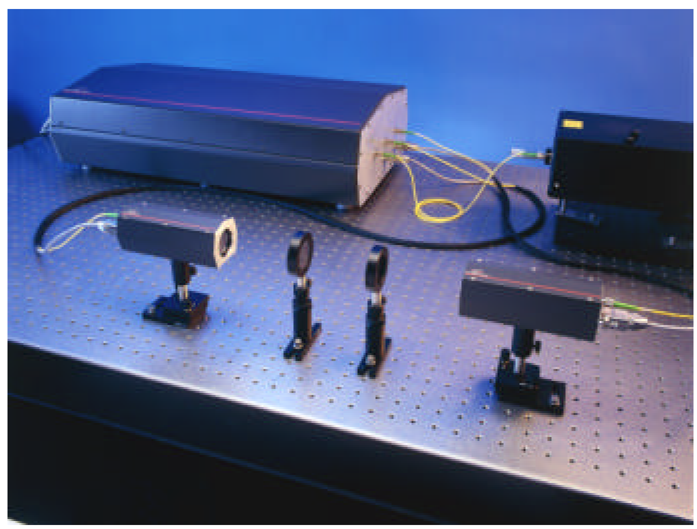
ACCOMPLISHMENT REPORT

PROPULSION DIRECTORATE
March 2000

SBIR DEVELOPED T-RAY TECHNOLOGY ENTERING PRODUCTION: During the past several years, researchers at a number of prestigious organizations including Lucent Technologies and IBM have been exploring terahertz radiation or “T-rays.” T-rays act much like Superman’s X-ray vision, permitting the nondestructive evaluation of myriad opaque samples. Novel published applications of this technology include examining circuit traces/interconnects inside integrated circuits, detecting tooth decay, locating watermarks in currency, reading text inside envelopes or beneath paint, counting almonds in packaged Hershey’s® bars, and identifying raisins in cereal boxes. Future applications include inspecting luggage, detecting subsurface rust, assessing burned flesh and other damaged tissues, and even seeing through clothing. Several years ago, researchers in the Propulsion Directorate’s Combustion & High Speed Systems Branch (AFRL/PRSC) recognized the potential combustion and fuels applications of this exciting technology and funded SBIR efforts to explore the possibilities. Terahertz transmission characteristics suggest the prospect of combustion measurements in windowless ceramic combustors. T-rays also permit the quantification of trace water in jet fuel since fuel transmits T-rays while water absorbs them. A PRSC sponsored Phase II SBIR program with Picometrix, Inc has produced a commercial terahertz radiation system based on a proprietary transmitter/receiver pair. The system, which is now entering production, will be submitted for consideration in this year’s R&D 100 competition. PRSC personnel recently witnessed a demonstration of the T-ray system at Picometrix’s Ann Arbor, Michigan, facilities. (J. Gord, AFRL/PRSC, (937) 255-7431)

