project was concerned with determining a method for predicting the static and dynamic assembly properties of nano-structures using laser tweezers. The other project was to investigate the generation of Laguerre-Gaussian modes using a spatial light modulator incorporated into an optical tweezers system.

Concerning the first project, I initially pursued the approach suggested by my NASA colleague Dr. Art Decker. This approach involved mimicking the model of the structure of atomic nucleus for the assembly of 1 to 100 atoms using allowed quadruple transitions induced by orbital angular momentums of a Laguerre-Gaussian (Doughnut) laser mode. After realizing the inaptness of the nuclear model with the nanostructure model as far as the binding forces and transitions were concerned, I focused on using quantum dot model. This model was not attuned also for the host lattice influences the electronic structure of the quantum dot. Thus one other option that I decided to pursue was the approach of molecular quantum mechanics. In this approach the nanostructure is treated as a large (10-100 nm) molecule constructed from single element or multi-elements. Subsequent to consultation with Dr. Fred Morales, a chemical engineer at NASA GRC, and Dr. David Ball, a computational chemist at Cleveland State University, I acquired a molecular-quantum computation software, Hyperchem 7.0. This software allows simulation of different molecular structures as far as their static and dynamic behaviors are concerned. The time that I spent on this project was about eight weeks. Once this suitable approach was identified, I realized the need to collaborate with a computational quantum chemist to pursue searching

for stable nanostructures in the range of 10-100 nm that we can be assembled using laser tweezers.

The second project was about generating laser tweezers that possess orbital angular momentum. As shown in the figure below, we were able to generate laser tweezers modes of different orbital angular momentum using a spatial light modulator incorporated into a laser tweezers system. The motivation for investigating these types of modes stems from being able to spin particles at high speeds and also to orient two particles in separate traps and then join them together. Also, there has been recent intense interest on fundamental physics research on orbital angular momentum of light.[1]

The fact that circularly polarized light may have associated with it angular momentum that relates to the spin of individual photons (spin 0 for the plane polarized light, spin +1 for the right-circularly polarized light and spin −1 for the left-circularly polarized light) was first demonstrated by Beth in 1936.[2] Orbital angular momentum is, however, distinct from spin in that the spin angular momentum of light is intrinsically linked to the behavior of the electric field in the light whereas orbital angular momentum is a consequence of inclined wavefronts. In 1992 L. Allen, et al showed that the Laguerre-Gaussian (LG) modes could possess well-defined orbital angular momentum that can exceed $1\hbar$, i.e. $\ell\hbar$ per photon, where ℓ is the azimuthal index of the mode.[3]

Figure: From left to right the "doughnut "modes corresponding to P=0, L=5; P=0, L=15; and P=1, L=5.

References:

[1] Kishan Dholakia, Gabriel Spadling and Michale Maconald, "Optical tweezers: the next generation" Physics World October 2002 pp 31-35.
[2] R.A. Beth, Phys.Rev. 50, 115 (1936).
[3] L. Allen, M.W. Beijersbergen, R.J. C. Spreeuw and J. P. Woerdman, Phys Rev. A 45, 8158 (1992).

Name: **Michael J. Kaufman**
Education: Ph.D., Metallurgical Engineering
                  University of Illinois, Urbana

Permanent Position: Professor, Materials Science and Engineering
                      University of Florida

Host Organization: Materials Division
Colleague: 5120/Ronald D. Noebe

Assignment:

Development of High-Temperature Shape Memory Alloys

This project will involve research in the development, processing, and characterization of high-temperature shape memory alloys based on NiTiPt alloys. Research will focus on the effect of alloying additions and composition on the martensitic transformation temperature and structure of these alloys and will include development of a ternary Ni-Ti-Pt phase diagram. Also, alloying additions that can replace Pt without significantly lowering the Ms temperature will be investigated. Characterization of these alloys will include detailed analysis by optical, scanning electron, and transmission electron microscopy techniques. Another aspect of this work will focus on the development of processing maps for the determination of appropriate thermophysical processing parameters (temperature, rate, stress, etc.).

Research Summary Submitted by Fellow:

Ti-Ni-Pt-X Shape Memory Alloys for Higher Temperature Applications: Current Status

Overview

Last summer, I was involved in the characterization of twenty-three ternary, quaternary and quinary alloys based on the Ti-Ni-Pt ternary system. These alloys are being investigated to determine their suitability as smart materials for high temperature applications such as automatic actuators, valves, etc. given that they have higher transformation temperatures than all of the other Nitinol-based shape memory alloys studied to date. This summer, I continued to investigate the alloys in this system and many interesting results along with several unexpected complications were discovered. Working closely with Dr. Ron Noebe, Ms. Tiffany Biles and Dr. Anita Garg, who helped in all aspects of this study, along with the oversight of Dr. Mike Nathal, we analyzed a series of binary, ternary and quaternary alloys in order to gain a better understanding of their microstructure-property-processing relationships. The major accomplishments are described in the following.

Major Accomplishments

1. A series of $Ti_{50}Ni_{50-x}Pt_x$ alloys with x ranging from 0 to 50 were analyzed by DSC. The starting materials were disks cut from arc melted buttons that had been given a two-step homogenization treatment at 1050°C, 24h followed by 1200°C, 24h, furnace cooled. The martensite and austenite start, peak and finish temperatures are plotted in Figure 1 where it can be seen that small additions (up to 10%) cause these temperatures to actually drop slightly whereas the larger additions exhibit a linear slope of transformation temperature vs. Pt content. The slope of this response is approximately 25°C per atom percent Pt. This data is useful for selecting particular temperatures where actuation is desired. It should be mentioned that there were some unexpected and unexplained features. For example, the alloy containing 5% Pt substituted for Ni exhibited a reproducible double peak on cooling. The source of this extra peak is uncertain at this time and further work is underway to resolve this apparent anomaly.

2. The second notable finding is that these alloys are very sensitive to interstitial concentrations due to the observation that the austenite (B2) and martensite (B19) phases which exhibit shape memory behavior have low solubilities for interstitials. Consequently, the alloys invariably have at least a small volume fraction of secondary and tertiary phases that contain the rejected interstitials. These include Ti_4Ni_2O, Ti(CN) and a previously unidentified oxide found in "binary" Ti-Pt alloys that contains both Ti and Pt in an approximate ratio of 2. The structure of this latter phase was identified using electron diffraction methods as tetragonal (a~1.26nm, c~0.66nm) with a 4/mmm point group. The space group remains undetermined at this time. Electron energy loss spectroscopy was used to prove that this phase contains oxygen as expected.

3. The third significant observation is that the published Ti-Pt phase diagram is incorrect. Specifically, we discovered at least two new phases with compositions between TiPt and Ti_3Pt where no phases are shown on the phase diagram. One of these was identified using electron diffraction as hexagonal with a $P6_3$/mcm space group (a~ 0.5 nm and c~ 0.8 nm) while the other appears to be either trigonal or hexagonal. Unfortunately, the point and space groups of this latter phase are difficult to determine due to the heavy faulting present in the microstructure as well as the very large unit cell (a~0.8 nm and c~2.36nm). If hexagonal, the unit cell volume is approximately 1.295 nm^3 compared with .027 nm^3 for the B2 TiPt compound. This suggests that the faulted phase contains somewhere around 96 atoms per unit cell.

4. Since there are additional phases present in this portion of the phase diagram, we made preliminary attempts to analyze an as-cast structure of an intermediate Ti-34Pt alloy. The solidification structure was complex and

the arrangement of the phases was used to speculate on the nature of the phase diagram, i.e., how the phases are related to one another. Attempts were also made to homogenize this material in order to determine what phases are stable at this temperature and composition. It was found that the homogenization kinetics are extremely sluggish, i.e., holding it for 114h at 1200°C caused some spheroidization but the structure still had not attained equilibrium. This indicates that the diffusivity of Pt in these alloys is extremely slow.

5.   A fourth new phase with a Ti:Pt ratio of ~4 was observed in the binary Ti-34Pt alloy. This phase is cubic (m3m point group) with a lattice constant of around 0.8nm. Based on the composition, morphology, location and volume fraction of this phase in the microstructure, it was speculated that it must be an interstitial compound. Unfortunately, our attempts to use electron energy loss spectroscopy to determine if interstitial elements are present have been unsuccessful to date.

The importance of these analyses lies in the observations that one or more of these secondary phases is present in essentially all of the binary, ternary and higher order alloys studied. Thus, as the property data base is developed, it will be important to understand the role of these minor phases. Unlike the Nitinol alloys that are used near room temperature, these alloys will experience considerably higher temperatures and, therefore, microstructural stability (particle coarsening, grain growth, etc.), creep behavior, oxidation behavior, impact resistance, etc. are important and may be influenced somewhat by these phases. If indeed this is the case, it is necessary to know their identities and the regimes in which they form given that some will probably be less desirable than others.
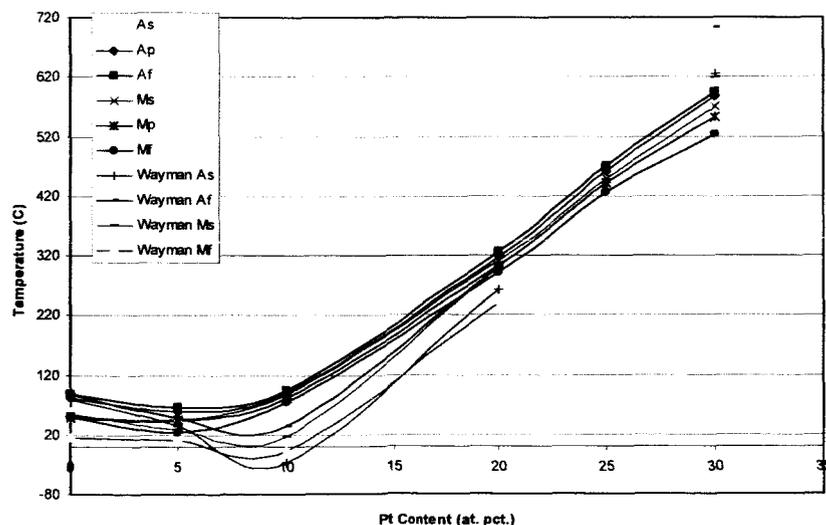

Figure 1. Transformation temperatures of current alloys along with those from the study by Lindquist and Wayman. A corresponds to the austenite phase, M to the martensite; the subscripts s, p and f correspond to the start, peak and finish temperatures, respectively.

Name:	**Walter M. Kocher**
Education:	Ph.D., Environmental Engineering
	Drexel University

Permanent Position:	Associate Professor, Civil and Environmental
	Engineering
	Cleveland State University

| Host Organization: | Office of Safety and Assurance Technologies |
| Colleague: | 0540/Daniel D. White |

Assignment:

Development of a Real-Time Environmental Monitoring System, Life Cycle Assessment Systems, and Pollution Prevention Programs

Pollution prevention (P2) opportunities and Greening the Government (GtG) activities, including the development of the Real-Time Environmental Monitoring System (RTEMS), are currently under development at the NASA Glenn Research Center. The RTEMS project entails the ongoing development of a monitoring system which includes sensors, instruments, computer hardware and software, plus a data telemetry system.

Professor Kocher has been directing the RTEMS project for more than 3 years, and the implementation of the prototype system at GRC will be a major portion of his summer effort. This prototype will provide mulitmedia environmental monitoring and control capabilities, although water quality and air emissions will be the immediate issues addressed this summer. Applications beyond those currently identified for environmental purposes will also be explored.

A wide range of P2/GtG opportunities are being investigated, including the implementation of a life-cycle analysis system for NASA GRC. Professor Kocher will also continue his ongoing development of two life cycles assessment models and applications, with a focus upon the Life Cycle Based Environmentally Preferred Products system. This developing program will establish policies and procedures for applying life cycle assessment principles to facility operation and practicing environmentally preferable purchasing strategies at GRC.

Professor Kocher will also work with students to complete the development of the prototype Garnet Recycling System for the Fabrication Shop. This system will provide for the reclamation and reuse of garnet abrasive with the water jet cutting equipment housed in Building 50.

Supervision of student activities may also becomea part of Professor Kocher's effort, as necessary, for the active P2/GtG projects mentioned above.

Research Summary Submitted by Fellow:

Professor Kocher has been directing four projects this summer related to Pollution Prevention and Greening the Government initiatives.

The creation and development of a Life Cycle Assessment (LCA) program at GRC was initiated last summer, and the project has progressed into testing and implementation phases. Professor Kocher developed LCA evaluation tools to be used by NASA researchers and project managers. He also authored a chapter for the GRC Environmental Programs Manual (EPM) that establishes policies and procedures for applying life cycle assessment principles to facility operations. He also made presentations to GRC personnel explaining this program, fielding questions and suggestions from participants to make the program more helpful to the people who will be conducting the assessments. These LCA tools must be customized for each type of application to produce tools that are not only useable, but also beneficial to project managers and engineers. The tools to be used for several uses of Ozone Depleting Substances, including refrigerants, are currently being developed. This project will continue into the academic year.

A related project involved the establishment of the Affirmative Procurement / Environmentally Preferred Products (AP/EPP) program. This required the adaptation of life cycle principles to perform life cycle assessments of many off-the-shelf products. Professor Kocher completed detailed life cycle evaluation matrices (spreadsheets) and detailed instructions for future product evaluators to prepare AP/EPP product lists. He also authored another EPM chapter that addressed the implementation of the AP/EPP program at GRC which will promote and facilitate the purchase of environmentally friendly and recycled products at GRC. He also presented the AP/EPP system at both GRC-only and NASA meetings. He has authored a proposal seeking funding to the test and implement this AP/EPP system at all NASA facilities, utilizing website user interfaces. This proposal would support the AP/EPP project for the next two years.

Another ongoing project is the design, construction and implementation of a prototype Real-Time Environmental Monitoring System (RTEMS) at the NASA Glenn Research Center. Professor Kocher has served as the project director for more than 3 years. The current RTEMS project entails the ongoing development of a monitoring system, which includes sensors, instruments, computer hardware and software, plus a data telemetry system. This RTEMS will provide proactive and response capability for environmental issues such as regulatory compliance, facilities operations, emergency response, and pollution prevention. The system applications are being expanded to include homeland security concerns, both interior and exterior of buildings and facilities. The first phase of this application will be incorporated into the GRC prototype, with additional objectives targeted

for the next year. Since there are two major proposals pending on RTMS applications, this project may be significantly expanded during the coming year.

