Status Report

...iod June 1988 to April 1992

...Carolina State University
and
...rolina A&T State University

...SSION RESEARCH CENTER

...pace Engineering Research Center
...by NASA Grant NAGW-1331

...onautics and Space Administration
...eronautics and Space Technology
Code RS
...ashington, DC 20546

...R. DeJarnette, Director
...Mission Research Center
...Carolina State University
...aleigh, NC 27695-7921

April 1992

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North Carolina State University
and
North Carolina A&T State University

MARS MISSION RESEARCH CENTER

a University Space Engineering Research Center
supported by NASA Grant NAGW-1331

National Aeronautics and Space Administration
Office of Aeronautics and Space Technology
Code RS
Washington, DC 20546

Fred R. DeJarnette, Director
Mars Mission Research Center
North Carolina State University
Raleigh, NC 27695-7921

April 1992

EXECUTIVE SUMMARY

The Mars Mission Research Center (M^2RC) is one of nine University Space Engineering Research Centers established in June 1988 by NASA's Office of Aeronautics and Space Technology to broaden the nation's engineering capability to meet the critical needs of the civilian space program. It includes North Carolina State University (NCSU) at Raleigh and North Carolina A&T State University (A&T) at Greensboro. The goal of the Center is to focus on research and educational technologies necessary for planetary exploration, especially transportation to and from our Moon and Mars. The research combines mission analysis and design, hypersonic aerodynamics, structures and controls, composite materials, and fabrications. This report covers activities of the Center from June 1988 to April 1992.

The Center supports 26 graduate students, 29 undergraduates, 27 faculty and 6 staff. An additional 88 undergraduates worked on four special projects.

Over the past four years, the Center has graduated 66 B.S., 35 M.S., and 25 Ph.D. students. The faculty and students published 244 articles of which 71 are refereed journal publications. One patent was granted, one is under review, and two applications have been filed.

Three facilities at A&T were renovated and a new 7,000 square foot facility was occupied at NCSU in October 1991. Five laboratories have been developed - composite processing and fabrication facility (A&T), materials testing (A&T), weaving (NCSU), braiding (NCSU), and structures (NCSU).

During the past two years, the Center added a new dimension to its program - special projects which involve analysis, design, construction, and testing. The first two projects were full-scale research models of a Mars aerobrake and the HL-20 Personnel Launch System. Both projects received considerable news coverage and appeared in national publications. Additional projects include a model of a Mars Excursion Vehicle, an Orbiter Ejector, and a Remotely Operated Vehicle. The Orbiter Ejector is scheduled to fly on Shuttle Flight STS-47 in October 1992. Special projects have increased undergraduate student participation and provided a mechanism for more interaction between the Universities, NASA Centers, and industries.

The faculty developed 26 new courses related to the activities of the Center. They conducted four workshops on Interplanetary Spacecraft, Lunar/Mars Aerobrakes, Spacecraft Controls, and Aerodynamic Heating.

The Outreach Program has developed into a significant component of the Center. Faculty and students have conducted 12 tours of facilities and given 67 lectures to schools (grades k-12) and civic organizations.

Dr. Walberg conducted an aerobrake design methodology study with the groups in the Center. This study combined all the technical areas of the Center in an integrated design to determine where the technologies were applicable to aerobrakes.

Funding from NASA was \$7.8 million with an additional cost sharing of \$2.7 million from NCSU and A&T for the period June 1988 to October 1992. The faculty have obtained supplemental funding of \$7.1 million in contracts and grants. This is indicative of the progress of the Center towards becoming self-sufficient.

The Center plans to initiate two new thrusts in 1992. With the increased interest in *nuclear propulsion*, we plan to expand the mission analysis and design and hypersonic aerodynamics groups to include studies of nuclear electric and nuclear thermal propulsion systems. Near term space missions involve *robotic exploration* of our Moon and Mars. We plan

to add a faculty member in the robotics area to work with Dr. Gordon Lee on robots and mini-rovers. The new thrusts will be coordinated with the Office of Exploration, Lunar/Mars Project Office at NASA Johnson Space Center, and the SEI Office at NASA Langley Research Center.

Over the past four years the Mars Mission Research Center has developed academic and research programs which are making significant contributions to the space program. The enthusiasm of the students and faculty continues to grow, and we look forward to even greater challenges in the Space Exploration Initiative.

INTRODUCTION

The Mars Mission Research Center includes North Carolina State University (NCSU) at Raleigh and North Carolina Agricultural and Technical State University (A&T) at Greensboro. The goal of the Center is to focus on research and educational technologies necessary for planetary exploration, especially transportation to and from our Moon and Mars: for the near term, robotic exploration and for the far term, human exploration.

The Mars Mission Research Center (M^2RC) can trace its origins to August 1987 when NASA issued an RFP for universities to propose research and training programs to broaden the nation's engineering capability to meet the critical needs of the civilian space program. Faculty at NCSU requested faculty at A&T to join with them in submitting a proposal which would build on the strengths of the two universities. In particular, NCSU had an on-going program in Hypersonic Aerodynamics and one of the nation's premier Textiles Colleges, while A&T had established a Center for Composite Materials Research.

A cooperative effort produced a strong proposal which was evaluated in an elaborate reviewing process by NASA. Of the 115 total proposals submitted, our Center was one of 25 selected for an on-site visit by a team of NASA evaluators in April 1988. NASA then selected nine universities to fund for a minimum of five years, provided their performance was satisfactory. We were delighted to have been selected as one of the nine Centers, and the cooperation between NCSU and A&T has been outstanding. The Administrations of both universities have provided the Center with strong support and cost-sharing.

The Mars Mission Research Center will complete its fourth year in July 1992. It has grown from 14 faculty members, 8 graduate students, and 9 undergraduate students to the current 27 faculty, 26 graduate, and 30 undergraduate students. Originally, the Center focused on the areas of hypersonic aerodynamics, composite materials, and light-weight structures. As the Center grew, new areas were added -- mission analysis, design, and spacecraft controls. In addition, the composite materials group was reorganized into two groups -- composite materials and fabrication methods. The current Center structure was formed to provide better balance of personnel and to facilitate more coordination between the research areas.

Students and faculty spend part of their time on-site at one of the NASA Centers or participating industries. Included are NASA's Ames and Langley Research Centers and McDonnell Douglas Space Systems Company at Huntington Beach, California. The interactions with these organizations expose the students to world-class researchers and facilities, as well as provide thesis and dissertation topics on the cutting edge of technology. We plan to increase the interaction with other NASA Centers and industries in the future.

During the past two years, the Center added a new dimension to its program -- special projects which involve analysis, design, construction, and testing. The first two projects were full-scale research models of a Mars aerobrake and the HL-20 Spaceplane. They were followed by a Mars Excursion Vehicle, Orbiter Ejector, and Remotely Operated Vehicle. These projects have increased student participation, especially undergraduates, and provided a mechanism for more interaction between NCSU and A&T as well as the research groups.

The past four years have been exciting and challenging for students and faculty. We look forward to even greater challenges in the Space Exploration Initiative.

This report presents activities of the Center from its beginning (June 1988) to April 1992.

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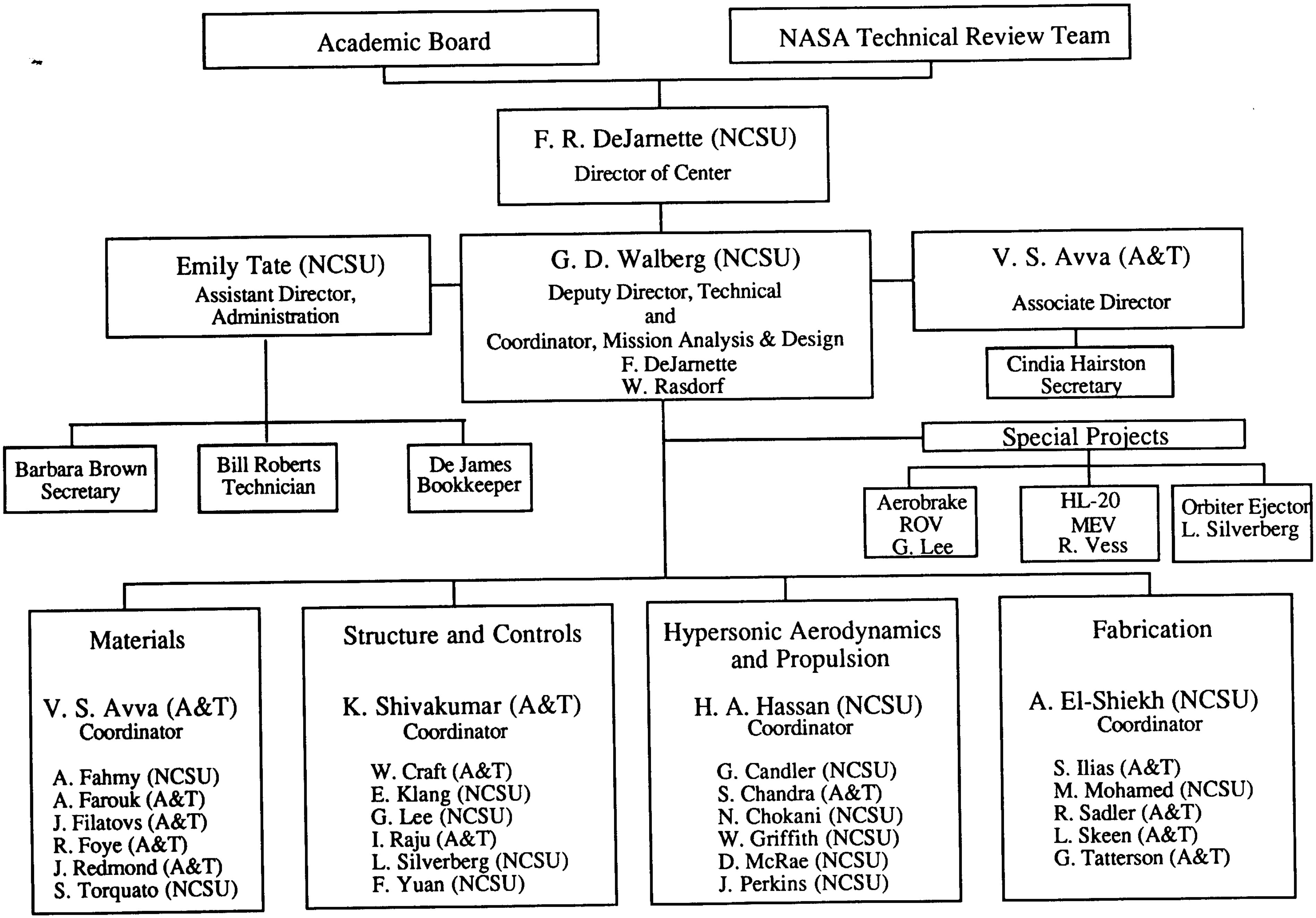

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ACADEMIC BOARD

PURPOSE:

1. Work with Center Director to insure that the research and academic programs are consistent.
2. Coordinate personnel, space, and equipment requirements of the Center.

MEMBERSHIP:

Deans and Department Heads of Participating Faculty

CHAIRPERSON:

Rotating for Three-Year Period

CURRENT MEMBERSHIP:

Dean R. A. Barnhardt, Dean of Textiles, NCSU, Chairperson

Dean Wilbur Meier, Dean of Engineering, NCSU

Dean H. L. Martin, Dean of Engineering, A&T

Dr. J. A. Bailey, Head of Mechanical and Aerospace Engineering, NCSU

Dr. E. D. Brill, Head of Civil Engineering, NCSU

Dr. W. J. Craft, Head of Mechanical Engineering, A&T

Dr. J. J. Hren, Head of Materials Science and Engineering, NCSU

Dr. Frank King, Head of Chemical Engineering, A&T

Dr. C. D. Livengood, Head of Textile Engineering, Chemistry, and Science, NCSU

MARS MISSION RESEARCH CENTER

Director: Fred R. DeJarnette (NCSU)
Deputy Director: Gerald D. Walberg (NCSU)
Associate Director: V. Sarma Avva (A&T)

Mission Analysis and Design
Gerald Walberg, NCSU, Coordinator
Fred R. DeJarnette, NCSU
William Rasdorf, NCSU

Hypersonic Aerodynamics
Hassan Hassan, NCSU, Coordinator
Graham Candler, NCSU
Suresh Chandra, A&T
Wayland Griffith, NCSU
Scott McRae, NCSU
John Perkins, NCSU

Structures and Controls
Kunigal N. Shivakumar, A&T, Coordinator
Bill Craft, A&T
Eric Klang, NCSU
Gordon Lee, NCSU
Ivatury Raju, A&T
Larry Silverberg, NCSU
Fuh-Gwo Yuan, NCSU

Materials
Sarma Avva, A&T, Coordinator
Abdul Fahmy, NCSU
Alamgir Farouk, A&T
Juri Filatovs, A&T
Ray Foye, A&T
Jim Redmond, A&T
Sal Torquato, NCSU

Fabrication
Aly El-Shiekh, NCSU, Coordinator
Shamsuddin Ilias, A&T
Mansour Mohamed, NCSU
Bob Sadler, A&T
Leon Skeen, A&T
Gary Tatterson, A&T

HL-20 Research Model and Mars Excursion Vehicle Projects
Robert Vess, NCSU, Project Director
Dean Driver, NCSU

Orbiter Ejector Project
Larry Silverberg, NCSU, Project Director

Aerobrake and Remotely Operated Vehicle Projects
Gordon Lee, NCSU, Project Director

Other faculty participating in but not supported by M²RC:

Mission Analysis and Design
Tony Danby, NCSU

Hypersonic Aerodynamics
ND Chokani, NCSU
Lonnie Sharpe, A&T

Structures and Controls
Bert Chukwu, NCSU
Wes Doggett, NCSU
Tom Miller, NCSU

Current Graduate Students in the Mars Mission Research Center (58 MS, 38 PhD)

North Carolina State University (44 MS, 37 PhD)

Name	Advisor	Previous University	Degree Program
Grigorios A. Alexopoulos	Hassan	North Carolina State University	MS
Robert A. Baurle	Hassan	North Carolina State University	MS
Lance H. Benedict	Griffith	North Carolina State University	PHD
Rusty A. Benson	McRae	North Carolina State University	PHD
Frank J. Brauns	Hassan	North Carolina State University	MS
Patrick W. Canupp	Candler	North Carolina State University	MS
Cheryl L. Carlson	Mohamed	Auburn University	MS
Mark C. Cassada	Lee	North Carolina State University	MS
Joel E. Cate	Klang	North Carolina State University	MS
Pusheng Chen	El-Shiekh	China University	PHD
K. Choi	Yuan	State University of New York	PHD
Eric J. Clark	Lee	Virginia Polytechnical Institute & State Univ.	MS
Stephen P. Cook	Chokani	North Carolina State University	MS
Aaron B. Cozart	Perkins	North Carolina State University	MS
Paul S. Dekker	Lee	University of California at Berkley	
Larry C. Dickinson	Mohamed/Klang	North Carolina State University	MS
Glen P. Doggett	Chokani	North Carolina State University	MS
Ryan Donnally	Lee	North Carolina State University	MS
Donna Downs	El-Shiekh	North Carolina State University	MS
Jack R. Edwards	McRae	North Carolina State University	PHD
Charles C. Fenno, Jr.	Hassan	North Carolina State University	PHD
Thomas Fetner	El-Shiekh	North Carolina State University	MS
Robert G. Gabel	Fahmy	Institute of Textile Technology	PHD
Jianhua Gao	El-Shiekh	University of Arkansas	PHD
Gerrit Gest	Lee	North Carolina State University	MS
Shen S. Giang	Lee	Taiwan University	PHD
Nathan M. Gittner	Chokani	North Carolina State University	MS
Pu Gu	Mohamed	China Textile University	PHD
Jay D. Hardin	Perkins	North Carolina State University	MS
David B. Hash	Hassan	North Carolina State University	MS

North Carolina State University (continued)

Name	Advisor	Previous University	Degree Program
Basil Hassan	Candler	North Carolina State University	PHD
John A. Hatifeld	Candler	Auburn University	PHD
Brian R. Hollis	Griffith	North Carolina State University	PHD
Mary L. Hudson	Candler	Stanford University	PHD
Clint L. Ingram	McRae	North Carolina State University	MS
Kenneth M. Jones	DeJarnette	North Carolina State University	PHD
Jong-Bong Kang	Fahmy	Seoul University	PHD
James A. Keenan	Candler	West Virginia University	PHD
Insun Kim	Chokani	University of Texas	PHD
Hanke Kim	Yuan	Yonsei University	PHD
Carl W. Kirby	Klang	North Carolina State University	MS
Dean A. Kontinos	McRae	North Carolina State University	PHD
Mark Lake	Klang	Old Dominion	PHD
D. Brian Landrum	Candler	Texas A&M	PHD
Lyle Lee	Lee	North Carolina State University	MS
Joseph Mensah	Fahmy	North Carolina Central University	MS
John L. Meyer	Silverberg	North Carolina State University	PHD
William E. Milhollen, II	Chokani	North Carolina State University	MS
Randi A. Muir	Mohamed	North Carolina State University	MS
Andrew Myers	Lee	North Carolina State University	MS
Joel D. Nicholson	Silverberg	North Carolina State University	MS
Roger Ogburn	Lee	North Carolina State University	MS
John R. Olds	Walberg	Stanford	PHD
David P. Olynick	Hassan	North Carolina State University	PHD
Donald B. Owens	Perkins	North Carolina State University	PHD
James D. Packard	Griffith	North Carolina State University	PHD
Kisoon Park	Silverberg	U. S. Naval Post Grad School, Monterey, CA	PHD
Eric R. Perrell	Candler	University of Tennessee/Space Institute	PHD
Brian Potter	Yuan	North Carolina State University	MS
Chris L. Radcliff	McRae	University of Illinois	PHD
James M. Redmond	Silverberg	North Carolina State University	PHD
Rona L. Reid	El-Shiekh	North Carolina State University	MS
Hughart O.C. Roberts	Lee	North Carolina State University	MS
David F. Robinson	Lee	North Carolina State University	MS

North Carolina State University (continued)

Name	Advisor	Previous University	Degree Program
Robert Robinson	Lee	North Carolina State University	MS
Stacey G. Rock	Candler	Auburn University	MS
Elsaid H. Salem	Mohamed	North Carolina State University	PHD
M. C. Selek	Yuan	University of Istanbul	MS
Simon D. Senibi	Klang	A&T State University	PHD
Lisa K. Spainhour	Rasdorf	North Carolina State University	PHD
Rebecca L. Squires	Chokani	North Carolina State University	MS
Robert J. Stanley	Lee	North Carolina State University	MS
Theresa A. Stone (Hurban)	Rasdorf	North Carolina State University	MS
Jeff C. Taylor	Hassan	North Carolina State University	PHD
Cirrelia R. Thaxton	El-Shiekh	North Carolina State University	MS
Stefan Voss	Fahmy	University of North Carolina at Charlotte	MS
Gregory N. Washington	Lee	North Carolina State University	PHD
Jeffry C. Windsor	Lee	Louisiana State University	MS
S. C. Wu	Yuan	National Taiwan University	MS
Terry W. Young	Hassan	North Carolina State University	MS
Seungil Yu	McRae	North Carolina State University	PHD

A&T State University (12 MS, 1 PhD)

Name	Advisor	Previous University	Degree Program
Harold Allen	Shivakumar	A&T State University	MS
Scott Crews	Farouk	North Carolina State University	MS
Kevin Davie	Avva	North Carolina State University	MS
Marvin Dixie	Sankar	A&T State University	MS
Eric Goforth	Craft	A&T State University	MS
Yashpal Hanspal	Avva	Muslim University of India	MS
Malcolm Lyon	Avva	A&T State University	MS
Jaret Riddick	Shivakumar	Howard University	MS
Davis Rogers, Jr.	Raju	A&T State University	MS
Simon Senibi	Avva	North Carolina State University	PHD
Michael Siegel	King	North Carolina State University	MS
Michael Walton	Raju	North Carolina State University	MS
Prentiss Ward	Dunn	A&T State University	MS

George Washington University/JIAFS (2 MS)

Name	Advisor	Previous University	Degree Program
Gregory Fruth	Walberg	Univ. of California at Berkley	MS
Jason Shimshi	Walberg	Boston University	MS

Current Undergraduate Students of the Mars Mission Research Center (59)

North Carolina State University (31)

Name	Advisor	Department
Andy M. Barefoot	Mohamed	Textile Engineering and Science
Fredrika M. Becker	El-Shiekh	Textile Management
Keith S. Black	El-Shiekh	Textile Technology
Terry G. Brasier	El-Shiekh	Textile Management
Lloyd B. Bruce	Mohamed	Textile Engineering
Craig Crowther	Lee	Mechanical Engineering
Mary B. Everett	Rasdorf	Civil Engineering
Christopher W. Hipps	El-Shiekh	Textile Science
Rodney L. Hockaday	El-Shiekh	Textile Management
Vincent Huckle	Lee	Aerospace
Brian L. Jacobs	Hassan	Aerospace
Franklin M. Kriegsman	El-Shiekh	Textile Science
Mary E. Locklear	El-Shiekh	Textile Management
Robert J. Long	Vess	Aerospace
Jerome N. Lucky	El-Shiekh	Textile Engineering
Thomas C. Martin	El-Shiekh	Textiles
Brian McCallister	Lee	Mechanical
Ray P. McCormick	Mohamed	Textile Engineering and Science
Chris Moore	Lee	Mechanical
Todd M. Morgan	Mohamed	Textile Engineering and Science
Andrew T. Mueller	Lee	Electrical
Robert Nance	Klang	Aerospace
John Page	Lee	Mechanical
Joseph W. Park	Mohamed	Textile Engineering and Science
Claudia B. Perich	El-Shiekh	TAM
Kaaryn W. Rogers	Rasdorf	Civil Engineering
Eric L. Scott	Hassan	Computer Science
Alan C. Shepard	Vess	Aerospace
Steve Strand	Lee	Mechanical
My Hao Tran	El-Shiekh	Textiles
Jeff Windsor	Lee	Aerospace

A&T State University (28)

Name	Advisor	Department
Deryl Alexander	Avva	
Tonya Armstrong	Avva	Mechanical
Anthony Berry	Lai	
Thomas Blunk	Avva	Mechanical
Bruce Bradley	Klette	
Jennie Caudle	Avva	
Donna Day	Dunn	Mechanical
Frederick Dixon	Ofori	
Sonya Drumgoole	King	
Jelvoner Ellison		Chemical Engineering
Charles Englebert	Min	Mechanical
Connie Gray	Clark	Chemical Engineering
Angela Hardy	King	Chemical Engineering
Charles Hickman	Avva	Mechanical
Jerry Hoggard	Kelkar	
Raphael Jones	Min	Mechanical
Osborne Martin	Min	
Dana McMillan	Min	Mechanical
Nurhan Menderes	Dunn	Mechanical
Craig Miller	Filatovs	Mechanical
Kimberly Powell	Bailey	
Pedro Santiago	Kelkar	Mechanical
Nanette Smith	King	Chemical Engineering
Erica Smith	Pai	Mechanical
R. Wilson Stabler	Clark	
Roy Staggers	Dunn	
Gregory Stanton	Bailey	
Andrew R. Thomas	Filatovs	

NOTE: Students who worked on specialprojects are not included in the list above, but they are listed at the end of the section on special projects.

FACULTY AND STUDENTS SUPPORTED BY M2RC

(All U.S. Citizens, Minorities in Parentheses)

Five-Year Goals and Actual Numbers

Year	Faculty	Graduate Students	Undergraduates
1988-Actual	14(0)	8(1)	9(7)
1988-Goal	14(0)	14(3)	12(6)
1989-Actual	21(1)	15(4)	17(9)
1989-Goal	21(2)	15(4)	12(6)
1990-Actual	27(2)	22(4)	30(11)
1990-Goal	22(4)	20(7)	12(7)
1991-Actual	27(1)	26(4)	30(8)
1991-Goal	23(4)	20(7)	12(8)
1992-Goal	24(5)	20(8)	12(8)

Current Faculty and Students

	Faculty	Graduate Students	Undergraduates
NCSU	15 (1)	20 (3)	12 (2)
A&T	12	4 (1)	18 (6)
GWU		2	
TOTAL	27 (1)	26 (4)	30 (8)

Participating Colleges and Departments

College	Departments
ENGINEERING	Mechanical and Aerospace, Civil, Electrical and Computer, Material Science and Engineering, Chemical
TEXTILES	Textile Engineering, Chemistry, and Science, Textile Materials and Management
PHYSICAL & MATHEMATICAL SCIENCES	Mathematics, Physics
TECHNOLOGY	Manufacturing Systems (for projects)

Appendix A lists all students graduated who worked with the Center and the thesis and dissertation titles.

RESEARCH OVERVIEWS

Research overviews for the five technical groups in the Center are given on the pages which follow. Descriptions of the research projects are given in the format of technical highlights in Appendix B.

MISSION ANALYSIS AND DESIGN

G. Walberg, Coordinator

The research in mission analysis and design has been carried out in three primary areas: (1) the comparative evaluation of various Mars mission scenarios studied by NASA, in the aerospace industry and here in the Mars Mission Research Center, (2) the assessment of aerobraking as a feasible strategy for reducing the energy requirements for Mars missions, and (3) the conceptual design and analysis of a Lunar-return aerobraking vehicle.

In the area of mission scenario evaluation, the starting point was a review of prior and ongoing studies in NASA and the aerospace industry. This was followed by complementary M^2RC studies and the identification of near consensus mission profiles and vehicle designs for the baseline opposition-class Mars missions. Physiological constraints on deceleration during aerocapture were assessed and Earth-return aerobraking studies were carried out to identify the preferred strategies for manned return from Mars.

Next, detailed studies of parking orbit precession and lifetimes were carried out for Mars and the Moon and optimal strategies for Martian ascent and rendezvous were defined.

Most recently, a complete survey of both near term and far term Mars mission scenarios was carried out and the primary candidates for initial manned missions were compared with regard to (a) exposure to reduced gravity, (b) exposure to space radiation, and (c) initial mass in low Earth orbit. It was shown that the choice of initial mission scenario depends to a large extent on the amount of physical deconditioning caused by long-term exposure to Martian gravity and that both chemical/aerobraking and nuclear thermal systems are strong candidates.

Aerobraking studies demonstrated the interaction between mission strategy and aerobrake design, identified mission opportunities compatible with aerobraking and demonstrated large potential mass savings. Studies were carried out which showed that the greatest mass savings occurred for missions with relatively high Mars entry velocities. One significant finding was that aerobraking is specially beneficial for fast-transfer conjunction class missions.

Various flowfield analysis techniques were studied to assess their ability to predict accurately the aerodynamic characteristics of aerobraking vehicles. The Sine-Squared Deficiency Method was shown to be significantly superior to Newtonian theory while still being simple enough for use at the conceptual design level. As part of these studies, it was pointed out that the opportunity exists to validate flowfield codes by carrying out highly refined CFD analyses of available flight and ground test data that have never been subjected to rigorous analysis. Several theses are presently being written based on such analyses.

The Lunar-return aerobrake design activity has been carried out to promote interactions between the Mission Analysis, Hypersonic Aerodynamics, Structures and Controls, and Materials and Fabrication Teams within the center. An aerobrake geometry similar to the Viking aeroshell was chosen and used as a focus for aerodynamic, structures and controls analyses. Three structural concepts-truss, semi-monocoque and honeycomb shell have been analyzed.

Distributions of aerodynamic loads and heating have been computed and a fuel-optimal control algorithm has been developed. A two-pass aerobraking strategy was developed which has the potential for producing significant reductions in aerobrake heating, aerodynamic loads and mass.

Future work in mission analysis and design will continue to address aerobraking Mars missions but will be broadened to include advanced propulsion systems, especially nuclear electric and nuclear thermal vehicles, as well as robotic Lunar and Mars missions. This research will be closely coordinated with the new research being carried out in the Hypersonic Aerodynamics Group on aerothermochemical analysis of nuclear electric and nuclear thermal systems, and the new research on robotics in the Structures and Controls Group.

Selected highlites from the Mission Analysis and Design research are presented in Appendix B.

Hypersonic Aerodynamics Research

H. A. Hassan, Coordinator

Hypersonic Aerodynamics research at the Mars Mission Research Center has two major objectives. The first is the development of analytical and computational tools needed to define the thermal environment for both Mars and Earth entry. This entails the efficient calculations of flows in the presence of thermal, chemical and radiation nonequilibrium using both continuum and Monte Carlo approaches. The task is being accomplished through the development of in-house codes that use a variety of computational techniques combined with appropriate grid adaptation and through the continual improvements of underlying physical models.

The second is the development of the instrumentation for, and the performing of, measurements in fluid flow facilities that are capable of simulating reentry flows. Because of the lack of facilities at the Center, we had to rely on facilities at NASA's Ames and Langley Research Centers and the Naval Surface Warfare Center at White Oak.

It became evident as a result of interaction with the above Centers that the flow quality of some of the existing experimental facilities leave a great deal to be desired. As a result, an effort is underway devoted to the development of modern techniques for the design of hypersonic nozzles. These methods are based on the complete or parabolized Navier-Stokes equations and not boundary layer/method of characteristic approaches.

Our hypersonic aerodynamics research is sufficiently mature so that we are now computing 3-D flows about candidate aerobrake configurations. The heat transfer and surface pressure distributions resulting from these computations are being used in our mission analysis, materials, and structures research.

Appendix B gives a summary of the advances and contributions made by our students and faculty. As may be seen from the summary, the depth and breadth of the Hypersonic research carried out has no parallel at any other university. In addition, course offerings in Hypersonic Aerodynamics and related areas make this University the premier university for training prospective leaders in this important area of research.

Structures and Controls Research

K. N. Shivakumar, Coordinator

The primary focus of the structures and controls research was to develop a technology base and guidelines to design weight efficient structures and their control systems for space applications, in particular for a manned mission to Mars. Although the technology developed in this program has wide applications in aerospace structures, the case studies were conducted on aerobrakes. The structures research was focused on three areas: design, analysis, and packaging of aerobrake structures; basic research to develop advanced theories and numerical methods to model nonlinear problems (material, deformation, and boundary); and damage tolerance design methodology for pressurized space structures. The aerobrake design was based on the "hot-cold" concept. The aerobrake structure was designed as a two layer system, an outer hot layer made up of a heat resistant thermal protection system (TPS) and the inner cold layer made up of aerospace structural material. The two critical design requirements of the aerobrake structures are the aerobrake mass (sum of structure, structural joints, and the TPS) must be less than 15% of the vehicle mass, and the local deformations of the structure must satisfy the pop-out deflection criteria of the rigid TPS (0.1 inch over a span of 40 inches). Several axisymmetric shell aerobrakes suggested by the aerodynamic configuration studies were analyzed. Three types of constructions, namely, composite tubular truss, shell-stringer, and sandwich concepts were considered. The linear stress and local-global buckling analyses were conducted, and the weight efficiency of different configurations and material systems was evaluated and compared with each other. An interesting conclusion from this study was that the mass (or the thickness) of the aerobrake is strongly dependent on the pop-out deformation criteria of the TPS. Test studies on a kinematically scaled 1/10 model of a sandwich honeycomb aerobrake are underway to verify the analysis and to understand the failure mechanisms. In addition, fundamental studies were undertaken in the area of stress analysis, buckling analysis, and new algorithms development. A higher-order shear deformable shell theory for nonlinear composite materials and buckling solutions for rectangular plates with cut-outs and partial support restraint were developed. New analysis methods and finite-element algorithms for vector and parallel processing supercomputers were developed. Existing finite-element codes are being rewritten for parallel processing computers. A finite-element algorithm and the code DYAN3D, based on the dynamic relaxation method, were developed for CRAY type parallel processing computers.

Research in the area of controls was focused on the development and implementation of controls algorithms on test articles representative of a variety of spacecraft (for example, lightly damped platforms, satellites, antennas, aerobrakes transfer vehicles). Two types of algorithms were developed, namely, impulse control for minimum fuel and minimum time performance and adaptive compensation. In the impulse control method the spacecraft performs a reorientation maneuver using minimum fuel or minimum time. The algorithms govern the switching of valves in the propulsive control system. In the adaptive compensation method, the spacecraft or space robotic system is controlled by assuming that either the dynamics of the system is partially unknown (model uncertainty), or the environment is unknown. For example, the mass of a payload attached to a manipulator can be unknown, or an aerobrake can be subjected to unknown aerodynamic disturbances. The ground test verification of the above control methods was conducted on flexible beams, multi-bay truss structures, aerobrake shells, and multilink robotic systems.

Specific research conducted by various investigators in the structures and controls group are summarized in Appendix B.

Composite Materials Research

V. Sarma Avva, Coordinator

Introduction :

The overall objective is to assess the suitability of textile and other composites as structural materials in the design of spacecraft components. The research topics in textile and other composite materials being addressed by the M^{2}RC faculty may broadly be divided into three areas, viz., (1) Modeling and analyses of textile preforms and composites, (2) testing for and evaluation of the basic mechanical properties of the textile composite materials, and (3) study of the mechanical behavior of some of the generic spacecraft components that are fabricated using the textile preform and traditional tape-laying technologies. Some of our colleagues in the processing and fabrication group are using various infiltration/molding techniques to achieve consistent properties from testing the 3-D textile composites.

Modeling and Analyses :

Prof. Filatovs' work, in part, is concerned with the study of the properties, structure, and the fracture toughness of 3-D braided composites. A number of property limiting correlations have been made in this study between the load condition and the structural features resulting in a rule based description of the failure process. In particular, worst-case conditions for runaway crack growth have been determined. The principal geometric features needed for modeling, such as fiber inclination, tow architecture, and fiber distribution and homogeneity, have been identified and a surface/volume mapping of the braid structure has been made. A simulation-modeling has also been made of the random packing of a typical braided structure to determine intra- and inter-tow packing densities.

Specimen geometries and testing procedures have been developed to measure the crack initiating force for various notch orientations. This force has a two to one ratio depending on whether the notch is parallel or perpendicular to the braid axis. A qualitative understanding of the fracture characteristics and a quantitative estimate of the critical energy release rate to initiate cracking have been determined. The influence of anisotropy and symmetry have been studied. The early stage energy absorbing mechanisms, and their sequence, have been identified. The tendency of braided composites to diffuse the damage over a wide volume makes the unscrambling of the contributions of specific mechanisms difficult. In order to reduce the effect of large volumes of inherently present brittle matrix, microballoons have been embedded in the matrix as crack path deflectors. Preliminary results appear promising.

Prof. Foye is concerned with the strength analysis of braids. Conventional laminate analysis is insensitive to most observed braid failure mechanisms. Unit cell analyses are complex and unproven for strength prediction. A simpler model is needed which predicts all the observed failure phenomena, cut edge effects, specimen size effects, tow size effects, open hole effects, and notch effects as well as braid geometry and constituent material property effects. Such a model is presently being developed based on a lattice beam element attached to similar adjacent elements by sets of discrete mechanical springs which model the interstitial matrix functions. The resulting analysis resembles that of a finite length beam on discrete shear, tension and moment spring supports.

Profs. Fahmy and Foye are also working to evaluate some of the thermal properties of composites. In particular, Prof. Foye has written a very general computer analysis program that predicts all the 3-D coefficients of thermal expansion for fabric reinforced composites. Experimental correlation has been obtained.

Prof. Fahmy's approach to predict the thermal conductivity of fibers and fibrous composites incorporates a variety of isotropic fibers in an epoxy matrix, each to produce an unidirectional composite of the same volume fraction (40%). A master curve was developed relating the transverse conductivity of the composite to that of the fiber. This master curve is then used to calculate the transverse conductivity of any fiber (whether isotropic or anisotropic) by measuring the transverse conductivity of the composite incorporating it. It was found that the above technique for transverse fiber conductivity while viable, can only be used for fibers that have conductivity ranging from an order of magnitude above to an order of magnitude below that of the matrix. Other master curves have to be produced with matrices of widely different conductivities. Experimental results of the P120 graphite reinforced composites were in agreement with analytical predictions for the unidirectional and cross-ply composites.

Prof. Fahmy was also studying to characterize the microstructural changes that occur when 3-D textile composites are thermally cycled and to evaluate the effect of such changes on the elastic, strength, and thermal expansion behavior. It was found that the principal effect of thermal cycling resulted in extensive cracking of the resin in the resin pockets of the preform composites and, to a lesser extent, cracking in the resin of the fiber tows. Cracks were transverse to the fibers as well as on the resin pocket-tow interface. No damage to the fibers was observed. Both the modulus and strength of the composites deteriorated with thermal cycling and the thermal expansion coefficients were reduced. Most of the changes occurred after a small number of thermal cycling with little or no change on further cycling. The changes in properties are attributable to changes in properties of the bulk resin, which were also determined, as well as deterioration of the resin/tow interface.

Prof. Foye is also involved in the analytical prediction of the changes in some of the thermoelastic properties of a fabric reinforced composite as a result of introducing interstitial voids and fillers in the bulk matrix. Through this study, a computer analysis method has been established for predicting the effects of interstitial matrix voids and fillers on the various elastic moduli and coefficients of thermal expansion of fabric reinforced composites. The analysis is applicable to a broad range of design problems related to composite struts and secondary structural elements of aerospace vehicles. It will provide guidance for the corresponding ongoing experimental work related to fabrication and testing of braids with filled resins.

Materials Testing and Evaluation :

Many factors affect the mechanical properties of the fiber-reinforced composite materials. In particular, in the case of textile composites, factors such as the quality of preform, 'tightness' of preform, braid angle, degree of curing, fiber volume ratio, specimen location, voids and air pockets, uniform density, uniform fiber distribution, and others affect the properties.

The research work of Prof. Ilias attempts to address on such factor, viz., to provide reliable data on fiber-volume content of graphite-epoxy textile composites. The fiber content of a composite must be determined to ascertain the apparent strength and modulus of the composite. It may be further used to evaluate the quality of a fabricated specimen. This work is an on-going activity.

It is a common understanding that 3-D textile composites may exhibit superior impact damage tolerance as compared to the traditional 2-D laminated and woven composites. Prof. Fahmy has undertaken a study to evaluate and compare the property retention after high velocity impact of 2-D ply and cloth laminates and 3-D woven composites, and to determine the usefulness of the four-point bending test in monitoring the property degradation. As expected, the findings are that the projectile impact caused significantly greater damage to 2-D composites than to 3-D composites. The superiority of the 3-D composites was more evident in strength retention than in modulus retention. The impact energy for barely visible damage and for penetration in all constructions of 3-D composites, and for cloth reinforced laminates did not vary much from one to the other but was much lower in the case of regular laminates. The easier to perform four-point bend test proved to be a sensitive and consistent way for assessing the impact damage.

In the design of aerospace components with any textile composites, the basic mechanical properties and the factors that affect these properties are to be evaluated. With this in the background, Prof. Avva has been evaluating the tensile properties of 3-D braided and, to a lesser extent, the woven composites fabricated from textile preforms. Since the braided composites are 'inherently' weaker in tension mode when compared with their 'equivalent' tape laminates, axial fibers were introduced in the 3-D braids to improve the mechanical properties further, and the preliminary test results are found encouraging. In order to improve the specific mechanical properties of the textile composites, a novel approach to fill the voids or 'excess' resin with glass microballoons was undertaken. Preliminary results indicate that the suggested approach has good potential to realize improved specific properties in textile composites.

Our experience to-date with 3-D textile composites indicates that novel or improved specimen fabrication techniques are necessary in order for these composites to compete with, or perhaps exceed, the capabilities of 'traditional tape laminates, including the 'unit' cost. With this in mind, a novel approach to fabricate axial test coupons from 3-D tubular geometries is being addressed. The specimen geometry falls between that of a 3-D braid and a triaxial braid. Initial experimental results are very promising in determining the mechanical properties of braided composites in a cost effective manner. Upon gaining additional experience with this technique, the fatigue behavior of this type of braided composite material will be studied.

Applications to Spacecraft :

As alluded to earlier, textile composites, on a selective basis, may have a good potential to replace either traditional metallic or tape laminates in the design of spacecraft structural components. The structural analysis group has been developing several aerobrake models suitable for transportation to Mars and, more recently, to the Moon. The processing and fabrication group has been building these as scale-down models for the purpose of model validation and testing. A Moon aerobrake model (1/10 scale) is being built using polyester resin, two fiberglass skins sandwiching a polyvinyl foam. Prof. Farouk will soon be instrumenting this Moon aerobrake model to test for shell deflections (or for local buckling) under an aerodynamic (pressure) loading. The ensuing results are expected to validate the analytical predictions.

Prof. Farouk is also evaluating the effectiveness of integrally braided or woven stiffened (two stiffeners) composite panels using experimental and analytical methods. The results are also being compared with results from testing 'equivalent' aluminum and fiberglass composite panels. Several sets of bending tests have been performed to assure repeatability. The analytical methods have been validated for an aluminum panel, for which the material properties are well established. Process induced variations in panel geometry require extensive normalization of test results. Detailed analyses, using FEM, unit cell modeling of constitutive properties, and beam theory have been used to cross-check all such normalizations. The final results, however, show excellent consistency and indicate that braids are more effective than weaves for use as reinforcements in the type and geometry of stiffened panels studied. The weakness of weaves can be explained by considering the fiber orientation within the composite, which shows that weaves expose the transverse side of fiber bundles to load, a direction in which the fibers are almost useless as reinforcement. However, other 3-D weave architectures may fare well in comparison to 3-D braids on a selective basis.

As an application, Prof. Filatovs is developing methods of joining and attachment for 3-D braided composites. The introduction of loads into these materials raises the issues of load concentration, clamp-up, and load distribution. It is planned to test coupons, tubes, and small components using commercial aircraft fasteners and fabricated joints. It is anticipated that a hybrid method involving braids, conventional laminates, and metal inserts will be required. Learning specimens have been fabricated and tested; braided tubes with filament-wound over-layers have been fabricated, as have node joints with inserts. Pull-out and shear-out tests have been made on braided coupons and T-sections. We have gained an intuitive sense of the material behavior and have some provisional data on bolt hole behavior. In addition to the need to fasten braided materials, their toughness and energy absorption may be advantageous for components, such as attachments, and in high impact areas. It is also important to study braided composites under realistic, and complex, load conditions.

Design with tubular geometry is basic in many aerospace structures using truss members. With this in mind, Prof. Foye was working to provide a program for minimizing structural weight and maximizing the critical safety margin for individual composite truss members. A computer program was written that presents graphically the results of changing fiber orientation angles and tube diameter on composite truss member design. The critical margins of safety from stress, stiffness and stability analyses are plotted for each incremental design change. The optimum design can be observed visually. This approach permits the design selection process to consider all forms of constraints such as lack of an adequate data base or cost and manufacturing considerations that are ignored in mathematical optimization routines. Many examples of truss member design were considered. Load and stiffness requirements were taken from prior aeroshell truss design studies. Modest savings in the weight of tension members were realized. Large savings were realized in compression members. Reorienting fibers had much less effect on truss weights than tube diameter changes. Average weight savings were in the 10 to 15% range with over 30% savings in some highly loaded compression members.

Future Plans :

We propose to continue our future research activities with advanced composite materials with applications to the aerospace components in the following major areas:

Materials Modeling and Analyses
Materials Testing and Evaluation
Applications to Aerospace Vehicles

Individual faculty have expressed their proposed future research plans on the brief technical highlights in Appendix B. Their proposed work, individually and collectively, is still under the above three major areas.

Complimenting the current and proposed individual areas of research are also the following overall thrusts that must be satisfied by the materials research group :

- The research must fit the needs of different generic propulsion mechanisms (Chemical/Aerobraking or Nuclear)
- Thin-walled pressure cylinders (tankage, life supporting modules, etc.)
- Optimum designs for truss members using a combination of conventional and textile technologies
- Optimum designs for structural members and sections
- Continue to study the basic factors that affect the mechanical properties of materials
- Develop rapid evaluation techniques to improve the quality of textile composite materials processing
- Continue to develop realistic scale-down component models for better visualization of changing physical phenomena

Fabrications

A. El-Shiekh, Coordinator

Faculty and students from both NCSU and A&T have worked extensively together on the area of fabrications. A free exchange of information and experience has allowed students from both universities to get hands on experience in preform production and consolidations. Through these cooperative efforts, members of the fabrications group have worked on the following areas:

- Development of textile machinery for the production of preforms for composite materials
- Production of complex, near-net shape preforms
- Determination of causes of voids and methods of void minimization
- Determination of fiber volume fraction through established ASTM test methods
- Development of consolidation techniques for 3-D textile preforms, both simple and complex in shape (including compression, autoclave, and resin transfer molding)
- Introduction of glass microballoons to improve crack resistance
- Use of pultruded axials to improve compressive strength
- Mechanical evaluation of composite materials (including tensile, compression, damage tolerance, three and four point bending, bearing behavior

Researchers have developed machines and techniques to successfully produce and consolidate textile preforms. This work has resulted in one issued patent, one pending patent and two patents under consideration. Findings from the various projects have been the subject of 50 scientific presentations of which 36 were published. Furthermore, three courses at the universities are incorporating information on composite materials.

The achievements of the fabrications group have sparked the interest of a great number of companies both in the United States and abroad. Investigators are working with the following organizations:

- Amercom
- Applied Research Associates
- Duke University
- Du Pont
- General Electric
- Kaiser Aerotech
- Lawrence Livermore National Labs
- Lord Corporation
- MBB
- Michigan Molecular Institute
- Nippon Oil
- Pratt and Whitney
- Rolls Royce
- TRW

Graduate and undergraduate students alike have gained valuable hands on experience, preparing them for careers in composites and the affiliated industries. Details of the research projects are given as technical highlights in Appendix B.

The future of the fabrications group includes projects in the following areas:

- Development of fabrication processes which enhance the mechanical performance of 3-D textile composites, especially improving mechanical damage tolerance and vibration damping
- Determine the biaxial mechanical properties of cylinders made from 3-D textile preforms
- Development of additional textile machinery for the production of composite materials
- Development of a statistical correlation from resin digestion tests
- Development of a data base for design applications in space structures
- Comparison of various textile composites to maximize their use in space structures

Details of the research are presented as technical highlights in Appendix B.

SPECIAL PROJECTS

HL-20 Personnel Launch System
Project Director: Robert Vess

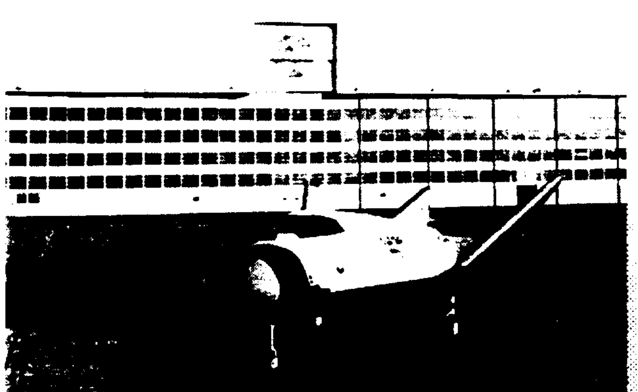
Students and researchers from the Mars Mission Research Center and NASA Langley Research Center unveiled a full-scale research model and cradle of the HL-20 Personnel Launch System on Friday, September 14, 1990 at N. C. State University. Participants in the unveiling ceremony included Dr. Larry K. Monteith, Chancellor of NCSU; Dr. Edward B. Fort, Chancellor of A&T; Fourth District Congressman David Price; Mr. William Piland, Chief of Space Systems Division at NASA Langley; Robert Vess, Thurman Exum, and Fred DeJarnette.

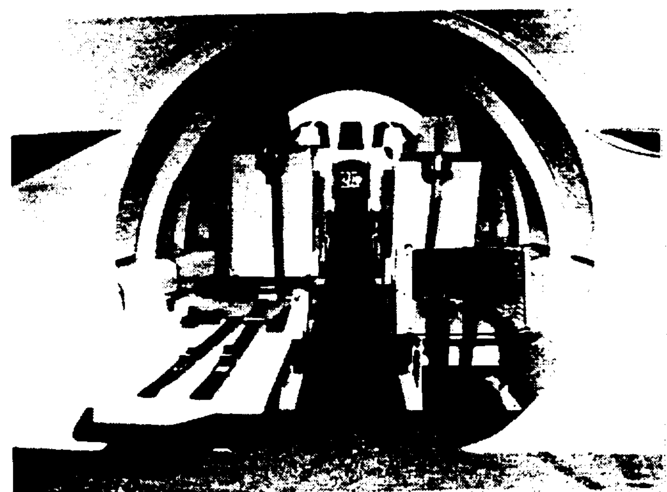
Robert Vess, lecturer in Mechanical and Aerospace Engineering at NCSU, was the project director. He was assisted by Dean Driver, '85 graduate of NCSU and previously with Scaled Composites, Inc. Thurman Exum, professor in the Department of Manufacturing Systems at A&T served as the project leader in Greensboro. Howard Stone, Del Freeman, and Bill Piland of the Space Systems Division, NASA Langley Research Center provided overall coordination as well as the external geometry of the HL-20. Charlie Cockrell and Mac MacConochie provided invaluable assistance.

Robert Vess and Dean Driver started with a class of 55 students at NCSU in January 1990 to develop the structural design of the model. Seven of these students worked full time on the construction of the fiber glass model from May 1990 until the unveiling. Thurman Exum, Don Wilson, Dennis Hugley, and Robert Williams worked with five students at A&T on the design and construction of the cradle and interior arrangements for the model. Installation of interior components is to be done later.

The model, which is 29.5 feet long and has a wingspan of 23.5 feet, is designed to hold eight passengers and two crew members for a three-day journey. With its wings folded, it can fit into the cargo bay of a space shuttle. The HL-20 is designed to have an approximate weight of 24,000 pounds and be able to achieve speeds of 20-25 thousand mph.

The model will be used at Langley and at Johnson Space Center to study crew seating arrangements, habitability, equipment layout, crew ingress and egress, and maintenance and handling operations.





The cradle is a steel truss structure twenty three feet long, eight feet wide, and three feet deep. The primary purpose of the cradle is to support the HL-20 fully loaded and to raise it from a horizontal to a vertical position. It will also serve as a support for the HL-20 when it is transported by truck.

The PLS is currently being studied by NASA researchers as a possible supplement to the Space Shuttle Program. It would be used to carry personnel and small cargo to and from an Earth-orbiting space station, where a Mars spacecraft would be built and launched. Other possible uses for the PLS vehicle include satellite maintenance and astronaut rescue.

NASA/NCSU Orbiter Ejector Project
Project Director: Larry Silverberg

In October 1990, NASA Johnson Space Center asked our engineering students at NCSU to design and fabricate a prototype of a "get away special" shuttle flight experiment that ejects calibration spheres into orbit. The purpose of the project is to improve our ability to detect smaller objects (less than 10 cm diameter) in space using ground-based tracking systems.

The Mars Mission Research Center responded to this request by forming an interdisciplinary design project composed of 40 undergraduate students in aerospace, mechanical, and electrical and computer engineering. The project is being carried out this spring.

General Background

Natural meteoroids are part of the interplanetary environment. They sweep through Earth orbital space at an average speed of 20 km/s. A total meteoroid mass of 200 kg is currently within 2000 km of the Earth's surface. Most of this mass is made up of meteoroids on the order of 0.1 mm in size.

In contrast, within this same 2000 km altitude range, we find as estimated 3,000,000 kg of man-made orbiting objects called space debris. These objects are found in mostly high inclination orbits and sweep past one another at an average speed of 10 km/s. Most of this mass is concentrated in approximately 3000 spent rocket stages, inactive payloads, and a few active payloads. A smaller amount of mass, approximately 40,000 kg, comprises the remaining 4000 objects currently being tracked by U.S. Space Command radars. These objects are predominantly fragments that originated from more than 90 satellites.

Recently, high resolution ground telescope measurements of orbiting debris have revealed smaller objects in space. A total mass of approximately 1000 kg of orbital debris of 1 cm or smaller has been detected. Furthermore, analysis of hypervelocity impact pits on the returned surfaces of the Solar Maximum Mission satellite has shown that these objects are traveling at relatively high velocities. This quantity of mass traveling at high relative velocities poses a serious problem. Indeed, the previously described orbital debris environment is much more hazardous than the natural meteoroid environment to spacecraft orbiting within the 2000 km altitude range. Orbital debris will also be a concern for Space Station Freedom.

Experiment Background

The NASA/NCSU Calibration Spheres Project is one component of a research effort that will ultimately improve our understanding of the debris in low Earth orbit (LEO). More specifically, signatures of the calibration spheres (man-made and/or natural) will be collected from optical and radar telescopes. These signatures will then be analyzed, and estimates of the albedo (reflectivity) and size of each object will then be correlated with the known calibration spheres. The specific purpose of the Calibration Spheres Experiment (conducted by NASA JSC engineers and scientists) will be to correlate controlled empirical optical and radar signatures to objects of known physical dimensions and compositions have predetermined albedo and scattering properties.

Student Teams:

The 40 participating students have been divided into five teams: four competing design teams and an orbital safety team. The competing design teams are each fabricating a prototype of the "get away special" flight experiment that ejects calibration spheres into orbit, while the orbital safety team will investigate issues associated with orbital safety. The teams are each composed of eight students: one electrical and computer engineering student and seven mechanical and aerospace engineering students.

The project is being carried out in three phases. The first phase is a conceptual design phase ending with a preliminary design review (PDR-1). The next phase involves refining the conceptual design to prepare for the second preliminary design review (PDR-2). The PDR-2, like the PDR-1, consists of presentations made by each member of each team; however, unlike the PDR-1, it represents the end of the conceptual design phase. At this time NASA JSC Science Advisory Board members will be present in the audience evaluating the designs and viewing the early versions of the prototypes.

The third phase finalizes the conceptual design, the prototypes, and the shop drawings in preparation for the critical design review (CDR). The CDR was held at NASA JSC in Houston, Texas in May 1992. The review concluded with a dinner and an announcement of the design team winner.

The orbiter ejectors and spheres have been fabricated and tested at JSC. The experiment is scheduled for STS-47 flight in October 1992.

Aerobrake Project
Project Director: Gordon Lee

One option for delivering large aerobrakes to space entails shipping the structure in pieces, followed by on-orbit assembly. This effort focused upon the fabrication of a Mars aerobrake mock-up and testing the structure in a series of underwater neutral buoyancy tests that address this on-orbit assembly issue. The effort was sponsored by McDonnell Douglas Space Systems Company (MDSSC) in Huntington Beach, California. The aerobrake mock-up design (done in the Fall of 1989 and Spring of 1990) was based upon a baseline shape of 32m by 27m to provide an L/D of at least 0.5. Three pieces (petals) and part of the central core were selected for fabrication; these pieces provide candidate assembly tasks under the constraint that the mock-up must fit into the 21.3m diameter, 10m deep underwater test facility (UWTF) tank at MDSSC.

