ACCOMPLISHMENT REPORT

PROPULSION DIRECTORATE
April 1999

ARCJET OPERATES SUCCESSFULLY IN SPACE: The Electric Propulsion Space Experiment (ESEX), launched as a payload of the Air Force Space and Missile Command's Advanced Research and Global Observation Satellite (ARGOS) on 23 Feb 99, is now operating in space. On 15 Mar 99, the ESEX completed its first successful firing in space. The arcjet fired for 2 minutes and 21 seconds at a power of 27.5 kW, and the system is reported to have executed perfectly. The thrust was approximately 2 N (about 1/3 lb) and the specific impulse, a measure of propulsive efficiency, was about 800 seconds. Measurements confirm that the firing increased the orbital altitude by 215 meters (approximately 700 ft). Prior to the test, there had been speculation that the high power electric propulsion system would reek havoc on delicate satellite subsystems; however, there was no measurable effect on the ARGOS vehicle or any of the subsystems. Thus, there appears to be no issue with electromagnetic interference (EMI). To date, ESEX is the highest power subsystem to fly in space exceeding the power of Skylab, the Space Shuttle, and Mir. The ESEX electric propulsion system has the potential to control the satellite's position in space, insert the satellite into various orbits, and efficiently move the satellite from one position to another. The arcjet system's long lifetime and fuel efficiency extend the useful lifetime of the satellite that it propels. (L. Quinn, AFRL/PRR, (661) 275-5630)

The ARGOS Satellite

The ESEX Arcjet

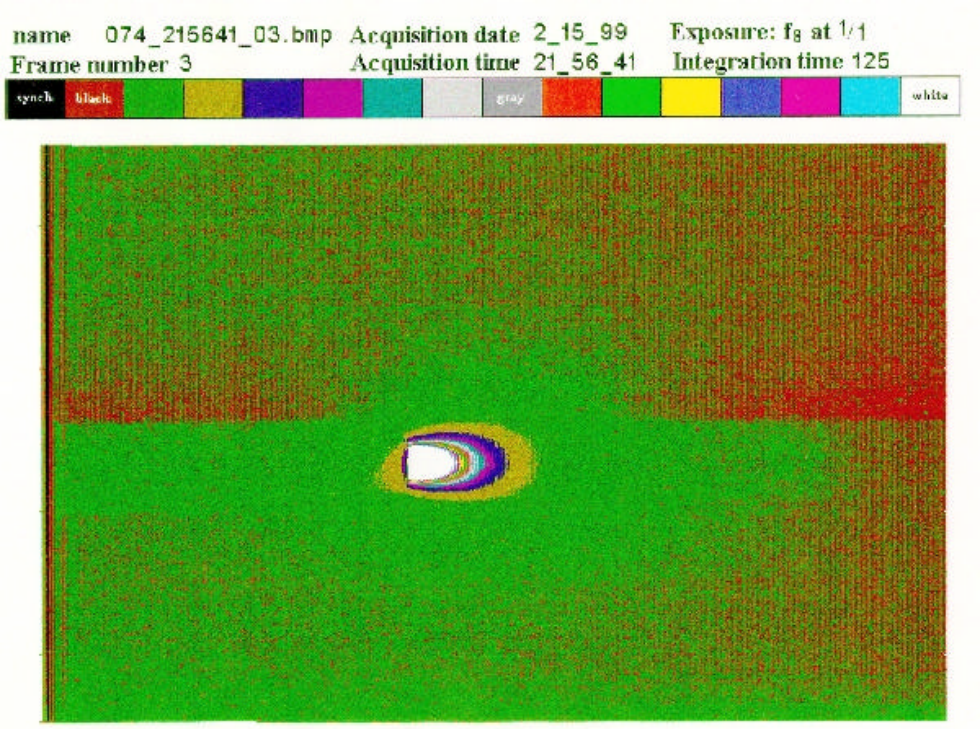
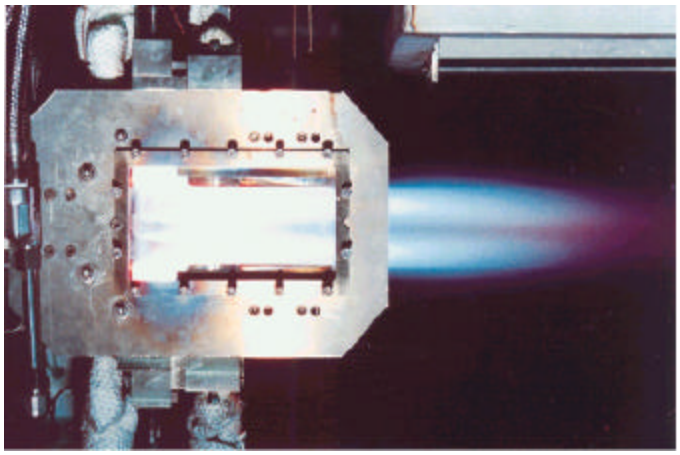


