PROPULSION DIRECTORATE

Monthly Accomplishment Report
April 2002

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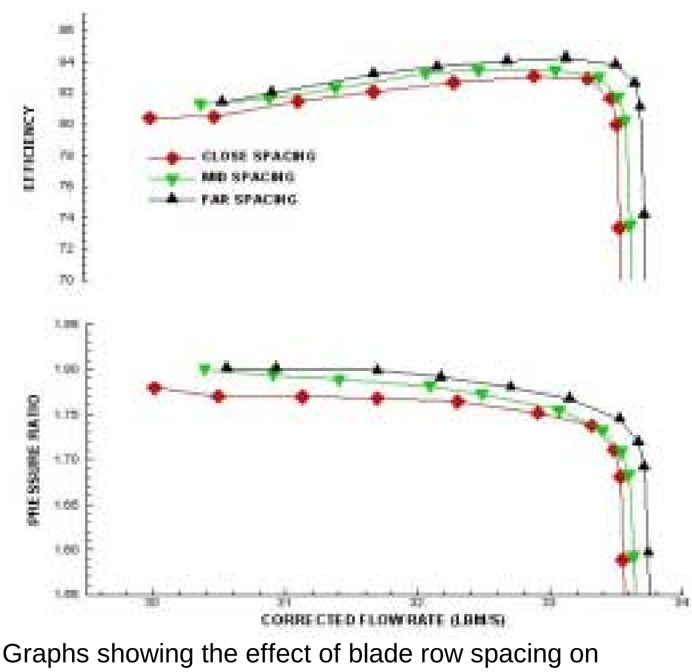
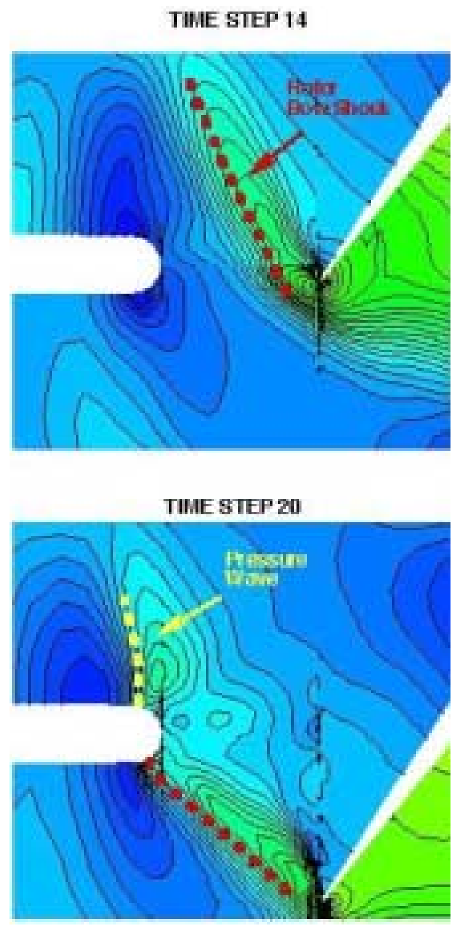
STRIDES IN PLASMA RESEARCH BENEFIT HYPERSONICS: Researchers in the Propulsion Directorate's Electrical Technology and Plasma Physics Branch (AFRL/PRPE) have recently made significant progress under an AFOSR-supported task titled "Collisional Plasma and Discharge Physics." Strides have been made in two in-house research areas: (1) Laser Diagnostics of Energetic Nitrogen Species, and (2) Ionization and Ion-Molecule Reaction Rates Applicable to Combustion. This research is providing valuable benefits to programs under the National Hypersonics Strategy. The study of energetic or "excited" nitrogen with laser diagnostics has provided benefits to many fields of research and development including research into magneto-hydrodynamic (MHD) electrical power for hypersonic vehicles. Significant progress has been made toward defining the distribution of excited nitrogen states within an energized airflow by the development and refinement of various laser techniques for detecting excited states of atomic and molecular nitrogen. Ionization may play a significant role in spark ignition of fuels, which in-turn may be important for efficient hypersonic combustion. The PRPE in-house group has recently reported the first comprehensive set of ionization cross sections and ion-molecule reaction rates for the prototypical fuel molecules octane and decane. In addition, measurements of ionization cross sections of NO_2, a common pollutant in combustion, have just been completed and are being prepared for publication. This project was recently named the Propulsion Directorate In-House Project of the Quarter. The following individuals were honored as part of the winning team: Drs. Charles DeJoseph and Steve Adams, and Mr. Anthony DeCerbo of AFRL/PRPE, and Drs. Charles Jiao and James Williamson of Innovative Scientific Solutions, Inc. (J. Weimer, AFRL/PRPE, (937) 255-6235)

Members of the PR In-House Project of the Quarter Team (from L to R): Dr. Jiao, Dr. Williamson, Dr. DeJoseph, Dr. Adams, and Mr. DeCerbo