The mock-up contains several features which may be used in on-orbit assembly: hard docking latches to connect the petals, soft docking alignment pins, truss assembly with joint fasteners, close-out panels for the thermal protection system (TPS), hand and foot restraints for extra vehicular activity (EVA) and visual cues for assembly ease. The entire work was made neutrally buoyant to simulate in-space operation.

Swim through tests were performed in June using scuba-equipment to verify both the structural soundness of the mock-up and viability of the proposed assembly procedures while a second series of tests were done in October with an EVA-suited subject and telerobotic arm.

The results demonstrated that astronauts can align large dimensional components and activate hard docking latches with reasonable time and effort. The candidate TPS close-out concept proved to be less effective than anticipated and further development will be necessary. MDSSC is continuing with this effort with additional hardware; other assembly scenarios are scheduled for March 1992.

Another option for shipping an aerobrake into space involves "folding" the structure during launch and deploying the device once in space.

During the 1990-91 period, senior students designed a deployable LTV (lunar transfer vehicle) aerobrake and fabricated a 1/10 model, for demonstration purposes. The design included components attached to the shell, including payload, crew module and propellant tanks. Deployment was achieved by having the centerpiece attached to a stationary fixture, say the Shuttle RMS, while the two ends of the aerobrake are deployed and fastened automatically. Check-out procedures to guarantee complete deployment were developed. Further, a typical launch scenario for a lunar-earth return was constructed to illustrate the capability and feasibility of a deployable aerobrake. The design was presented at the Southeastern Regional AIAA Student Design Conference April 1991.

Remotely Operated Vehicle (ROV) Project
Project Director: Gordon Lee

There exists many similar issues between planetary exploration rovers and underwater exploration vehicles. In particular, both types of devices must operate in buoyant conditions and many designs use human remote operation to generate commands and receive sensor data. Limited visual conditions may exist for both types of vehicles. Test scenarios usually include obtaining samples of the environment.

In order to address some of the issues associated with remotely operated manipulators as well as in order to satisfy some of the desired functional requirements of an existing underwater ROV, UNCW/NOAA sponsored a project with M^2RC to design and fabricate water and ocean floor samplers to be attached as end-effectors to the ROV manipulator arm. In the Fall of 1991, four undergraduate student design teams developed several sampler designs, analyzed the concepts with prototype working models, presented preliminary design reviews and critical design reviews and began fabrication. Two water samplers and two ocean floor samplers will be delivered to UNCW/NOAA this spring 1992. These devices will be used in actual underwater research activities through the Marine Research Center located in Wilmington, North Carolina. Further, some of these designs warrant further study as candidate end-effectors for planetary rovers.

Mars Excursion Vehicle
Project Director: Robert Vess

A North Carolina State University team of faculty and students in the Mars Mission Research Center (M^2RC) has completed a one-twentieth scale model of a Mars Excursion Vehicle for Boeing Defense & Space Group of Huntsville, Alabama.

Boeing is studying the concepts for such vehicles and is making recommendations to NASA. Since most of the mission profiles incorporate an aerobrake as a primary and/or secondary element, extensive analysis of aerobrake configurations which address the trajectory definition, aerocapture, heating, and descent/ascent issues has been undertaken. The present configuration represents a High L/D aerobrake configuration which has emerged from such studies.

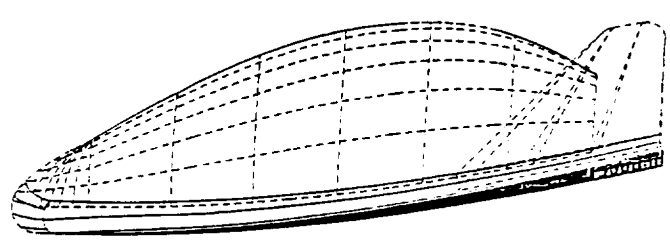
The extensive composite prototyping capabilities which NCSU demonstrated through the fabrication of the NASA HL-20 Full Scale Research Model prompted Boeing to commission the M^2RC to design and build a scale model of a specified High L/D Mars Excursion Vehicle concept. The project was cooperatively funded by Boeing, the M^2RC, and the North Carolina Space Grant Consortium.

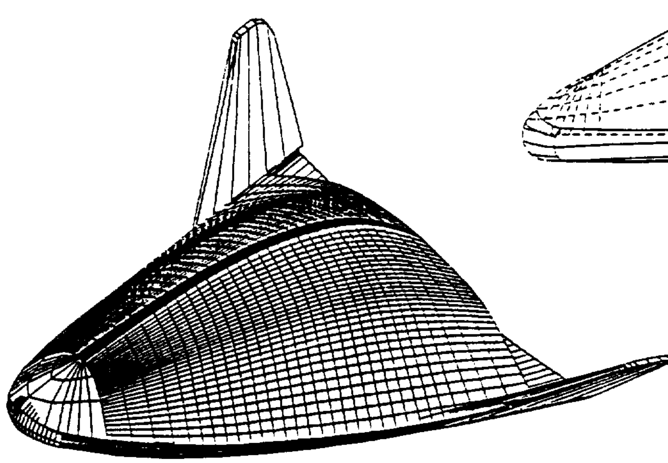
A four-man team was assembled to fabricate the vehicle. Robert Vess, a lecturer in mechanical and aerospace at NCSU, was the project director. Dean Driver, a 1985 graduate of NCSU and former engineer with Scaled Composites, Inc., served as the composite specialist. Two undergraduate aerospace engineering seniors, Erik Johnson and Alan Shepard, were the student members of the team.

Since Boeing intended to investigate internal component layout options with the model, a shell structure which allowed complete access to the available internal volume was required. This dictated the use of typical composite molding methods.

Geometric definition of the vehicle was provided by Boeing in the form of a digital CAD file. This data was post-processed at NCSU in order to smooth the loft contours and allow the extraction of specified planar cross sections. These cross sections were plotted, transferred to polystyrene foam sheets, and cut to shape. The individual foam sections were bonded together on a jig and then contoured and fiberglassed to form a master. Several plies of fiberglass/epoxy were applied over the master to form the models. The fiberglass/foam/epoxy sandwich parts were then formed in these molds. Structural details and fasteners were added to complete the assembly.

Although the fabrication process was only briefly described above, it is actually a rather exhaustive process. However, the combination of innovative and experienced staff members with the obviously enthusiastic students provides a level of productivity which is hard to find in many work environments. In this case, a high quality Mars Excursion Vehicle Model was completed in less than six weeks in order to meet Boeing's obligation to make it available for the company's 75th Anniversary Commemoration in late September.





An evaluation of this and other such industry/university projects reveals significant and mutual benefits for all involved parties. In addition to receiving a high quality model at an extremely reasonable cost, the contracting organization establishes firm contact with the University and the M^2RC, which leads to obvious research-related possibilities and interaction with possible future employees. The University, and more specifically the M^2RC, further fulfill their chartered task of attracting good students and establishing a foundation on which to educate them in areas which parallel the direction of the aerospace industry. And finally, the students are offered an opportunity to participate in a high visibility project which contributes to a current large-scale industry program. This not only provides experience, which makes them more marketable upon graduation, but also serves as a remarkable motivational tool which enhances their appreciation for their chosen course of study.

STUDENT PARTICIPATION IN SPECIAL PROJECTS

AEROBRAKE PROJECT

Undergraduates (20):

Jonas M. Batten, ME
Kenneth Beasley, ME
Kenneth Beaty, AE
Robert Bendl, AE
Steven Bouchelle, ME
Frank Brauns, AE
Paul W. Carpenter, AE
Inho Choi, AE
Price Cook, AE
Blake Deal, ME
Scott Goller, ME
Alan D. Hoffler, AE
Samuel Moses, ME
Ray Neel
P. D. Nguyen, AE
Scott Ruta, AE
D. C. Smith, ME
Russell Smith, ME
Robert Stanley, II, ME
Gary Tao, AE

Graduates (2):

Eric Clark, AE
Jonathan Hamilton, ME

HL-20 PERSONNEL LAUNCH SYSTEM

Undergraduates (20):

Greg Alexopoulos, AE
Robert Brewer, AE
Mike Burchell, AE
Kevin Burton, AE
Joel Cate, AE
Keith Cochran, AE
Mike Duncan, AE
Chris Edge, AE
Bill Gibbons, AE
Adam Kelly, AE
Michael Lewis, AE
Robert Long, AE
Stephen McLeod, AE
Heather Pauley, AE
Brian Platz, AE
David Robinson, AE
Alan Shepard, AE
Joe Steffen, AE
Scott Tetterton, AE
Matt Young, AE

ORBITER EJECTOR PROJECT

Undergraduates (41):

Ayberk Abayhan, ME
Trey Arthur, III, AE
Greg Ashe, ME
Bernard M. Blell, AE
Christopher P. Budahl, AE
John G. Bulluck, ME
William K. Carpenter, AE
Brad Clark, ME
Joseph T. Cody, ME
Michael H. Duncan, AE
Chris Edge, ME
Navin Jafer, ECE
Erik W. Johnson, ME
James Joy, ME
Morton Knutsen, ECE
Chad Leatherwood, ME
Michael R. Lewis, ME
Edward James, ME
Robert Long, AE
Julie Manning, AE
Samuel L. Martin, ME
Stephen McLeod, AE
Thomas Hunter, ME
Andy Mueller, ECE
Michael A. Norton, ME
Michael M. Orwin, ME
Carmon Parkinson, AE
David F. Robinson, ME
Paul J. Schumacher, ME
Alan Shepard, AE
Peter Sramka, ME
John C. Thomason, ME
Matt Thompson, ME
Robert Trask, ECE
Christopher Tridico, ME
John D. Tucker, ME
Eric S. Warren, ME
Karen Watts, ME
Theodore M. Yost, ME

REMOTELY OPERATED VEHICLE

Undergraduates (16):

Cynthia Allred (ME)
Patrick Baker (ME)
Gary Bulluck (ME)
Jeff Cope (ME)
James Dalton (ME)
Jon Dewar (ME)
Paul Fontenrose (AE)
John Kandara (ME)
Kris Kemp (ME)
Tom Kingsley (ME)
Todd Lee (ME)
Mike Norton (ME)
Marco Orsini (ME)
Brian Peterson (AE)
Joe Sechler (AE)
Darrell Soyars (ME)

MARS EXCURSION VEHICLE

Undergraduates (2)

Erik Johnson (ME)
Alan Shepard (AE)

NEW COURSES

During the past 4 years the faculty of the Mars Mission Research Center have developed 26 courses to complement the research being performed at the Center. The courses, along with the title and instructor, are listed below.

Course No.	Title	Instructor
	North Carolina State University	
MAE 589A	Mechanics of Composite Structures	Klang
MAE 589E	Optimal Control Theory	Lee
MAE 589I	Ascent and Energy Vehicle Analysis	Walberg
MAE 589M	Composite Shell Structures	Yuan
MAE 589N	Viscous Elasticity	Yuan
MAE 495N	Aerospace Structural Design	Klang
MAE 589G	Estimation Theory	Lee
MAE 589W	Digital Filtering-Control	Lee
MAE 589R	Methods in Aerospace Engineering	Perkins
MAE 686H	Computational Methods Structural Vibration	Silverberg
MAE 686K	Viscous Hypersonic Flow I	DeJarnette
MAE 686J	Computation of Materials	Klang
MAE 686M	Computational Fluid Dynamics	McRae/Hassan
MAE 686O	Re-entry Aerothermodynamics	Hassan
MAE 686D	Computation of Reacting Flows	Candler
MAE 686K	Viscous Hypersonic Flow II	Candler
MAE 686A	Numerical Analysis of Anisotropic Structures	Klang
MAE 686R	Classical Analysis of Anisotropic Structures	Klang
MAE 686	Computation of Hypersonic Flows	Candler
MAE 559/659	Molecular Gas Dynamics I & II	Hassan
MAE 686	Physical Gas Dynamics	Hassan/Candler

Course No.	Title	Instructor
	A&T State University	
ME 346	Materials Laboratory	Sadler
ME 574	Mechanical System Design	Filatovs
ME 660	Computational Fluid Dynamics	Chandra
ME 708	Energy Method in Applied Mechanics	Shivakumar

RESEARCH FACULTY

Dr. Gerald D. Walberg joined the NCSU faculty in July 1991 as professor of mechanical and aerospace engineering and is serving as deputy Director of the Mars Mission Research Center. Prior to assuring his present position, Dr. Walberg worked for 32 years at the NASA Langley Research Center and, following his retirement from NASA, taught for two years at the George Washington University/NASA Joint Institute for Advancement of Flight Sciences.

Dr. Walberg attended Virginia Polytechnic Institute and State University (VPI & SU), receiving a B.S. degree in 1956 and an M.S. degree in 1961, and North Carolina State University, receiving a Ph.D. in 1974. Following graduation from VPI & SU, he worked for a year at Aircraft Armaments, Inc., in Baltimore, Maryland, and then in 1957, joined the staff of the Langley Laboratory of NACA. From 1957 to 1961, Dr. Walberg carried out research on transonic aerodynamics, with special emphasis on unsteady aerodynamic theory and aeroelastic phenomena. After NACA became NASA, Dr. Walberg switched his field of research to high-temperature gas dynamics and ablation theory. In this work area, he published numerous papers and was involved in the analysis and testing of the ablative heat shield for the Apollo Command Module. Since 1970, Dr. Walberg's research has centered around the phenomena of radiatively coupled flow fields, the aerothermodynamic characteristics of planetary entry vehicles, and the analysis of advanced space transportation systems. He was selected Head of the Aerothermodynamics Branch of the Space Systems Division at NASA Langley Research Center in 1975 and in this capacity, directed a broad-based research program which included both theoretical analyses and experimental investigations. A major portion of this research was aimed at supporting NASA's planetary probe missions (Viking, Pioneer Venus, Jupiter Probe) by developing more accurate methods for predicting heating and aerodynamic characteristics.

Continuing his career at NASA, in 1979, Dr. Walberg selected to participate in the NASA Executive Development Program, being assigned to NASA Headquarters' Space Systems Division, OAST. Also in 1979, Dr. Walberg was selected as Chief of the Space Systems Division at Langley Research Center. In October of 1988, Dr. Walberg was promoted to the position of Deputy Director for Space at Langley. In this capacity, he assisted the Director for Space in planning, directing and coordinating the space-related research, technology and science activities of the Center.

In July 1989, following his retirement from NASA, Dr. Walberg accepted the position of research professor of engineering and applied science with the NASA/George Washington University Joint Institute for Advancement of Flight Sciences (JIAFS). Dr. Walberg also leads a cooperative George Washington University/North Carolina State University program to carry out mission analyses under the NASA-sponsored Mars Mission Research Center at North Carolina State University.

The author of more than 40 scientific papers, Dr. Walberg has lectured at major European aerospace research centers and also throughout Australia. In 1983, he received the NASA Medal for Outstanding Leadership, and in 1988 he received the Presidential Rank of Meritorious Government Executive.

Dr. Walberg has been an active member of the AIAA since his student days, serving in many leadership capacities. He is a Fellow of the AIAA and has served as Associate Editor for the AIAA *Journal of Spacecraft and Rockets*, and member of the Space Systems and Space Transportation Technical Committees. He currently is an Associate Editor of the *Journal of Thermophysics and Heat Transfer.*

Dr. Gordon K. F. Lee was appointed a research professor in the Department of Mechanical and Aerospace Engineering at NCSU in July 1989. He directed the Lunar/Mars aerobrake mockup project sponsored by McDonnell Douglas.

Dr. Lee received his B.S. in Electrical Engineering from the University of Hawaii in 1972 and his M.S. and Ph.D. degrees in Electrical Engineering from the University of Connecticut in 1974 and 1978, respectively. He was a member of the faculty at Colorado State University from 1978 to 1989, where he held the position of Professor and Director of the Institute of Robotic Studies in the Department of Electrical Engineering.

Dr. Lee has been involved in the areas of digital and optimal control for many years. His research interests are in the area of computer-aided control analysis and design, nonlinear and decentralized control, and parallel architectures for control methodologies. Recently, Dr. Lee has been investigating flexible structures, focusing on non-collocated issues and on the development of experimental testbeds for real-time control.

Over the past few years, Dr. Lee has been collaborating with the Structure Dynamics Branch at NASA's Langley Research Center on issues associated with test methods for multiflexible body structures and currently has a NASA contract in this area.

Dr. Lee has published over 100 technical reports, conference papers, and journal articles.

Dr. Fuh-Gwo Yuan joined the NCSU faculty as assistant professor of mechanical and aerospace engineering in July 1989. Dr. Yuan previously worked as a research engineer at the National Center for Composite Materials Research at the University of Illinois, Urbana-Champaign.

Dr. Yuan received his B.S. degree in engineering Science from the National Cheng-Kung University, Taiwan in 1977; his M.S. and Ph.D. degrees in Theoretical and Applied Mechanics from the University of Illinois, Urbana, Illinois in 1981 and 1986, respectively.

Dr. Yuan's areas of research include buckling and postbuckling analyses of composite structures; stress, failure and fracture analysis of composites, polymeric materials and structures; and high-temperature mechanics and mechanical behavior of advanced composites.

Dr. Yuan is an active number of AIAA, the American Academy of Mechanics, and the American Society of Testing and Materials.

HONORS AND AWARDS

Dr. Eric C. Klang, assistant professor of mechanical and aerospace engineering at NCSU, has received three distinguished awards for his teaching this past year. He was selected as one of four recipients of an Alumni Outstanding Teacher Award at North Carolina State University. At the May 12, 1990 graduation exercises, he received a certificate and a $1000 cash award.

In addition, Dr. Klang was one of eighteen NCSU faculty members in 1989-1990 selected to receive an NCSU Outstanding Teacher Award with its $1000 cash prize. Nominated by committees of students and fellow faculty, he will become a member of NCSU's Academy of Outstanding Teachers.

Dr. Klang was also chosen to receive the 1989 Ralph R. Teetor Educational Award for his outstanding work involving engineering students. The award was given during the Aerospace Technology Conference and Exposition that was sponsored by the Society of Automotive Engineers on September 25-28.

Dr. Fred R. DeJarnette, professor of mechanical and aerospace engineering at NCSU, received the O. Max Gardner Award from the UNC Board of Governors. He was honored for his outstanding accomplishments as a scientist, engineer, and teacher. The award, given annually since 1949, was established by the will of former Governor O. Max Gardner to recognize faculty who have "made the greatest contributions to the welfare of the human race." It is the only honor for which all faculty members of the 16 UNC campuses are eligible. The 1990 award includes a citation and $5,000 cash prize.

Dr. DeJarnette was the recipient of the 1988 RJR Award for Excellence in Teaching, Research and Extension. The award was presented at a ceremony on October 4, 1989. This prestigious award was established through the NC Engineering Foundation to recognize annually "the superior accomplishment" of an engineering faculty member in areas relating to the university's three-fold mission of teaching, research, and extension.

As part of the award, a lecture was presented on November 9, 1988 entitled "Humans to Mars: How Do We Get There."

Serving as the director of both the Hypersonic Aerodynamics Program and the Mars Mission Research Center, Dr. DeJarnette is the author of more than 45 papers in refereed journals and symposia and is internationally known in the area of computational and experimental aerodynamics. Concepts and methods he developed in computational fluid dynamics and heat transfer are used today throughout the aerospace industry.

In recognition of his outstanding faculty service to the university, Dr. DeJarnette was also named Alumni Distinguished Graduate Professor at NCSU in 1990. This award was $3,000 for each of two years.

Dr. Graham C. Candler, assistant professor of mechanical and aerospace engineering at NCSU, received the Best Technical Paper Award in Thermophysics at the 1990 AIAA Conference on Thermophysics. Dr. Candler received his Ph.D. from Stanford University and is participating in the activities of hypersonic aerodynamics. Prior to coming to NCSU, Dr. Candler was employed at NASA Ames Research Center, Moffett Field, California.

Dr. William R. Rasdorf, associate professor of civil engineering at North Carolina State University, has been awarded the 1990 Walter L. Huber Civil Engineering Research Prize by the American Society of Civil Engineers (ASCE). The award was presented during ceremonies at the ASCE annual convention in San Francisco in November. The ASCE has honored up to five top researchers each year since the award was established in 1946.

Rasdorf, who works in the area of engineering design, is exploring innovative ways to use computing and computer data bases to store information for use in computer-aided engineering design, and analysis systems. Dr. E. Downey Brill, Jr., head of the NCSU Civil Engineering Department, noted that the number of research grants Rasdorf has received from the National Science Foundation, NASA, and industry, indicates the quality and significance of his research. Rasdorf is frequently called upon to take part in national and international professional conferences.

Rasdorf has been a two time NASA-ASEE Summer Research Fellow at NASA Langley and has a number of students participating in both the Langley Aerospace Researchers Summer Scholars Program and the Graduate Student Researchers Program. In 1985, he received the National Science Foundation Presidential Young Investigator Award. In addition to being a member of a number of scientific advisory boards and committees, he is an editorial board member for the Journal of Research in Engineering Design and editor of the Journal of computing in Civil Engineering.

Dr. William J. Rasdorf, associate professor of civil engineering at NCSU has been selected as the UPS Foundation Visiting Professor at Stanford University in Palo Alto, CA during the 1991-92 academic year and will spend a portion of the year at the Center for Integrated Facilities Engineering in Stanford's Civil Engineering Department. There he will offer a seminar course entitled Developments in Engineering Computing Research and will investigate computational models that can integrate and support facility analyses and design from a total system perspective. Dr. Rasdorf will also be establishing cooperative research endeavors between the two institutions and gaining information that will help NCSU develop a program patterned after Stanford's Center for Integrated Facilities Engineering.

Dr. Mansour H. Mohamed, professor of textile engineering and technology in North Carolina State University College of Textiles, has been named Burlington Industries Professor of Textile Engineering and Technology. Mohamed's appointment to the professorship of distinction was announced by NCSU Chancellor Larry K. Monteith, following approval by the NCSU Board of Trustees. Dr. Mansour Mohamed received the distinguished Scholarly Achievement Award from NCSU during the Honors Convocation, October 1991.

Born in Alexandria, Egypt, Mohamed received degrees from Alexandria University and Manchester University. He came to NCSU as a visiting lecturer and researcher and has served as a professor since 1976. Mohamed is recognized in this country and abroad for his expertise in weaving technology, his research in the design and analysis of three-dimensional and multilayer woven fabrics, and his work on the development of automated, three-dimensional weaving machinery.

Dr. Mansour H. Mohamed and Zhong-Huai Zhong, Textile Engineering Chemistry and science, were recently awarded a U.S. patent on "Method of Forming Variable Cross-Sectional Shaped Three-Dimensional Fabrics." The development is part of the research carried out under the Mars Mission Research Center.

Dr. Hassan A. Hassan, professor of mechanical and aerospace engineering, has been named NCSU Alumni Distinguished Graduate Professor. Dr. Hassan received the award from the NCSU Alumni Association at its annual awards luncheon at McKimmon Center. This award was given in recognition of outstanding service in teaching graduate courses and supervising research of graduate students and for commitment to excellence in graduate education. Dr. Hassan joined the NCSU faculty in 1962, as a professor of mechanical engineering. He is an active participant in research relevant to the activities of the Mars Mission Research Center.

Dr. Hassan was selected to receive NASA's Public Service Medal for over 30 years of outstanding service. The medal was presented at the Center's 1992 Annual Honor Awards Ceremony held on Friday, March 27, 1992.

Dr. Wayland C. Griffith received a certificate of appreciation plaque for Outstanding Service at the Naval Surface Warfare Center, Silver Spring, Maryland for the period 1988-1992.

PUBLICATIONS

There were 244 publications during the period 1988 - 1992. A detailed listing by faculty member is given in Appendix C. The Center also publishes a Newsletter twice a year. Faculty publications, presentations, and the Newsletter, coupled with our workshops, provide the means to disseminate our research to others.

CONTRACTS AND GRANTS

M^2RC Faculty have received additional funding in the amount of $7.1 million during the last 5 years to accomplish the research objectives of the Center. A breakdown of contracts and grants is given in Appendix D. This is an indication of the progress of the Center towards becoming self sufficient.

STUDENT AND FACULTY INTERCHANGES

Every summer about 15 students work with various branches at NASA Langley Research Center.

Rona Reid, Cirrelia Thaxton, and Stan Smeltzer worked with faculty and students on the A&T campus during the summer, and Smeltzer continued during the Fall 1990 semester.

Evans Lyne, James Packard, and Dean Kontinos spent the summer of 1989 at the NASA Ames Research Center through an interchange program between NASA Ames scientists and NCSU engineering faculty and graduate students, pursuing MS and PhD degrees under the Mars Mission Research Center at NCSU and A&T.

Ken Jones worked with the Naval Surface Warfare Center, White Oak, Maryland during the summer of 1990 on a project "Effect of Supercooling in Design of NSWC's Hypersonic Tunnels."

Jonathan Hamilton worked in 1989 with McDonnell Douglas Huntington Beach, CA as a summer intern on conceptual design of an aerobrake for a Mars transfer vehicle which is propelled by a large solar sail.

Robert Stanley (NCSU) and Dwayne Crawford (A&T) worked on the structural design and assembly tests of the Mars Aerobrake mockup in the Underwater Facility at McDonnell Douglas Space Systems Company in Huntington Beach, California during the summer of 1990.

Dr. W. D. Erickson (Chief Scientist, Hypersonic Technology Office, NASA Langley) was hired as Visiting Professor for one year to take over the duties previously carried out by Dr. W. C. Griffith. Dr. Erickson's visit has been made possible through a special IPA agreement between NCSU and NASA.

Dr. C. P. Young, NASA Langley Research Center, was hired as Visiting Associate Professor and participates in the activities of the Mars Mission Research Center.

Dr. S. Chandra of A&T worked in the Mechanical and Aerospace Engineering Department at NCSU from January 1, 1989 to June 30, 1989. He also worked at NASA Langley Research Center on a one year sabbatical from 1989 - 1990. He is presently working in computational fluid dynamics (CFD) and plans to integrate this area into the program at A&T.

We plan to increase interchanges in the future. Discussions are in progress with Dr. Mikhail Marov in Russia about a one-year sabbatical to work with our Center. Dr. Marov has worked on every major USSR Space Project including Mars 94/96.

RECRUITMENT OF STUDENTS, FACULTY, AND STAFF

From the beginning of the Center, we have had no difficulty recruiting students to work with the Center at NCSU. A&T will be able to attract more graduate students in the future since they are now planning for a Ph.D. program in Mechanical and Electrical Engineering. We attribute our ability to attract outstanding students to the research being conducted by the Center. Students are looking for highly visible programs which will prepare them for a challenging career, and the space program provides this incentive. A copy of our graduate flyer is given in Appendix E.

The following faculty were recruited during the period July 1988-June 1989 to work with the Center. Dr. Gordon K.F. Lee, spacecraft controls, NCSU; Dr. Wadida Oraby, composite materials, A&T; Dr. I. S. Raju, composite materials and modeling, A&T; Dr. F. Yuan, light-weight structures and materials, NCSU. Staff recruited for the Center were Bruce Alston, mechanical technician, A&T; Robert Jackson, polymer processing and fabrication technician, A&T; Bill Roberts, machine shop technician, NCSU; and Emily Tate, administrative assistant, NCSU.

Faculty recruited during the period July 1989-June 1990 were Dr. William Rasdorf, mission analysis and design, NCSU; Mr. Ray Foye, materials, A&T; Mr. Leon Skeen, fabrication, A&T; and Gary Tatterson, fabrication, A&T. Barbara Brown was hired to fill the secretarial position at NCSU in 1989 and Ms. Cindia Hairston was hired to fill the secretarial position at A&T in 1991.

Dr. Kunigal N. Shivakumar joined A&T in July 1991 as Research Professor of Mechanical Engineering and Coordinator of the structures and Controls Group in M^2RC. Dr. Shivakumar comes to M^2RC from A,S & M, Inc. in Hampton, Virginia.

Dr. Suddin Ilias, faculty member in Chemical Engineering, is a new member of the Materials Group at A&T effective July 1991.

Dr. Gerald Walberg, Research Professor at GWU/JIAFS, was appointed Professor of Mechanical and Aerospace Engineering at NCSU effective July 1991. He was also appointed Deputy Director of the Mars Mission Research Center to direct technical activities of the Center and direct the Aerobrake Design Methodology Project.

Dr. Shamsuddin Ilias, Professor of Chemical Engineering (A&T), became a member of the Fabrication Group in July 1991.

Dr. Alamgir Farouk joined A&T in October 1991 as an Adjunct Assistant Professor in Mechanical Engineering. Dr. Farouk is a graduate of Rutgers University and will work with the Materials Group in the M^2RC.

ORGANIZATIONAL CHANGES

Emily Tate was appointed Assistant Director for administrative activities in January 1992. The duties formerly performed by Dr. John Perkins have been distributed to Ms. Tate and Dr. Walberg. Dr. Perkins has left the Center to devote his efforts to research in subsonic aerodynamics.

Dr. Lonnie Sharpe became Assistant Dean of Engineering in 1989.

Dr. Wadida Oraby resigned due to relocation to another area.

Dr. Ivatury Raju left A&T in early 1991 to return to NASA Langley Research Center; however, he continues to work with this Center as an adjunct research professor at A&T.

Dr. Wilbur L. Meier, Jr. became the new Dean of Engineering at NCSU in July 1991 and is therefore a member of the M^2RC Academic Board.

Dr. Larry K. Monteith, formerly Dean of Engineering at NCSU and Chairman of the M^2RC Academic Board, was installed as Chancellor of NCSU on October 23, 1991.

Mr. Steve Wander, Chairman of the NASA Technical Review Committee, transferred to the Propulsion, Power and Energy Division (Code RP) at NASA Headquarters in January 1991.

Dr. William Feiereisen (Code RS) at NASA Headquarters, has been appointed the Chairman of the NASA Technical Review Committee in 1992.

Dr. Sal Torquato has accepted a position as a full professor at Princeton University and will leave NCSU after the spring semester 1992.

OUTREACH PROGRAM

Director: Jim Redmond

Much of the recent activity in the Mars Mission Research Center has focused on establishing the program for Education Outreach in Engineering Science. Directed by a steering committee composed of members from balanced and complimentary backgrounds, this program serves to coordinate and to enhance the outreach activities that have been an important part of M^2RC since its inception. The steering committee members are Jim Redmond (Researcher, M^2RC-A&T), Larry Silverberg (Associate Professor, M^2RC-NCSU), Lee Stiff (Associate Professor, Department of Mathematics and Science Education-NCSU), Dennis Dubay (Director, North Carolina Science and Mathematics Alliance), Sue Redmond (Math Teacher, Cardinal Gibbons High School), and Eric Ennis (Student, Cardinal Gibbons High School). The objectives of the Outreach program are to increase public awareness of research activities in M^2RC and to raise interest among pre-college students in engineering and other scientific careers. These objectives are being met primarily by providing tours of M^2RC laboratories, by offering lecturers to schools (grades K-12) and organizations, and by presenting a workshop for high school math teachers.

In the past year, 12 tours of M^2RC facilities have been completed (see Table 1 in Appendix F). Led by M^2RC faculty and students, tours are planned to address the ability level of the audience. As a result, groups of all ages have responded with enthusiastic reviews of this program. With the recent completion of the new facilities on Centennial Campus at North Carolina State University, plans are underway to expand this activity.

Providing lecturers to schools and other organizations has been an important part of outreach efforts since the creation of the Mars Mission Research Center. To date, M^2RC members have addressed 67 different audiences in Raleigh, Greensboro, and surrounding areas (see Table 2 in Appendix F). Members of inquiring organizations either choose a topic from a list of 13 prepared lectures or request a personalized topic if necessary. Recently obtained NASA videos and slide programs will help to diversify and to increase the number of available presentations. In addition, a slide program highlighting current and past research at M^2RC is currently being assembled and will be ready in time for the 1992-93 school year. Additional faculty and student lecturers will be recruited in order to meet the growing demand for this important service.

In response to recent studies that suggest that pre-college math instruction should emphasize applications, the M^2RC and the North Carolina Space Grant Consortium are cosponsoring the First Annual Applied Mathematics for Teachers Workshop. Ten high school math teachers from the Raleigh area have agreed to take part in this workshop to be held at the NCSU McKimmon Center August 3-7, 1992. Each of these teachers has supplied the Outreach steering committee with a topic of interest from a course that they are currently teaching. During the workshop, these teachers will work with select faculty and graduate students to develop an application based lesson plan for their topic of interest. Afterward, each teacher will instruct a few of his or her own students from the lesson plan and will lead the group in related project work. The workshop will conclude with presentations from each of the groups and distribution of the collective lesson plans to each of the participating teachers. Four informal follow-up discussions will be held during the 1992-93 school year in order to evaluate the success of the workshop. Decisions concerning continuation and expansion of this workshop in subsequent years will be based on the evaluations of the participating teachers, students, and the Outreach Steering Committee.

Future plans for the Education Outreach program in M^2RC are centered on the expansion of the existing activities. However, the steering committee is currently considering a number of proposed projects that are meant to raise student awareness of math applications and to further increase student interest in engineering and other sciences. One project involves the development of a series of educational videos that demonstrate the use of basic mathematics in NASA sponsored research. Production of a pilot video is being planned for next year.

CONFERENCES AND WORKSHOPS

The M^2RC sponsored four workshops related to research in the Center. The agenda for these workshops is given in Appendix G. In addition, the Center co-sponsored with professional societies the following six conferences:

Space 90

The Space 90 Engineering, Construction, and Operations in Space Conference was held April 22-26, 1990 in Albuquerque, New Mexico. Participants from the Mars Mission Research Center included Fred DeJarnette, Gordon Lee, Larry Silverberg, William Rasdorf, and Theresa Stone. The Mars Mission Research Center was an affiliated organization of this conference.

Space 92

The Space 92 Conference on Engineering, Construction, and Operations in Space will be held May 31-June 4, 1992 in Denver, Colorado. Mars Mission Research Center faculty and students participating in this conference are Eric Klang, John Hairr, Greg Washington, Fred DeJarnette, Gordon Lee, and Juri Filatovs. Mars Mission Research Center is an affiliate organization for this conference.

Fibre Tex Conference

The Fibre Tex Conference sponsored by NASA, DOD, Drexel University, and NCSU was held October 15-17, 1991 at NCSU's College of Textiles. Participants from the Mars Mission Research Center included Genevieve Dellinger, T. M. Kuo, Malcolm Lyon, Rona Reid, Randy Stabler and Professors Sarma Avva, Fred DeJarnette, Aly El-Shiekh, Juri Filatovs, Ray Foye, Eric Klang, Mansour Mohamed, Bob Sadler, and Gary Tatterson.

The 30th Aerospace Sciences Meeting was held in Reno, Nevada January 6-9, 1992. Faculty presenting papers included H. A. Hassan, Graham Candler, John Perkins, and Fred DeJarnette. Fred DeJarnette also co-chaired a special session entitled Exploration of Mars which is part of the International Space year.

The Sampe Conference and Exhibition was held on March 7-11, 1992 in Anaheim, California. Those attending from NCSU were Aly El-Shiekh, Mansour Mohamed, Rona Reid, Cirrelia Thaxton, and Keith Black. A new braiding machine, purchased by NCSU, was on display.

ASME Winter Annual Meeting

The NASA University Space Engineering Research Centers will be featured in three special sessions of the ASME Winter Annual Meeting which will be held November 8-13, 1992 in Anaheim, California. The sessions will focus on technologies and sciences of interest to space concepts, Advances in Space Structures, and General Advances in Space Systems Materials.

SEMINARS

The Mars Mission Research Center hosted a number of seminars during the past 4 years in all of the Center's focus research areas. Selected presentations are given below.

HYPERSONIC FLIGHT EXPERIENCE SEMINAR

Dr. Gerald Walberg of George Washington University's and NASA Langley's Joint Institute for Advancement of Flight Sciences presented a seminar in January 1991 on Hypersonic flight experience at the Mars Mission Research Center. Walberg reported that the flight test results from the X-15, Asset, Prime, Reentry F, and Shuttle Orbiter flight research programs have been reviewed and compared with theory and ground-based experiments.

The seminar emphasized our capability to predict aerodynamic coefficients and stability derivatives, and distributions of surface pressure and aerodynamic heating rate for typical orbital and sub-orbital hypersonic vehicles. Overall, this comparison demonstrated the feasibility of designing hypersonic vehicles based on tests in conventional, perfect-gas wind tunnels supplemented by state-of-the-art Computational Fluid Dynamics (CFD) analysis.

According to Walberg, at Mach numbers up to approximately 8, real gas effects are small, and Mach number-Reynolds number simulation is sufficient to insure accurate prediction of aerodynamic characteristics. At higher Mach numbers, real gas effects become important but appear to affect primarily pitching moment and to have little influence on other aerodynamic characteristics. Viscous interaction effects appear to be well correlated by the viscous interaction parameter, and to affect primarily axial force. With the exception of RCS jet interactions, stability and control derivatives are well predicted throughout the hypersonic flight regime.

Walberg reported that state-of-the-art aerodynamic heating techniques appear to be accurate predictions for laminar and fully turbulent attached flows so long as there are no strong shock interactions or non-equilibrium chemistry effects. For such flows, heating rate distributions depend only weakly on Mach number and hence wind tunnel results can be used throughout the hypersonic speed range. For high-speed, high-altitude flight, surface catalycity effects can have a major influence on heating rates; however, modern, finite-rate boundary layer analyses are capable of predicting such major trends.

According to Walberg, the major remaining challenges are the accurate prediction of 1) real gas effects on longitudinal trim, 2) the effectiveness of blended high altitude control systems, 3) shock interaction heating, 4) heating rates for separated vortex-dominated leeside flows, and 5) boundary layer transition and relaminarization. He also pointed out that there are no flight data on the propulsion-airframe integration effects that are so important for airbreathing launch vehicles.

SPACE EXPLORATION SEMINAR

Dr. Mikhail Ya. Marov of the Keldysh Institute, Moscow, Russia presented a seminar entitled "The Russian Space Program" on March 10, 1992. Professor Marov has made several pioneering studies in developing scientific instrumentation for the study of planetary and cometary atmospheres, including Earth, Mars, Venus, and the comet Haley. He has also developed original approaches to develop and refine theoretical models for these atmospheres, using hydrodynamics, rarefied gas dynamics and kinetics. These experimental studies and theoretical models are important to better define the operational mode of spacecraft used for solar system studies.

Dr. Marov was in the United States for planning of the International Space University and to visit several of the NASA centers.

MISSION TO MARS LAUNCH PARTY

Dr. Fred DeJarnette was the featured speaker at a special Mission to Mars Launch Party on March 29, 1992 at Discovery Place in Charlotte, NC. His topic was "Humans to Mars". The event was sponsored by the Planetary Society in conjunction with the Mission to Mars exhibit on display at Discovery Place. The exhibit will travel to 12 museums around the country over a four year period for an average stay of three months at each location.

SELECTED AEROSPACE SEMINARS

Gary L. Bennett, Deputy Director, Transportation and Platforms Division, National Aeronautics and Space Administration, Washington, DC presented a seminar April 9, 1992 entitled "Back to the Future: Using Nuclear Propulsion to Go to Mars." In July 1990, President Bush committed the U.S. to a long-term vision of space exploration: completing Space Station Freedom, returning to the Moon to stay and then sending a manned mission to Mars. Over the years NASA has performed a number of studies which show that nuclear propulsion (both nuclear thermal propulsion and nuclear electric propulsion) offer tremendous benefits in a manned mission to Mars. Beginning in Fiscal Year 1991, NASA is again funding studies on nuclear propulsion with the long-term objective of selecting the best concepts for system testing in time to support a decision to go to Mars. NASA has sponsored workshops and has established tri-agency planning process to ensure that the appropriate resources are brought to bear to meet this exciting technical challenge.

Ruth H. Pater, NASA Langley Research Center, Hampton, VA presented a seminar April 7, 1992 on "New High Temperature Polymeric Composites: LaRC™RP46."

LaRC^{TM}RP46 polymides are a family of ultra high performance composite matrix resins developed recently at NASA Langley. As a family, its development was prompted by an aerospace industrial need for an environmentally sound PMR-15 replacement. PMR-15 has been the standard ultra high temperature composite matrix resin used worldwide by aerospace companies for the last 2 decades. However, one of the three monomers used in PMR-15 is 4,4'-methylenedianiline (MDA). This monomer is a suspected human carcinogen. Due to rising manufacturing costs and increasing environmental restrictions, an intensive search has been conducted in the last few years for a less toxic PMR-15 replacement. Several MDA-free PMR polymides have been developed. These include British Petroleum's B1 formulation, Ferro's CP1-2310, United Technologies' 3,3'-DDS-PMR-16.5 and Rohr's PMR-15-MDAF. However, none of these MDA-free materials have a combination of low cost, ease in processing and outstanding thermal and mechanical properties as attractive as the attributes in PMR-15. LaRC^{TM}RP46 is also an MDA-free material formulated by replacing the MDA in PMR-15 with a novel diamine, 3,4'-oxydianiline (3,4'-ODA). Unlike the other non-MDA systems, however, LaRC^{TM}RP46 not only retains all the attributes of PMR-15, but also features significantly improved properties. In fact, LaRC^{TM}RP46 is the most cost-effective ultra high temperature matrix resin known. The processing, performance and durability of these new thermosetting polymide composites will be presented.

Professor M. W. Hyer, Department of Engineering Science and Mechanics, VPI&SU, Blacksburg, VA gave a seminar on March 27, 1992 on "The Influence of Layer Waviness on Hydrostatically Loaded Thick Composite Cylinders. There has been interest in using fiber-reinforced composite materials for the construction of submersible structures such as submarines. This seminar discusses one aspect of the possible application of composite materials to such structures. In particular, due to the cylindrical nature of submersible structures, and the severe compressive loading experience in the hydrostatic environment, the response of thick composite cylinders to a hydrostatic loading is of interest. The primary focus of the seminar will be a discussion of the influence of layer waviness on the response of hydrostatically loaded cylinders. Layer waviness is a commonly observed anomaly in thick fiber-reinforced structures, the waviness being an artifact of the manufacturing process. It has been speculated that waviness is responsible for the premature failure often observed in hydrostatically loaded cylinders. To study this possibility, the effect of a single wave in an otherwise perfect cylinder is investigated. The single wave is identified by the length of the wave and its amplitude. The specific location of the wave within the cylinder wall is also an identifying characteristic of the wave. These three parameters, along with cylinder geometry, can be varied to identify specific effects of the waviness. The perfect cylinder is used as a basis for comparison. A finite-element analysis coupled with an elasticity solution is used to study the problem. The results are limited to a single laminate, but one considered for this application. It shown that waviness can cause interlaminar shear stresses of a magnitude that can lead to failure. Interlaminar shear stresses are not present in the perfect cylinder. Waviness can also cause excessive fiber-direction compressive stresses which lead to failure. Interestingly enough, waviness can also cause interlaminar tensile stresses. This despite the fact the hydrostatic loading is generally perceived as a triaxial composition problem.

Dr. Michael Cohen, NASA Ames Research Center, presented a seminar in March 1991 on "Biological Effects of Gravity and Long Duration Spaceflight." All life on Earth has developed under the continual influence of the terrestrial environment. This environment includes the Earth's atmosphere, with its unique mixtures and pressures of gases, the periodic changes in radiant energy from the sun, the unique and limited ranges of temperature and humidity, and, particularly, the effects of the Earth's gravitational field. Gravity has not only influenced the form and development of several organ systems and the sizes of animals and plants, but it has also imposed time and velocity constraints on terrestrial organisms that have dictated behavioral and neuromuscular requirements for the functioning of their nervous systems.

The following factors were discussed: Physiological Adaptation to Space, Physiological Aftereffects of Adaptation to Space, and Artificial Gravity: the Ultimate Countermeasure.

As one of the most experienced former American astronauts, Owen Garriott, argued, the critical issue is to establish which approach is best; neither microgravity nor artificial gravity is without its serious potential difficulties for future missions in space. Although long term exposure to microgravity presents several potential physiological problems, it is a "devil" that we know, at least partially. In contrast, artificial gravity in space is a "devil" that we generally do not know. Clearly, extensive scientific research, and both engineering and operational analyses will be needed before the decision can intelligently be made whether to implement artificial gravity for long duration missions, or not.

Michael Tauber, NASA Ames Research Center, presented a seminar in March 1991 on "Aerobrake Design Studies for Manned Mars Missions." Many studies have shown that large weight and cost savings can be achieved by using atmospheric braking at Mars instead of decelerating propulsively. The objective of the present study is to determine the vehicle's mass fraction (fraction of total vehicle mass at entry) that must be devoted to the aerobrake's structure and thermal protection systems. Both low and medium lift-drag ratio (L/D) shapes are considered. An inertial reference entry speed of 8.6 km/sec (8.4 km/sec with respect to the rotating atmosphere) is considered. The entry velocity is representative of fast (14 to 16 months long) missions and is near the upper limit usually considered for manned Mars entries. Therefore, the aerobrake's thermal protection and structural requirements are stringent.

The configuration of the aerobrake depends primarily on the L/D that is required to achieve an adequately large entry corridor and to observe physiologically realistic deceleration limits. Present guidance and control capabilities call for an energy angle corridor width at Mars of at least 1° at an attitude of 122 km. A deceleration limit of 5 (Earth) g is used based on the Soviet's long duration, space flight experience. A blunt, low L/D, configuration with ballistic coefficients (m/C_DA) of 100 and 200 kg/m^2 has been studied. The aerobrake's shape is the same as that of the proposed aeroassist flight experiment vehicle. In addition, a delta-winged vehicle, with a medium L/D and a ballistic coefficient of 375 kg/m^2, has been studied. This vehicle has an L/D of 0.85 at an angle of attack of 37°. Since winged vehicles have less drag than blunt shapes, their ballistic coefficients are larger, which results in a more intense and longer heating pulse, thus requiring more heat shielding. However, high L/D vehicles also have many advantages. Increasing the L/D from the AFE's value of 0.3 to 0.85 nearly doubles the entry flightpath angle corridor width and provides an order of magnitude increase in cross-range capability. The latter is very important for descent from orbit. Finally, the winged vehicle has the potential of being launched into Earth orbit fully assembled. In contrast, the blunt shapes will probably have to be assembled in orbit, which may become a very costly and potentially hazardous procedure.

Both insulative, radiatively cooled heat shields and ablators have been considered. After adding heat shielding and optimizing the structure, the aerobrake's total mass fractions (defined as heat shield plus aerobrake mass divided by the vehicle's total mass) varied from about 15 to 13% for ballastic coefficients of 100 and 200 kg/m^2, respectively, for the blunt shapes and was slightly under 17% for the winged vehicle. The winged vehicle's aerobrake mass fraction was somewhat greater than that of the blunt shapes because the former required a higher mass fraction for thermal protection. The aerobrake's mass fractions range from less than to slightly over the 15% value that is considered to make aerobraking indisputably superior to propulsive braking. In fact, using the best chemical propellants yields a propulsion system mass fraction that exceeds the aerobrake's values by factors of 4 to 5.

Special Note: Dr. Malcolm Cohen and Professor Mike Tauber served on the Ph.D. committee for **J. Evans Lyne, MD.** Evans had his MD prior to starting a Ph.D. program in Aerospace Engineering at NCSU. He performed most of his dissertation research at NASA Ames and completed the Ph.D. degree in March 1992. Now Evans will pursue a career which combines medicine and Aerospace Engineering. His dissertation has already been acclaimed as a significant contribution to human exploration.

SEMINARS AT A&T

Faculty and students at NCSU and A&T coordinate their research by visits to the two campuses and televideo meetings held twice a month.

The faculty and students at A&T receive the televised seminar series in composite materials initiated from the University of Illinois. The following is a schedule of seminars from the Spring Semester 1989. Students and faculty have an opportunity to interact with the speakers through telephone. These seminars are being televised live by GTE Gstar 1 Satellite (Ku-Band) from 4:00-5:30 p.m. (eastern time).

Date	Guest Speaker	Title of Presentation
2/10	Dr. Hatsuo Ishida Macromolecular Science Case Western Reserve Univ.	Interface Molecular Characterization of High Performance Composite Materials
2/24	Professor C. T. Sun Aeronautics & Astronautics Purdue	Intelligent Tailoring of Laminates
3/10	Dr. John L. Kardos Dir. Materials Res. Lab. Washington University	New Processing Science for High Performance Polymer-Matrix Composites
3/31	Dr. Paul Lagace Aeronautics & Astronautics M. I. T.	The Sensitivity of Kevlar-Epoxy and Graphic-Epoxy Structure to Damage from Fragment Impact
4/21	Professor R. A. Schapery Civil Engineering Texas A & M University	Mechanical Characterization Analysis of Inelastic Composite Laminates with Damage
5/05	Dr. N. J. Pagano Air Force Materials Lab Wright-Patterson, AFB	Issues in Micromechanical Modeling of Brittle-Matrix Composites
5/19	Prof. Zvi Hashin Mechanical Engineering Dept. Tel Aviv University and Professor of Mechanical Engineering University of Pennsylvania	Analysis of Cracked Composite Laminates

INTERACTIONS WITH OTHER ORGANIZATIONS

Students and faculty working with the Center have worked very closely with NASA personnel in the following branches:

NASA Ames Research Center

Aerothermodynamics
Applied Computational Fluid Dynamics

NASA Langley Research Center

Aerothermodynamics
Transonic Aerodynamics
High-Reynolds-Number Aerodynamics
Supersonic/Hypersonic Aerodynamics
Computational Aerodynamics
Theoretical Flow Physics
Experimental Methods
Experimental Hypersonics
Vehicle Analysis
Space Exploration Initiative Office
Controls-Structures Interaction Office
Polymeric Materials
Mechanics of Materials
Applied Materials
Aircraft Structures
Spacecraft Structures
Computational Mechanics
Spacecraft Dynamics
Spacecraft Controls

NASA Johnson Space Center

Aerothermodynamics
Lunar and Mars Exploration Projects Office

Additional interactions have been conducted with the following organizations:

Naval Surface Warfare Center at White Oak and Dahlgren
Oak Ridge National Laboratory
Los Alamos Laboratory
McDonnell Douglas Space Systems Co.
Huntington Beach, California and Kennedy Space Center, FL
Boeing/Huntsville
Institute for Space and Terrestrial Studies and
University of Toronto Space Institute
Corning Glass Works
Amercom
Applied Research Associates
Duke University
DuPont
General Electric
Kaiser Aerotech
Lawrence Livermore
National Labs
Lord Corporation
MBB
Michigan Molecular
Institute
Nippon Oil
Pratt and Whitney
Rolls Royce
TRW

COORDINATION WITH OTHER PROGRAMS

National Space Grant

Dr. Gerald Walberg is the Director of the National Space Grant College and Fellowship Program at NCSU.

The basic objective of the Space Grant Consortia is to help maintain, through the nation's universities, an expanded focus on the U. S. capabilities in aerospace science and technology. In response to NASA's phase II program, the State of North Carolina plans to initiate, under a program Grant, an interactive program directed towards aerospace research, education and public service. Specifically, two sister institutions in the University of North Carolina System, North Carolina State University (NCSU) at Raleigh and North Carolina Agricultural and Technical State University (A&T) at Greensboro, have joined in partnership to work together to make significant contributions to the nation's effort to solve aerospace problems.

Aeronautical and aerospace studies became strong in North Carolina in the late forties, have grown over the years and are now considered one of the top programs in the nation and the world. The major leadership in space research is provided by the Mars Mission Research Center. This is a joint effort between the two Universities. Its role is to develop the technologies and train the scientists and engineers that will enable us to travel to Mars and return safely to Earth. We cite as an example work in the design and fabrication of space vehicles for both Mars and Lunar missions, work relevant to the design and construction of the space station, and work in human factors related to the survival and performance of humans under extended reduced gravity environment.

The two Universities have programs in place designed to attract highly qualified and highly motivated students especially minority students. Their commitment to find more effective means of recruiting, retaining and graduating minority students with excellent technical skills is a matter of public record. In the last two academic years, A&T was a national leader in graduating blacks in Engineering.

The program focuses on: outreach and pre-college education, undergraduate education, graduate education and research and technology transfer. Funding in the amount of $320,000 support student development, laboratory enhancement and outreach activities.

Center for Composite Materials Research

This Center was established at A&T in September 1988 with Dr. V. Sarma Avva as director. The objectives and goals of the Center are:

- To develop advanced and state-of-the-art research capabilities of faculty and to improve upon existing research facilities with the objective of developing a center of excellence in the area of composite materials
- To train undergraduate and graduate students in those areas associated with the emerging advanced materials research and technologies
- To provide additional summer training opportunities for the students in the research and development laboratories of the participating agencies and corporations
- To train personnel from the public and private sectors in the Piedmont area and elsewhere with the latest developments in the use of advanced materials to their specific applications.

This Center has established a national reputation and complements the research in Mars Mission Research Center.

The NASA Center of Research Excellence (NASA-CORE)

NASA Headquarters has selected North Carolina A&T SU for a grant as a Historically Black College and University (HBCU) Research Center of Excellence for Aerospace Research. The goal of this research center is to achieve a broad-based competitive aerospace research capability. The center of excellence is to establish a quality aerospace research and educational program to increase the participation of minority faculty and students in the areas of aerospace engineering. The center will focus on research initially in hypersonic vehicle technologies. The center is expected to integrate four NASA funded research areas into an effective research team. These research areas include Aerospace Structures, Controls and Guidance, Computational Fluid Dynamics and Human Engineering.

Currently, the School of Engineering at A&T State University has research groups to support center activities. This research effort will complement existing programs of the university including the Center for Composite Materials Research. The Mars Mission Research Center, a jointly established center between North Carolina State University and North Carolina A&T State University; and the Space Technology Development and Utilization Program. The research in progress at NCA&TSU complements, to a large extent, work that is being carried out at NASA Langley Research Center. Over the Years, A&T has developed a good relationship with NASA Langley in such areas as materials, structures, computational fluid dynamics, controls, and human-machine systems. A number of students have used and are using NASA's facilities to complete their graduate work. The association with NASA/LaRC and NCSU should help A&T develop a strong program in aerospace engineering.

The Center will be managed by a Director at NCA&TSU. A board of directors consisting of the Deans and Department Heads of participating faculty, two representatives from the collaborative NASA Center and two representatives from collaborating industries will be formed. The Board of Directors will have a rotating Chairman, elected by the members for a one year period. It will meet twice a year to review the operation and progress of the Center. Dr. Steven H. Y. Oai is the Director with responsibility for overall coordination of the program. He will be the primary point of contact with NASA relative to management of the center. Dr. William J. Craft will serve as the head of the educational committee. He will coordinate the educational and training aspects of the program which will eventually lead to an established aerospace engineering program in the Department of Mechanical Engineering.

