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THE NASA/UTA CENTER FOR HYPERSONIC RESEARCH

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Abstract

The NASA/UTA Center for Hypersonic Research is one of three NASA-sponsored centers for graduate-level education and research in hypersonic aeronautics. The primary objectives of the Center are to develop modern educational programs in hypersonics, and to provide graduate students with opportunities to conduct state-of-the-art research in the technical disciplines that are critical to the development of hypersonic flight vehicles. The NASA/UTA Center is co-sponsored by the Lockheed Fort Worth Company - a major aerospace company in the Dallas-Fort Worth area with active programs in hypersonics.

A comprehensive educational program leading to M.S. and Ph. D. degrees in Aerospace, Mechanical, or Materials Science and Engineering, with specialization in hypersonics is being developed. The educational program builds on a solid base of fundamental courses in the mathematical and engineering sciences, and provides specialized courses in hypersonic aerodynamics, aerothermodynamics, propulsion, high-temperature materials, structures, flight dynamics, and hypersonic vehicle design. Complementary research programs focus on the high-temperature aspects of sustained flight at hypersonic speeds, with particular emphasis in the areas of aerodynamics, aerothermodynamics, propulsion, structures and materials. A detailed description of the education and research programs in hypersonics at UTA, as well as a description of the supporting research facilities, is presented in the paper.

Introduction

Following an intense period of activity associated with the DoD ballistic missile program and the NASA manned space and planetary entry programs, a drastic reduction in the U.S. hypersonics program occurred during the early 1970's with the culmination of the development work on the Space Shuttle. A low level of activity was maintained between the early 1970's and mid 1980's, but many hypersonic research facilities and industry design teams were dissolved during this period. As a result, when a resurgence of interest in hypersonics occurred during the mid 1980's, fueled largely by the National Aerospace Plane and the Strategic Defense Initiative programs, the nation was faced with a critical shortage of scientists and engineers with experience in hypersonics. Moreover, the current experience base in hypersonics was dominated by people who would soon approach retirement. Thus a critical need existed to resupply the pool of technical specialists if the U.S. were to maintain a competitive edge in hypersonics. In response to this need, the NASA Office of Aeronautics initiated a university research and education grant program in the field of hypersonic aeronautics in September, 1993. Three universities; The University of Maryland, Syracuse University, and The University of Texas at Arlington (UTA) were selected to establish graduate programs in hypersonics. The hypersonics program being developed at UTA is described in this paper.

Organizational Structure

The primary objectives of the NASA/UTA Center for Hypersonic Research are to develop a modern science and engineering-based educational program in hypersonics, and to provide students with opportunities to conduct leading-edge experimental and computational research in the technical disciplines that are critical to the development of hypersonic flight vehicles. Our long-range goals are to establish a nationally-recognized center for research and education in hypersonics, and to contribute to the development of a highly-skilled pool of

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scientists and engineers to support future hypersonic programs of national interest.

The UTA Center for Hypersonic Research is an integral part of the Mechanical and Aerospace Engineering Department, and involves faculty members with expertise in Aerospace Engineering, Mechanical Engineering, and Materials Science and Engineering. The Center Director is Dr. Donald R. Wilson, Professor of Aerospace Engineering and Director of the Aerospace Engineering Program at UTA. His technical specialties include high-temperature gasdynamics, propulsion and high-speed aerodynamics, and he is directly responsible for coordination of the educational program in hypersonics. Associate Directors include Dr. Dale A. Anderson, Professor of Aerospace Engineering and Director of the Computational Fluid Dynamics Center, and Dr. Wen S. Chan, Professor of Mechanical Engineering and Director of the Center for Composite Materials. Dr. Anderson is responsible for coordination of the research activities in fluid dynamics, whereas Dr. Chan coordinates the research activities in structures and materials. Other faculty members and their technical areas of expertise include Dr. Pranish Aswath, high-temperature materials, Dr. A. Haji-Sheikh, heat transfer, Dr. S.P. Joshi, composite structures, Dr. Kent Lawrence, structural dynamics, Dr. Frank Lu, experimental fluid dynamics, and Dr. Ijaz Parpia, computational fluid dynamics. and Dr. B.P. Wang, structures and design optimization.

The educational program in hypersonic aeronautics is of sufficient breadth to address the important technologies necessary for the development of hypersonic flight vehicles. The current full-time faculty have substantial expertise in the areas of high-temperature gasdynamics, hypersonic aerodynamics, air-breathing propulsion, computational and experimental fluid dynamics, high-temperature materials, composite structures, and flight dynamics and controls. Additional expertise is available in the areas of hypersonic vehicle systems integration and design optimization in the form of part-time faculty members from the local aerospace industry. By combining the available talents of both the full and part-time faculty, we are able to offer a broad range of courses in hypersonics.