IN-HOUSE RESEARCH REVEALS LOSS SOURCE IN TRANSONIC COMPRESSORS: Research performed by the Propulsion Directorate's Compressor Research Group has shown that blade-row interactions have a significant impact on the performance of a transonic compressor stage. This research addresses some of the technical challenges that make it difficult to meet IHPTET (Integrated High Performance Turbine Engine Technology) and VAATE (Versatile Affordable Advanced Turbine Engines) objectives for increased stage loading and efficiency. Experimental measurements from the Stage Matching Investigation (SMI) rig acquired at the Compressor Aero Research Lab (CARL) document how mass flow rate, pressure ratio, and efficiency all decreased significantly as the spacing between a stator blade-row and a rotor blade-row was reduced. A numerical simulation of the SMI rig at close and far spacing using a three-dimensional, viscous, time-accurate code reveals a previously unidentified loss producing mechanism resulting from the interaction of the transonic rotor blade-row with an upstream stator blade-row. At close spacing the rotor bow shock is chopped by the stator trailing edge. The chopped bow shock becomes a pressure wave on the upper surface of the stator that is nearly normal to the flow and that propagates upstream. In the reference frame relative to this pressure wave, the flow is supersonic; thus, a moving shock wave that produces additional loss is experienced. At far spacing the rotor bow shock degenerates into a bow wave before interacting with the stator trailing edge and no significant pressure wave forms on the stator upper surface. For this condition, no additional loss is produced. For close axial spacing between blade rows, factors affecting the strength of the moving pressure wave and resultant loss production are the local flow velocity near the stator trailing edge upper surface and the rotor bow shock strength at the location it interacts with the stator. This research demonstrates the importance of considering blade-row interactions when designing transonic fans and compressors because the consequent penalties in performance can be significant. (S. Gorrell, AFRL/PRTF, (937) 255-4738)



Graphs showing the effect of blade row spacing on efficiency and pressure ratio



Computational results showing the interaction of the rotor bow shock with the stator

<u>LUBRICATION RESEARCHERS WIN STLE'S BISSON AWARD</u>: Drs. Lewis Rosado and Nelson H. Forster of the Propulsion Directorate's Mechanical Systems Branch (AFRL/PRTM) were selected as the 2002 recipients of the prestigious Edmond E. Bisson Award. The Society of Tribologists and Lubrication Engineers (STLE) presents the Bisson Award for the best written

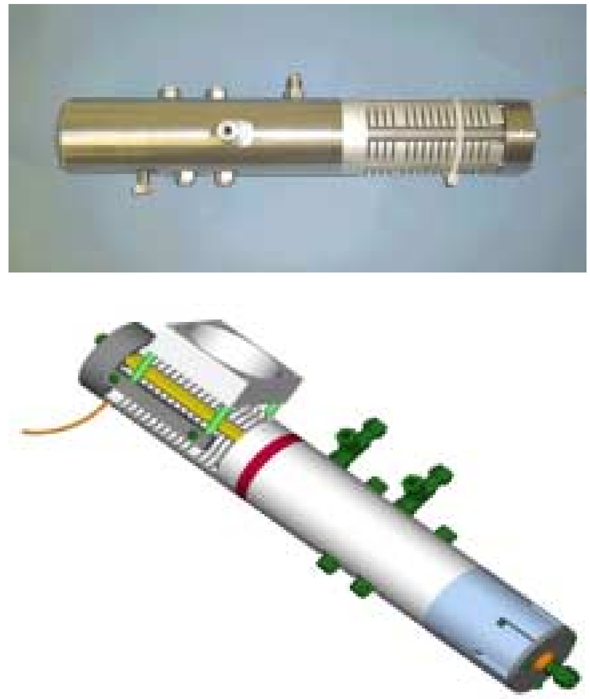

Drs. Nelson H. Forster (L) and Lewis Rosado (R) recently won STLE's prestigious Bisson Award

technical contribution published by a member of STLE in a Society publication during the preceding year. The award winning paper, titled "Solid Lubrication of Silicon Nitride with Cesium-Based Compounds: Part I – Rolling Contact Endurance, Friction, and Wear," was published in STLE's *Tribology Transactions* journal. Dr. Rosado was the lead author on the paper, and Dr. Forster, Mr. Hitesh K. Trivedi (UES), and Dr. James P. King (Desilube, Inc) were co-authors. This paper defined a new state of the art in high-temperature solid lubrication of ceramics for limited life components. It is notable that this paper was selected for the Bisson Award from a field of some 300 papers. The award will be presented on 21 May 2002 at STLE's Annual Meeting in Houston, Texas. (L. Rosado, AFRL/PRTM, (937) 255-6519)

Want more information?

- More information on STLE and the Bisson Award is available at www.stle.org.

ACTIVE COMBUSTION CONTROL FUEL VALVES READY FOR DEMONSTRATION: Scientific Monitoring Inc (SMI), a small business with expertise in advanced fuel control systems, has completed performance testing of a novel High Response Fuel Valve (HRFV) under a SBIR Phase II program managed by the Propulsion Directorate's Turbine Engine Division (AFRL/PRT). Accomplishments under this program include development of three advanced high frequency fuel valves, actuators, and controls for a turbine engine augmentor application. PRT is leading the development and fabrication of high flow, HRFV technology, which are key components for achieving active control of the engine combustion process. Active combustion control is a high payoff technology with the potential to reduce engine production, maintenance, and development cost. The technology will enable increased engine thrust-to-weight ratio; a key figure of merit for both IHPTET (Integrated High Performance Turbine Engine Technology) and VAATE (Versatile Affordable Advanced Turbine Engines). Ongoing in-house and contracted combustion test programs at NASA and Pratt & Whitney will incorporate HRFV hardware. Recent combustion testing makes a case that the HRFV has the capability to track combustion instability. This necessitates a component that can potentially vary its frequency and phase of operation. Because the HRFV provides proportional (continuous) control of the fuel flow, it potentially meets this difficult challenge. This flexibility also allows operation on a variety of test rigs and engines without design modification. Developing high response fuel controls for the turbine engine is a difficult problem because of the need for both high flow and high modulation capability. SMI's piezoelectric actuated valve employs a novel bending cylinder flow control device, which enables modulating 20% of the fuel flow at the required pressure and mean flow rate of 2,000 pounds per hour. Performance of the Phase II valve was improved over five times compared with the Phase I prototype. Conclusion of the bench test at SMI is the first step in demonstrating HRFV technology. Delivery of the hardware to the Air Force is expected by the end of April 2002, followed by installation on Pratt & Whitney's PRDA-VI Active Combustion Control test rig. Future demonstrations of the HRFV hardware are planned for testing on an F119/SE engine. (K. Semega, AFRL/PRTA, (937) 255-6741)