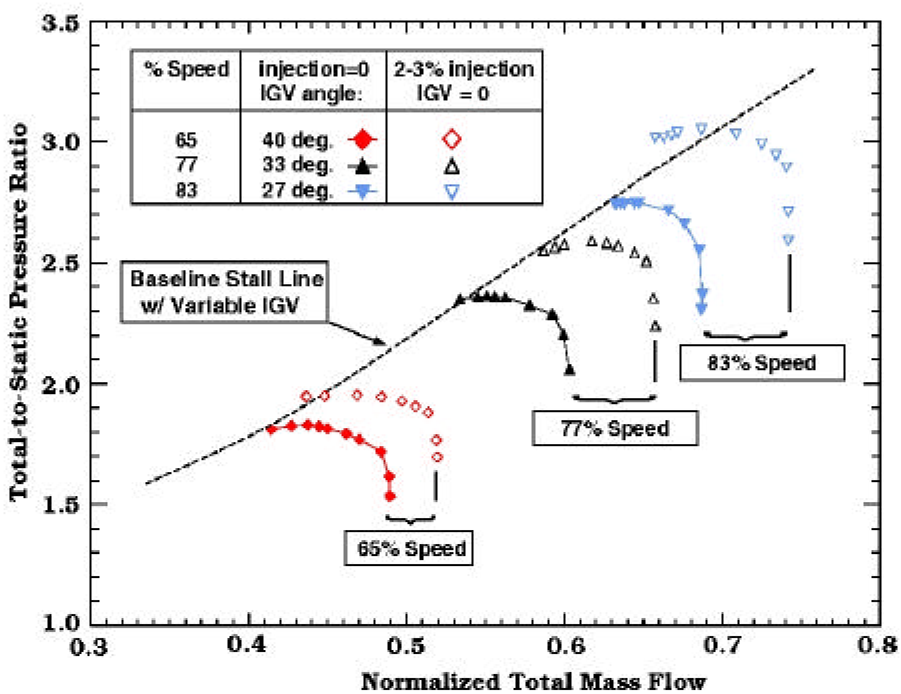


Picometrix’s commercial T-ray system

ADVANCED MATERIAL ENABLES HIGH TEMPERATURE CAPACITORS: Current state-of-the art (SOTA) power capacitors are becoming unreliable in military systems due to the high temperature operating environment. Under the High Temperature Dielectric Program led by the Propulsion Directorate’s Electrical Technology Branch (AFRL/PRPE), a Fluorene Poly Ester (FPE) capacitor film was developed with properties superior to the SOTA polycarbonate and polypropylene films. While current SOTA capacitors have a temperature capability of 125°C, FPE film can be used to produce capacitors that operate at up to 250°C. This film also has two times the voltage breakdown strength of polycarbonate films. These characteristics allow the production of capacitors capable of handling the temperatures seen in current weapons systems. Furthermore, power capacitors fabricated with the FPE film feature a 40 percent weight reduction and a 30 percent increase in reliability. Although this technology was developed in response to stringent military requirements, commercial interests dominate the capacitor market. As such, several commercial applications for high temperature capacitors have been identified including “in hole” oil well applications, aircraft engine ignition systems, “under the hood” automotive systems, and medical defibrillators. In October 1999, a capacitor grade 12-micron FPE film was made available to capacitor manufacturers, and there is also a need for thinner (2 to 6-microns) films. Efforts by AFRL/PRPE have resulted in one firm working to produce the casting process for these thinner films and two other firms who will use the casting process in a production mode. (S. Fries-Carr, AFRL/PRPE, (937) 255-6016)

Fluorene Poly Ester capacitor film

PR AND NASA INVESTIGATE ACTIVE STALL CONTROL: Researchers from the Propulsion Directorate’s Turbine Engine Research Center (TERC) and NASA Glenn Research Center (GRC) recently teamed to investigate the benefits of active stall control on multistage transonic compressors. This is the first time active stall control has been attempted on a multistage axial flow compressor. The technique employs injecting air in the compressor tip region through as many as 12 different jets. These jets were positioned between the compressor inlet guide vanes and the first stage rotor. This concept was used to investigate two approaches. The first approach was a “turn on and forget it” scheme, while the second was an



attempt to actively modulate the injected airflow to suppress stall. To date, data analysis has only been performed on the steady-state concept. The results show that air injection enabled the nominal surge line to be met or exceeded without the need for variable geometry. If variable geometry can be eliminated through the use of active stall control, more affordable compressors would be possible. Further, if the stall margin can be increased, then for a given speed, more work could be added to the airflow resulting in more powerful turbine engines for the same size and weight. This cooperative research will continue in a follow-on test program in the Compressor Research Facility (CRF) in FY01. (D. Rabe, AFRL/PRTE, (937) 255-6802, ext 231)