The research program is designed to complement the educational program by providing opportunities for students to become involved in cutting-edge research topics of current interest. Due to the existence at UTA of a unique capability in high-temperature gasdynamics, materials, and structures, the research program focuses on these specific areas. The individual projects are designed to increase understanding of underlying physical phenomena, and to develop improved experimental and computational techniques for modeling these phenomena. Thus, the results of these investigations should be relevant to current and future NASA and DoD programs involving a wide range of specific hypersonic flight vehicles.

The principal objective of the NASA/UTA Center is the training of students to provide a pool of technical specialists for support of future national programs in hypersonics. Thus the recruitment and training of highly qualified graduate students is an effort of highest priority. Currently, we have a total of 13 graduate students directly involved in the hypersonics program. Their names, educational background, and areas of technical interest are summarized in Table 1. Additionally, we have supported seven undergraduate research assistants in the program - two of whom have gone on to become participants in the graduate program in hypersonics. All of the students involved in the hypersonics program participate in a regular seminar series, which includes presentations from invited experts in the field of hypersonics on topics of current national interest, and from participating faculty and graduate students who discuss on-going research programs at the Center.

The University of Texas at Arlington is ideally suited to be a major center for hypersonic research. UTA is centrally located in the Dallas/Fort Worth region, which includes major aerospace companies such as BEI Defense Systems, Bell Helicopter TEXTRON, E-Systems, Lockheed Fort Worth Company, Loral Vought Systems Corporation, Texas Instruments, and Vought Aircraft Company. The Lockheed-Fort Worth Company (LFWC) is actively participating in the operation of the Center by providing financial support, technical advice, and assistance in developing specialized courses in hypersonic vehicle design. Several of the other companies in the area are providing support to specific technical projects. The Center also collaborates closely with appropriate technical staff members at the NASA-Langley, Lewis and Ames Research Centers, and is establishing a co-op program with the Navel Surface Warfare Center.

Educational Program in Hypersonics

Educational Philosophy

The study of hypersonics requires a substantial background in a number of fundamental areas. For example, specialization in hypersonic aerodynamics requires a solid grounding in the fundamental subjects of classical potential flow theory, gas dynamics, boundary layer theory, heat transfer, computational and experimental fluid dynamics, and applied mathematics. Because of this background requirement, we do not recommend designing programs at the B.S. or M.S. level specializing in hypersonics. A far better educational philosophy is to insist on a thorough grounding in necessary fundamentals. This approach provides the best possible foundation for advanced work and is also the best long-term investment even for students who do not continue past the B.S. or M.S. level. For this reason, these degree programs continue to stress fundamentals and only introductory courses in hypersonics are offered as part of the educational program. Major emphasis on those areas specifically associated with hypersonics are at the Ph.D. level.

The graduate program in hypersonic aeronautics offers specialization into either hypersonic fluid dynamics, including aerodynamics, aerothermodynamics, and propulsion, or high-temperature materials and structures. Building upon a solid base of fundamental courses in aerodynamics, propulsion and flight dynamics, the doctoral program in hypersonic fluid dynamics emphasizes hypersonic flow theory, high-temperature equilibrium and non-equilibrium gas dynamics, molecular and radiation gas dynamics, and gas-material interactions. The program is heavily weighted toward viscous, real gas behavior in the high Mach number range. The course sequence in hypersonic aerodynamics consists of a single introductory offering in classical inviscid theory followed by a course in hypersonic viscous flow of a perfect gas. In this way, the concepts of weak and strong interaction, entropy layers and vorticity effects can be clearly elucidated without the additional complications introduced by real gas and gas-solid interface problems. Equilibrium and non-equilibrium phenomena are covered in a two-semester sequence in high-temperature gasdynamics, stressing in-depth understanding of the fundamental physics, development of mathematical models, and applications to both aerodynamics and propulsion. These courses are normally followed by courses in molecular and radiation gasdynamics. A course introducing experimental techniques for hypersonic aerodynamics has been developed to provide the working tools necessary for conducting experimental research. Finally, a series of courses covering hypersonic air breathing propulsion and flight dynamics and control rounds out the educational program in hypersonic fluid dynamics.

The educational program in high-temperature materials and structures also builds upon the solid base of fundamental courses in structural mechanics and materials at the M.S. level. This program has an interdisciplinary curriculum with equal emphasis on materials and structures fundamentals. The material science course sequence consists of two introductory courses in engineering materials followed by a course in thermodynamics of materials. The structures course sequence consists of courses in fundamentals of composites, structural dynamics, theory of plates and shells, structural optimization and finite element methods. These courses are followed by specialized subject material in high temperature composites, creep and oxidation of materials, continuum damage modeling, and design of structures subjected to thermal gradients.