Professor Kocher has also been directing the development, design, construction and implementation of a garnet abrasive recycling system. Based upon the results of a bench-scale study, the final prototype construction and implementation is currently underway. This unit is currently being installed for use at the Fabrication Shop at GRC. An operation and maintenance document will also be completed, based upon the ongoing testing of the unit. Discussions have been initiated to consider the construction and implementation of additional recycling units at other water-jet cutting knives within GRC.

Potential pollution prevention opportunities continue to be investigated by Professor Kocher, and two additional projects have been identified for possible future funding: 1) development of a reclamation and recycling system for modeling polyamide powder; 2) creation of a website-based artificial-intelligence system to conduct pollution prevention opportunity evaluations with linkages to the life cycle based AP/EPP system. These projects will be discussed by the GRC Pollution Prevention Team. Decisions regarding the pursuit of these projects and funding possibilities will be made by this team.

Name:	**Milivoje Kostic**
Education:	Ph.D., Mechanical Engineering
	University of Illinois, Chicago

Permanent Position:	Associate Professor, Mechanical Engineering
	Northern Illinois University

Host Organization:	Turbomachinery and Propulsion Systems Division
Colleague:	5830/Chi-Ming Lee

Assignment:

Professor Kostic will work on the current UEET program of the Aerosol and Particulate task.

This task will focus on:

1) how to acquire experimental data through Labview software
2) how to make the data acquisition system more efficient
3) trouble existing problem of the labview software
4) recommend a better system
5) improve existing system with better data and usually friendly

Research Summary Submitted by Fellow:

Particulate and Gaseous Emissions Measurement System (PAGEMS) Project

During my participation in the Summer 2003 NASA Faculty Fellowship Program at Glenn Research Center (GRC) in Cleveland, Ohio, I have been working on the Particulate and Gaseous Emissions Measurement System (PAGEMS) Project, leaded by Dr. Paul Penko of NASA. PAGEMS is a state-of-the-art NASA facility used to measure particulate and gaseous emissions from combustors and full-scale aircraft gas turbine engines. All PAGEMS equipment and instrumentation are located in a mobile van, which facilitates easy transition to different testing locations. PAGEMS has been used to measure particulate emissions from flame tubes and sector rigs at NASA GRC, full-scale gas turbine engines at Pratt & Whitney, and different jet exhaust emissions at NASA Langley Research Center. A dedicated computer controls the data acquisition and operation of PAGEMS. The operating software is written using LabVIEW application software. Extractive sampling of combustion gases from aircraft gas turbine combustors and engines is employed. Differential Mobility Analyzers (DMA) and Condensation Nuclei Counters (CNC) are used to characterize the emissions in terms of particulate total concentration, size distribution, hydration property, and volatility. A gas analysis suite measures HC, O_2, CO_2, CO, NO_x, and SO_2 levels in the sample gases. Data can be collected over a wide range of operating conditions,

pressures from sub atmospheric up to 60 *atm*, particulates in the size range 10 - 450 *nm* (nanometer), and gas species down to the *ppm* level.

The research objective of the PAGEMS project is to provide a comprehensive database of particulate and gaseous emissions from combustors and jet engine exhausts that are correlated to engine/combustor parameters. Clean burning aircrafts that do not harm human and the global environment is a major NASA research objective of this project.

I have been working on three different assignments related to the PAGEMS project:

I. Particle-Size Distribution Data Presentation:

Critical issues related to proper evaluation and presentation of aerosols' *particle property distribution*, as a function of a characteristic particle property itself is studied, relevant conclusions drawn and documented in a written report. Aerosol particle distributions often span over several orders of magnitudes, necessitating the particle distribution data presentation in a semi-logarithmic plot. Some researchers present their particle distribution data, not only in the semi-logarithmic coordinate system, but also define new, the so-called *logarithmic density distribution*. This 'artificial scaling' with value of independent coordinate of actual density distribution, will not only skew the distribution, but also shift the modal vales and thus further misrepresents the actual particle distribution, since the maximums of the two density distributions are not at the same modal values. It is concluded that it is often necessary and useful to graphically represent the particle true *density distribution* in semi-logarithmic coordinate system, but it is <u>meaningless and unnecessary</u> (does not serve any purpose) to evaluate the *logarithmic density distribution*, since it may introduce dimensional and scaling problems, and misrepresentation of actual or true *density distribution*, including shifting of the *modal* values, as demonstrated in the written report.

II. Error or Uncertainty Analysis of Measurement Results:

Uncertainty or error analysis of measurement results is not a deterministic (exact), but rather holistic and probabilistic in nature. Its complexity and ambiguity (not only what is measured, but what contributes to measurement errors and uncertainty, the latter being open ended), contributes that the uncertainty analysis is often misunderstood, misrepresented or even avoided. Objectives of this assignment were to resolve existing confusion, to embrace the very concept of measurement uncertainty, and to provide effective guidelines to account for the most contributing sources of errors (which is important and possible!), since accounting for all sources of measurement errors is not necessary (and also impossible). A written report includes initial uncertainty analysis of PAGEMS measurements using MS Excel functions. A related presentation was given on August 1, 2003, at Ohio Aerospace

Institute (OAI) as part of the NASA Faculty Fellowship Lecture Series, and also during a Combustion Branch meeting at NASA GRC.

III.   Enhancement of LabVIEW Data Acquisition Program for GRC PAGEMS Project:

Existing LabVIEW application software program for PAGEMS is modified and enhanced with the following Data Acquisition (DAQ) functions. In addition to one Analog Input (AI) signal measurements, the program is modified to include five (5) analog input measurements, for flow rate, humidity and temperature sensors, with an easy interface for adjustments of sensors' calibration parameters. More analog inputs channels, up to the capacity of the DAQ card (8 differential or 16 single-reference-ended) may be added when needed. One Analog Output (AO) is added to control actuator of the flow rate valve. Another AO has been used to control Differential Mobility Analyzer's (DMA) voltages. Since the existing DAQ card has only two AO channels, for more AO channels a new DAQ card will be needed. The LabVIEW program interface is enhanced with user-friendlier features, and all measured data are written to a file for future post-processing, including the date and time of measurements. It is recommended to further enhance the LabVIEW application program to include all necessary monitoring and recording of all measured parameters, as well as interactive processing and presentation of results in numerical and graphical form.

Name: **Christian Madubata**
Education: Ph.D., Electrical Engineering
Catholic University of America

Permanent Position: Assistant Professor, Electrical Engineering
Tuskegee University

Host Organization: Communications Technology Division
Colleague: 5610/Calvin T. Ramos

Assignment:

Hybrid Network Architectures for the Next Generation NAS

The current Communications, Navigation, and Surveillance (CNS) infrastructure for the National Airspace System (NAS) is an analog, voice-based architecture that is error-prone, inefficient, and not scalable to support complex air traffic management concepts of mobility, safety, and security and capacity. Additionally, the surveillance and communications coverage in remote and oceanic regions is incomplete and inadequate; while voice communications and data links are vulnerable to security intrusion and jamming. Furthermore, communications capacity growth is limited by a congested frequency spectrum. The current NAS infrastructure is composed of functionally separate and independent communications, navigation, and surveillance systems that do not allow for sharing of data, efficient use of spectrum resources, and world-wide navigation coverage.

To meet the needs of the 21st Century NAS, an integrated, network-centric infrastructure is essential that is characterized by secure, high bandwidth, digital communication systems that support precision navigation capable of reducing position errors for all aircraft to within a few meters. This system will also require precision surveillance systems capable of accurately locating all aircraft, and automatically detecting any deviations from an approved path within seconds and be able to deliver high resolution weather forecasts – critical to create 4-dimensional (space and time) profiles for up to 6 hours for all atmospheric conditions affecting aviation, including wake vortices. The 21st Century NAS will be characterized by highly accurate digital data bases depicting terrain, obstacle, and airport information no matter what visibility conditions exist.

This research task will be to perform a high-level requirements analysis of the applications, information and services required by the next generation National Airspace System. The investigation and analysis is expected to lead to the development and design of several national network-centric communications architectures that would be capable of supporting the Next Generation NAS.

Research Summary Submitted by Fellow:

Hybrid Network Architecture Requirements Analysis for the Next Generation NAS

"The current Communications, Navigation, and Surveillance infrastructure within the NAS is an analog, voice–based architecture that is error prone, inefficient, and not scalable to support complex air traffic management concepts of safety, mobility, and security". "Surveillance and communications coverage in remote and oceanic regions is incomplete and inadequate". Current voice and data communication links within the NAS are not secured and are vulnerable to security intrusion and jamming. The NAS infrastructure of today consists of separate and independent network systems that do not have the capability for information sharing to coordinate the communications, navigation and surveillance needs of the nation's air traffic system.

The thrust of my research effort this summer was to:

A. Review some of the ongoing research into the future NAS architecture by: BOEING, ITT Industries, RTCA Incorporated, ARINC, Science Applications International Corporation (SAIC), TRW, and Computer Networks & Software, Inc.

Analyze these in terms of: 1.   Technology gaps, 2. Approach, 3. Strength and weakness with respect to NAS requirements/FAA evolution plan for the NAS

Major Activities

I carried out a study of the following literature and analyzed their content based on the research objectives stated above:
1. National Airspace System Architecture, Version 4.0, Department of Transportation, Federal Aviation Administration, January 1999
2. National Airspace System (NAS) Concept of Operations and Vision for the Future of Aviation, RTCA, Incorporated, 2002
3. Future Aviation CNS Technologies presented to GRC, Computer Networks & Software, Inc., February 21, 2003
4. Advanced ATC CNS Concepts/ITT Experience and Capabilities, ITT Industries, July 8, 2003
5. Communications System Architecture Development for Air Traffic Management & Aviation Weather Information Dissemination Research Task Order 24 Subtask 4.6, Develop AATT 2015 Architecture (Task 5.0) Prepared By ARINC, Science Applications International Corporation (SAIC) & TRW Submitted to NASA Glenn Research Center under Contract NAS2-98002, May, 2000
6. BOEING Concept of Use for Global Communications, Navigation, and Surveillance System (GCNSS), Updated Draft, CDRL A016, Content Owner:

Systems Analysis & Requirements Team: Jim Mast, Richard Palace, Mike Mullens, Bob Ott, Doug Stoll, Mike Ryanczak, June, 2003.

Summary

The next generation National Airspace System (NAS) Architecture is envisioned as an integrated and automated network of several hybrid network architectures within the NAS that will be used for Communications, Navigation, and Surveillance (CNS) within the national airspace. The future NAS will provide the technology for a coordinated, collaborative, and efficient Air Traffic Management (ATM) operation within the NAS. The projected NAS is a system of systems that fosters collaboration and provides information on demand and in real time for users and service providers to be able to make informed decisions. This NAS architecture should include the technology for air to ground communication and vice versa. It should also incorporate systems for communicating weather situations to pilots, service providers and other users who need such information for planning and carrying out flight operations safely. The envisioned system of networks should provide capabilities for situational awareness to agencies that may need them for security purposes. This NAS of the future should be scalable and also include systems for safe and secure flight operations over oceanic domain and remote areas.

The BOEING GCNSS views the aircraft as a node within the future network-centric NAS architecture. Their concept is that of a Space-based CNS, in conjunction with existing ground-based systems that gives global reach to service providers for voice and data exchange, accurate navigation for users, and shared situational awareness of aircraft position through communicated dependent surveillance". The Common Information network (CIN) consists of the common transport network (CTN) which performs the network functions and the common information base (CIB) which provides global information storage and relationships for shared situational awareness. "CTN includes global, ubiquitous coverage; secure communications, open architecture, with common standards and technologies". It has controllable quality of service, dynamic bandwidth management, network mobility and is in compliance with the NAS requirements.

The research by Computer Networks & Software, Inc. is focused on the SWIM aspect of the NAS concept of operations. Their work identified the new concepts that resulted from the NAS CONOPS and the constraints to the NAS.

The ITT Industries' research towards the realization of the future NAS Architecture dealt with several issues surrounding the design, implementation, management and the cost of making the modernized NAS a reality. Their approach also recognized the SWIM concept and its envisioned network architecture or structure as the key network to realize the future NAS.

Name: **John H. Scofield**
Education: Ph.D., Physics and Astronomy
Cornell University

Permanent Position: Associate Professor, Physics and Astronomy
Oberlin College

Host Organization: Power and On-Board Propulsion Technology Division
Colleague: 5410/Aloysius F. Hepp

Assignment:

Thin-Film Photovoltaic Device Fabrication

This project will primarily involve the fabrication and characterization of thin films and devices for photovoltaic applications. The materials involved include II-VI materials such as zinc oxide, cadmium sulfide, and doped analogs. The equipment ot be used will be sputtering and physical evaporations. The types of characterization includes electrical, XRD, SEM and CV and related measurements to establish the efficiency of the devices. The faculty fellow will be involved in a research team composed of NASA and University researchers as well as students and other junior researchers.

Research Summary Submitted by Fellow:

Window-layers for thin-film copper-indium-disulfide solar cells

The goal of this project was to investigate the possibility of fabricating transparent, conducting window layers for thin film solar cells by using a multilayer zinc-oxide/aluminum-oxide structure fabricated by alternately sputtering from zinc and aluminum targets.

Background
Photovoltaic arrays are important for providing electrical power in space. The weight and size of such an array is of critical importance since these factors are directly related to the cost of putting them into space. Performance degradation due to exposure to high levels of ionizing radiation present in space is also an important consideration.

The thin-film photovoltaics group at NASA-Glenn is engaged in a project to develop thin film solar cells on flexible substrates. A low-temperature chemical vapor deposition process has been developed for depositing the p-type, copper-indium-disulfide ($CuInS_2$) absorber layer at low temperatures, in principle, making it possible to fabricate these cells on plastic sheets. Completion of these cells requires subsequent deposition of an n-type, transparent wide bandgap window layer on top of the absorber. My work has focused on fabrication and characterization of a zinc-oxide (ZnO) window layer for this purpose.

My work

The ZnO window layer is typically deposited using RF-sputtering from an alumina (Al_2O_3) doped ZnO target in partial pressures of argon (Ar) and oxygen (O_2) gases.[1] Two years ago we explored the possibility of reactively sputtering ZnO layers from a metallic Zn target using Ar and O_2 gases. Transparent, insulating ZnO films were readily obtained by reactive sputtering from a pure Zn target with an O_2/Ar gas mixture. Al doping of similar films was achieved by covering approximately 10% of the Zn target during the sputtering process with aluminum foil. This technique was used to fabricate 1-μm-thick films having a sheet resistance of 11 Ω/sq. and absorbance below 10% for wavelengths ranging from 500 to 1000 nm.