The High Response Fuel Valve (top) and a 3-D model of the valve (bottom)

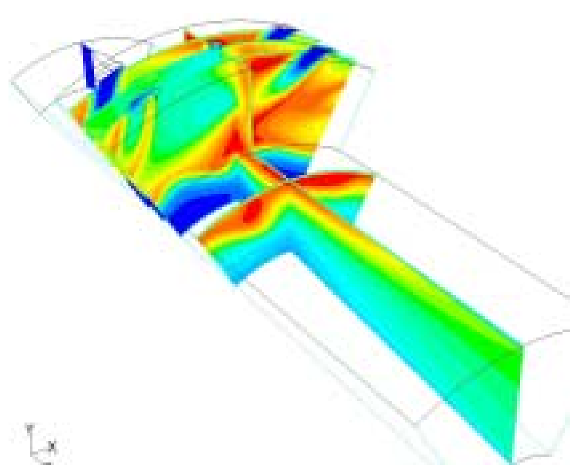
<u>SCRAMJET REFERENCE DOCUMENT PUBLISHED</u>: In early April 2002, CPIA Publication 710 (1st Edition), "Scramjet Propulsion Testing Recommended Practices and Guidelines," was released. Both the Propulsion and Air Vehicles Directorates provided substantial support to the development of this document, both in terms of personnel and funding. AFRL was the single largest contributor to the document, with 18 of the 54 individuals acknowledged as contributors to the document being either AFRL personnel or on-site contractors. Significant contributions to the document were also made by various NASA centers (NASA Langley Research Center, in particular), other government agencies, industry, and academia. This comprehensive document is the first of its kind on the ground testing of scramjet engines, and it is expected to be a valuable resource to researchers in the burgeoning field of hypersonic airbreathing propulsion. Work has already commenced on the 2nd Edition of CPIA Publication 710, with the ultimate goal of maturing the document into a set of standards on scramjet engine testing. On 9 April 2002, three Propulsion Directorate personnel were honored by the JANNAF Airbreathing Propulsion Subcommittee (APS) for their work on this document. Mr. Edward Gravlin, PR Emeritus, received the APS Sustained Contribution Award for his efforts. In addition, Dr. F. Donald Stull and Mr. Jeff Pearce, both PR on-site contractors with Universal Technology Corp, received the APS Outstanding Achievement Award. (J. Pearce, AFRL/PRA (UTC), (937) 255-5451)

<u>Want more information?</u>

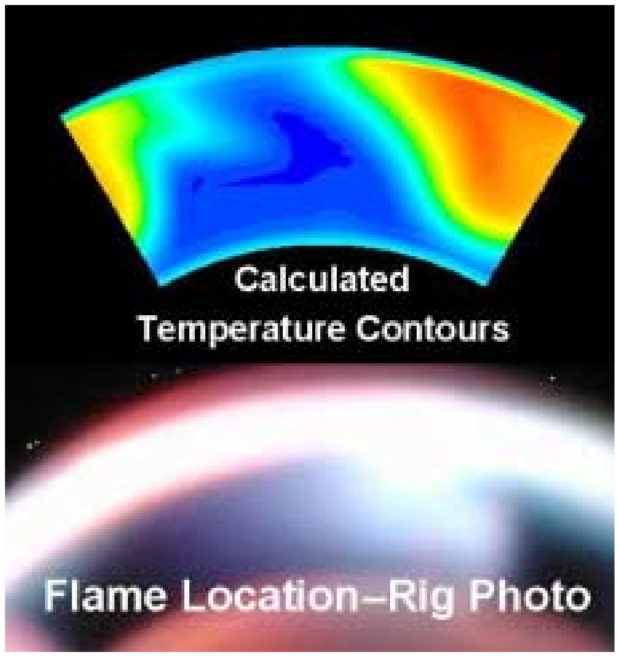
- ❖ Information on ordering CPIA Publication 710 or other CPIA/JANNAF publications is available at the following website: http://www.cpia.jhu.edu/Publications/pubs.html.