A new course in Hypersonic Vehicle Design is being developed in cooperation with Lockheed technical staff members to introduce the students to the system integration and design synthesis process required to produce an effective vehicle design. All students in the program are expected to take this course.

The program of study for the M. S. degree requires a minimum of 24 hours of approved courses, including 6 hours of mathematics, and

6 hours of credit for thesis. The Doctoral program requires an additional 45 hours of approved courses, including 9 hours of mathematics, and 24 hours of credit for dissertation.

Research Program

We have chosen to adopt a more focused approach to the development of the research part of the program. UTA occupies a unique position among universities in the US in that we have committed substantial resources to the development of modern experimental hypersonic aerodynamic and aerothermodynamic research facilities, as well as facilities for research in computational fluid dynamics, and high-temperature materials and structures. Thus the research part of our program is designed to utilize this capability and focus on in-depth research that addresses critical problems associated with the high-temperature aspects of sustained hypersonic flight. Specific technical areas include hypersonic aerodynamics, aerothermodynamics, propulsion, structures and materials. The program emphasizes the development of fundamental physical understanding and employs a combined analytical, computational, and experimental approach. The individual research projects have been configured to concurrently support the proposed educational program by providing challenging thesis and dissertation topics for the graduate students supported by the training program. Each student works with a faculty member on a research project every semester. Research is the most important component of any graduate program and student participation and interaction with faculty on a one-on-one basis is the single most important element of this program. All faculty and students affiliated with this effort are expected to perform high-quality research and publish the results of this research.

Brief summaries of the current research projects are given below. Principal investigators are listed in parentheses behind the project title.

Shock-Induced Boundary Layer Transition (Prof. Frank Lu)

The objective of this project is to experimentally define the flow field conditions at which a laminar boundary layer will transition to turbulent flow as a result of shock impingement on the laminar boundary layer. The experimental investigation is being conducted in the UTA Hypersonic Shock Tunnel. Parametric variations of Mach number, Reynolds number and shock strength (via the shock angle α) will determine the interaction behavior in terms of a scaling parameter $M_\infty{}^a/Re_L{}^b$, where a and b are positive constants. Experimental data consists of surface pressure and heat transfer measurements, pitot probe surveys, and schlieren flow field visualization.

Effect of Chemical and Thermal Nonequilibrium on the Performance of Hypersonic Propulsion Nozzles (Prof. Don Wilson)

The objective of this project is to experimentally characterize the effect of chemical and thermal nonequilibrium on both the design point and off-design performance of hypersonic propulsion nozzles. Specific goals include the development of improved techniques for simulation of hypersonic propulsion nozzle flow fields (pressure, temperature, velocity and chemical composition), evaluation of hot flow (full chemistry simulation) vs. cold flow techniques using argon-freon mixtures to simulate specific heat ratio variations, assessment of the relative importance of nozzle pressure ratio, velocity ratio free stream Mach number, flow chemistry, and flow uniformity on nozzle testing, and evaluation of the effect of chemical and thermal nonequilibrium on nozzle performance. The tests will be conducted in the 1.6 MW DC electric arc heater facility in the Aeropropulsion Lab at UTA., Nitrogen/water vapor mixtures will be used to simulate the flow chemistry of a hydrogen-air combustor. Experimental data will include surface pressure and heat flux measurements, total pressure and enthalpy probe flow field surveys, and schlieren flow field visualization.

Development of Pulsed Detonation Wave Engine Concepts (Prof. Don Wilson)

The objective of this project is to develop a new pulsed detonation wave engine concept for application to supersonic and low-hypersonic speed propulsion systems. Specific goals include definition of potential operating cycles for the PDE engine, experimental testing of a *cylindrical/coannular PDE research engine*, experimental determination of the effect of combustor geometry, various fuel injection and ignition schemes, fuel/oxidizer combinations and mixture ratios, turbulent mixing enhancement and fuel injection/ignition frequency on PDE performance, and comparison of experimental results with CFD code predictions. Experimental data will consist of surface pressure, temperature and heat flux measurements, wave speed via time of flight measurements, fuel/oxidizer flow rates, and the igniter current, voltage, power and frequency characteristics. The single-cycle test program has been initiated, and successful detonations have been achieved with near stoichiometric propane/oxygen and hydrogen/oxygen mixture ratios.