But the method had its limitations. For one thing it was not logistically easy to cover 10% of the Zn target with Al. Secondly, films deposited this way lacked spatial uniformity owing to the asymmetry associated with the distribution of Al foil around the Zn target. And finally, the thin Al foil degraded quickly leading to an ever-changing target and inconsistent results.

Hence we decided to sputter instead from two metal targets. The vacuum system contained two, Sloan S-guns, each with its own metal target. One gun was equipped with a pure Zn target and the other with a pure Al target. Since 2001 the deposition system had been equipped with a second power supply (allowing simultaneous use of the two sputter guns) and a computerized sample manipulator that allowed a substrate to be moved back and forth between the two sputter guns without breaking vacuum. The idea, then, was to spend most the time over the Zn target with only a small time over the Al target. Aluminum doping would be controlled by the time spent over the Al target.

Initial effort was spent characterizing deposition from single targets. Films were sputtered from the pure Zn target with a gas pressure in the range 11-18 mTorr, Argon flow rates ranged from 7-14 sccm, and oxygen-to-argon flow ratios ranged from 0 to 56%. Films sputtered without oxygen were highly conducting, metallic, and opaque. Films sputtered with O_2/Ar flow ratios 33% or higher were insulating and highly transparent. Films sputtered with less oxygen exhibited conduction with loss in transmission – ranging from yellowish and barely conducting at 30% to dark brown and highly-conducting at lower ratios.

Films were sputtered from the Al target with gas pressure in the range 15-17 mTorr, an Argon flow rate ranging from 10-12 sccm, and an oxygen-to-argon flow ratio ranging from 0 to 8%. Films sputtered without oxygen were highly conducting, metallic, and opaque. Films sputtered with O_2/Ar flow ratios 5% or higher were insulating and highly transparent. Films sputtered with less oxygen were semi-transparent with brown or yellowish color. The Al sputter gun was not stable with greater than 8% oxygen. (With too much oxygen the target surface oxidized and became insulating. The dc magnetron sputter gun cannot function under these conditions.)

With deposition from the individual sputter targets characterized we set about to fabricate ZnO/Al$_2$O$_3$ layered films with overall Al doping of about 2%. For practical reasons Al layers were deposited without O$_2$ gas. (Al oxidizes so readily we believed that, even without using O$_2$, Al atoms would oxidize when they interact with the ZnO atoms at the substrate.) Samples were fabricated with as few as 8 and as many as 48 layers (24 ZnO and 24 Al). Substrates were heated to either 100 or 200°C during deposition to promote inter-diffusion of the layers.

The ZnO layers for all multilayer structures were deposited under conditions known to produce transparent, semiconducting films. Adding aluminum layers, in some cases rendered the structures opaque. For cases in which resulting structures remained transparent they were no more conducting than were the underlying ZnO layers. In other words, to date our method for adding Al to these multilayered structures was not achieved the desired doping without significantly compromising film optical properties. Work continues to resolve this issue.

[1] A. E. Delahoy and M. Cherny, "Deposition schemes for low cost transparent conductors for photovoltaics," *Materials Research Sociity Symposium Proceedings*, Vol. **426** (MRS 1996), pp. 467-477.

Name: **George W. Sidebotham**
Education: Ph.D., Chemical Engineering
                               Princeton University

Permanent Position: Associate Professor, Chemical Engineering
                               The Cooper Union for the Advancement of Science
                                  and Art

Host Organization: Microgravity Science Division
Colleague: 6711/Sandra L. Olson

Assignment:

Unique Fire Hazards Associated with Surgery in Space

In all of the studies to date on surgery in space, none have considered the increased risks of a fire event during surgery. Safety begins with understanding or awareness of a hazard. The fire dangers on a terrestrial operating room are significant, and it is hypothesized here that these risks are even higher in space, and thus merit study.

The objective of this proposed research is to mitigate the unique fire hazards associated with space medicine. These unique hazards a combination of 1) ignition hazards due to lower ignition energy requirements in microgravity (lasers, cauterizing devices, etc), 2) accidental ignition upon misalignment of lasers, etc due to improper restraint of patent, surgeon, and tools in microgravity, 3) increased risk of electrical arcing in low pressure atmospheres that may be present on future missions, 4) elevated local or ambient oxygen concentrations in the absence of buoyant flow, and 5) accumulation of toxic and flammable vapors from the patient.

The proposed program is a three-prong approach to mitigate the unique fire hazards in space medicine. The three-pronged approach addresses each of the sides of the classic fire triangle.

1. Ignition Sources: We will conduct normal and low gravity experiments to evaluate the potential for increased ignition susceptibility in microgravity, especially under altered atmospheres (higher oxygen, lower pressure), specifically due to electrical arcs and cauterizing or laser devices. Based on these results, recommend equipment and procedures to mitigate the ignition hazards during medical procedures.

2. Oxidizers: Conduct the ignition testing in current and potential future spacecraft atmospheres with lower pressure and higher concentrations of oxygen.

3. Fuels: Review current materials used in medical equipment and supplies, and select one or two of the current materials for the above ignition testing. For example, a cotton cloth soaked in alcohol and a polyethylene tube.

Research Summary Submitted by Fellow:

Unique Fire Hazards Associated with Surgery in Space

PROJECT DESCRIPTION:
Procedures to address medical emergencies on spacecraft must be planned for, especially as the duration of manned flight missions increases. Terrestrial surgery frequently involves the simultaneous use of flammable materials (drapes, endotracheal tubes, intestinal gases), strong oxidizers (oxygen, nitrous oxide) and high-energy surgical tools (lasers, electrocautery) and there is thus significant fire risk. While rare, operating room fires have been reported, and it is likely that many unreported fires have occurred. Since 1989, Professor Sidebotham has studied several operating room fire safety issues with Gerald Wolf (an anesthesiologist) and their Masters level graduate students. One conclusion of this work is that medical procedures were developed without primary consideration of fire risk. If they had, it is possible that many of the inherent risks associated with surgery could have been avoided. The long-term goal of the present project is to guarantee that the same mistake is not made in the space program.

The initial phase of the project was conducted this summer at the NASA Glenn Research Center in the 2.2 second drop tower. An experimental investigation was conducted to determine the role of gravity on endotracheal tube fires. Previous work in normal gravity has shown that the accidental ignition of polyvinyl chloride (PVC) endotracheal tubes (breathing tubes used during general anesthesia) by high energy surgical devices results in an opposed flow flame spreading process along the inner surface of the tube. This primary flame consumes oxygen fed to it, and produces fuel vapors, which can ignite secondary flames depending on where they exit. The nature and severity of these flames are strongly dependent on the flow rate of oxidizer supplied.

A general purpose rig (PIG4) was modified to allow for videotaping the flame spread process in horizontal and vertical PVC tube samples in normal and microgravity for 100% flow rates up to 500 sccm. A safety permit was granted and approximately 50 tests were performed. Each test was videotaped. Video was then digitized and analyzed to obtain flame spread rates. Ambient pressure was 14.7 psia for most tests. A series of tests at lower pressure (7.35 psia) was also conducted.

RESULTS:

The flame spread rates as a function of oxygen flow rate are shown in Figure 1 for all tests conducted. The vertical lines show cases for which ignition was attempted but no achieved. These represent ignition limits associated with the hot wire ignition used in this study, and not necessarily flammability limits. Above approximately 100 sccm, the flame spread rate is the same in normal and microgravity. For lower flow rates, the flame spread rate is higher in normal gravity than in microgravity. Furthermore, the effects of gravity are greater for the horizontal flames than for vertical flames. Finally, lower pressure lowers the flame spread rate primarily above 100 sccm.
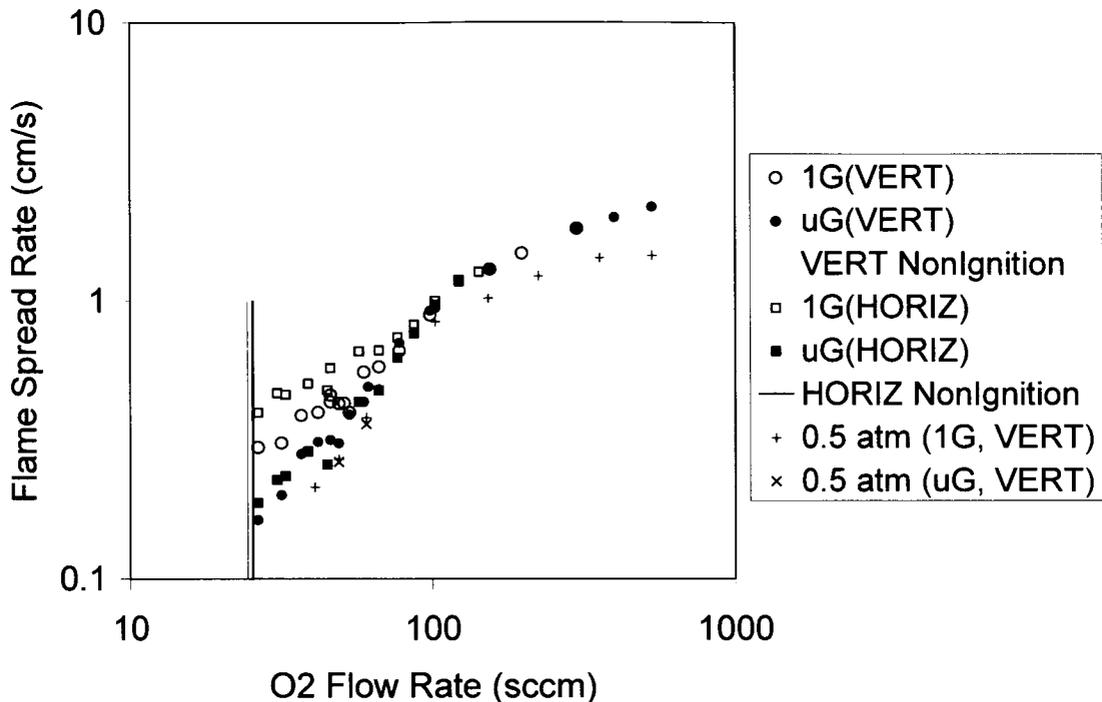

Figure 1

Images of horizontal flames at a relatively low flow (30 sccm) are shown in normal (Fig. 2) and microgravity (Fig. 3). The basic structure of the flames is similar, with the flame running along the bottom of the tube, and a visible vapor trail. There are subtle differences in the shapes of the flames, while the flame speeds vary considerably (0.66 cm/sec and 0.43 cm/sec for the normal and microgravity tests, respectively).

Flames at higher flows show different behavior. For intermediate flow rates (100 – 120 sccm), a second leading edge runs along the top surface (Fig. 4). Above a critical flow rate (approximately 140 sccm) the leading edge completely wets the inner surface in a symmetric flame shapes and the flame speeds are the same in normal and microgravity (Fig. 5), indicating that these flames are controlled by the forced flow of oxygen.

CONCLUSIONS:

- Gravity affects endotracheal tube fires for flow rates below 100 sccm.
- Low gravity environments are safer than normal gravity for this flame type.
- Gravity effects are greater in horizontal tubes than in vertical tubes.
- There is a low flow quenching limit in both normal and low gravity, which may be used to advantage in designing safe procedures for general anesthesia in space.
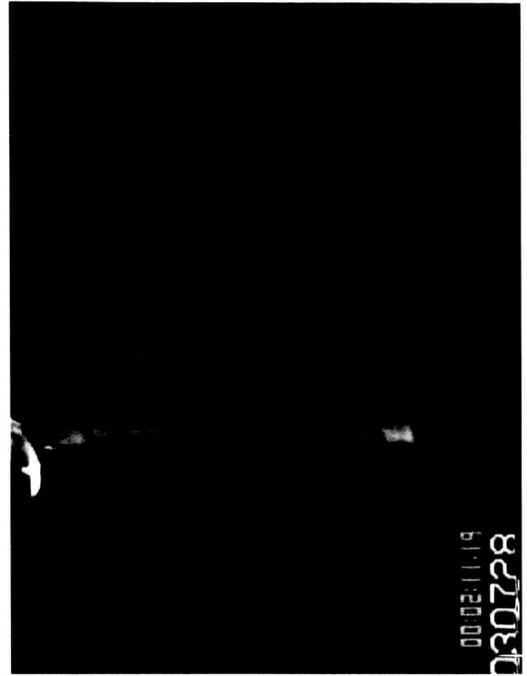
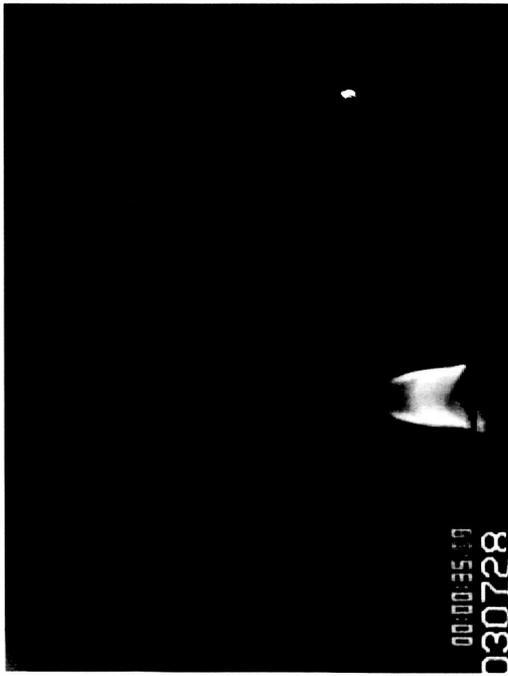Figure 2: Normal gravity, 30 sccm

Figure 3: Microgravity, 30 sccm

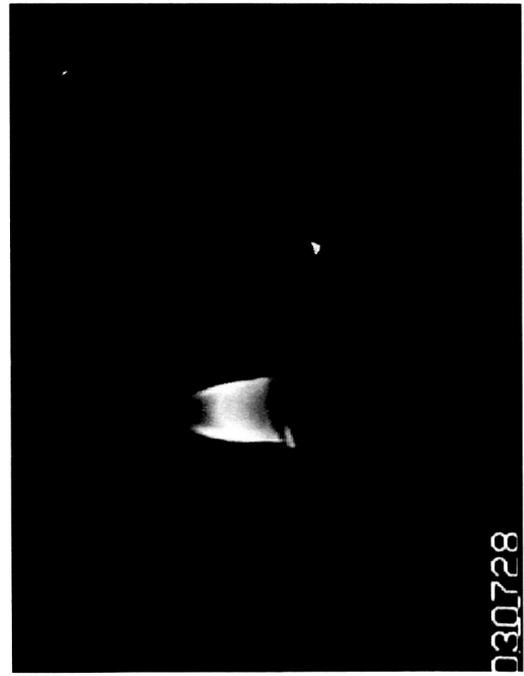Figure 4: Microgravity, 120 sccm

Figure 5: Normal gravity, 140 sccm

Name:	**Thomas M. Ticich**
Education:	Ph.D., Physical Chemistry
	University of Wisconsin, Madison

Permanent Position:	Associate Professor, Chemistry
	Centenary College of Louisiana

Host Organization:	Microgravity Science Division
Colleague:	6711/Daniel Dietrich

Assignment:

Optical and Probe Diagnostics Applied to Reacting Flows

The general theme of the research my NASA colleague and I have planned is "Optical and probe diagnostics applied to reacting flows". We plan to explore three major threads during the fellowship period. The first interrogates the flame synthesis of carbon nanotubes using aerosol catalysts. Having demonstrated the viability of the technique for nanotube synthesis, we seek to understand the details of this reacting system which are important to its practical application. Laser light scattering will reveal changes in particle size at various heights above the burner. Analysis of the flame gas by mass spectroscopy will reveal the chemical composition of the mixture. Finally, absorption measurements will map the nanotube concentration within the flow.