<u>PRTS ENHANCES MODELING AND SIMULATION CAPABILITIES</u>: The Propulsion Directorate's Combustion Science Branch (AFRL/PRTS) has enhanced its modeling and simulation (M&S) capability by using the FLUENT computational fluid dynamics (CFD) code as

part of the preliminary combustion design process. This code will be used to optimize combustion system performance and to aid in understanding the physical processes involved in combustion. Simulations of PRTS's atmospheric Ultra-Compact Combustor (UCC) concept are complete. The results of the CFD simulation have been validated using test data from baseline combustor tests conducted in the Atmospheric Pressure Combustor Research Complex (APCRC) located at Wright-Patterson AFB, Ohio. Comparison of the calculated temperature distribution at the exit of the UCC with digital photographs of the combustor during rig tests has been accomplished. The CFD predictions are in good qualitative agreement with the test results. The validated code is now being used to iterate on the design parameters to improve combustion performance. Recent tests, coupled with CFD analysis, have provided a direction that future modifications to the UCC will follow. The code will be used to predict the aerodynamic flowfield, pollutant emissions formation, combustion efficiency, and exhaust gas temperature distribution. Initial design iterations are focused on fuel injection techniques and location and size of air injection ports. PRTS has teamed with Parker Hannifin Gas Turbine Fuel Division to investigate fuel injector spray angle and injector air swirl. Several fuel injector designs will be investigated using the CFD code before hardware fabrication is initiated. Testing will be conducted with several configurations to further validate the CFD code. PRTS will continue to use this M&S tool to improve the UCC/ITB design, and to identify key combustor design parameters that impact combustion performance. (1Lt J. Ehret, AFRL/PRTS, (937) 255-8623 and J. Zelina, AFRL/PRTS, (937) 255-7487)



Calculated temperature field inside the UCC at different plane locations



Calculated temperature profile at the combustor exit compared to a digital photograph at the same location

CAPACITATING STRUCTURES BECOMING A REALITY: In-house work performed by the Air Vehicles and Propulsion Directorates has proved the concept of integrating composite materials and cylindrical capacitor technology into airframe structures for unmanned aerial vehicles (UAVs). This work is documented in a report titled "Structurally Integrated Textile Capacitor" (AFRL-VA-WP-TR-2001-3015, February 2002) which was co-authored by AFRL/VA's William Baron and Maxwell Blair and AFRL/PR's Sandra Fries-Carr. These structures can provide a tremendous amount of power that can be used to operate a host of on-board systems, such as communications, surveillance, sensors, or even weapon systems. The structures are fabricated by weaving the capacitor "wires" through the composite. This composite capacitating structure weighs no more than one composed of standard aircraft structural composites. The "wires" can be electrically connected in series or parallel to obtain the voltage/capacitance required to operate a particular system. Depending on the combined load, many systems could feasibly be operated from the energy stored in the structure. Batteries could be used to charge the structure, as could the static charge generated in flight or even photovoltaic cells. This concept has the potential to reduce the energy storage system weight on selected UAVs by hundreds of pounds, free up valuable space within the aircraft, and offer tremendous savings in fuel consumption and operating costs. The imbedding of electrical conductors is a concept proven in earlier applications, such as wire imbedded into fabric for heated suits or blankets, or resistance wire in automobile windshields for a defrosting/defogging function. However, the incorporation of electrical capacitor elements within a woven structural fabric had not been previously demonstrated. The vendor, Phelps-Dodge, has produced thousands of feet of FPE (Flourene Poly Ester)-coated capacitor "wires" for use in creating these fabrics. Experimental results have been extremely promising thus far, and the construction of Marx Bank/PFN circuits using this structural concept is now proceeding. The authors of the technical report filed for a patent on this invention on 28 March 2002. This pending patent is titled "Airframe Structure Integrated Capacitor" and was assigned the provisional number 60/279,532. (S. Fries-Carr, AFRL/PRPE, (937) 255-6016)

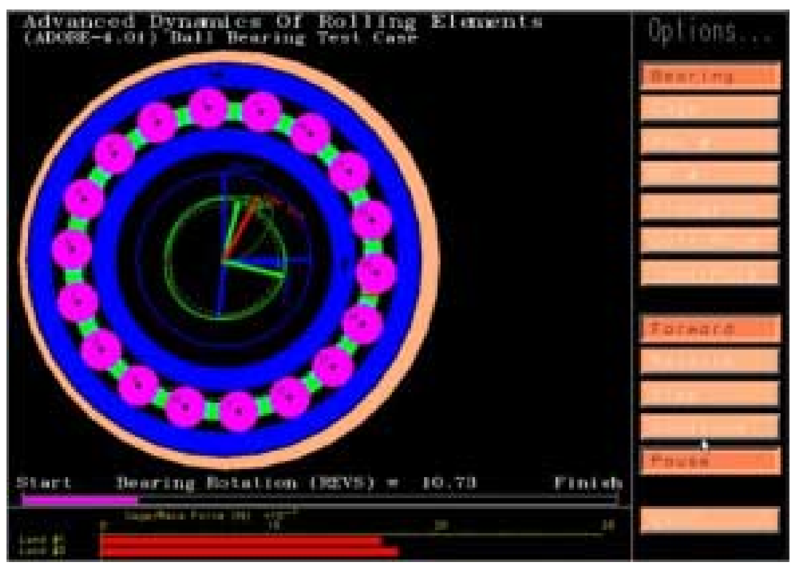
Examples of the woven structure

<u>SPACE MATERIALS RESEARCH EARNS PhD FOR GONZALEZ</u>: In April 2002, Capt Rene Gonzalez successfully defended his PhD in Chemical Engineering from the University of Florida. Capt Gonzalez, a researcher in the Propulsion Directorate's Propulsion Materials Applications Branch (AFRL/PRSM) at Edwards AFB, California, performed his doctoral research on the development, testing, and mechanistic investigations of Space Survivable POSS (polyhedral oligomeric silsesquioxanes)-polymers. One of the highlights of his research was showing the in-situ formation of a protective SiO_2 (silicon dioxide) layer when POSS-Kapton is exposed to a simulated Low Earth Orbit environment. This results in a 9-fold improvement in erosion resistance. While completing his PhD, Capt Gonzalez led a team that earned accolades as the Propulsion Directorate's Project of the Month for October 2001. This team succeeded in