The proposed work will be conducted initially by fourteen faculty members. To ensure the continued growth and vitality of the Center, a new research faculty member will be added to the staff every year. Through this arrangement, the Center will grow from 14 faculty and 20 students in the first year to 23 faculty and 32 students in the fifth year. The University will meet the space needs of the Center, cost share in the purchase of equipment, and provide for facility preparation and renovation. The proposed 5-year budget for NASA is about $8.5 million and A&T will cost share approximately an additional $2.5 million.

The proposed center program includes a strong academic program concurrent with the research effort designed to prepare students for careers with direct relevance to aerospace engineering. The center plans to offer a sequence of courses in the areas of aerospace engineering including flight vehicle structural design, controls and guidance, aerodynamics, and human-machine systems. Dr. David E. Klett and a research associate will help develop the wind tunnel and advanced fluids laboratory for courses in aerodynamics and gas dynamics. Dr. William Craft will help develop the aerospace structures laboratory to support flight vehicle design. Dr. Steven Lai and a research associate will develop a control and guidance laboratory to support the control course. Dr. Cerlesting Ntuen will be responsible for upgrading the human factors research laboratory to support the human-machine systems course.

FUNDING FOR CENTER

Year	Budget period	Months	NASA funds ($M)	Cost sharing ($M)	% cost sharing
1	6-1-88 to 2-28-89	9	0.500	0.219	43.7
2	3-1-89 to 2-28-90	12	1.963	0.945	48.1
3	3-1-90 to 2-28-91	12	1.979	0.437	22.1
4	3-1-91 to 10-31-91	8	1.463	0.347	23.7
5	11-1-91 to 10-31-92	12	1.896	0.758	40.0
1-5	6-1-88 to 10-31-92	53	7.800	2.706	34.7

FUNDING BY UNIVERSITIES

Year	Months	NASA Funding ($M)			Cost Sharing (%)	
		NCSU	A&T	GWU	NCSU	A&T
1	9	0.300	0.200	–	103	74
2	12	1.088	0.875	–	63	30
3	12	1.152	0.779	0.048	25	19
4	8	0.890	0.547	0.026	25	21
5	12	1.140	0.738	0.018	52	22
1-5	53	4.570	3.139	0.092	46	27

MAJOR EQUIPMENT PURCHASED BY THE MARS MISSION RESEARCH CENTER

North Carolina State University

C-Scan Machine

Carrier 194 Braider

Components to build automated 3-D braiding machine

Components for telerobotic system

Components to build an aerobrake maneuvering experiment

Components to build automated 3-D weaving machine

Components to construct filament winder and enhance two braiders

Extensometer

Hot Press

Comparative Thermal Conductivity Measuring Instrument

Instron Environmental Chamber and Test Oven

Instron 20 Kip Testing Machine

Computer Terminals (2)

Workstations (8)

A&T State University

Axial/Torsional Machine

Carbonization Furnace

Dynamic Mechanical Analyzer

Laser Measuring Com. System

Oven

Polisher

Press (2)

Universal Testing M/C

Viscometer

Winder

RENOVATED AND NEW FACILITIES

As part of cost sharing from the university, A&T has renovated the Composite Processing and Fabrication Facility, Composite Materials Testing Laboratory, and the Light and Scanning Electron Microscope Laboratory. In addition, several facilities for smaller scientific equipment were renovated.

The Mars Mission Research Center at NCSU moved into a new building, Research II, on the new Centennial campus in October 1991. The Center occupies 7,000 square feet which is about one-third of the building. The facilities for the Center include offices for the director, assistant director, secretary/receptionist, bookkeeper, 11 faculty, and cubicles for 20 graduate students. In addition, it has a conference and board room, a computer room, two workstation rooms, an instrument room, a processing room, and an 1800-square foot high-bay laboratory facility with a structural testing wall and an overhead crane.

A dedication of the facility was held on April 21, 1992 and the ceremony included speeches by Congressmen David Price and Tim Valentine, Dr. Mike Griffin and Greg Reck from NASA Headquarters, and Mr. Ray Hook from NASA Langley. The ceremony also included remarks by Chancellor Monteith (NCSU) and Dean Harold Martin (A&T). The new facility will provide more space for the students and faculty and increase the laboratory space significantly for structures, controls, and materials groups.

ACCOMPLISHMENTS

Accomplishments from the beginning of the Center (June 1988) to April 1992:

- Recruitment of graduate students (26), undergraduate 30), faculty (27), and staff (6) supported by the Center.
- Total students working with Center: 59 B.S., 58 M.S., 38 Ph.D plus an additional 88 B.S. students working on Special Projects.
- Recruitment of Minorities: graduate students (4), undergraduates (8), and faculty (1).
- Students graduated by the Center: 66 B.S., 35 M.S., and 25 Ph.D.
- 244 publications of which 71 are refereed journal publications.
- Patents: one granted, one under review, and two applied for.
- Laboratories developed (5): composite processing and fabrication, materials testing, weaving, braiding, and structures.
- Performed Aerobrake Design Methodology Study.
- Developed 26 new courses.
- Distributed 4 newsletters and 3 Annual Reports.
- Conducted 4 workshops: Interplanetary Spacecraft, Lunar/Mars Aerobrakes, Aerodynamic Heating, and Spacecraft Controls.
- Special Projects (5): HL-20 Personnel Launch System, Aerobrake Mockup, Mars Excursion Vehicle, Orbiter Ejector, and Remotely Operated Vehicle.
- 3 Renovated Facilities at A&T.
- Occupied new 7,000 square foot facility at NCSU.

- Supplemental Funding: 39 projects with total funding of $7.1 million.
- Outreach Program: 12 tours of facilities and 67 lectures.
- Students and Faculty spend time at NASA Centers and Participating Industries.

FUTURE PLANS

Consistent with the Report of the Synthesis Group on *America's Space Exploration Initiative* and Vision 21 - *The NASA Strategic Plan* , the Mars Mission Research Center plans to initiate two new thrust areas in 1992.

1. **Advanced Propulsion Systems - nuclear electric and nuclear thermal**

   The Mission Analysis and Design Group will be expanded to include these propulsion systems in their analyses. In addition, the Hypersonic Aerodynamics Group will start aerothermochemical analysis of nuclear electric and nuclear thermal systems.

2. **Robotic Missions - Lunar and Mars**

   The Mission Analysis and Design Group will coordinate their studies with the NASA Office of Exploration , the Lunar/Mars Office at NASA Johnson Space Center, and the SEI 0ffice at NASA Langley Research Center. A faculty member in the robotics area will be added to the Center to work with Dr. Gordon Lee on robots and mini-rovers for lunar and Mars robotic missions.

Aerobraking will be involved with either chemical or nuclear propulsion systems for missions to Mars; therefore, the Center will continue aerobrake studies. The Mission Analysis and Design Group will study missions with chemical, nuclear, and hybrid propulsion systems with aerobraking. The Hypersonic Aerodynamics Group will continue studying chemically reacting flowfields to predict aerodynamic characteristics, convective and radiative heating, and validation of computer codes by flight and ground test data.

The Materials and Fabrication Groups will continue studies of conventional and textile composite materials. Emphasis will be placed on damage tolerance and 3-D stress applications such as joints. NASP materials will be analyzed for spacecraft applications.

The Structures and Controls Group will study structural design with the high performance composites. New designs with NASP materials will be investigated also. Spacecraft controls will be continued and the new robotic program mentioned will be implemented.

Projects have proven to be a valuable asset to the Center. We plan to initiate new projects which involve analysis, design, construction, and testing. Undergraduate students are well suited for these projects and flight experiments are particularly attractive. Discussions are currently underway with NASA and industry for a new project starting the fall of 1992.

The Outreach Program has grown to be a significant part of the Center. It is planned to expand these activities in collaboration with the National Space Grant and other programs at the two universities.

ICES

ALL STUDENTS GRADUATED WHO WORKED WITH THE CENTER

North Carolina State University

Name	Advisor	Degree	Date of Graduation	Employer
Jassim A. Al-Saadi	DeJarnette	PhD	1991	NASA Langley
Kenneth I. Beaty	Lee	BS	1990	General Electric/Engineer
Robert A. Bendl	Lee	BS	1990	General Electric/Engineer
Jinan G. Bennett*	Mohamed	BS	1990	Asten Press Fabrics, Inc.
James R. Benton	Perkins	MS	1989	Boeing
Melissa A. Boring*	El-Shiekh	BS	1990	State Conserv. Centre/S. Australia
Frank Brauns*	Hassan	BS	1990	MS/North Carolina State University
Tracey Bullock	Lee	BS	1991	
Ann B. Carlson	Hassan	PhD	1990	NASA Langley/Research Scientist
Paul W. Carpenter*	Lee	BS	1990	Automatic Guided Vehicles/Engineer
Vikas Chandra*		BS		
Foy M. Cheatwood	DeJarnette	PhD	1991	Vigyan, Hampton, VA
Bernard Chi	Lee	BS	1991	
Inho E. Choi	Yuan	BS	1990	Newport News Shipbuilding/Engineer
Keith Cochran	Lee	BS	1991	
Aaron Cozart*	Perkins	BS	1988	MS/North Carolina State University
Eric Critchley	Lee	BS	1991	
Kevin R. Cunningham	Hassan	MS	1990	
Genevieve A. Dellinger*	Klang	MS	1991	NASA Langley/Lockheed Contractor
Larry Dickinson*	Mohamed/Klang	BS/MS	1990	NASA Langley/Lockheed Contractor
Michael Duncan*	Hassan	BS	1991	MS/North Carolina State University
Dean R. Eklund	Hassan	PhD	1989	NASA Langley
Nancy M. Evans	Mohamed	BS	1990	Hoechst-Celanese Corp.
Lester A. Foster	Silverberg	PhD	1989	Grumman SSEIC/Engineer
Steven H. Frankel	Hassan	MS	1990	Pursuing PhD at University of Buffalo
Richard L. Gaffney	Hassan	PhD	1990	NASA Langley/ Research Scientist
Howard Gage*	Silverberg	MS		
Ian T. Gallimore*	Silverberg	BS	1989	Naval Air &Test Center/Maryland
John R. Gardiner	Silverberg	MS	1990	General Research Corp./Engineer
Thomas P. Gielda	McRae	PhD	1987	McDonnell Douglas/Research Scientist

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North Carolina State University (continued)

Name	Advisor	Degree	Date of Graduation	Employer
Arthur C. Grantz	DeJarnette	PhD	1989	Rockwell International
Francis A. Greene	DeJarnette	MS	1989	NASA Langley
John W. Hairr*	Klang	BS/MS		Lockheed/Structural Engineer
Arthur O. Hall*	Lee	BS	1991	Graduate School (other)
Jonathan R. Hamilton*	Lee	BS/MS		Boeing Aerospace
Mohamed Hammad	El-Shiekh	PhD	1991	Alexandria University/Assistant Professor
Lin C. Hartung	DeJarnette	PhD	1991	NASA Langley
Basil Hassan	DeJarnette	MS	1990	Pursuing PhD at N.C. State University
Scott D. Holland	Perkins	PhD	1991	NASA Langley/Research Engineer
Douglas J. Hudson	McRae	MS	1990	SAIC Inc./Computational Aerogynamicist
Kathryn S. Hudson (Thomas)	Griffith	MS	1989	NASA Marshall/Engineer
Kevin Jones*	Klang	BS/MS		Lockheed, Marietta, Structural Engineer
Douglas E. Kieffer*	Griffith	MS	1991	England/visitor
Soek Bam Kim	Fahmy	PhD	1986	Korean University/Assistant Professor
Kevin Kinzie	Griffith	BS	1989	Penn State/ Graduate Student
Carl Kirby*		BS		
Marc W. Kniskern	Perkins	MS	1990	Sandia
Dean Kontinos*	McRae			
John J. Korte	McRae	PhD	1989	NASA Langley/Research Scientist
Wei Li	El-Shiekh	PhD	1990	BASF/Research Engineer
J. Evans Lyne	DeJarnette	PhD	1992	NASA Ames Research Center
Glen A. MacMillan	Hassan	MS	1992	GE/Engineer
Jonathan C. McArthur	Griffith	MS	1989	NASA Lewis/Engineer
John Meyer*	Silverberg	BS/MS		
Charles A. Miller*	Torquato	PhD	1990	EPA/Research Scientist
Robert A. Mitcheltree	Hassan	PhD	1989	NASA Langley
Cary A. Moskovitz	DeJarnette	PhD	1989	Grad Student/Architecture/Virginia Tech.
Nancy Nimmo	Lee	MS	1991	NASA Langley/Technical Engineer
Roger Ogburn*		BS		
Paul D. Orkwis	McRae	PhD	1990	University of Cincinnati/Assistant Professor

North Carolina State University (continued)

Name	Advisor	Degree	Date of Graduation	Employer
Vicki L. (Britt) Owen	Klang	MS	1990	NASA Langley/Engineer
Gregory W. Page	Silverberg	BS	1990	
Songtae Park	Silverberg	PhD	1990	University of Ulsan/Assistant Professor
Brian C. Platz*	Hassan	BS	1991	Pursuing MS at NCSU
Jay E. Polo*	Silverberg	BS	1990	Charleston, SC/Engineer
James Redmond*	Silverberg	MS,PhD		A&T State University/Adjunct Asst. Prof.
Rona Reid*	El-Shiekh	BS	1988	MS/North Carolina State University
Graham S. Rhodes	Perkins	MS	1990	Model Engineering
Christopher J. Riley	DeJarnette	PhD	1992	NASA Langley
Melisa M. Ringer*	El-Shiekh	BS	1990	Hoechst Celanese/Process Engineer
Hughart Roberts*		BS		
Magdi Said	Fahmy	PhD	1989	NASA/Materials Engineer
Elsaid Salem*	Mohamed	MS		Pursuing PhD at NCSU
Aida Semunegus*	El-Shiekh	BS	1990	Far East
Simon Senibi	El-Shiekh	MS		PhD/A&T State University
Mike Siegel*				
Stan St. Clair Smeltzer	Klang	MS	1991	NASA Marshall/Research Engineer
Robert Stanley	Lee	BS	1990	MS/North Carolina State University
Joseph Steffen		BS	1991	
James Spliedt*	Lee	BS	1991	
Theresa Stone*	Rasdorf	BS		MS/North Carolina State University
Gary Tao*	Lee	BS	1990	
G. Scott Tetterton*	Vess	BS	1991	N. C. State University
Cirrelia Thaxton*	El-Shiekh	BS	1990	MS/North Carolina State University
Steffen Voss*	Lee	MS	1991	
Richard A. Wahls	DeJarnette	PhD	1990	Vigyan, Hampton, VA
James Ward*	Lee	BS	1991	
Greg Washington*	Lee	BS/MS		Pursuing PHD at N. C. State University
James E. Weger	Chokani	MS	1990	Army/Ft. Ruckers/Maj./System
Yvette C. White*	Rasdorf	BS	1990	University of Maryland/Student
David W. Witte	Griffith	MS	1989	NASA Langley/Engineer
Margaret Woloschek	Lee	BS	1991	
Shawn H. Woodson	DeJarnette	PhD	1988	General Dynamics
Isam S. Yunis	Silverberg	MS	1988	NASA Lewis/Engineer

A&T State University

Name	Advisor	Degree	Date of Graduation	Employer
Harold Allen*		BS		M/SA&T State University
Sheila Black*	Fallahi	BS	1991	
Joseph Blunt*	Avva	BS	1990	
Jack Crawford*	Avva	BS	1991	
Marvin Dixie*		BS		
Cedric Dobson*	Craft	BS	1991	Graduate Student/Georgia Tech
Desiree Drew-Lyon*		BS		MS/A&T State University
Carlto Gibbs*	Filatovs	BS	1991	Charlotte, NC
Derrick Giles*	Klett	BS	1992	
Eric Goforth*		BS		MS/A&T State University
Alphonso Hall*	Fallahi	BS	1991	Graduate Student/Georgia Tech
Charles Hickman*		BS		MS/A&T State University, Mech. Engr.
Malcolm Lyon*		BS		MS/A&T State University
Jennifer Riddick*	Shivakumar	BS	1988	General Motors
Davis Rogers, Jr.*		BS		MS/A&T State University
Orlando Sellers*	Craft	BS	1992	A&T State University
Jeneen Uzzel*	Avva	BS	1991	
N. Vaidyanathan*		MS	1991	Pursuing PhD at Pennsylvania State Univ.
Mike Walton*		BS		
Prentiss Ward*		BS		
Cynthia Worth*	Googerdy	BS	1990	
R. Yarlagadda*	Lala	BS	1991	Sun Micro Systems/California

George Washington University/JIAFS - 6 MS

Name	Advisor	Degree	Date of Graduation	Employer
Brian A. Beaver*	Walberg	MS	1991	NASA Lewis/Contractor
Robert D. Braun	Walberg	MS	1989	Pursuing PhD at Stanford University
Presun N. Desai	Walberg	MS	1990	NASA Langley

George Washington University/JIAFS - 6 MS

Name	Advisor	Degree	Date of Graduation	Employer
Miles O. Duquette	Walberg	MS	1990	
Kurt W. Meyer	Walberg	MS	1991	Pursuing PhD at University of Colorado
Tahernia, Louis A.	Walberg	MS	1990	

*indicates students funded by Center

Total Students Graduated by the Center (parentheses indicates those funded by Center)

Degree	NCSU	A&T	GWU	Total
BS	46 (37)	20 (20)		66 (57)
MS	28 (14)	1 (1)	6 (1)	35 (16)
PhD	25 (2)			25 (2)

THESIS AND DISSERTATION TITLES OF THE MARS MISSION RESEARCH CENTER

North Carolina State University

Name	Advisor	MS Thesis Title	Year
Lance H. Benedict	Griffith	Quantification of Vapor Screen Analysis	1991
Rusty A. Benson	McRae	A Dynamic Solution – Adaptive Grid Algorithm in Two and Three Dimensions	1990
James R. Benton	Perkins	Design and Navier-Stokes Analysis of Hypersonic Wind Tunnel Nozzles	1989
Kevin R. Cunningham	Hassan	Laminar – Turbulent Transition Using Non-Periodic Boundary Conditions	1990
Genevieve A. Dellinger	Klang	Numerical and Experimental Investigation of the Impact Response of 3-D Woven and Laminated Composite Materials	1991
Larry C. Dickinson	Mohamed/Klang	Evaluation of 3-D Woven Carbon/Epoxy Composites	1990
Jack R. Edwards	McRae	An Efficient Solution Technique for Shock-Wave Boundary Layer Interactions with Flow Separations and Slot Suction Effects	1990
Charles C. Fenno, Jr.	Hassan	A Computational Viscous-Inviscid Interaction Technique for Transonic Air Foils Using Cartesian Grids	1988
Steven H. Frankel	Hassan	A Hybrid Reynolds Averaged/PDF Closure Model for Supersonic Turbulent Combustion	1990
Howard D. Gage	Silverberg	Mapping Networks for Analysis of the Forced Expires Volume Signal	1989
John R. Gardiner	Silverberg	The Headless Water Skier	1990
Francis A. Greene	DeJarnette	A Space Marching Algorithm for the Thin-Layer Navier-Stokes Equations	1989
John W. Hairr	Klang	Design of a Stiffened Shell for a Mars Aerobrake Structure	1991
Jonathan R. Hamilton	Lee	Transfer from High Earth Orbit to Low Earth Orbit Using Aeroassisted Vehicles	1989

North Carolina State University (continued)

Name	Advisor	MS Thesis Title	Year
Basil Hassan	DeJarnette	Calculation of Streamlines and Metrics from Pressure Distributions for Predicting Heating Rates	1990
Brian R. Hollis	Griffith	A Fine-Wire Thermocouple Probe for Measurement of Stagnation Temperatures in Real Gas Hypersonic Flows of Nitrogen	1991
Douglas J. Hudson	McRae	Upwind Solution of Supersonic/Sonic Injection into a Supersonic Cross Stream Using a Conjugate Gradient Type Method	1990
Kathryn S. Hudson (Thomas)	Griffith	Condensation and Supercooling in Hypersonic Nitrogen Wind Tunnels	1989
Douglas E. Kieffer	Griffith	A Method of Analyzing Holographic Interferograms of Ballistic Models in Hypersonic Free Flight	1991
Marc W. Kniskern	Perkins	Analysis of a Six-Component, Nonwatercooled, Flow Through Strain-Gage, Force Balance Used for Hypersonic Wind Tunnel Models with Scramjet Exhaust Flow Simulation	1990
Dean A. Kontinos	McRae	An Explicit Rotated Upwind Algorithm for Solution of the Euler/Navier Stokes Equation	1990
NFN Machfud	Mohamed	Properties of Intermingled Carbon/PEEK 3-D Woven Composites	1990
Jonathan C. McArthur	Griffith	Laser Holographic Interferometric Measurements of the Flow in a Scramjet Inlet at Mach 4	1989
Nancy Nimmo	Lee	Sensor Filter Designs for Large Flexible Spacecraft	1991
David P. Olynick	Hassan	Influence of Afterbodies on AOTV Flows	1991
Vicki L. (Britt) Owen	Klang	Shear Buckling of Anisotropic Plates with Centrally Located Circular Cutouts	1990
Donald B. Owens	Perkins	Exploratory Wind Tunnel Investigation of the Stability and Control Characteristics of a Three-Surface Forward-Swept Wing Advanced Turboprop Model	1990
James D. Packard	Griffith	A Ballistic Investigation of the Aerodynamics Characteristics of a Blunt Vehicle at Hypersonic Speeds in Carbon Dioxide and Air	1990

North Carolina State University (continued)

Name	Advisor	MS Thesis Title	Year
James M. Redmond	Silverberg	Uniform Damping Control of one-Dimensional Structures	1989
Graham S. Rhodes	Perkins	Low-Speed Wind Tunnel Investigation of the Static Stability and Control Characteristics of an Advanced Turboprop Configuration with the Propellers Placed Over the Tail	1990
Christopher J. Riley	DeJarnette	An Approximate Method for Calculating Inviscid Flow Fields Over Three Dimensional Blunt-Nosed Bodies in Hypersonic Flow	1988
Elsaid H. Salem	Mohamed	Tensile Properties of Textile Polyester Woven Fabrics	1989
Stan St. Clair Smeltzer	Klang	A Two Dimensional Boundary Element Method for Generally Anisotropic Materials	1991
Lisa K. Spainhour	Rasdorf	A Computer-Aided Analysis System for Fiber-Reinforced Compsite Materials	1991
Gregory N. Washington	Lee	Modeling and Analysis of Doubly Curved Aerobrake Truss Structures	1991
James E. Weger	Chokani	Experimental Design of a Supersonic Shock Wave/Vortex Interaction at Mach 3	1990
David W. Witte	Griffith	Protuberance Interference Heating on a Slender-Body Cone Surface In Hypersonic Flow	1989
Seungil Yu	McRae	Comparison of Boundary Representations for Finite Volume Solution for the Euler Equations	1988
Isam S. Yunis	Silverberg	The Compromise Inherent in Structural Feedback Control	1988

North Carolina State University

Name	Advisor	PhD Thesis Title	Year
Jassim A. Al-Saadi	DeJarnette	Wall Interference Calculation in a Transonic Wind Tunnel with Discrete Slots	1991
Ann B. Carlson	Hassan	Direct Simulation Monte Carlo with Ionization and Radiation	1990

North Carolina State University (continued)

Name	Advisor	PhD Thesis Title	Year
Foy M. Cheatwood	DeJarnette	An Approximate Viscous Shock Layer Approach to Calculating Hypersonic Flows about Blunt-Nosed Bodies	1991
Dean R. Eklund	Hassan	Numerical Modeling of Supersonic Turbulent Reacting Free Shear Layers	1989
Lester A. Foster	Silverberg	Advanced Topics in Structural Dynamics: Maneuver of Flexible Spacecraft and On-Off Decentralized Control of Flexible Structures	1989
Richard L. Gaffney	Hassan	An Abbreviated Reynolds Stress Turbulence Model for Airfoil Flows	1990
Arthur C. Grantz	DeJarnette	An Approximate Viscous Shock Layer Method for Calculating the Hypersonic Flow Over Blunt-Nosed Bodies	1989
Mohamed Hammad	El-Shiekh	Staple Fiver Spinning Technology: "3-D Braiding"	1991
Lin C. Hartung	DeJarnette	Nonequilibrium Radiative Heating Prediction Method for Aeroassist Flowfields with Coupling to Flowfield Solvers	1991
Scott D. Holland	Perkins	A Computational and Experimental Investigation of a Three-Dimensional Hypersonic Scramjet Inlet Flow Field	1991
John J. Korte	McRae	An Explicit, Upwind Algorithm for Solving Parabolized Navier-Stokes Equations	1989
Wei Li	El-Shiekh	On the Structural Mechanics of 3-D Braided Preforms for Composites	1990
J. Evans Lyne	DeJarnette	Physiologically Constrained Aerocapture for Manned Mars Missions	1992
Charles A. Miller	Torquato	Studies in Ramdom Media: Effective Properties of Heterogeneous Materials and Behavior of Reactive Solids	1990
Robert A. Mitcheltree	Hassan	A One Equation Turbulence Model for Transonic Airfoils	1989
Cary A. Moskovitz	DeJarnette	An Experimental Investigation of the Physical Mechanisms Controlling the Asymmetric Flow Past Slender Bodies at Large Angles of Attack	1989

North Carolina State University (continued)

Name	Advisor	PhD Thesis Title	Year
Paul D. Orkwis	McRae	A Newton's Method Solver for the Two-Dimensional and Axisymmetric Navier-Stokes Equations	1990
Songtae Park	Silverberg	Dynamic Interactions and Globally Optimal Maneuver of Distributed Systems	1990
James Redmond	Silverberg	Fuel Optimal Propulsive Control of Structures	1992
Christopher J. Riley	DeJarnette	An Engineering Method for Interactive Inviscid-Boundary Layers in Three-Dimensional Hypersonic Flows	1992
Magdi Said	Fahmy	Residual Porosity in Polymeric Latex Films	1989
Richard A. Wahls	DeJarnette	Development of a Defect Stream Function, Law of the Wall/Wake Method for Compressible Turbulent Boundary Layers	1989
Shawn H. Woodson	DeJarnette	An Interactive Three-Dimensional Laminar and Turbulent Boundary-Layer Method for Compressible Flow Over Swept Wings	1988

A&T State University

Name	Advisor	MS Thesis Title	Year
Eric Goforth	Craft	Automatic Thermal Strain and Data Acquisition System	
Yashpal Hanspal	Avva	Fatigue Property	
Michael Walton	Raju	A Shell Analysis of the Aerobrake	
Simon Senibi	Avva	Fluid Flow Through Multiple Layers of Thin Nonwoven Fabrics	1990

George Washington University/JIAFS

Name	Advisor	MS Thesis Title	Year
Brian A. Beaver	Walberg	Aerodynamic Performance of Aerobrake Shapes for Mars Missions	1991
Braun, Robert D.	Walberg	The Effect of Interplanetary Trajectory Options on a Manned Mars Aerobrake Configuration	1989

George Washington University/JIAFS (continued)

Name	Advisor	MS Thesis Title	Year
Presun N. Desai	Walberg	Aspects of Parking Orbit Selection in a Manned Mars Mission	1990
Miles O. Duquette	Walberg	Mass Estimating Relationships for Interplanetary Spacecraft Subsystems	1990
Kurt W. Meyer	Walberg	Lifetimes of Lunar Satellite Orbits	1991
Marcus A. Shaw	Walberg	Ascent and Rendezvous Strategies for Manned Mars Missions	1992
Louis A. Tahernia	Walberg	Thermal Distortation of Geostationary Microwave Radiometer Antenna Systems and Consequent Effects on Antenna Peformance Parameters	1990

	MS	PHD
NC State University	38	23
A&T State University	4	
GWU/JIAFS	7	
TOTAL	49	23

DIX B

SEARCH

FRE

Review of Manned Mars Mission Scenarios

Gerald Walberg, Principal Investigator
Dept. of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
Review the previously proposed scenarios for manned Mars missions. Identify primary candidates for the initial missions. Compare these primary candidates with regard to: (1) reduced gravity effects, (2) exposure to space radiation, and (3) initial mass in low earth orbit, which is used as a rough indicator of mission cost.

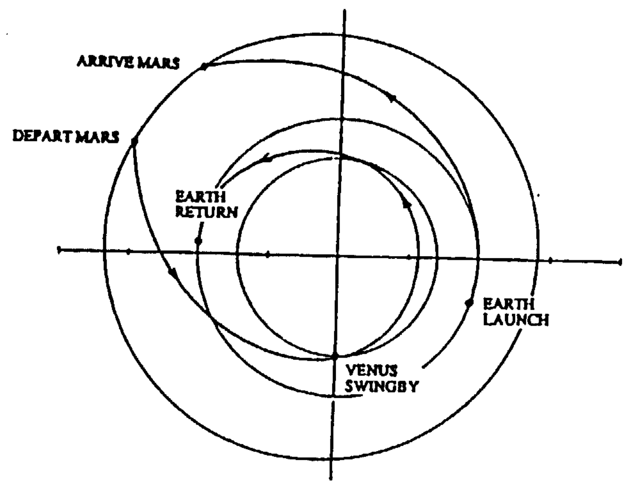
Approach:
Use previously published trajectory data for conjunction -, fast transfer conjunction -, opposition - and split sprint - class mission opportunities covering a complete 15-year Mars - Earth geometry cycle. Evaluate reduced gravity effects in terms of exposure time. Assess space radiation doses using state-of-the-art charged - particle transport analyses. Evaluate initial mass in Earth orbit using approximate solutions to the rocket equation for Isp = 480 sec (chemical propulsion), Isp = 480 + aerobraking and Isp = 960 sec (nuclear thermal propulsion).

Accomplishment:
It is concluded that the choice of mission scenario depends to a large extent on the amount of physical deconditioning caused by long term exposure to the 3/8 Earth gravity environment of the Martian surface. While important, exposure to space radiation is not a clear discriminator because, even with conservative assumptions, none of the mission scenarios exceed significantly the NCRP limits. If it is assumed that 3/8 Earth gravity is as harmful as zero gravity, the only acceptable mission scenario is the split sprint. Because of the high energy transfers involved, this scenario is marginally feasible (with regard to Earth departure mass) for chemical propulsion with aerobraking and is truly attractive only when nuclear thermal propulsion is used. If on the other hand , it is assumed that during their stay on the Martian surface, the astronauts experience neither recovery nor further deconditioning, the mission scenario of choice is the fast-transfer conjunction class because of its low radiation doses, short exposure to zero gravity and low Earth departure masses for either chemical propulsion with aerobraking or nuclear thermal propulsion. When mission cost factors other than mass are considered, it is argued that chemical propulsion with aerobraking and nuclear thermal propulsion are quite competitive for this scenario.

Significance:
Better definition of man's ability to live and work under reduced gravity must be obtained before a choice of mission scenario and propulsion system can be made. In the near term, research on chemical and nuclear propulsion and aerobraking should be pursued.

Future Plans:
Extend mission studies to address fast transfer conjunction class missions in more detail. Begin in-depth studies of precursor (unmanned) missions.

Publications:
Walberg, Gerald, "How Shall We Go To Mars? A Review of Mission Scenarios," AIAA paper 92-0481, January 1992.
Walberg, Gerald, "Aerocapture for Manned Mars Missions - Status and Challenges," AIAA paper 91-2870, August 1991.



Outbound flight time = 172 - 334 days
Mars stopover 60 days
Inbound flight time 250 - 375 days
Mission duration 531 - 714 days

ΔV_{TM1} = 3.72 - 4.89 km/sec

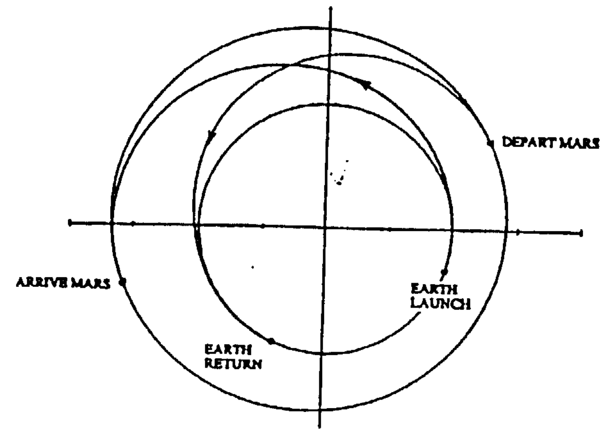
ΔV_M = 1.78 - 3.93 V_M = 6.42 - 8.58

ΔV_{TEI} = 1.24 - 3.30

ΔV_E = 3.77 - 5.20 V_E = 11.39 - 12.8

Closest approach to Sun 0.6-0.7 AU

Fig. 1 Opposition class missions with Venus swingbys: 2002-2015



Outbound flight time = 202 - 402 days
Mars stopover 286 - 551 days
Inbound flight time 191 - 335 days
Mission duration 935 - 1025 days

ΔV_{TM1} = 3.5 - 3.85 km/sec

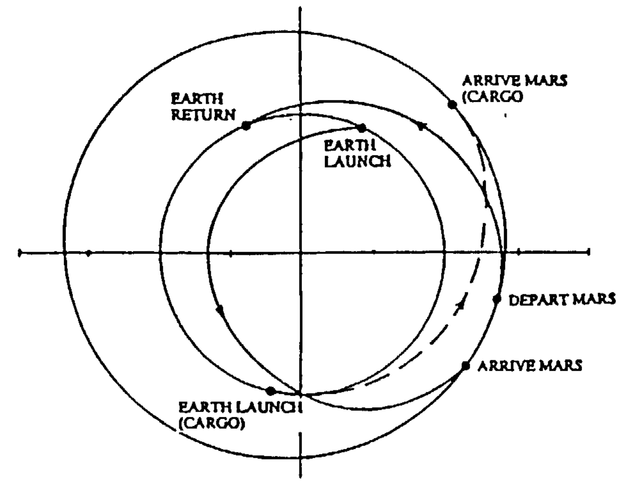
ΔV_M = 0.80 - 2.59 V_M = 5.44 - 7.23 km/sec

ΔV_{TEI} = 0.73 - 1.44

ΔV_E = 3.52 - 4.49 V_E = 11.13 - 12.10

Closest approach to Sun = 1 AU

Fig. 2 Conjunction class missions: 2003-2018



Outbound flight time = 238 - 287 days
Mars stopover 30 days
Inbound flight time 145 - 172 days
Mission duration 440 - 470 days

ΔV_{TM1} = 4.01 - 6.04 km/sec

$\Delta V_{MID\ COURSE}$ = VSB - 3.47 km/sec

ΔV_M = 3.93 V_M = 8.57

ΔV_{TEI} = 1.99 - 4.21

ΔV_E = 3.71 - 4.26 V_E = 11.32 - 11.87

Closest approach to Sun = 0.6 AU

Fig. 3 Split sprint missions: 2002-2015

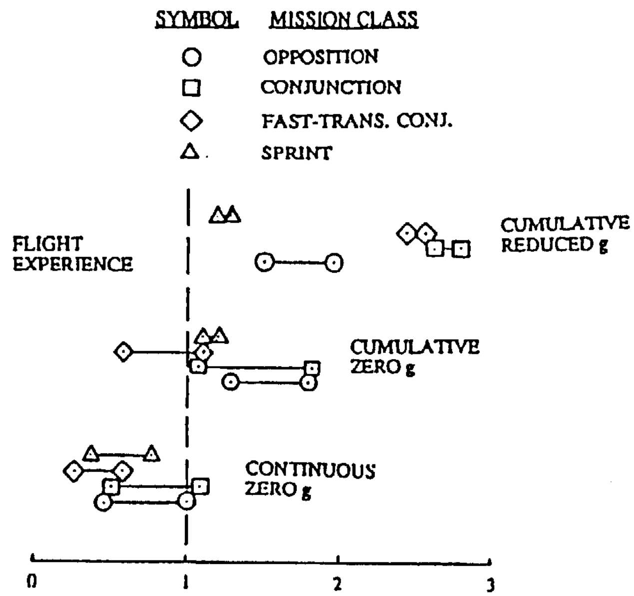


Fig. 9. Ranges of crew exposure to reduced gravity

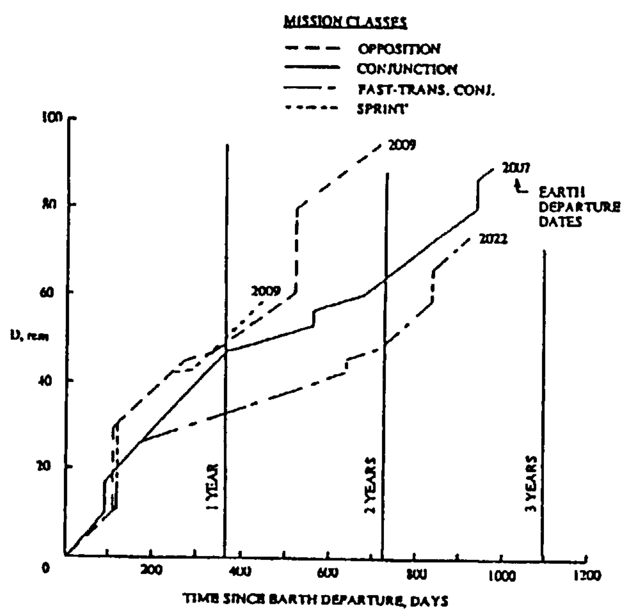


Fig. 10. Blood forming organ (BFO) radiation doses

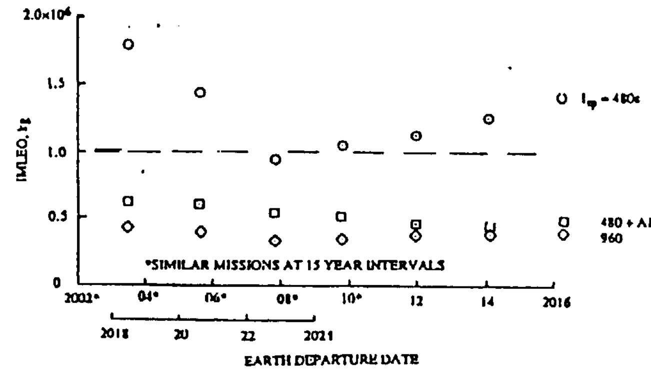


Fig. 14. Earth departure masses for fast-transfer conjunction-class missions

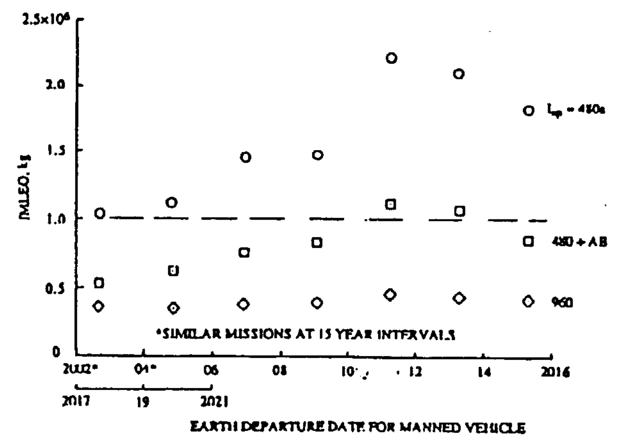


Fig. 15. Earth departure masses for split sprint missions

Lifetimes of Lunar Satellite Orbits

G. D. Walberg, Principal Investigator
Co-Investigator: K. W. Meyer
GWU/NASA Joinst Institute for Advancement of Flight Sciences

Research Objectives:
To determine the lifetime of nearly circular lunar parking orbits.

Approach:
In this study, a particular lunar gravitational model (the Ferrari 5x5 model) was chosen to determine the lifetimes for 100 km and 300 km perilune altitude nearly circular parking orbits. By investigating the effects that initial conditions have on the subsequent lifetime of an orbit, a technique is introduced that will aid mission planners in the selection of lunar parking orbits. The need to analyze orbital lifetimes for a large number of initial orbital parameters motivated the formulation of a simplified gravitational model from the original model.

Accomplishments:
According to results generated using this model, orbital lifetimes were found to be heavily dependent on the initial conditions of the orbit, particularly the initial inclination and argument of perilune. This selected model yielded lifetime predictions of less than 40 days for some orbits, while other orbits had lifetimes exceeding a year. Five distinct bands of short lifetime orbits appear as a function of the initial inclination, separated by bands of high lifetime orbits. Of particular interest is a set of orbits with an inclination of approximately 70° which yields long lifetimes while providing high inclination orbits desirable for various missions.

Significance:
Although inconsistencies and limitations are inherent in all existing lunar gravity models (due primarily to a lack of information about the far side of the Moon), the methods presented in this analysis are beneficial for incorporating the Moon's nonspherical gravitational effects on the preliminary design level for future lunar mission planning.

Future Plans:
Continue the development of efficient methods to account for nonspherical gravity effects and develop sensitivity coefficients to address the possible error in orbital lifetimes due to uncertainties in the gravitational coefficients.

Publications:
Meyer, K., "Development of a Simplified Gravitational Model for Lifetime Studies of Lunar Satellite Orbits," presented at AAS/AIAA Space Flight Mechanics Conference, Colorado Springs, CO, February 1992.

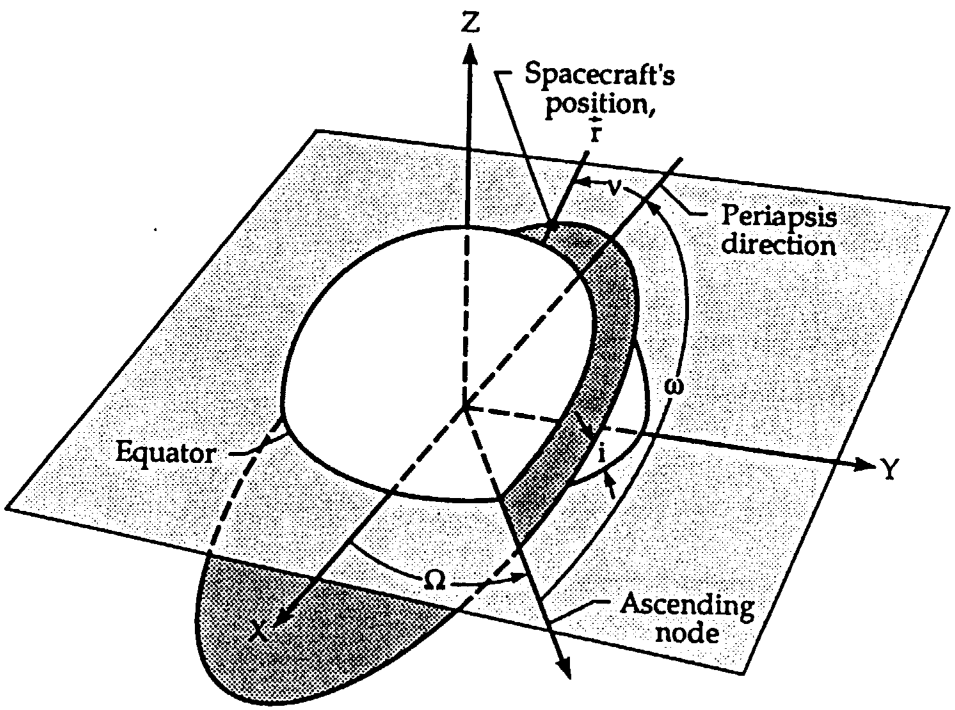


Figure 11: Orbital geometry.[40]

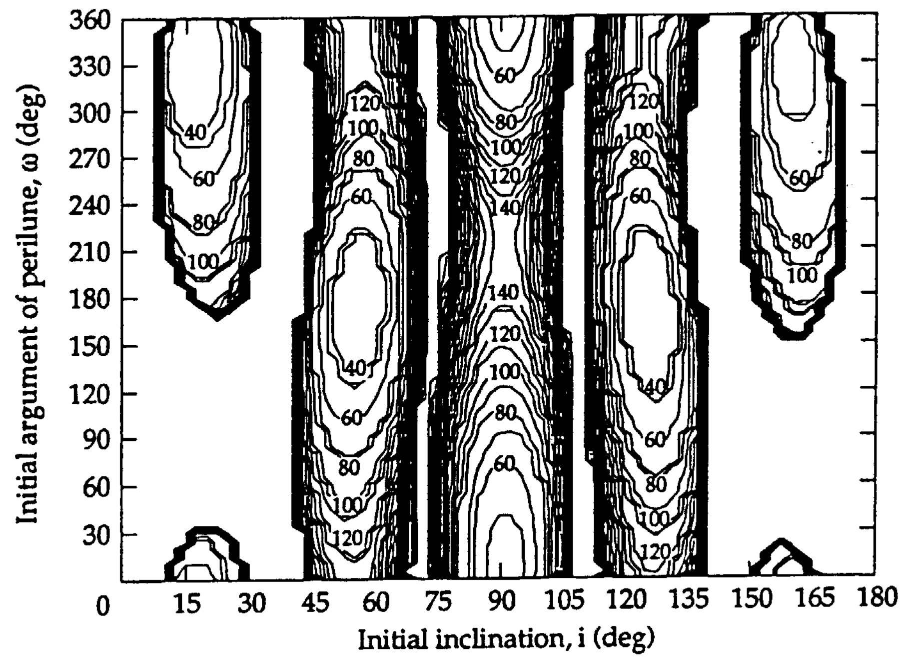


Figure 24: Contour plot of orbital lifetimes in days versus initial i and ω (initial Ω = 0°). The large white regions represent lifetimes of longer than a year.

A Computer-Aided Analysis System with DBMS Support For Fiber-Reinforced Thick Composite Materials

William J. Rasdorf, Principal Investigator
Co-Investigator: Lisa K. Spainhour
Department of Civil Engineering
North Carolina State University

Research Objectives:
The objective of this research is to explore the integration of several components of engineering software using an integrated material properties database. More specifically, a conceptual finite element material preprocessing system for fiber-reinforced composite ;materials analysis and design is sought.

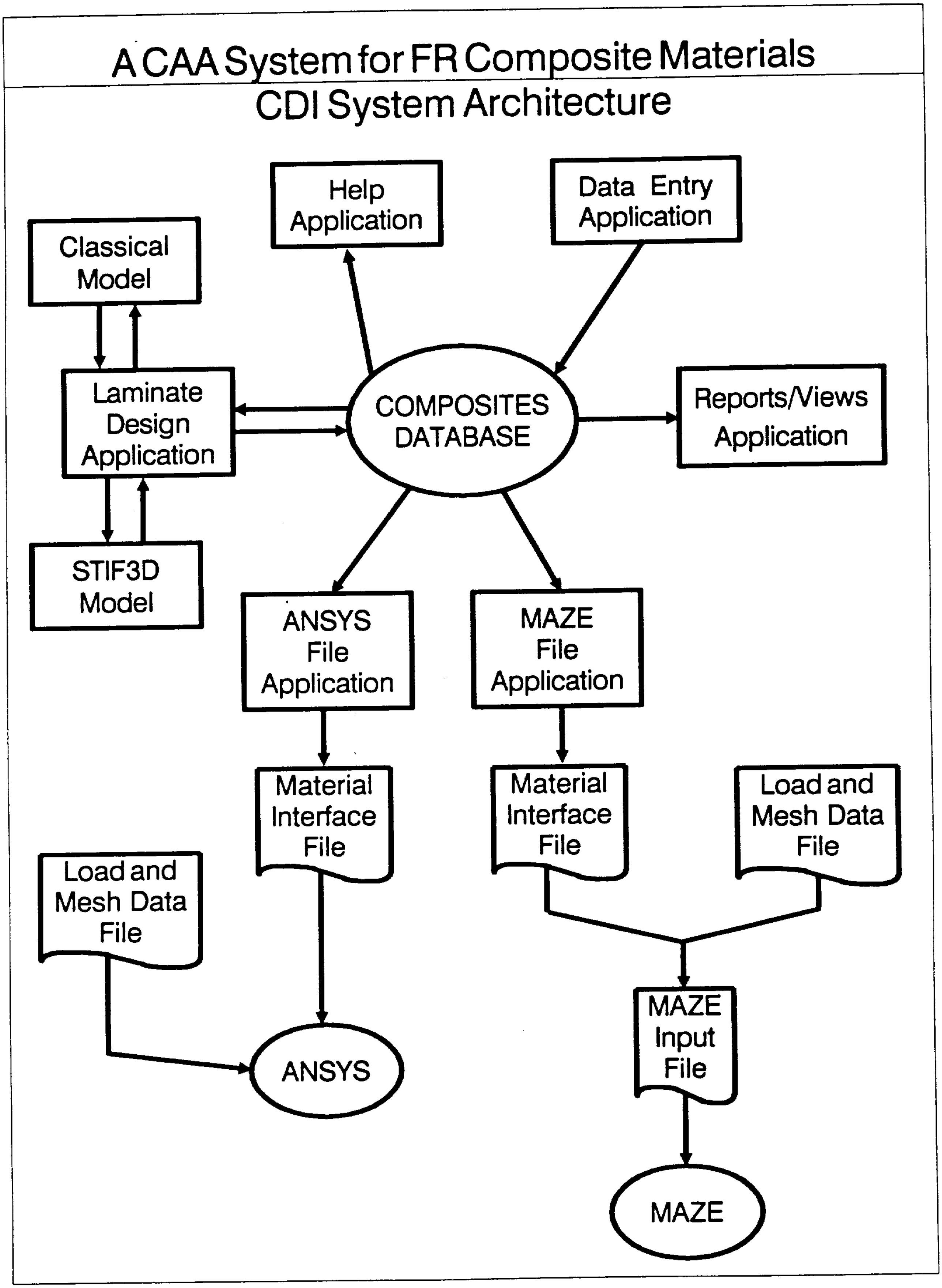
Approach:
A materials database was integrated with several software components, including commercially available finite element analysis (FEA) programs and preprocessors, and tools for the design of laminated composite materials. The capabilities of the integrated system include tasks such as composite laminate design, data entry, report generation, and material data file generation, performed in support of the finite element analysis capability.

Accomplishments:
The focus of the work has been on the integration of two-and three-dimensional composite materials data into several finite element analysis programs. Particular attention was given to analysis and design of components and structures using thick composite materials. The primary objective in developing the composites analysis system was to enhance data transfer between, and interaction among, several engineering software programs with a minimum of user interaction. A major accomplishment, therefore, is the twofold role of the materials database in the analysis system, as both a passive data repository and as a dynamic data transfer mechanism. Interface programs and direct integration techniques are used to pass materials data between the user and the database, and between the database and the various system components or application programs. Currently, the system enables the user to generate materials data files to support FEA of orthotropic materials, in either axisymmetric structures or two-dimensional structures subjected to membrane forces.

Significance:
Many engineering applications exist for thick composite structures, however, they have received less critical attention than thin composite structures. Furthermore, although a vast amount of software is available to solve many complex engineering problems, integration among the programs is often lacking. This research has addressed these issues, both of which are important in supporting proposed missions to Mars, by developing analysis and design tools to support the finite element analysis of thick fiber-reinforced composite materials.

Future Plans:
Future research plans include expanding the scope of current work to support fully three-dimensional finite element models. Additionally, the composite material properties data needs of engineers will be investigated and the current composites database will be expanded both in scope and in data representation to support a much broader set of composite materials data.

Publications:
None to date.


A CAA System for FR Composite Materials
CDI System Architecture
Help Application
Data Entry Application
Classical Model
Laminate Design Application
COMPOSITES DATABASE
Reports/Views Application
STIF3D Model
ANSYS File Application
MAZE File Application
Material Interface File
Material Interface File
Load and Mesh Data File
Load and Mesh Data File
MAZE Input File
ANSYS
MAZE

The Effect of Thermo-Chemical Nonequilibrium on the Aerodynamics of Aerobraking Vehicles

Graham V. Candler, Principal Investigator
Co-Investigator: Basil Hassan
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
During the development of the Apollo re-entry capsule, significant wind tunnel testing was performed. When compared to flight data, these near perfect gas simulations resulted in higher trim angles of attack and lift-to-drag ratios for Mach numbers greater than 6. It is believed that this difference is due to chemical reactions and thermal nonequilibrium in the shock layer. The objective is to perform both perfect and reacting gas computations to compare with the available Apollo flight and wind tunnel data and resolve the trim angle issue.

Approach:
A three-dimensional computational fluid dynamics algorithm has been developed to study the effect of chemical and thermal nonequilibrium on trim angle and lift-to-drag ratio. Comparisons between the computational results and experimental data will be made at various flight conditions in the re-entry trajectory of the Apollo capsule.

Accomplishments:
Both three-dimensional perfect gas and reacting gas codes have been developed using the diagonal implicit scheme of Yoon and Jameson. Inviscid solutions on the Apollo forebody require 19.2 $\mu sec/it \cdot pt$ for a perfect gas and 66.5 $\mu sec/it \cdot pt$ for a five species air model with two temperatures on a Cray Y-MP. Memory requirements are significantly less than most implicit algorithms. Preliminary inviscid results on the forebody with an assumed symmetric ablator show the expected behavior. Good comparison is achieved between the reacting gas calculation and flight data and between the perfect gas and wind tunnel data.

Significance:
An efficient, three-dimensional computational fluid dynamics algorithm has been developed for computing flows in thermo-chemical nonequilibrium. The design of future aerobraking vehicles will require detailed knowledge of flight aerodynamics and heat transfer during re-entry. By comparison to experimental data, we can determine the limitations of our physical models and how much confidence can be placed in our numerical solutions.

Future Plans:
Future work will include running the complete geometry with both the afterbody and the correct asymmetric ablator. Also a more accurate chemistry model with additional species will be employed, including effects of ionization which are important in these high Mach number flows. In addition, viscous effects will be included so the predicted heat transfer can be compared with the flight data. Once these effects have been included, the numerical trim angle of attack will be determined and compared to the experimental results. Finally, other candidate aerobrake shapes including lunar-return vehicles will be investigated.

Publications:
Hassan, B., Candler, G. V., and Olynick, D. R., "The Effect of Thermo-Chemical Nonequilibrium on the Aerodynamics of Aerobraking Vehicles," AIAA Paper 92-2877.