The second thread explores soot oxidation kinetics. Despite the impact of soot on engine performance, fire safety and pollution, models for its oxidation are inhibited by uncertainty in the values of the oxidation rate. We plan to employ both optical and microscopic measurements to refine this rate. Cavity ring-down absorption measurements of the carbonaceous aerosol can provide a measure of the mass concentration with time and, hence, an oxidation rate. Spectroscopic and direct probe measurements will provide the temperature of the system needed for subsequent modeling. These data will be benchmarked against changes in soot nanostructures as revealed by transmission electron microscopic images from directly sampled material.

The third thread will explore the details of turbulent flame dynamics, which is pertinent to many practical systems. We have already obtained laser induced incandescence images of turbulent flames under a variety of conditions. Analysis of these data will reveal fluctuations in the soot volume fraction and its average. Analysis of seed tracer particles by planar laser light MIE scattering will reveal the elemental fuel mixture fraction in the flames. Cavity ring-down spectroscopy, a pulsed transient absorption method, will determine the instantaneous mass loading and its fluctuation. Finally, fluorescence measurements will investigate the formation of PAH's in these flames.

Research Summary Submitted by Fellow:

My work this summer focused on two rather different areas – fluid physics and aligned carbon nanotube synthesis. The fluid physics project was part of a larger effort that explores the fundamental process of a droplet impinging on a hard surface or thin film. Steven Mozes (Co-op student) had collected a great deal of data prior to my arrival that examined the splashing characteristics of droplets of various diameters and velocities. In particular, his data defined a boundary surface between splashing and not splashing on a plot of Ohnesorge number ($(We)^{1/2}/Re$) versus Reynolds number ($uD\rho/\eta$), where $We=\rho u^2 D/\sigma$, u is the droplet velocity, D is the droplet diameter, ρ is the fluid density, η is the viscosity and σ is the surface tension. To further test this boundary, it was desirable to generate droplets with a greater range of diameters and velocities. Toward this end, I got a vibrating orifice droplet generator working and then assisted Steve in using the device to expand his experimental matrix. Appropriate adjustment of the frequency of a square wave signal on the piezoelectric creates a stream of uniform diameter droplets with nearly uniform spacing. Another contribution I made to the project was the development of a laser-based trigger. Future measurements by co-workers of Randy Vander Wal as well as colleagues in the Icing Branch will require the use of a digital camera capable of nanosecond resolution to examine droplet behavior. Since the total window for data collection with this camera is too small to allow mechanical synchronization of droplet event and camera shutter, it is necessary to do so opto-electronically. In my design, light from a CW frequency-doubled Nd:YAG laser (pumped by a diode laser) intersects the droplet stream. Scattered light from the droplet is detected by an amplified photodiode, outfitted with a narrow band-pass filter. This signal can be modified by a pulse generator to produce an inverse TTL pulse appropriate to trigger the high-speed camera so that shutter and droplet event (e.g. splashing on a surface) are synchronous within the data collection window.

The major portion of my work centered on the synthesis of aligned carbon nanotubes using plasma-enhanced chemical vapor deposition. The synthesis of carbon nanotubes is an active area of research due to their potential application in molecular-sized circuits, composite materials, hydrogen storage and scanning microscope tips. Some of these applications will require selective positioning and growth of the nanostructures. Recent work has demonstrated the feasibility of a plasma DC glow discharge as a fruitful environment for growing aligned carbon nanotubes. Our goal was to learn the technique and then apply it to new catalysts and to adapt it to applications of interest. The first step was to get a custom-built apparatus to work using published parameters. I invested considerable effort in identifying appropriate heaters, temperature measurement approaches and holders for the high voltage electrode. I then began a number of tests. The general approach is to heat the substrate (Ni on either quartz or a stainless steel mesh) to 700°C under an inert atmosphere and then allow it to remain at temperature for 15 minutes to promote sintering in the catalyst layer.

The plasma is then established under NH_3 flow to which C_2H_2 is then added. After a growth period of 15 to 30 minutes, the plasma is turned off and the sample allowed to cool to room temperature. Scanning Electron Microscopy (SEM) analysis of the substrate determines the success of a particular run. The parameters explored include the nature of substrate, plasma voltage, growth time, electrode material and geometry, NH_3 pre-etch time, and C_2H_2 concentration.

Name: **Christina Taylor**
Status: Undergraduate Student
Institution: Centenary College of Louisiana

Accompanying Student under the direction of Professor Thomas M. Ticich.

Research Summary Submitted by Student:

Fire Signatures of Materials Used in Spacecraft Construction

The focus of my work this summer was fire safety, specifically determining fire signatures from the combustion of materials commonly found in the construction of spacecraft. This project was undertaken with the aim of addressing concerns for health and safety onboard spacecraft. Under certain conditions, burning electronics produce surprisingly large amounts of acrid smoke, release fine airborne particles and expel condensable aerosols. Similarly, some wire insulation and packing material evolves smoke when in contact with a hot surface. In the limited, enclosed space available on spacecraft, these combustion products may pose a nuisance at the very least – at worst, a hazard to health or equipment. There is also a concern for fire safety in early detection on spacecraft. Our goal for the summer was to determine the most effective methods to test the materials, develop a protocol for sampling, and generate samples for analysis. We restricted our testing to electronic components, packaging and insulation materials, and wire insulation materials.

We tested several kinds of electronic components – primarily capacitors, resistors and inductors – of various compositions. Electronic components were subjected to both gradual and sudden overvoltage and, where applicable, reversed polarity. To generate samples, the desired component was attached across the terminals of a voltage source. We stimulated a smoldering combustion using gradual overvoltage; this process generated the greatest amount of airborne particulate. The combustion reaction was contained in a glass reaction chamber with a Gelman filter apparatus attached to the top of the chamber. Airflow was introduced into the system by an inflow line connected at the bottom of the apparatus and a vacuum line connected above the Gelman filter. This setup encouraged the soot and airborne particles to circulate and collect on the filter. The resulting solid residue was collected on Teflon filters, which were dried and weighed after the collection of each sample. Elemental analysis was performed on each of the filters by Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES). As expected, results showed that the residues from the combusted components had distinct chemical properties, dependent on the composition of the original electronic component. The soot from the components tended to contain metals, including, in some cases, significant amounts of cadmium and lead.

Insulation and packaging materials were heated to combustion with canthol wire. We selected white silicone, polyurethane, polyimide, and melamine foams as representative samples of the packaging and insulation materials. For the combustion tests, canthol wire was wound tightly around a one-inch cube of the foam. The wire was connected across the terminals of a voltage source and the voltage was gradually increased, heating the canthol wire. When heated to smoldering, the foams evolved thick smoke. The fine particles evolved were collected on lacey and ultrathin transmission electron microscopy (TEM) grids and analyzed by TEM to determine the relative sizes and structures of the soot particles from the respective foams. The same technique was used to sample several colors and gauges of Teflon and wire insulation. Preliminary analysis of the samples did not indicate any significant differences in the evolved particles.

Most of the work accomplished this summer was preliminary. Future goals involve further sampling, expansion of the current procedure, and replicating the experiments in a microgravity environment. By obtaining a more thorough understanding of the nature and quantities of the products evolved in the combustion of spacecraft materials, we hope to ascertain their potentials as hazards. We also hope to use these results to develop an early warning system and to supplement the current fire detection systems with sensors specific to the compounds evolved in combustion events.

Name: **James A. Turso**

Education: Ph.D., Mechanical and Nuclear Engineering
                    Pennsylvania State University

Permanent Position: Assistant Professor, Mechanical Engineering
                    Pennsylvania State University, Erie

Host Organization: Vehicle Technology Directorate
Colleague: 0300/Jonathan Litt

Assignment:

Dynamic and Structural Gas Turbine Engine Modeling

Model the interactions between the structural dynamics and the performance dynamics of a gas turbine engine. Generally these two aspects are considered separate, unrelated phenomena and are studied independently. For diagnostic purposes, it is desirable to bring together as much information as possible, and that involves understanding how performance is affected by structural dynamics (if it is) and vice versa. This can involve the relationship between thrust response and the excitation of structural modes, for instance. The job will involve investigating and characterizing these dynamical relationships, generating a model that incorporates them, and suggesting and/or developing diagnostic and prognostic techniques that can be incorporated in a data fusion system. If no coupling is found, at the least a vibration model should be generated that can be used for diagnostics and prognostics related to blade loss, for instance.

Research Summary Submitted by Fellow:

Modeling and Analysis of Turbofan Foreign Object Ingestion: Combining Health Parameter Estimates and Structural Response to Identify Possible FOD Events

For approximately two decades techniques based on the Kalman filter algorithm have been applied to turbofan engine diagnostics[1,2]. Specifically, Kalman filters have been used for detection of engine degradation via estimation of a set of health parameters, which are generally not measurable themselves and are calculated via knowledge of measurable quantities e.g., compressor efficiency. The degradation monitored may be gradual in nature e.g., worn components result in increased internal clearances, resulting in decreased component efficiency, or may be due to an abrupt event as is the case when foreign objects are ingested into the engine. Changes in component efficiencies, high and low spool speeds, as well as changes in thermodynamic parameters have been determined/observed during foreign object damage (FOD) events[3]. In some cases, these parameter changes alone may not be conclusive proof that a FOD

event has occurred. Absent from these investigations are the incorporation of structural vibration signals as a means to aid in positive identification of a FOD event.

To successfully apply available sensor fusion techniques, the same event should be detected using sensors that have significantly different physical characteristics (e.g., thermocouples compared to accelerometers) and rely on measuring physically different parameters (e.g., temperature vs. acceleration)[4,5]. It would appear that fusing health parameter estimates with structural response information acquired during a FOD event could provide conclusive evidence that a FOD event had occurred. For example, aircraft maneuver/operating condition scenarios could conceivably result in health parameter changes similar to those experienced during a FOD event. Similarly, vibration signals alone may possess FOD – like characteristics depending on the maneuver e.g., a rapid change in thrust demanded from the engine would result in temporary impulse-like force imbalances that are transmitted through the engine structure. The combination of specific changes in health parameter estimates combined with application of state-of-the-art signal processing techniques applied to structural vibration signals (e.g., wavelet analysis[6,7]) could the provide the "finger print" necessary to positively identify a FOD event.

A reduced-order dynamic structural model (ROM) of a turbofan engine design has been developed (Figure 1) and implemented in the MATLAB /SIMULINK software environment using modal analysis output from a commercially available Finite Element turbomachinery analysis code[8,9]. The turbofan structural model has been combined with a thermal performance model in SIMULINK. A Kalman Filter is used to estimate engine thermal-performance health parameters. The health parameter estimates, combined with the information provided by vibration sensors (e.g., the reduced-order structural model developed), may provide conclusive evidence that a foreign object damage (FOD) event has occurred. The use of wavelet analysis of engine vibration sensor signals for FOD detection has also been investigated (using the ROM). Wavelet decomposition of the engine vibration signals may provide input to a sensor/data fusion algorithm that combines health parameter estimates with engine structural information to detect a FOD event (Figure 2). Future work in this area may investigate using a probabilistic method e.g., Bayesian classification, to perform the fusion.

References:

[1] Kobayashi, T. and D.L. Simon, "Application of a Bank of Kalman Filters for Aircraft Engine Fault Diagnostics," Proceedings of the ASME Turbo Expo 2003, Power for Land, Sea, and Air, June 16-19, 2003, Atlanta, Georgia.

[2] Simon, Dan and Donald L. Simon, "Kalman Filtering With Inequality Constraints for Turbofan Engine Health Estimation'" NASA/TM-2003-212111.

[3] Kerr L.J., Nemec T.S., Gallops, G.W., "Real-Time Estimation of Gas Turbine Engine Damage Using a Control Based Kalman Filter Algorithm", ASME 91-GT-216, International Gas Turbine and Aeroengine Congress and Exposition, Orlando, FL, June 3-6, 1991.

[4] Klein, Lawrence A., *Sensor and Data Fusion Concepts and Applications*, 2nd Ed., SPIE Press Vol. TT35, 1999.

[5] Doebelin, Ernest O., *Measurement Systems Application and Design*, 5th Ed., McGraw Hill Publishing, 2004.

[6] Lim, Meng Hee and M. Salman Leong, "Diagnosis for Loose Blades in Gas Turbines Using Wavelet Analysis," Proceedings of the ASME Turbo Expo 2003, Power for Land, Sea, and Air, June 16-19, 2003, Atlanta, Georgia.

[7] Juluri, Naresh and S. Swarnamani, "Improved Accuracy of Fault Diagnosis of Rotating Machinery Using Wavelet De-Noising and Feature Selection," Proceedings of the ASME Turbo Expo 2003, Power for Land, Sea, and Air, June 16-19, 2003, Atlanta, Georgia.

[8] Gunter, E.J., DyRoBes Rotor Dynamic Analysis software training manual.