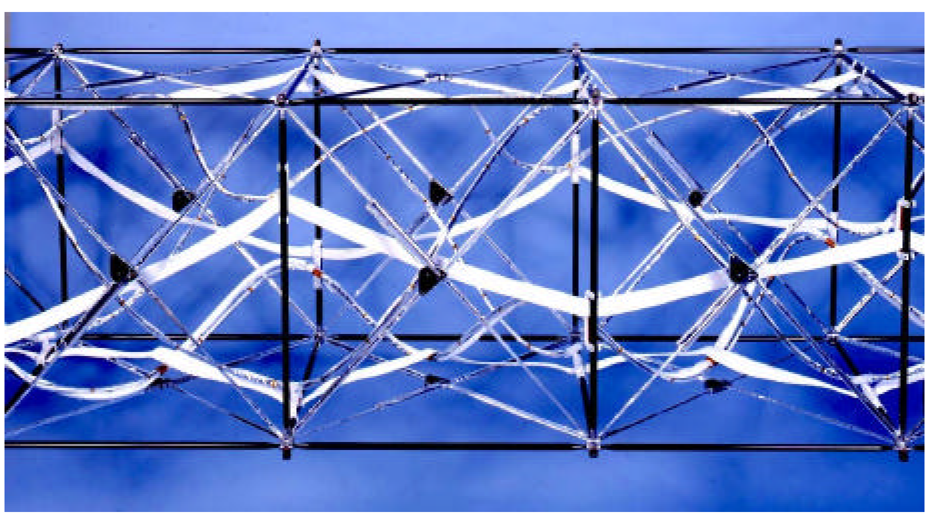
ADVANCED COMBUSTOR SHOWS FURTHER IMPROVEMENT: Researchers in the Propulsion Directorate's Combustion & High Speed Systems Branch (AFRL/PRSC) have completed the latest series of tests of the Trapped Vortex Combustor (TVC). The TVC is a unique turbine engine combustor concept that offers reduced emissions and improved performance in a small, simple, low cost package. Benefits from the TVC concept can be realized for aircraft propulsion as well as marine, industrial, and electrical power generation applications. In the latest test series, ignition and lean blowout (LBO) tests were conducted on the sixth TVC configuration to be tested to date. These tests characterized the ignition and LBO performance at pressures ranging from 3 psia, which simulates an altitude of approximately 40,000 ft, up to 75 psia. Compared to previous TVC configurations, the results indicate that the stability of the combustor has been improved by approximately 15 percent. In addition, ignition has been improved by nearly 40 percent. The test data currently is being compared to previous data to characterize the effects of minor changes in the amount of combustion air brought into the TVC's cavity. (D. Shouse, AFRL/PRSC, (937) 255-4636)

Images of the flame in the TVC just prior to extinction

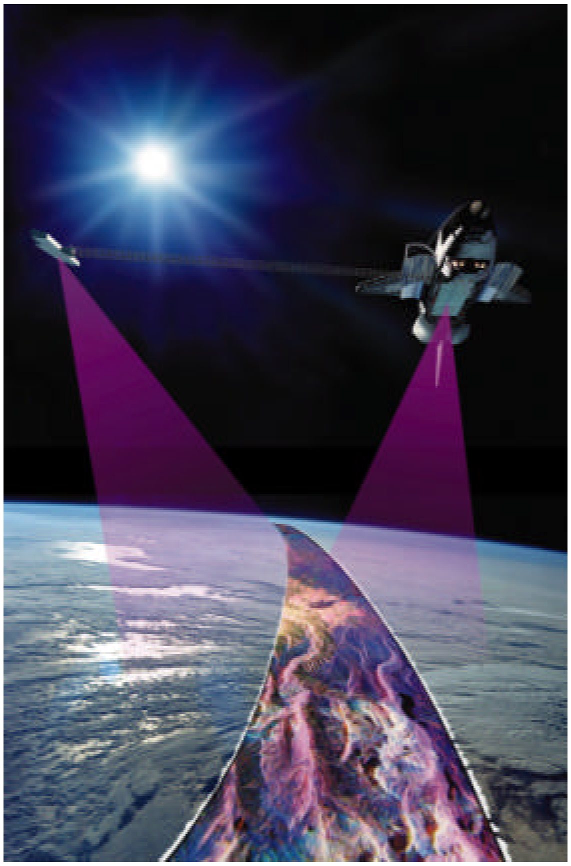
200-FOOT LONG MAST UTILIZED FOR TOPOGRAPHY MISSION: The 200-foot long Able Deployable Articulated Mast (ADAM™) for the Shuttle Radar Topography Mission (SRTM) was successfully deployed on 11 February 2000. ADAM™ was built by AEC-Able Engineering Company and carried into space aboard the Space Shuttle Endeavour (STS-99). The SRTM's mission was to map 70 to 80 percent of the Earth's landmass in three dimensions using an interferometric synthetic aperture radar. ADAM™ technology enables the SRTM system to perform at the high baseline

