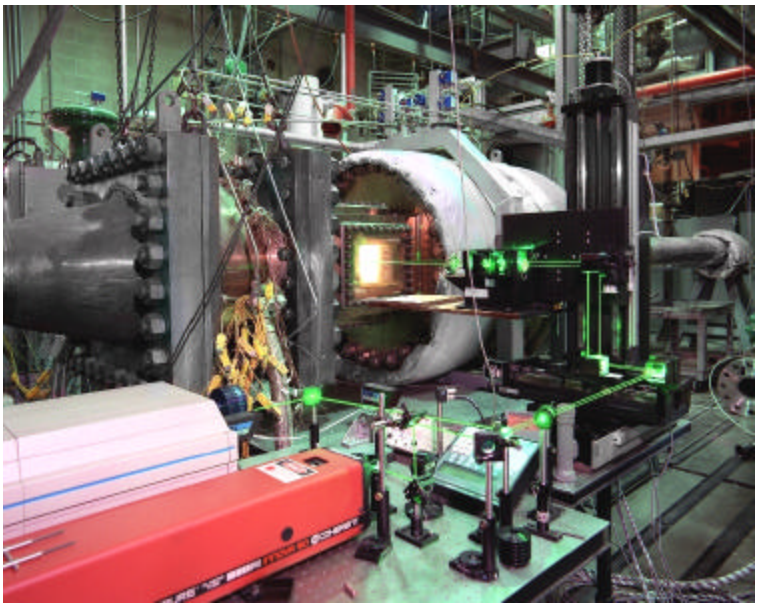
ACCOMPLISHMENT REPORT

PROPULSION DIRECTORATE
August 1999

COMBUSTOR CONCEPT EVALUATION COMPLETED: Testing of four different Trapped Vortex Combustor (TVC) geometries in the Propulsion Directorate's High Pressure Combustion Research Facility was completed in June 1999. During this testing, which commenced in July 1998, Combustion Branch (AFRL/PRSC) engineers collected performance, stability, and temperature data for each of the four 12-inch sector geometries over a range of conditions. Tests were conducted at pressures ranging from 3 psia, simulating an altitude of about 40,000 feet, to 300 psia with inlet air temperatures ranging from 70°F to 1150°F. The TVC sectors logged over 250 hours of hot test time during the program. The test results have demonstrated the feasibility of the TVC for both military and commercial gas turbine applications. The TVC is an innovative combustor concept conceived to improve flame stability and reduce undesirable emissions (e.g., NO_x, volatile organic compounds, and carbon monoxide). The TVC's simple geometry also offers the potential benefit of reduced production cost. (D. Shouse, AFRL/PRSC, (937) 255-4636)



The Trapped Vortex Combustor is tested in the High Pressure Combustion Research Facility

CRYOGENIC CERAMIC MULTI-LAYER CAPACITORS: The Propulsion Directorate's Electrical Technology Branch (AFRL/PRPE) has funded an extremely successful research program to develop "one-of-a-kind" cryogenic capacitors. The cryogenic ceramic devices operate at liquid nitrogen temperatures (77 K or -321°F) and feature extremely high dielectric constants, low dissipation factors, and low relaxation times. At cryogenic conditions, these devices can obtain a dielectric constant of 16,000 while a typical ceramic provides a dielectric constant of only 2,000 with the same dissipation factor. These devices also offer tremendous reductions in capacitor size and weight. This cryo-ceramic capacitor technology will have tremendous benefits for both ground-based and/or space-based systems. These devices appear to be suitable for DC filtering applications as well as energy storage and quick pulse-power energy delivery. Potential applications for this technology include space-based lasers (SBL), high power microwaves (HPM), Marx banks, and directed energy weapons (DEW). This