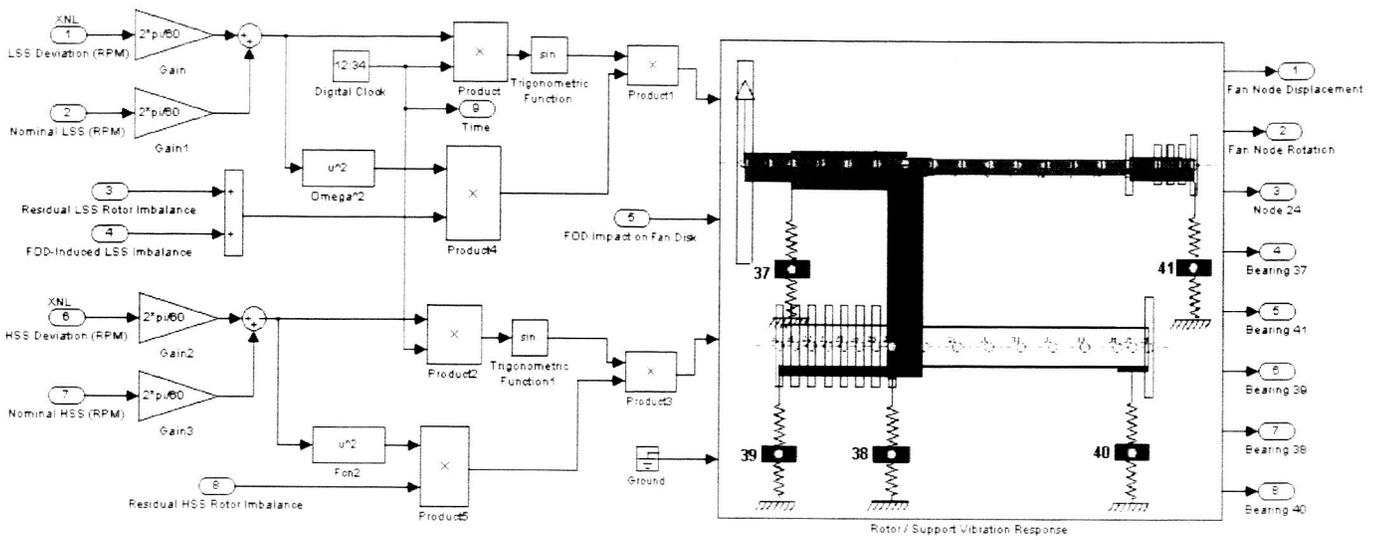[9] Lawrence, C., personal communication, NASA Glenn Research Center, summer 2003.

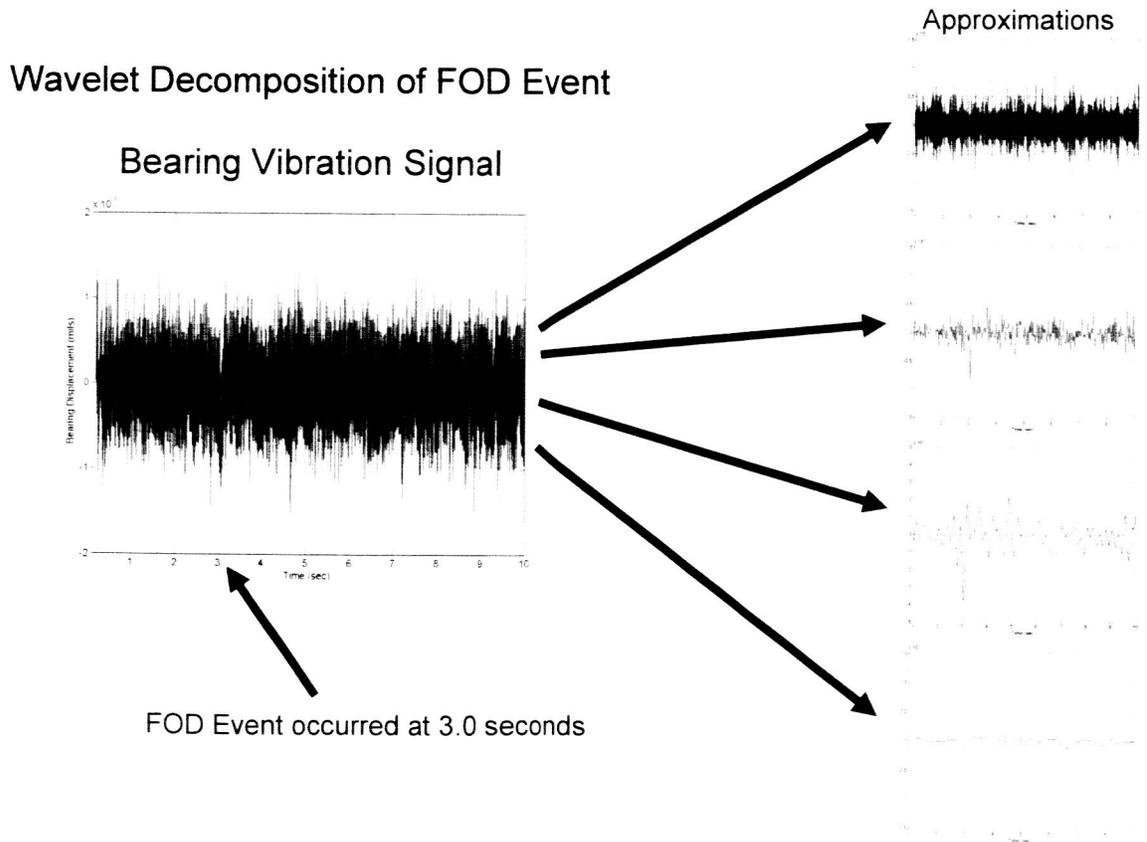Figure 1. MATLAB/SIMULINK turbofan rotor structural dynamics module.

Figure 2. Wavelet decomposition of a (simulated) turbofan rotor bearing vibration signal.

Name: **Stephen F. Tytko**
Education: Ph.D., Chemistry
Northwestern University

Permanent Position: Assistant Professor, Chemistry
Baldwin-Wallace College

Host Organization: Materials Division
Colleague: 5150/Chun-Hua (Kathy) Chuang

Assignment:

Synthesis and Characterization of Polymers for Fuel Cells Applications

The goal of this summer research is to prepare Polymer Exchange Membranes (PEM's) for fuel cell application. Several high temperature polymers such as polybenzimidazoles and polyether ketones were known to possess good high temperature stability and had been investigated by post-sulfonation to yield sulfonated polymers.

The research project will involve two approaches:

1. Synthesis of polybenzimidazoles and then react with alkyl sultonse to attach an aliphatic sulfonic groups .
2. Synthesis of monomers containing sulfonic acid units either on a aromatic ring or on an aliphatic chain and then polymerize the monomers to form high molecular weight sulfonate polymers.

Research Summary Submitted by Fellow:

Fuel cells promise to be economical, environmentally friendly energy sources of the future. Electricity is produced by chemical reaction resulting in water as the only byproduct. One requirement to make fuel cells a reality is a proton exchange membrane, made of a polymeric material. We have sought to synthesize such proton exchange membranes and test their conductivity. To that end, we have sought to synthesize poly(2,2'-octamethylene-3,3'-bis(propanesulfo)-5,5'-bisbenzimidazole) **(1)** and poly(2,2'-octamethylene-5,5'-bisbenzimidazole-2,2'-octamethylene-4,4'-disulfo-5,5'-bisbenzimidazole) **(2)** **(Figure 1)**.
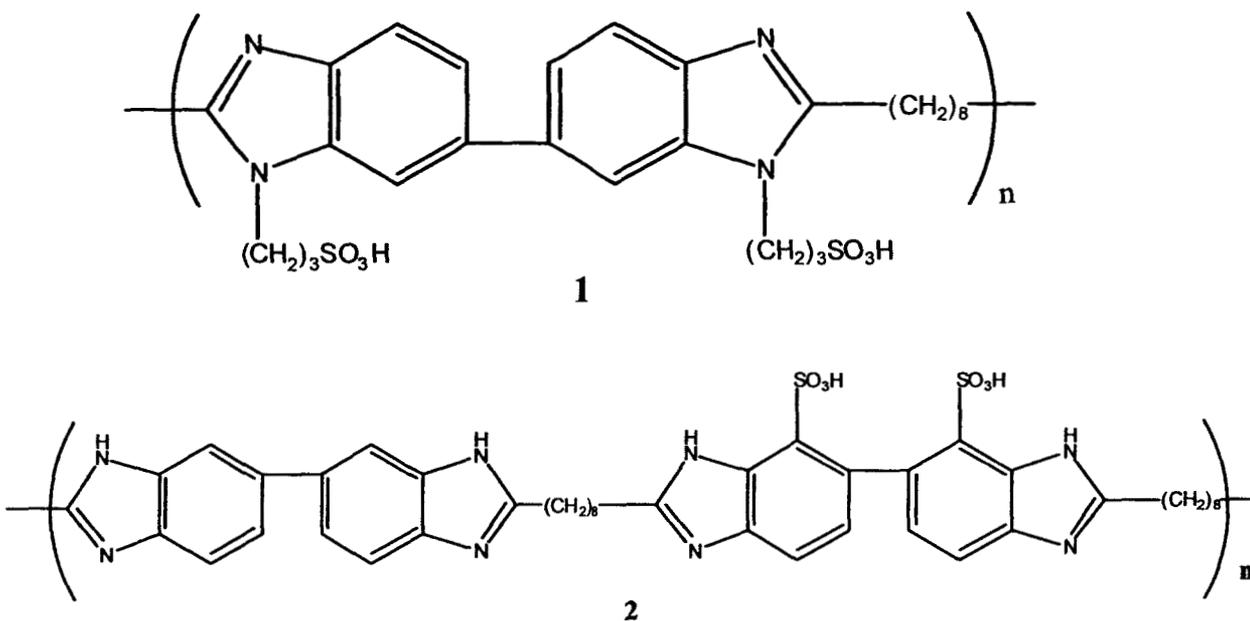
Figure 1

Literature reports indicate that polymerization of aromatic tetraamines and dicarboxylic acids may be performed in polyphosphoric acid (PPA) at temperatures up to 200°C. However, all attempts to polymerize 3,3'-diaminobenzidine and it's derivatives and sebacic acid in PPA resulted in low molecular weight polymers unsuitable for our applications. Eaton, et al.[1] have used a 1:10 mixture of phosphorous pentoxide and methane sulfonic acid (PPMA) as a useful replacement for PPA. The use of PPMA in the preparation of PBI's has been shown by Ueda, et al.[2] The reaction of 3,3'-diaminobenzidine (3) and sebacic acid (4) in PPMA at 130°C afforded the desired polymer 5 (**Scheme 1**).

The methodology for elaboration of 5 to 1 has been reported by Gieselman and Reynolds[3] and Kawahara, et al.[4] In each of these procedures, a solution of the polymer was deprotonated with lithium hydride to form the polyanion, followed by an appropriate sulfonating agent. Unfortunately, with polymer 5, the polymer was insoluble in any useful solvents (NMP, DMSO, DMF, DMAc).

It was decided to attempt the polymerization with the pendant propanesulfonic acid groups already attached to the monomer. Thus, 3 was reacted with 1,3-propanesultone, 6, to provide disulfonic acid 7 (**Scheme 2**). Subsequent polymerization of 7 with diacid 4 afforded polymer 1.

Scheme 1

i. DMF, rt; ii. **4**, PPMA, 130 °C.
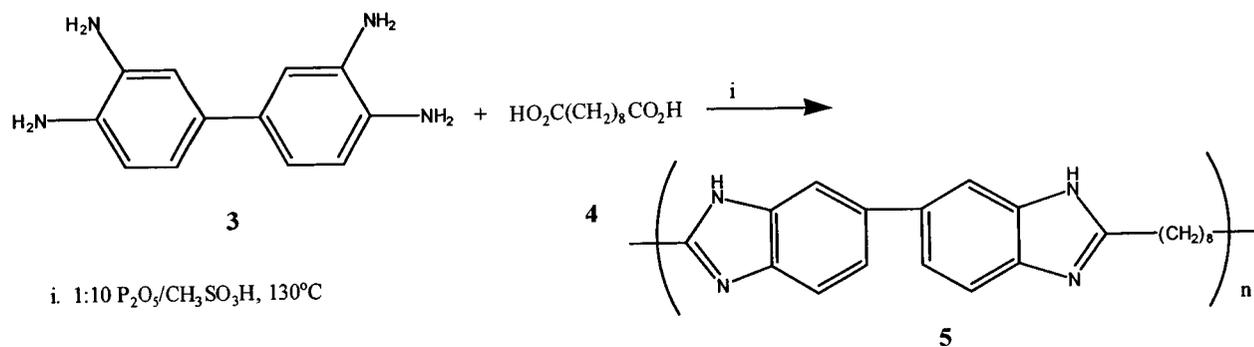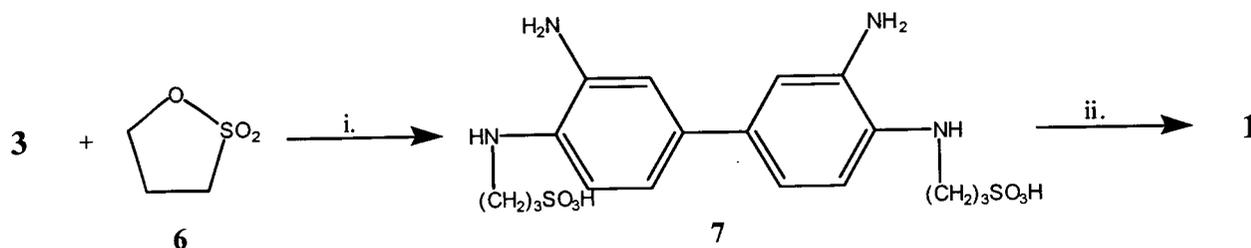
Scheme 2

In order to prepare polymer **2**, it was necessary to sulfonate tetraamine **3**. Thus, **3** was treated with fuming sulfuric acid at 80°C, to provide 3,3'-diamino-2,2'-benzidinedisulfonic acid, **8** (**Scheme 3**). Reaction of one equivalent of **8** with one equivalent of **3** and two equivalents of **4** provided polymer **2**.

i. H_2SO_4, SO_3, 80°C; ii. **3**, **4**, PPMA, 130 °C.