precision necessary to achieve the desired mapping resolution. ADAM™ is the longest rigid structure ever to be deployed in space. The 605-pound mast's web of utility lines includes 440 pounds of coaxial and fiber-optic cables, stranded copper wire, and a single thruster gas line. Remarkably, when stacked (including all cables) the mast fills a space just 56 inches wide or about 2 percent of its deployed length. The Survivable Power Subsystem (SUPER) Program, managed by the Propulsion Directorate's Power Division (AFRL/PRP), advanced technologies that enabled the development of ADAM™. The SRTM may not be the last flight for ADAM™ as talks are under way with NASA's Jet Propulsion Laboratory (JPL) for a re-fly. This technology has application to future Air Force Space Radar concepts that require large structures for solar arrays and reflectors. (G. Fronista, AFRL/PRPE, (937) 255-9392)
[See NASA's website for the SRTM at http://www.jpl.nasa.gov/srtm]
[To see an animation of the mast deployment, see AEC-Able's website at http://www.aec-able.com/corporate/srtm3.htm]

ADAM™ fully deployed (left) and deployed from Endeavour's bay (right)

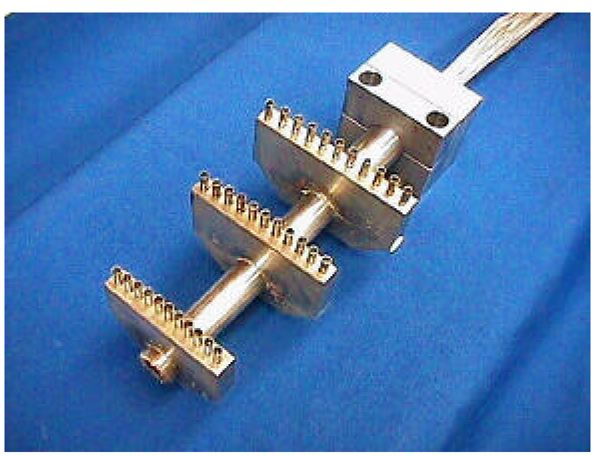


Detail of ADAM™ structure and cabling



Artist's rendering of ADAM™ performing topography mission

TECHNOLOGY TRANSITION OF FLOW MEASUREMENT TECHNOLOGY: A technology transition success was recently achieved by the Propulsion Directorate's Turbine Engine Research Center (TERC). Flow measurement rakes are routinely designed and fabricated in-house for use in the measurement of transient total temperature and pressure in the TERC's Turbine Research Facility (TRF). This technology base was used to develop two rakes for a compressor test in the TERC's Compressor Research Facility (CRF). Using the TRF rake design and fabrication capability, TERC engineers and technicians designed and built two arc rakes to measure the steady-state exit total pressure and temperature from the test compressor. Each of the rakes consists of 33 pressure and temperature measurements arranged in three arcs at different radii. By using two rakes, performance can be measured at six different radial locations. The need for case modifications was eliminated through a creative design that allowed the rakes to be installed in existing case penetrations. Overall cost of the in-house design and assembly of the rakes is estimated to be only 25 percent of the cost of contracting out the work. Compressor assembly is under way and testing is scheduled to begin in the middle of March. These rakes will provide the required capability to determine the overall performance of the test compressor. (M. Kobelak, AFRL/PRTE, (937) 255-6802, ext 303)