Table 1. Aerodynamic Coefficients Comparison

	Five Species Air	AS-202 Flight	Perfect Gas	Wind Tunnel
α (deg)	17.5	17.5	21.0	21.0
C_L	- 0.357	- 0.33	- 0.390	- 0.406
C_D	1.401	1.26	1.267	1.27
L/D	- 0.255	- 0.265	- 0.308	- 0.32
$C_{M_{cg}}$	- 0.000251	0.0	- 0.0126	0.0

Development of a New Model for Vibration-Dissociation Coupling in Nonequilibrium Flows

Graham V. Candler, Principal Investigator
Co-Investigator: D. Brian Landrum
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
Early attempts such as the CVD (Hammerling *et al*, 1959) and the CVDV models (Treanor and Marrone, 1962 and 1963) do not adequately predict the inhibition of dissociation by vibrational nonequilibrium and therefore do not appear to embody the correct physical processes of the problem. The currently popular TT_{υ} model (Park, 1986) does not completely reproduce vibrational temperature data in compressing flows and does not perform well in expanding flows. Thus, the objective of this work is to model the coupling problem from a fundamental basis and then use the knowledge gained to derive a simple yet physically based model for vibration-dissociation coupling which can be applied to the reacting flowfield codes of current interest.

Approach:
The nonequilibrium vibrational relaxation of a system of rotationless nitrogen molecules is simulated when instantaneously heated or cooled under constant volume and temperature constraints. A set of coupled vibrational level Master Equations including vibration-vibration and vibration-translation exchanges, dissociation and recombination is numerically integrated. Exchange rates are based on Schwartz, Slawsky, and Herzfeld theory as modified by Keck and Carrier. Since the full Master Equation simulation is impractical for use in detailed reacting flowfield calculations, a more tractable analytic model which embodies the same physics will be derived.

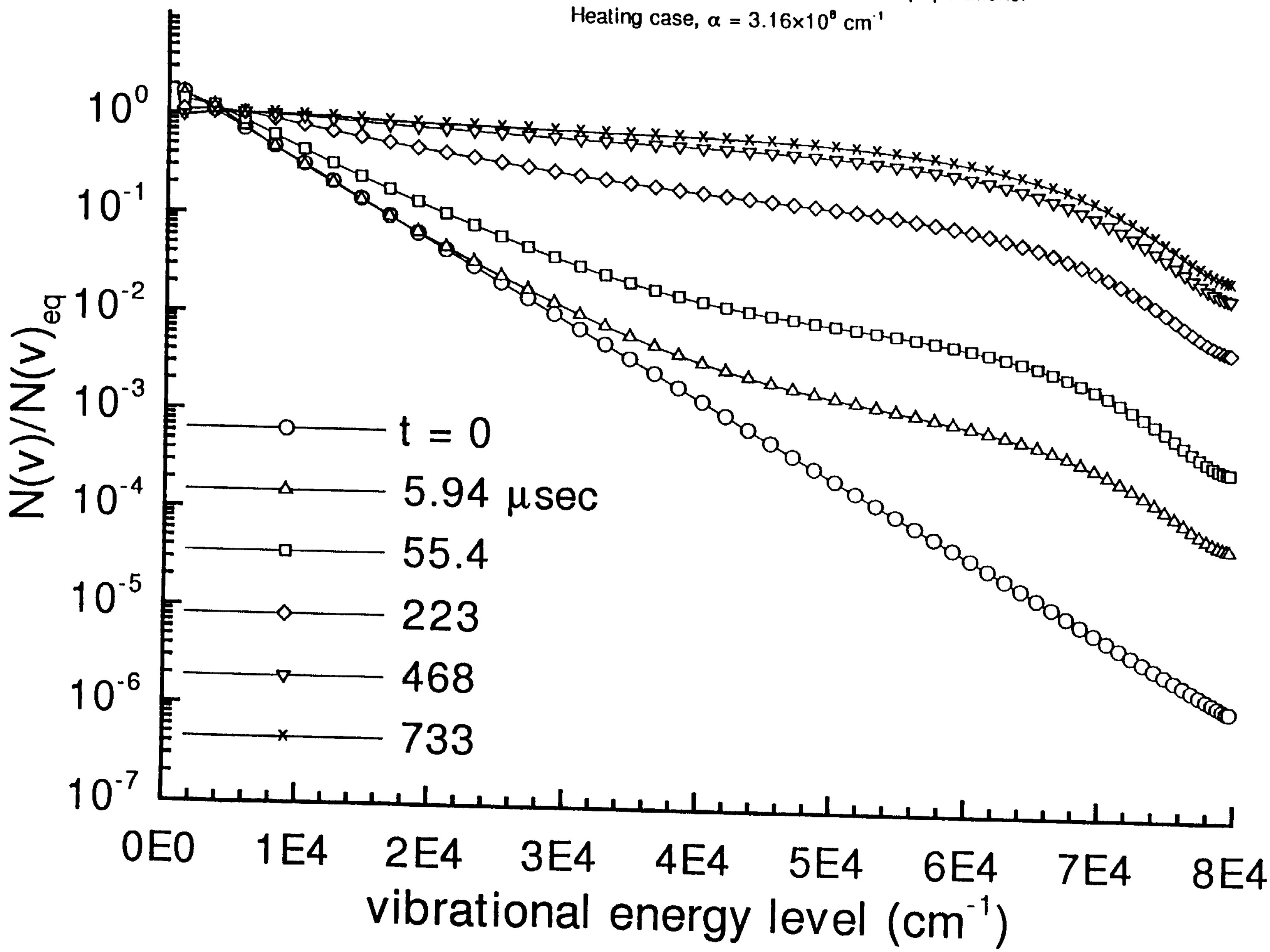
Accomplishments:
The simulation has been performed for a heating case (4000K – 8000K) which is qualitatively representative of the flow behind a normal shock. The reverse cooling case has also been run which simulates an expanding flow. Several significant characteristics of the relaxation process have been determined: (1) the vibrational relaxation of nitrogen is dominated by nearest-neighbor transitions, (2) only the uppermost vibrational levels contribute to dissociation, (3) the normalized populations of the highest two levels are equal.

Significance:
The above results indicate that a reasonably simple analytic model should be attainable.

Future Plans:
Development of the analytical model is ongoing. The final model will be incorporated into a reacting flowfield code for calibration and validation.

Publications:
Landrum, D. B. and Candler, G. V., "Development of a New Model for Vibration-Dissociation Coupling in Nitrogen," AIAA Paper 92-2853.
Landrum, D. B. and Candler, G. V., "Vibration-Dissociation Coupling in Nonequilibrium Flows," accepted for publication in the *AIAA Journal of Thermophysics and Heat Transfer*.

Figure 1: Relaxation of the normalized vibrational populations.
Heating case, $\alpha = 3.16\times10^{6}\ cm^{-1}$



Analysis of Thermo-Chemical Nonequilibrium Models for Carbon-Dioxide Flows

Graham V. Candler, Principal Investigator
Co-Investigator: Stacey Rock
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
The objective of this work is the validation and refinement of thermo-chemical nonequilibrium models employed in the simulation of re-entry aerodynamics. The ultimate objective is an efficient and accurate algorithm to aid in the design of Martian entry vehicles.

Approach:
The flowfield is described by the Navier-Stokes equations extended to account for multiple species and nonequilibrium vibrational energy. The computed flowfield is compared to experimental interferograms to judge the accuracy of the model. Two different reaction rate and vibrational relaxation rate models are used to simulate the experiment; the results are compared, and it is shown that one model gives very good agreement with the experiment.

Accomplishments:
The reaction rate models of Evans *et al* and Park *et al* along with the Landau-Teller vibrational relaxation model have been incorporated in a three-dimensional inviscid nonequilibrium flow solver. The computational results are used to produce interferograms that may be directly compared to those obtained in the experiments. Excellent agreement has been obtained for three out of the five cases simulated using the Park *et al* reaction model; the other model gives significantly worse results for all cases. The attached figure shows the comparison for one case. It is not certain why two cases do not compare as well with the experiment. The uncertainty in the experimental conditions is being investigated.

Significance:
The design of proposed missions to Mars will depend on the accurate solution of thermo-chemical nonequilibrium flows about aerobrakes. This work shows that the reaction rate model of Park *et al* compares very well with experimental results taken at conditions similar to those encountered during entry into the Martian atmosphere. This work validates the computational method and the reaction rate model so that aerobrakes may be designed using computational techniques.

Future Plans:
Further effort is underway to examine why the two cases do not agree with the current computational model. Grid refinement studies are in progress.

Publications:
Rock, S. and G. V. Candler, "Analysis of Thermo-Chemical Nonequilibrium Models for Carbon Dioxide Flows," AIAA Paper 92-2852.

Figure 1. Comparison of computed (top) and experimental (bottom) finite-fringe interferograms over a 2″ diameter cylinder for the partially reacted CO_2 flow at 4.24 km/sec.

Numerical Methods for Nonequilibrium Hypersonic Flows

Graham V. Candler, Principal Investigator
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
Develop and validate efficient numerical methods for the simulation of hypersonic nonequilibrium flows. These algorithms should use minimal amounts of memory and computer time. Also, flexibility, robustness, and ease of use are desirable.

Approach:
The Lower-Upper Symmetric Gauss-Seidel (LU-SGS) method developed by Yoon and Jameson and extended by Eberhardt *et al* has been improved. By modifying the equation set so that elemental conservation is strongly enforced, improved convergence rates have been obtained. Additionally, memory use is minimized while still allowing vectorization on supercomputers. The method extends easily to three-dimensions and shows similar computational times as the much more complex Gauss-Seidel Line Relaxation method of MacCormack.

Accomplishments:
A general two- or three-dimensional computational fluid dynamics code has been developed to simulate thermo-chemical nonequilibrium hypersonic flows. The method is computationally efficient and uses limited memory. The method is easy to use, simple to program, and robust. Three-dimensional, five-species reacting air simulations have been performed on a Sun workstation. The method shows promise for the simulation of a wide range of hypersonic flows.

Significance:
The newly-developed computational fluid dynamics algorithm will allow the efficient simulation of many nonequilibrium hypersonic flows. The computational costs and memory use are small. The method has been applied to reacting air and carbon dioxide flows as well as to complex perfect gas flows. It is flexible and efficient.

Future Plans:
Further development of the method is underway with extensions to include the introduction of particulates, turbulence models, and flexible thermo-chemical nonequilibrium models.

Publications:
Candler, G. V. and Olynick, D. R., "Hypersonic Flow Simulations Using a Diagonal Implicit Method," *Proceedings of the 10th International Conference on Computing Methods in Applied Sciences and Engineering*," Ed. R. Glowinski, Nova Science Publishers, Inc., New York, 1991.

Computation of Flows with Condensing and Evaporating Water in a Combustion Heated Hypersonic Wind Tunnel

Graham V. Candler, Principal Investigator
Co-Investigator: Eric R. Perrell
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
The objective is to develop a method for modeling finite-rate condensation and evaporation of water vapor in a hydrocarbon combustion heated hypersonic wind tunnel, such as the NASA Langley 8 Foot High Temperature Tunnel (8'HTT). NASA personnel believe that these processes are the cause of significant differences between experimental observations and single-phase gas dynamic computational results.

Approach:
A computer program using Steger-Warming flux-vector splitting and Yoon and Jameson's diagonal implicit method will be written for use as a test bed for two-phase flow modeling concepts. Similar programs have been successfully applied to hypersonic flows with other nonequilibrium phenomena. Results will be evaluated by comparison with existing data from the nozzle and test section of the 8'HTT. Initially, emphasis will be placed upon the nozzle and characterization of the flowfield entering the test section.

Accomplishments:
Code development is in the early to intermediate stage. A review of the literature on hypersonic gas/liquid flow modeling has been completed.

Significance:
The 8'HTT is used primarily for testing hypersonic propulsion and vehicle concepts. Test results may not be directly comparable to design calculations based on atmospheric flight. A two-phase model that is easily portable to vehicle design and analysis will enable this comparison.

Future Plans:
Deterministically modeling interphase mass, momentum, and energy transport will require knowledge of the statistical distributions of water droplet size, velocity, and temperature. Some experimental work to validate assumptions regarding these distributions is tentatively planned.

Publications:
None to date.

Ablation of Heat Shields During Atmospheric Entry

Graham V. Candler, Principal Investigator
Co-Investigator: James Keenan
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
The objective of this work is to simulate the flowfield around a blunt, two-dimensional body and the rate of heat shield ablation during atmospheric entry.

Approach:
To determine the flowfield and interaction with the ablator shield, two major steps are required. The first will be to calculate the initial flowfield around the blunt body. This calculation will be done using the LU-SGS method of Yoon and Jameson. In this step, the flowfield species will be allowed to react with one another. Also, thermal nonequilibrium is permitted. During this step, no ablation is allowed. The second step permits time-dependent interaction between the ablator and the flowfield and the ablator species are allowed. The boundary conditions at the ablator surface must account for the injection of mass into the flow.

Accomplishments:
The work is just beginning, but a computational technique to simulate thermo-chemical nonequilibrium flows has been developed. Effort is underway to include the ablation species and the moving boundary condition required for ablator simulation.

Significance:
Missions to the Moon or Mars would require re-entry vehicles that experience heat transfer rates beyond the capabilities of reusable non-ablative heat shields. This study will allow the efficient design of these ablators.

Future Plans:
Much of the work outlined above has yet to be completed. Further additions include the simulation of the heating pulse through the ablator and into the aerobrake to determine structural heat loads.

Publications:
None to date.

High Pressure Hypersonic Nozzle Simulation

Graham V. Candler and John N. Perkins, Principal Investigators
Co-Investigator: Patrick W. Canupp
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
The objective of this study is to compute high pressure hypersonic nozzle flows. Due to the presence of vibrational nonequilibrium and significant intermolecular force effects, a modified Navier-Stokes analysis is necessary.

Approach:
For these simulations, a Navier-Stokes computational fluid dynamics algorithm is used. A finite-rate energy exchange model is used to account for vibrational relaxation. Additionally, due to intermolecular force effects, a general equation of state that is accurate over a wide range of conditions is used. Curve fits are also used for the transport properties. The ideal gas flux-vector splitting technique is altered in order to use a general equation of state. Pressure and temperature are calculated through iteration at each grid point during the solution procedure. Finally, subsonic inflow boundary conditions are devised for a non-ideal gas.

Accomplishments:
The high-pressure nozzle code has been developed and tested. Various nozzles have been simulated and the effects of vibrational nonequilibrium and intermolecular forces have been demonstrated. It has been shown that these two non-ideal effects cause the nozzles to operate at off-design conditions unless they are included in the design of the nozzle. These effects generally raise the Mach number in the test section of the nozzles simulated.

Significance:
It has been shown that vibrational nonequilibrium and intermolecular forces have a major influence on the flow in high-pressure nozzles. Only through the use of a Navier-Stokes analysis may these flows be correctly simulated. Thus, by completing this study, a new technique of hypersonic nozzle design which relies on Navier-Stokes solutions can be developed.

Future Plans:
It is planned to use this nozzle simulation code to develop a design procedure for hypersonic nozzles. This would allow us to design hypersonic nozzles taking into account all of the relevant non-ideal effects.

Publications:
Canupp, P. W., Candler, G. V., Perkins, J. N., and Erickson, W. D., "Analysis of Hypersonic Nozzles Including Vibrational Nonequilibrium and Intermolecular Force Effects," AIAA Paper 92-0330.

Non-Intrusive Diagnostics for Ground Test Facilities

N. Chokani, Principal Investigator
Co-Investigators: Glen P. Doggett, S. Price Cook, and Rachel J. Leonard
Department of Mechanical and Aerospace Engineering
North Carolina State University

In cooperation with Turbulent Flows Measurement Group, Experimental Methods Branch, NASA Langley Research Center.
Funded by Chemical and Thermal Systems Division, National Science Foundation.

Research Objectives:
To develop non-intrusive flow diagnostic methods for the study of steady and unsteady, three-dimensional, compressible flows in conventional ground testing facilities.

Approach:
Ground test facilities are mostly equipped with conventional Schlieren systems which are suited to qualitative study of two-dimensional flows. However, flows of practical interest are three-dimensional in nature, and facility modifications to study such flows with available widely used techniques are expensive or impractical. The focusing Schlieren technique enables the non-intrusive measurement of density gradients in three-dimensional flows. A laser holographic method was combined with this technique to obtain a complete three-dimensional record of the instantaneous flowfield. This approach is well suited to large size, short duration facilities. Recent advances in electro-optic hardware are presently being implemented in the hologram reconstruction process to evaluate methods of determining the flowfield densities.

Accomplishments:
A laser holographic focusing Schlieren system has been designed, built and tested. The experimental study of the flows past a sphere, cone and wedge in a high-speed flow have been examined. The experimental data has been evaluated by comparison with Navier-Stokes computations and show good agreement.

Significance:
This is the first application of the large-field focusing Schlieren method with laser holographic techniques. This non-intrusive method is well suited to large ground test facilities. The system is relatively easy to set-up, relatively inexpensive and should thus gain widespread usage.

Future Plans:
In ongoing work, a laser holographic interferometric system is being implemented to evaluate the density determination methods of the focusing Schlieren technique. In future work, a dynamic sharp focusing system will be developed for the study of unsteady flows and compressible turbulence.

Publications:
Doggett, G. P. and Chokani, N., "A Large Field Laser Holographic Focusing Schlieren System," AIAA Paper 92-3936.

Hypersonic Boundary Layer Transition on a Blunt Flared Model

N. Chokani, Principal Investigator
Department of Mechanical and Aerospace Engineering
North Carolina State University

In cooperation with Quiet Tunnel Group, Experimental Methods Branch, NASA Langley Research Center.

Research Objectives:
To examine and define the instability phenomena in a laminar hypersonic boundary layer in well controlled wind tunnel experiments; to compare the experimental data with compressible linear stability theory experiments.

Approach:
Stability experiments are those in which the mechanisms responsible for transition are identified and studied, in contrast to transition experiments where the transition location is determined and the underlying flow processes are not examined. A hypersonic stability experiment has been defined to be conducted in the new, NASA Langley Mach 6 slow expansion, quiet nozzle, tunnel. Very low disturbance levels are attained in the test section core, due to the unique nozzle design. Consequently, detailed boundary layer studies can be conducted in both "noisy" and "quiet" conditions. In support of the experiments, numerical computations are being conducted in tandem with experiments. The experimental data are used to validate the numerical codes, and the codes in turn used to examine additional test parameters.

Accomplishments:
A blunt hemisphere cone model has been built and instrumented with thin film sensors for measurement of fluctuations associated with the flow instability. Preliminary test data indicate a need to improve the sensor S/N ratio. Preliminary calculations of the mean flow, using a Navier-Stokes solver, and stability characteristics, using a compressible linear stability code, have been conducted.

Significance:
The identification of the instability modes and their subsequent development are essential to understanding hypersonic transition. This study represents an effort to obtain experimental data for this purpose.

Future Plans:
Detailed wind tunnel experiments will be conducted to obtain both surface and off-surface quantitative data at Mach 6. The data will be used to evaluate and validate numerical codes which, in turn, will be used for the purpose of parametric studies.

Publications:
None to date.

Engineering Method for 3-D Interactive Inviscid/Boundary Layer Hypersonic Flow Fields

Fred R. DeJarnette, Principal Investigator
Co-Investigator: Christopher J. Riley (Ph.D. student)
Department of Mechanical and Aerospace Engineering
North Carolina State University

In cooperation with the Aerothermodynamics Branch, NASA Langley Research Center.

Research Objectives:
To develop an approximate, user-friendly method to calculate 3-D, interactive inviscid/boundary layer, hypersonic flow fields efficiently and expeditiously.

Approach:
Previously an approximate inviscid method using a modified Maslen pressure equation was developed. An approximate boundary layer method has now been coupled to the inviscid solution to calculate laminar and turbulent heating rates. The displacement effect of the boundary layer on the outer inviscid flow is included as a boundary condition in the inviscid method. The boundary layer method uses the axisymmetric analog and Zoby's approximate heating relations. Equilibrium air and perfect gas models are available as options in the code.

Accomplishments:
The method has been applied to blunted circular and elliptic cones and paraboloids at angle of attack. The results compare favorably with experiment, viscous shock layer and thin-layer Navier-Stokes solutions for shock shapes, surface pressures, and heat transfer rates. The viscous interaction affects surface pressures and heating rates significantly at the lower Reynolds numbers. Results for a blunted 2.1 elliptic cone are shown on the attached figure where δ^* is the boundary layer displacement thickness and LAURA is a thin-layer Navier-Stokes solution.

Significance:
A rapid, reasonably accurate method has been developed for calculating interactive inviscid shock layer properties and surface heat transfer rates. The technique significantly improves current engineering methods for predicting 3-D flow field properties.

Future Plans:
We plan to adapt a fast-solver Euler code for the inviscid solution and develop approximate heating relations for nonequilibrium flows.

Publications:
Riley, C. J. and DeJarnette, F. R., "Engineering Calculations of Three-Dimensional Inviscid Hypersonic Flow Fields", *Journal of Spacecraft and Rockets*, Vol. 27, No. 6, pp. 597-605, Nov.-Dec. 1990.
Riley, C. J. and DeJarnette, F. R., "An Engineering Aerodynamic Heating Method for Hypersonic Flow", AIAA Paper 92-0499, accepted for publication in *Journal of Spacecraft and Rockets*.

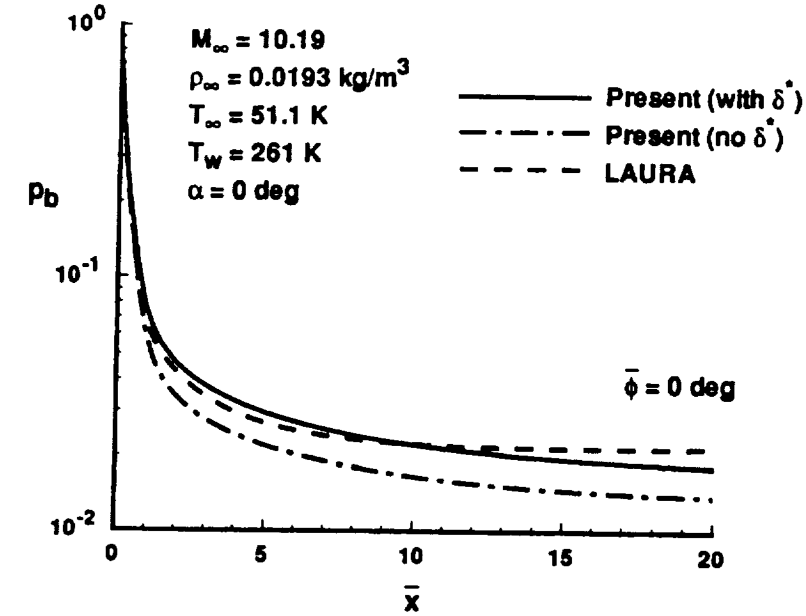


Figure 1. Axial body pressure comparison for blunted 2:1 elliptic cone, $R_{\bar{Z}}$ = 0.000254m

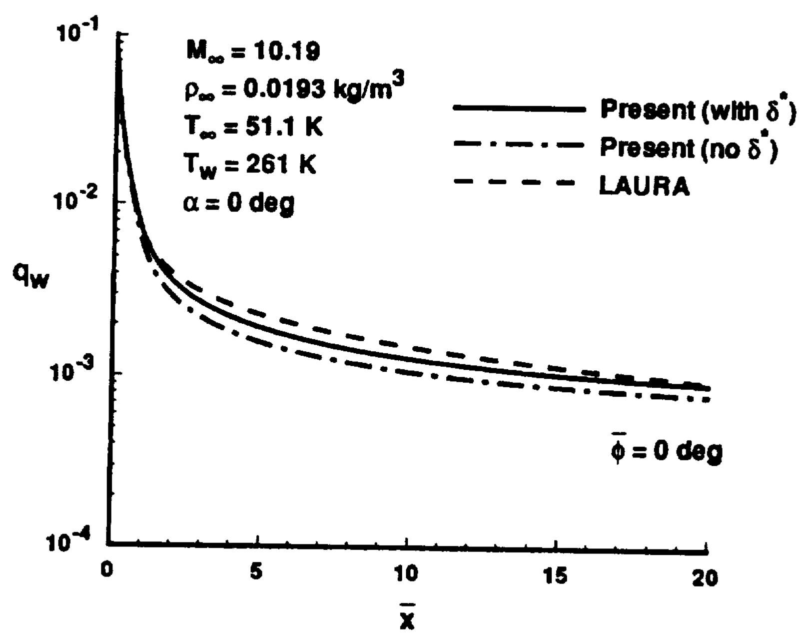


Figure 2. Axial heat transfer comparison for blunted 2:1 elliptic cone, $R_{\bar{Z}}$ = 0.000254m

Boundary Layer Study on Nozzle Wall at Hypersonic Velocities

F. R. DeJarnette, W. C. Griffith, and W. J. Yanta (NSWC), Principal Investigators
Co-Investigator: Kenneth Jones
Department of Mechanical and Aerospace Engineering
North Carolina State University

In cooperation with the Aerodynamic Branch, NSWC, White Oak, MD.

Research Objectives:
Make accurate measurements in the boundary layers of M = 14 and 18 Tunnel 9 walls at NSWC. Validate CFD codes for tunnel design and flow analysis.

Approach:
Use a pitot rake, traversing pitot and total temperature probe, and wall-mounted instruments to gather data on the wall boundary layer. Phase I surveys were made at M = 14 standard conditions. Phase II, also at M = 14, used varying degrees of supercooling. Phase III surveys were conducted at M = 18 with supercooling. Employ CFD codes to interpret the data sets.

Accomplishments :
Data has been obtained and reduced for Phases I and II. Phase III data has been obtained but it is still in the process of being reduced. Presently, a vibrational nonequilibrium Navier-Stokes computational algorithm is being used as an analytical comparison for the experimental data. The initial results from the numerical analysis give a Mach number from the numerical code of 13.15 compared to 14 from experimental data. This low Mach number has been attributed to the grid spacing in the first section of the diverging nozzle. This case is presently in the process of being rerun with a finer grid spacing.

Future Plans:
The final paper will present a compilation of the experimental data. In addition, the paper will present the comparison of the experimental data with the results obtained from two CFD codes: (1) a vibrational nonequilibrium Navier-Stokes algorithm, and (2) a Navier-Stokes algorithm that includes vibrational nonequilibrium and intermolecular force effects. A third comparison will be with E. C. Anderson's boundary layer code.

The results of this study will help nozzle designers to assess the effects of vibrational nonequilibrium and intermolecular forces on the nozzle flow characteristics. In addition, the study should determine if the classical technique of coupling an inviscid code to a boundary layer solution procedure is valid for nozzles at these Mach numbers.

Publications:
Jones, K. M., DeJarnette, F. R., and Griffith, W. C., "Boundary Layer Study on Nozzle Wall at Hypersonic Velocities", submitted for AIAA 17th Aerospace Ground Testing Conference, July 1992, Nashville, TN.

Condensation and Supercooling in Hypersonic Nitrogen Wind Tunnels

W. C. Griffith and W. J. Yanta (NSWC), Principal Investigators
Co-Investigator: Susan T. Hudson
Department of Mechanical and Aerospace Engineering
North Carolina State University

In cooperation with the Aerodynamics Branch, NSWC, White Oak, MD.

Research Objectives:
Investigate experimentally the extent of supercooling in the hypersonic nitrogen tunnels at the Naval Surface Warfare Center, White Oak, MD.

Approach:
Using tunnel run pitot data and an analytical model to distinguish supercooled from equilibrium partially condensed flows, identify the limits of supercooling for Mach 10, 14 and 18 nozzles.

Accomplishments:
Supercooling is the persistence of a metastable vapor state into the region of partial condensation below the equilibrium saturation line. From the pitot data analyzed from a large number of tunnel runs and a dedicated series at constant Reynolds number in Tunnel 9, a consistent pattern of isobaric supercooling of 20-25 K was found over a range of test section static pressures covering two orders of magnitude. The corresponding mass fraction condensed upon the appearance of condensation was 12–14%. During the course of this research, a second, independent means for detecting the onset of condensation was conceived and tested. Backscattering from a laser beam perpendicular to the flow direction was measured using a collimation system focused on a photomultiplier. The resulting data for both onset and disappearance of condensed (light scattering) particles was found to be in excellent agreement with the pitot data analysis.

Significance:
The prospect of using supercooled flows for tunnel testing offers two attractions; reduced supply temperatures with the same supply pressure gives an increased unit Reynolds number for testing, and a nozzle designed for higher test Mach number may be run using existing supply heater systems. Both these options are under study.

Publications:
Hudson, S. T., Griffith, W. C., Lederer, M., Ragsdale, W. C., and Yanta, W. J., "Condensation Shocks in Hypersonic Nitrogen Tunnels," *Proceedings of the 17th International Symposium on Shock Waves and Shock Tubes*, Lehigh University. A.I.P. Conference Proceedings No. 208, New York, 1989.

High School and Undergraduate Student Projects and Teaching

W. C. Griffith, Principal Investigator
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
Interest students in aerospace through involvement in research problems pitched at their level of preparation.

Approach:
Serve as mentor or advisor to students participating in existing programs aimed at supplementing their educational opportunities.

Accomplishments:
Dr. Griffith was Mentor to a student from the NC School of Science and Math, Skip Everhart, who came to the university for one afternoon a week during an academic year. The project selected drew upon his physics and computer courses to find the orbital properties of the moons and artificial satellites of the Earth and Mars. Results were put in the form of presentation-quality viewfoils. Mr. Everhart is now a Junior in the MAE Department at NCSU. Griffith served as advisor to two aerospace engineering juniors, David Wu and Kevin Kinzie, in the College's Engineering Scholars Program. They worked on a project to calculate return to Earth of a synchronous satellite using atmospheric aerobraking. Kevin later gave a paper at the Student AIAA Conference in Atlanta on his research. He is now in the Ph.D. program at Penn State working in fluid mechanics.

Publications:
None to date.

Quantification of Vapor Screen Analysis

W. C. Griffith and W. J. Yanta (NSWC), Principal Investigators
Co-Investigator: Lance Benedict
Department of Mechanical and Aerospace Engineering
North Carolina State University

In cooperation with the Aerodynamics Branch, NSWC, White Oak, MD.

Research Objectives:
Explore the feasibility of using particle scattering of a laser light sheet to measure carrier gas density.

Approach:
Laser vapor screens have been used to obtain a visual qualitative picture of complex 3-D flows in the plane of the thin laser light sheet. Applying this technique to a steady 2-D flow for which the density field is known, use intensity digitization to obtain scattering intensity and hence gas density.

Accomplishments:
With a bi-convex model in a 2-D supersonic flow and a laser light sheet in a plane normal to the model, video frames were digitized and the light intensity related to that in the uniform flow upstream of the shock waves about the model. The particles were water condensed from the humid air used as the tunnel working fluid; a uniform population in the free stream for all pixel elements was assumed. Data reduced for several axial planes at three angles of attack was in good agreement with densities found in a CFD computer solution.

Publications:
Benedict, L., Griffith, W., Yanta, W., Spring, W., and Boyd, C., "Quantification of Vapor Screen Analysis," AIAA Paper 91-1691.

Protuberance Interference Heating on a Slender-Body Cone Surface in Hypersonic Flow

W. C. Griffith and A. S. Collier (NSWC), Principal Investigators
Co-Investigator: David W. Witte
Department of Mechanical and Aerospace Engineering
North Carolina State University

In cooperation with the Aerodynamics Branch, NSWC, White Oak, MD.

Research Objectives:
Determine feasibility of using a commercially available infrared imaging system to measure surface temperatures on a typical stainless steel wind tunnel model. Develop a 2-D heat transfer analysis and compare with the IR and thermocouple data.

Approach:
An 8 degree blunt nosed stainless steel cone well instrumented with surface thermocouples for prior tests was fitted with a 1"D, 1" high cylindrical protuberance 9.5" from the nose for this experiment. Tests were made at M = 14 in Tunnel 9. The IR system was installed to look at the cone with the protuberance lying in the plane of symmetry.

Accomplishments:
The IR system scans in a 200x256 pixel array at 60 Hz to give a transient temperature picture that can be computer processed for comparison with the thermocouple readings. Both 1-D and 2-D numerical heat transfer models were developed for the region around the protuberance and it was found that the 2-D analysis was necessary in accounting for the data. The major problem encountered in this investigation was an adequate determination of the emissivity of the model surface. Some improvement over handbook values was obtained by preheating the model with a jacket for calibration but achieving a uniform temperature with the model in the tunnel was not feasible. Possible solutions to this problem would seem to be in treating the surface to assure uniform emissivity or coating it with a material having unit emissivity.

Publications:
Collier, A. S., Lafferty, J. F., Swinford, S. S., and Witte, D. W., "Aerodynamic Heat Transfer Testing in Hypersonic Wind Tunnels Using an Infrared Imaging System," AIAA Paper 90-0189.

C-2

Laser Holographic Interferometric Measurements of the Flow in a Scramjet Inlet at Mach 4

W. C. Griffith and W. J. Yanta (NSWC), Principal Investigators
Co-Investigator: J. Craig McArthur
Department of Mechanical and Aerospace Engineering
North Carolina State University

In cooperation with the Aerodynamics Branch, NSWC, White Oak, MD

Research Objectives:
Investigate the potential for getting quantitative data from an interferogram created from two holographic plates.

Approach:
Interferometric pictures of flow fields have traditionally been made using purely optical means for reconstructing fringe patterns from flow and no-flow holograms. In this work a digitizing camera and accompanying data processing software were used to calculate density values on a pixel by pixel basis. To reduce the effects of signal noise and optical system imperfections, three data reduction techniques were tried.

Accomplishments:
Determination of the flow density field requires relative phase and integer fringe shifts for each location. Once a density value is determined by whatever means at any one point in the field of view, phase analysis can give the rest of the density pattern. In this channel flow, pitot traverse and wall-mounted Preston probe data were used to identify the density next to one channel wall. Because imperfections in windows and other parts of the optical system introduce spurious phase shifts to the flow-generated phases, three data reduction techniques were tested for internal consistency and comparison with the pitot traverse results. The so-called four-bucket method was found to be superior; ultimate accuracy is limited by the (optical) quality of the holograms.

Significance:
Holographic Interferograms can be processed satisfactorily using the computer-based system described faster and with more accuracy than the traditional method. Extension to axisymmetric flows and more complicated patterns is within reach.

Future Plans:
The Aerothermodynamics Branch, NASA Ames Research Center, is considering this technique for use in the ballistic range and shock tunnel facility there.

Publications:
McArthur, J., Yanta, W., Spring, W., and Gross, K., "Laser Holographic Interferometric Measurements of the Flow in a Scramjet Inlet at Mach 4," AIAA Paper 89-0043.

Yanta, W., Spring, W., Gross, K., and McArthur, J., "Phase-measuring Laser Holographic Interferometer for Use in High Speed Flows," *Proceedings of the 13th ICIASF*, Gottingen, W. Germany, 1989.

A Fine-Wire Thermocouple Probe for Measurement of Stagnation Temperatures in Real Gas Hypersonic Flows of Nitrogen

W. C. Griffith, W. J. Yanta (NSWC), Principal Investigators
Co-Investigator: Brian Hollis
Department of Mechanical and Aerospace Engineering
North Carolina State University

In cooperation with the Aerodynamics Branch, NSWC, White Oak, MD.

Research Objectives:
Modify the design and supporting data analysis of a supersonic flow stagnation temperature probe for application to free stream and boundary layer hypersonic nitrogen flows.

Approach and Accomplishments:
A fine-wire thermocouple probe was used to determine freestream stagnation temperatures in hypersonic flows. Data were gathered in the Naval Surface Warfare Center's Tunnel 9, N_2 blowdown wind tunnel with run-times of one to five seconds. Tests were made at supply pressures between 30 and 1400 atm. and supply temperatures between 700 and 1900K, with Mach numbers of 14 to 16. An iterative procedure requiring thermocouple data, pitot pressure measurements and supply conditions was employed to determine test cell stagnation temperatures. Probe conduction and radiation losses, as well as real gas behavior of N_2 were accounted for during analysis. Temperature measurement error was found to be 5 to 10%. A correlation was drawn between thermocouple diameter Reynolds number and temperature recovery ratio. Transient probe behavior was studied and was found to be adequate in temperature gradients up to 1000 K/sec.

Significance:
This stagnation temperature probe provides a new, independent property measure for hypersonic boundary layers. It is in use at NSWC in a new M=18 tunnel and is being considered for use in the NASA Langley M=17 nitrogen tunnel.

Publications:
Hollis, B. R., Griffith, W. C., and Yanta, W. J., "A Fine-Wire Thermocouple Probe for Measurement of Stagnation Temperatures in Real Gas Hypersonic Flows of Nitrogen, IEEE Publication 91, CH 3028-8, 14th ICIASF, Rockville, MD (Oct. 27-31, 1991), ICIASF '91.

A Ballistic Investigation of the Aerodynamic Characteristics of a Blunt Vehicle at Hypersonic Speeds in Carbon Dioxide and Air

W. C. Griffith and A. W. Strawa (NASA Ames), Principal Investigators
Co-Investigator: James Packard
Department of Mechanical and Aerospace Engineering
North Carolina State University

In cooperation with the Aerothermodynamics Branch, NASA Ames Research Center

Research Objectives:
From shadowgraphs taken in the NASA Ames ballistic range of Pioneer Venus models, determine the aerodynamic coefficients and evaluate two alternative data reduction methods.

Approach and Accomplishments:
Future missions to Mars will require the successful development of aerobraking technology. As part of the research being conducted through the Mars Mission Research Center at North Carolina State University, a blunt cone representative of aerobrake shapes has been investigated. Ballistic tests of the Pioneer Venus configuration were conducted at NASA Ames Research Center, California, in carbon dioxide and air at Mach numbers from 7 to 20 and Reynolds numbers from 0.1×10^5 to 4×10^6. Because carbon dioxide research is important to the development of Mars mission vehicles, the aerodynamics of this probe have been studied. Experimental results show that for defined conditions aerodynamic research can be conducted in air rather than carbon dioxide, providing savings in time and money. In addition, the results offer a prediction of flight aerodynamics during entry into the Martian atmosphere. Also discussed in a comparison of results from two data reduction techniques, showing that a five-degree-of-freedom routine employing weighted least-squares with differential corrections analyzes ballistic data more accurately.

Publications:
Packard, J., Griffith, W., Yates, L., and Strawa, A., "A Ballistic Investigation of the Aerodynamic Characteristics of a Blunt Vehicle at Hypersonic Speeds in Carbon Dioxide and Air, AIAA Paper 92-0328.

Limits on Supercooling in Nitrogen Hypersonic Wind Tunnels

W. C. Griffith, W. J. Yanta (NSWC), Principal Investigators
Department of Mechanical and Aerospace Engineering
North Carolina State University

In cooperation with the Aerodynamics Branch, NSWC, White Oak, MD.

Research Objectives:
Investigate experimentally the limits of supercooling in the NSWC nitrogen tunnels designed for M = 10, 14, and 18. Develop a thermodynamic model from which the observed metastable states of the test cell gas can be understood. Analyze the performance of a new experimental M = 18 nozzle designed to utilize supercooling in NSWC's Tunnel 9.

Accomplishments:
Experiments in Tunnels 9 (M = 10, 14) and Tunnel 8A (M = 18) exhibit a consistent pattern of 20-25°K isobaric supercooling (i.e., metastable pure gas states below the equilibrium sublimation line) over a range of test cell pressure levels of about two orders-of-magnitude. A thermodynamic model based on Gibb's concept of the spinodal line is under study. Preliminary results using NBS data for the equation of state of N_2 at low temperatures and pressures suggest that condensation occurs when the gas is supercooled to about 60% of the temperature difference between the sublimation line and the spinodal.

Significance:
If wind tunnels can be operated effectively in the super cooled region, then the range of available unit Reynold's number may be extended and new nozzle designs for higher Mach numbers may be made for existing gas supply and dump facilities. A draft report on real gas effects in nitrogen tunnels has been prepared and distributed in NCSU and NSWC for comment.

Future Plans:
Continuing work on the limits of super cooling and real gas effects in N_2 at low temperatures is intended. The NSWC is testing a Mach 18 throat insert in Tunnel 9. A related investigation of wind tunnel wall boundary layers at M = 14 and 18 is reported separately.

Publications:
None to date.

A Method of Analyzing Holographic Interferograms of Ballistic Models in Hypersonic Freeflight

W. C. Griffith and Tim Tam (NASA Ames), Principal Investigators
Co-Investigator: Douglas Kieffer
Department of Mechanical and Aerospace Engineering
North Carolina State University

In cooperation with the Aerothermodynamics Branch, NASA Ames, Moffett Field, CA.

Research Objectives:
Develop means for quantitative analysis of holographic interferograms for the density in wake region of models.

Accomplishments:
The use of optical techniques to analyze aerodynamic flows is a powerful diagnostic tool. One such method is holographic interferometry. The holograms used in this work were created with a dual-plate technique and a double-pass configuration. These holograms are able to record phase and amplitude information of models flying through ballistic range at hypersonic speed. The holograms were then reconstructed to form finite-fringe interferograms. This paper presents a method of extracting integrated density values from these finite fringe interferograms. The method is separated into two main subdivisions. The first relates the fringe numbers inside the wake region to the freestream fringe-numbering scheme. This is necessary because refraction effects and model motion preclude the ability to follow a fringe from the freestream directly into the wake. The second major step is the calculation of integrated density values. After extrapolating the freestream fringe pattern into the wake region, it is possible to identify the locations of fringe shifts due to the presence of the disturbance. Using the locations of these fringe shifts along with the assumption of a bielliptic wake shape, it is possible to find the values of integrated density everywhere in the wake. These experimental values of integrated density may then be compared to the results of a CFD code which computes the density everywhere in the wake.

Significance:
The technique devised can be readily implemented using computer-based digitization and photometry for improved speed and accuracy in image analysis and may be applied to the Ames shock tunnel.

Publications:
Kieffer, D., Griffith, W., Tam, T., and Cavalowsky, J., "A Method of Analyzing Holographic Interferograms of Ballistic Models in Hypersonic Freeflight," AIAA Paper 92-0378.

Direct Simulation with Vibration-Dissociation Coupling

H. A. Hassan, Principal Investigator
Co-Investigator: David B. Hash
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
The objective is to develop an expression for the probability of dissociation that accounts for vibrationally-favored dissociation without having to rely on experimental inputs.

Approach:
An approach based on collision theory and probability theory is used to derive a new expression for the probability of dissociation.

Accomplishments:
Haas and Boyd developed a vibrationally favored dissociation model for N_2 using traditional collision theory expression times a factor ε_v^{ϕ}, which increased with vibrational energy ε_v. The parameter ϕ is a free parameter to be determined from experiment. The expression developed by Haas and Boyd has a number of limitations: for a given ε_v, it has a maximum that is unbounded, moreover it is not clear how to determine ϕ if suitable experiments are not available. An approach has been developed which results in expressions that do not require experimental input, always bounded, and can be used in gas mixtures in the presence of any number of dissociation reactions.

Significance:
Understanding vibration-dissociation coupling is important for developing correct physical models for hypersonic flows.

Future Plans:
Plans are to use resulting functions for calculating rates in the absence of thermal equilibrium for implementation into CFD codes.

Publications:
Hash, D. B. and Hassan, H. A., "Direct Simulation with Vibration-Dissociation Coupling," AIAA Paper 92-2875.

Monte Carlo Simulation Using Attractive-Repulsive Potentials

H. A. Hassan, Principal Investigator
Co-Investigator: David B. Hash
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
To derive a new class of molecular models suited for direct simulation Monte Carlo (DSMC) methods and capable of allowing for attraction and repulsion. Another objective is to infer interaction potentials of dissimilar molecules.

Approach:
Kinetic theory based approaches are used to determine interaction potential for similar molecules by using viscosity measurements. Binary diffusion coefficients are used to deduce interaction potentials for dissimilar molecules.

Accomplishments:
Current implementation of DSMC uses a Variable Hard Sphere (VHS) model of Bird. The model does not allow for both attraction and repulsion. In addition, computational convenience dictates the use of a one interaction potential for all species involved in the simulation.

The new model uses a total cross section, σ_T, given by

$$\frac{\sigma_T}{\sigma^2} = \Sigma\, \alpha_j (E_t/\varepsilon)^{-\omega_j}, \qquad E_t = \frac{1}{2} m_r c_r^2$$

where σ and ε are a collision parameter and maximum energy of attraction, respectively and are determined from interaction potentials. α_j and ω_j determine the type of interaction potential from viscosity and binary diffusion coefficients.

Significance:
A major limitation encountered in current implementation of DSMC, namely, that all interactions in a mixture follow the same interaction potential, is removed.

Future Plans:
Plans are to implement the model in future DSMC simulations.

Publications:
Hash, D. B. and Hassan, H. A., "Monte-Carlo Simulations Using Attractive-Repulsive Potentials," to be presented at the 18th Rarefied Gas Dynamics Symposium.

A New Two-Temperature Model for Reacting Flows

H. A. Hassan, Principal Investigator
Co-Investigator: David P. Olynick
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
Nonequilibrium radiation calculations are sensitive to the vibrational temperature. Thus, there is a need to develop a two-temperature model free of any empirical inputs.

Approach:
An approach based on kinetic and collision theory is presented. First, an expression for the rate of the reaction

$$AB(V) + M \rightleftarrows A + B + M \quad (1)$$

is derived from collision theory. A Hinshelwood distribution is assumed for the various vibrational levels of AB(V). The dissociation rate for the reaction

$$AB + M \rightleftarrows A + B + M \quad (2)$$

is then obtained which reverts to the one temperature expression when translational temperature equals vibrational temperature.

Accomplishments:
As a result of the above approach an expression for the forward rate is given by

$$\frac{k_f(T,T_v)}{k_f(T,T)} = \frac{(\zeta_v/2)}{(\alpha D/kT_v)^{\zeta_v/2}} \gamma\left(\frac{\zeta_v}{2}, \frac{\alpha D}{kT_v}\right) \quad (3)$$

with $\alpha = 1 - T_v/T$.

Comparisons of the predictions of the present model with that of Park show that low temperatures, present model is closer to $(T\,T_v)^{1/2}$, while at higher temperatures it is closer to $T^{.7}\,T_v^{.3}$.

Significance:
This development removes a major uncertainty resulting from Park's two temperature model.

Future Plans:
We plan to incorporate this model in future computation of nonequilibrium radiation.

Publications:
Olynick, D. P. and Hassan, H. A., "A New Two-Temperature Dissociation Model for Reacting Flows", AIAA Paper 92-2943, July 1992.

Monte Carlo Simulation of Flows over Aerobrakes for Martian Entry

H. A. Hassan, Principal Investigator
Co-Investigator: David B. Hash
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
The objective is to develop computational techniques for the calculation of flows over typical aerobrakes for Martian entry.

Approach:
A Monte Carlo simulation is used. Results were restricted to Knudsen numbers greater than 0.1. This is the region beyond which Navier-Stokes equations begin to breakdown.

Accomplishments:
Two sixty degree spherically blunted cones of radii 1.0 and 2.3 meters were considered. Calculations were carried out at 80, 70 and 60 Km altitudes for typical trajectories and an entry velocity of 7.387 Km/sec. The results show that significant nonequilibrium effects exist for altitudes above 70 Km. At 60 Km altitude and 2.3 m spherically blunted cone radius, CO_2 is completely dissociated in the shock layer, but thermal nonequilibrium effects are not significant.

Significance:
Proposed missions to Mars and return require calculation of nonequilibrium flows that may not be modeled correctly by the Navier-Stokes equations. Therefore, it is important that an alternative simulation procedure be developed and perfected.

Future Plans:
Plans are to extend this work to include ionization and radiation.

Publications:
Hash, D. B. and H. A. Hassan, "Monte Carlo Simulation of Entry in the Martian Atmosphere", AIAA Paper 92-0494.

Monte Carlo Simulation of Reentry Flows with Ionization

H. A. Hassan, Principal Investigator
Co-Investigator: Jeff C. Taylor
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
The objective of this research is to incorporate an ionization model based on ambipolar diffusion principles for calculating reentry flows. The configuration considered is that of Fire II.

Approach:
A direct simulation Monte Carlo Simulation is employed. This simulation incorporates a newly developed ionization model and procedure for treating sheaths.

Accomplishments:
The flow over Fire II for a velocity of 11.35 Km/sec at 84.7 Km altitude is considered. For these flow conditions, radiation effects were found to be insignificant. Because of the low degree of ionization, the concept of a supercell, which is a collection of computational cells, is introduced. Charge neutrality is enforced in the supercell in advance of electric field calculation. The electric field is calculated by requiring the average velocity of ions to be equal to the average velocity of electrons. Studies were conducted to determine the effect of the size of supercell on heat transfer calculations. Comparison of afive species air model with an eleven species model suggests that all surface properties with the exception of heat transfer coefficient, are insensitive to the ionization.

Significance:
This work is one of the milestones that have to be accomplished before developing a model for calculating nonequilibrium radiation.

Future Plans:
The next step in this work is the incorporation of a radiation model that accounts for bound-bound and bound free radiation.

Publications:
Taylor, Jeff C., Carlson, A. B. and Hassan, H. A., "Monte Carlo Simulation of Re-Entry Flows with Ionization", AIAA Paper 92-0493.

Multidimensional Upwind Solvers for Hypersonic Flows

D. S. McRae, Principal Investigator
Co-Investigator: Dean A. Kontinos
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
The objective of this research is the development of a new upwind solver for use in the accurate prediction of reentry flowfields in the continuum region.

Approach:
Most current computational algorithms for solution of the governing equations of fluid flow use upwind techniques to increase stability and to reduce numerical dispersion around shock waves. The upwind solver that gives the best results is Roe's flux difference splitting scheme which is based on an approximate solution of the Riemann problem. Implementation of Roe's scheme in multidimensions is typically accomplished by applying the one-dimensional operator in each coordinate direction. However, this approach is inaccurate when discontinuities lie oblique to the computational grid. An alternative approach is to rotate the Roe solver in a direction aligned with flow discontinuities.

Accomplishments:
An algorithm based on the Rotated Riemann solver has been developed and installed in two codes. The Navier-Stokes equations are solved in a locally rotated reference frame in which Roe's scheme is used in one coordinate direction and central differencing in the other. The codes use MacCormack's explicit scheme and a new implicit solver based on the LU-SSOR method of Yoon and Jameson. Approximation of the flux Jacobian creates a diagonal matrix coefficient of the solution vector at a given grid point so that inversion is not required to update the solution vector. Large time steps can be taken at the computational price no more than that of an explicit scheme. The new method has reduced a rotated test case CPU time from 100 seconds to 23 seconds on the CRAY YMP.

Significance:
True multidimensional upwind schemes will increase the accuracy of complicated flow structures such as shock-shock and shock-shear interactions that are expected in reentry flow fields. Formulation of the real gas effects is difficult in second order accurate schemes. The present scheme has shown near second order accurate results in a first order scheme.

Future Plans:
The new implicit solver will allow improved accuracy when vibrational and chemical processes are included. Alternative multidimensional upwind schemes are being researched. Funding of this effort will be assumed by the Applied Computational Fluids Branch at NASA Ames in May 1992. The applications area will probably change at this time.

Publications:
Kontinos, D. A. and McRae, D. S., "An Explicit, Rotated Upwind Algorithm for Solution of the Euler/Navier-Stokes Equations," AIAA Paper 91-1531.

Upwind Solution of Supersonic/Sonic into a Supersonic Cross Stream Using a Conjugate Gradient-type Method

D. S. McRae, Principal Investigator
Co-Investigator: Douglas J. Hudson
Department of Mechanical and Aerospace Engineering
North Carolina State University

In cooperation with Computational Fluid Dynamics Group, FIMM, Wright Research and Development Center.

Research Objectives:
The principal goal of this work is to develop a two-dimensional perfect gas Navier-Stokes code capable of efficiently solving the flowfields associated with gaseous injection at various angles into a supersonic cross stream.

Approach:
The 2-D Navier-Stokes equations were discretized using a modified form of van Leer's Flux Vector Splitting with second-order upwind differencing for the inviscid fluxes and standard central differences for the viscous derivatives. The resulting discretized equations are then linearized and integrated in a fully implicit manner to steady-state. The large set of linear equations resulting from this procedure are solved at each step by application of the preconditioned Conjugate Gradient Squared algorithm. Effects of turbulence were incorporated through the use of an algebraic eddy viscosity model.

Accomplishments:
Laminar code validation was accomplished by comparison with the exact solution for flow over a flat plate and by comparison with experimental data for flow over a ten degree compression corner and for a tangential slot injection case. Additional turbulent code validation was done by comparison with experiment for cases involving sonic injection at angles of fifteen and ninety degrees into a turbulent boundary layer. Each computation examined here required less than ten minutes of CPU time on a Cray-YMP. Memory requirements for most cases are under 8 megawords. Example results were obtained for an underexpanded parallel jet from a rearward facing step and for 0° to 90° sonic injection into a $M = 3.5$ stream.

Significance:
The code developed in this work has proven itself capable of accurately and efficiently computing the flowfields associated with gaseous injection into a supersonic cross stream at angles ranging from zero to ninety degrees. The applications involving secondary gas injection include reaction control jets, surface cooling, boundary layer control, and fuel injection into a scramjet engine.

Future Plans:
Mr. Hudson completed the requirements for the M.S. degree in August 1990 and is presently working at SAI Inc. as a computational fluid dynamicist. The technology proven by this code is now available for use in other projects.

Publications:
None to date.

A Newton's Method Solver for the Navier-Stokes Equations

D. S. McRae, Principal Investigator
Co-Investigator: Paul D. Orkwis
Department of Mechanical and Aerospace Engineering
North Carolina State University

Funded by U. S. Army Research Office, research in cooperation with Ballistic Research Laboratory, Aberdeen Proving Ground.

Research Objectives:
To develop an efficient and accurate code for computing supersonic and hypersonic flow over base-burning projectiles.

Approach:
When chemical reactions are added to the governing equations of fluid/flow, source terms result which can make the equation set very stiff and thereby difficult to solve. An investigation was conducted using model equations containing source terms to determine which type solvers were most effective. Newton's Method was found to be an excellent candidate based on these studies. A code has been developed that applies Newton's Method to the nonlinear governing equations using Roe's flux difference splitting technique. This code is unusual in that it uses the complete exact Jacobian matrix which results from differentiating the discretized equation by the vector comprising all of the discrete conservative dependent variables. This procedure is made possible by use of the symbolic manipulation package MACSYMA. The resulting Jacobian matrix of thirteen block bands is inverted via a direct literative scheme that uses nested disection and the Boeing routine RSLIB applied to an incomplete form of the matrix.

Accomplishments:
The Newton's code has been written and verified for supersonic and hypersonic flow over flat plate, flat plate-wedge combinations and for flow over axisymmetric projectile secant-ogive-cylinder (SOC) configurations. Convergence of the method was demonstrated to be nearly quadratic for these cases once the solution initial guess was improved by Venkatakrishna's artificial time term.