Image of the arcjet engine firing in space

CBS AIRS HIGH TEMPERATURE MATERIAL TESTING: The CBS news program *48 Hours* recently aired footage of high temperature material testing at Edwards AFB, California. On 1 Apr 99, *48 Hours* aired a special show titled "Strike It Rich!" that examined how ordinary people made their fortunes. One of the segments featured Pat Billings, a 72-year-old artist who invented a new material called Geobond. The Propulsion Material Applications Branch (AFRL/PRSM) has an interest in Geobond as a protective insulation for rocket test stands because it is an excellent insulator and does not burn. Since Billings' company is not scientifically based, PRSM has worked prodigiously to optimize Geobond for their applications. On 22 Feb 99, a CBS crew filmed the synthesis, modification, and testing of Geobond samples and witnessed Geobond's ability to withstand direct impingement by a rocket plume. For this test, a PI-K motor was fired 6" from the Geobond sample for more than 9 seconds, resulting in a 4500°F plume impacting the sample. Though significant erosion of the material occurred, no catastrophic failure (complete erosion, explosive cracking, or meltdown) was observed. This was an extremely encouraging result as Geobond possesses many attractive features. It is readily processed, requires only 7 to 14 days of air drying to reach its full strength, and is extremely low cost (less than $0.75/lb). These rocket motor tests allow a determination of how to reduce the ablation rate of the material. Further testing and characterization of Geobond is planned to better understand how to best utilize the material. (S. Phillips, AFRL/PRSM, (661) 275-5416, H. Nguyen, AFRL/PRRM, (661) 275-5629; and P. Ruth, AFRL/PRSM, (661) 275-5759)

TURBINE ENGINE INNOVATION MAY GO GLOBAL: AFRL, in conjunction with General Electric Aircraft Engines (GEAE), has validated an innovative turbine engine flame stabilization concept. This concept, known as Trapped Vortex (TV), offers reduced emissions and improved performance in a smaller, simpler, lower cost package. Benefits from the TV concept are not restricted to aircraft engines, but also include marine, industrial, and electrical power generation applications throughout the world. Recent testing of a TV combustor sector gave performance that was as good as or better than conventional combustors. Simulated altitude relight was achieved at 45,000 feet at ambient temperature compared to 30,000 feet for conventional combustors. Weak-extinction stability performance was found to be 68% better than for conventional combustors. Exhaust emissions measurements of nitrous oxides (NO_x) were as low as those in GEAE's dual annular low-NO_x aircraft turbine engine combustors. Hydrocarbon and NO_x emissions measured with diesel fuel were about 35% lower than those in the LM2500 engine used to power US Navy ships. The TV flame stabilization scheme has been adopted by the GEAE/Allison Advanced Development Company (AADC) team as part of their development approach to meet the Integrated High Performance Turbine Engine Technology (IHPTET) Phase III combustor objectives. (C. Arana, AFRL/PRTC, (937) 255-5974)