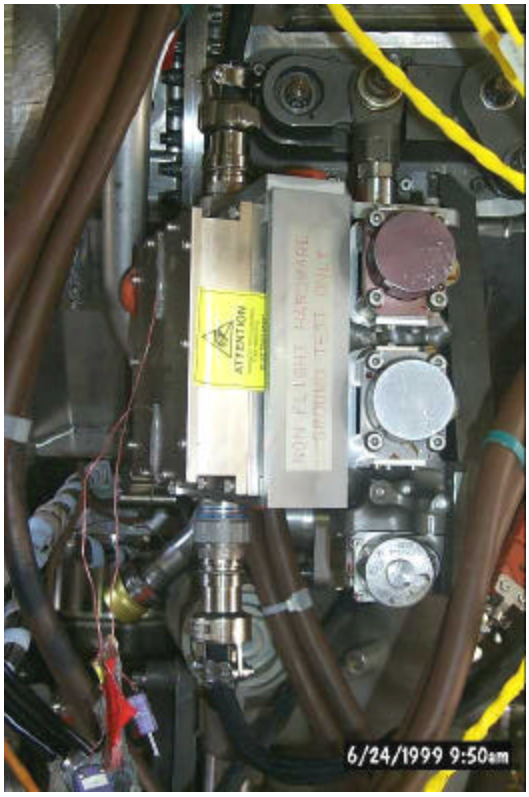
cryogenic technology will also provide capacitor devices that will alleviate many problems associated with utility uninterruptible back-up power systems. Interest from corporations such as Liebert and American Electric Power has been enough to provide substantial supporting funds to enhance the research outlay of PRPE. Liebert is the world's largest supplier of uninterruptible power supply (UPS) systems. The worldwide UPS market is approximately $4 billion, of which the domestic US market is

$1.2 billion. (S. Fries Carr, AFRL/PRPE, (937) 255-6016)

Comparison of Cryogenic Multilayer Capacitor with late '80s capacitor technology

FIRST EVER DEMONSTRATION OF A HIGH TEMPERATURE SMART ACTUATOR: The High Temperature Distributed Control System (HiTeC) consortium has completed the first ever demonstration of a high temperature smart variable vane actuator. This demonstration was the critical milestone of the HiTeC Program, a dual-use (military and commercial) technology development agreement awarded under the 1995 Technology Reinvestment Project solicitation sponsored by DARPA. The high temperature actuator control module demonstrated is the critical component for a distributed engine control system, and distributed control is the key to achieving Integrated High Performance Turbine Engine Technology (IHPTET) Phase III Controls and Accessories' objectives for reducing weight, production cost, and maintenance cost. This two-phase demonstration was accomplished on Pratt & Whitney's (P&W's) XTE66 Joint Technology Demonstrator Engine (JTDE). During the first phase, the smart actuator was mounted on the engine test stand strongback and operated passively. It received the same Full Authority Digital Electronic Control (FADEC) position commands as the installed compressor inlet variable vane (CIVV) actuator and was monitored to

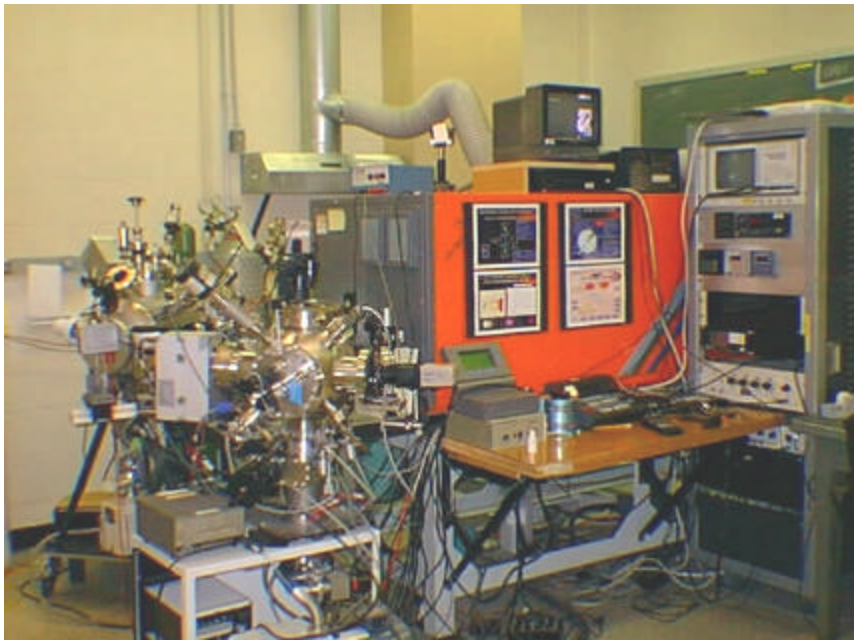
ensure that it operated identically. Once proper operation was confirmed, the "dumb" CIVV actuator was replaced with the HiTeC actuator. Upon resumption of testing, the actuator performed flawlessly as engine speed was varied from idle to military power. With testing complete, the actuator will be returned to the supplier for extended testing at 200°C to enhance the high temperature durability database initiated earlier in the HiTeC Program. (T. Lewis, AFRL/PRTA, (937) 255-6690)