Significance:
This is the first known successful application of an exact Newton's solver to hypersonic flow with shock waves and separations. Newton's method is memory intensive but has been shown to give very accurate results. We expect this technique to become widely used as computer memory size increases. Note that none of the standard acceleration techniques were applied in this work (such as Jacobian freezing).

Future Plans:
Dr. Orkwis was awarded the Ph.D. degree in December 1990. The work is being continued at the University of Cincinnati, where Dr. Orkwis is an assistant professor, and at Eglin AFB.

Publications:
Orkwis, Paul D. and McRae, D. Scott," A Newton's Method Solver for the Navier-Stokes Equations," AIAA 90-1524, AIAA 21st Fluid Dynamics Conference.
Orkwis, P.D. and McRae, D.S., "A Newton's Method Solver for the Axisymmetric Navier-Stokes Equations," AIAA 91-1554 presented at the AIAA 10th Computational Fluid Dynamics Conf., Honolulu, Hawaii, June 1991. Also to *AIAA Journal* (accepted for publication).
Orkwis, P. D. and McRae, D. S., "Newton's Method Solver for High-Speed Viscous Separated Flow Fields," *AIAA Journal*, Vol. 30, No. 1, Jan. 1992, pp. 78-85.

Explicit Upwind Algorithm for the Parabolized Navier-Stokes Equations

D. S. McRae, Principal Investigator
Co-Investigator: John J. Korte
Department of Mechanical and Aerospace Engineering
North Carolina State University

In cooperation with NASA Langley Research Center

Research Objectives:
The object of this work was an accurate and efficient PNS solver that did not exhibit the difficulties encountered with the standard implicit solvers. These difficulties include inability to compute flow over long bodies, difficulties in viscous layers for upwind versions, and inaccuracy due to excessive damping required for stability.

Approach:
A code was written based on the explicit code of Gielda that applied Roe's approximate Riemann solver to MacCormack's explicit method. A blended rotation technique was developed to more closely align the Riemann solver with the actual local pressure gradient. The hyperbolic character of the equation set was maintained in the viscous layer through use of Vignerons technique. This code vectorized very completely, resulting in execution times competitive with the standard implicit schemes.

Accomplishments:
The accuracy of this code was demonstrated by comparison of computation with experiment for supersonic and hypersonic Mach numbers. Accuracy was excellent for all of the test cases. Flow over a 104 ft. generic hypersonic aircraft configuration, including wings, at M = 24 was computed and compared with results obtained with a 3-D time dependent Navier-Stokes solver. The flow field results obtained with the explicit PNS solver were more detailed, of higher quality and appeared to be more accurate then the 3-D Full Navier-Stokes Results.

Significance:
This solver has proven to be more robust and accurate than previously available PNS solvers.

Future Plans:
Development of this code has been continued at NASA Langley by Dr. Korte. High temperature chemistry has been added to the code and it has been incorporated in an optimization routine for the design of hypersonic wind tunnel nozzles. Results obtained with this routine exhibit heretofore unobtainable flow quality in the nozzle designs.

Publications:
Korte, John J. and McRae, D. S., "Explicit Upwind Algorithm for the Parabolized Navier-Stokes Equations," AIAA 88-0716, AIAA 26th Aerospace Sciences Meeting, Reno, Nevada, January 1988.
Korte, J. J. and McRae, D. S., "Numerical Simulation of Flow Over a Hypersonic Aircraft Using an Explicit Upwind PNS Solver," AIAA 89-1829, AIAA 20th Fluid Dynamics, Plasma Dynamics and Lasers Conference, Buffalo, NY, June 1989.

Spike Tipped Body Flows

D. S. McRae, Principal Investigator
Co-Investigator: Clint Ingram
Department of Mechanical and Aerospace Engineering
North Carolina State University

Funded by ACD Branch, NASA Langley Research Center

Research Objectives:
To achieve time and spatially accurate unsteady solutions for the self-excited oscillatory hypersonic flows around a spike tipped bluff body.

Approach:
The explicit 2-D code developed by Benson and McRae will be modified for solution of the axisymmetric Navier-Stokes Equations. Also, the code and adaptive mesh solver will be modified to accept multi-block grids generated by GRIDGEN or other appropriate grid generator.

Accomplishments:
Project start was September 1991. Code modifications are in progress. The 2-D code has been modified for axisymmetric flow, and solutions have been obtained for flows with attached shocks. Work is underway on blunt body flows.

Significance:
Information gained will be useful for improving the accuracy of entry vehicle flows.

Future Plans:
To extend this effort to 3-D and more complex shapes. The extension of the block adaptive mesh to 3-D will be valuable in order to model aerobrake/payload shapes.

Publications:
None to date.

Efficient Numerical Algorithms for High Speed Internal Flow Fields

D. S. McRae, Principal Investigator
Co-Investigator: Jack R. Edwards
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
The object of this work is to develop efficient 2-D and 3-D Navier-Stokes solvers that accurately simulate the complex flow fields associated with high-speed engine components. Initial attention will be focused on inlet geometries with emphasis placed on the accurate simulation of the effects of flow separation control devices within hypersonic configurations.

Approach:
A family of fully implicit solvers for the 2-D and 3-D Reynolds-averaged Navier-Stokes equations has been developed. The numerical method is based on a non-linear line/planar Gauss-Seidel iteration sequence enhanced by a two-stage residual updating procedure. Acceleration techniques based on Quasi-Newton procedures are presently being implemented and tested.

Accomplishments:
Two-D computations involving shock/boundary layer interactions with and without slot suction effects have been completed with boundary conditions designed to simulate transpiration flow in an open slot. Validation of the three-dimensional solver is underway. A sample calculation on a 51 x 51 x 50 grid converged in approximately 12.5 Cray Y-MP CPU minutes. A turbulence model based on the Baldwin-Barth technique has been installed to allow computation of high Re flows. Modifications to the turbulence model are in process to improve performance in 3-D flows.

Significance:
In a supersonic or hypersonic inlet, the multiple shock interactions necessary to raise the pressure and decrease the velocity of the fluid can result in large, three-dimensional pockets of reversed flow. The presence of these regions can cause significant deviations from the design condition. A detailed analysis of the applicability of various separation control methodologies to high temperature, chemically-reacting hypersonic inlet flow fields will be investigated as part of this research effort. The code will also be useful for hypersonic external flows.

Future Plans:
An option for equilibrium air chemistry will be added, initially in a weakly-coupled form. Appropriate boundary conditions for the simulation of various viscous layer control devices will be implemented.

Publications:
Edwards, J.R. and McRae, D.S., "An Efficient Solution Technique for Shock Wave/Boundary Layer Interactions with Flow Separation and Slot Suction Effects," AIAA Paper 91-0652.

A 3-D Dynamic Flow Adaptive Mesh Algorithm

D. S. McRae, Principal Investigator
Co-Investigator: Rusty Benson
Department of Mechanical and Aerospace Engineering
North Carolina State University

In cooperation with the Computational Fluid Dynamics Group FIMM, Wright Research and Development Center.

Research Objectives:
To develop a dynamic automatic flow adaptive mesh algorithm that will efficiently cluster mesh points for any shape body in conjunction with any numerical solver.

Approach:
An adaptive mesh algorithm has been developed that relocates mesh points dynamically in all three dimensions simultaneously in order to cluster points where gradients of appropriately chosen dependent variables are large.

Accomplishments:
The scheme has been applied to high speed flows in two and three dimensions. Two codes have been written to solve the 3-D Navier Stokes equations using Kwak and Yoon or Jameson type dissipation, respectively. Both use the dynamic adaptive mesh scheme to place mesh points where needed as the flow evolves. Computational overhead for the adaptive mesh is approximately 20% for both two and three dimensions. Results have been obtained for $M = 8$ flow over a spherical segment protruding through a flat plate and for $M = 3$ axial flow over two intersecting 9 1/2° wedges (Figure 1).

Significance:
This code has been shown to provide enhanced accuracy in all cases that it has so far been used. It is the first solver that will dynamically cluster points in all three dimensions simultaneously. Overhead has proven to range from 6 to 20% of solver CPU time. The primary benefit will result from no longer having to arduously tailor the mesh in order to achieve accurate results.

Future Plans:
The algorithm will be applied to compute time accurately the "unstart" process in hypersonic and supersonic inlets under AFOSR sponsorship and will be installed in one of Dr. Candler's continuum codes with full flow chemistry. Work by Jack Edwards has shown that much improved accuracy can be achieved with the mesh algorithm in first order steady codes. Another separate project is being initiated under NASA Langley sponsorship to compute time accurate flows over spike-tipped bodies for conditions which result in self-excited flow oscillations.

Publications:
Benson, R. A. and McRae, D. S., "A Three-Dimensional Dynamic Flow Adaptive Mesh Algorithm," AIAA 90-1566, AIAA 21st Fluid Dynamics Conference. Also *AIAA Journal* (accepted for publication).
Benson, R.A., and McRae, D.S., "A Solution Adaptive Mesh Algorithm for Dynamic/Static Refinement of Two and Three Dimensional Grids," *Proceedings, The Third International Conference on Numerical Grid Generation in Computational Fluid Dynamics and Related Fields*, Barcelona, Spain, June 1991, pp. 185-200.

Analysis of Mechanical Properties of Mars Mission Structural Composites Aerobrake

W. J. Craft, Principal Investigator
Co-Investigator: I. S. Raju
Department of Mechanical Engineering
North Carolina A&T State University

Research Objectives:
The purpose of this research was to develop analytical models of the bulk mechanical properties of textile fabric materials so that a structural analysis could be performed on them when used as components of an aerobrake. The textile fabric materials of interest included braids and weaves based on a knowledge of the constituent properties (matrix and tow) and of a knowledge of the geometries and fiber orientations.

Approach:
The authors above have developed a cell model of fabric materials and have extended that model to include more general three dimensional weaves and 4-step braids. They have predicted thermal expansions and modulii for plain, 5-harness and 8-harness weaves and are developing models for several classes of three dimensional fabrics.

Significance:
The significance of the work to date is the development of an analytical method which will help predict the material properties for a large class of textile, three dimensional composites of interest to NASA and to the aerospace community in general.

Future Plans:
Future work will include an additional analysis of various configurations of the 4-step braided composites in two configurations including: 1) rectangular solids and 2) braided tubes. In addition, the 2-step process will be analyzed for braided tubes. An experimental program will be completed in which modulii and coefficients of thermal expansions will be determined and compared to those projected by theory.

Publications:
None to date.

Aerobrake Structural Design

E.C. Klang, Principal Investigator
Co-Investigators: J. Hairr, G. Washington, C. W. Kirby, S. Senibi
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
Two different aerobrake construction concepts are shown in the figure. The truss concept shown on the left is comprised of a tubular truss frame which supports the heat shield panels which in turn form the aerodynamic surface of the aerobrake. The semi-monocoque design shown on the right utilizes a more conventional stiffened skin construction concept. The objective of this study was to compare the two concepts using a common surface geometry and comparable materials.

Accomplishments:
A FORTRAN code was developed which sizes a doubly curved truss based on input parameters such as geometry, number of rings, depth of the truss etc. The truss was analyzed using appropriate boundary conditions and an existing finite element code. Truss members were sized and masses were calculated. Using the same finite element code and similar materials, a design was formulated using a semi-monocoque structure. In this case the stiffener geometry, shell thickness, and attachment geometry were varied to produce a near optimal design.

Significance:
The two studies show the truss to be a very efficient design, however there is more uncertainty in the truss mass. Additionally, the depth of the truss may exceed limits placed on the structure for aerodynamic reasons.

Future Plans:
We plan to further study the semi-monocoque structure using more realistic loading and more detailed geometry. Additional work on linear joints and in-space construction concepts is planned.

Publications:
Klang, E. and Washington, G., "Aerobrake Construction Concepts for the Mars Mission," 2nd International Conference on Engineering, Construction, and Operations in Space, SPACE 90, Albuquerque, NM, April 1990.
Washington, G. and Klang, E., "Modeling and Analysis of Doubly curved Aerobrake Truss Structures," 3rd International Conference on Engineering, Construction, and Operations in Space, SPACE 92, Denver, CO, May 1992.
Hairr, J. and Klang, E., "Structural Design Considerations in the Design of a Mars Mission Aerobrake," 3rd International Conference on Engineering, Construction, and Operations in Space, SPACE 92, Denver, CO, May 1992.

High Velocity Impact

E.C. Klang, Principal Investigator
Co-Investigators: G. A. Dellinger, T. M. Kuo, J. Cate
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
A schematic drawing of the NCSU 19mm, 1.2 km/s light gas gun and associated instrumentation is shown in the upper left corner of the figure. Normal stress (Manganin) gages were used to measure the pressures on the fore and aft surfaces of the composite specimens with a typical plot shown in the upper right corner of the figure. The objectives of this work were to develop appropriate instrumentation (enclosed in the dotted line) and give a preliminary comparison between the laminated and 3-D orthogonal woven composite materials.

Accomplishments:
A specialized instrument setup was developed which could measure the pressures caused by the projectile impact for the composite panels under investigation. Difficulties in protecting the normal stress gages were overcome and a pulsed power supply was used to acquire data for the relatively short (20-30 microsec) duration of the test. Both laminated and 3-D woven composites were tested successfully. Results indicate that the woven material has a much higher transverse wave speed due to the 3-D reinforcement.

Significance:
The higher transverse wave speed of the 3-D woven material should lead to more rapid dissipation of energy during impact. This makes this material an attractive candidate for bumper designs used in protecting spacecraft from hypervelocity impact of space debris.

Future Plans:
Recent purchase of an Ultrasonic C-Scan instrument has allowed us to determine the extent of damage produced within the materials tested. Future work will center on the characterization of damage and degradation in the strength and stiffness due to impact.

Publications:
Klang, E. C., Dellinger, G. A., and Kuo, T. M., "Experimental and Numerical Investigation of the Impact Response of 3-D Woven and Laminated Composite Materials," ASME Winter Annual Meeting, Dallas, Nov.1990.

Stability of Plates with Cutouts

E.C. Klang, Principal Investigator
Co-Investigators: V. Owen and K. Jones
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
The goal of this work was to develop a more efficient method for predicting the critical buckling loads of plates with cutouts.

Accomplishments:
An analysis was developed which combined the Ritz and collocation methods for the solution of the buckling problem of an anisotropic plate with a cutout and elastically restrained edges as shown in the upper left-hand figure. Results were compared with experiment for an orthotropic material as shown in the table. The maximum error is approximately 5% which is well within acceptable limits. Results were also found for restrained anisotropic plates with circular holes loaded in compression and shear. The upper right figure shows the critical buckling loads (K_x) for a displacement loaded panel with varying hole size (d/w) and varying edge restraint stiffness (ε). Edge restraint equal to zero represents simply supported while infinite restraint represents clamped edges. It is apparent that both hole size and edge restraint stiffness greatly affect the results. The lower right figure shows the results for the same laminate loaded in shear. It is important to note that there is a difference between the critical buckling loads when the sign on the applied shear stress is changed. The performance of this laminate is greater for negative shear loading.

Significance:
The method developed produced design curves with much less effort than other currently available methods and is therefore a useful preliminary design tool.

Future Plans:
Work has begun on a new way of formulating the problem. Recent solution of the fundamental problem for bending of anisotropic plates will enable us to use the Boundary Element method thus replacing the combined Ritz/Collocation method used so far. It is anticipated that this new formulation will be more efficient and flexible.

Publications:
V. Owen and E. Klang, "Shear Buckling of Specially Orthotropic Plates with Centrally Located Cutouts," Eighth DOD/NASA/FAA Conf. on Fibrous Composites in Structural Design, Norfolk, VA, Nov. 1989.
K. Jones and E. Klang, "Buckling Analysis of Fully Anisotropic Plates Containing Cutouts and Elastically Restrained Edges," AIAA Paper No. 92-2279.

Distributed Signal Processors for Large Space Structures

Gordon K. F. Lee, Principal Investigator
Co-Investigators: Nancy Nimmo, Andrew Meyers, Charles Hall
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
The objectives of this effort are two-fold: (1) develop several digital low-pass filter designs in order to extract information from sensory data corrupted by noise and (2) design and construct a real-time embedded controller hardware to implement these filters as well as control strategies for real-time distributed processing.

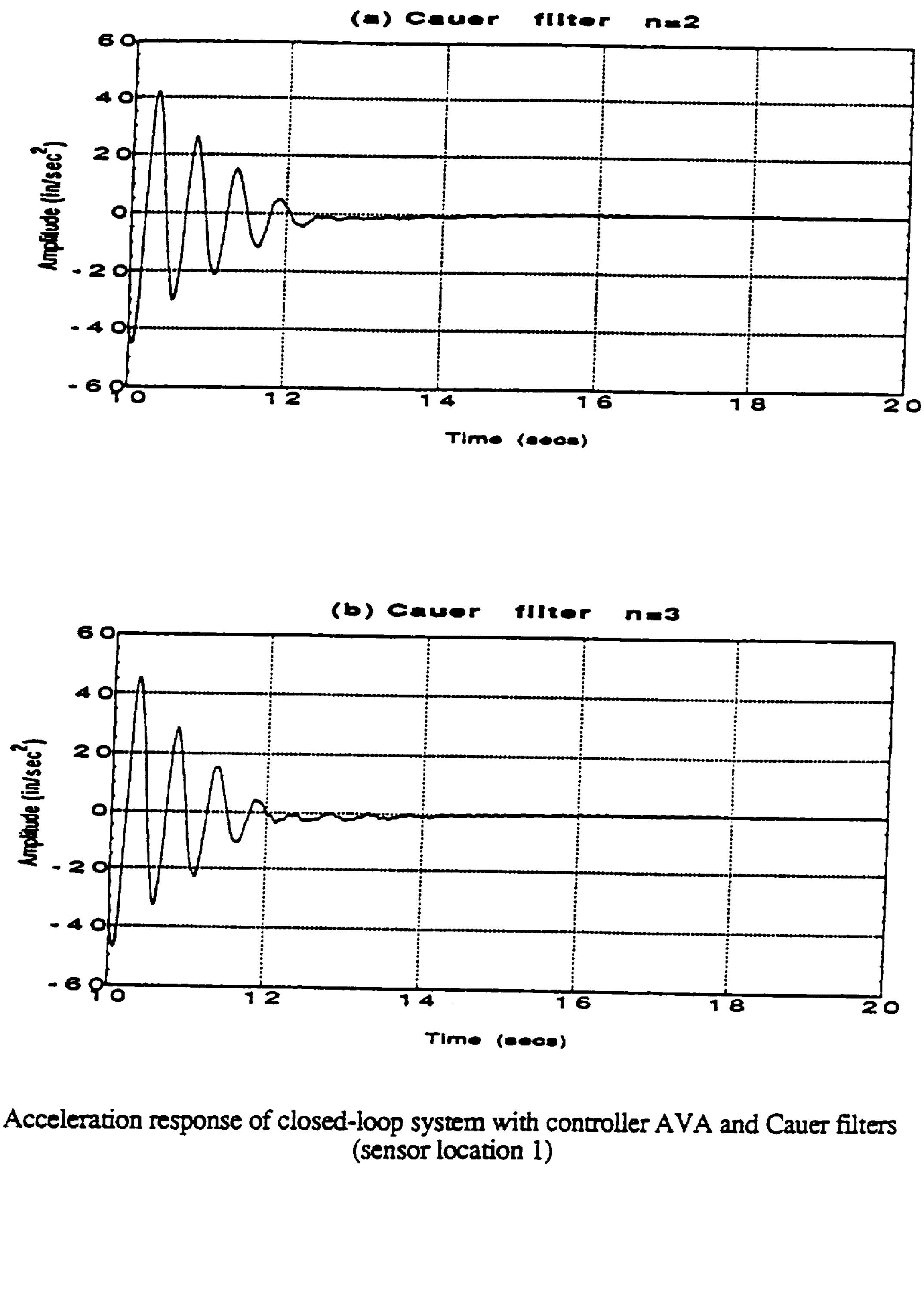
Approach:
Four digital low-pass filters are designed and evaluated in terms of cut-off characteristics, passband ripple and stopband attenuation. Further the interaction of such filter designs with two control strategies (static dissipative control and robust virtual passive control) are investigated using both numerical simulations and actual experimental tests. For the distributed processor hardware unit (DPU), an embedded controller with appropriate data acquisition modules is selected for local processing.

Accomplishments:
Results suggest that classical Butterworth and Cauer Filters provide the best characteristics that satisfy system specifications. A modest phase distortion is exhibited but these filters satisfy the passband and stopband requirements necessary for the NASA CSI Evolutionary Model. Numerical simulation with both controllers verify the filter designs capability in closed–loop. Experimental results illustrate that exact modeling of the experimental hardware is required in order to effectively employ the filters.

Significance:
Large space structures contain many sensors and actuators; the data collected from such sensors need be appropriately conditioned, in real-time, before being processed by the controllers for command signal generation. Results indicate that a distributed architecture is an efficient approach whereby a supervisor performs global decision making during spacecraft maneuvering while each local processor filters and actuates signals as local functions.

Future Plans:
The research effort will now focus on developing self-tuning adaptive filters for space structures. Because the actual system may contain unknown parameters or may be imperfectly modeled, the filters may be required to learn about the system on-line as it processes the sensory data. In parallel to this effort, the DPU will be tested on the 10-bay truss structure located at NASA Langley Research Center using the filters and control algorithms recently developed.

Publications:
Nimmo, N. and Lee, G.K.F., "Digital Low Pass Filter Designs for the CSI Experimental Test Article," *Proceedings of the International Conference on Computer Applications in Design, Simulation and Analysis*," Orlando, FL, 1992.
Hall, C. and Lee, G. K. F., "An Embedded Control Architecture for Real-Time Processing," *Proceedings of the International Conference on Computer Applications in Design, Simulation and Analysis*," Orlando, FL, 1992.



Acceleration response of closed-loop system with controller AVA and Cauer filters (sensor location 1)

Adaptive Controllers for Space Structures

Gordon K. F. Lee, Principal Investigator
Co-Investigators: Cheng-Wen Chen, Eric Clark, S. S. Giang
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
Develop self-tuning and robust adaptive controllers for large space structures and formulate these algorithms in a discrete-time architecture for real-time implementation.

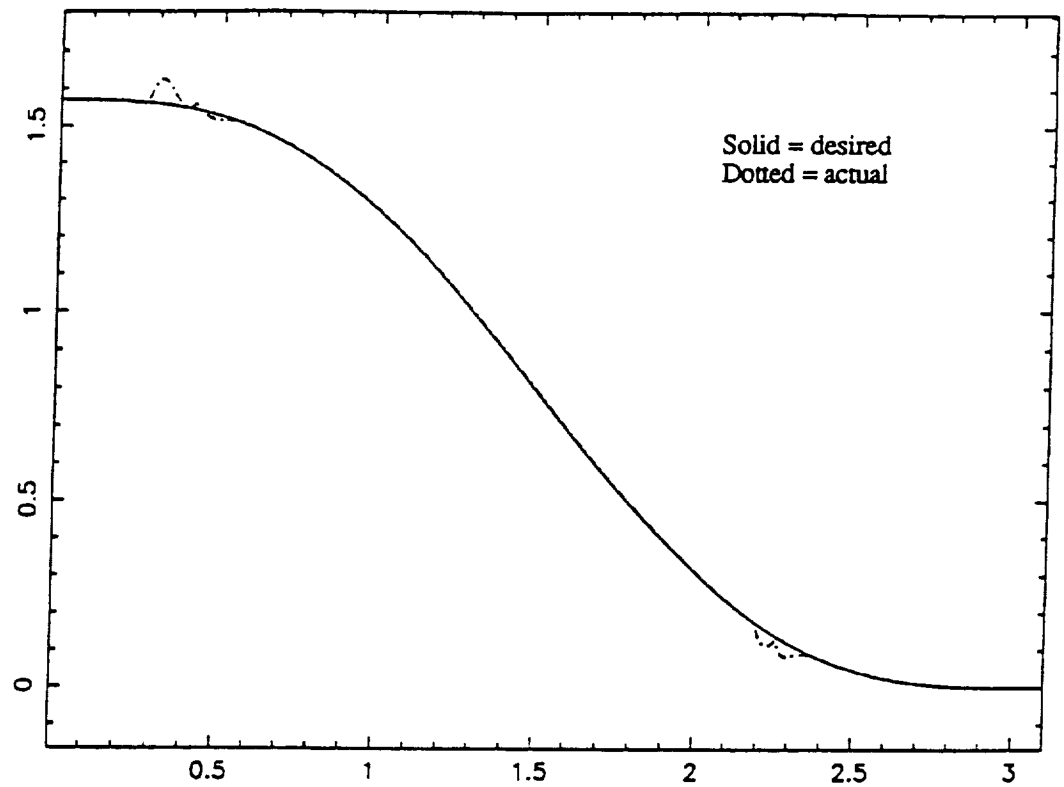
Approach:
In self-tuning control, the approach is to separate the system identification problem from the control strategy. In system identification, several algorithms have been developed. One method uses a recursive maximum likelihood estimator driven by a Kalman filter. This algorithm was extended to the nonlinear and distributed cases. Another system ID method employs an ARMA model with external inputs to construct the system and uses a fast transversal filter or fast least-squares lattice filter structure. Three control algorithms were developed: a time-varying discrete adaptive controller for nonlinear systems, a discrete-time virtual passive controller and a fuzzy logic controller.

Accomplishments:
The system identifier - Kalman filter algorithm employing the transversal filter has been tested using several numerical models. The algorithm is fast and thus seems feasible for real-time implementation. The fuzzy logic controller has been applied to nonlinear robotic models and has shown promise over classical methods. The discrete-time virtual passive controller has been investigated and a stability criterion has been developed for closed-loop analysis. Thirdly, the self-tuning controller for nonlinear dynamics has been investigated and for the indirect form, it was found that selection of the reference model parameters (particularly the damping coefficient) has a great influence on convergence rates.

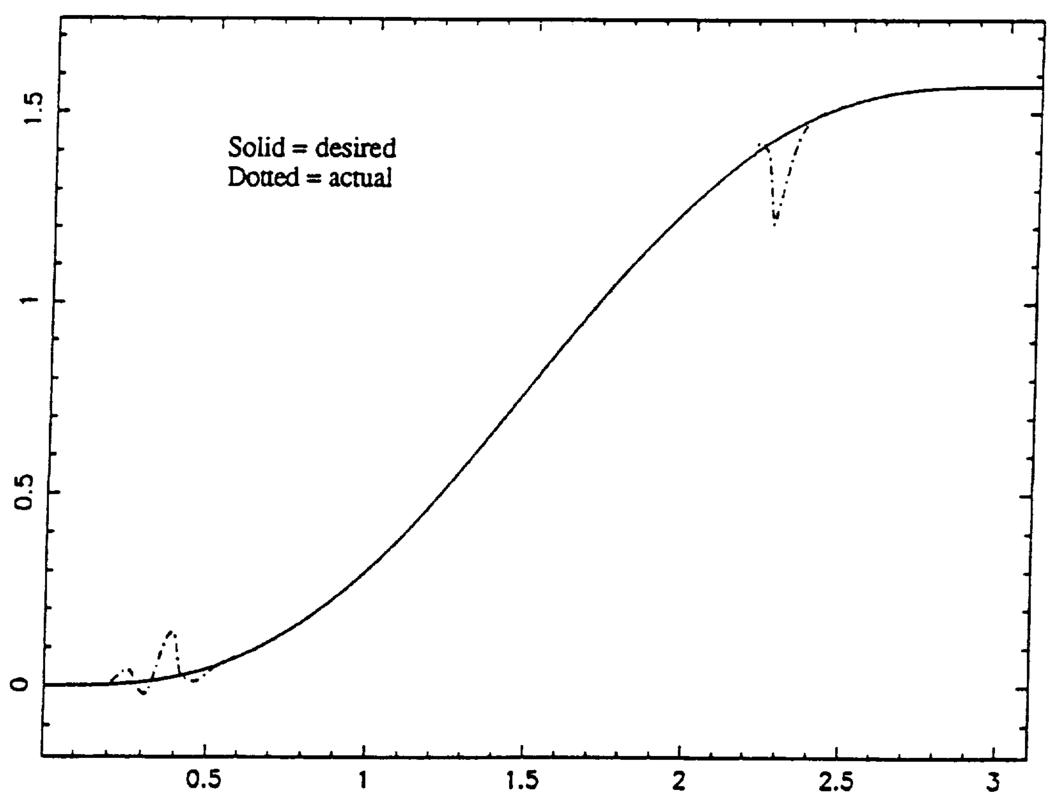
Significance:
Space structures are usually complex to model and may be subject to uncertain environments. Hence controlling such systems is challenging. These algorithms provide adaptivity for closed-loop control, thus improving system performance under possibly unknown conditions.

Future Plans:
Over the next year, we plan to investigate power spectrum estimation issues using the system identifier - Kalman structure. Further it is planned to apply the discrete-time virtual passive controller to the actual 10-bay truss structure at NASA Langley. Finally, we plan to complete both the direct self-tuning controller development and fuzzy logic controller and apply these algorithms to robotic system models.

Publications:
Giang, S.S. and Lee, G.K.F., "Preliminary Investigations of a Self-Tuning Adaptive Controller for Nonlinear Robotic Models," ISMM Conference on Computer Applications in Industry and Engineering, Long Beach, CA, 1991.
Clark, E. and Lee, G. K. F., "Modeling and Control Issues for a 10-Bay Mockup of Flexible Structures," *Proceedings of the ISMM Conference on Microcomputer Applications*, Long Beach, CA, 1990.



Trajectory of 1st link using adaptive control



Trajectory of 2nd link using adaptive control

Design and Implementation of Real-Time Controllers for Space Robotic Systems

Gordon K. F. Lee, Principal Investigator
Co-Investigators: Darrell Gerber, Jeffry Windsor, Robert Stanley
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
Develop a robust robot controller algorithm for a mobile coordinated telerobotic system and verify the approach through hardware ground test simulations.

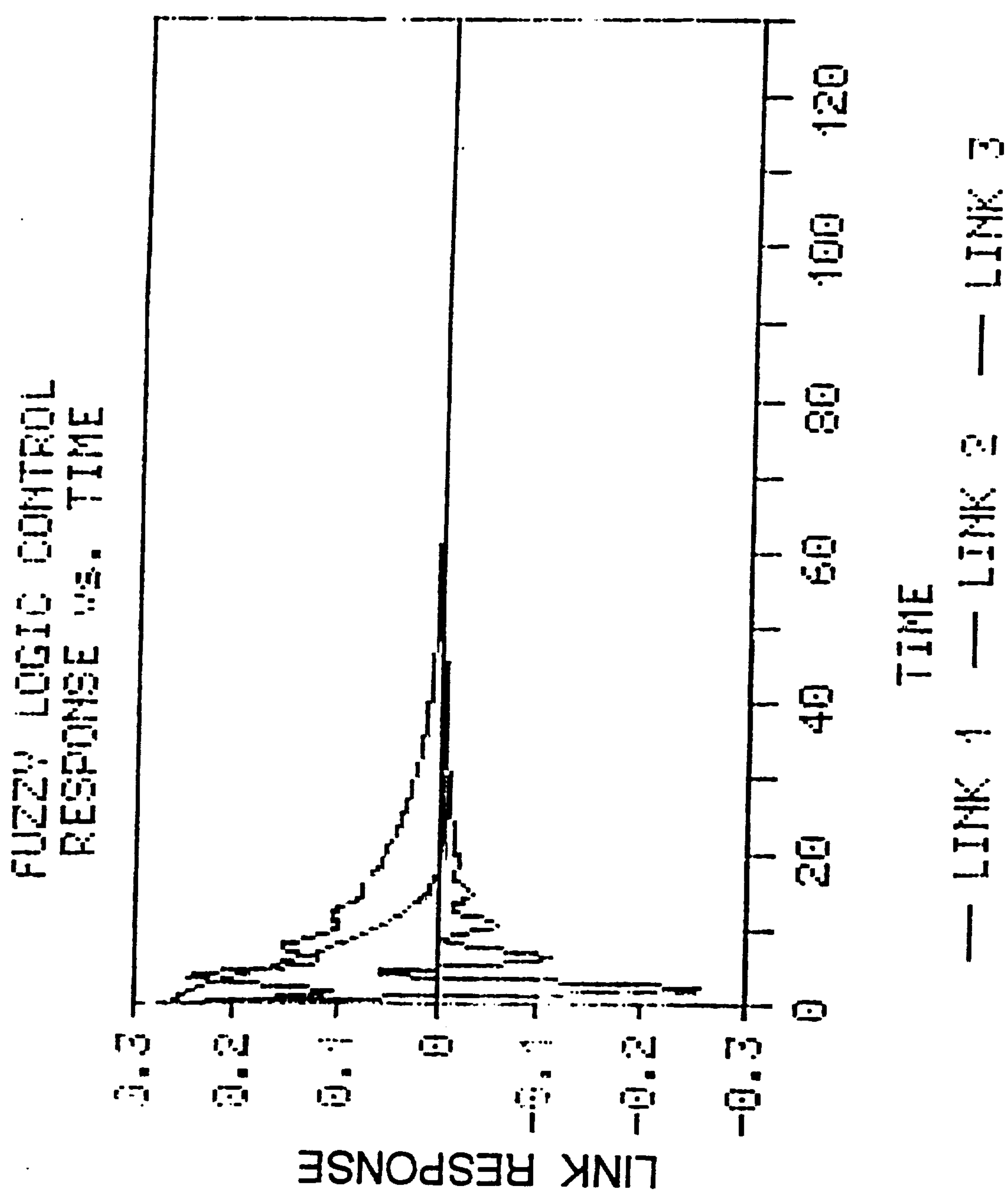
Approach:
A fuzzy logic scheme is proposed to control the robotic system. The approach is selected due to its robustness properties for systems with unmodelled or incomplete dynamic and uncertain disturbances. The robotic system under consideration has two six-degree-of-freedom manipulators with a single flexible mode. Teleoperation and a mobile platform are under design.

Accomplishments:
We are currently focusing on the design of one of the manipulator arms with the interest of having the flexible mode around $2H_Z$. An end-effector has been designed whereby the gripper can grasp an assembly tool and perform single turning actions (on-orbit assembly tasks). A fuzzy logic control algorithm has been developed which includes time delays to compensate for measurement and processing times. Initial results look promising, particularly when compared to classical compensators under varying payload scenarios.

Significance:
Results of experiments using the fuzzy logic controller on the teleoperated mobile coordinated robotic system will provide further insight into on-orbit assembly scenarios using robotics totally or robotics with human-in-the-loop.

Future Plans:
We plan to complete the fabrication of one of the manipulator arms shortly. A mobile platform will then be constructed and the fuzzy logic controller will be implemented and tested. A teleoperated feature will be added so that a human can input the desired trajectory command while the digital fuzzy logic controller will suppress unwanted disturbances as it tracks the desired time trajectory.

Publications:
None to date.


FUZZY LOGIC CONTROL
RESPONSE VS. TIME
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
LINK RESPONSE
0
20
40
60
80
100
120
TIME
LINK 1
LINK 2
LINK 3

Smart Structures Using Distributed Actuators

Gordon K. F. Lee, Principal Investigator
Co-Investigators: Paul Dekker, Gary Bullock, Fuh-Gwo Yuan
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
The purpose of this effort is to investigate distributed and embedded actuators for space structures with the final goal of having an intelligent structure that can compensate for uncertainties (including failures and environmental disturbances) through structural adaptability.

Approach:
The approach is to build distributed sensors, intelligent control and distributed actuators into the material, thereby integrating materials, structural dynamics and control into a smart structure configuration.

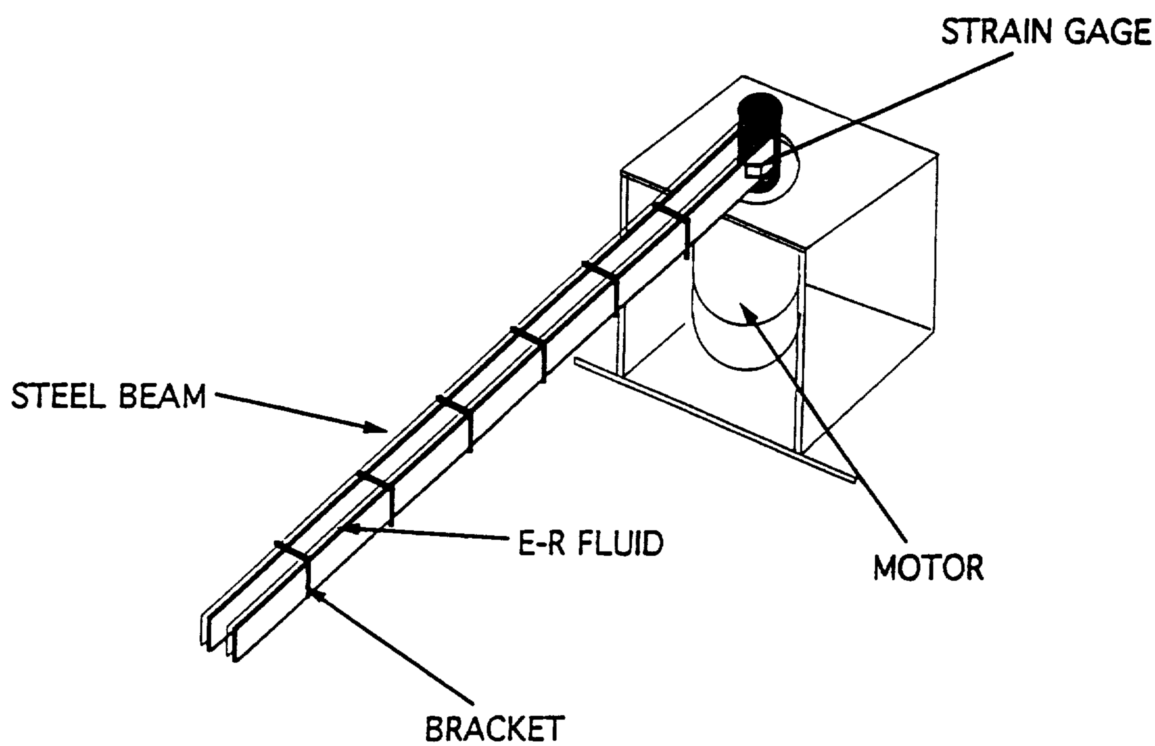
Accomplishments:
A flexible robotic link has been designed which uses electrorheological fluids as the distributed actuator. This work is based upon previous studies on flexible structures possessing noncollocated control/sensor pairs. This actuator allows varying structural damping as the link executes a slewing maneuver. Another experimental testbed using electrostatic dynamics (charged nodes) has been designed for studies on surfaces shape control. Fabrication has started for both of these test articles.

Significance:
The ER fluid experiment has direct applicability to space robotics such as the SPACE CRANE. Speed versus controllability can be adjusted by a variable damping actuator. The electro-static studies have applicability to lightweight, deployable space structures such as large space antennas.

Future Plans:
Activities include completing the fabrication of the ER-fluid-based flexible robotic link, modeling the structure and applying several distributed control strategies. Further fabrication of the electro-test article will be completed in the near future and studies on the feasibility of surface shaping control will be initiated.

Publications:
Lee, G. K. F., Strand, S., and Bird, W., "A Two-Beam Flexible Testbed for Non-Collocated Control Studies," *Proceedings of the International Symposium on Computer Applications in Design, Simulation and Analysis*, Las Vegas, 1991.

E-R FLUID BEAM EXPERIMENT



Analysis and Sizing Algorithm for Space Frame Aerobrake Structures

I. S. Raju, Principal Investigator
Co-Investigator: W. J. Craft
Department of Mechanical Engineering
North Carolina A&T State University

Research Objectives:
To develop an analysis and sizing algorithm (to arrive at minimum mass) for space frame aerobrake support structures to be used in Mars missions.

Approach:
A cone-sphere aerobrake configuration with a 135 feet diameter and 60 degree cone angle is used in this study. A load bearing structure for this aerobrake configuration is proposed. A finite element analysis program is developed to analyze this space frame structure. The deformations and stresses are calculated by this program assuming the same initial thickness for all the space frame members. The allowable stresses in tension, compression, bending torsion type loadings and also for Euler buckling are compared to the corresponding stresses calculated for each of the members. From these comparisons, the thickness of the members needed to withstand the stresses are calculated. The mass of the structure is then calculated and the analysis is performed once again to calculate the new deformations and stresses in each of the space frame members. This iterative process is continued until the mass of the structure does not change by a predetermined amount; in the present study by 2 percent.

This sizing algorithm is integrated into the finite element analysis program and is used to analyze and size the 135 feet diameter aerobrake load bearing space frame structure. A constant aerodynamic pressure of 2 psi is assumed on the aerobrake structure. This pressure loading is applied as either lumped to the joints as concentrated loads or treated as consistent concentrated loads and moments at the joints of the space frame structure. The analysis and sizing is performed for both of these loadings.

Accomplishments:
The minimum mass of the space frame structure for the lumped loading is calculated as about 2.5 percent of the spacecraft mass, while the consistent loading gave the minimum mass as about 5 percent of the spacecraft mass. Aerobraking becomes competitive when the mass of the load bearing structure is less than 10 to 15 percent of the spacecraft mass. The present results appear to suggest that even with the assumption of constant pressure, the mass appears to be competitive with propulsion braking.

Significance:
The present algorithm is general and can be used for other aerobrake structures other than cone-sphere configurations.

Future Plans:
The free vibration frequencies and global buckling characteristics of the minimum mass aerobrake structural configurations obtained with the present algorithm are being studied. The present algorithm will be modified so that space truss type aerobrake structures can also be analyzed.

Publications:
None to date.

Thermal Expansion Characteristics of Woven Fabric Composites

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Co-Investigators: W. J. Craft and V. S. Avva
Department of Mechanical Engineering
North Carolina A&T State University

Research Objectives:
To develop a simple analytical/numerical method to calculate the thermal coefficients of expansion from the properties of the constituents for woven fabric composites.

Approach:
Three types of woven fabric composites, plain weave, 5- and 8-harness satin weaves are widely used. The objective here is to determine the coefficients of thermal expansions of these composites from the properties of the fibers, matrix and the fiber architecture. Therefore, a typical fabric element is first considered. An infinitely repeating unit in the fabric element is identified and is termed as the unit cell. Due to a change in temperature, ΔT, the unit cell will expand in the three coordinate directions by amounts $\alpha_x \cdot \Delta T$, $\alpha_y \cdot \Delta T$, and $\alpha_z \cdot \Delta T$. In general, a unit cell will also experience shear strains due to a temperature change. However, in the composite under consideration, the shear strains are identically zero. To evaluate the coefficients of thermal expansions, a superposition method that avoids the solution of a three-dimensional (3D) mixed boundary value problem is developed. In this method, three simple subproblems, a 3D finite element (3D FE) analysis is used. The finite element models of the unit cell are developed neglecting the undulations at the fiber cross over regions, and hence. these models are termed as 3D mosaic models.

Accomplishments:
The superposition method with the 3D FE mosaic models are used to predict the coefficients of thermal expansions for plain weave, 5- and 8-harness satin weave fabric composites. The results are compared to those obtained with a bridging model and experimental values from the literature. All the three sets of results are within 5 percent of each other.

Significance:
The present superposition method with the 3D FE mosaic models can be used to predict the coefficients of thermal expansions for a variety of woven composites from the properties of their constituents. These models thus can be used to rank fabric woven composites made up of various fiber tows and resins without actually fabricating the composite.

Future Plans:
The future plans are to extend, develop and use similar methods for braided composites and compare the results with the available experimental values.

Publications:
None to date.

Mass Efficiency of Spherical Sandwich Honeycomb Aerobrake Made up of Various Aerospace Materials

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North Carolina A&T State University

Research Objectives:
To evaluate the mass efficiency of different aerospace structural materials for a 50 feet diameter spherical sandwich honeycomb aerobrake.

Approach:
A spherical aerobrake of diameter 50 ft., depth 7.5 ft. and spherical radius 44.5 ft., proposed by NASA Langley Research Center for lunar mission, was considered. The aerodynamic loading corresponding to 5 g deceleration was represented by $p = p_o \cos^2\phi$ where the stagnation pressure p_o is 0.986 lb/in^2. The aerobrake shell wall was assumed to be honeycomb construction. Four skin materials, namely, aluminum (7076-T6), titanium, graphite/epoxy, and graphic/polyamide were considered. Linear stress analysis (using FRAC3D) and buckling analysis (using ANSYS) of the aerobrake were conducted for all four materials. A parametric study was conducted to establish skin and core thickness which satisfy the strength, buckling and TPS deformation criteria. A factor of safety of 1.4 was chosen in the design.

Accomplishments:
Calculated skin and core thickness of all four materials are listed in Table 1. The TPS allowable deformation (0.1 inch central deflection for a span of 40 inches) appears to be the most stringent criteria. Furthermore, the continuous support along with a stiff honeycomb core fulfilled the TPS deformation criteria better. Aerobrake masses for all four materials are listed in Table 1. Here, the joints mass (slice-type) was assumed to be about 30% of the structure mass, and the TPS mass was about 0.958 lbs/sq ft (minimum gage design).

Significance:
Mass of the sandwich aerobrake is restricted by the skin material minimum gage thickness and the TPS deformation criteria. Among the four materials, graphite/epoxy is the lightest.

Future Plans:
Test studies on a kinematically scaled 1/10 aerobrake model are underway to verify some of the analytical results and to understand failure mechanism in sandwich shells. Mass efficiency studies on different aerobrake constructions (truss, sturin-panel, and sandwich) and configurations (spine-cone, bionic, and AFE) are planned.

Publications:
None to date.

MASS EFFICIENCY OF AEROBRAKE MADE OF DIFFERENT SKIN MATERIALS

(Spherical honeycomb aerobrake , Radius 44.5 ft, L/D=0.15)

Material	Thickness, inch		Aerobrake Mass		
	Skin	Core	Structure (lbs)	Total * lbs (kg)	Percent of Aeropass Mass**
Aluminum	0.02	3.55	3,781	6,974 (1,538)	8.6
Titanium	0.015	3.25	3,814	7,018 (1,547)	8.6
Gr/Epoxy	0.045	2.0	3,188	6,203 (1,368)	7.7
Gr/Polyimide	0.045	2.65	3,487	6,592 (1,453)	8.2

* Mass of aerobrake structure +joints+TPS
** Aeropass mass = 16,365 kg

kns/craft

Global-Local Buckling Criteria For Truss Structures

K. N. Shivakumar, J. C. Riddick and W. J. Craft
Mechanical Engineering Department
North Carolina A&T State University

Research Objectives:
To develop a global-local buckling criteria for commonly used space truss components and aerobrake.

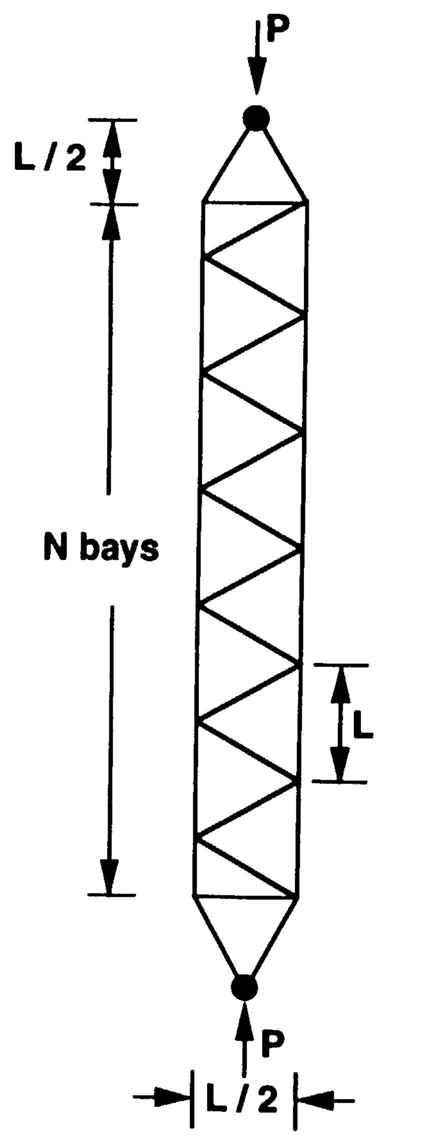
Approach:
Linear global buckling analysis of planer and space trusses, namely, Thompson strut, cubic-space truss module, circular arch, and isogrid aerobrake was conducted using a commercial finite-element code, ANSYS. Numerical experiments were conducted on geometrical parameters (length, depth, bay and spacing, etc.) of trusses. Normalized global buckling load expression was developed. Local buckling load was calculated from the Euler buckling equation after identifying the critical member in the truss from a linear stress analysis. The two solutions were used to establish a global - local buckling factor β. The value of $\beta > 1$ represents the local buckling, $\beta < 1$ represents the global buckling, and $\beta = 1$ represents the global - local buckling conditions.

Accomplishments:
Global - local buckling analysis was conducted on a number of trusses subjected to loads that cause buckling. Figure 1 shows an example of a Thompson strut subjected to a compression load. The first global buckling mode (see Figure 1) was used to establish global - local buckling criteria. Calculated global - local buckling for the Thompson strut is $\beta = 0.06 \{L/(Nr)\}^2$. Where L is the bay length, N is the number of bays, and r is the radius of gyration. This equation is valid for both isotropic and composite truss members.

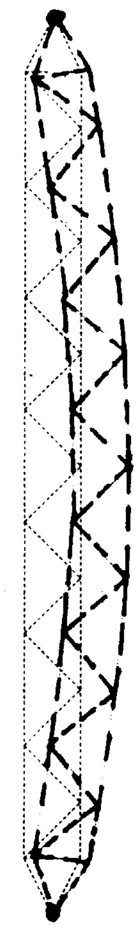
Significance:
Global - local buckling criteria would provide guidelines to size (section properties), individual truss members, and/or select efficient truss configurations.

Future Plans:
The global - local analysis will be continued for isogrid truss aerobrake configuration. The concept needs to be extended to buildup shell structures (example, grid stiffened shells) and other space structures. Further investigation is needed to evaluate the effect of imperfections on global - local buckling and post buckling response of truss structures.

Publications:
None to date.



Thompson's Strut



Mode-I
$\lambda = 0.0186$

Global-local buckling factor

$$\beta = 0.06\left(\frac{L}{N\,r}\right)^2$$

$\beta > 1$, Local buckling
$\beta < 1$, Global buckling

L = Length of the bay
N = Number of bays
r= Radius of gyration

(Valid for Isotropic/orthotropic members)

Figure1. Global-local buckling analysis Thompson's strut

Lunar Transfer Vehicle Aerobrake Test Model Design and Analysis

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Department of Mechanical Engineering
North Carolina A&T State University

Research Objectives:
To develop a kinematically compatible scaled test model of the lunar transfer vehicle (LTV) aerobrake proposed by the NASA Langley Research Center.

Approach:
NASA Langley Research Center proposed LTV spherical aerobrake configuration with sandwich honeycomb construction and radius (R) 45 ft, chord (C) 50 ft, and depth (d) 7.8 ft was selected. The shell wall is made up of 8-ply quasi-isotropic graphite/epoxy skin and aluminum honeycomb core. The docking ring, which supports the pay load, is located at half-depth of the shell. The membrane analysis of the shell showed that the maximum hoop stress occurs at the ring and is equal to $-(pR)/(2t)g$, where t is the shell skin thickness and g is a function of location of the docking ring. Dimensional analysis was used to kinematically scale the aerobrake shell to a one-tenth size model. The configuration, material strength, and the loading pressure of the test model and the true structure are related by an equation $(p_m/p_s) = (S_m/C_m)(t_m/t_s)\ f(d/C, d_m/d_s)$, where subscripts m and s represent the model and structure respectively. The parameter S is the inplane strength of the material. The test model was designed to be buckling safe.

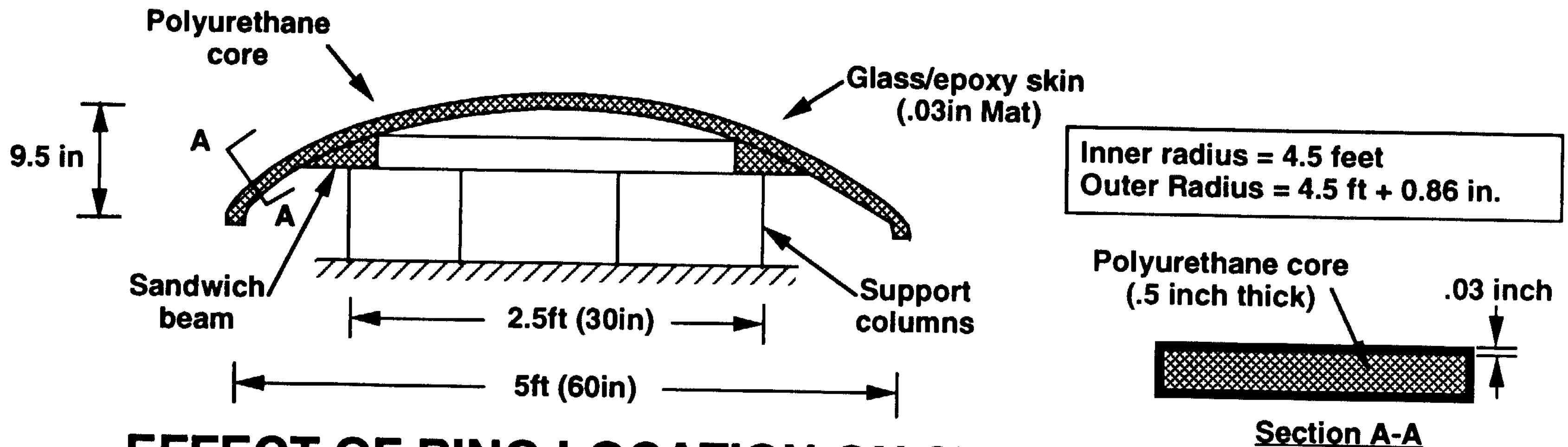
Accomplishments:
The one-tenth test model of the LTV aerobrake shown in the figure was developed. The test model is a spherical sandwich shell with inner radius 4.5 ft. The docking ring is at half-depth of the shell, and it is a sandwich beam with depth 1.5 inch and skin thickness .06 inch. Effect of location of the docking ring on the hoop stress distribution along the meridian of the shell is shown in the figure. To achieve an equal value of maximum stress to material strength ratio, the model needs to be pressurized to 1 psi. The test model is buckling safe, and critical buckling pressure is about 5.7 psi. Test study and analytical verification is underway.

Significance:
The test model will be used to study the deformation and failure mechanisms of the aerobrake shell under various loading and support conditions and to validate the finite-element solutions. The test model will guide in developing techniques for the assembly, packaging and joining of the aerobrake. The test model will also guide in developing more complex non-axisymmetric aerobrake configurations for Mars Transfer Vehicles.