The Trapped Vortex Combustor

MICRO-CAPILLARY PUMPED LOOP PROGRAM AWARD: A research team consisting of the Power Generation and Thermal Management Branch (AFRL/PRPG), the University of California-Berkeley, and the Harris Corp was recently awarded $3.0 million from DARPA to design, fabricate, and demonstrate a micro-capillary pumped loop (micro-CPL). This recently awarded DARPA program leverages off of a Ballistic Missile Defense Organization (BMDO) funded technical effort with the University of California-Berkeley demonstrating the feasibility of the micro-CPL. The objective in developing a micro-cooler such as the micro-CPL is to use micro-electromechanical systems (MEMS) technologies for the fabrication of integral cooling into electronic devices. By targeting specific heat sources within electronic devices and taking advantage of the high surface to volume ratios, integral cooling provides a new stratagem in the thermal management of electronics packages. Initial modeling used a macro approach, typically used in designing conventional CPLs, to demonstrate the feasibility of the micro-CPL. Fabrication approaches and techniques are being developed with subsequent experimental activities to identify the effects of micro-scale physics in heat transfer and fluid dynamics. The DARPA technical effort will continue the development of the micro-CPL and address several science issues ranging from the identification of micro-scale physics to packaging for specific electronic components. (K. Yerkes, AFRL/PRPG, (937) 255-6241)

NEW PREBURNER PASSES THE TEST: A new generation of rocket preburner technologies is one-step closer to fielding due to successes achieved in recent testing. Aerojet, under contract to the Propulsion Directorate's Rocket Propulsion Division (AFRL/PRR), recently completed ignition tests of a fuel preburner. This preburner burns hydrogen and oxygen to provide hot gases necessary to drive the fuel turbine in a high performance rocket engine. The successful ignition tests provide verification of the preburner design and also furnish performance data needed to complete the engine start sequence design. These new preburner technologies significantly reduce fabrication costs, and they also improve temperature uniformity that prolongs turbine life. The fuel preburner is the first hardware from the Integrated Powerhead Demonstration (IPD) project to be ready for full power integrated tests. The IPD project offers significant reduction in life cycle costs and increased performance for highly reusable rocket engines in future force application systems. (L. Quinn, AFRL/PRR, (661) 275-5630)

SUCCESS IN QUEST FOR LOW TEMPERATURE FUEL: The Fuels Branch (AFRL/PRSF) has embarked on a program to transform JP-8 into a suitable fuel for the high-altitude U-2 reconnaissance plane through the use of additives. Motivation for this effort stems from a desire to replace JPTS, the fuel used for the U-2, with the more economical JP-8 which is about one-third the cost of JPTS ($0.80/gallon vs $2.50/gallon). JP-8 currently meets JPTS thermal stability requirements through the use of the +100 additive package, but it falls short of JPTS's low temperature capabilities. Though the program is in its early stages, scientists working in PRSF have already identified additives that drastically change the behavior of fuels at temperatures below their freeze point. Steady fuel flow has been demonstrated at temperatures 15°F below the fuel's typical freeze point. These encouraging results have caught the attention of the U-2 SPO, and they have asked PRSF to make a determination of what it would take technically and fiscally to develop and test JP-8 for use in the U-2. The U-2 SPO is also entertaining the notion of installing heaters in the wing fuel tanks to overcome low temperature concerns; however, this solution is estimated to cost roughly $1 million per aircraft and has not been demonstrated. The additive-based approach is deemed to be a far more economical and simpler approach to solving this problem. This technology also has potential commercial applications, as commercial airlines are concerned about fuel freezing because many now fly colder Arctic routes instead of the warmer southern routes. PRSF is uniquely qualified to tackle this problem, as PRSF is the only organization with the instrumentation and personnel to execute such a program. (C. Obringer, AFRL/PRSF, (937) 255-6390)