The HiTeC actuator

FOIL BEARING PROGRAM INITIATED: The Propulsion Directorate's Lubrication Branch (AFRL/PRSL) recently initiated a Phase I SBIR with Mohawk Innovative Technology, Inc to develop high speed foil bearings. The kickoff meeting for the "Compliant Foil Bearings for Advanced Oil-Free Turbomachinery" was held on 14 July 1999 and was attended by representatives from the Propulsion Directorate, the Navy, and Williams International. The objective of this program is to develop high-speed foil bearings for advanced turbine engines and Integrated Power Units (IPUs). The program is structured such that hardware resulting from a successful Phase II effort will be applicable for demonstration in an Integrated High Performance Turbine Engine Technology (IHPTET) Phase III Joint Expendable Turbine Engine Concept (JETEC) engine and/or an IPU demonstrator. Compliant foil bearings support the rotor on a hydrodynamic air film, thus eliminating the need for rolling element bearings and the associated liquid lubrication system. Among the many potential benefits for turbomachinery are increased rotational speed and operating temperature, improved storability, reduced maintenance, and a 15 to 20 percent reduction in cruise missile engine cost and weight. (M. Wagner, AFRL/PRSL, (937) 255-7406)

HIGH CURRENT DENSITIES DEMONSTRATED: The AFRL Superconductivity Group, including participation from the Propulsion Directorate's Power Division (AFRL/PRP), has demonstrated current densities in excess of 1 MA/cm^2 on a YBCO (yttrium barium copper oxide) coated conductor sample. Pulsed laser deposition (PLD) of the high temperature superconducting YBCO and underlying buffers was used on textured pure nickel substrates provided by Plastronic, a subsidiary of EURUS. This result was announced during the Department of Energy's 1999 Annual Peer Review of the Superconductivity Program for Electric Systems (26-27 July 1999) in Washington DC. Representatives of Oak Ridge National Laboratory (ORNL) commented that this is the first time that this result was obtained by any group using the Rolling Assisted Biaxially-Textured Substrate (RABiTS) approach without using material or assistance from ORNL. Long lengths of the high temperature superconducting YBCO coated conductor are being developed by AFRL for use in airborne MegaWatt power generators that support directed energy weapons. (P. Barnes, AFRL/PRPS, (937) 255-2923)