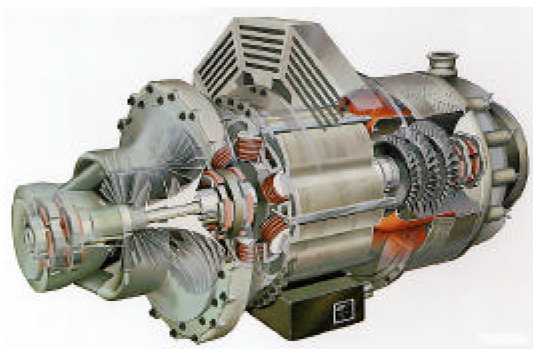
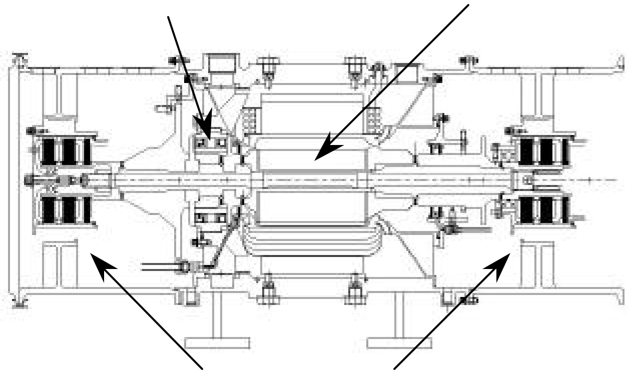


Arc rake designed and built by TERC personnel

PATENT ISSUED FOR DISSOLVED-OXYGEN DIAGNOSTIC: The Air Force was recently awarded US Patent Number 5,919,710 for an "Optical Technique for Quantitating Dissolved Oxygen in Fuel." This patent protects the Air Force investment in novel diagnostics essential to the continued development of high-heat-sink aviation fuels. Autoxidation is an important process that impacts the thermal stability of aviation fuels. During autoxidation, hot fuel reacts with dissolved oxygen to yield oxidized fuel products that contribute to the formation of gums, varnishes, and deposits. While developing fuel-additive antioxidants, fuel engineers utilize the dissolved-oxygen diagnostic to assess oxygen concentration and additive performance. This laser-based instrument provides continuous, noninvasive, nondestructive, near-real-time quantification of dissolved oxygen in aviation fuel. The dissolved-oxygen diagnostic was developed through a joint in-house effort that involved the Propulsion Directorate's Combustion & High Speed Systems Branch (AFRL/PRSC), Innovative Scientific Solutions, Inc (ISSI), and Columbus State University, Columbus, Georgia. The effort was funded through PRSC's 6.1 program with AFOSR and the AFOSR Summer Faculty Research and Summer Research Extension Programs. Dr. James R. Gord (AFRL/PRSC), Dr. Steven W. Buckner (Columbus State University, Columbus GA), Dr. William L. Weaver (ISSI) and Mr. Keith D. Grinstead, Jr., (ISSI) are credited with the invention recognized through this patent. (J. Gord, AFRL/PRSC, (937) 255-7431)

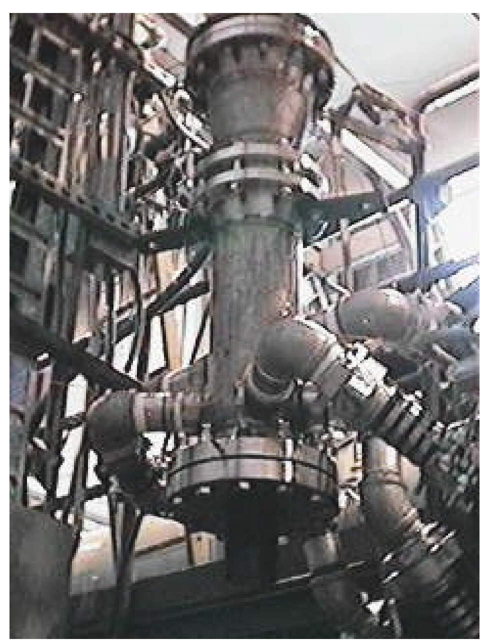
Dr. Jim Gord with the dissolved-oxygen diagnostic device