Capt Rene Gonzalez

having several POSS-polymer samples tested in space as part of the Materials for the International Space Station Experiment (MISSE). MISSE was deployed in August 2001, and the various material samples on-board are being exposed to the space environment for a period of one year after which they will be examined for degradation. Congratulations to Capt Gonzalez for this noteworthy academic achievement. (S. Phillips, AFRL/PRSM, (661) 275-6270)

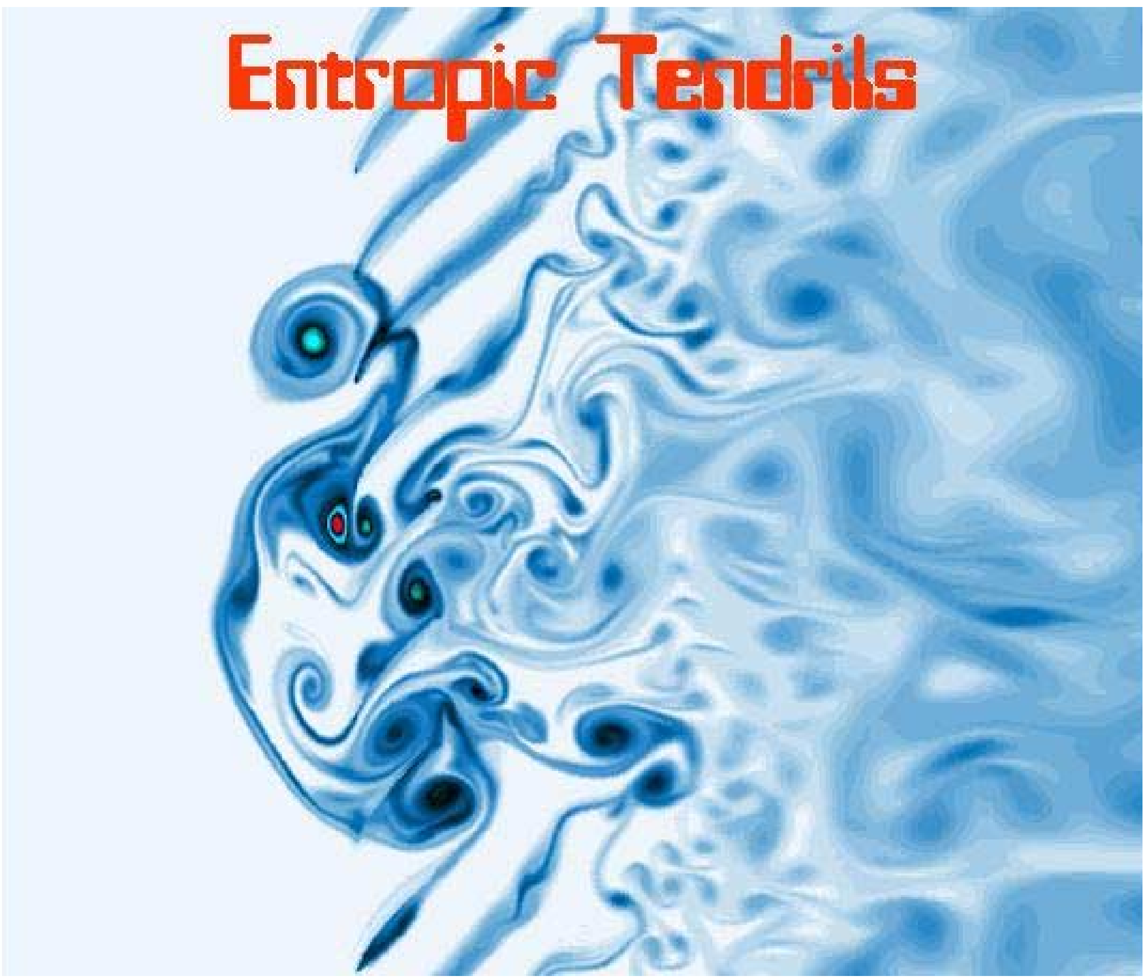
CRITICAL BEARING ANALYSIS SOFTWARE ENHANCED: PKG, Inc made their final presentation on the "Thermal Interactions in Rolling Bearing Dynamics" program to the Propulsion Directorate's Mechanical Systems Branch (AFRL/PRTM) on 12 April 2002. This effort, which began as a Phase II Small Business Innovation Research (SBIR) program in 1996, included a complete re-write and conversion of the Advanced Dynamics of Rolling Elements (ADORE) software from Fortran-77 to Fortran-90. A key enhancement to the code is the ability to use bearing heat generation and boundary conditions to determine a bulk bearing temperature and the associated changes in bearing geometry such as internal clearance. Other critical enhancements to the software included generalized equilibrium formulations and incorporation of an enhanced fatigue life model. Validation of these predictions is critical, and much of this work will be accomplished in-house in AFRL/PRTM. The ability to link the bearing code with ANSYS finite element software has been demonstrated in AFRL/PRTM, and this capability can provide excellent comparison data for the ADORE validations. The ADORE software is a key part of AFRL/PRTM's in-house bearing analysis efforts. (J. Brown, AFRL/PRTM, (937) 255-7477)