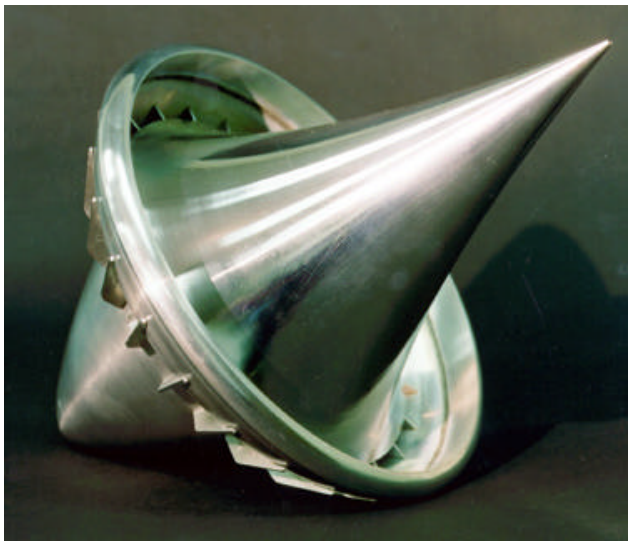


Pulsed Laser Deposition (PLD) facility

IHPTET ENGINE COST ESTIMATION TAKES ANOTHER STEP FORWARD: American Technology & Services, Inc (ATS) of Cincinnati OH has launched a 34-month program entitled "Component Cost Analysis Program (CCAP)." In this effort, a cost modeling system will estimate the complete production cost of advanced technology aircraft gas turbine engines and their components, such as the fan, compressor, combustor, turbine, exhaust nozzle, control system, and the mechanical system. The system will also provide subcomponent assembly costs. The model will forecast component costs based on size, configuration, and manufacturing process for components and major subassemblies related to Integrated High Performance Turbine Engine Technology (IHPTET) Phase III and beyond engine configurations. The CCAP system will cover a broad range of advanced material and manufacturing process technologies which are candidates for IHPTET Phase III and beyond. This program will deliver an extremely valuable tool for use by new engine designers and program managers responsible for planning future efforts. The ability to conduct "what if" exercises with a component and to assess the true savings of a proposed modification or design change will enable more informed engineering decisions to be made. (C. Skira, AFRL/PRTA, (937) 255-6690)

LIGHTCRAFT PREPARING FOR HIGHER FLIGHTS: The Propulsion Directorate's Lightcraft Technology Demonstrator recently received funding from NASA Marshall Space Flight Center to conduct experiments in "handing off." Handing off is the method by which laser light is transferred to consecutively larger telescopes during a Lightcraft launch. Initially, the laser light is directed through a small diameter telescope at the start of the launch. As the Lightcraft speeds to higher and higher altitudes, the laser light is suddenly shifted, at a prearranged altitude, to a larger diameter telescope. The larger telescope allows the beam to be appropriately focused at the higher altitudes. This focusing should enable the Lightcraft to reach much higher altitudes than in previous tests conducted without it.

The goal of the Lightcraft program is to develop a new low-cost space transportation system using a ground-based laser as the energy source for the propulsion system. The Lightcraft is being developed to launch 1 kg nanosatellites and eventually microsatellites weighing up to 100 kg into Low Earth Orbit. (C. Ousley, AFRL/PRSP, (661) 275-6346)
[For more information on the Lightcraft, see the Propulsion Directorate's Lightcraft Technology Demonstrator website at http://www.ple.af.mil/technology/lightcraft/ltd.html]