Scheme 3

70
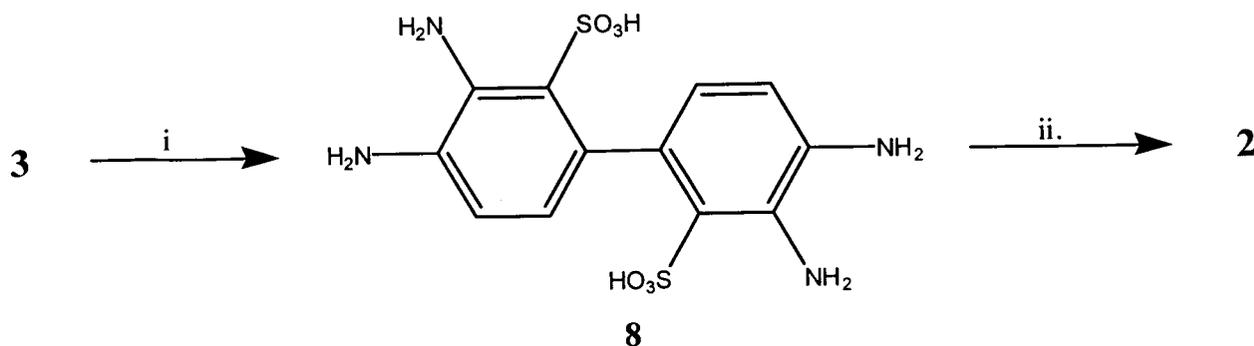
Due to concerns about the long-term stability of the polymers in a fuel cell environment, we sought to synthesize the perfluorenated versions of polymers **1** and **3**. In an effort to determine the feasibility of the synthetic plan, we first attempted the polymerization of **3** with perfluorododecanedioic acid, **9** (**Scheme 4**). Unfortunately, no polymeric product was isolated using either PPA or PPMA as the reaction medium. In all likelihood, the fluorine is too electron withdrawing to allow for the formation of the acylium ion, which is the likely intermediate in this reaction.

3   + $HO_2C(CF_2)_{10}CO_2H$ $\xrightarrow{\text{i}}$

9

10

i. 1:10 P_2O_5/CH_3SO_3H, 130°C
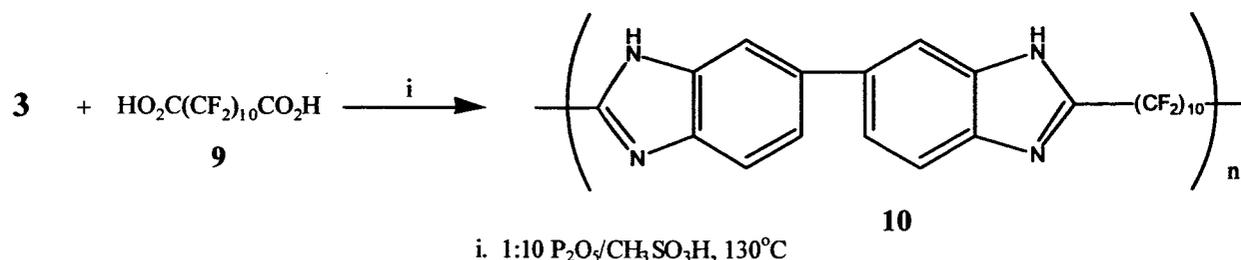
Scheme 4

References:
[1] Eaton, P.E.; Carlson, G.R.; Lee, J.T. *J. Org. Chem.*, **1973**, *38*, 4071.
[2] Ueda, M.; Sato, M.; Mochizuki, A. *Macromolecules*, **1985**, *18*, 2723.
[3] Gieselman, M.B.; Reynolds, J.R.; *Macromolecules*, **1992**, *25*, 4832.
[4] Kawahara, M.; Rikukawa, M.; Sanui, K.; Ogata, N. *Solid State Ionics*, **2000**, 1193.

Name: **Okechukwu C. Ugweje**
Education: Ph.D., Electrical Engineering
Florida Atlantic University

Permanent Position: Assistant Professor, Electrical and Computer
Engineering
The University of Akron

Host Organization: Space Communications Office
Colleague: 6120/Roberto Acosta

Assignment:

Propagation Measurement and Analysis

1. Developed MATHLAB codes to analyzed post process data files
(propagation files) for statistical analysis. These codes are in GUI type
format in MATHLAB and they should be in userfriendly format.

2. Modified exciting link analysis MATHLAB code for describing GEO and
LEO spacecraft links. These new codes should be in GUI type format and
userfriendly.

3. Developed Simulink MATHLAB code to analyzed phased array antennas
from LEO spacecraft.

Research Summary Submitted by Fellow:

On the Design of High-Throughput Distributed Spacecraft Network

- Provided an analysis of the report on "High-Throughput Distributed
Spacecraft Network"
- Studied the feasibility of using wireless PCS concept for the communication
infrastructure for the distributed spacecraft network.
- Presented seminars on wireless PCS to the members of Space
Communication Office and the Communication Technology Divisions in the
Blue Room at building 55.
- Presented a seminar for the Research and Technology forum at NASA Glenn
Research Center community on previous and current research at NASA.

### Summary of Study
The future NASA planned spacecraft networks involving multiple non-GEO
satellites consisting of variable nodes, altitudes, and transmission rates are
shown in Fig. 1. The nature and requirements of the spacecraft networks can
vary broadly depending on specific design criteria and intended missions. The
networks have flexible spacecraft configuration, data rates, and constellation.

A: Critical Review of the BBN Report

The preliminary design document presented in [1] characterizes the network as being composed of space-based satellites and aircrafts, and earth-based sensors arranged in 3 levels namely, a) spacecraft at multiple low-altitude orbits (LEO), b) mobile nodes aircrafts at lower altitudes, and c) network elements on earth surface. Communication requirements (data rates, gain, modulation and encoding techniques) were defined. System architecture and functions for the space-based systems are defined. A description of the probable network architecture was presented using a "reference" network. The network configuration, Physical Layer, Multiple Access Protocol, MAC Protocol and sub-network algorithms were presented.

After a careful analysis of the system design document the following conclusions can be made:

a) The design and technology characterization presented in the report is highly speculative. The lack of detailed or tangible information regarding the proposed network is of concern and it is very difficult to understand the design requirements without further explanation. For example, the Physical Layer description suggests the use of antenna array with digital beamforming. The information presented on this topic is confusing and how it fits into the overall network architecture is unclear.
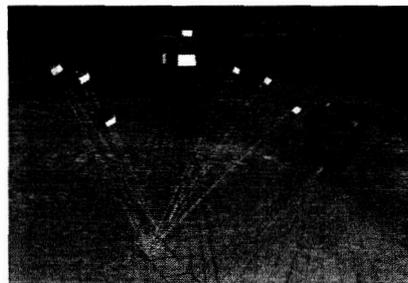
6-12 nodes, 0.3-3.0 Gbps, d: 100-2000 Km, Δd:<50 m
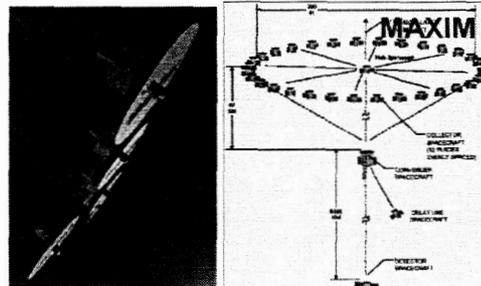
5-36 nodes, < 1 Mbps, d: 100 -1000 m, Δd: millimeter
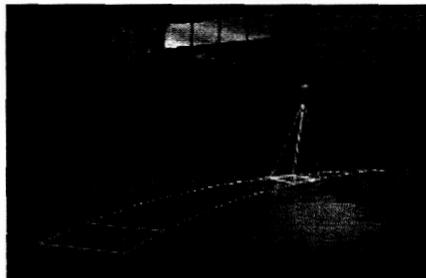
Expandable # nodes, 20 kbps -100Mbps, d: 100 -2000 Km

5 nodes, < 1Mbps, d: 10 -20,000 Km, Δd: 100 m

Fig. 1: Future NASA distributed spacecraft network

b) A major problem is the use of proprietary information in the report such as "TCeMA" protocol. Extensive search of published record was not helpful. The usefulness of this technology should be carefully examined.

c) Another problem is the "reference network" used in the design. The reference network is unrealistic and is not representative of the complexity of the proposed network. It is not clear how satellite, aircraft and ground systems were integration. The systems design requirements of such large and complex spacecraft networks were not properly presented.

We can therefore conclude at this point, that more details are needed to accurately determine the feasibility of the proposed network presented in [1].

B: PCS Concept

An alternative to [1] is to apply the well-known concept of mobile satellite communication to the analysis, design and simulation of the proposed networks. In this case, much-detailed study of different configurations and communication requirements for different spacecraft network can be studied. The Physical Layer consisting of the communication medium and the transceiver front ends can be studied more carefully. The application of digital beamforming (or smart antenna) technology can be correctly modeled using the PCS concept. Hence, multiple and independent groups can investigate the system design requirements and present comparable results. Secondly, this will eliminate the used of proprietary modulation schemes or protocols.

Reference

[1] "High-Throughput Distributed Spacecraft Network" A draft report prepared by BBN Technologies for NASA under contract no. NAS3-01101

Name: **Stephen E. Webber**
Education: Ph.D., Chemistry and Biochemistry
University of Chicago

Permanent Position: Professor, Chemistry and Biochemistry
University of Texas, Austin

Host Organization: Materials Division
Colleague: 5150/Michael A. Meador

Assignment:

Functionalization of Carbon Nanotubes

These project will explore the functionalization of carbon nanotubes via the formation of molecular complexes with perylene diimide based systems. It is anticipated that these complexes would be soluble in organic solvent and enable the homogenous dispersion of carbon nanotubes in polymer films. Molecular complexes will be prepared and characterized using standard spectroscopic and thermal analytical techniques. Polymer films will be prepared with these complexes and their properties (electrical and thermal conductivity, mechanical properties, stability) evaluated.

Research Summary Submitted by Fellow:

Solublization of Purified Single Wall Carbon Nanotubes

Single wall carbon nanotubes (referred to as NT hereafter) produced by the so-called "HiPCO" process contain a significant fraction of Fe that should be removed for many proposed applications. NASA research has led to a method of purification of the as-supplied HiPCO NT that greatly reduces the Fe content. It is highly desirable to disperse this material as individual NT in suitable organic solvents but NT have a strong tendency to aggregate. We have used branched-chain perylene derivatives as additives with the expectation that they will form π-complexes with the NT and this will enhance their dispersability. Unfortunately this expectation has not been borne out for the experiments carried out to date. As part of this research a new freeze-drying method has been used to prepare the purified NT and this has led to a significant improvement in the amount of NT that can be dispersed in the organic solvents DMF and NMP. It has also been found that NMP is considerably more effective than DMF in dispersing NT regardless of the NT preparation method. The combination of using the freeze-dried NT and NMP has led to a NT suspension that is ca. 3x more concentrated than the original methods of dispersion tried at NASA. Additionally the stability of the dispersion against loss of material during centrifugation has been dramatically improved (from 60% loss to essentially 0% loss).

New Method of Preparing NT - Post Filtration Freeze Drying

The purification of HiPCO NT requires refluxing the as-received NT in concentrated HNO_3, followed by filtration and water washing to remove excess acid. The "freeze-dry" method involves washing the wet filtered mat of purified NT with water or dioxane, freezing the saturated mat and then freeze-drying. The concept behind this approach is that voids within the mat will be filled with solvent and by subliming the frozen solvent the void spaces will be left behind. SEM images support this picture (See Figure 1(a)). The characteristics of the BP can be modified by the nature of the solvent used in the last wash. For example, the material washed and freeze-dried with dioxane tends to disperse easily into DMF or NMP while the material washed with H_2O/NH_4OH is wet by water and disintegrates but retains its integrity to a much great extent in DMF.

A preliminary through film conductivity of the dry freeze-dried BP has indicated a conductivity on the order of 10^{-5} S/cm, i.e. not an insulator but not a particularly conductive material either. However the materials tends to be composed of a series of detached lamellae (see Figure 1(a)), so the conductivity between these layers may be the limiting factor in the overall conductivity.

Dynamic Light Scattering Measurements

DLS measurements were carried out on various NT dispersions with and without exposure to perylene derivatives.[1] Prior to the DLS measurement the solution was usually centrifuged for 10 minutes at 10,000 to 14,000 rpm on a small bench-top centrifuges (Eppendorf Minispin Plus). CONTIN analysis based on the distribution of the light scattering intensity usually showed a bimodal distribution with one peak centered around 100-150 nm and another centered around 300 - 400 nm (this analysis treats the particles as spheres; note that the DLS technique cannot distinguish spheres or rods).

SEM images of particles from the dispersion

Although an optimal SEM sample preparation method has not been found to date the initial images of NT dispersed in NMP (no solubilization agent) showed a layer of NT that appeared to be individual tubes rather than large amorphous aggregates (see Figure 1(b)). Many individual NT can be seen with a dimension of 500 nm or more, suggesting that the DLS was observing individual NT of variable length. Unfortunately the CONTIN analysis is not appropriate for length analysis *per se*. However it is not possible from the SEM or the DLS to discount the possibility of NT ropes still existing (for SEM they could be formed during the solvent evaporation of the sample preparation step). Better dispersion of the NT solution in the SEM sample preparation may settle this issue.

[1] Dr. Kwang Suh of Dr. Ansari's group carried out these measurements for us.