A sample screen in the ADORE software

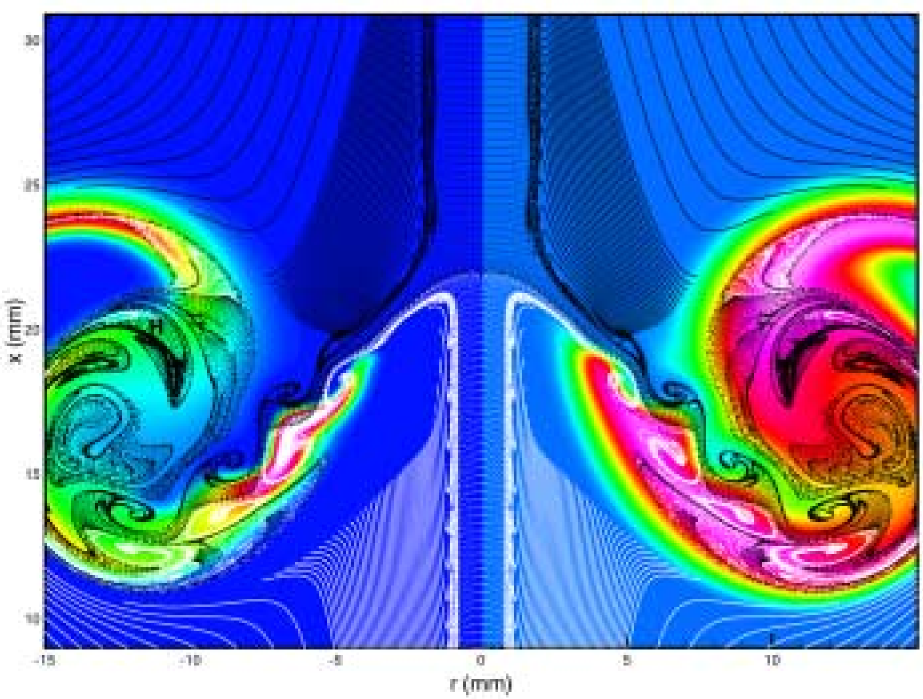
PR SWEEPS ART-IN-THE-SCIENCE AWARDS: The Propulsion Directorate swept the Art-in-the-Science Awards at the 27th Annual Dayton-Cincinnati Aerospace Science Symposium held in Dayton, Ohio, on 5 March 2002. The American Institute for Aeronautics and Astronautics (AIAA) sponsors this symposium, which for many years was known as the "AIAA Mini-

Symposium." Drs. William Copenhaver and Dave Car of the Turbine Engine Division (AFRL/PRT) carried the day with their submission titled "Entropic Tendrils." This entry shows the unsteady simulation of a stalling compressor blade row. Marlin Vangsness of the University of Dayton Research Institute, who works on-site with AFRL/PRT, took second place with his entry titled "Photomicrograph of partially crystallized JET A1 with 1.4% added hexadecane." The third place winner, titled "Crash and Burn," was submitted by a team including Drs. Vish Katta and Terrence Meyer of Innovative Scientific Solutions, Inc (ISSI) and Drs. James R. Gord and W. Melvyn Roquemore of AFRL/PRT. This entry shows processes that take place during turbulent combustion by overlaying vortical structures on maps of the temperature field (right) and hydrogen radical concentration (left). The winners will be formally recognized at the Dayton-Cincinnati Section AIAA Annual Honors and Awards Program to be held at the University of Dayton on 22 May 2002. (J. Gord, AFRL/PRTS, (937) 255-7431)



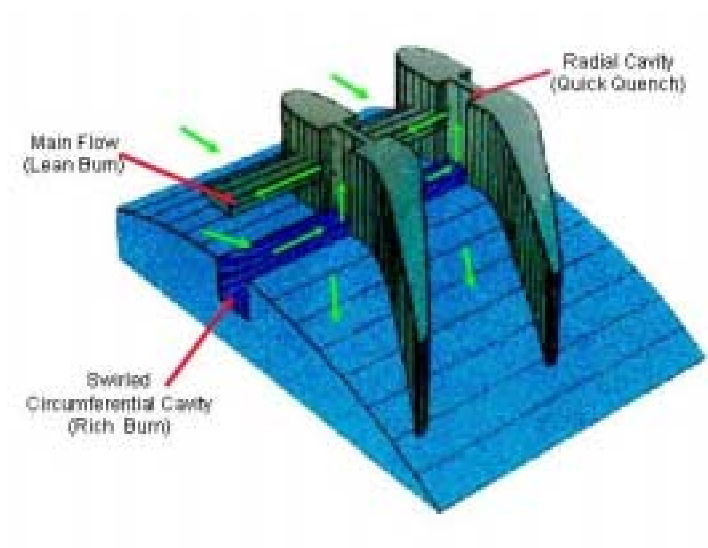
First Place - "Entropic Tendrils" - Unsteady simulation of a stalling compressor blade-row. Flow is normally left-to-right in the figure. However, as the exit back pressure is increased the flow along the surface of the airfoils in the center of the blade-row breaks down, and large scale separation occurs. This is evident by the contours of high entropy level that propagate upstream of the blade-row. This region of separated flow will propagate along the blade-row as it rotates from the top to the bottom of the figure.

Second Place - "Photomicrograph of partially crystallized JET A1 with 1.4% added hexadecane."