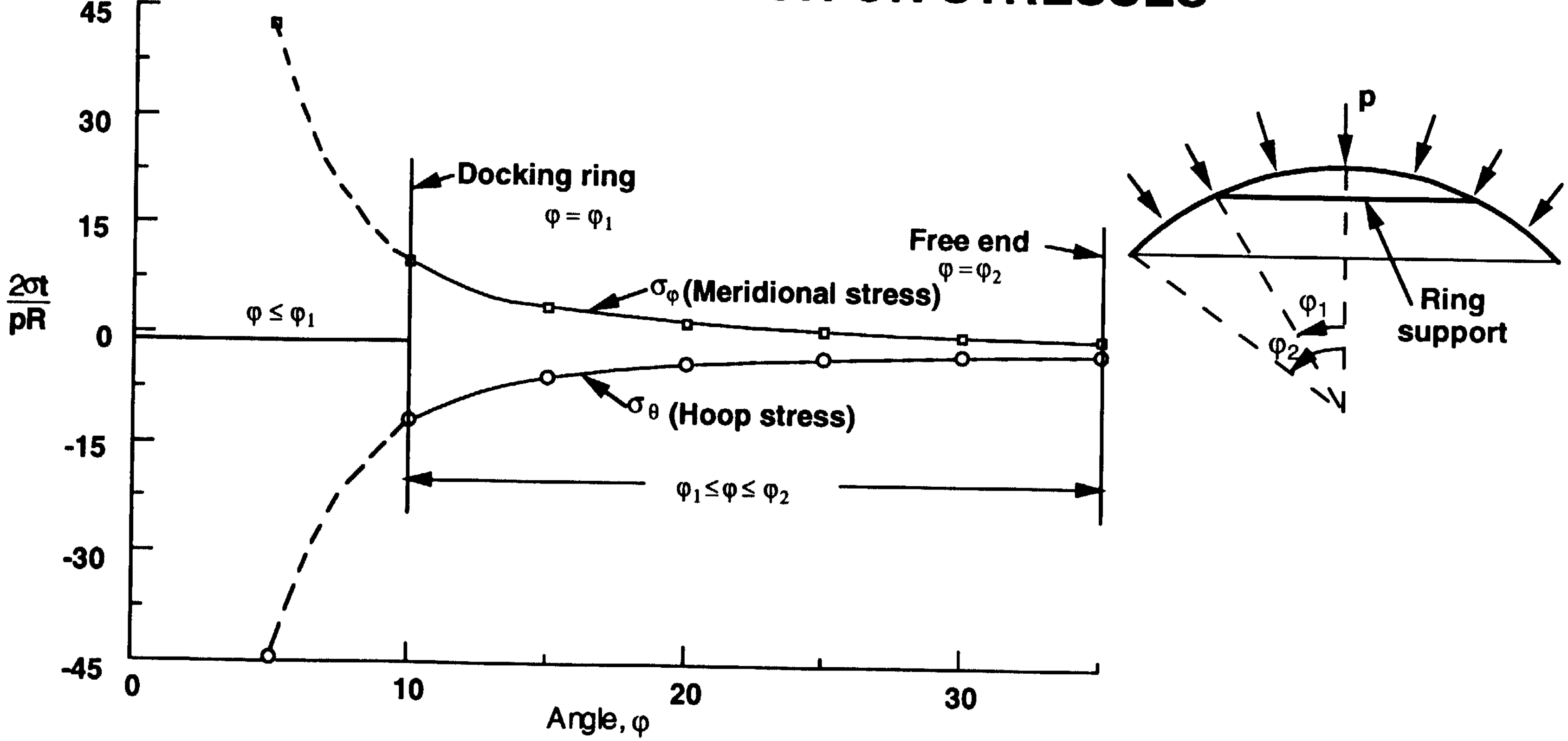
Future Plans:
Test and analysis of aerobrake models will be conducted under uniform and aerodynamic pressure loadings for various pay-load support conditions. Buckling tests will be conducted for typical configurations.

Publications:
None to date.

LTV AEROBRAKE TEST MODEL



EFFECT OF RING LOCATION ON STRESSES



Mixed Mode Fracture Mechanics Parameters for Out-Of-Plane Loaded Thin-Walled Structures

Kunigal N. Shivakumar
Department of Mechanical Engineering
North Carolina A&T State University

Research Objectives:
To develop three-dimensional mixed mode stress-intensity-factors (SIF) for thin walled structures (example, liquid fuel tanks, aircraft fuselage) subjected to out-of-plane loads.

Approach:
Three-dimensional finite-element analysis of middle-crack panels subjected to an out-of-plane load was conducted using a fracture mechanics code, FRAC3D. An antisymmetric loading, referred to as the mode-III loading [Fig. 1(b)] was used. Mixed mode stress-intensity-factors (mode-I, mode-II, and mode-III) were calculated using the virtual crack closure and the equivalent domain integral methods. The FRAC3D code calculates fracture mechanics parameters based on the above two methods for both metallic and composite materials. The analysis was conducted for a wide range of panel thicknesses.

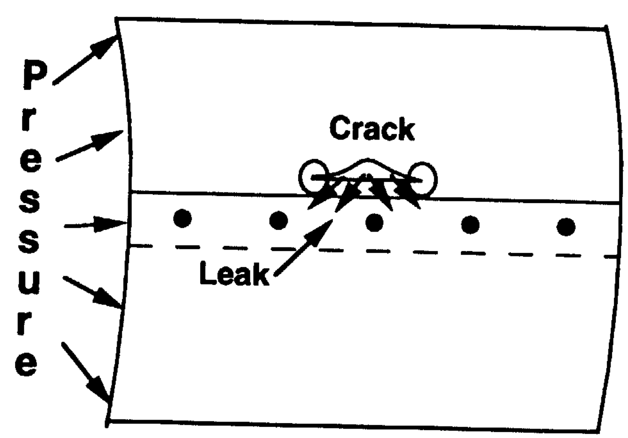
Accomplishments:
Normalized stress-intensity-factors (K_I, K_{II}, and K_{III}) versus thickness for a middle crack panel subjected to mode-III type loading is shown in Figure 1. The SIF is averaged through the thickness of the panel. For very thick panels, K_{II} is very small and K_{III} agrees very well with the anti-plane solution. However, for thin panels (practical range), K_{II} is equal to or larger than K_{III}. The change in the response from thick to thin panel can be explained by the free boundary layer effect.

Significance:
Structural configuration and/or load unsymmetry about the crack plane in cracked solids causes a mixed mode stress field at the crack tip. The stress field in thin structures is radically different from that of thick structures because of the boundary layer effect. The present solutions would provide a data base to design a mixed-mode fracture test specimen so that the mixed-mode fracture strength and fatigue lives of aerospace materials can be measured.

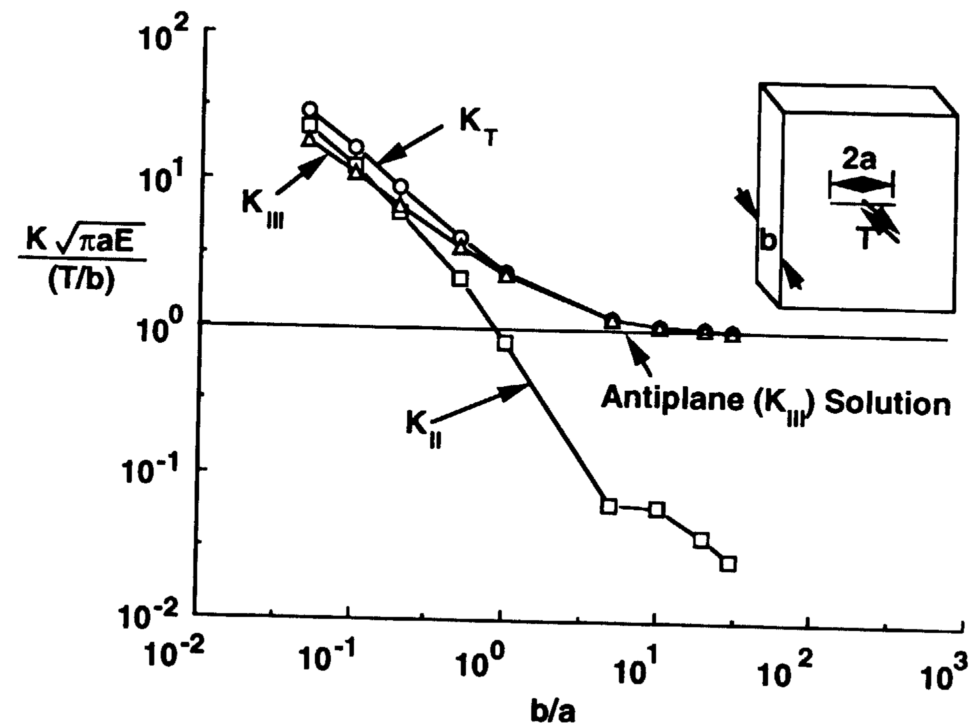
Future Plans:
The analysis is continued along with NASA Langley Research Center's test program to establish a mixed-mode fracture and fatigue crack growth criteria for aerospace materials. A fundamental research on elastic-plastic analysis of cracked pressure vessels is needed to establish a leak-before-burst criteria.

Publications:
None to date.

MIXED MODE STRESS-INTENSITY-FACTORS FOR A MODE-III LOADED CRACKED PANEL



(a) Typical cracked pressure vessel
(Configuration unsymmetry
about the crack plane)



(b) Effect of panel thickness
on stress-intensity-factors

An Efficient Finite-Element Formulation for Vector and Parallel Processing Computers

Kunigal N. Shivakumar
Department of Mechanical Engineering
North Carolina A&T State University

Research Objectives:
To develop an efficient finite-element algorithm for vector and parallel processing super computers to analyze linear elastic multibody contact problems.

Approach:
The method is based on the principle that in reality all structural problems are dynamic. Solution to a dynamic problem with damping at time infinity is the static solution (see Figure). At any intermediate time, the solution is temporary, and any change in the boundary condition due to contact or separation can be introduced. Finite-element formulation of this method using the explicit central difference time integration scheme leads to an algorithm involving vector and parallel computations (see figure). This method of analysis is called the "Dynamic Relaxation Method." Two three-dimensional F-E codes, DYAN3D and DYAN3DP, based on 20-node isoparametric element were developed to analyze isotropic and anisotropic bodies. DYAN3D is for vector processing super computers, and DYAN3DP is for parallel processing computers. The Cray parallel processing technique called "autotasking" was used in DYAN3DP. The two codes have the capability to analyze multibody contact problems and cracked bodies.

Accomplishments:
DYAN3D and DYAN3DP were verified by solving a number of simple problems (bar and beam). Both codes were used to calculate 3-D stress-concentration-factors at countersunk rivet holes in plates. Solutions from the two codes agreed well with the previously established solutions.

Significance:
The conventional F-E method of analysis is tedious for multibody contact problems and suffers from communication problems in massively parallel processing computers due to large size stiffness matrix. The present method overcomes both drawbacks. The largest vector length in a problem is equal to the total degrees-of-freedom.

Future Plans:
The codes will be used for analyses of 3-D multibody contact problems. The codes will be extended to analyze elastic-plastic and large deformation problems.

Publications:

None to date.

Educational Outreach in Engineering Science

L. Silverberg, Principal Investigator
Co-Investigator: Jim Redmond
Department of Mechanical and Aerospace Engineering
North Carolina State University

Outreach Objective:
The outreach objective is to provide community schools and organizations with organized lectures, laboratory tours, workshops and other special functions in the area of engineering science.

Approach:
The Educational Outreach in Engineering Science Program is coordinated by a steering committee composed of members from complimentary and balanced backgrounds. The members are Jim Redmond (Adjunct Assistant Professor, A&T), Sue Redmond (High School Math Teacher), Dennis Dubay (North Carolina Science and Math Alliance, Director), Lee Stiff (Math and Science Education Professor) and Larry Silverberg (Mechanical and Aerospace Engineering Professor).

Accomplishments:
(1) lecture series composed of 14 lectures
(2) lab tour series with 5 laboratories participating
(3) summer workshop entitled "Applied Mathematics for Teachers"
(4) Education Outreach literature

Future Plans:
Existing outreach functions will be expanded to include more lectures, lecturers and laboratories. Reviews of existing functions will be conducted. Future functions under consideration include the development of educational videos to schools on NASA applications of scientific/mathematical concepts (supported by NASA) and cross-college senior design course of outdoor interactive sculptures that demonstrate physical principles. (Supported by Wake County Park and Recreation Department and the North Carolina Science and Math Alliance.)

Publications:
None to date.

Spacecraft Controls for Mars Mission Vehicles: Structural Electrodynamics

L. Silverberg, Principal Investigator
Co-Investigators: Joel Nicholson and Mark Cassada
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
The research objective is to develop analytical methods and to conduct experiments for the engineering characterization of structural electrodynamic/electromagnetic forces. The engineering characterizations are being applied to satellite antennae surfaces as an enabling technology. Enabling performances potentially include varying aperture, rapid deployment/retractment, 95% reduction of antenna surface mass and near-elimination of thermally-induced surface deformations.

Approach:
Structural electrodynamics refers to the dynamics of structures caused by highly mobile surface charge distributions. The charge distributions are controlled through the application of a surface grid of applied electrical potentials. Charge mobility time constants are on the order of 1 μsec. Initial analytical work and experiments focused on simple planar discrete systems, i.e., the electrodynamic pendulum, the fixed-charge planar electroscope, and the electrodynamic string. Structural electromagnetics refers to the structural dynamics of structures caused by an embedded grid of electromagnetic sources. Variations in the electromagnetic field cause predicted shape distortions. These studies are being applied as well to thin elastomeric fabric surfaces.

Accomplishments:
Analytically predicted equilibrium angles of the electroscope agreed with experimental measurements within a 0.2° error. Analytically predicted natural frequencies of oscillation agreed with experimental measurements within an expected 10%-20% linearization error.
These results indicate that the dynamics electrodynamic structure is dominated by linear approximations, under the proper conditions. This enables designs based predominantly on the linear theories.

Significance:
With increased demands placed on space-based antennae in broad frequency ranges, surface accuracy, minimal weight, and deployment/retractment become driving considerations. Toward these ends, the structural dynamic interactions of surface electrical forces and surface electromagnetic forces are characterized in these investigations.

Publications:
"Planar Electrodynamics of Interconnected Charged Particles," presented at the *Southeastern Meeting of the American Physical Society*, Durham, NC, Nov. 11-13, 1991 (with W. O. Doggett and K. Park).

Spacecraft Controls for Mars Mission Vehicles: Fuel Optimal Control

L. Silverberg, Principal Investigator
Co-Investigators: James Redmond and John L. Meyer
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
The research objective is to develop and experimentally verify fuel-optimal propulsive control methods for Mars Mission Vehicles. The methods developed are being applied to aerobrake roll modulation, space station reboost, reorientation of axisymmetric spin-stabilized satellites, and control of large flexible space structures.

Approach:
The solutions of fuel-optimal control problems admit impulses as the form of the applied forces. The exact solutions of algorithms governing when the values are switched on and off in a fuel optimal manner were never before obtained thereby necessitating heuristic approximations as the only alternative. Our approach is to develop a numerical method for the exact solution of the fuel optimal control problem. The exact solution would then be analyzed and overall properties of the exact solution would be extracted. These properties in turn would be used in developing relatively simple algorithms governing when the values are switched on and off.

Accomplishments:
The fuel-optimal control problem was formulated as the minimization problem $\alpha = \min_{H} \max_{1\le j\le m} \sup_{0\le t\le T} |g_j(\eta,t)|$, where H is a hyperplane containing n-dimensional elements η, m is the number of thrusters, T is the maneuver time, and $g_j(\eta,t)$ is called the index of the control. The determination of α is the essential problem. The numerical method of solution is based on discretizing the hyperplane into an n-dimensional grid. Then, the $\max_{1\le j\le m} \sup_{0\le t\le T} |g_j(\eta,t)|$ is determined numerically for points on the grid in the neighborhood of postulated solution η_p. The process is repeated using an adaptive grid bisection approach until the solution is obtained. The method is numerically attractive since it is guaranteed to converge to a global minimum.

Significance:
With the coming of larger more complicated space structures (space trusses, large platforms, larger satellites with redeployable appendages, aerobrakes, etc...) fuel-optimal control of such future systems becomes important. This research develops fuel-optimal control methods for these future systems.

Future Plans:
Currently developed numerical methods will be applied to Earth aerobrakes and multi-mode beams. Also research is directed toward refining the numerical procedures to increase numerical speed.

Publications:
"Fuel Consumption in Optimal Control," *Journal of Guidance, Control and Dynamics*, to appear (with J. Redmond).
"Light Impulsive Damping of Spacecraft Exhibiting Normal Mode Behavior," *Journal of Guidance, Control and Dynamics*, to appear.
"Fuel-Optimal Control of an Experimental Multi-Mode System," presented at the 8th VPI&SU/AIAA Symposium on Dynamics and Control of Large Structures, Blacksburg, VA, May 6-8, 1991 (with John L. Meyer and James Redmond).

Buckling of Composite Aerobrake Trusses Under Axial Compression

Fuh-Gwo Yuan, Principal Investigator
Co-Investigator: S. C. Wu
Department of Mechanical and Aerospace Engineering
North Carolina State University

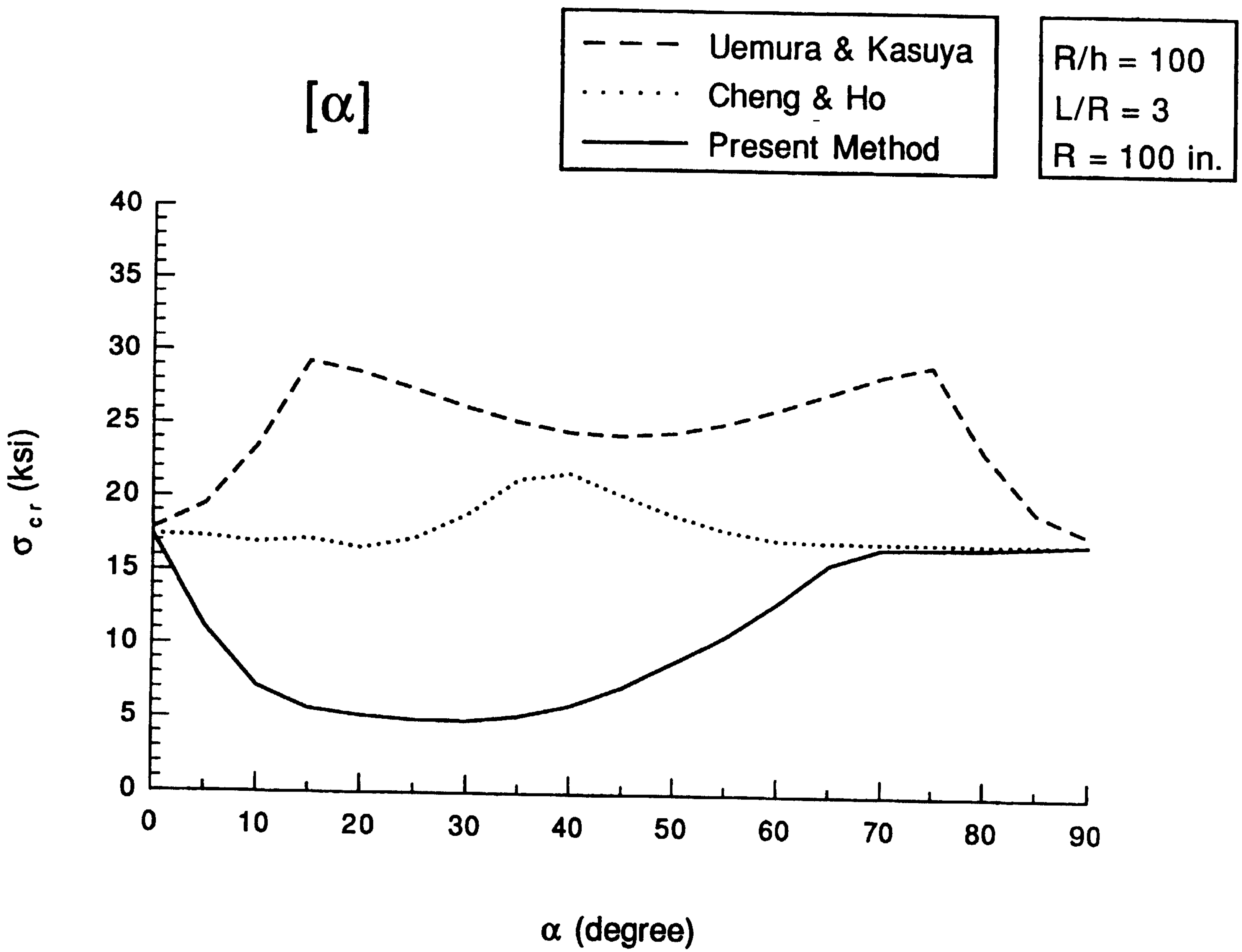
Research Objectives:
The objectives of the effort are: (1) to develop an analytical solution for calculating the buckling loads of composite shell-type trusses in an aerobrake, (2) to assess the effect of coupling between stretching, in-plane shear, bending and twisting on the buckling loads for these laminated structures, and (3) to validate the methodology with existing experimental data.

Accomplishments:
All the existing buckling predictions of the trusses are based on Donnell's theory or various advanced shell theories. None of the analyses has taken the coupling into account. To assess the role of coupling effects on the buckling loads of the trusses, a Flugge's thin shell theory in conjunction with linearized buckling analysis is performed for the shells under axial compression with simply supported ends. The coupling effects are taken into account in the prebuckling state. The figure illustrates the buckling loads for off-axis composite trusses. Two previous analyses, Donnell's theory from Uemura and Kasuya, and Flugge's shell theory, without considering coupling effects obtained from Cheng and Ho, are also plotted for comparison. The figure reveals that the previous theories overestimate the buckling loads several times for some fiber orientations. The minimum buckling load occurs at $\alpha = 30^\circ$ due to the pronounced coupling between bending and twisting. This fact has also been confirmed experimentally by Uemura and Kasuya. Although these predictions give correct buckling loads for longitudinal or hoop wound trusses, they overestimate the buckling loads for laminated trusses.

Significance:
Large aerobrake structures consist of many buckling-critical trusses. Since light weight is critical, the relatively few plies employed frequently resulted in unsymmetrical and/or unbalanced laminate ply layups. Furthermore, the trusses are usually of slender type, the structural instability becomes a significant concern in the safe and reliable design of the trusses. Due to the inherent mechanical coupling effects, and both in-plane and bending anisotropy, the buckling behavior and associated buckling modes are much more complicated than those occurring in conventional metallic structures. For instance, the trusses are under axial compression with simple supports at the ends. The buckling modes, in general, undergo unique a warping pattern. Results indicate that the buckling equations, which have been used to design the minimum weight and the sizing of the aerobrake trusses, may be modified. The reduction of buckling loads due to the coupling should be taken into consideration.

Future Plans:
In practice, the trusses may experience complex loadings, such as bending, torsion and various end boundary conditions due to the interconnected joints. The effect of these combined loadings and associated boundary conditions on the buckling loads will be examined. Maximizing the buckling strength by optimizing architecture and stacking sequence will be also investigated.

Publications:
None to date.



Comparisons of Present Buckling Method with other Two Theories in [α] Composite Shells Under Axial Compression

Nonlinear-Viscoelastic Characterization in High-Temperature Composite Laminates

Fuh-Gwo Yuan, Principal Investigator
Co-Investigator: Brian Potter
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
The objectives of this research are two-fold: (1) to study the fundamental deformation behavior and failure mechanisms of LaRC-RP46 based composites under sustained loading with different temperatures and determine elevated temperature nonlinear viscoelastic constitutive behavior of the composites and (2) to develop advanced experimental methods and measurement techniques for elevated temperature creep deformation of the composites and establish a master curve to predict long-term nonlinear viscoelastic response from short-term laboratory tests.

Accomplishments:
High temperature systems have been purchased through the Mars Mission Research Center. The test chamber is designed which can numerically control the required temperature and gaseous environment. The extensometer allows us to measure specimen elongation during the tests, and the special high temperature grip is used to transmit the load from the test machine to the specimen inside the chamber. Fabrication of specimens has started for the test.

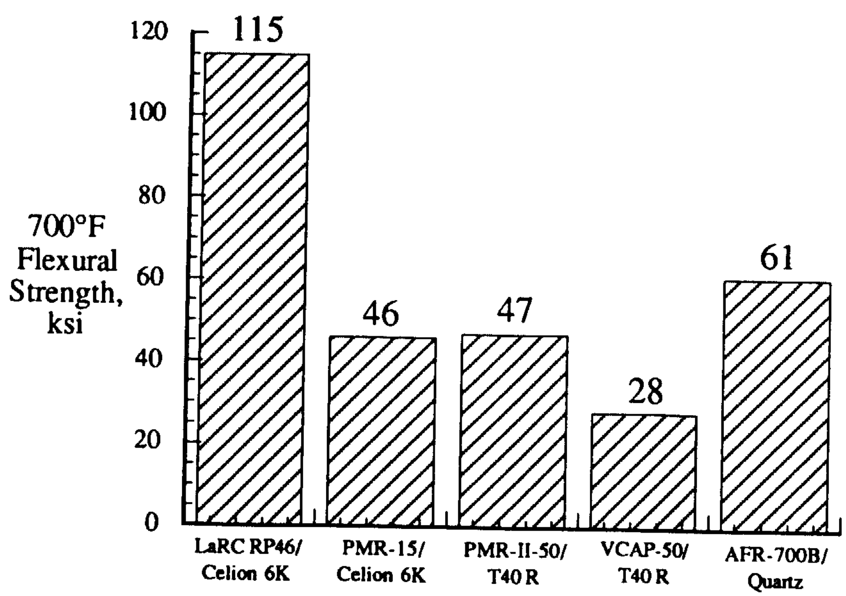
Significance:
One of the keys to a successful space mission is to develop a light weight thermal protection system for the launching vehicles. Advanced composite hardware exposed to temperature environments above 127°C (260°F) must be fabricated from materials with resin matrices whose thermal resistance is superior to that of conventional epoxy-matrix systems. Polyimide based resins such as LaRC-RP46 has evolved during the past few years that exhibits excellent thermal stability for high-temperature(700°F) technology applications. Besides, the attractive features such as better health and safety, greater toughness, easier to process, and lower material and processing cost have been identified. Since polymide composite materials reveal a significant amount of time- and temperature- dependent mechanical behavior, the efficient design and utilization of such composites in load bearing members and in other structurally related applications under severe temperature environments demands a good understanding of time and temperature dependent behavior.

Future Plans:
Mr. Potter, a new graduate student, is planning to spend three summer months at the NASA Langley Research Center. He will be working at the Material Division under the guidance of Dr. R. Pater with particular emphasis on the microcracks of LaRC-RP46 composites under elevated temperature.

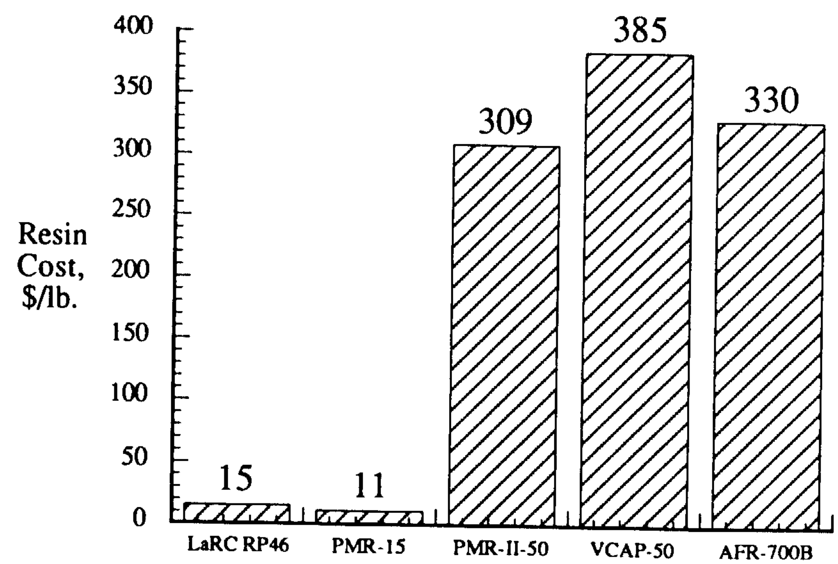
Publications:
None to date.

LaRC RP46 Has By Far the Highest 700°F Performance Per Dollar Among All the Existing PMR Polyimides

700°F Composite Flexural Strength



Estimated Resin Cost



Transverse Cracking in Composite Laminates

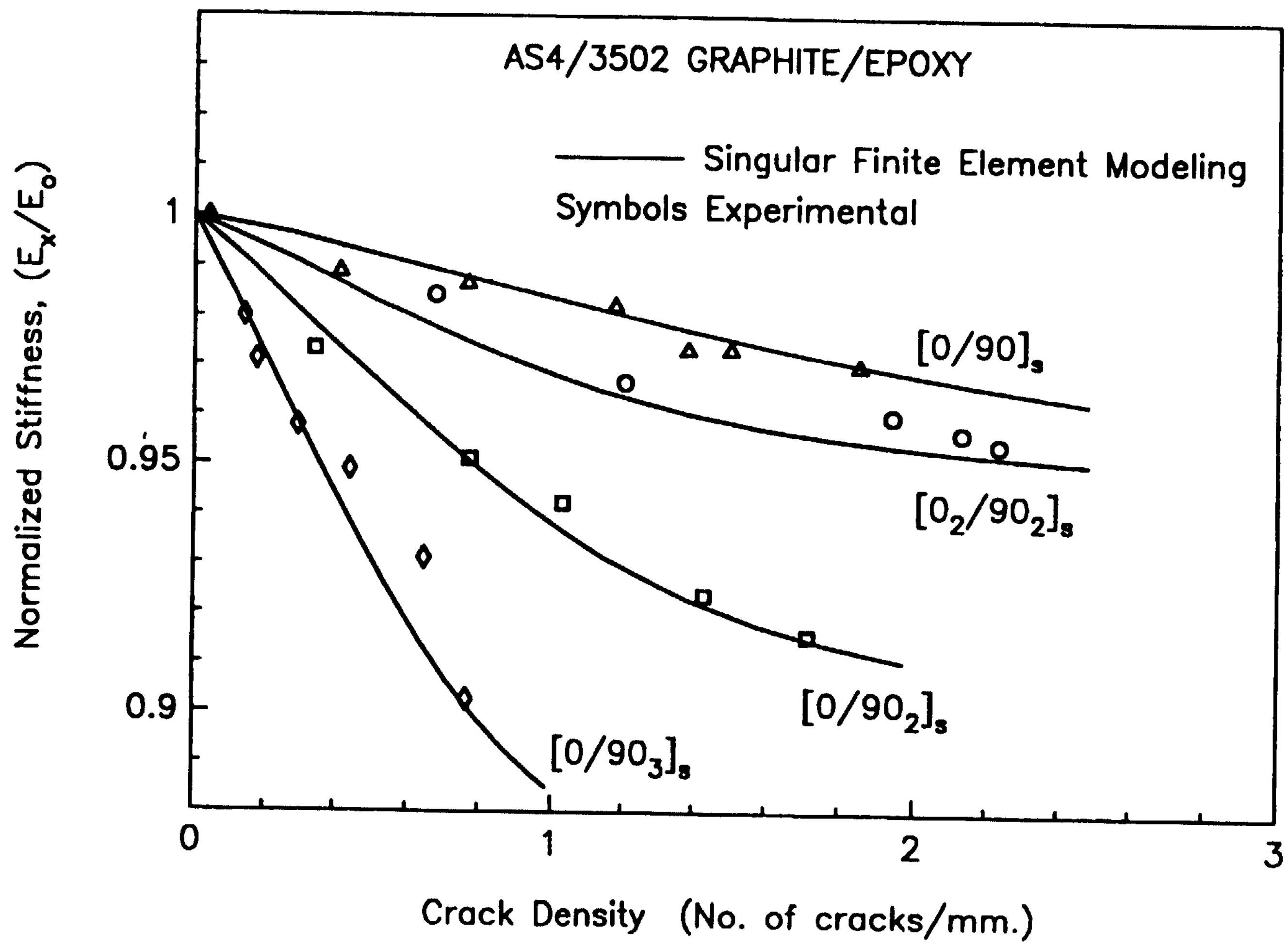
Fuh-Gwo Yuan, Principal Investigator
Co-Investigator: M. C. Selek
Department of Mechanical and Aerospace Engineering
North Carolina State University

Research Objectives:
Develop a singular anisotropic elasticity solution and a singular hybrid finite element model for the analysis of failure mechanism due to transverse cracks in fiber-reinforced composite laminates when the transverse cracks are formed on the 90° plies under uniaxial extensional loading.

Accomplishments:
Singular hybrid element modeling exhibits very good prediction of the stress fields, especially in the singular domain near the transverse crack where the conventional finite element model fails to model the stress distribution accurately. Predictions of the analysis for axial stiffness reduction, due to transverse cracks, also exhibit very good agreement with experimental results obtained by Lim and Hong shown in the figure. Furthermore, comparisons of the current method with shear lag method reveal that the approach is more suitable for predicting the stiffness change. In addition, stress intensity factors have been found to decrease with the increasing number of transverse cracks and approach a definite limit. Evidence of crack saturation patterns before delamination may occur along the interface.

Significance:
Composite materials offer desirable performance characteristics and a unique advantage of design flexibility. The deformation behavior and failure mechanisms of composite structures are, however, much more complicated than those occurring in conventional metallic structures because of their heterogeneous construction and/or material anisotropy. Failure mechanisms in laminates are mainly interlaminar and intralaminar cracking at the macrostructural level. Interlaminar cracks which are formed between plies cause delamination of the composite laminate. Intralaminar cracks(transverse cracks) run perpendicularly to the interface of the composite laminate and terminate there before the ultimate load is reached. It has been also found that transverse cracks form periodic saturation patterns which are called Characteristic Damage State. The CDS is achieved after certain high static loads or fatigue cycles at the lower stress levels and remains constant thereafter. These failure mechanisms result in change of fracture phenomena and destruction of load transfer and thereby lead to reduction of global stiffness, loss of structural integrity, and hence deterioration in the performance. A predictive capability of the long-term performance of composite structures would be achieved if the physical characteristics of these failure mechanisms that limit overall strength are fully understood.

Publications:
M. C. Selek, and F. G. Yuan, "Singular Hybrid Finite Element Analysis of Transverse Cracking in Composite Laminates," Second International Symposium on Composite Materials and Structures, Beijing, China, 1992.



Stiffness Reduction of $[0_n/90_m]_s$ AS4/3502 Graphite/Epoxy Composite Laminate Family as a Function of Transverse Crack Density

Elastic Moduli of Ceramic Matrix Composites with Interfacial Debonding

Fuh-Gwo Yuan, Principal Investigator
Co-Investigator: Dr. N. J. Pagano
Department of Mechanical and Aerospace Engineering
North Carolina State University

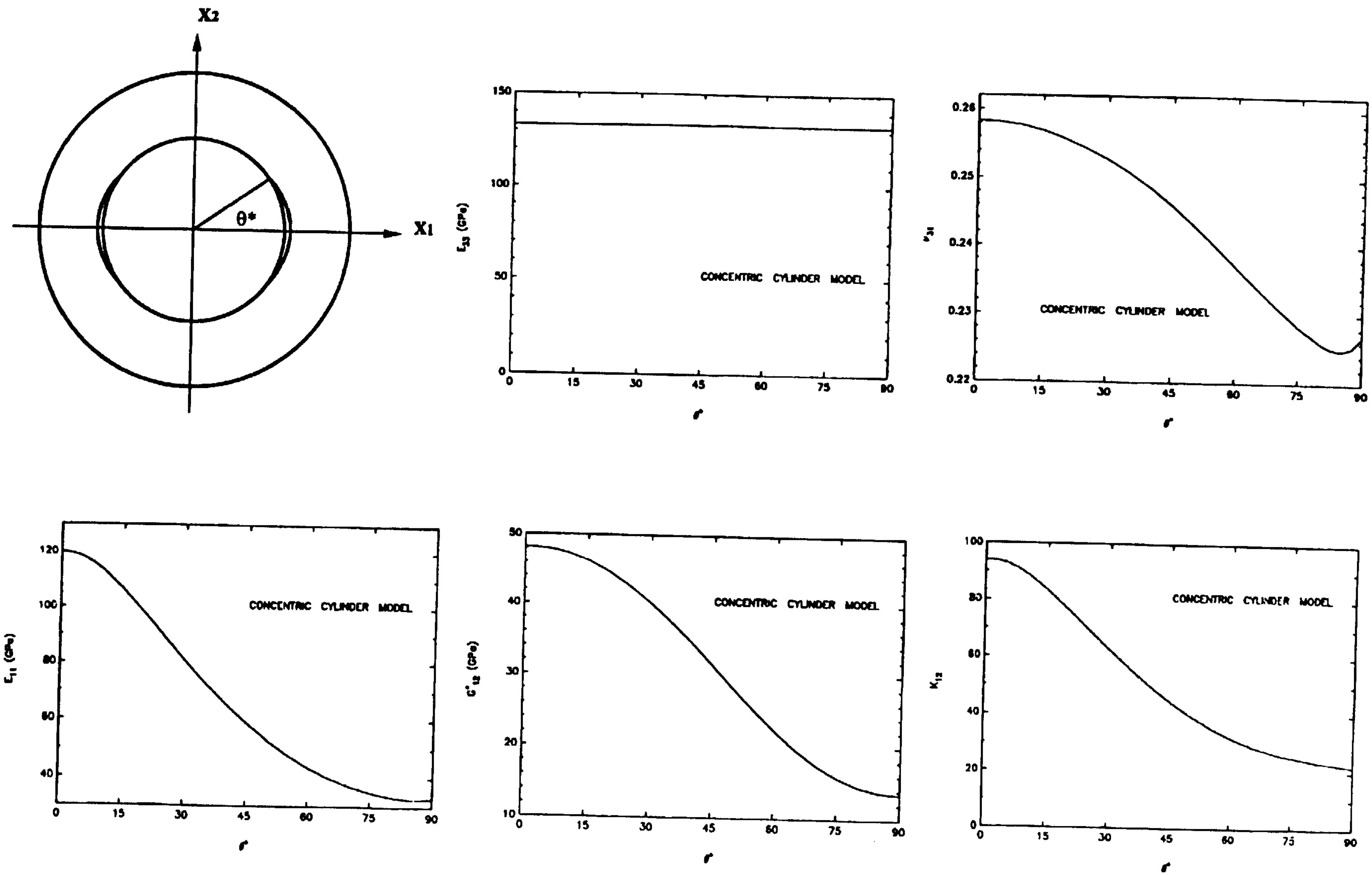
Research Objectives:
The objectives of the effort are three-fold: (1) to develop analytical methods and numerical schemes to predict the effect of the debonded interface on elastic moduli of debonding in ceramic matrix composites, (2) to guide development of ceramic matrix composites tailored for specified performance, and (3) to predict mechanical performance and life times in expected service conditions.

Accomplishments:
Two types of geometry layout of the composites (a) composite cylinder model and (b) periodic square array model are considered in the analysis. The results based on the composite cylinder model shown in the figure indicate that effective axial modulus has little effect on the debonded interface conditions. However, the debonded interface may have significant effect on transverse Young's moduli, transverse shear moduli, longitudinal Poisson's ratio, and plane strain bulk moduli.

Significance:
The mechanical properties of fiber-reinforced ceramic matrix composites are significantly affected by the bond between the various constituents materials at the microscale level, such as the interface between fiber-interphase or interface-matrix. In polymer-matrix composites in general, $E_f/E_m > 10$, the composite systems consist of brittle fibers such as graphite and boron in relatively soft matrix materials such as epoxy, a strong fiber/matrix bond is desired. In ceramic-matrix composites, $E_f/E_m \approx 2\text{-}4$, the constituents are both brittle in nature; the fibers are loosely bonded to the matrix. Although this loose bond is detrimental to compressive and transverse strength properties, it is believed to be the most important source of enhancing strength and fracture toughness in these composite systems. Recent experimental studies on ceramic matrix composites have also shown that the nature and degree of bonding between the fiber and the matrix dominate their mechanical properties and associated failure modes. In order to achieve optimal performance between strength and stiffness for composite development, the effect of weak bond or debonded interface condition on the mechanical properties of composite materials needs to be fully understood.

Future Plans:
The effect of debonding on the effective thermal expansion coefficients is currently analyzed. The future investigation will consist of two parts. In the first of these, the role of the friction between fiber and matrix on the thermomechanical properties will be assessed. In the second part, the crack growth path, either along the interface or deflected from the interface, will be studied based on a proper energy criterion.

Publications:
None to date.



Effective Engineering Constants for Concentric Cylinder Model

Thermal Conductivity of Fibers and Fibrous Composites

A. A. Fahmy, Principal Investigator
Co-Investigator: Robert Gabel
Department of Materials Science and Engineering
North Carolina State University

Research Objectives:
One objective of this work is to review and evaluate the techniques utilized in the measurement of the transverse thermal conductivity of anisotropic fibers and devise a method which is independent of any assumed structure-property relationship between the conductivity of the fibers and those of composites incorporating them. Another is to use analytical methods including finite element analysis to predict the thermal conductivity of fiber composites in terms of the properties of the fibers, matrices and the fiber reinforcement architecture and verify with experimental results.

Approach:
By incorporating a variety of isotropic fibers in an epoxy matrix, each to produce an unidirectional composite of the same volume fraction(40%), a master curve was produced relating the transverse conductivity of the composite to that of the fiber. This master curve is then used to calculate the transverse conductivity of any fiber (whether isotropic or anisotropic) by measuring the transverse conductivity of the composite incorporating it. Unidirectional cross-ply and 3-D braided preform composites were prepared using the high conductivity P120 AMOCO's graphite fiber and their thermal conductivity measured along the three mutually orthogonal materials symmetry axes. Results were compared with analytical results obtained for the unidirectional and the cross-ply composites. A theoretical analysis was conducted for predicting the thermal conductivity of composites with continuous, straight, randomly oriented high conductivity fibers and a simple formula obtained.

Accomplishments:
It was found that the above technique for transverse fiber conductivity while viable, can only be used for fibers that have conductivity ranging from an order of magnitude above to an order of magnitude below that of the matrix. Other master curves have to be produced with matrices of widely different conductivities. Experimental results of the P120 graphite reinforced composites were in agreement with analytical predictions for the unidirectional and cross-ply composites.

Future Plans::
Thermal conductivity of 3-D woven and several additional 3-D braided preform composites will be studied, as well as, adapting a finite element computer code for the prediction of the thermal conductivity of 3-D fibrous composites.

Publications:
None to date.

High Velocity Impact Damage in 2-D Laminates and 3-D Woven Graphite Fiber Reinforced Composites

A. A. Fahmy, Principal Investigator
Co-Investigator: Stefan Voss
Department of Materials Science and Engineering
North Carolina State University

Research Objectives:
To evaluate and compare the property retention after high velocity impact of 2-D ply laminates, 2-D cloth laminates and 3-D woven CFRP and to determine the usefulness of the four-point bending test in monitoring the property degradation.

Approach:
Coupons of graphite fiber epoxy resin composites were prepared with six different fiber spatial distributions, two were regular laminates, one cloth reinforced and three 3-D woven preform reinforced, with 3 different levels of through-thickness reinforcement. These were subjected to the impact of gas gun fired projectiles of varying speeds (and energies). The parameters used to assess the damage tolerance were the residual flexural modulus, and flexural strength as well as the "BVID" energy and the energy for full penetraton. Microscopic examination to characterize the damage is performed.

Accomplishments:
Projectile impact caused significantly greater damage to 2-D composites than to 3-D composites. The superiority of the 3-D composites was more evident in strength retention than in modulus retention. This is shown in Figs. 1 and 2. The impact energy for barely visible damage BVID, for penetraton for all three constructions of 3-D composites, and for cloth reinforced laminates did not vary much from one to the other but was much lower in the case of regular laminates. This is shown in Table 1. The easy to perform four-point test proved to be a sensitive and consistent way for assessing the impact damage.

Future Work:
More work is needed to characterize the damage by optical microscopy, SEM and acoustic microscopy.

Publications:
None to date.

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Future Plans:
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Publications:
None to date.

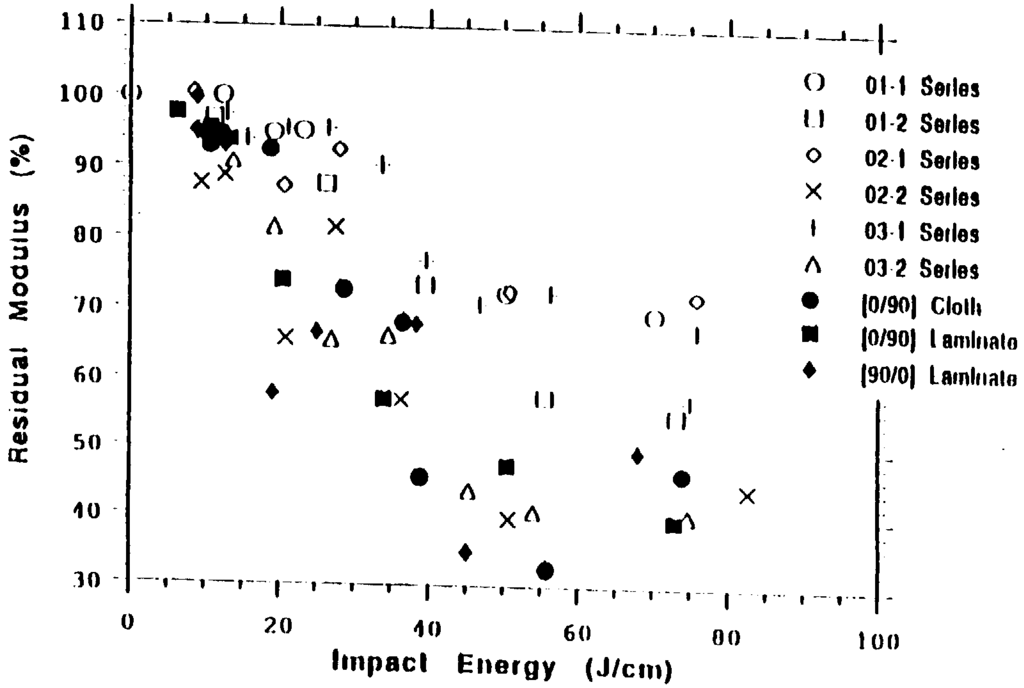


Fig 1

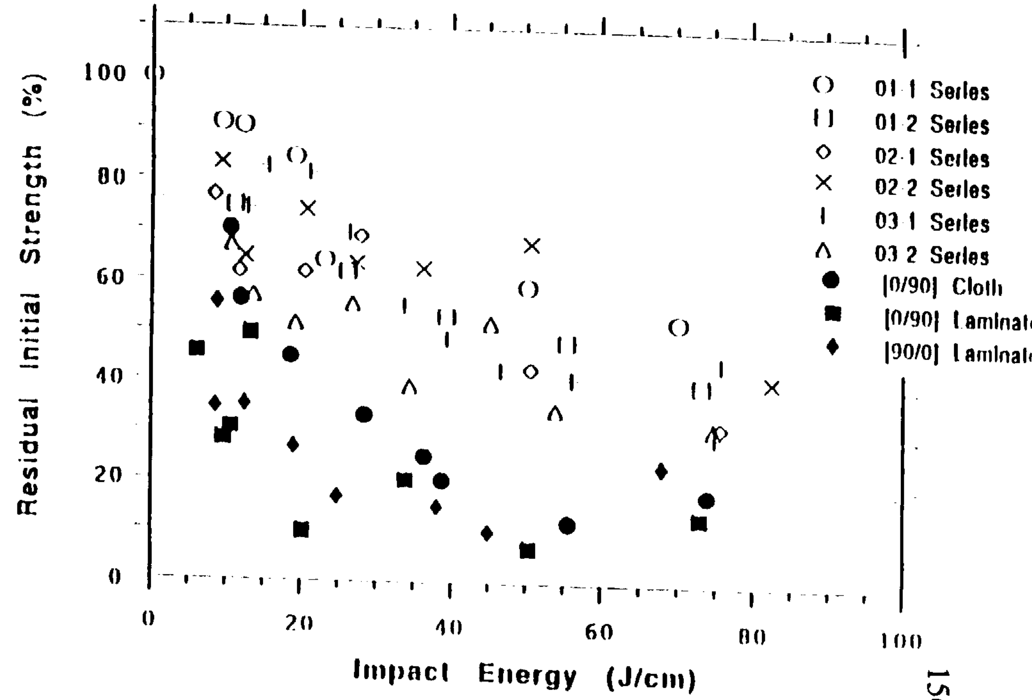


Fig 2

Impact Energies necessary for Barely Visible Impact Damage and Coupon Penetration

Sample Series	Impact Energy (J) for	
	BVID (J/cm)	Penetration (J/cm)
[0/90], [90/0]	6 to 9	36 to 40
[0/90] Cloth	10 to 12	51 to 64
01-1, 01-2	11 to 12	56 to 69
02-1, 02-2	12 to 20	50 to 74
03-1, 03-2	13 to 19	55 to 73

Table I

The Effect of Thermal Cycling on the Microstructure and Properties of 3D-Woven Preform Composite

A. A. Fahmy, Principal Investigator
Co-Investigator: Joseph Mensah
Department of Materials Science and Engineering
North Carolina State University

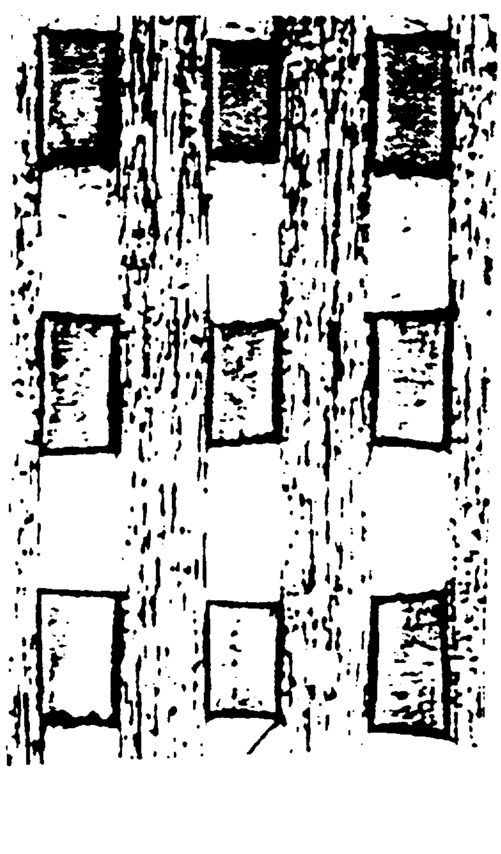
Research Objectives:
To characterize the microstructural changes that occur when 3-D graphite preform epoxy matrix composites are thermally cycled and evaluated, and the effect of such changes on the elastic, strength, and thermal expansion behavior.

Approach:
3-D woven preforms of BASF graphite fiber GY30-500 were impregnated with EPON 9405/9470 epoxy resin system and cured to produce structural composite panels. These were microscopically examined for uniformity and structural integrity. Young's modulus, tensile strength and the coefficient of thermal expansion of the panels along the two materials principal directions were determined. Samples were then cycled between 150°C and - 196°C for predetermined numbers of cycles after which they were again examined microscopically to observe any microstructural changes and their elastic, strength and thermal expansion properties determined. The panels were also modeled and their properties estimated theoretically and by finite element analysis.

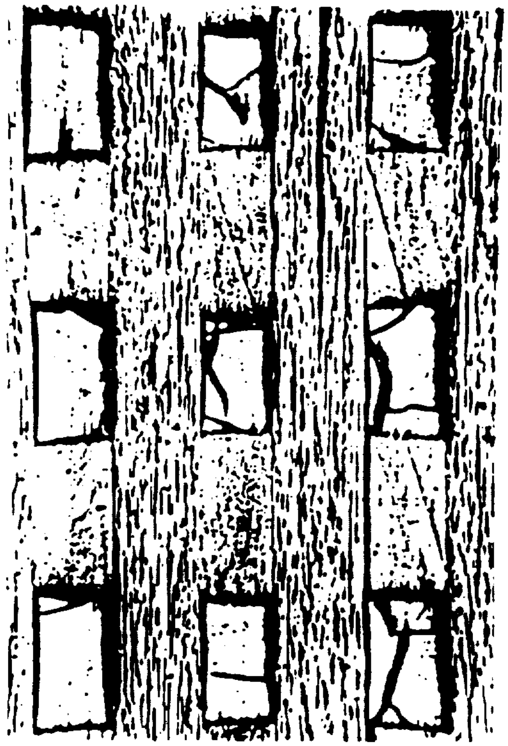
Accomplishments:
The principal effect of thermal cycling was found to be extensive cracking of the resin in the resin pockets of the preform and, to a lesser extent, cracking in the resin matrix of the fiber matrix tows transverse to the fibers, as well as, separation on the resin pocket-tow interface. No damage to the fibers was observed. Both the modulus and strength of the composites deteriorated with thermal cycling, and the thermal expansion coefficients were reduced. Most of the changes occurred after a small number of cycles with little or no change on further cycling. The changes in properties are attributable to changes in properties of the bulk resin which were also determined, as well as deterioration of the resin tow interface.

Future Plans:
Since the damaged matrix resulted in property deterioration, attention will be given to matrix selection and possibly matrix modification by the introduction of a second phase so as to increase resistance to extensive cracking and tow boundary separations.

Publications:
None to date.



Before Cycling



After Cycling

Study of Integrally Stiffened Composite Panels

Alamgir Farouk, Principal Investigator
Department of Mechanical Engineering
North Carolina A & T State University

Research Objectives:
To evaluate experimentally and analytically the effectiveness of integral stiffeners for composite plates.