INTEGRATED POWER UNIT PROGRAM SUCCESSFULLY COMPLETED: Honeywell's More-Electric Aircraft Integrated Power Unit (MEA IPU) Program with the Propulsion Directorate's Power Division (AFRL/PRP) has been successfully completed. This program focused on developing two key technologies: an air-cooled starter/generator switched reluctance machine (SRM) and a non-lubricated magnetic bearing support system for the IPU rotor system. These technologies form the cornerstone of the effort to greatly increase reliability and reduce ground support equipment requirements for future aircraft power systems. The high-speed operation of an IPU turbogenerator also enhances power density, which allows higher power for future Air Force mission needs in directed-energy power, vehicular systems, and high-altitude engine restart. Previous subsystem testing demonstrated a 140 kW peak electric generator power at the operating design speed of 55 krpm (where 125 kW continuous and 250 kW peak power were the IPU design goals). A maximum speed of 54.5 krpm was also demonstrated for the magnetic bearings in a separate IPU rotor simulator test rig. The initial tests supported Honeywell's program with AFRL/VA to develop an SRM for its Thermal Energy Management Module (T/EMM). The final IPU technology demonstrator rig integrated these key technologies for the first time in FY99, and this demonstrator provided 30 kW power output at 270 VDC and 30 krpm speed. The IPU technology demonstrator, which did not include live air-breathing turbo-machine components, has been transferred for further tests in a dual-use program with Honeywell that will later combine a turbine engine and SRM for integrated operation. The demonstrator rig is presently providing additional insight into the interactions between the SRM and the magnetic bearings. (E. Hoffman, AFRL/PRPG, (937) 255-6241)

IPU conceptual design (left) and IPU Technology Demonstrator Rig schematic (right)

<u>FLOW QUALITY IN TRF IMPROVED</u>: Propulsion Directorate engineers have dramatically improved the quality of the inlet flow to the turbine stage in the Turbine Research Facility (TRF). This was accomplished by utilizing boundary layer bleeds to remove the large, highly fluctuating inlet boundary layer from the flow before it approaches the high-pressure turbine. Facility modifications included drilling five staggered rows of 0.63 cm holes into the inner and outer casing and plumbing to bring the flow to an adjustable critical flow venturi. This venturi was designed in-house to provide for an accurate measurement of the amount of mass flow being removed. Measurements of the boundary layer were acquired with the use of radially traversing total temperature probe that was designed and instrumented in-house. Before bleeding the boundary layer, the temperature fluctuations near the casing walls were 10°C on the outer diameter and about 20°C on the inner diameter and the boundary layer thickness averaged 1.5 cm. By removing about 16 percent of the core flow through the boundary layer bleeds, the boundary layer thickness at the inlet to the stage was reduced to about 1 cm. More importantly, temperature



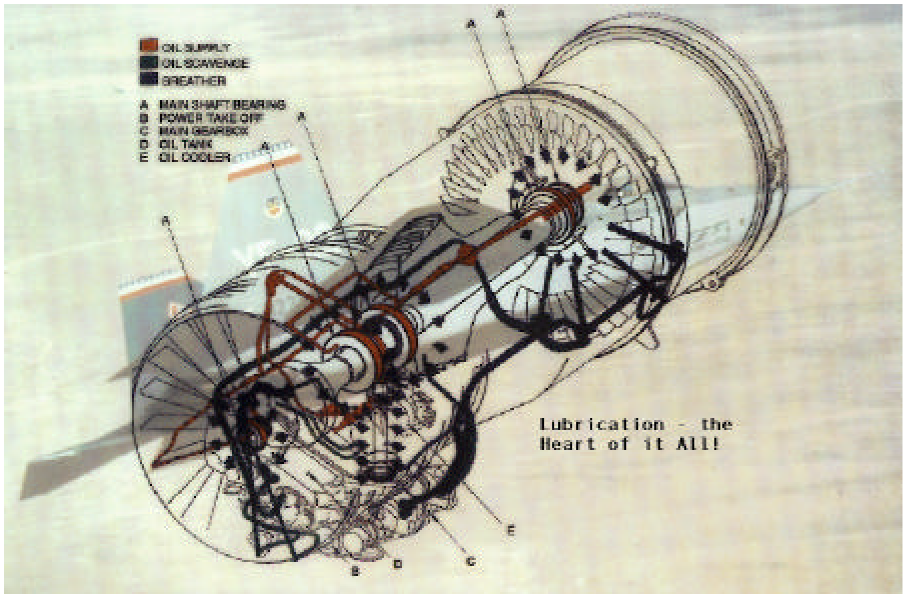
New 10 cm critical flow venturi used to measure the mass flow of the boundary layer flow fluctuations were reduced to about 4°C on the outer diameter and 6°C on the inner diameter. This constitutes a significant improvement to the uniformity of the inlet flow thereby enabling a more accurate measurement of the turbine efficiency. This will aid in the ability to understand the performance of all Integrated High Performance Turbine Engine Technology (IHPTET) turbines. (M. Polanka, AFRL/PRTT, (937) 255-6768)