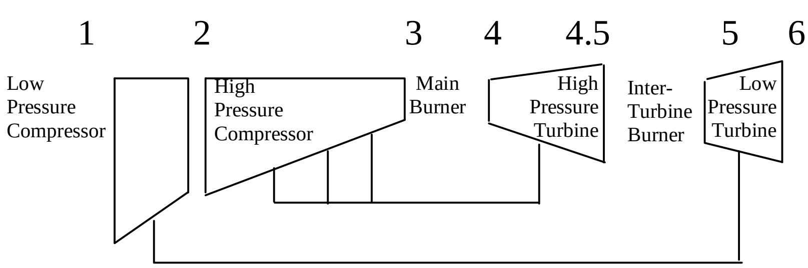


Third Place - This figure shows processes that take place during turbulent combustion by overlaying vortical structures on maps of the temperature field (right) and hydrogen radical concentration (left).

HIGH BYPASS RATIO INTER-TURBINE BURNER CYCLE ANALYSIS: A collaborative effort between the Propulsion Directorate's Engine Integration and Assessment (AFRL/PRTA) and Combustion Science (AFRL/PRTS) Branches and Innovative Scientific Solutions, Inc (ISSI) has been initiated to assess the feasibility of an Inter-Turbine Burner (ITB) enhanced high bypass ratio transport engine. The ITB concept involves the addition of a combustor between the high and low pressure turbines. The ITB permits a temperature rise which is capable of generating large amounts of available shaft power on the low pressure spool. This additional power may be used in conjunction with a lower peak (turbine rotor inlet) temperature to create an engine with the same thrust and nearly the same specific fuel consumption. This enhancement over a conventional engine has the potential to reduce NO_x emissions while simultaneously increasing hot section life and lowering operating costs. Preliminary results show that a 400°F drop in peak temperature can be achieved with less than a 2% penalty in specific fuel consumption. This cycle has characteristics that may allow it to be both smaller and lighter in configuration compared to the conventional cycle configuration. Such an engine may also be less expensive to produce due to reduced material and parts count. The lighter weight may also make up for the increased fuel consumption when studied at the system level. PRTS has contracted ISSI through a SBIR effort to quantify the benefits of the ITB cycle. PRTA will support the effort by providing cycle performance throughout the flight envelope for both conventional and ITB configurations. ISSI will use the data to do configuration layouts to account for weight and/or size differences and to quantify the system level benefits through a mission analysis. Since this type of study has not been accomplished before, the results will provide a significant insight into the possible benefits of the ITB cycle and will aid in defining the direction of future AFRL resources. (S. M. Gahn, AFRL/PRTA, (937) 255-4778)