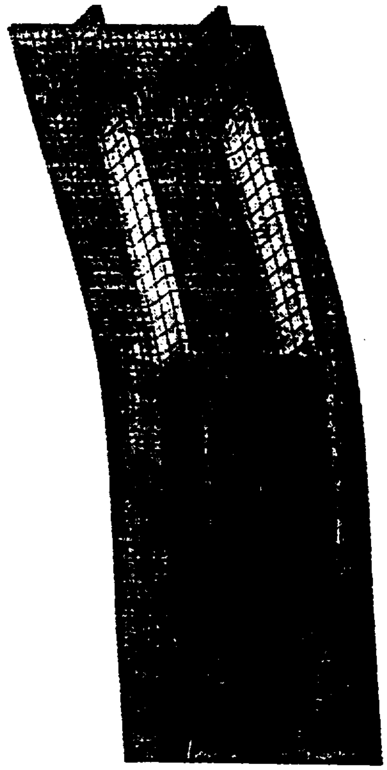
Approach:
Textile preforms are (a) woven and (b) braided using graphite fibers. These preforms have integral stiffeners woven or braided, as the case may be, into the flange portion, obviating the need for any bonding or joining actions. Using the resin transfer molding (RTM) method, these preforms are infiltrated with epoxy resins, and cured to form the composite panels. The panels are tested in 3-point bending with extensive deflection and strain measurements being made during the test. Analysis is performed using the finite element method. Material properties, used in the FEM analysis, are obtained from previously developed constitutive model solutions. The analysis and experimental results are used to evaluate the effectiveness of the stiffeners in improving the deflection characteristics of the panels. Aluminum and fiber-glass/epoxy composite panels are included in both analysis and experiment to allow comparison of the textile composites with such conventional materials.

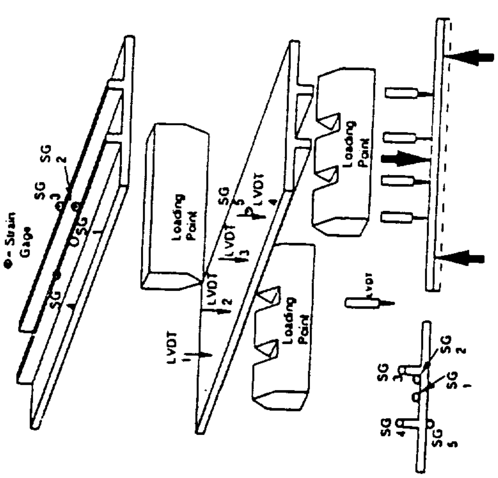
Accomplishments:
The data acquisition system has been calibrated and tested for all channels of measurements. Several sets of bending tests have been performed to assure repeatability. The analysis methods have been validated for aluminum panels, for which the material properties are well established. Preliminary results indicate that care must be taken in the interpretation of data due to the large processing related variations between different composite panels.

Significance:
Stiffeners or ribs are added to plate or sheet structures, in many applications, to improve the rigidity of the plate. High stresses, that develop during loading at the joints between the stiffener and the plate, require that the bond strength must be sufficient to prevent delamination in that region. For isotropic materials, the stiffener can be produced integral with the plate which provides a bond strength at least as high as the body of the plate. In the case of laminated composites, however, the bond strength is usually lower, since the reinforcing fibers are absent at the joints. This problem may be circumvented by braiding or weaving the stiffeners integral with the plate section and the preforms thus produced would then be infiltrated with resin. The braiding or weaving process, on the other hand, introduces new problems as the fibers are crimped more frequently which may be detrimental from the stiffness point of view. This study attempts to evaluate these braided and woven stiffened panels and compare them with conventional and laminated composite panels.

Future Plans:
In the near future, the test and analysis scheme will be extended to include strength and failure behavior of the stiffened panels. It is expected that textile composites will be considerably different from isotropic materials in post-damage behavior.

Publications:
Farouk, A. and Weng, G. J., "Modulus Prediction of a Cross-ply Fiber Reinforced Fabric Composite with Voids," *Polymer Composites*, (accepted for publication).





STIFFENED PANEL TEST SETUP

PROPERTIES AND STRUCTURE OF 3-D BRAID COMPOSITES

G. J. Filatovs, Principal Investigator
Co-Investigator: Desiree Lyon
Department of Mechanical Engineering
North Carolina A & T State University

Research Objectives:
A broad, exploratory program to explore the fracture processes in carbon/epoxy braided composites by correlating the microstructure, loading mode, and micro-failure mechanisms.

Approach:
Experimental micromechanics based on using small-scale compression, bending and tension specimens. Optical and scanning electron microscopy techniques, including in-situ testing, are used to determine the failure sequence and failure controlling microstructural features.

Accomplishments:
A number of property limiting correlations have been made between the load condition and structural features resulting in a rule based description of the failure process. In particular, worst-case conditions for runaway crack growth have been determined. The principal geometric features needed for modeling, such as fiber inclination, tow architecture, and fiber distribution and homogeneity, have been identified and a surface/volume mapping of the braid structure has been made. A simulation-modeling has also been made of the random packing of a typical braided structure to determine intra- and inter-tow packing densities.

Significance:
3-D braided composites have apparent advantages for use in spacecraft structures. These include near net shape, high energy absorption, and absence of delamination. The difficulty of characterizing and modeling these materials has prevented development of design procedures.

Future Plans:
Development of quantitative models for micro-failure mechanisms for use in computation and as a bridge to macro-scale behavior.

Publications:
None to date.

TABLE 1. Energy release rates of 3-D braid composites for notched compact tension specimens.

I. D.	Load	Crack Extension	Area Method: Loop Area	Area Method: G	Compliance Method: dC/dA	Compliance Method: G
1	156 N	2.61 mm	6.33×10^{-3} J	808 Jm^{-2}	4.45 N^{-1}	1805 Jm^{-2}
2	120	2.52	3.88	513	2.87	688
3	142	2.73	6.76	825	4.56	1532
4	116	4.03	9.71	803	3.61	810
5	111	.50	7.32	1627	6.99	1435
6	125	2.88	12.09	1399	6.56	1708
7	147	3.07	13.03	1443	6.32	1916

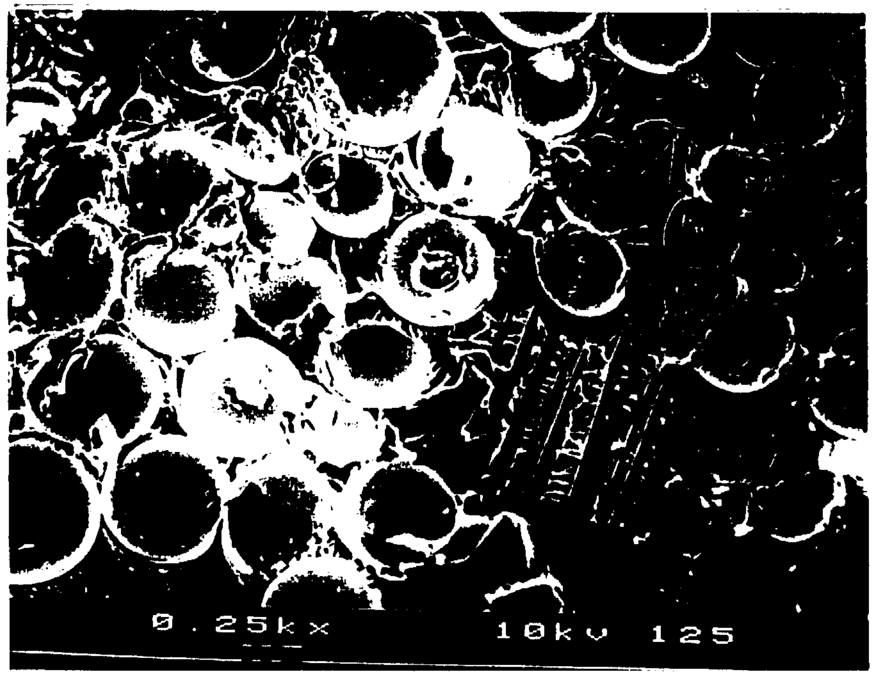


Figure 1. Microballoons used to reduce matrix brittleness.

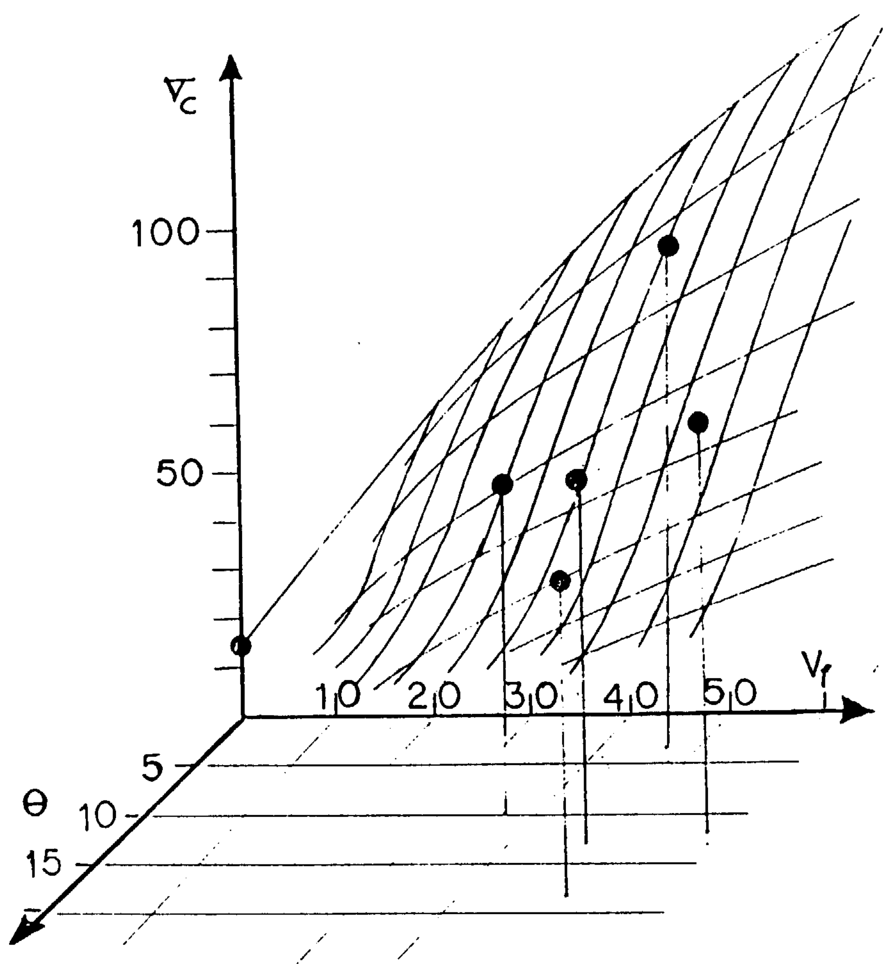


Figure 1. Compression failure stress, σ_c (psi) as a function of the principal braiding angle, Ø, and the fiber volume

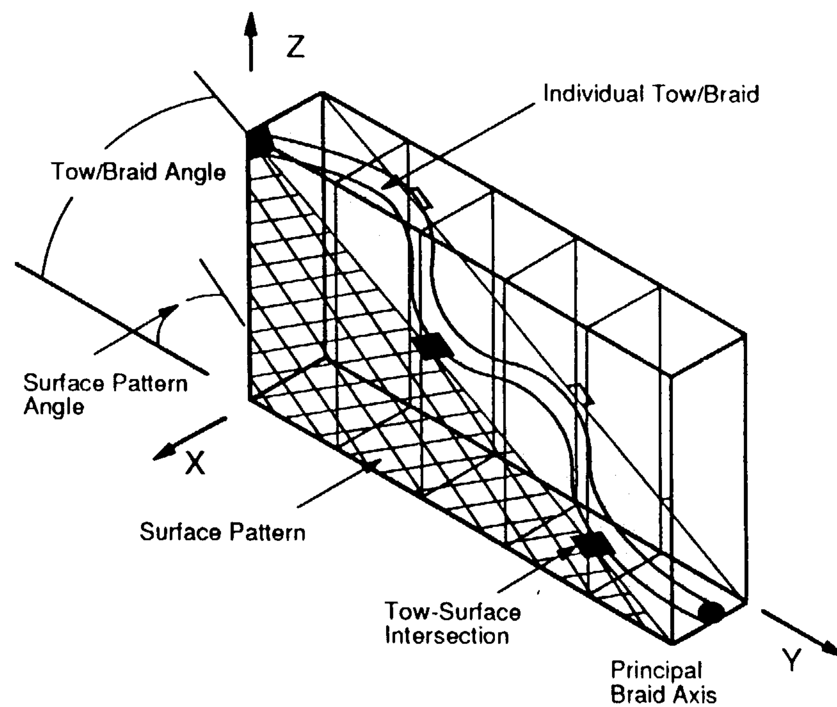


Figure 2. Surface - Volume mapping of 4 - step V_f.braid composite.

Fracture Toughness of 3-D Braid Composites

G. J. Filatovs, Principal Investigator
Co-Investigator: Bagher Bagherpour
Department of Mechanical Engineering
North Carolina A & T State University

Research Objectives:
Determination of the fracture behavior, notch sensitivity, and the feasibility of applying fracture mechanics methodology to 3-D braid reinforced carbon/epoxy composites.

Approach:
Side notched compact tension specimens were used and three data reduction techniques employed. Complementary optical and scanning electron microscopy evidence were used to identify failure controlling microstructural features.

Accomplishments:
Specimen geometries and testing procedures have been developed to measure the crack initiating force for various notch orientations. This force has a two/one ratio depending whether the notch is parallel or perpendicular to the braid axis. A qualitative understanding of the fracture characteristics and a quantitative estimate of the critical energy release rate to initiate cracking have been determined. The influence of anisotropy and symmetry have been studied. The early stage energy absorbing mechanisms, and their sequence, have been identified. The tendency of braided composites to diffuse the damage over a wide volume makes unscrambling the contributions of specific mechanisms difficult. To reduce the effect of large volumes of brittle matrix, microballoons have been used as crack path deflectors. Preliminary results appear promising.

Significance:
Fracture mechanics parameters are necessary for any quantitative design with braided composites.

Future Plans:
Develop specimens and testing methodology which will provide more detailed information about specific deformation mechanisms and energies and will allow the stress-intensity and J-integral approaches. These are more useful for design. The energy absorption in later stages of cracking are important, and a method to determine the R-curve will be investigated.

Publications:
None to date.

Joining of 3-D Braid Composites

G. J. Filatovs, Principal Investigator
Co-Investigator: Kevin Davie
Department of Mechanical Engineering
North Carolina A & T State University

Research Objectives:
Develop methods of joining and attachment for 3-D braided composites. The introduction of loads into these materials raises the issues of load concentration, clamp-up, and load distribution. The project investigates methods of joining and attachment and to study the material response from a micromechanics viewpoint.

Approach:
Test coupons, tubes, and small components using commercial aircraft fasteners and fabricated joints. It is anticipated that a hybrid method involving braids, conventional laminates, and metal inserts will be required to be required.

Accomplishments:
Learning specimens have been fabricated and tested; raided tubes with filament-wound overlayers have been fabricated, as have node joints with inserts. Pull-out and shear-out tests have been made on braided coupon and T-sections. We have gained an intuitive sense of the material behavior and have some provisional data on bolt hole behavior.

Significance:
In addition to the need to fasten braided materials, their toughness and energy absorption may be advantageous for components such as attachments and in high impact areas. It is also important to study braided composites under realistic, and complex, load conditions.

Future Plans:
Continuation of ongoing research as outlined above.

Publications:
None to date.

Braid Strength Analysis

Ray Foye, Principal Investigator
Department of Mechanical Engineering
North Carolina A & T State University

Research Objectives:
Analytical models of braid reinforced composites have already predicted the principal linear elastic design constants but have yet to be successfully applied to static strength prediction. The objective of this work is to develop a math model of braid strength mechanisms for the purpose of predicting static strength of the material.

Approach:
Conventional laminate analysis is insensitive to most observed braid failure mechanisms. Unit cell analyses are complex and unproven for strength prediction. A simpler model is needed which predicts all the observed failure phenomenon, cut edge effects, specimen size effects, tow size effects, open hole effects, and notch effects, as well as, braid geometry and constituent material property effects. Such a model is presently being developed based on a lattice beam element attached to similar adjacent elements by sets of discrete mechanical springs which model the interstitial matrix functions. The resulting analysis resembles that of a finite length beam on discrete shear, tension and moment spring supports.

Accomplishments:
The programming of this analysis is in progress.

Significance:
No composite structural element design program can function well without good material strength prediction capabilities. This has been a major drawback in space and land based design studies to date. This analysis will fill this need for braided structure.

Future Plans:
This analysis will be extended to other fabric reinforced composites and will fill a much needed vacancy in the composite truss design/analysis study.

Publications:
None to date.

Thermal Property Prediction

Ray Foye, Principal Investigator
Department of Mechanical Engineering
North Carolina A & T State University

Research Objectives:
The objective of this task is the estimation of the various coefficients of thermal expansion for fabric reinforced composites.

Approach:
Several earlier methods for predicting the coefficients of expansion of fabric reinforced composites exist but lack the generality necessary to apply them to a wide range of fiber reinforcing geometries. The present work is very general and is based on the "unit cell" model of the composite microstructure which usually contains one repeat of the fabric design pattern. The analysis is based on 3-D finite elements which subdivide the unit cell structure into smaller subcells. In this analysis, the subcell boundaries need not correspond to constituent material boundaries. The subcells are usually chosen to be physically meaningful units, such as, a warp/fill crossover in a weave. The application of a single thermal load case to the unit cell model establishes all six coefficients of expansion. Experimental correlation is obtained for various different graphite/epoxy weave geometries.

Accomplishments:
A very general computer analysis program has been written that predicts all the 3-D coefficients of thermal expansion for fabric reinforced composites. Experimental correlation has been obtained.

Significance:
Thermoelastic property prediction is basic to composite use in all space applications and essential to predicting thermal stresses, residual curing stresses and creep response.

Future Plans:
These analyses will be simplified and incorporated into the composite truss design program.

Publications:
None to date.

Effects of Voids & Fillers on Fabric Reinforced Composite Properties

Ray Foye, Principal Investigator
Department of Mechanical Engineering
North Carolina A & T State University

Research Objectives:
The objective of this work is the analytical prediction of the changes in some of the thermoelastic properties of a fabric reinforced composite as a result of introducing interstitial voids and fillers in the bulk matrix. The analysis is applicable to a broad range of design problems related to composite struts and secondary structural elements of Mars Mission vehicles.

Approach:
Secondary structural elements which are cured in the space environment may be expected to have larger void contents than normal. These may be needed in the repair or rework of truss structure. Also, interstitial matrix material is known to contribute to weight inefficiency in stiffness critical designs. Adding voids or microballoons to the interstitial matrix can reduce composite element weight. The present unit cell analysis is sensitive to microballoon content and sphere wall thickness, as well as, mechanical properties of the materials. The analysis consists of two stages. The first stage predicts the reduced moduli of the voided or filled interstitial matrix. The second stage predicts the effect of these bulk matrix property changes on the composite thermoelastic properties.

Accomplishments:
A computer analysis method has been established for predicting the effects of interstitial matrix voids and fillers on the various elastic moduli and coefficients of thermal expansion of fabric reinforced composites.

Significance:
This analysis will provide guidance for the corresponding experimental work at North Carolina A & T State University related to fabrication and testing of braids with filled resins. These relate to truss and secondary structural design.

Future Plans:
Parameter studies on the effects of various void and filler contents on a few chosen fabric reinforced microgeometries relevant to the Mars Mission vehicle will be conducted.

Publications:
None to date.

Composite Truss Member Design

Ray Foye, Principal Investigator
Department of Mechanical Engineering
North Carolina A & T State University

Research Objectives:
The objective of this work is to provide a program for minimizing structural weight and maximizing the critical safety margin for individual composite truss members.

Approach:
A computer program was written that presents graphically the results of changing fiber orientation angles and tube diameter on composite truss member design. The critical margins of safety from stress, stiffness and stability analyses are plotted for each incremental design change. The optimum design can be observed visually. This approach permits the design selection process to consider all forms of constraints, such as, lack of an adequate data base or cost and manufacturing considerations that are ignored in mathematical optimization routines.

Accomplishments:
A structural design program has been written which optimizes an individual truss member configuration and bridges the gap between aeroshell hardware and materials analysis work.

Significance:
Many examples of truss member design were considered. Load and stiffness requirements were taken from prior aeroshell truss design studies. Modest savings in the weight of tension members were realized. Large savings were realized in compression members. Reorienting fibers had much less effect on truss weights than tube diameter changes. Average weight savings were in the 10 to 15% range with over 30% savings in some highly loaded compression members.

Future Plans:
As improved analytical predictions are developed in the areas of moduli, static strength, thermal properties, loads analysis, environmental effects, buckling, crippling analysis, and fatigue analysis, they will be incorporated into this design program which serves as a focal point for other materials analysis work.

Publications:
None to date.

Automation of 3-D Braiding

Aly El-Shiekh, Principal Investigator
Co-Investigators: Wei Li, Mohamed Hammad, Rona Reid
Textile Engineering
North Carolina State University

Research Objectives:
The objective of this work is to automate the 3-D braiding process to allow the production of preforms that are uniform, reproducible, and economical.

Approach:
Established braiding techniques are presently processed manually, allowing variability in the preforms. By designing a computer controlled braiding and converging or beat up system, the problems of variability can be solved. In addition, the process can be made more efficient with the addition of continuous supply carriers.

Accomplishments:
The 3-D braiding group has made numerous advances in the area of machine development with the design and construction of the laboratory scale models listed below.

- a fully automated 4-step, 3-D braider with mechanical beat up capability
- a fully automated 4-step, 3-D braider with mechanical beat up and continuous supply carriers
- a semi automated 4-step, 3-D braider with 4000 end capacity
- two semi automated 4-step circular braiders, one with 330 end capacity and one with 2300 end capacity
- a fully automated 2-step 3-D braider with continuous supply carriers
- a circular 2-step braider (automation in progress)
- a new and novel 6-step braider (automation in progress and a patent is being prepared)
- a fully automated filament winder

In addition to the development of laboratory scale models, the group has purchased a 192 carrier triaxial braider (the largest in the U.S.) for future studies.

Significance:
Through this work, a Variable Retraction Carrier was developed. A patent was applied for and is pending .

Future Plans:
The future in machine development will include the upgrading and development of new computer controlling systems as well as the optimization of mechanical converging systems.

Publications:
Li, W., and El-Shiekh, A., "The Effect of Process and Processing Parameters on 3-D Braided Preforms for Composites," *SAMPE Quarterly*, Vol. 19, No. 4, July 1988.
Li. W., Hammad, M., and El-Shiekh, A., "On the Mechanics of 3-D Braiding: Process Automation," High-Tech Fibrous Materials, American Chemical Society Symposium Series 457, Miami, FL, Sept. 1989.
Li, W., Hammad, M., and El-Shiekh, A., "Automation and Design Limitation of 3-D Braiding Processes," Fiber-Tex '89 Conference, Greenville, SC, Oct. - Nov. 1989, pp. 115-140.

Structural Geometry of Cartesian 3-D Braided Preforms for Composites

Aly El-Shiekh, Principal Investigator
Co-Investigator: Wei Li
Textile Engineering
North Carolina State University

Research Objectives:
The objective of this project is to determine the structural geometry of cartesian 3-D braided preforms and the relationship between geometric parameters and preform properties.

Approach:
The microstructure of cartesian 3-D braided composites was determined through the use of experimental models.

Accomplishments:
Based on the actual yarn paths and interlacing patterns, geometric relationships between the structural parameters were developed. Equations were developed to predict the critical jamming condition, maximum orientation angle, and the fiber volume fraction. The effect of machine operating parameters on preform properties was observed experimentally and compared to theoretical predictions.

Significance:
By establishing the effect of geometric parameters, the ability to predict preform properties and design preforms can be improved.

Future Plans:
As soon as a suitable student is identified, the work in this area will be continued using a model which incorporates actual tow shapes - rectangular shapes instead of the circular shapes used in the above analysis.

Publications:
Li, W., Kang, T., and El-Shiekh, A., "Structural Mechanics of 3-D Braided Preforms for Composites, Part 1: Geometry of Fabric Produced by 4-Step Process," Fiber-Tex '87 Conference, Greenville, SC, *NASA Conference Publication 3001*, Nov. 1987.
Li, W. and El-Shiekh, A., "Structural Mechanics of 3-D Braided Preforms for Composites, Part 2: Geometry of Fabric Produced by 2-Step Process," Fiber-Tex '88 Conference, Greenville, SC, *NASA Conference Publication 3038*, Sept. 1988.

Damage Tolerance After Impact

Aly El-Shiekh, Principal Investigator
Co-Investigator: Wei Li, Mohamed Hammad, Rona Reid
Textile Engineering
North Carolina State University

Research Objectives:
The objective of this work is to experimentally determine the effect of the preform unit cell size on the impact damage tolerance of 3-D braided composite materials.

Approach:
The specimens were prepared using both the 4-step and the 2-step braiding processes. The different unit cell sizes were achieved through a variation in the tow size and the operating conditions. After being impacted under a controlled impact energy, the damage areas on the specimens were studied. Specimens were then subjected to compression testing to evaluate the compressive strength after impact.

Accomplishments:
Results revealed that the unit cell size of the braided preform plays a significant role in affecting the impact damage tolerance of 3-D braided composite materials. This investigation indicates that, in general, the shorter the pitch length, the higher the impact damage tolerance. Similarly, smaller tow sizes yield smaller damage areas. Thus, it is suggested that the smaller the unit cell size, the higher the damage tolerance.

Significance:
The probability of a space craft colliding with space particles and debris has been established, with one aspect of the problem being investigated through the Orbiter Ejector Project. Therefore, there is a need to design materials that can impact with space debris and still be functional. Thus, any knowledge of the damage tolerance of proposed materials is essential to the selection and design of aeronautical materials.

Future Plans:
A more detailed investigation is required to assess the effect of the unit cell size quantitatively. This investigation should also include the compressive strengths of the specimens in the lateral direction.

Publications:
Li, W., Hammad, M., and El-Shiekh, A., "Effect of Braiding Process on the Damage Tolerance of 3-D Braided Graphite/Epoxy Composites," *Proceedings of 34th International SAMPE Symposium*, Reno, Nevada, May 1989, pp 2109-2117.
Li, W., Hammad, M., Reid, R., and El-Shiekh, A., "The Effect of Unit Cell Size on Impact Damage Tolerance of 3-D Braided Graphite/Epoxy Composites," International Conference on Composite Materials - VII, Beijing, China, August 1 - 4, 1989.

Development of a 10 Axis Single Tow Laying Process

Aly El-Shiekh, Principal Investigator
Co-Investigators: Wei Li, Pusheng Chen
Textile Engineering
North Carolina State University

Research Objectives:
The objective of this project is to develop a computer controlled tow laying machine to produce multilayer composites.

Approach:
As a feasibility study for Lawrence Livermore National Laboratory, a 10 axis automatic fiber tow laying machine was developed to produce layered wedges with varying fiber orientations.

Accomplishments:
A 64 layer wedge has been produced on this system and consolidated successfully.

Significance:
The development of an automated tow laying machine will considerably reduce the amount of waste associated with hand laid laminates. Furthermore, with reliable computer programs, this machine will eliminate the human errors possible during the stacking sequence.

Future Plans:
The system is being modified to incorporate tow laying on concave and convex surfaces as well as laying contour shaped structures.

Publications:
None to date.

Structural Geometry of Circular 3-D Braided Preforms for Composites

Aly El-Shiekh, Principal Investigator
Co-Investigator: Mohamed Hammad
Textile Engineering
North Carolina State University

Research Objectives:
The objective of this project is to develop mathematical relationships between machine and preform parameters.

Approach:
Geometric relationships were developed based on the idealized structural models for tubular structures.

Accomplishments:
Equations relating the structural parameters were developed. Theoretically predicted effects of machine variables were experimentally verified.

Significance:
By establishing the effect of geometric parameters, the ability to predict preform properties and design preforms can be improved.

Future Plans:
After the identification of a suitable student, the investigation will continue with the incorporation of real tow cross sections into the above analysis.

Publications:
Hammad, M., Li, W., and El-Shiekh, A., "Structural Mechanics of 3-D Braiding Preforms for Composites, Part 3: The 2-Step Circular Braiding," ASME 109th Winter Annual Meeting, Chicago, Illinois, Nov. - Dec. 1988.
Hammad, M., El-Messery, M., and El-Shiekh, A., "Structural Mechanics of 3-D Braided Preforms for Composites, Part 4: The 4-Step Tubular Braiding," 36th International SAMPE Symposium, Vol. 36, April 1991, pp. 114-128.

Strength of Bolted Composite Joints

Aly El-Shiekh, Principal Investigator
Co-Investigators: Rona Reid and Wei Li
Textile Engineering
North Carolina State University

Research Objectives:
The objective of this work is to determine which of three hole formation techniques - cutting a hole, opening a hole, or braiding a hole - produces composite materials with the best bearing behavior.

Approach:
Coupons were made using each of the hole formation techniques and subjected to separate tensile and compression tests, with the load being applied to the bolt hole. The resulting bearing strength was calculated, and the averages for each hole formation were compared.

Accomplishments:
A preliminary investigation of the bearing behavior has been completed. Upon review of the results, the study is being repeated to verify the findings with larger sample sizes. In the second phase of the investigation, two groups of coupons are being tested; the first with a w/d of 2 and the second with a w/d of 5.

Significance:
A great number of space craft components are mechanically joined, specifically using rivets or bolts. With 3-D braided composites being considered for components, it is necessary to have a better understanding of the effect of mechanical joining techniques on their properties. This study not only creates a basis for property prediction, but also gives insight as to which hole formation technique is best suited for Mars Mission Materials.

Future Plans:
Experiments are currently in progress to verify the results of the preliminary study. In addition, other joint designs are being considered for production by this laboratory.

Publications:
Li, W., Hammad, M., Reid, R., and El-Shiekh, A., "Bearing Behavior of Holes Formed Using Different Methods in 3-D Braided Graphite/Epoxy Composites," 35th International SAMPE Symposium, Anaheim, California, April 1990, pp. 1638-1646.
Reid, R. and El-Shiekh, A., "An Investigation of the Bearing Behavior of Single Bolt Holes in 3-D Braided Graphite/Epoxy Composites," 7th Yugoslav Conference on Fibre Reinforced Polymer Composites, Zagreb, Yugoslavia, September 25 - 26, 1991.

Strength of Carbon/PEEK Composites

Aly El-Shiekh, Principal Investigator
Co-Investigator: Thomas Fetner
Textile Engineering
North Carolina State University

Research Objectives:
The objective of this project was to assess the effect of PEEK distribution on the mechanical properties carbon/PEEK composites.

Approach:
Thermoplastic materials, such as poly (ether ether ketone) or PEEK, are being used extensively as matrices for composite materials. One concern with the use of thermoplastics is the ability to evenly distribute the matrix material to produce high quality composites. Thus, this investigation focused on the effect of varying PEEK distribution through four arrangements - commingled carbon/PEEK tow, plied carbon/PEEK tow, separate carbon and PEEK braiding tracks, and alternating carbon and PEEK braiding tracks.

Accomplishments:
The four types of coupons were consolidated, with strength assessment through four point bending. Load-deflection curves imply that the best PEEK distribution, and thus the best composite, were accomplished through the use of commingled carbon/PEEK tow.

Significance:
By establishing the best arrangement for optimum PEEK distribution, quality thermoplastic composites can be produced.

Future Plans:
Future work should include microscopic evaluation of PEEK distribution and continued mechanical testing.

Publications:
None to date.

Characterization of Voids Using Scanning Acoustic Microscopy (SAM)

Aly El-Shiekh, Principal Investigator
Co-Investigator: Donna Downs
Textile Engineering
North Carolina State University

Research Objectives:
The objective of this project is to develop nondestructive evaluation methods for composite materials using the Scanning Acoustic Microscopy.

Approach:
A number of nondestructive test methods are being used to evaluate composite materials. One possibility is the use of Scanning Acoustic Microscopy (SAM) to determine the void content in composite materials. Starting with the evaluation of control materials of known porosity, methods can be developed to assess the porosity of composites, developing a nondestructive method of assessing the void content of a composite.

Accomplishments:
Methods have been developed to use SAM to evaluate the surface characteristics of materials.

Significance:
SAM can provide both surface and internal images of composite materials with little or no sample preparation. This technique can be used to pinpoint defects or problem areas within the larger composite part.

Future Plans:
Developments in data interpretation for the subsurface of control materials is needed in order to use SAM to investigate the internal porosity of composites.

Publications:
Downs, D., El-Shiekh, A., Russ, J., and Tucker, P., "Characterization of Composites by Acoustic Microscopy," *Proceedings of the 1989 Annual Meeting of the Electron Microscopy Society of America*, San Antonio, Texas, Aug.1989.
Downs, D., El-Shiekh, A., Russ, J., and Tucker, P., "A Study on Composites Damage Using Acoustic Microscopy," *Proceedings of the EMAG-MICRO'89* - The Future of Microscopy, Sept. 1989, The Royal Microscopy Society, Oxford, England.

Effect of Axial Distribution and Percentages on 3-D Braided Carbon/Epoxy Composites

Aly El-Shiekh, Principal Investigator
Co-Investigator: Cirrelia Thaxton
Textile Engineering
North Carolina State University

Research Objectives:
The objective of this project is to develop a braided structure which optimizes the use of axial fibers.

Approach:
To optimize the use of axials in 3-D braided composites, coupons with various axial distributions and percentages will be tested to assess the effect of axial distribution and percentage on the mechanical properties of composite materials.

Accomplishments:
Preform and composite production is currently underway.

Significance:
Uniaxial tows are often included in textile structural composites to improve the tensile and compressive strengths. A better understanding of the effect of axial distribution will improve the design capabilities.

Future Plans:
After the mechanical evaluation of braids with uniaxial tow, a similar assessment will take place for the 6-step structure incorporating 3-D braiding and the xyz structure.

Publications:
None to date.

Compressive Strength of Multilayer Carbon/Epoxy Composites

Aly El-Shiekh, Principal Investigator
Co-Investigator: Pusheng Chen
Textile Engineering
North Carolina State University

Research Objectives:
The objective of this project is to assess the efficiency of a recently developed tow laying machine through the mechanical evaluation of the laminates produced.

Approach:
Using the tow laying machine developed for Lawrence Livermore National Laboratory, an experimental investigation is being undertaken to automatically lay a 12 layer composite with fiber orientations of $90°$ and $\pm 45°$ to be tested for compressive strength.

Accomplishments:
Samples are being produced and will be tested shortly.

Significance:
A major cost in the production of laminates is the amount of waste material. These experiments will prove that the same quality composite can be made with a cost reduction through waste reduction.

Future Plans:
A comparable system will be laid by hand to compare the efficiency and reliability of the automatic tow laying system.

Publications:
None to date.

Computer Modeling of 3-D Braided Preforms for Composites

Aly El-Shiekh, Principal Investigator
Co-Investigator: Jian Li
Textile Engineering
North Carolina State University

Research Objectives:
The objective of this research is to develop a computer program to model 3-D braided preforms.

Approach:
The development of computer models of textile preforms, essential to the design of materials for composite structures, will be based on real preforms. This will be accomplished through a newly initiated project.

Significance:
Through the development of three dimensional models relating preform structure to composite properties, the ideal preform can be designed for each end use as well as making the design of hybrid preforms easy.

Publications:
None to date.

Strength of Machined Threads in 3-D Braided Carbon/Epoxy Composites

Aly El-Shiekh, Principal Investigator
Co-Investigator: Keith Black
Textile Engineering
North Carolina State University

Research Objectives:
The objective of this project is to determine the strength of threaded holes in 3-D braided composite materials.

Approach:
The experiments undertaken will design different preform geometries with different tow sizes and fiber volume fractions, cut and thread the holes, and measure the force required to pull a bolt from these structures.

Accomplishments:
The preliminary results show that composites in the form of a .125 inch thick panel have a pull out strength comparable to that of 6061 aluminum of the same thickness.

Significance:
One of the most important space structures is space joints which have many threaded points. Thus, to develop a successful joint configuration using 3-D braids, a study of the strength of threads in carbon/epoxy composites is essential.

Future Plans:
This work will be at full course during the summer when Mr. Black joins us as a full time graduate student.

Publications:
None to date.

Fiber-Volume Fraction Determination of Carbon-Epoxy Composites

Shamsuddin Ilias, Principal Investigator
Co-Investigators: Mike Siegel, Sonya Drumgoole and Jelvoner Ellison
Department of Chemical Engineering
North Carolina A&T State University

Research Objectives:
To provide reliable data on fiber-volume content of carbon-epoxy composites.

Approach:
The fiber/matrix ratio determination of carbon-epoxy composite is essentially based on the ASTM Methods D-3171 and D-792. The Method D-792 is used to determine the density of the specimen by a liquid displacement technique. The Method D-3171 consists of digesting the resin portion of a weighted composite specimen in HNO3 (Nitric acid, 70% soln) at 75^{o}C. The residue is filtered, washed, dried, and weighed. The weight percent of fiber can be converted to volume percent if the fiber density is known. A correction for the weight loss of fiber may be made by running acid digestion of fiber (blank).

Accomplishments:
We have analyzed fifteen composite samples by digestion. The samples were prepared under controlled environment, and the resin and fiber contents were predetermined. These samples were analyzed for fiber-resin contents by acid digestion. A comparison of the wt. % of the fiber content of the samples with that obtained after digestion is shown in Figure 1. A close look in Figure 1 reveals that after digestion there is a loss in fiber in the sample. This is expected. An estimate of this loss may be established by running blank digestion test. This will enable us to correct fiber content of the sample. Furthermore, usually fibers are coated with some organic film for protective purpose, which is also digested in the acid digestion. The blank test will also account for this loss of coating. Blank digestion of carbon fibers of two types of coating have been performed. The percent loss of fiber for various sample sizes is shown in Figure 2. It appears that the loss of fiber during acid digestion is in the range of 0.5% for EPO6 finish fibers and 1.00% for EPO3 finish fibers. This loss of fibers appears to be insignificant and thus, for unknown composite samples, a correction for fiber loss will not be of any significant importance.

Significance:
The fiber content of a composite must be determined to calculate the apparent strength and modulus of the reinforcing fibers in composite. It may be further used to evaluate the quality of a given specimen.

Future Plans:
We plan to continue the acid digestion of composite resin-fiber samples as required by the fabrication and materials group's research.

Publications:
None to date.

From this sample digestion, it appears that the estimate of the fiber content before and after digestion is consistent and a statistical correlation may be obtained from a set of digested sample.

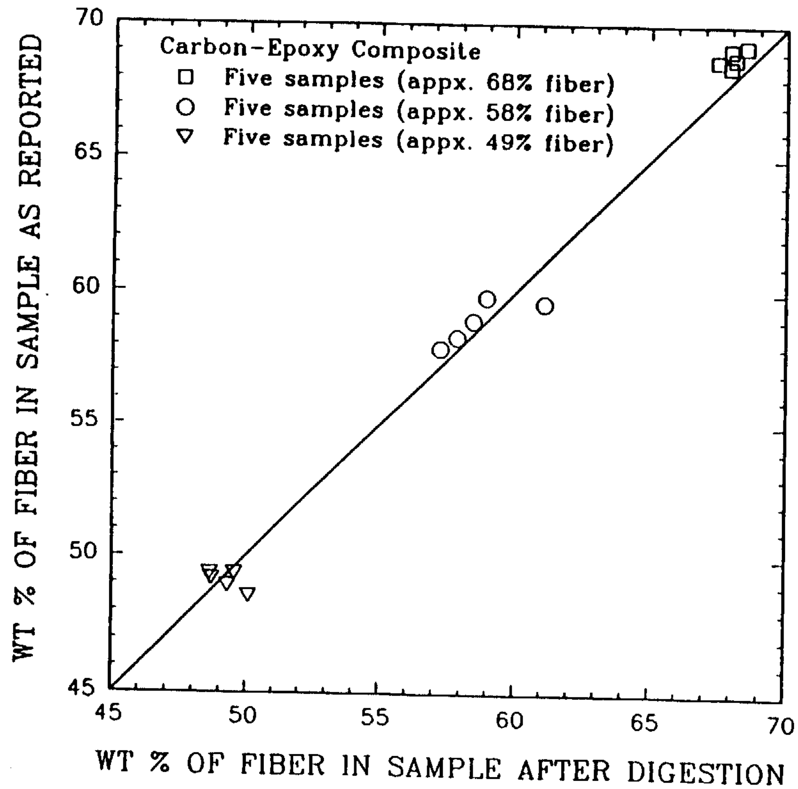


Figure 1: Comparison of the wt. % of fiber in actual sample and that obtained after acid digestion.

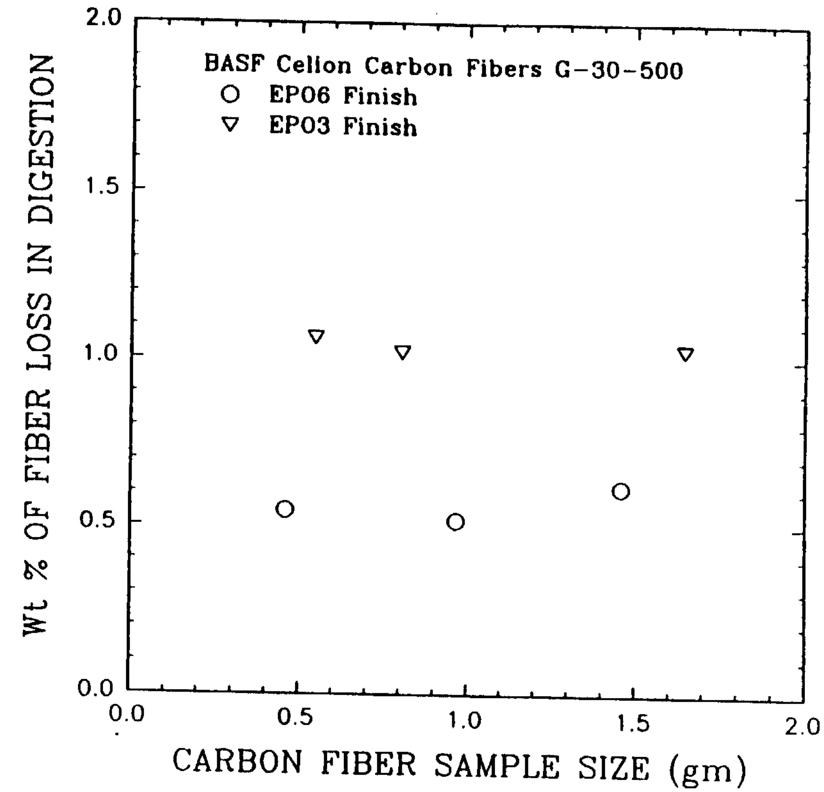


Figure 2: Wt. % of fiber loss in blank digestion of carbon fibers with EPO3 and EPO6 finishes.

3-D Weaving for Structural Composites

Mansour H. Mohamed, Principal Investigator
Co-Investigators: Cheryl Carlson, Pu Gu, and Elsaid Salem
Textile Engineering, Chemistry, and Science
North Carolina State University

Research Objectives:
The objectives of this work are:
(1) To develop 3-D weaving technology and machines for the manufacture of 3-D integrated preforms for structural composites
(2) To explore different composite consolidation techniques and different fiber and matrix materials
(3) To compare between 3-D woven and other preforms in order to maximize their specific properties
(4) To develop a data base which can be used to design appropriate structures for a space craft

Approach:
A new process of weaving 3-D net shapes has been developed and two machines were designed and built. The process involves simultaneously inserting a number of filling yarns between stationary layers of warp yarns. This assembly is then held together by means of the third direction yarns (the Z-yarns).

Accomplishments:
Of the two machines built, the first proto-type has four harness frames for moving the z-yarns and, thus, is only capable of weaving 3-D orthogonal structures. Preforms up to 8 inches wide and 1.5 inch thick with practically no limitation on length can be woven. The second machine can produce preforms up to 10 inches wide. In addition, the use of an electronic jacquard head on the second machine enables the production of structures other than orthogonal, as well as weaving of holes and slots. This will eliminate the need to machine the composites and thus enhance their properties. Both machines are pneumatically operated and computer controlled.

Straight and stiffened panels have been produced. Several composites using carbon fibers and different types of matrix materials have been produced and tested. The results of compression tests before and after impact, comparing composites produced with our preforms and other types of preforms, showed the superior performance for our preforms.

U.S. Patent No. 5,0851,252 for the developed technology was issued on February 4, 1992. Patent application in Japan, as well as protection in Europe, Canada, and South Korea have also been filed.

The use of intermingled carbon/PEEK yarns has been successfully tried. A study of the influence of consolidation parameters on the bending and tensile behavior of carbon/PEEK composites has been completed.

A new structure produced by the combination of 3-D weaving and 2-D braiding has been disclosed and is under investigation. The disclosure has been approved by the University Intellectual Property Committee for patent application.

Significance:
The developed process of 3-D weaving adds a new dimension to the technology of weaving preforms for structural composites needed in various space applications. Interest on the part of the German Aerospace Company, MBB and the Japanese company, Nippon Oil indicates the importance of this development. After funding a small joint research project, MBB has entered into negotiations with North Carolina State University to develop a wide prototype 3-D weaving machine under a contract for $200,000.

Future Plans:

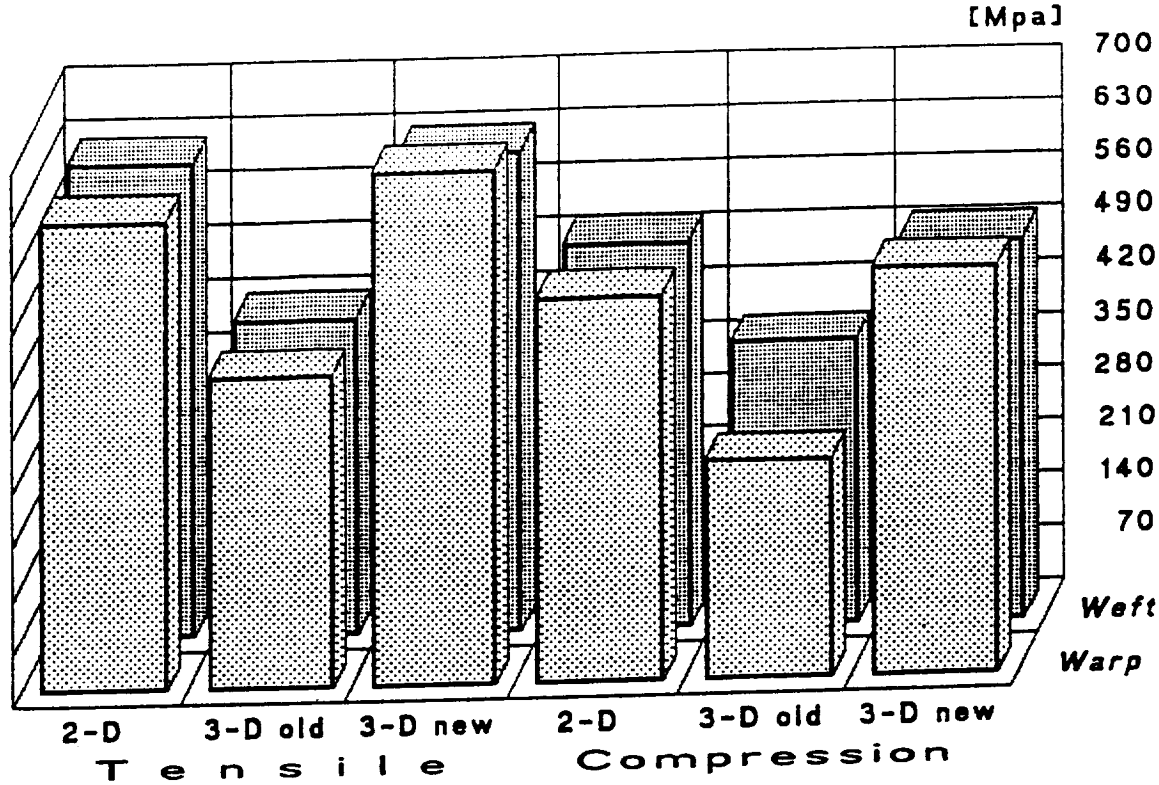
Future work includes the following areas:

(1) Continued development of the 3-D weaving machines to increase the range and size of the structural components which can be produced,
(2) Application of high modulus carbon fibers in all three directions in the preforms
(3) Study of variations in the fiber architecture by using combination of fiber placement techniques
(4) Continue the investigations on matrix material, such as thermoplastic fiber and powder, as well as the influence of void content on the properties of the composites

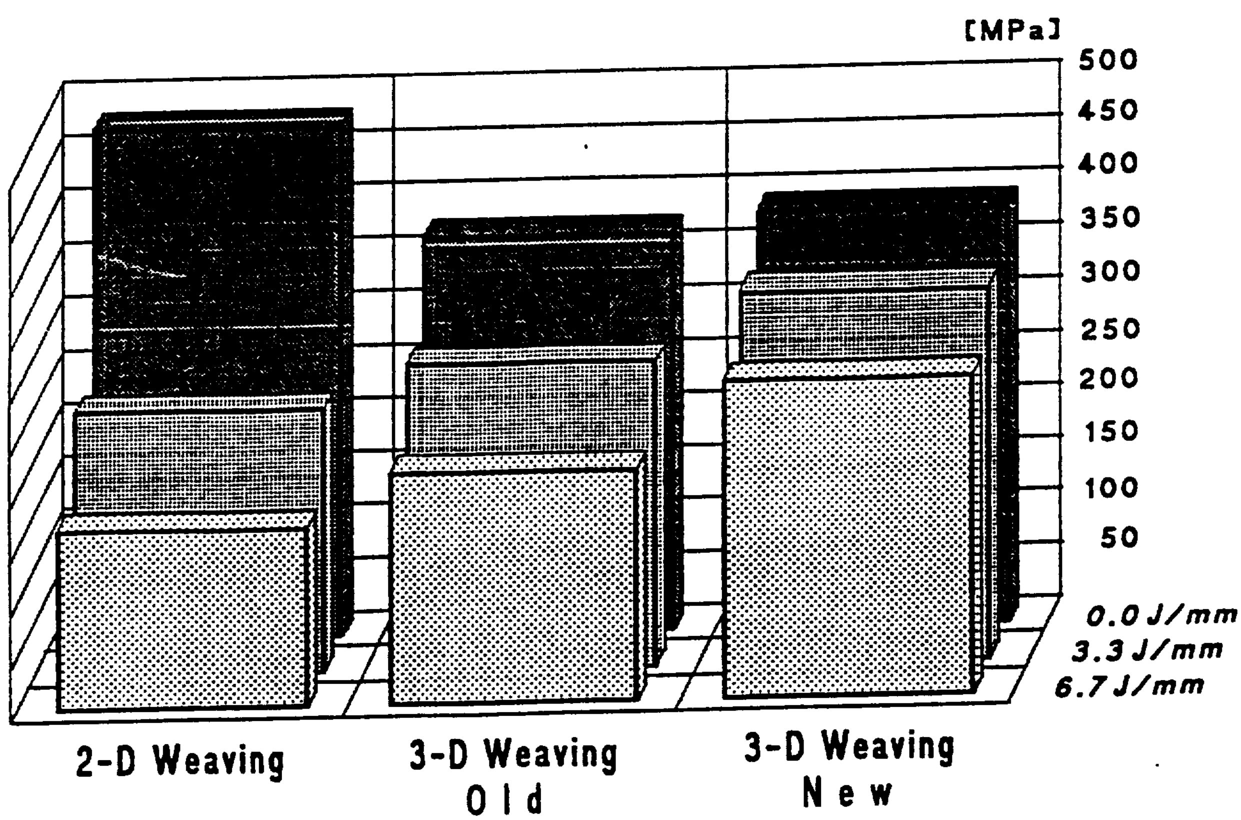
Publications:

None to date.

Tensile and Compression Strength



Compression Strength after Impact



3-D Weaving Machine Development

M. H. Mohamed, Principal Investigator
Co-Investigators: Pu Gu, Elsaid Salem, and Cheryl Carlson
Textile Engineering, Chemistry, and Science
North Carolina State University

Research Objectives:
The object of this work was to develop 3-D weaving technology and machines for the manufacture of 3-D integrated preforms for structural composites.

Approach:
A new process of weaving 3-D net shapes has been developed, and two machines were designed and built. The process involves simultaneously inserting a number of filling yarns between layers of warp yarns. This assembly is then held together by means of the third direction yarns (the Z-yarns).

Accomplishments:
Of the two machines built, the first proto-type has four harness frames for moving the Z-yarns and this is only capable of weaving 3-D orthogonal structures. Preforms of up to eight inches wide and 1.5 inches thick with practically no limitation on length, can be woven. The second machine can produce preforms up to 10 inches wide. In addition to 3-D orthogonal structures, the use of an electronic jacquard head enables the production of structures such as angle and warp interlock, as well as weaving of holes and slots. This will eliminate the need to machine the composites and thus enhance their properties. Both machines are pneumatically operated and computer controlled.

Straight and stiffened panels have been produced. Several composites using carbon fibers and different type of matrix materials have been produced and tested. The results of compression testing before and after impact, comparing composites made with our preforms and other types of preforms, showed superior performance for our preforms.

U.S. Patent No. 5,852,152 for the developed technology was issued on February 4, 1992. Patent application in Japan, as well as, protection in Europe, Canada and South Korea have also been filed.

Future Plans:
Continued development of the 3-D weaving machines to increase the range and size of the structural components which can be produced. Variation in fiber architecture, especially introduction of ±45° fibers, will also be investigated.

Publications:
None to date.

US005085252A

United States Patent [19]

Mohamed et al.

[11] Patent Number: 5,085,252

[45] Date of Patent: Feb. 4, 1992

[54] METHOD OF FORMING VARIABLE CROSS-SECTIONAL SHAPED THREE-DIMENSIONAL FABRICS

[75] Inventors: Mansour H. Mohamed, Raleigh, N.C.; Zhong-Huai Zhang, Shanghai, China

[73] Assignee: North Carolina State University, Raleigh, N.C.