The U-2 Reconnaissance Plane

RIVIR NAMED ONE OF DAYTON'S OUTSTANDING ENGINEERS AND SCIENTISTS: Dr. Richard B. Rivir of the Turbine Engine Division (AFRL/PRT) has been selected by the Affiliate Societies Council of the Engineering and Science Foundation of Dayton as one of the area's outstanding engineers and scientists for 1999. This award, presented each year as part of National Engineers and Scientists Week, recognizes both career accomplishments and significant individual contributions to the

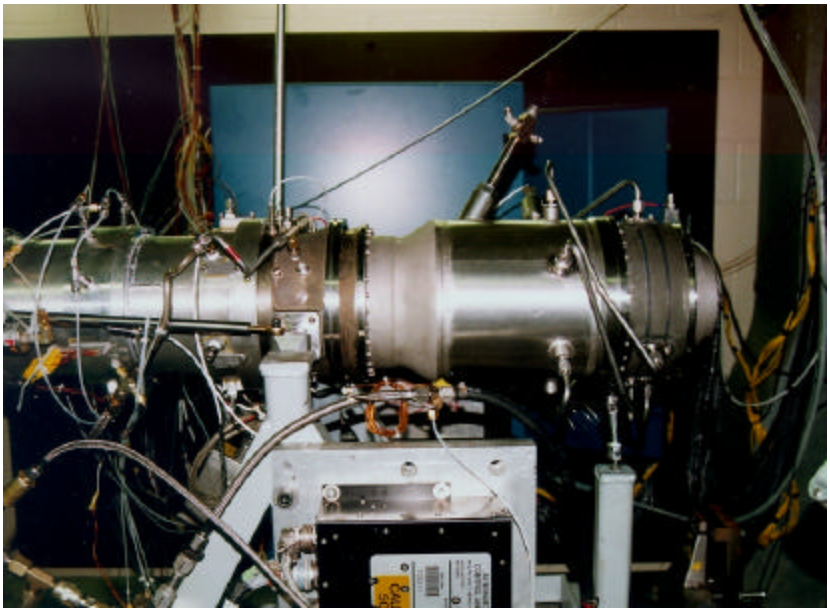
awardee's professional field. Dr. Rivir received his award at a banquet on 18 February 1999 at Sinclair Community College in Dayton, Ohio. (C. D. MacArthur, AFRL/PRTT, (937) 255-2367)

QUICK AND CHEAP COMBUSTION CHAMBERS: The Rocket Propulsion Division (AFRL/PRR) is successfully examining methods for the economical fabrication of rocket engine combustion chambers. The recent completion of a combustion chamber demonstrated the advantages of using the rapid prototype concept to reduce development time. Using selective laser sintering, the time required to create casting preforms is significantly reduced. Consequently, the cost of generating prototype parts by casting is cut by nearly 80 percent. This makes casting an attractive alternative to forging and machining for the fabrication of prototype hardware. As a result, prototype parts can be cast for about half the cost of forming the part by forging and machining. Furthermore, the scrap rate in forming the CuCrNb (copper-chromium-niobium) chamber liner is reduced from more than 90 percent for the forged part to less than 10 percent for the part formed by rapid prototyping. The cast liner also has the advantage of greater strength at elevated temperatures. The rapid prototype design, pressure bonded assembly, and circular chamber to square nozzle analysis are now being used in the production of the chambers for the NASA X-33 Program. (L. Quinn, AFRL/PRR, (661) 275-5630)