AFRL MONOPROPELLANT WORK SUPPORTS ICBM SPO: The Propulsion Directorate's Propellants Branch (AFRL/PRSP) is conducting research on advanced monopropellants for the ICBM System Program Office (SPO) at Hill AFB, Utah. PRSP's monopropellant research supports the ICBM SPO's mission of developing, acquiring, and supporting silo-based ICBMs. The "Phase IV" monopropellants sought by the ICBM SPO would be the highest performance monopropellants ever developed with performance significantly exceeding Integrated High Payoff Rocket Propulsion Technology (IHPRPT) Phase III monopropellant goals. Trade studies indicate that Phase IV monopropellants offer significant advantages for the next-generation ICBM, which is the follow-on to the Minuteman. A Phase IV monopropellant would have a volumetric impulse up to 12 percent greater than nitrogen tetroxide/monomethyl hydrazine (NTO/MMH), the fuel currently used in the 4^{th} stage of Peacekeeper and Minuteman ICBMs. Also, tankage mass reductions of greater than 8 percent could be realized for the 4^{th} stage of the next-generation ICBM. Furthermore, advanced monopropellants offer an environmental advantage since NTO/MMH is highly toxic and increasingly difficult to store, transport, and use under today's more stringent environmental regulations. (T. Hawkins, AFRL/PRSP, (661) 275-5449)

AFRL AND NIST TO COOPERATE ON SUPERCONDUCTIVITY RESEARCH: Superconductivity researchers from the Propulsion Directorate's Power Systems Branch (AFRL/PRPS) and the National Institute of Standards and Technology (NIST) recently met to discuss potential cooperative research efforts. The AFRL group has worked in the past on magnetic flux pinning in the high temperature superconducting (HTS) YBCO (yttrium barium copper oxide) material to improve its current carrying ability and to lower its AC losses. The NIST group currently works on the phase transition diagrams for a variety of superconductors. The phase diagram work may provide essential information on a potential flux pinning mechanism where lattice site substitutions provide the pinning. The PRPS superconductivity group will fund a NIST NRC fellowship recipient to work on-site in the PRPS facilities. Flux pinning of the YBCO in superconducting-coated conductor is especially important to Air Force high-power applications, since HTS generators that use the coated conductor in its magnetic coils operate at higher frequency and will have higher AC losses. (P. Barnes, AFRL/PRPS, (937) 255-2923)

HIGH RESPONSE AIR VALVE SUCCESSFULLY TESTED: The High Response Air Valve System (HRAVS) Program, sponsored by the Propulsion Directorate's Turbine Engine Division (AFRL/PRT), has completed prototype fabrication. The HRAVS is a critical link to active control systems of the future enabling the design of higher performance turbomachinery with reduced life cycle and maintenance costs. This development builds on Honeywell's independent research and development efforts to build a no moving parts high frequency air valve using the latest piezoelectric actuator technology. The Honeywell high response air valve employs a unique bending beam diaphragm design that provides a 10 to 1 mechanical advantage (amplification) of the small displacement piezoelectric actuator. Alternatives using a lever system can only provide about half the amplification and control authority, and magnetically operated valves also have restrictions. Laboratory testing to verify performance is progressing at a rapid pace. The prototype HRAVS has achieved pressure capabilities four times the baseline air valve (400 psi) and double the baseline flow rate (22 pounds per minute). Also, the frequency response of the actuator is 500 Hz, which is a significant improvement over the electromagnetic actuator which is limited to 300 Hz. Because the HRAVS is based on piezoelectric technology, it can be designed in a small, compact package; however, the prototype does not demonstrate a potential flight-weight component. Future program milestones include prototype hardware evaluation at NASA Glenn in April 2000 and delivery of eight HRAVS to NASA in August 2000 for compressor rig demonstration. Additional valve demonstrations are planned at AlliedSignal Engines in Phoenix, Arizona, and at PR's Compressor Research Facility (CRF). (K. Semega, AFRL/PRTA, (937) 255-6690)