Figure Captions

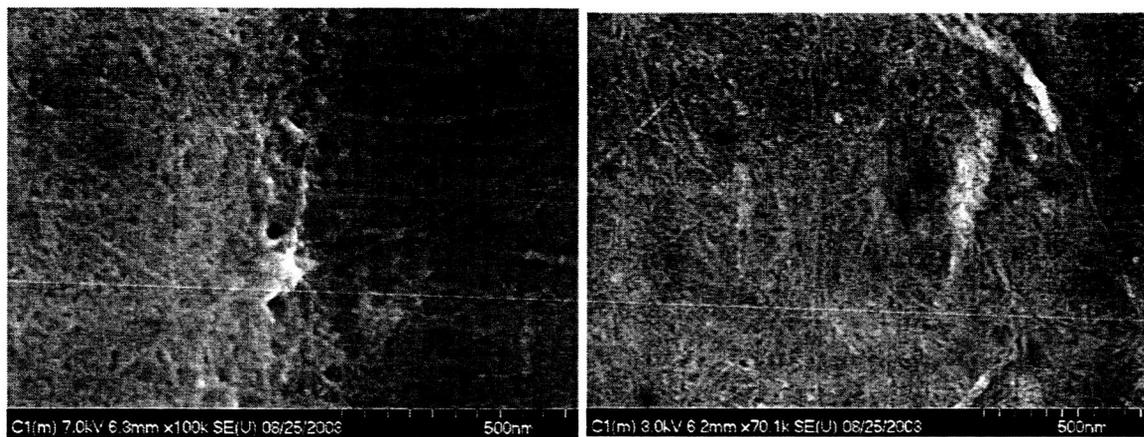Figure 1 SEM images of (a) a cross-section of freeze-dried BP (prepared using dioxane as the final wash) and (b) NT particles dispersed in NMP (solution spread onto Al disk and dried)

(a) Images: Dioxane-10, -11, -13;
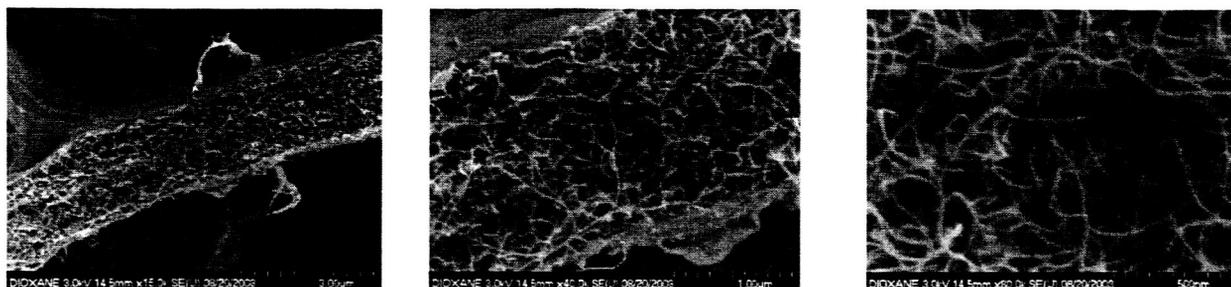
(b) Images: C1(m)-01, -06

Name: **Fuqin Xiong**
Education: Ph.D., Electrical Engineering
University of Manitoba

Permanent Position: Professor, Electrical and Computer Engineering
Cleveland State University

Host Organization: Communications Technology Division
Colleague: 5650/Kue S. Chun

Assignment:

Robust Timing Synchronization for Aviation Communications, and Efficient Modulation and Coding Study for Quantum Communication

One half of Professor Xiong's effort will investigate robust timing synchronization scemes for dynamically varying characteristics of aviation communication channels. The other half of his time will focus on efficient modulation and coding study for the emerging quantm communications.

Research Summary Submitted by Fellow:

Introduction and Acknowledgements

My tenure at NASA Glenn research center is from May 12 to July 18, 2003. My hosts are Mr. Kue Chun and Marc Seibert of ORG. Code 5650, Digital Communications Technology Branch, Communication Technology Division. I had two research tasks. One was to investigate robust synchronization techniques for AATT program and another was to research on error control coding techniques for quantum communication project. The first five weeks were devoted to synchronization and the second five weeks were devoted to coding.

Kue and Marc have been in close collaboration with me in my research. Other NASA colleagues also supported me in my research. I would like to thank all colleagues of 5650 Branch. Particularly, I would like to thank the Branch Chief, Gene Fujikawa, for his leadership, Kue Chun and Marc Seibert for their sponsorship and collaboration in synchronization and coding research.

Once again the Summer Fellowship Program has definitely benefited all of us in advancing the technology for NASA missions and in improving the education programs at Cleveland State University. I am looking forward to having more collaboration with my NASA colleagues in the future.

Major Accomplishments

1. Robust Synchronization Techniques for CDMA for the AATT Program

This is a continuation of the research started in 2001 for AATT program. After researching robust symbol timing synchronization in the last two years, our focus has been shifted to PN code acquisition and tracking in CDMA systems.

The AATT program is wrapping up, and a new program, temporarily called NexTNAS, was conceived. It is an opportunity to propose new projects to NexTNAS. To prepare for the new projects, I have studied books [1, 2] and other literatures on PN code acquisition and tracking. In a CDMA system, PN code acquisition is the technique to recognize the desired signal among many other signals. It is the first step to establish communications between intended parties. PN code tracking is to bring the acquired signal in complete synchronization with the local timing clock. Thus PN code tracking is a concrete application of symbol timing techniques in a CDMA system. The Sliding Window Synchronizer we have been working on will be useful for the PN tracking technique. Special features maybe added due to the special environment of a CDMA system.

I have given two seminars on the robust synchronization. On May 29, a Brown Bag Seminar entitled "Sliding Window Synchronizer" was given for the Communication Technology Division. This seminar summarized the research results on robust symbol timing we have obtained so far. On July 11, a presentation was given specifically for the AATT group. This seminar reviewed our past research on the robust synchronization techniques, and proposed research in areas of PN acquisition and tracking. Both presentations were well received.

2. Coding Techniques for Quantum Communication

Marc Seibert has been working in a team of scientists and engineers of NASA GRC for a quantum communication system intended for deep-space exploration such as a land rover for Mars. Modulation and error control coding are essential parts of this system, and coding, in particular, is critical since this system is prone to high bit error rates. I was invited to join the team to help out on modulation and coding issues.

After studying quantum communications, through reading the book *Quantum Computation and Quantum Information* [3] and other papers [4, 5, 6], it is understood that a quantum state is a not a discrete state, instead, it is a continuum of states based on superposition of the binary 0 and 1 states. Error control codes therefore are different from the classical codes for the classical digital communications. However, codes for quantum communications were invented based on classical codes [6].

One of the team members, student intern Michelle Hannon has been working on a MathCAD simulation for a photon image transmission and reception system. Michelle's simulation is not using quantum states yet.

One of the challenging issues for this system is that the reception bit error rate is extremely high due to various reasons. The major source of bit error rate is the probability of miss (P_m) due to the divergence of the laser beam of the transmitter. Ignoring any other error sources, the P_m contributes $0.5 P_m$ to the BER (assuming binary data bits are equally likely, only half of the missed bits are received in error). According to Michelle, the last measured miss probability is about 98%. This translates into 49% in BER, which dwarfs any other sources of bit errors.

The requirements for BER vary with applications. The lowest requirement (highest BER) is for speech communications, which is about 10^{-3}. Usually coding can reduce the BER by 2 to 3 orders of magnitude, depending on the types and rates of the codes. Therefore, to have an acceptable BER, first, the raw BER (without coding) should be at least in the range of 10% to 1%. Then, the miss probability should be in the range of 20% to 2%. Therefore, effort should be directed to reduce the divergence of the laser beam to make the miss probability less than 20%. Second, powerful error control codes that can correct 20% erroneous bits are needed.

Since Michelle's system is not using quantum states, the code needed is still classical first order Reed-Muller code R(1, 5) which was recommended to Michelle. In making this recommendation, two factors were considered. First, the code must be powerful in terms of error correction capability. Second, the code must not be too complicated to decode. Decoding must not be lengthy and computational complexity must be low. Decoding also must not involve advanced mathematical concepts and algorithms. These considerations led to the first order Reed-Muller codes R(1,m) [7], which are codes that are powerful yet simple to decode [7]. There are other more powerful codes like BCH codes, convolutional codes, and the recently invented turbo codes. But their decoding is complicated in that it either involves advanced mathematical concepts (e.g., finite fields for BCH codes) or complicated algorithm (e.g., Viterbi algorithm for convolutional codes) [8].

A simple decoder means lower mass and lower power consumption, which is critical to the quantum communication system under development for deep space applications such as Mars exploration. If the system can afford more hardware and more power, more powerful but more complex codes can be recommended.

The recommended Reed-Muller R(1, 5) code was used in the Mariner deep space probes flown between 1969 and 1977. This code's parameters are: code length n = 32, message length k = 6, minimum distance d_{min} = 16 and it can correct t = 7 errors among 32 bits (21.9%). This roughly matches the maximum miss probability (20%) of the laser beam mentioned above. The code rate is very

low: $6/32 \approx 0.19$. This translates into roughly a 5-fold bandwidth expansion. Thus to use this code, adequate bandwidth must be assumed.

A report was submitted to the quantum communication research team, which quantitatively determined the beam miss probability and gave a detailed tutorial for the Reed-Muller code to make it easy to understand. The tutorial includes code generator matrix, decoding methods, examples, and exercises. The report was well received. Michelle has implemented the encoder and decoder in MathCAD and it works!

References

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[2]   M. K. Simon, J. K. Omura, R. A. Scholtz, and B. K. Levitt, *Spread Spectrum Communications, Volume III*, Computer Science Press, Rockville, Maryland, 1985.

[3]   M. A. Nielsen and I. L. Chuang, *Quantum Computation and Quantum Information*, Cambridge University Press, Cambridge, UK, 2000.

[4]   M. Grassl and T. Beth, "Relation Between Classical and Quantum Error-Correcting Codes," *Workshop on Physics and Computer Science,* DPG-Fruhjahrstagung, Heidelberg, March 15-16, 1999.

[5]   V. A. Vilnrotter and C. W. Lau, "Quantum Detection and Channel Capacity for Communications Applications," *Proceedings of SPIE Vol.* 4635, 2002.

[6]   A. M. Steane, "Quantum Reed-Muller Codes," *IEEE Transactions on Information Theory*, Vol. 45, NO. 5, July, 1999.

[7]   S. B. Wicker, *Error Control Systems for Digital Communication and Storage*, Prentice-Hall, 1995.

[8]   S. Lin and D. Costello, *Error Control Coding: Fundamentals and Applications*, Prentice-Hall, 1983.

Name: **Judith C. Yang**
Education: Ph.D., Physics
                             Cornell University

Permanent Position: Assistant Professor, Materials Science and Engineering
                             University of Pittsburgh

Host Organization: Power and On-Bard Propulsion Technology Division
Colleague: 5480/Bruce A. Banks

Assignment:

Atomic Oxygen Durability of Aluminized Polymers

The atomic oxygen durability of aluminized polymers will be investigated. Such aluminized polymers are commonly used in space and specifically on the International Space Station. Recent data from in-space results indicates that vapor deposited aluminum coatings are highly defected with many small pin windows. However, electron microscopy to validate the size and aerial density of such defects remains to be demonstrated. The research project is planned to compare electron microscopy analysis of pristine and atomic oxygen exposed aluminized polyimide Kapton with the results of ground laboratory atomic oxygen erosion data, in-space results and computational Monte Carlo modeling to develop a self consistent understanding of the atomic oxygen degradation processes and effects.

Research Summary Submitted by Fellow:

Thin Film Coatings for the Protection of Polymers in the Low Earth Orbit

Space vehicles to be employed in low earth orbit (LEO) will be subject to harsh environments that can greatly hasten their failure. Primary damage results from collisions with hyperthermal atomic oxygen (AO). Atomic oxygen ($O(^3P)$) at these altitudes is produced by the vacuum UV dissociation of O_2 molecules at wavelengths < 243 nm. The density of atomic oxygen at 250 km is ~10^9 O/cm^3, and at orbital velocity the normal flux of atomic oxygen on a surface is about 10^{14}-10^{15} O/cm^2s. The incident energy of the O atoms on a surface moving at orbital velocity (about 8 km/s for the space shuttle) is 5.3 eV. Other primary factors for LEO degradation mechanisms include thermal cycling at ±150°C, vacuum ultraviolet radiation (electromagnetic radiation below 200nm). Secondary effects include X—rays from solar flares, electron and photon radiation (the sun ejects electron and protons as solar wind, and violent eruptions from the sun results in X-rays and extremely high flux of electron and proton radiation), particulate damage due to debris in space, outgassing or oxygen loss due to the vacuum in LEO (10^{-8} torr). Materials undergo rapid degradation in this harsh environment. Polymer materials are particularly susceptible to such

damage, where the atomic oxygen creates gaseous species via various chemical reaction paths. Metallic and semiconductor coatings are commonly used to protect polymer materials in space. These coatings reduce the rate of the mass loss of the polymer material during AO exposure, but not as much as would be expected from a uniform protective film. My aim is to investigate various thin film coatings on a model polymer system and characterize the films before and after degradation, to gain insights into the coating failure and possible methods to improve the coating performance.

The thin films used in this experiment include Al, SiO_2 and Ge, with and without a dendrimer monolayer (G4). Dendrimers are globular, highly-branched macromolecules made up of a central core surrounded by repetitive unit cells (generation (G) number) all enclosed by a terminal group "shell". Previous research on deposition of very thin metal films on silica revealed that dendrimers form a monolayer surfactant that can dramatically improve film uniformity, adhesion and hardness (Rar, Zhou, Liu, Barnard, Bennett, & Street, *Applied Surf. Sci.*, (2001), **175**, 134-9). Hence, coatings with and without dendrimer monolayer were prepared to test whether the dendrimer could improve film uniformity on Kapton H and thereby provide greater protection. Three different thicknesses of Al films were investigated: ~250 nm Al evaporated on Kapton H (produced by NASA Lewis), 100 nm Al and 20 nm Al evaporated onto Kapton H in an ultra-high vacuum (UHV) evaporation system, ~100 nm SiO_2 and ~100nm Ge deposited onto Kapton H by dual ion beam sputter deposition. Also, all three films were prepared with and without dendrimer, G4, monolayer on the Kapton H.

A RF plasma asher (SPI Prep II), using air, was utilized to simulate the degradation in LEO. Previous investigations by Bank's group have shown that the degradation in the RF plasma is greater than that experienced in space, and the nitrogen species does not have significant effect on the polymer degradation. Mass loss of the various coating materials is shown in Figure 1 as function of effective fluence. The effective fluence was determined by the mass loss of uncoated Kapton H, since the erosion yield of Kapton is well-calibrated for LEO environment.
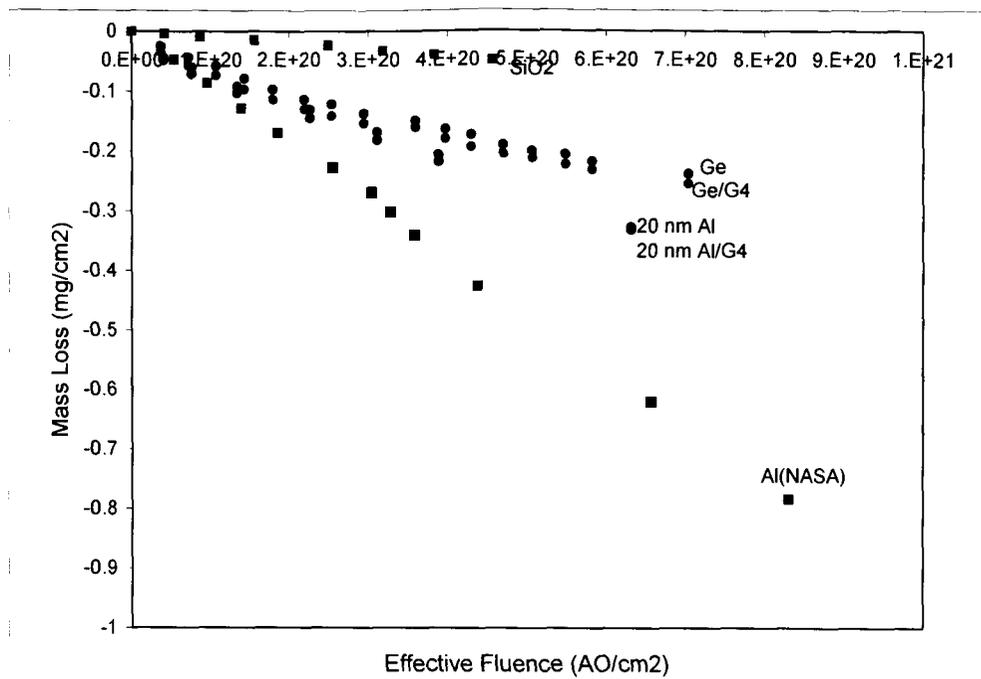
Figure 1: Mass loss of various coating materials on Kapton H as function of effective fluence.