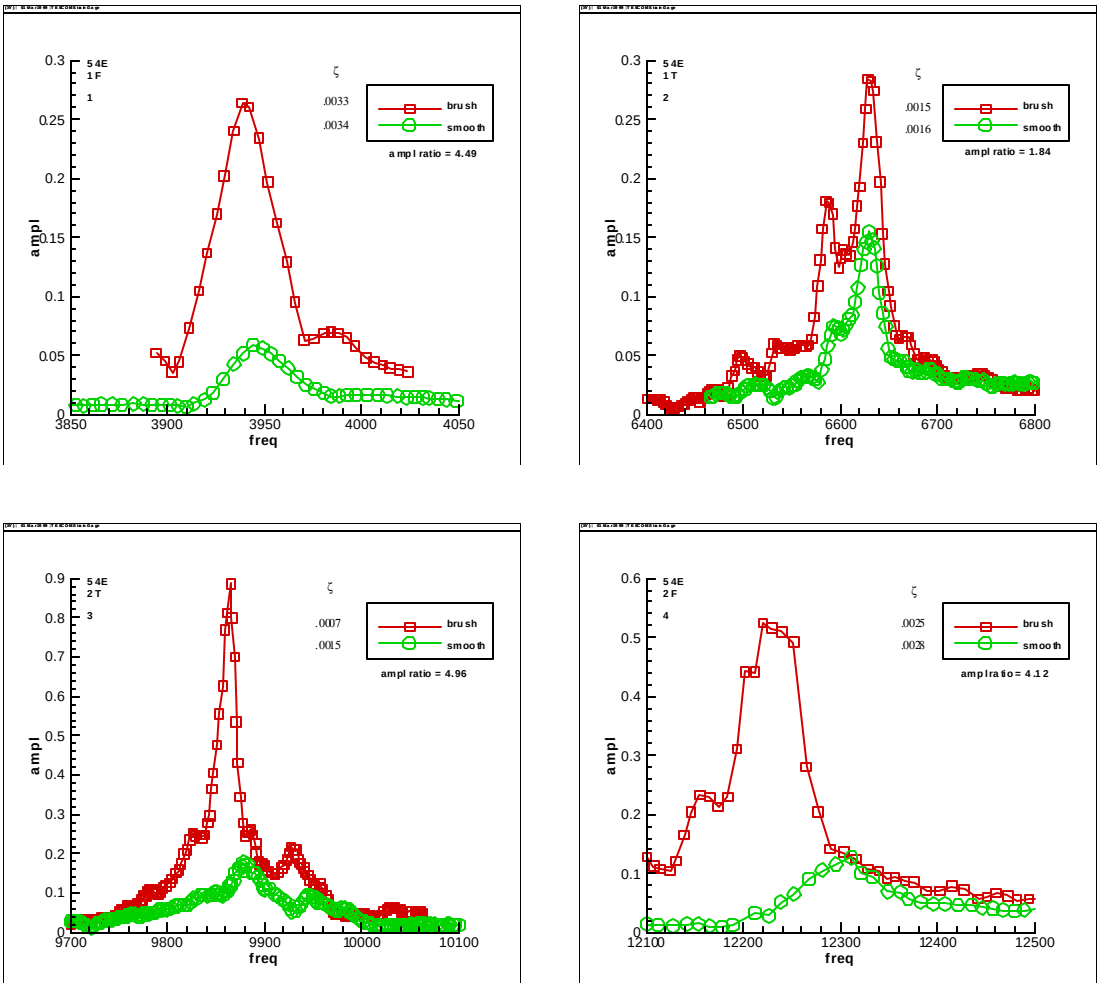


A Lightcraft model

Time lapsed photo of a Lightcraft test

INVESTIGATING THE EFFECT OF BRUSH SEALS ON COMPRESSOR BLADE LIFE: A new concept being investigated in modern compressor design is the use of brush seals to reduce the tip clearance between compressor blades and case walls. Research has shown that reducing this clearance can improve the performance of the compressor; however, the new design concept can affect the mechanical response of the compressor blades. Understanding this effect is important as high amplitude vibrations can lead to High Cycle Fatigue (HCF) failures. A preliminary study of the effect of contacting brush seals on the response of compressor blades was recently conducted in the Propulsion Directorate's Compressor Research Facility (CRF). Four blade modes were excited aerodynamically during testing with and without brush seals. Blade vibration data was obtained and analyzed to determine dynamic stress amplitudes, resonant frequencies, and damping at each of the four modes. Results from the investigation revealed that the presence of the brush seal increases the dynamic stress amplitude and shifts the resonant frequency in comparison to the response obtained with a smooth case. Surprisingly, for three of the four modes, the brush seal does not change the total damping of the blade. Moreover, for the one mode whose damping was changed by the seal, the seal decreases the total damping. These results give the first insight into the HCF effect of using brush seals, indicating that the brush seal may act more like an excitation source than a damping mechanism. These studies will be

continued in vibration tests on the blades in the Turbine Engine Fatigue Facility (TEFF). (D. Johnston, AFRL/PRTX, (937) 255-6802, ext 402)



Blade response for different excitation modes

REDUCING DANGEROUS PARTICULATES: The Environmental Protection Agency (EPA) has determined that particulates smaller than 2.5 microns are a health hazard. This is of interest to the Propulsion Directorate because the majority of particulate matter emitted by gas turbine engines is in this size range. The Combustion (AFRL/PRSC) and Fuels (AFRL/PRSF) Branches are collaborating to investigate this problem. A new research combustor, the Generic Swirl-Stabilized Combustor (GSSC), was operated for the first time during the week of 7 June 1999 to evaluate the potential of several particulate-reducing fuel additives. Special facility modifications were made to allow the additives to be injected "on the fly," permitting additive concentration to be quickly and easily changed. Nearly 20 fuel additives were tested and the data from these tests are still being reduced. Several additives evaluated previously in an advanced combustor showed significant promise by reducing particulates by 50 percent. These recent tests were conducted in conjunction with the University of Missouri at Rolla, who

provided the particle count and size distributions. Additional evaluation of these particulate-reducing additives in an actual engine (i.e., T-63) and in a high-pressure research combustor is planned. (Capt R. Anthenien, AFRL/PRSC, (937) 255-2243 and Capt R. Mantz, AFRL/PRSF, (937) 255-7423)