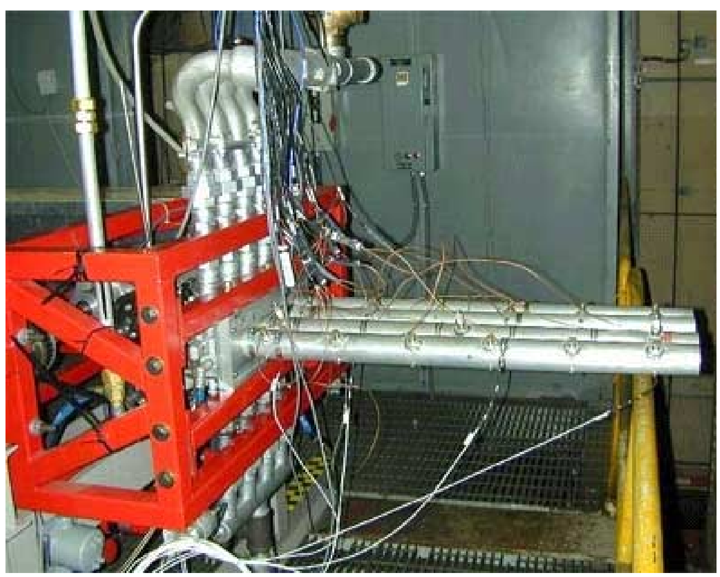


Ultra-Compact Combustor integrated vanes

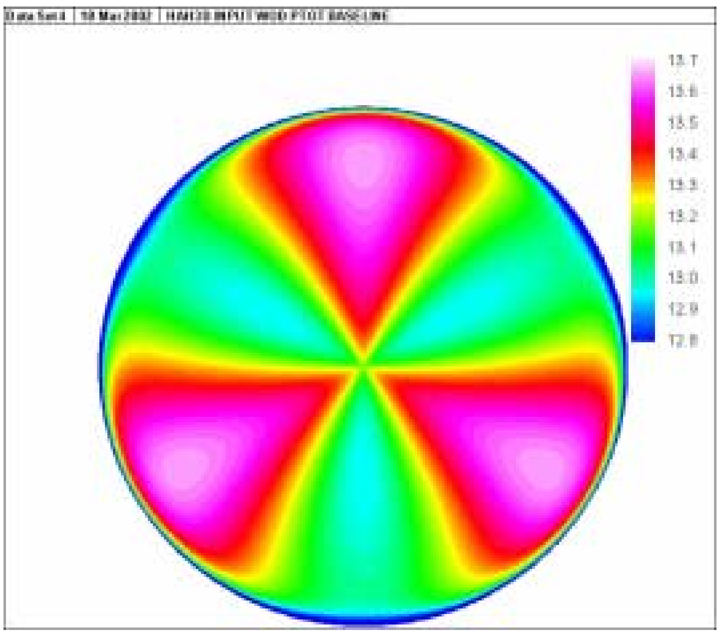


Inter-Turbine Burner Engine Schematic

PULSED DETONATION PERFORMANCE MODEL DEVELOPMENT: Pulsed detonation has been the subject of much renewed interest, particularly within the Propulsion Directorate's Turbine Engine Division (AFRL/PRT). A number of different engine components and configurations which incorporate pulsed detonation have been proposed, and in some cases investigated experimentally. The Engine Integration and Assessment Branch (AFRL/PRTA) has developed an in-house model to predict the performance associated with a variety of plausible pulse detonation concepts, such as pulsed detonation combustors, augmentors, and duct burners. The in-house model is sufficiently detailed to allow comparison with experimental data, including that generated by Dr. Frederick Schauer's team within the Combustion Science Branch (AFRL/PRTS). Predictions of the in-house model have also been compared with those of other contractor-developed pulsed detonation models, as this is helpful in determining the impact of various modeling assumptions on the validity of the results. Virtually all pulsed detonation concepts, including those that have been proposed for use with turbomachinery, consist of rapidly fired detonation chambers that are cylindrical in shape. The in-house model assumes a simple-geometry detonation chamber, attached to which are an inlet valving system and an exhaust nozzle. Gross thrust (FG), net thrust (FN), thrust specific fuel consumption (TSFC), and gross thrust nozzle coefficient (CFG) are among the parameters calculated at each time step by the model. These parameters are time-averaged for one complete cycle to calculate overall cycle performance in a manner that is consistent with turbine engine convention. The performance model has been and will continue to be used to conduct trade studies to investigate the impact of various pulsed detonation design parameters and operating conditions on overall performance. The effects of tube geometry, nozzle area ratio, equivalence ratio, and operational flight conditions have thus far been estimated with the in-house model. Continued enhancement to PRTA's pulsed detonation performance model will involve the utilization of additional experimental data and the consideration of a wider range of operating conditions and design parameters. Of particular interest is the behavior of individual pulsed detonation components in turbomachinery. With a compressor upstream and a turbine downstream of a pulsed detonation combustor, for example, the thermodynamic performance and the aerodynamic flowpath become unrelated to those of the conventional "steady-flow" problem. PRTA's Analysis Group will use their in-house model to ensure that projected performance improvements due to pulsed detonation from a variety of sources are realistic. (G. Bruening, AFRL/PRTA, (937) 255-4798 and N. Kuprowicz, AFRL/PRTA, (937) 255-5258)


The in-house pulsed detonation engine rig

MODEL CREATED FOR INLET FLOW STUDY: A mathematical model of the inlet flow total pressure of the ADLARF/CRFER (Advanced Damping Low Aspect Ratio Fan/Compressor Research Facility Experimental Rig) transonic compressor has been created. This model will be used to generate specific inlet flowfields that create forcing functions for the HAH3D CFD program. The CFD program will then be used to determine the transient blade loading on the compressor. The resulting blade load data is used to evaluate blade response and high cycle fatigue resistance. Although any flowfield can be generated, the model has been used to develop a three-cycles-per-revolution distortion pattern that has been used in testing to intentionally send distorted flow into the compressor. The inlet flow model can be easily changed to represent higher or lower levels of flow distortion. Different model sets will be run in the CFD program to determine how blade loading changes with changing distortion. After the effects of total pressure are studied, this technique will be used to study other flow parameters such as swirl, temperature, and turbulence. It is anticipated that this study, conducted at the Propulsion Directorate's Compressor Research Facility in cooperation with NASA Glenn Research Center, will provide an understanding of the level of importance of different inlet flow parameters in transient transonic compressor blade loading. Ultimately, these results will be used to improve the high cycle fatigue test protocol. (G. Ostdiek, AFRL/PRTE, (937) 255-6802, ext. 402)



Mathematical model of the inlet total pressure for a transonic compressor

SHEA NAMED EMPLOYEE OF THE MONTH FOR MARCH: Mrs. Jeanette Shea of the Information Technology Branch (AFRL/PROI) has been named PR's Employee of the Month for March 2002 in the Staff Support category. Mrs. Shea spearheaded the FY02 data call for PR-West. In this role, she ensured appropriate rollover of all continuing projects, documented current project information in PR-West's MIS System, and obtained annual progress reports to update DTIC. As part of this process, she discovered serious software errors in the DTIC reporting system, and she is helping to rectify these errors to ensure that DTIC reflects accurate information for programs Air Force wide. While these data call activities were occurring, Mrs. Shea also worked with Lt Col Hamrick to monitor and coordinate on all of the in-house research program summaries for the Space and Missile Propulsion Division (AFRL/PRS). She developed a method to allow both Lt Col Hamrick and herself to simultaneously update the progress of a summary as it was transferred for signature approval between Branch, Experimental Operations, Safety, and Programs prior to being forwarded to the PR Chief Scientist. Mrs. Shea also served as the team leader to identify and track all case files in preparation for the AFRL Management Assistance Visit (MAV). The spreadsheets she developed greatly simplified the


Mrs. Jeanette Shea

inspection process, and her efforts in tracking case files have helped PR-West determine the exact status and location of all case files. In addition, she assisted in the training of all PR-West employees in case file management. Finally, Mrs. Shea formed and led the team that put on the best ever PR-West Awards Banquet. This banquet required extensive after hours duty, and largely due to Mrs. Shea's tireless efforts, the banquet was a tremendous success. The Edwards AFB invited Commanders were so impressed with Mrs. Shea's organizational skills that they have sought her advice on similar functions within their own organizations. (E. Koppisch, AFRL/PROI, (661) 275-5346)