[21] Appl. No.: 574,693

[22] Filed: Aug. 29, 1990

[51] Int. Cl.[5] D03D 41/00; D03D 47/04; D03D 13/00

[52] U.S. Cl. 139/22; 139/11; 139/DIG. 1

[58] Field of Search .... 139/22, 11, 457, DIG. 1, 139/408, 411

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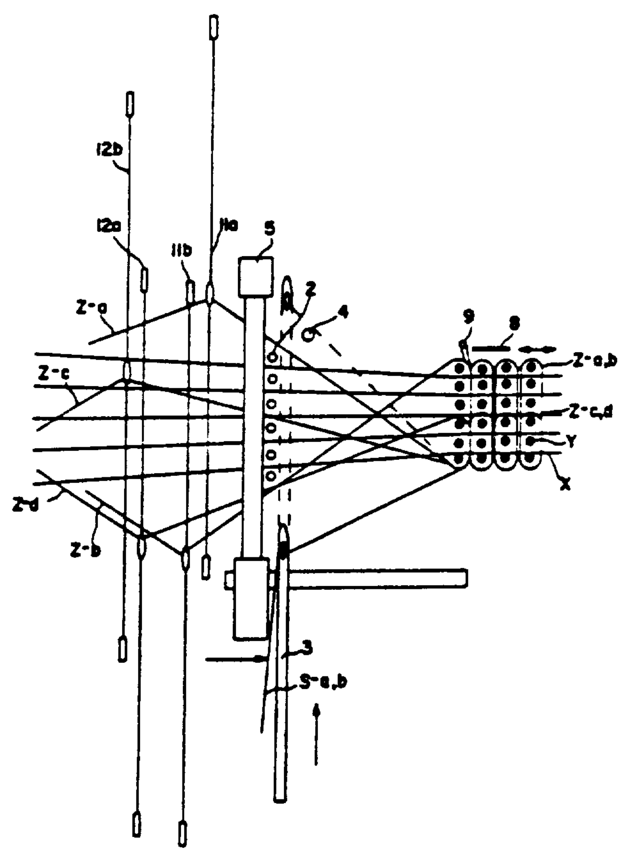
Primary Examiner—Andrew M. Falik

Attorney, Agent, or Firm—Richard E. Jenkins

[57] ABSTRACT

Method of weaving a variable cross-sectional shaped three-dimensional fabric which utilizes different weft yarn insertion from at least one side of the warp layers for selectively inserting weft yarns into different portions of the fabric cross-sectional profile defined by the warp yarn layers during the weaving process. If inserted from both sides of the warp yarn layers, the weft yarns may be inserted simultaneously or alternately from each side of the warp yarn layers. The vertical yarn is then inserted into the fabric by reciprocation of a plurality of harnesses which separate the vertical yarn into a plurality of vertical yarn systems as required by the shape of the three-dimensional fabric being formed.

14 Claims, 10 Drawing Sheets



Microballon Infiltration

M. H. Mohamed, Principal Investigator
Co-Investigators: Cheryl L. Carlson and Bob Sadler
Textile Engineering, Chemistry and Science
North Carolina State University

Research Objectives:
The object of this work is to investigate the influence of adding microballoons to 3-D woven carbon/epoxy composites on the properties of the composites. The addition of microballoons should decrease the density of the material and reduce the occurrence of microcracks in the resin. The fatigue behavior of the final composites will also be investigated.

Approach:
PREFORMS: Woven rectangular cross section 3-D preforms were used. All were approximately 6 inches wide by 0.25 inches thick.

CONSOLIDATION: Three sets of conditions were used:

Sample	Pressure	Time	Temperature	Microballoons
1	low	2 hours	100°C	6.6 wt. % in resin
2	high	3 hours	100°C	3.3 wt. % in resin
3	high	2 hours	100°C	6.6 wt. % in resin

A sample with no microballoons was made at each set of conditions for comparison. The matrix material used was resin Shell Epon 828 and hardener T-403.

Microscopical analysis of cross sections was performed to obtain information about the number and location of voids and microballoons inside the structure.

Accomplishments:
Preliminary work carried out by Randi Muir showed that samples consolidated at low pressure had fewer voids, but the addition of microballoons did not appear to affect penetration of matrix between the fibers. The addition of 6.6% microballoons lowers the density from 1.48 grams/cc to 1.29 grams/cc.

The density of 3-D composites can be decreased by infiltration of microballoons, but high percentages of microballoons and short processing times are required for sufficient infiltration.

Future Plans:
Continue the microscopical examination of samples containing at least 6.6% microballoons followed by testing of mechanical properties of these materials. Variation in the size and type of the microballoons used, as well as the percentage of microballoons in the matrix will also be investigated. Fatigue behavior of the composites will also be tested.

Publications:
None to date.

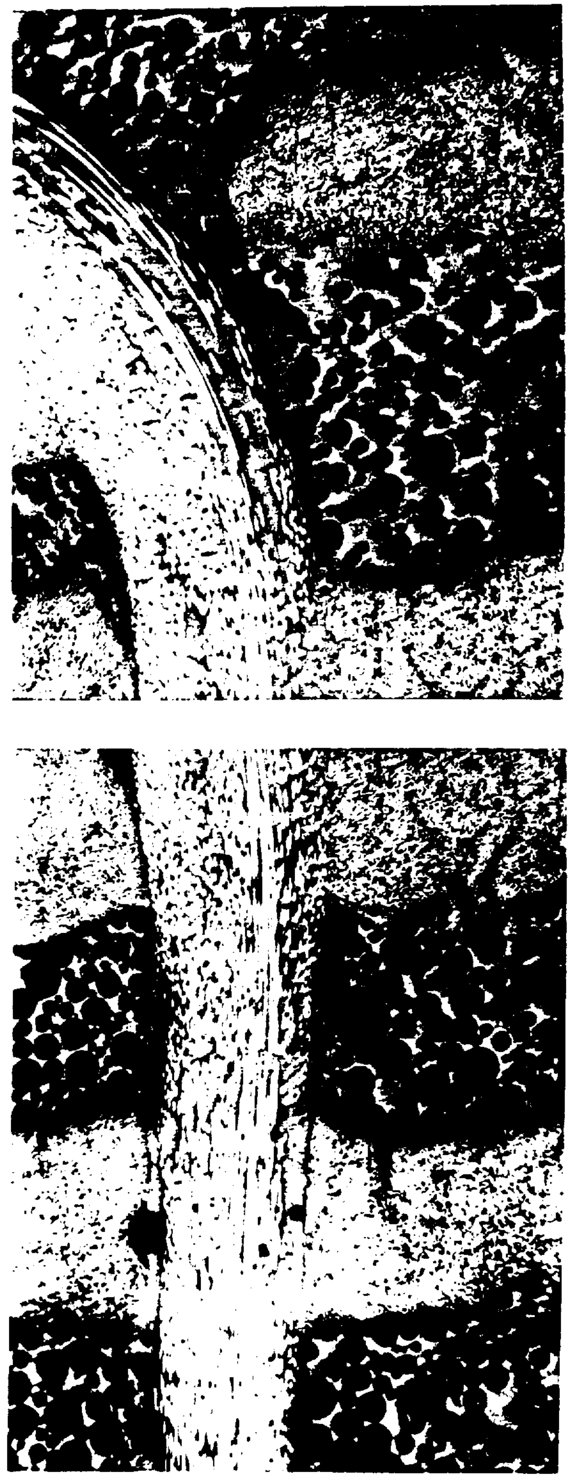


Figure 1: 6.6% Microballoons
Few voids or microcracks present
Microballoons are evenly distributed

Woven/Braided Preforms

M. H. Mohamed, Principal Investigator
Co-Investigators: Elsaid Salem and A. Fahmy
Textile Engineering, Chemistry and Science
North Carolina State University

Research Objectives:
The object of this work is to investigate the influence of adding a layer of 2-D braid on the surface of 3-D woven preforms on bending properties. The addition of the braid increases the number of fiber orientation axes from 3 to 5 which is expected to improve the shear properties of the composite.

Approach:
PREFORMS:

Samples of Woven rectangular cross section 3-D preforms were used as a mandrel for braiding. A 16-yarn 2-D layer was braided on the surface of the preform. The angle of braiding was 45°, providing a -45° and a +45° orientation.

CONSOLIDATION:
The following conditions apply for all samples:

- The consolidation pressure was held constant at 100 PSI.
- Consolidation time was three hours at a constant temperature of 100°C.
- Each sample was left to cure in the mold for 24 hours.

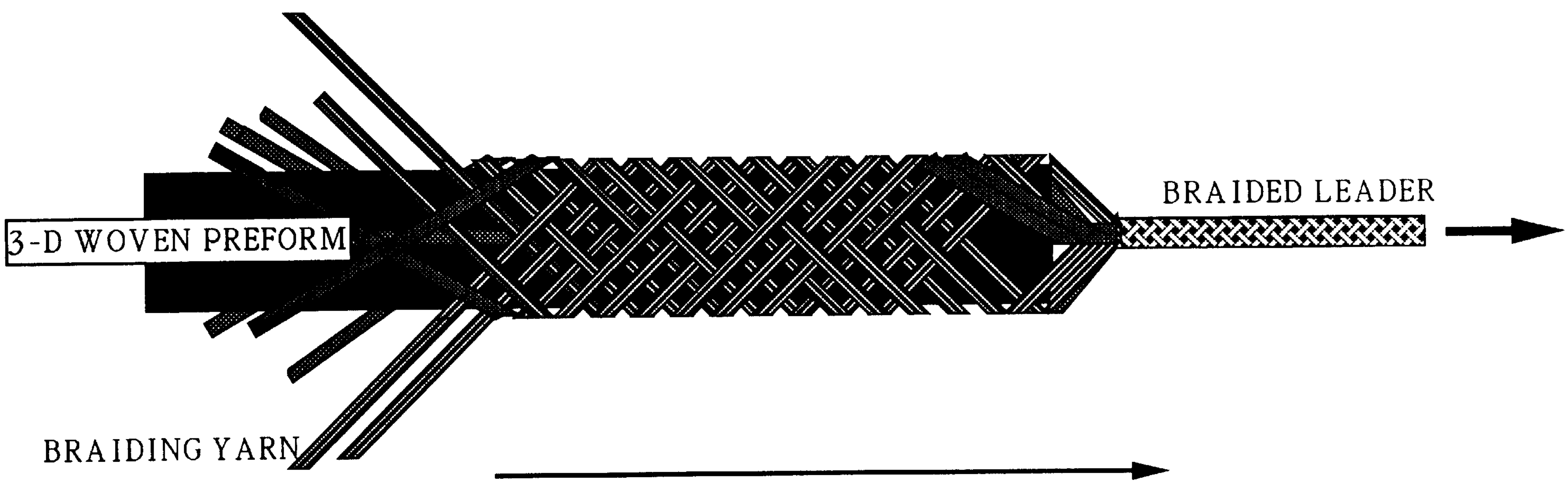
Four-point bending test was applied to the samples. Span length of the tester was two inches with support diameter of 0.5 inch.

Accomplishments:
Adding a layer of 2-D braid increased the volume fraction of fibers in the preform and also added two more fiber axes. An increase in the normalized bending modulus was observed (from 4.3 E6 to 5.0 E6). The normalized flexural strength was increased from 55.5 E3 to 83.2 E3 PSI.

The bending modulus and the flexural strength of 3-D woven composites can be increased by adding a layer of 2-D braid on the surface of the preform. The flexural strength showed higher response to the change in structure than the bending modulus.

Future Plans:
Torsion testing of aerobrake truss members of different cross sectional shapes.

Publications:
None to date.



BRAIDING A 3-D WOVEN PREFORM

Intermingled Carbon/PEEK 3-D Woven Composites

M. H. Mohamed, Principal Investigator
Co-Investigators: NFN Machfud and H. Hamouda
Textile Engineering, Chemistry, and Science
North Carolina State University

Research Objectives:
The presence of voids is perceived to be a major problem associated with resin infiltration techniques when using 3-D woven preforms. The use of PEEK fibers intermingled with carbon fibers appears to be very promising. Influence of processing parameters such as temperature, pressure, and consolidation time, on the composite was investigated. One of the issues emphasized is the effect of pressure on buckling of the Z-reinforcement fibers. Bending and tensile behavior of the composite were also investigated.

Approach:
MATERIAL
Intermingled Carbon/PEEK yarn was used. The yarn was 3K and consists of 65% Carbon and 35% PEEK by weight.

PREFORM CONSOLIDATION
3-D Woven preforms were consolidated by several consolidation treatments. Three levels of pressure, temperature and time were used.

TESTING PROCEDURE
Three-point bending test was applied to the samples. Span length of the tester was two inches with support diameter of 0.5 inch.

Accomplishments:
From microscopical examination, it was found that the matrix distribution is not similar for each treatment, especially when using different consolidation pressure. The higher the pressure the more uniform is the distribution of the matrix in the composites, but this increases the buckling of the Z-yarns. Bending tests showed increased bending modulus and bending strength as well as increased tensile modulus and tensile strength with the increase of all three parameters.

Within the range of temperature, pressure, and time investigated, bending modulus and bending strength as well as tensile modulus and tensile strength were increased with the increase of the three parameters. Pressure plays an important role in determining the matrix distribution and the void content. The higher the pressure, the better is the PEEK distribution within the composite. The only disadvantage of high pressure is the increased buckling of the Z-yarns which may affect the impact resistance of the composite.

Future Plans:
Impact resistance and the possibility of using this type of composite for aerobrake truss members, will be investigated.

Publications:
None to date.

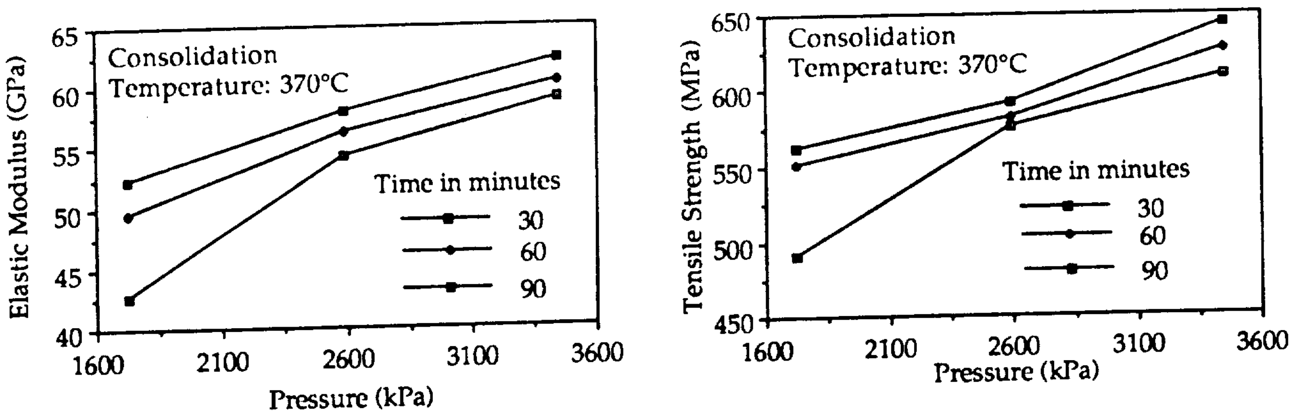


Figure 4.: Relationship between tensile modulus, tensile strength and consolidation pressure for 370 °C consolidation temperature.

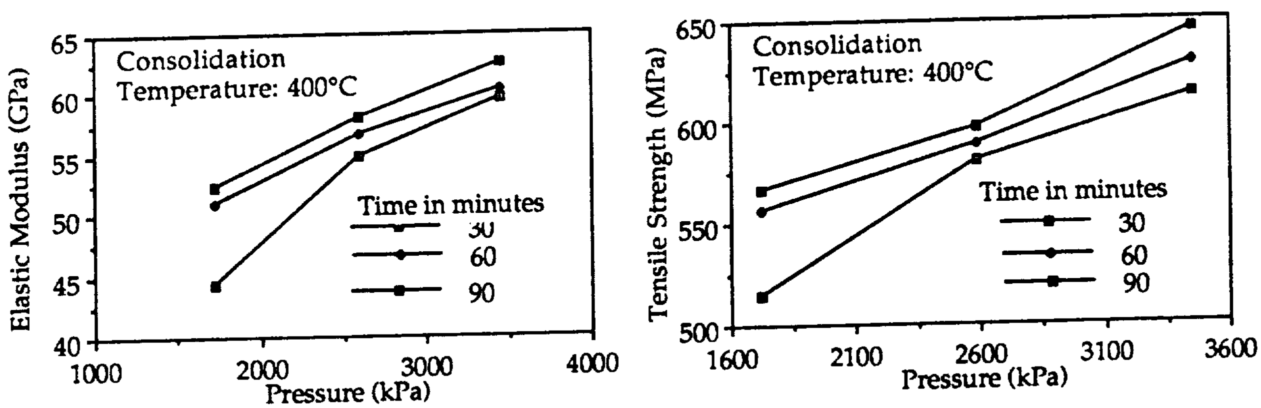


Figure 5.: Relationship between tensile modulus, tensile strength and consolidation pressure for 400 °C consolidation temperature.

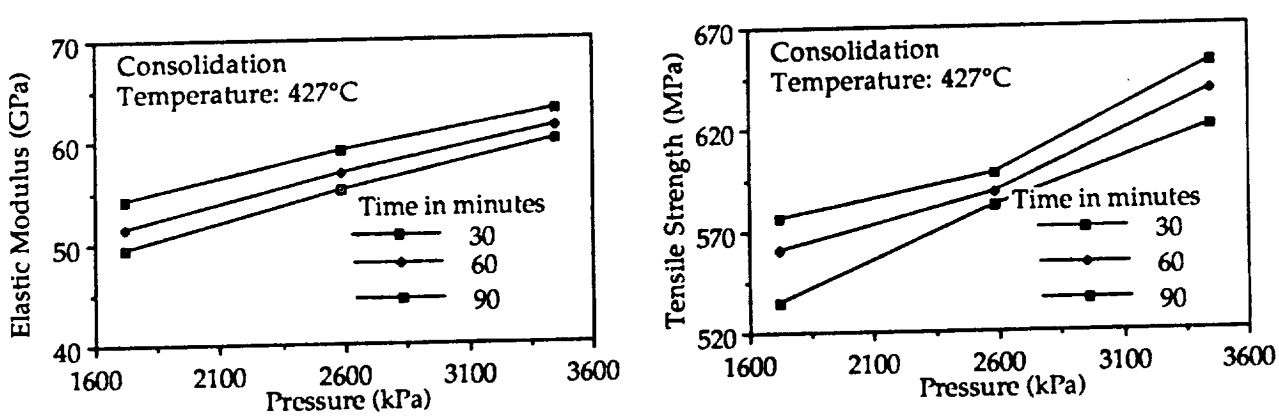


Figure 6.: Relationship between tensile modulus, tensile strength and consolidation pressure for 427 °C consolidation temperature.

C-3

Fabricating Mechanical Test Coupons

R. L. Sadler, Principal Investigator
Co-Investigator: Leon Skeen
Department of Mechanical Engineering
North Carolina A&T State University

Research Objectives:

The Composite Fabrication Laboratory at A&T was put in place to support the various M^2RC activities. Primarily the effort has been to produce quality composite coupons for mechanical property determination utilizing the various 3-D braids and weaves fabricated by the research staff in the School Textiles at N. C. State University. Dr. Mohamed has been active in producing 3-D composite preforms by several weaving processes, and Dr. El-Shiekh has been likewise active in producing 3-D composite preforms by several braiding processes. At A&T these preforms have been fabricated into composite specimens. Some of the composites have been fabricated to demonstrate a capability and others to provide mechanical property data. The activities of the fabrication group have been closely coordinated, first by Dr. Avva and now by Dr. El-Shiekh.

Accomplishments:

The composite fabricating facilities at A&T have been put in place and the skills required for operation have been obtained. Both graduate and undergraduate students have been trained in the various methods of composite fabrication. Compression molding, autoclave molding and resin transfer molding (RTM) have become everyday practices. Hundreds of composite samples of various types have been fabricated and provided to members of the staff for property determination.

Significance:

A&T now has the facilities and capability to fabricate the various composite specimens required to support the needs of M^2RC faculty and students.

Future Plans:

The Composite Fabrication Laboratory will continue to provide composite coupons to the M^2RC composite research staff. An effort will continue to improve the processes and the fabrication skill of the student research assistants.

Publications:

None to date.

Improving the Properties of Composite Fabricated from 3-D Textile Preforms by Process Innovations

R. L. Sadler, Principal Investigator
Co-Investigator: Leon Skeen
Department of Mechanical Engineering
North Carolina A&T State University

Research Objectives:
The analysis of composites fabricated from 3-D textile preforms has revealed two problems that limit the potential use of this type of composite. In analyzing the cross-section of these 3-D composites, large matrix pockets have been identified in the locations where tows cross. A reduction in the size of these resin pockets would be desirable. Additionally, it has been noticed that axial fibers of these textile constructions are not axial on a micro scale. To maximize the axial properties of these composites, methods of obtaining the axial alignment on a micro level need to be explored.

Approach:
The matrix pockets can be reduced by the introduction of Glass Microballoons into the matrix during processing. The microballoons dilute the matrix concentration and act as crack arrestors. Further they will reduce the specific gravity of the composite which is also advantageous. Truly axial fibers may be achieved by incorporating pultruded graphite/epoxy tow rods which are now commercially available.

Accomplishments:
Many test coupons have been fabricated using glass microballoons as a filler in the matrix. It has been determined that the glass microballoons fill the matrix pockets and act as crack arrestors. Tensile property data indicates the balloons slightly improve the tensile properties with a decrease in density. A source for pultruded tow rods has been found, and three sizes of rods have been ordered.

Significance:
The success of these concepts could greatly enlarge the possible applications of composites fabricated from 3-D textile preforms.

Future Plans:
Work will continue to explore the value of GMB in composites fabricated from 3-D textile preforms. Composites will be fabricated from 3-D textile preforms containing pultruded axial tow rods. An improvement in compression properties is expected.

Publications:
None to date.

Fabricating Composite Structures

R. L. Sadler, Principal Investigator
Co-Investigator: Leon Skeen
Department of Mechanical Engineering
North Carolina A&T State University

Research Objectives:
Fabricate scale composite structures designed by the Structure Group to verify computer models.

Approach:
The Structure Group has designed two Aerobrakes utilizing structural models they have developed. The models were designed utilizing a cored panel shaped as an Aerobrake. The shape of the scale models are obtained through the use of a pattern. For the first design, the shape was obtained with a plaster pattern and the second with a wooden pattern. In both cases, a mold was constructed on the pattern with polyester resin and fiberglass. Several scale models were fabricated from the first mold using polyester resin and fiberglass skins, but polyvinyl foam was used as the core.

Accomplishments:
Four scale models were constructed from the first mold. Three of the models were used as visual aids for display purposes, and the third was structurally tested. For the second scale model design, a pattern and mold have been fabricated. The first part is still under construction. It is planned for structural testing.

Significance:
This area of activity offers the opportunity for designers to see and test a scale model of their designs. This offers a unique opportunity for designers to effectively evaluate their structural designs.

Future Plans:
It is expected that the mechanical test on this second design will suggest structural modifications which will need mechanical verification. Since the basic mold is available, these modifications can be incorporated into additional models for further mechanical testing. It is anticipated that structural model building will continue, not only with the Aerobrake but with many other target structures on the Mars vehicle.

Publications:
None to date:

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ADDITIONAL SUPPORT FOR MARS MISSION RESEARCH CENTER FACULTY

39 Projects; Total support (over 5 year span) = $ 7.1M, average yearly support = $ 1.4M

North Carolina State University

Principal Investigator	Agency	Beginning Date	Ending Date	Title	Amount
Candler	NASA	02/01/90	04/30/92	A Study of Numerical and Physical Issues Associated with Continuum Hypervelocity Re-Entry Flows	136,327
Candler	NASA	06/01/90	05/31/92	Vibration-Dissociation Coupling in Nonequilibrium Flows	69,513
Candler	NASA	10/01/91	09/30/92	Computational Techniques for Flows with Finite-Rate Condensation	35,143
Chokani	NSF	08/15/90	08/31/91	Quantitative Investigaton of the Density Field of Aerodynamic High-Speed Flows/Holograms for a Schlieren System	59,998
Chokani	NSF	09/01/90	08/31/91	Engineering Research Equipment Grant: 30 MJ Pulsed Holographic Ruby Laser	25,000
DeJarnette	McDonnell Douglas	05/10/89	01/10/90	Stapat II Computational Algorithm	45,000
DeJarnette	McDonnell Douglas	07/06/89	12/22/89	Conceptional Design of an Aerobrake for Manned Mars Transfer	20,000
DeJarnette	NASA	04/01/90	10/31/92	Development of a Model Systems Dynamics Measurements and Monitoring System for the National Transonic Facility	264,823
DeJarnette	NASA	04/15/87	06/30/92	Graduate Training and Research Program in Hypersonic Aerodynamics	1,000,000
DeJarnette	NASA	05/15/87	10/31/89	An Analytical Inner Layer and Finite-Difference Outer Region Method for Solving the Navier-Stokes Equations	123,968
DeJarnette	NASA	12/01/87	11/30/92	Approximate Numerical Methods for Calculating Nonequilibrium Viscous Flow Fields and Aerodynamic Heating Over Three-Dimensional Bodies	269,643
DeJarnette/ Chokani	NASA	10/01/87	11/15/92	Investigation of the Aerodynamic Characteristics of Leading Edge Vortex Flaps	117,882
DeJarnette/ Chokani	NASA	01/01/88	05/20/92	An Experimental Study of a Juncture Flow in the NASA Langley 0.3-Meter Transonic Cryogenic Tunnel	190,547

North Carolina State Univeristy (continued)

Principal Investigator	Agency	Beginning Date	Ending Date	Title	Amount
El-Shiekh	National Res. Ctr.	03/01/92		Composite Research	89,231
Griffith	SCEEE	04/27/89	09/30/89	Condensation in Hypersonic Wind Tunnels	21,396
Griffith	SCEEE	05/15/90	02/01/91	Effect of Supercooling in Design of NSWC's Hypersonic Tunnels	29,666
Griffith/ McRae	NASA	06/01/89	08/31/89	Laboratory Experimentation and Numerical Simulation on Gas Dynamic Processes Related to Mars Missions	4,950
Hassan	NASA	03/15/88	03/14/92	Study of the Transitional Flow Regime Using Monte Carlo Methods	402,000
Hassan	NASA	09/01/87	08/31/92	Numerical Solutions of the Complete-Navier Stokes Equations	298,620
Hassan/ DeJarnette	NASA	09/15/87	09/14/93	Computational Fluid Mechanics	56,270
Klang	NASA	10/17/88	12/31/91	Shear Buckling of Specially Orthotropic Plates with Centrally Located Cutouts	73,859
Lee	Colorado State Univ.	07/01/89	12/31/89	Computational Tools for Multi-Linked Flexible Structures	66,376
Lee	McDonnell Douglas	05/29/90	12/31/90	Design and Construction of an Aerobrake Mockup	80,000
Lee	NASA	05/01/90	04/30/92	Distributed Digital Signal Processors for Multi-Body Flexible Structures	63,569
Lee	NASA	06/01/91	05/31/92	Telerobotic Control of a Mobile Coordinated Robotic Servicer	77,202
McRae	NASA	06/01/90	09/15/90	Numerical Simulation on Gas Dynamic Processes Related to Mars Mission	2,365
McRae	NASA	09/01/91	08/31/92	Time Accurate Computation of Unsteady Spike Tipped Body Flows with a Dynamic Flow Adaptive Mesh	25,000
Mohamed	National Res. Ctr.	03/01/92		Composite Research	92,603

North Carolina State University (Continued)

Principal Investigator	Agency	Beginning Date	Ending Date	Title	Amount
Perkins	NASA	05/01/91	04/30/92	A Computational and Experimental Investigation of a Three-Dimensional Hypersonic Scramjet Inlet Flow Field	43,238
Perkins	NASA	05/15/91	05/14/92	Assist in Transport High-Lift Research	26,056
Perkins	NASA	06/01/89	06/30/90	Assist in Study of Integrated Propulsion and Airframe Effects of Advanced Turboprop Aircraft	25,141
Perkins	NASA	09/01/89	08/31/92	An Experimental Study of a Generic Three-Dimensional Scramjet Inlet	57,150
Perkins	NASA	11/27/90	11/26/91	A Computational and Experimental Investigation of a Three-Dimensional Hypersonic Scramjet Inlet Flow Field	9,460
Perkins	Naval Air Test Ctr.	05/16/90	08/15/90	Investigation of Technical Performance Enhancements for the BQM-147-UAV	25,000
Perkins/ Griffith Sadler	NASA	03/01/89	12/31/89	Hypersonic Nozzle Design	18,729
Perkins/ Walberg	NASA	03/01/91	02/29/92	National Space Grant College Fellowship Program Phase II Space Grant Consortia	150,000

A&T State University

Principal Investigator	Agency	Beginning Date	Ending Date	Title	Amount
Avva	General Electric Aircraft	08/90	12/91	Stress Concentration Study of Fiber Reinforced Ceramic Matrix Composite Materials	55,585
Avva/ Sadler/ Pai	AFWAL/ Flight Dynamics	09/87	03/91	Study of the Behavior of Aircraft Tire Coupons Under Various Loading Conditions	299,000
Avva/ Filatovs/	ONR/	09/86	09/92	Micro/Macro Studies of Fiber Reinforced Composites Materials	2,207,337

Graduate Programs in Space Engineering

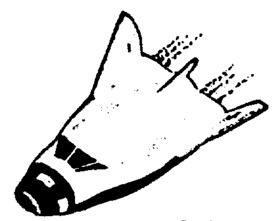
MARS MISSION RESEARCH CENTER

North Carolina State University
and
North Carolina Agricultural and Technical State University

The Mars Mission Research Center is one of nine University Space Engineering Research Centers established by NASA in 1988 to broaden the nation's engineering capability to meet the critical needs of the civilian space program. It is a cooperative effort between North Carolina State University (NCSU) at Raleigh, NC and North Carolina Agricultural and Technical State University (A&T) at Greensboro, NC. Graduate programs are established for Master of Science and Doctor of Philosophy Degrees. Areas of specialization are:

Aerobrake

- **Mission Analysis and Design**
- **Hypersonic Aerodynamics**
- **Spacecraft Structures and Controls**
- **Composite Materials**
- **Fabrication**



HL-20 Personnel Launch System

Research projects focus on new technology to design space transportation systems for planetary travel with particular emphasis on the exploration of Mars. A significant feature of the program is that students and faculty spend part of their time at one of the NASA Centers or participating industries. While there, students work on their thesis or dissertation project and coordinate the research with outstanding researchers off campus as well as on campus. Some students participate in projects such as the design and construction of full-scale mockups of the Mars aerobrake and Personnel Launch System shown above.

The M.S. degree requires 24 semester credits of course work and a thesis. Typical programs of study require one to two years. Typical Ph.D. programs have two or three semesters of course work beyond the M.S. degree and dissertation project which generally requires about two years of full-time effort. The Ph.D. degree is granted by NCSU and offered by A&T through a cooperative program with NCSU.

Graduate Research Assistantship stipends range from $900 to $1,050 per month for half-time work on campus with rates increased to almost double for research periods at one of the NASA Centers or participating industries. Highly qualified applicants are considered for supplemental fellowships available in the College of Engineering at NCSU. These fellowships are for one year only and provide stipends from $3,000 to $6,000 plus all tuition and fees to supplement the Graduate Research Assistantship. This program is limited to U.S. citizens, and participants are exempt from out-of-state tuition.

Highly qualified applicants should contact one of the following:

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NCSU and A&T are committed to equality of educational opportunity and do not discriminate against applicants, students, or employees based on race, color, national origin, sex, age, or handicap.

Table 1. Mars Mission Research Center Outreach Laboratory Tours

Date	Organization	Group (size, content)
January 18, 1991	Carnage Middle School MSEN Pre-College Program	50, Grades 4-6
March 6, 1991	Daniels Middle School	40, Grade 7
March 13, 1991	Cardinal Gibbons High School	30, Grades 9-12
April 11, 1991	Lacy Elementary School Brownie Troop	15, Grade 3
April 18, 1991	Explorer Post	10, Grades 11-12
May 24, 1991	NC Science and Math Alliance	20, Grades 9-12
July 16, 1991	Shaw University Upward Bound Students	52, Grades 9-12
June 19, 1991	NCSU- Physical and Mathematical Sciences Science Camp	15, Grades 9-12
September 19, 1991	Raleigh Parks and Recreation Department	15, Senior Citizens
November 4, 1991	E.C. Brooks Elementary School	110, Grades 4-6
March 25, 1992	North Carolina School of Science and Math	3, Grade 12
April 2, 1992	NCSU International Programs	5, Professors from Magdeburg Technical Institute, Germany

Table 2. Mars Mission Research Center Outreach Lectures

Date	Speaker	Group	Audience (size,content)
June 9, 1988	Dr. Fred DeJarnette	Rotary Club Apex, NC	70, club members
June 23, 1988	Dr. Fred DeJarnette	WRDU Radio Raleigh, NC	2 hour radio talk and call-in program
Sept. 21, 1988	Dr. Fred DeJarnette	Rotary Club Knightdale, NC	36, club members
Sept. 23, 1988	Dr. Fred DeJarnette	NCSU Alumni Class 1978 Raleigh, NC	92, alumni and family
Sept. 27, 1988	Dr. Fred DeJarnette	IEEE NCSU Raleigh, NC	116, students
Sept. 29. 1988	Dr. Fred DeJarnette	WTVD Channel 11 Durham, NC	Television News Program
Nov. 4, 1988	Dr. Fred DeJarnette	Rotary Club Res. Triangle Park, NC	55, club members
Nov. 17, 1988	Dr. Fred DeJarnette	Air Force Association Tarheel Chapter Raleigh, NC	34, retired Air Force
Jan. 17, 1989	Dr. Fred DeJarnette	West Raleigh Rotary Club Raleigh, NC	89, club members
January 1989	Dr. Eric Klang	ASME Senior Section Raleigh, NC	50, Adult ASME Members
Feb. 9, 1989	Dr. Fred DeJarnette	Capital City Rotary Club Raleigh, NC	73, club members

February 1989	Dr. Eric Klang	ASME Student Section Raleigh, NC	50, College Students
March 21, 1989	Dr. Fred DeJarnette	Undesignated Freshman in Engineering at NCSU Raleigh, NC	117, students
March 30, 1989	Dr. Fred DeJarnette	National Society of Professional Engineers Raleigh, NC	47, practicing engineers
April 19, 1989	Dr. Fred DeJarnette	Phi Zeta- Psi Chapter NCSU Vet. School Raleigh, NC	96, students and faculty
April 28, 1989	Dr. Fred DeJarnette	NC School of Science and Math Durham, NC	83, teacher workshop
May 18, 1989	Dr. Fred DeJarnette	ASME Wilmington, NC	38, practicing engineers
July 12, 1989	Dr. Fred DeJarnette	4-H Space Camp NCSU Raleigh, NC	27, high school students
August 2, 1989	Dr. Fred DeJarnette	North Raleigh Rotary Club Raleigh, NC	31, club members
August 14, 1989	Dr. Fred DeJarnette	Rotary Club Zebulon, NC	45, club members
August 16, 1989	Dr. Fred DeJarnette	Rotary Club Garner, NC	37, club members
Aug. 17-19, 1989	Dr. Fred DeJarnette	NC Professional Engineers Summer Meeting Myrtle Beach, SC	84, engineers
August 1989	Dr. Eric Klang	North Raleigh Rotary Club	50, Club Members

Sept. 12, 1989	Dr. Fred DeJarnette	Watauga Club Raleigh, NC	15, Management and Political
Oct. 20, 1989	Dr. Fred DeJarnette	Biological and Agricultural Eng. NCSU Raleigh, NC	26, students
Nov. 9, 1989	Dr. Fred DeJarnette	University of Virginia Charlottesville, VA	72, students and faculty
Dec. 1, 1989	Dr. Fred DeJarnette	Old Dominion University Norfolk, VA	57, students and faculty
Dec. 12, 1989	Dr. Fred DeJarnette	Civil Air Patrol Raleigh, NC	36, high school students
Dec. 14, 1989	Dr. Fred DeJarnette	Rotary Club of Crabtree Raleigh, NC	75, club members
Feb. 2, 1990	Dr. Fred DeJarnette	Raleigh Academy of Medicine Raleigh, NC	215, medical doctors
March 15, 1990	Dr. Fred DeJarnette	Eastern NC Chapter of Professional Engineers Greenville, NC	26, engineers
March 23-25, 1990	Dr. Fred DeJarnette	Rotary Youth Leadership Conference Ahoskie, NC	125, high school students
July 2, 1990	Dr. Fred DeJarnette	Kiwanis Club Durham, NC	43, club members
Nov. 2, 1990	Dr. Fred DeJarnette	National Engineering Student Council Conference, NCSU Raleigh, NC	86, students
November 1990	Dr. Eric Klang	ASME Student Section Raleigh, NC	50, College Students

November 1990	Dr. Eric Klang	Delft University Delft, The Netherlands	50, University Faculty and Students
Dec. 20, 1990	Dr. Fred DeJarnette	McDonnell Douglas Space Systems Co. KSC, Florida	11, engineers
April 1991	Dr. Eric Klang	4-H Raleigh, NC	35, Grades 4-7
May 1, 1991	Dr. ND Chokani	Lynn Road Elementary School, Raleigh, NC	25, Grades 4-6
Sept. 4, 1991	Dr. Fred DeJarnette	ASME Student Branch NCSU Raleigh, NC	150, College Students
Sept. 12, 1991	Mr. John Meyer	Raleigh Parks and Recreation Raleigh, NC	15, Senior Citizens
Oct. 28, 1991	Dr. Fred DeJarnette	University Extension NCSU Raleigh, NC	55, Encore Members
Oct. 31, 1991	Dr. Fred DeJarnette	Rotary Club Fuquay Varina, NC	35, Club Members
Dec. 10, 1991	Mr. Greg Washington	Carnage Middle School Raleigh, NC	12, Grades 6-8
Jan. 25, 1992	Mr. Greg Washington	Martin Luther King Celebration at NCSU Raleigh, NC	200, High School and College Students
Jan. 29, 1992	Mr. Andy Mueller	Leroy Martin Middle School Raleigh, NC	90, Grades 6-8
Jan. 31, 1992	Mr. Greg Washington	YMCA Raleigh, NC	35, Ages 12-16

Jan. 31, 1992	Dr. ND Chokani	Lincoln Heights Magnet School Fuquay-Varina, NC	100, Grades 5-7
Feb. 1, 1992	Dr. Fuh-Gwo Yuan	PAGE Saturday Morn. Program Raleigh, NC	10, Ages 9-11
Feb. 8, 1992	Dr. Jim Redmond	PAGE Saturday Morn. Program Raleigh, NC	10, Ages 9-11
Feb. 14, 1992	Mr. Greg Washington	Fred A. Smith Elementary School Raleigh, NC	78, Grades 3-4
Feb. 15 , 1992	Dr. Gordon Lee	PAGE Saturday Morn. Program Raleigh, NC	10, Ages 9-11
Feb. 20, 1992	Mr. Greg Washington	National Society of Black Engineers Res. Triangle Park, NC	20, Society Members
Feb. 21, 1992	Mr. Andy Mueller	East Wake Middle School Wendell, NC	175, Grade 8
Feb. 22, 1992	Mr. Nathan Gittner	PAGE Saturday Morn. Program Raleigh, NC	10, Ages 9-11
Feb. 27, 1992	Mr. Ken Jones	P.S. Jones Middle School Washington, NC	120, Grades 6-8
Feb. 29, 1992	Mr. John Meyer	PAGE Saturday Morn. Program Raleigh, NC	10, Ages 9-11
March 13, 1992	Dr. Jim Redmond	St. Patrick's Elementary School Charlotte, NC	25, Grade 8
March 14, 1992	Mr. Greg Washington	Peer Mentor Program NCSU Raleigh, NC	110, College Students

March 14, 1992	Dr. Larry Silverberg	PAGE Saturday Morn. Program Raleigh, NC	10, Ages 9-11
March 14, 1992	Dr. Larry Silverberg	Junior Engineering Technology Garner, NC	50, Grades 9-12
March 14, 1992	Ms. Rona Reid	Junior Engineering Technical Society Garner, NC	50, Grades 9-12
March 19, 1992	Dr. Fred DeJarnette	Faculty Club NCSU Raleigh, NC	125, Faculty Wives Club Members
March 30, 1992	Dr. Fred DeJarnette	Discovery Place Charlotte, NC	150, Planetary Society Members
April 11, 1992	Dr. Jim Redmond	4-H Rocketry Day Raleigh, NC	50, Grades 5-8
April 11, 1992	Mr. Andy Mueller	4-H Rocketry Day Raleigh, NC	50, Grades 5-8
April 11, 1992	Mr. Eric Clark	4-H Space Camp	60, Grades 4-7

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ORKSHOPS

Workshop

TECHNOLOGY FOR LUNAR/MARS AEROBRAKES

Sponsored by

North Carolina State University and North Carolina A&T State University
MARS MISSION RESEARCH CENTER (M^2RC)
a NASA University Space Engineering Research Center

Mission Valley Inn, Raleigh, NC
October 30 - 31, 1990

PROGRAM

Tuesday, October 30, 1990

7:45 - 8:30 am	Registration, Mission Valley Inn
8:30 - 8:45	Welcoming Remarks, James Ferrell, Dean of Engineering, NCSU Overview of M^2RC, Fred DeJarnette, Director
8:45 - 9:15	"An Overview of the Space Exploration Initiative (SEI) and Exploration Technology Programs" Invited Speaker - Steve Wander, NASA Headquarters
9:15 - 9:45	"The Space Exploration Initiative Aerobraking Technology Project" Invited Speaker - Chuck Eldred, NASA Aerobraking Technology Project Manager
9:45 - 10:15	"Recent Developments in Mars/Lunar Mission Studies" Gerald Walberg, JIAFS/George Washington University
10:15 - 10:30	Break
10:30 - 11:00	"Integration of Aerobrake Technologies into Mars Mission Systems" Invited Speakers - Irwin E. Vas and Gordon R. Woodcock, Boeing Aerospace and Electronics
	McDonnell Douglas-M^2RC Aerobrake Project
11:00 - 11:05	Introductory Remarks Gordon Lee, NCSU
11:05 - 11:20	"Mars Aerobrake Assembly Demonstration" Invited Speaker - John Garvey, McDonnell Douglas Space Systems Company
11:20 - 11:35	"Design, Fabrication, and Testing of an Aerobrake Mock-up" Robert Stanley, NCSU
11:35 - 11:45	Concluding Remarks and Future Activities Gordon Lee, NCSU
11:45 - 1:00 pm	Lunch - Mordecai Room, Mission Valley Inn

	Hypersonic Aerodynamics
1:00 - 1:30	"Overview of Hypersonic Aerodynamics Research at the Mars Mission Research Center" Experimental Research - N. Chokani, NCSU Computational Research - H. Hassan, NCSU
1:30 - 1:45	"Surface Pressure Distribution on a 60° Blunt Cone" Graham Candler, NCSU
1:45 - 2:00	"Direct Simulation Monte Carlo with Ionization and Radiation" Invited Speaker - Ann Carlson, NASA Langley Research Center
2:00 - 2:10	"Equilibrium Radiation Calculations for Mars and Earth Entry" Brian Platz, NCSU
2:10 - 2:20	"Effect of Surface Deformation on Heating Rates" Stacey Rock, NCSU
2:20 - 2:30	"Ballistic Range Measurements of Lift, Drag, and Pitching Moment for a Blunt Cone at Mach Numbers 6 to 21 in Carbon Dioxide and Air" Jim Packard, NCSU
2:30 - 2:45	Discussion of Hypersonic Aerodynamics
2:45 - 3:00	Break
	Structures
3:00 - 3:20	"Overview of Aerobrake Structures - Structural Configurations, Modeling and Analyses" Ivatury Raju, A&T
3:20 - 3:40	"Modeling and Analysis of Aerobrake Space Frame Structures" William Craft, A&T
3:40 - 3:55	"Modeling and Analysis of Aerobrake (Space Frame) Structures Under Bending" Fuh-Gwo Yuan, NCSU
3:55 - 4:00	"Modeling and Analyses of Aerobrake (Truss and Semi Monocoque Structures)," (Introduction to Student Presentations) - Eric Klang, NCSU
4:00 - 4:15	"Modeling and Analyses of Aerobrake Truss Structures" Greg Washington, NCSU
4:15 - 4:30	"Modeling and Analyses of Semi Monocoque Structures" John Hairr, NCSU
4:30 - 4:45	Discussion of Structural Issues
6:30	Social Hour (with cash bar) - Expo Center, Mission Valley Inn
7:30	Pig Pickin' - Expo Center, Mission Valley Inn (informal dress) Speaker: John A. Bailey, Head of Mechanical and Aerospace Engineering, NCSU

Wednesday, October 31, 1990

		Materials
8:15 -	8:30	"Assessment of Materials for Aerobrake Components" Sarma Avva, A&T
8:30 -	8:45	"On the Thermal Conductivity of Fibers and Fibrous Composites" Abdul Fahmy, NCSU
8:45 -	9:00	"Fracture Mechanics Studies of Braided Composites" Juri Filatovs, A&T
9:00 -	9:15	"Composite Material Concepts for Semi-rigid Aerobrakes" Ray Foye, A&T
9:15 -	9:30	"Evaluation of Mechanical Properties of Braided Composites with and without Embedded Microballoons" Malcolm Lyon, A&T
9:30 -	9:45	Discussion of Materials for Aerobrake
9:45 -	10:00	Break
		Fabrication
10:00 -	10:05	Introductions of Student Presentations Aly El-Shiekh, NCSU
10:05 -	10:15	"An Overview of the Fabrications" Rona Reid, NCSU
10:15 -	10:30	"Liquid Transfer Molding of Structures and the Manufacture of a 1/30 Scale Fiberglass Aerobrake" Randy Stabler, A&T
		Spacecraft Controls
10:30 -	11:00	"*A Priori* Evaluations of the Terminal Descent Phase of the Viking Lander" Invited Speaker - Ray Montgomery, NASA Langley Research Center
11:00 -	11:15	"Introduction to Minimum Fuel/Time Control of Large Flexible Spacecraft" James Redmond, NCSU
11:15 -	11:30	"Development of Experimental Structure for Verification of Aerobrake Minimum Fuel/Time Control Techniques" John Meyer, NCSU
11:30 -	11:45	Discussion of Fabrication and Controls
11:45 -	12:30 pm	Visit to Centennial Campus
1:30 -	3:00	Informal Visit to Laboratories 2110A Broughton (Dr. Silverberg) 202C Nelson (Dr. Mohamed) 306B Nelson (Dr. El-Shiekh) 239A Riddick (Dr. Fahmy)

AEROBRAKE STRUCTURAL DESIGN

at

NASA LANGLEY RESEARCH CENTER

NATIONAL TRANSONIC FACILITY
5 WEST TAYLOR ROAD
BUILDING 1236, ROOM 108

Wednesday, June 19, 1991

8:30 - 8:45 am	Welcome and Introduction. Dr. C. P.Young, Jr., North Carolina State University
8:45 - 10:00	Overview of Ma4s Mission Research Center Design Activity and Mission Definition. Dr. G. D. Walberg, George Washington University
10:00 - 11:30	TPS Design Alternatives and Structural Interaction Issues. Jim Russell, Lockheed Engineering and Sciences
11:30 - 12:30	Lunch
12:30 - 2:00	Structural Design, Packaging, and Assembly: Concepts and Issues. John Dorsey, Structural Mechanics Division, NASA Langley
2:00 - 3:30	Structural Design, Integration, and Methodology. Don Hedgepath, Systems Engineering Division, NASA Langley
3:30 - 5:00	General Discussion
5:00 -	Adjourn

Attendance

Mars Mission Research Center Faculty and Students	25
NASA Personnel and Contractors	6
	31

Aerodynamic Heating Workshop
NASA Johnson Space Center
August 5-6, 1991

Dr. Fred R. DeJarnette conducted a workshop on Aerodynamic Heating Methods for personnel at NASA Johnson Space Center and Lockheed Space Company. Attendance was 18.

<u>Monday, August 5</u>

8:30 a.m.	Introduction	Dr. Carl Scott

8:40	Overview of Aeroheating Needs and Problems
	Project Needs
	Near-Term:
	  Orbiter
	  AFE
	  ACRV
	Long-Term:
	  Lunar/Mars Mission Vehicles
	Present Aeroheating Prediction Methods
	Proposed Improvements
		Stan Bouslog

9:00	Status and Recent Results of Axisymmetric Analog Description of Streamline Code Validation Effort Future Plans	Mike An
9:30	Overview of Methods for Predicting Heating to 3-D Bodies	DeJarnette

10:00	Using 3-D Boundary-Layer Codes with 2-Layer Method
	  General Description
	  Description of Existing BL Codes
	  Advantages/Problem
		DeJarnette
		Li-Lee

11:00	Calculating 3-D Stag.Pt. Heating Rates	DeJarnette
12:00	Lunch	

1:00 pm	Fundamentals of Axisymmetric Analog
	General Description of Method
	Range of Validity/Applicability
	Differences (Advantages & Disadvantages
	  of Pressure and Velocity Methods of Obtaining
	  Streamlines and Metrics)
	Sample Results
		DeJarnette

2:30	CFD Flowfield/Streamline Code Integration Problems	An/Wang

Monday, August 5 (continued)

3:00		Two-Layer Methods for Variable Entropy and Chemical Nonequilibrium Boundary-Layer Edge Conditions Effect of Entropy Layer Swallowing Entropy Trends near stag. pt. and further downstream Problems and cautions	DeJarnette
4:00		General Discussion	All

Tuesday, August 6

9:00	am	New Approach for Matching Boundary-layer Profiles with Inviscid Solution	DeJarnette
10:30		Thermal and chemical Nonequilibrium Effects	DeJarnette
12:00		Lunch	
1:00	pm	Methods for Near-Term Projects	DeJarnette
2:00		Methods for Long-Term Projects	DeJarnette
3:00		Discussion and Summary Statements	All
4:00		Adjourn	

THE LaRC GNC TECHNICAL COMMITTEE AND THE MARS MISSION RESEARCH CENTER PRESENTS
ONGOING PROGRESS IN SPACECRAFT CONTROLS

BUILDING 1192C, ROOM 124
NASA LANGLEY RESEARCH CENTER
HAMPTON, VIRGINIA
JANUARY 13, 1992

8:00 - 8:30 a.m.	Refreshments
8:30 - 9:00	**Keynote Speaker: Dr. Jerry Walberg (NCSU)** **Review of Mars Mission Scenarios**
9:00 - 9:30	**Questions and Open Discussion**
	TECHNICAL PROGRAM
9:30 - 10:00	Optimal Control of Hereditary Systems with Aerospace Applications, **Dr. E. N. Chukwu (NCSU)**
10:00 - 10:30	Sensor Filter Designs for Large Flexible Space Structures, **Nancy Nimmo (LaRC)**
10:30 - 10:45	Coffee Break
10:45 - 11:10	Fuel Optimal Maneuver: Experimental Testbeds, **John L. Meyer (NCSU)**
11:10 - 11:35	Fuel Optimal Reboost of Flexible Spacecraft, **Jim Redmond (NCSU)**
11:35 - 12:00	Initial Investigation of an Adaptive Discrete-Time Controller for Nonlinear Time-Varying Robotic Models, **S. S. Giang (NCSU)**
12:00 - 1:00 p.m.	Lunch Break
1:00 - 1:25	Identification of Linear System Models and State Estimators for Controls, **Dr. C. W. Chen (NCSU)**
1:25 - 1:50	Fuzzy Logic Controllers for Manipulator Systems: Preliminary Results, **R. Stanley, II and H. Roberts (NCSU)**
1:50 - 2:00	Break
2:00 - 4:00	**PANEL DISCUSSION**
	Long Term Research Requirements in Spacecraft Control
	Moderator: Dr. Gordon Johnston, NASA Headquarters

NASA LaRC Panelists:	MMRC Panelists:
Dr. Ray Montgomery	Dr. Larry Silverberg
Mr. Jerry Newsom	Dr. Gordon Lee
Mr. Lawrence W. Taylor, Jr.	Dr. E. N. Chukwu

Workshop

TECHNOLOGY FOR INTERPLANETARY SPACECRAFT

Sponsored by

North Carolina State University and North Carolina A&T State University
MARS MISSION RESEARCH CENTER (M^2RC)
a NASA University Space Engineering Research Center

Brownestone Hotel, Raleigh, NC
October 31 - November 1, 1989

PROGRAM

Monday, October 30, 1989

7:00 - 9:00 pm	Advance Registration, Brownestone Hotel

Tuesday, October 31, 1989

7:30 - 8:30 am	Registration, Brownestone Hotel
8:30 - 8:45	Welcome and Introductions
8:45 - 9:00	"The Mars Mission Research Center" - Fred DeJarnette, Director
9:00 - 9:30	"Interplanetary Aerobraking: Program Status Report" Invited Speaker - Robert Braun NASA/Headquarters
9:30 - 10:00	"Aerobraking for Mars Missions" Invited Speaker - Jerry Walberg, JIAFS/GWU
10:00 - 10:15	Break
10:15 - 10:45	"Aero Assist - Key to Space Transportation and a Case for the Aeroassist Flight Experiment (AFE)" Invited Speaker - Paul Siemers, NASA/Langley

Hypersonic Aerodynamics

10:45 - 11:30	Overviews of Research in M^2RC Graham Candler, Wayland Griffith, and Hassan Hassan, NCSU
11:30 - 12:00	Panel Discussion
12:00 - 1:30	Lunch Break

Structures

1:30 - 2:00	"Mars Aerobrake Assembly Demonstration: Invited Speaker - John Garvey, McDonnell Douglas/HB
2:00 - 2:30 pm	"Orbital Assembly of Large Structures" Invited Speaker - Harold Bush, NASA/Langley
2:30 - 3:00 pm	Overviews of Research in M^2RC William Craft, A&T and Eric Klang, NCSU

3:00 - 3:15 pm	Break	

Controls

3:15 - 3:45	"Research Activities in the Control/Structures Interaction Program" Invited Speaker - Jer-Nan Juang, NASA Langley
3:45 - 4:15	Overviews of Research in M^2RC Gordon Lee and Larry Silverberg, NCSU
4:15 - 4:45	Panel discussion - moderator: John Dorsey, NASA/Langley Brian Platz, NCSU
6:30	Pig pickin' at NCSU Faculty Club Invited Speaker - Samuel Massenberg, NASA/Langley "Long Duration Exposure Facility (LDEF)"

Wednesday, November 1, 1989

Composite Materials

8:30 - 9:00 am	"Use of Advanced Thermoplastic Composite Materials and Processes" Invited Speaker - George Husman, BASF
9:00 - 9:30	"The Performance of Polymer Matrix Fibrous Composites in Extreme" Environments" Invited Speaker - Roger Morgan, Michigan Molecular Institute
9:30 - 10:00	Overviews of Research in M^2RC Ivatury Raju and Robert Sadler, A&T
10:00 - 10:15	Break
10:15 - 11:15	Overviews of Research in M^2RC Ivatury Raju and Robert Sadler, A&T Abdel Fahmy and Sal Torquato, NCSU
11:15 - 11:45	Panel discussion
11:45 - 1:30	Luncheon at Brownestone Hotel Invited Speaker - James Starnes, NASA/Langley "Composite Structures Research at NASA Langley Research Center"

Fabrication

1:30 - 2:00	"Modeling of Textile Structural Composites" Invited Speaker - Frank Ko, Drexel University
2:00 - 2:30	Overviews of Research in M^2RC Aly El-Shiekh and Mansour Mohamed, NCSU
2:30 -	Visits to NCSU laboratories