DESIGN BEGINS FOR EXPERIMENTAL HIGH-SPEED ELECTROMACHINE: A task has been initiated to design an experimental switched-reluctance (SR) machine for the Propulsion Directorate's Power Generation & Thermal Management Branch (AFRL/PRPG). The SR machine type remains a key research topic for the More Electric Initiative due to the machine's fault tolerance capability and a simple rotor design that is suited to high operating speeds. The high-speed capability allows increased power density that is desirable for auxiliary power turbogenerators that must provide higher power levels within a constrained volume. A major challenge to high-speed, high-power SR machines is the increased heat generation due to windage air friction and high-frequency electromagnetic losses within the "soft" magnetic alloys. Also, the SR machine rotor, built up as a stack of very thin laminates, has very low rigidity unless under high compressive loads which can degrade the inter-laminate insulation. The purpose of the test machine is to investigate mechanical technologies that enhance rotor/stator surface cooling by air and improve the rotor rigidity without severe axial compression. An added electrical subsystem technology to be demonstrated is "bootstrapping" whereby low voltages and/or a separate stator winding can provide a small excitation for backup power. The machine's planned generator rating is 100 kW output at 60 krpm speed. The rotor/stator geometry has already been defined, and ElectroMechanical Engineering Associates is to provide the manufacturing drawings and specifications for the machine case, bearing mounts, shafting, and drive interface. Fabrication and installation are planned for FY00, and initial experiments are to test various schemes for rotor cooling airflow control. (E. Durkin, AFRL/PRPG, (937) 255-6241)

P&W XTE66 JTDE TESTING RESUMES: The Pratt & Whitney (P&W) XTE66 Joint Technology Demonstrator Engine (JTDE) recently resumed testing with a successful check-out run to idle speed. Testing is expected to continue for more than a month leading up to the demonstration of a 49.5 percent increase in Thrust-to-Weight over the 1987 baseline. This increase is approximately the halfway point to the Integrated High Performance Turbine Engine Technology (IHPTET) Phase III goal of increasing Thrust-to-Weight by 100 percent. JTDE testing was initiated in November 1998, but testing was stopped due to an internal oil leak caused by an instrumentation lead being left unsealed. Taking advantage of the partial engine teardown required to investigate the oil leak, further inspections revealed radial cracks in several of the 3rd stage low-pressure turbine blades. Due to this discovery, the test plan was modified to limit the number of temperature cycles since the cracks will grow during engine testing. Furthermore, preliminary analysis of the counter-rotating vaneless turbine indicates that an aerodynamic mismatch exists between the high and low pressure turbine which will be investigated further during this test. The successful demonstration of the counter-rotating, vaneless turbine will provide weight and cost improvements to the Joint Strike Fighter (JSF) F119 engine. Additional technologies that are being considered for transition to the JSF include the swirl augmentor with advanced ignition, common control, and active stability control. (M. Dale, AFRL/PRTP, (937) 255-2767)

AUSSIE RESEARCHER COLLABORATING WITH PRSC ON COMBUSTION EFFICIENCY MEASUREMENTS: A number of key performance parameters must be considered when evaluating

advanced propulsion systems such as high-heat-release combustors and pulsed-detonation engines (PDE). Among these parameters are the fuel-air ratio, emissions indices, and combustion efficiency. Combustion efficiency is defined by the ratio of the energy released during the combustion to the energy that would be realized were all the carbon in the fuel converted to carbon dioxide and all the hydrogen in the fuel converted to water vapor. Accurate measurements of this parameter are critical to engine development and evaluation but difficult to obtain in practice. In an effort to achieve laser-based measurements of combustion efficiency, Prof Paul Danehy of the Australian National University has joined the Propulsion Directorate's diagnostics team in the Combustion Branch (AFRL/PRSC) for the balance of the summer. Working with PRSC scientists and contractors from Innovative Scientific Solutions, Inc, Prof Danehy is exploring a number of laser-based approaches to combustion-efficiency measurements. Experiments recently commenced in the new Generic Swirl-Stabilized Combustor (GSSC) rig in PRSC's Atmospheric-Pressure Combustion Research Facility. Discussions now under way between Prof. Danehy and Dr. Jim Gord of PRSC may produce a Data Exchange Agreement (DEA) between Australia and the USAF. (J. Gord, AFRL/PRSC, (937) 255-7431)