Investigation of Unsteady Flow in Shock-Shock Interactions (Prof. Ijaz Parpia)

Peak heating and pressure load caused by shock/shock interaction is a key issue in the design of hypersonic vehicles. Extreme peak values of heat transfer and pressure on the surface can badly damage the structure of a vehicle in hypersonic flight. In this project, the Edney type IV interaction is numerically studied by using a 2-D full Navier-Stokes Equation code, using an equilibrium air-gas model.

To fully understand the unsteady nature of the type IV interaction, several physical phenomena are being investigated. The first is the transient phenomenon associated with the complicated flow pattern generated by double impinging shocks which interact with the strong bow shock in front of a blunt body in hypersonic flow. Since the way the flow started (initial condition) determines the transient process, a full nozzle (from reservoir to the model mounted in test section) starting process is simulated to calculate the real time needed for the flow to develop. The time-accurate simulation and analysis of the unsteadiness of the single impinging shock generated type IV interaction is also being considered. Cases are being studied that include a wide range of Mach numbers as well as different gas models.

Application of Optimization Techniques to IR-Seeker Window Design (Prof. Dale Anderson)

Instrumentation employed in numerous applications in the hypersonic flight regime relies on sensing infrared radiation. IR sensors are normally mounted as front or side looking devices where the sensing aperture is made of a high IR transmissivity material. In hypersonic flight, the aerodynamic heating of the sensor windows may obscure the target signal and prevent acquisition. However, if the temperature distribution in the window can be controlled for a given flight trajectory, any errors due to window heating can easily be accounted for with a minimum of effort. The goal of this project is to produce a window design that produces a given temperature distribution of a given shape once a flight trajectory is specified. The optimization of the window shape involves the coupling of the aerothermodynamics with the heat transfer in the window, and optimizing the window shape to minimize the difference between the temperature distribution and a target distribution.

3D Chemical Nonequilibrium CFD Code Development (Dr. Ganesh Wadawadigi)

The development of a 3D chemical non-equilibrium CFD code for performing tip-to-tail CFD simulation of both external and internal flow paths for hypersonic air-breathing flight vehicles is being continued. The 3D upwind parabolized Navier Stokes (UPS) code, contains a variety of turbulence models (Baldwin-Lomax, Hung *et al.* and Jones-Launder) and chemistry options (perfect gas, equilibrium air, non-equilibrium air, and nonequilibrium hydrogen-air). The code was validated by comparison with results from several experiments involving supersonic shear layer mixing and combustion, and will be used to generate CFD solutions to compare with experimental results from the hypersonic nozzle flow experiment described earlier.

Optimal Sizing of Composite Panels Exposed to Combined Thermal and Acoustic Environments (Profs. Bo Wang and Wen Chan)

The objective of this project is to develop and validate methods for optimal design of composite panels exposed to combined thermal and acoustic loadings. An automated methodology is being developed for sizing actively-cooled composite panels to meet fatigue life and thermal design constraints. Optimization methods being considered include classical non-linear programming methods, modern heuristic search methods, and response surface methods. Simplified analytical models will be developed for thermal/acoustic stress analysis and fatigue life predictions. The methodology developed under this project will be validated by test data to be supplied by LFWC.

Design and Analysis of Fin Structures for U.S. Army Hypersonic Missile (Profs. Wen Chan, Pranish Aswath and A. Haji-Sheikh)

The objective of this project is to understand failure modes and develop new analysis and design models for hypersonic missile fin structures. Specific goals include understanding the failure modes and constitute behavior of the microstructures of the ceramic matrix composite (CMC) and metal matrix composite (MMC) interface section and the MMC hinged structure, developing experimental techniques to measure CTE at elevated temperatures, and developing validated analytical models for residual stress analysis, and quantification of the effects of stress gradients in the area of geometric discontinuities. Improved design configurations for missile fin structures will be proposed.

Thermophysical Properties of Composite Materials at Elevated Temperatures (Profs A. Haji-Sheikh and Shiv Joshi)

The objective of this project is to develop improved techniques for measurement of thermophysical properties of composite materials in the temperature range from 1000 to 1500°K. Specific techniques to be developed include an optical interferometric method for thermal expansion coefficient, steady-state heat conduction analysis using temperature measurements from a guarded hot plate for thermal conductivity, gravimetric techniques for density, and inverse heat conduction analysis following calculation of thermal diffusivity for specific heat. The optical equipment required for the thermal expansion coefficient measurements was donated by Motorola Corporation.