AFRL/PRATT & WHITNEY TEAMING UP TO TEST ADVANCED OIL: AFRL and Pratt & Whitney (P&W) are entering into a Cooperative Research and Development Agreement (CRDA) to perform bench and engine testing of new candidate turbine lubricants. The high temperature (450°F), low coking optimal ester lubricants to be evaluated were jointly developed by the Propulsion (AFRL/PRSL) and Materials & Manufacturing (AFRL/MLBT) Directorates. To date, two candidate lubricants have essentially met Phase I target requirements and are ready for Phase II bearing deposition testing. P&W plans to perform numerous tests on the candidate oils including sludge tests, mixed phase hot liquid phase system (HLPS) tests, tribological mapping tests, and ultimately engine tests. P&W is targeting future Integrated High Performance Turbine Engine Technology (IHPTET) demonstrator tests for engine testing. These tests at P&W's East Hartford, Connecticut, facilities will evaluate the oils in one of the XTE 67 Phase III Joint Technology Demonstrator Engines (JTDE). P&W Canada has also expressed interest in conducting a 1500 horsepower gearbox test for helicopter gas turbine engines. These helicopter engines use separate oils for the gearbox and the engine. However, the advent of advanced, higher viscosity lubricants presents the possibility of using a single oil for both purposes, which could result in a significant reduction in logistics costs. This program is of mutual benefit to P&W and the Air Force in fostering technology transition and transfer. (L. Nelson, AFRL/PRSL, (937) 255-3100)



<u>HIGH TEMPERATURE SMART ACTUATOR UNDERGOES TESTING</u>: The High Temperature Smart Actuator being developed by General Electric/Honeywell (AlliedSignal) under sponsorship from the Propulsion Directorate's Turbine Engine Division (AFRL/PRT) is currently undergoing high temperature testing. The objective of this program is to develop a smart actuator for a distributed control system using high temperature electronic components packaged for the extreme environment in turbine engines. Testing will demonstrate the functionality and environmental capability of this smart device, which is to be capable of operating at 200°C. Testing of the actuator's electronics package has begun. The actuator successfully passed the first of 12 temperature cycles (from -55°C to +200°C) and also passed a 100-hour soak test at 200°C that followed the first cycle. During the remaining 11 temperature cycles, problems developed at the low end of the temperature range (below -45°C); however, this anomaly at low temperatures does not inhibit the demonstration of the project goal of high temperature operation. (D. Tasch, AFRL/PRTA, (937) 255-6690)

<u>PR AND ARC TO COLLABORATE ON MONOPROPELLANT RESEARCH</u>: The Propulsion Directorate's Propellants Branch (AFRL/PRSP) and the Atlantic Research Corp (ARC) have entered into a Cooperative Research and Development Agreement (CRDA) to perform research on monopropellants. A monopropellant is a fuel that does not require a separate oxidizer; therefore, a rocket engine based on a monopropellant requires only fuel delivery hardware rather than hardware for both a fuel and oxidizer. This simplification leads to a rocket engine that is lighter, less expensive, and more reliable. ARC's portion of this monopropellant research is to perform thruster demonstration assessments on at least one AFRL monopropellant. These thruster demonstrations will be similar in experimental design and operation to those previously performed for RK-618 and RK-315 monopropellants by the ARC Liquid Propulsion Center of Excellence in Niagara Falls, New York. In return, AFRL will assess the storage stability of two ARC monopropellants by studying the kinetics and products of decomposition at a minimum of two temperatures. Assessment of sensitivity to adiabatic compressibility at various temperatures and pressures will also be performed on three ARC monopropellants. Liquid propellant sensitivity to adiabatic compression is an important energetic material property with insensitivity to rapid compression (especially at high temperature) being a

desirable safety feature. This CRDA benefits both ARC and the Air Force by increasing the knowledge and technology base on the performance of liquid salt-based monopropellants. (T. Hawkins, AFRL/PRSP, (661) 275-5449)