LIGHTWEIGHT, COKE TOLERANT HEAT EXCHANGER: One approach to meeting the demanding Integrated High Performance Turbine Engine Technology (IHPTET) Phase III turbine inlet temperature requirements is to cool the compressor exit air via an air/fuel heat exchanger prior to its use for cooling the high pressure turbine. The challenge of this approach is to maximize heat transfer while minimizing heat exchanger weight and fuel coking. Under contract to the Propulsion Directorate, Saddleback Aerospace has demonstrated a novel subscale heat exchanger that meets this challenge. The Saddleback pin fin heat exchanger increases heat transfer to the fuel without coking, features decreased weight, and effectively utilizes cooling circuits to maximize safety. In testing, the pin fin design increased the heat transfer by a factor of 5 to 6 while decreasing the weight of the heat exchanger core by 50 percent. The design combats coking by optimizing pin placement for maximum heat transfer without allowing the fuel temperature to rise above the point where it begins to break down and coke. Future work will concentrate on improving the design and manufacturing process and establishing commercialization venues. Also, a full-scale heat exchanger core will be delivered for product demonstration on the XTC 67/2. This technology has far reaching potential to impact a variety of military and commercial engines. The pin fin heat exchanger has numerous commercial applications in the aerospace, chemical, nuclear power, and automotive industries as well as space-based applications for environmental control systems, batteries, computers, and other heat sources. (B. Kiel, AFRL/PRTC, (937) 255-5974)

MONOPROPELLANT TESTING CONTINUES: Atlantic Research Corporation (ARC) recently performed a successful monopropellant thruster test at their Liquid Propulsion Facility in Niagara Falls NY. This thruster test was run on a developmental monopropellant produced at the Propulsion Directorate's Propellants Branch (AFRL/PRSP). This propellant possesses a 50 percent improvement in theoretical density impulse over the industry standard propellant, hydrazine. During the test, the effects of propellant feed pressure and catalyst bed temperature were examined. Multiple pulse sequences were evaluated, and one series was successfully performed with 50 pulses. The AFRL monopropellant project is directed to develop high performance propellants capable of meeting the performance objectives of the Integrated High Payoff Rocket Propulsion Technology (IHPRPT) Program. These

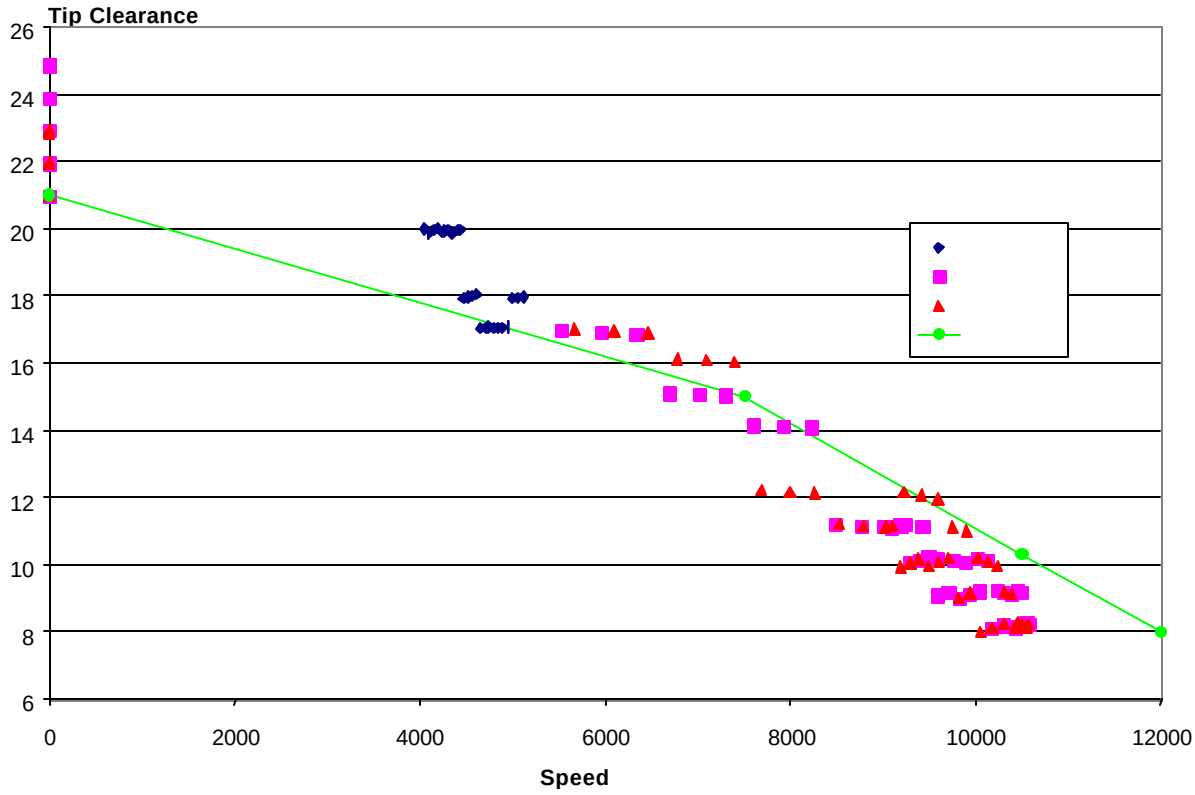
objectives include an increase in the propellant density impulse of 60 percent over that of hydrazine. This performance increase can enhance satellite missions in terms of increased satellite maneuvering lifetime, larger achievable maximum payload, or greater flexibility in satellite/thruster size. ARC expressed interest in continuing tests of this particular monopropellant. (T. Hawkins, AFRL/PRSP, (661) 275-5449)