Thermomechanical Analysis of Composite Heat Exchanger Panels (Profs. Kent Lawrence and Wen Chan)

The goal of this effort is to develop design optimization techniques for composite heat exchanger panels. Structural analysis models for a composite heat exchanger panel are being developed for MSC XL and NASTRAN. The models are nonlinear for both heat transfer and stress analysis. The nonlinearity is due to the temperature dependent material properties and the use of gap elements to model the air gap between the coolant tube and composite material. Grid point temperatures from the thermal analysis are output to a file that is imported into the structural analysis model. A partial factoral design of experiment method (Taguchi method) has been selected as the optimization technique and appropriate values for the design parameters (tube spacing, air gap, distance from top of tube to top of plate, and vertical thermal conductivity) have been specified.

Analytical Methodology Development for High Temperature Composites Under Thermomechanical Loads (Prof. Wen Chan)

The objective is to develop analytical methods capable of analyzing high temperature composite structures with damage. Specific goals include the development of an analytical method for predicting the influence of matrix cracking on titanium metal matrix composites, development of laminate constitutive relationships for composites with ply damage and delamination between plies, and development of analytical methods for prediction of fatigue life. An analytical model was developed for predicting the stiffness loss due to the presence of matrix cracking in the metal matrix composites under thermomechanical loads.

Experimental Characterization of β-21/SCS-6 Composites (Prof. Pranish Aswath)

The objective of this effort is to experimentally characterize the properties of β-21/SCS-6 composites. A study of the weight gain/loss characteristics of the neat matrix material and the composites in the temperature range of 500-700°C in air and pure oxygen has been conducted for times up to 100 hours, using a Perkin-Elmer Series 7000 Thermogravimetric Analyzer. The kinetics of the oxidation process and characteristics of the oxide formed were investigated by means of scanning electron microscopy, electron probe microanalysis, Auger electron microscopy, and optical microscopy. A study of the interfacial reactions at the fiber/matrix interface on long time exposure at the above mentioned temperatures was conducted. The oxidation behavior of the matrix followed a parabolic oxidation behavior while the composites exhibit a weight loss due to burn up of the graphite core during oxidation. Future studies will include a study of the creep behavior of the composite at a fixed temperature but at different stress levels. The creep testing system is currently being upgraded to be able to look at tensile creep behavior at temperatures up to 800°C.

Processing, Electrical and Mechanical: Properties of Blackglas™ Matrix Ceramic Matrix Composites (Prof. Pranish Aswath)

The purpose of this program is to determine the processing, electrical and mechanical properties of Blackglas™ matrix ceramic matrix composites. Specific goals include the determination of the role of processing variables, such as cure pressure, pyrolysis temperature, and pyrolysis environment, in the manufacture of Nicalon™ and Nextel™ fiber reinforced composites and their effect on the laminate electrical properties, and to determine the mechanical and thermomechanical behavior of coated and uncoated Nicalon™ and Nextel™ fiber reinforced composites for high temperature structural applications. To date, various panels of the Blackglas™ matrix composites have been processed, X-band dielectric constants have been evaluated before and after 500 hours of exposure at 1000°C, and both room temperature and 1000°C flexure properties have been measured.

Processing and Mechanical Properties of *In-situ* Whisker Reinforced Silicon Nitride-Barium Aluminosilicate Ceramic Matrix Composites (Prof. Pranish Aswath)

Specific goals of this project include an investigation of the processing and phase transformation kinetics in the Barium Aluminosilicate (BAS) - Silicon Nitride (SIN) system, and determination of the mechanical properties of the BAS - SIN ceramic matrix composite. To date, a series of composites with 30, 40, 60 and 70 percent BAS were sintered for different times to develop material for phase transformation and mechanical tests, two weeks were spent at Oak Ridge national Laboratory to perform HTXRD, DSC, DTA and Dilatometry testing, flexure tests have been performed at both room and elevated temperatures. The kinetics of the α to β transformation within the SIN was found to follow Avrsmi's rate equation. The chemistry involved in the processing of these composites is currently being examined, and possible chemical reactions are being identified.

Smart Structural Design of a Hypersonic Missile Fin (Prof Shiv Joshi)

The objective of this project is to develop smart materials, such as shape memory alloys, for application to control surfaces for steering hypersonic missiles. Specific goals include the identification of the transient loading environment and the mesoscale composite actuation configurations, design of a smart structural fin, fabrication of an experimental model and performance of concept validation experiments. This project has just begun, and work is in progress towards identification of the transient loading environment.

Facilities

The research facilities at UTA that will be available for use to support the NASA/UTA Center for Hypersonic Research include the Aerodynamics Research Center, the Materials and Structures Research Laboratories, and the Heat Transfer Laboratory. Descriptions of the facilities are provided in this section.