The dendrimer had negligible effects on all examined coating materials, which could be due to limited dendrimer interaction with the Kapton H and/or coating material. Further morphological investigations are required to determine whether the dendrimer impacts thin film growth on Kapton H and for which coating materials. The SiO_2 coating provided the best protection. However, a dramatic effect was observed on the Al films, where the evaporation in UHV environment significantly improved the mass-loss of Kapton. The 20 nm Al film evaporated within a UHV environment provided better protection than the ~250nm Al film produced by evaporation. Figure 2(a) is a plan-view TEM image of the Al film produced by NASA where the film consists of many fine grains. Figure 2(b) is the same film after all of the Kapton had been ashed away in the RF plasma, where pores are noted in the film. Figure 3 is a high resolution electron microscope image of the silica coating, where the selected area diffraction pattern (top inset) and Fourier transform of the HREM image (bottom inset) confirm the amorphous structure of the silica film.
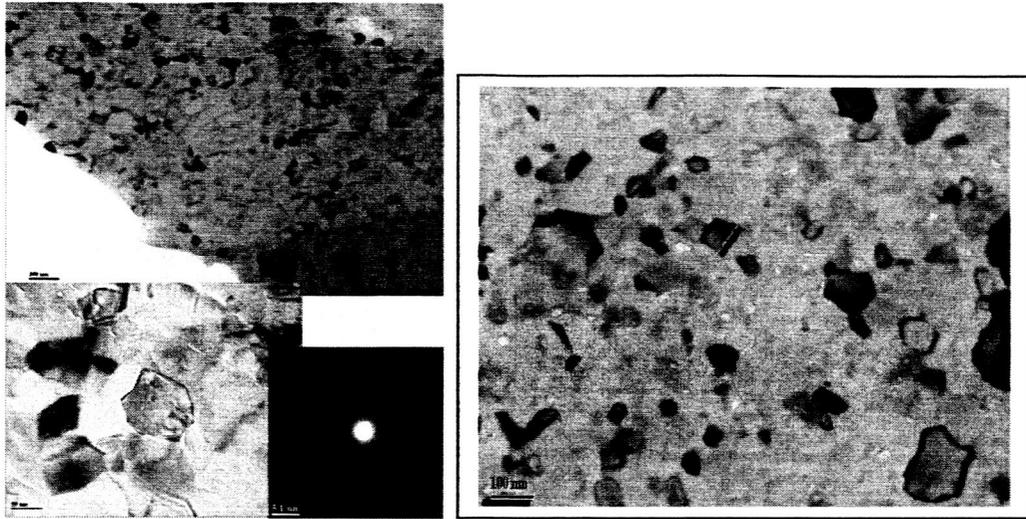
Figure 2(a): Plan view bright field images and selected area diffraction pattern of the pristine Al film from NASA Lewis. (b) The bright field image of the film after the Kapton was ashed completely off.
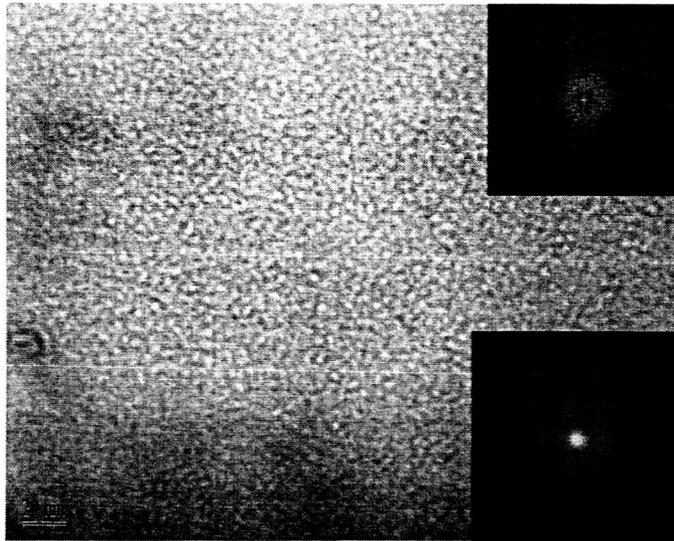

Figure 3: HREM image of the SiO$_2$ film after the Kapton H was completely ashed away. The top inset is the diffraction pattern and the lower inset is the Fourier transform of the HREM image.

Interestingly, the amorphous coating material, with no grain boundaries or defects, provided the best protection from atomic oxygen attack. Further studies on the grain structure of the UHV-evaporated Al films are being pursued to characterize the differences between the film structures that led to the vast improvement of the Al film protection. Further structural characterizations are needed to better identify the relationship between the defect structure and

protection of the underlying polymer in the LEO environment as well as provide fundamental information on the oxidation mechanisms by atomic oxygen.

Name: **Donald F. Zeller**
Education: MSEE
Massachusetts Institute of Technology

Permanent Position: Associate Professor, Engineering Technology
Cleveland State University

Host Organization: Instrumentation and Controls Division
Colleague: 5510/Gustave C. Fralick

Assignment:

Multifunction Sensor Algorithm Development

A multifunction sensor has been developed in the Sensors and Eelctronics Technology Branch. It is capable of measuring heat flux, surface temperature, and, in principle, strain magnitude & direction, while compensating for the apparent strain due to changes in operating temperature. In order to achieve this strain measuring capability, Mr. Zeller will work on improving the signal processing algorithm to include several special cases, such as when the principal strain axis lies either parallel to or perpendicular to one of the arms of the sensor. In addition, he will implement a GUI to make the sensor more user friendly.

Research Summary Submitted by Fellow:

Develop a National Instruments LabView Based Automated Testing System for Testing Thin Film Multifunctional Sensors

The Instrumentation and Controls Division of NASA GRC is developing multifunctional thin film sensors for high temperature (up to 2000 degrees C) applications. A multifunctional thin film sensor is a single sensor that measures strain, temperature, and heat flux at the same time. Presently, testing these sensors involves many operator data entry operations and setup activities. This is especially true in the case of "static" strain testing that requires that a variable stress load be applied manually. The main shortcoming with this manual testing is lack of accuracy and repeatability.

Automating the testing procedure can eliminate these shortcomings and consists of the following:
- Communications with the Keithley SourceMeter for setting, adjusting and monitoring source current to the strain gauge sensors
- Communications with the Precision Filters instrumentation amplifier system for setting gains, selecting filter cut off frequency, suppressing zero voltages (bias voltages), and adjusting offsets -- as well as monitoring all these parameters

- Communications with the static testing positioner in order to increment and cycle through steps of stress loading
- Selection and automatic start/stop and abort of static or dynamic testing
- Mathematical operations to implement theoretical analysis equations for strain calculations
- Automatic storage of all test data in Excel compatible file format with time and date stamp and run number stamp
- (Future) Communications with dynamic testing speed controller
- (Future) Communications with oven temperature controller

National Instruments LabView is a PC based software development package for data acquisition and control applications and provides all the functionality to implement the automatic testing requirements listed above.

Developing the LabView program for automated multifunctional sensor testing involved the following:
- Verifying the sensor signal integrity by examining the hardware system including amplifier signal processing, signal connections, noise levels and filtering
- Developing an automated positioning system for static testing
- Formatting the software application in a "menu selection" style to minimize operator actions and inputs
- Implementing mathematical calculations with adequate resolution
- Development a file naming and accessing operation for storage test run data results
- mplementing communication routines in software for communicating with Keithley and Precision Filters

The major innovations or improvements associated with this project are the following.
1. Worked with Precision Filters to develop a software interface with LabView for controlling and recovering Zero Voltage Suppress parameter for all strain signal channels
2. Worked with Keithley Instruments and National Instruments to implement an IEEE 488 communications interface with Keithley SourceMeter from LabView
3. Designed and implemented a mechanical mounting for OptoSigma micropositioner to be used in static testing of multifunctional thin film sensors
4. Designed LabView communications interface and application commands to control OptoSigma micropositioner automatically during static testing
5. Implemented strain calculation equations using LabView Function Node that allows equations to be written in more traditional text statement format rather than graphical format. This simplified format provided insights into the theory and calculations regarding strain angle.

Name: **Michael L. Zellers**
Education: BS, Computer and Information Science
Cleveland State University

Permanent Position: Instructor, Computer Information Systems
Lorain County Community College

Host Organization: Computer Services Division
Colleague: 7150/Linda M. McMillen

Assignment:

ResPlan Database

Develop a Project Management database.

Research Summary Submitted by Fellow:

Main Project

The main project I was involved in was new application development for the existing CISO Database (ResPlan). This database application was developed in Microsoft Access. Initial meetings with Greg Follen, Linda McMillen, Griselle LaFontaine and others identified a few key weaknesses with the existing database. The weaknesses centered around that while the database correctly modeled the structure of Programs, Projects and Tasks, once the data was entered, the database did not capture any dynamic status information, and as such was of limited usefulness. After the initial meetings my goals were identified as follows:

- Enhance the ResPlan Database to include qualitative and quantitative status information about the Programs, Projects and Tasks
- Train staff members about the ResPlan database from both the user perspective and the developer perspective
- Give consideration to a Web Interface for reporting. Initially, the thought was that there would not be adequate time to actually develop the Web Interface, Greg wanted it understood that this was an eventual goal and as such should be a consideration throughout the development process.

The following is a summary of the work done towards each of the goals:

Enhance the ResPlan Database to include qualitative and quantitative status information about the Programs, Projects and Tasks

After reviewing the database and based on conversations, I came to the conclusion that there was no need to re-write the application, as what was there was correct (although there were some naming inconsistencies). The database simply needed some additional components to make it more functional.

First Priority: Capture and Present Qualitative Status Information (Stoplight Status).
I created the required database tables as well as the necessary user interface to allow the users to maintain these tables. I also created 2 formats of the Stoplight reports which both export the information into Excel, duplicating the formats previously used. Allowing the data to be stored in a database and generating the required Excel Workbooks is expected to streamline the process of creating the monthly reports.
Second Priority: Capture and Present Quantitative Status Information (Cost and Workforce Information)
I created the required database tables as well as the necessary user interface to allow the users to maintain these tables. I also created 2 reports – Cost and Workforce - which both export the information into Excel, duplicating the formats previously used. A mechanism was created to allow the users to capture additional quantitative status information and to design additional reports should the requirements change. A mechanism was created to allow the importing of financial data from Excel spreadsheets which CISO receives which should allow for quicker and less error-prone entry of data. Allowing the data to be stored in a database and generating the required Excel Workbooks is expected to streamline the process of creating the monthly reports.

Train staff members about the ResPlan database from both the user perspective and the developer perspective
I conducted two kinds of training sessions: user and developer. Several of each kind of training session was held. The user training sessions focused on the normal usage of the database to perform ordinary job functions. The developer training sessions focused on the internals of the application – what programming techniques were used – to assist those who will be supporting the application after I leave. Additionally, I prepared documentation – both on the user level and developer level.

Give consideration to a Web Interface for reporting
Initially, it was stated that an eventual goal would be to have a web interface for the reports that come from the ResPlan database. It was not expected to be addressed this summer. However, because progress was quickly made on the other priority items, I was able to develop a Web Interface in PHP. The interface dynamically creates graphs from the database using PHP. For me, this was the most technically satisfying part of the project, as I have never worked in PHP before, nor dynamically generated graphs in any web-based scripting language.

Secondary Projects
When time allowed I worked on a number of other projects, they included:
• Working with Gail Perusek (my colleague last year) in the SDL to enhance the SDL Calendar application's time entry. This application was my project as part of the 2002 NFFP.

- Worked with Del Simonovich and Pete Wheeler to develop a pilot web-based application to allow visitors to request Access to the GRC Wireless Network.
- Develop a small contact database for CISO.
- Assisted and mentored my colleague, Linda McMillen, by resolving a number of support issues in a number of environments including Microsoft Access, Microsoft Project and Web Development (JavaScript).

Conclusions

This was my second summer at Glenn Research center and again was a very enjoyable and stimulating experience. Beyond the project I worked on, this is a wonderful environment and nearly everyone I dealt with was extremely helpful and I offer my gratitude. For example, I was able by contact with others in my building, to learn a lot about assistive technologies. While this was not part of my stated project, being in this environment provided this exposure that will enrich my classroom teaching.

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APPENDIX A

2003 LECTURE SERIES

2003 LECTURE SERIES

June 6
Probabilistic Analysis of Gas Turbine Field Performance
And
Gust Response Analysis of a Turbine Cascade
Rama S. R. Gorla
Department of Mechanical Engineering
Cleveland State University

June 13
Laboratory Experiments in Space
Joseph M. Prahl
Chair, Department of Mechanical and Aerospace Engineering
Case Western Reserve University

June 20
Energy Performance for Oberlin College's Lewis Environmental Center
John H. Scofield
Chair, Department of Physics and Astronomy
Oberlin College

June 27
Low Temperature Electronic Components and Systems for Deep Space Missions
Malik E. Elbuluk
Department of Electrical Engineering
University of Akron

July 11
Probabilistic Design and Reliability Analysis of Brittle MEMS Structures Using the NASA CARES/Life Code
Osama M. Jadaan
Department of General Engineering
The University of Wisconsin-Platteville

July 18
Modeling and Crack Detection in Rotating Shafts
Jerzy Sawicki
Department of Mechanical Engineering
Cleveland State University

July 25
Progress in Carbon Nanotube Synthesis
Thomas M. Ticich
Department of Chemistry
Centenary College of Louisiana

August 1
High Temperature Shape Memory Alloys
Michael J. Kaufman
Department of Materials Science and Engineering
University of Florida

August 8
Laser Tweezers
Baha Jassemnejad
Department of Physics and Engineering
University of Central Oklahoma