AIR MOBILITY BATTLELAB SUPPORTS DEW POWER GENERATION**:** Col Skuropa, the Director of the Air Mobility Battlelab at Ft Dix NJ, recently requested that members of the Propulsion Directorate's Superconductivity Group (AFRL/PRPS), AFRL/VA, and AFRL/DEH provide presentations on high-power directed energy capabilities for transport aircraft. The briefings were held at Ft. Dix on 22 June 1999 with a 23 July 1999 follow-up. The Battlelab desires to employ directed-energy devices in air mobility applications, and these devices are expected to require very high levels of peak electrical power. The Battlelab gave enthusiastic support for the recent work in PR on high-power electrical generators. This work includes the development of the YBCO (yttrium barium copper oxide) coated conductors for use in compact superconducting generators. Development of the YBCO is critical to the generator applications due to its ability to carry large current densities (MA/cm^2) at liquid nitrogen temperatures and maintain high current densities (100's of kA/cm^2) in the presence of large magnetic fields. The BSCCO (bismuth strontium calcium copper oxide) conductor that is currently used in superconducting motors/generators requires temperatures near 30 K (or -406°F) requiring a much larger cryogenic cooling system. (P. Barnes, AFRL/PRPS, (937) 255-2923)

NEW TOOL TO MODEL ADVANCED PROPULSION SYSTEMS: Personnel in the Propulsion Directorate's Applications and Assessment Branch (AFRL/PRST) have initiated the development of an enhanced capability for Rocket Based Combined Cycle (RBCC) engine analysis. The enhanced capability will be implemented in PRST's in-house RBCC performance analysis software, ENG92E. The enhancements planned for the ENG92E code will integrate existing airbreathing engine performance methods with rocket thermal-work balance methods, resulting in an important new analytical capability. The improvements will enable the code to model the functions of a complete RBCC engine, including using the cooling fuel flow to absorb heat from the engine and generate the enthalpy required to power the turbo pumps. Work is currently under way to formulate the equations and solution methodology. The level of detail provided by these enhancements will provide information on the operability of RBCC engines not currently available. These code improvements are of great interest since the RBCC engine is currently an attractive candidate for a number of missions requiring high speed propulsion systems. (S. Mozes, AFRL/PRST, (937) 255-9991)

TIP CLEARANCE BULLSEYE: The Propulsion Directorate's Turbine Research Facility (TRF) at Wright-Patterson AFB recently completed a successful series of rotor tip clearance measurements. The TRF team designed, built, and calibrated a probe to house an electronic controller manufactured by Rotadata Ltd and subsequently measured rotor tip clearance as a function of speed to 10,500 rpm. The predicted clearance matched the measured data over the speed range. Tip clearance has a large impact on turbine performance; therefore, the demonstrated capability to measure tip clearance is of great value to the Air Force and the turbine engine community. This capability will allow the evaluation of technological increases in turbine efficiency and work output, which are key component objectives in the

Integrated High Performance Turbine Engine Technology (IHPTET) Program. (M. Meininger, AFRL/PRTT, (937) 255-3150)



TRF Tip Clearance Measurements