Aerodynamics Research Center

The Aerodynamics Research Center occupies a 1000 square meter laboratory complex housing the experimental test facilities, central control room with an adjoining computer room for data processing, model shop, instrumentation lab, and adjoining staff office complex. The principal laboratories consist of the Low Speed Wind Tunnel Lab; High Speed Aerodynamics Lab, containing transonic, supersonic and hypersonic wind tunnels; and the Aeropropulsion Lab. The test labs have microprocessor-based data acquisition and control systems, and are equipped with modern optical flow visualization and diagnostics capability as well as standard force, pressure and heat transfer measurement systems.

Low Speed Wind Tunnel

The low speed wind tunnel is a conventional closed-circuit, continuous-flow tunnel with a 0.61 x 0.91 m test section and a speed range of 0 to 50 m/sec. It is equipped with an Aerolab 6-component pyramidal strain-gage balance system, and a three-component sting balance. Both closed and open jet test sections are available. A modified test section is also available for propulsion system-aerodynamic interaction research, and a Tech Development Model 602 engine simulator (GE CF-6) is available for programs of this type. The data system consists of a Hewlett-Packard Model 3497A data acquisition system, interfaced to an IBM-compatible 486DX2/33 computer. An Aerolab smoke flow visualization system is also available.

High-Reynolds Number, Transonic, Ludwieg Tube Wind Tunnel (HIRT)

The HIRT tunnel was obtained from the Air Force Arnold Engineering Development Center (AEDC) and placed into operation in January 1984. The capabilities of the tunnel include a Mach number range of 0.5 to 1.2, with a corresponding Reynolds number range of $4X10^6$ to $40x10^6$ per meter. A unique capability of the HIRT tunnel is the ability to independently vary Mach and Reynolds numbers over the full operating range. The test section size is 18.5 x 23.2 cm, and the 34 m length of the charge tube provides continuous flow for approximately 120 msec. The porous walls minimize shock wave reflections from the tunnel walls as well as provide for substantial alleviation of tunnel wall interference. The porous wall design also allows acceleration to low supersonic Mach numbers with a fixed-area ratio convergent nozzle.

A DSP Technology High-Speed Data Acquisition and Control System interfaced via an IEEE-488 GPIB bus to an IBM-compatible 486DX2/66 host computer is used to operate the tunnel.. The DSP Technology system provides 48 channels for data acquisition (pressure transducer, strain gage or thermocouple input) and 16 output channels for facility control. The system is based on a sample-and-hold concept, and provides simultaneous sampling of all 48 channels at a frequency of 100,000 samples/sec. The system has 12-bit accuracy, with dedicated variable-gain amplifiers and A/D converters for each channel. Optical windows are available in all four walls of the tunnel at the center-of-model rotation point, and conventional schlieren and laser holographic interferometry flow visualization systems are available.

Supersonic Ludwieg Tube Wind Tunnel

This facility is currently under development, and will utilize a variable area nozzle, test section and diffuser system donated to UTA by the LTV Aerospace and Defense Company in conjunction with a spare charge tube and starting valve obtained from AEDC with the transonic Ludwieg tube. The nozzle is based on the AMRAD flexible plate nozzle concept, and provides continuous Mach number variation over a range from 1.5 to 4.0, with Reynolds number capabilities of up to $20x10^7$ per meter. The steady flow time will be about 80 msec. The test section size is 15 x 15 cm, and can be configured as a closed jet test section for aerodynamic testing, or a semi-open jet test section for propulsion inlet or nozzle testing. Optical windows are located in the side walls of the test section. This facility will utilize the same data acquisition system and optical support system as the transonic tunnel.

Hypersonic Shock Tunnel

The hypersonic shock tunnel achieved operational status during the summer of 1989 and since then has been used extensively to investigate hypersonic shock-boundary layer interactions in support of the NASP Program. The shock tunnel uses either a Mach 8 contoured nozzle coupled to a 20 cm diameter test section, or a conical nozzle with interchangeable throat inserts to provide a

Mach number range from 5 to 16. The conical nozzle mates to a 33 cm diameter test section. Both nozzle/test section assemblies and the corresponding diffuser sections were donated to UTA by the LTV Aerospace and Defense Company. These components are coupled to a high-pressure (400 atm), helium-air shock tube driver and appropriate vacuum system developed at UTA. The driver is 3 m in length and 15 cm in diameter, whereas the driven tube is 8.25 m in length and 15 cm in diameter. The tunnel routinely operates in the "equilibrium" mode and provides run times in the 1-2 msec range. Both test sections contain optical windows, and flow visualization capability via schlieren and holographic interferometry is available as well as standard pressure, force and heat transfer instrumentation.

A LeCroy data acquisition system with a 32 channel model 8212A data logger (5kHz sampling rate) and 2 model 6810 wave form recorders (1 MHz sampling rate) is connected to an IBM-compatible 486DX2/66 computer by an IEEE-488 GPIB bus extender so that computer can be located in the control room and the data system beside the tunnel.

Shock Tube Facility

The shock tube facility employs a conventional pressure-driven tube with an area ratio of 4. The tube is capable of operation in either the conventional or reflected mode of operation. It was developed at UTA to support basic research in high-temperature gasdynamics and sensor development. Existing instrumentation includes conventional thin-film heat sensors, high-response pressure transducers, and a Hewlett-Packard two-channel digital storage oscilloscope for data acquisition. This facility can also be connected to the data acquisition system for the hypersonic shock tunnel for extended instrumentation capabilities.

Aeropropulsion Lab

The major components of the Aeropropulsion Lab include a Thermal Dynamics F-5000 2 MW DC electric arc heater, nozzle, test section, diffuser and vacuum tank; and the supporting DC power supply, cooling water, pneumatic, vacuum, and the facility instrumentation and data acquisition/control systems. The Thermal Dynamics F-5000 arc heater is vortex-stabilized and nominally rated at 2.0 MW. High pressure nitrogen gas is injected tangentially into the arc chamber through a swirl plate at the anode/cathode interface. This provides an intense vortex flow-field within the arc chamber that centers the arc between a tungsten electrode at the base of the cathode barrel and the rotating arc termination point at the entrance to the plenum chamber downstream of the anode barrel. Provisions for injection of oxygen in the plenum chamber downstream of the arc termination point are provided to create "simulated air" for the subsequent nozzle expansion. These injection ports can also be used for injection of other gases to simulate the exhaust chemistry of hydrocarbon-air or hydrogen-air combustors for research programs involving hypersonic propulsion nozzle flow-field studies.

The test section is a standard free-jet design. The nozzle exit diameter is 20.3 cm, and the free-jet test section length from the nozzle exit to the diffuser entrance cone is 61 cm. The diameter of the test cabin is 76.2 cm. Provisions for insertion of diagnostic probes or models are provided by means of a 25 cm diameter port hole on the top of the test cabin or a 40.6 by 61 cm model support plate in the bottom of the test cabin. Optical ports of 25.4 cm diameter are provided on each side of the test cabin to allow flow-field visualization via holographic interferometry or standard schlieren photography. A closed-jet test section, 20.3 cm in diameter and 91.4 cm long is also available, if needed.

A Hewlett-Packard model 3852S Data Acquisition/Control System, connected via an IEEE-488 interface bus to an IBM-compatible 486/DX2-66 host computer. Twenty channels of low-speed data acquisition (12-bit/5.5 kHz) for facility monitoring, and twenty-four channels of moderate-speed data acquisition (12-bit/100 kHz) for model instrumentation are available. In addition, the data acquisition systems for the impulse facilities in the adjoining High-Speed Aerodynamics Lab are available for special tests requiring high data rates.

Support Facilities

A large central air compressor system that was obtained from the U.S. Army Aeroflight-dynamics Lab at the NASA Ames Research Center provides dry air at a pressure level of 200 atm (3000 psi) and a flow rate of 57,000 l/min(2000 cfm). The compressor, together with two smaller compressors, is located in a 200 square meter building adjoining the main laboratory building. A well-equipped model shop and instrumentation lab is also located at the ARC.

Materials and Structures Research Laboratories

A broad variety of facilities are currently available at UTA which are used for research in high-temperature materials and structures. Most of these facilities have been acquired since 1980,

Thermal Analysis

DuPont 9900 thermal analysis equipment: DSC, TMA, TGA and DMA, Perkin-Elmer Series DSC, TGA and TMA Perkin Elmer-2400 CHN elemental analyzer,

Microscopy

JEOL-1200 EX scanning transmission electron microscope with Link AN 10,000 EDAX system, Cambridge Stereoscan 120 scanning electron microscope with KEVEX Delta I energy dispersive spectroscopy system, JEOL JSE-35 scanning electron microscope with Tracor Northern 2000 EDS system, CAMICA Electron Microprobe with XPS, Back Scattered & Secondary Electron Detector, KRONOS Auger Electron Microscope, Olympus BHTM optical microscope with Nomarski attachment and Monitor for image analysis, Optical microscopy, Porter-Blum ultramicrotome, Anatech Hummer VI-A vapor deposition unit, Edwards Carbon deposition unit, Lecomet materials sectioning unit, CRC-100 sputtering unit, Gatan Series 600 DuoMill with CAIBE attachment, Gatan dimple grinding unit, Gatan ultrasonic disc cutter.

Processing

Thermal Equipment Corp. computerized autoclave (850°F, 325 psi, 3' X 6' internal size), carver hot press, laboratory autoclave (850°F, work area 13" X 13" X 36"), hot wire anemometer system.

Mechanical Testing

100, 20, 5 kip MTS and Instron servohydraulic test systems instron tensile tester, 2.5 kip Instron high-rate servohydraulic system, computerized data acquisition system, ATS high temperature furnace with 3 and 4 point SiC bend fixtures for the 20 kip Instron servohydraulic machine, QM-1 high powered telescope system from Questar to monitor crack growth, high density video camera, video monitor and recorder to record crack growth information.

Damage Characterization Facilities

Cabinet X-ray System, Ultrasonic Imaging System.

Sensing and Control Facilities

Laser vibrometer, instrumented impact facilities, Concurrent real time Unix work station, high voltage amplifiers for piezoceramic actuators, multimeter and function generators.

Surface Analysis

Front view Low Energy Electron Diffraction System, Reverse view Low Energy Electron Diffraction System, Electron Induced Auger Electron Spectrometer, Positron Annihilation Induced Auger Electron Spectrometer, Ultra-High Vacuum Scanning Tunneling Microscope, Air Environment Scanning Tunneling Microscope, Perkin-Elmer X-Ray Photoelectron Spectrometer.

Heat Transfer Laboratory

HP 35852A data acquisition system with 80 channel input and 4 channel signal analyzer; HP-9000/300 data acquisition system; Dantec single channel Laser-Doppler Anemometer, National Instrument data acquisition (2 units) with AT-MIO-16, AMUX-64T (64 channels), GPIB, and LabWindows; FLUENT/BFC software by CREARE.X; Image processor with video camera; high pressure water pump (350 psi); high pressure compressor (200 psi).; and miscellaneous instruments, signal analyzers, oscilloscopes, etc.

Computing Resources

Computational resources available to support the research programs of the Center include the Computational Fluid Dynamics Center facilities, consisting of a network of 13 Sun workstations, and the departmental facilities which include Sun, Next, and Apollo workstations.

The Academic Computing Center operates a VAX 8800 (VMS), 2 IBM 4381 (MVS) and a CONVEX C-220 (UNIX) computers. Also a CRAY 4-MP8/864 (UNICOS) at the UT System Center for High Speed Computing is accessible to all UT System users. UTA also has access to the supercomputer facilities of the National Aerodynamic Simulation Facility at NASA-Ames Research Center for projects supported by the Center.

Concluding Remarks

The NASA/UTA Center for Hypersonic Research represents a major effort at The University of Texas at Arlington to contribute to the development of modern research and education programs in hypersonics. A total of ten faculty members and two research associates are actively involved in the NASA/UTA Center. Thirteen graduate students (five Ph.D. and eight M.S.) are being supported as part of the Center program. Seven students are working on related projects under support from other sources. The Center has also supported seven undergraduate students, two of whom have gone on to become involved in the Hypersonic Program at the graduate level. New courses specializing in hypersonics have been developed, and a number of new research projects have been initiated. The faculty and graduate students are beginning to publish results from the research programs, and have been active in presenting briefings to industry and government lab technical staffs. Additional sources of funding are being continually sought to provide an expanded research base for support of the critical mass of graduate students needed to develop and maintain a viable program in hypersonics.

The research and educational opportunities made available by the NASA/UTA Center for Hypersonic Research will contribute to building a valuable resource of highly-skilled scientists and engineers to support continued involvement of the nation's aerospace industry in future hypersonics programs.

Table 1
Graduate Student Profile

PhD

Steve Quander High Temp. Materials
BSMSE - Brown University
MSMSE - UT-Arlington

Chris Roseberry Hypersonic Propulsion
BSME - Texas Tech University
MSME - Texas Tech University

Mark Mellinger Heat Transfer
BSME - Northern Arizona University
MSME - UT-Arlington

Scott Stuessy Propulsion (PDE)
BSAE - UT-Arlington
MSAE -UT-Arlington

James August Composite Structures
BSME - Temple University
MSAE - Pennsylvania State University

MS

John Myklebust Aerodynamics (CFD)
BSAE - Iowa State University

Ken Pistone BLTransition (Exp)
BSAE - Univ. of Southern California

Dan Beall Thermomechanics
BSME - Auburn University

Steve Stanley Propulsion (PDE)
MSAE - Texas A&M University

Brian Venable Aerodynamics (CFD)
BSAE - UT-Arlington

Jason Spivey Composite Structures
BSAE - Texas A&M University

Karl Burge Propulsion (PDE)
BSAE - UT-Arlington

Mark Linteau High-Temp. Materials
BSME - UT-Arlington