SUPPORT FOR JP-8 FIELD QUALITY PROBLEMS: The Fuels Branch (AFRL/PRSF) and the University of Dayton Research Institute (UDRI) recently supported the analysis of a large quantity of contaminated JP-8 fuel. The problem fuel was discovered during a post-aircraft accident investigation at Nellis AFB, Nevada. Upon discovering the contaminated fuel, it was determined that up to 8 million gallons of this fuel may have been delivered to Air Force Bases in the Western US via the CALNEV pipeline. PRSF was called in to analyze the fuel and provide recommendations on whether the fuel could be salvaged. The PRSF/UDRI team analyzed the fuel for thermal stability (i.e., propensity to form deposits), trace metal contamination, and nitrogen levels. The fuel was found to have exceptionally poor thermal stability as tested by the Quartz Crystal Microbalance (QCM) and the JFTOT, an approved American Society of Testing and Materials (ASTM) test method for determining fuel thermal stability. In fact, the fuel attained the worst possible rating on the JFTOT test. Analysis also showed an appreciable level of copper in the fuel, and copper is known to exacerbate thermal stability problems. Remarkably, the addition of the +100 fuel additive allowed this fuel to pass the JFTOT test--this is a tribute to the efficacy of the +100 additive. PRSF recommended that the fuel could be rehabilitated through addition of the +100 fuel additive effectively salvaging millions of gallons of fuel that would have otherwise been discarded. (E. Strobel, AFRL/PRSF, (937) 255- 6935)

IHPTET COMPRESSOR MODIFICATIONS SUCCESSFUL: Williams International continues testing of their supersonic Joint Expendable Turbine Engine Concept (JETEC) demonstrator engine (XTL-86). The demonstrator is pursuing the Integrated High Performance Turbine Engine Technology (IHPTET) Phase II goals for supersonic expendable engines: a 45 percent cost reduction and a 70 percent increase in specific thrust. The engine was run up to 100 percent speed and did not surge at any condition. Preliminary indications are that the engine is slightly high in pressure ratio, slightly low in flow, and nominal in efficiency. Since the goal is engine specific thrust (thrust/airflow), this bodes well for goal demonstration. The original compressor was modified to accommodate the higher-than-expected axial Mach numbers that created high shock losses and subsequent low efficiency. The XTL-86 is being

tested in two configurations. The first build described above includes a forward swept shrouded compressor, a high heat release combustor, and hybrid ceramic fuel-lubed bearings. The second build will include an uncooled, high temperature hot section with a carbon silicon-carbide (C/SiC) turbine rotor, C/SiC turbine nozzle, and a carbon-carbon exhaust nozzle. This build will be tested at Mach 1.0+ at NASA Glenn Research Center in June 1999 to demonstrate Phase II goals and assess the performance/life of both the ceramics and the engine as a whole. (Capt C. Cunningham, AFRL/PRTP, (937) 255-2767)



The XTL-86 on the Test Stand

PRR SUPPORTS NEW ROCKET ENGINE TESTING: In support of the Evolved Expendable Launch Vehicle (EELV) Program, the Rocket Propulsion Division (AFRL/PRR) at Edwards AFB, California, continues to provide technical and facilities support to Boeing for the development of the RS-68 rocket engine. Last month, two initial firings on the second RS-68 development engine were conducted, which showed promising results. The RS-68 is the first new liquid rocket booster engine developed since the Space Shuttle Main Engines. The RS-68 is a completely new 650,000-lb_f-thrust oxygen/hydrogen boost engine that uses "low cost" manufacturing technology traceable to Air Force technology development programs of the late 1980s. The RS-68 will be the lowest-cost American rocket engine ever produced in terms of dollars per pound of thrust. Boeing's Rocketdyne Division is building this new booster engine for their Delta IV launch vehicle. Approximately two firings per week will be conducted on AFRL's Test Stand 1A. The program will soon reach long duration, full power testing on the engine. (L. Quinn, AFRL/PRR, (661) 275-5630)

The RS-68 Rocket Engine

Test Stand 1-A at Edwards AFB

SUMMER INTERN PROGRAM BEARS FRUIT: Ms. Deborah E. Hirt, a Chaminade-Julienne High School junior employed by the Combustion Branch (AFRL/PRSC) during the summer of 1998, recently traveled to Orlando, Florida, to present her research findings. She presented a paper titled "Determination of Water in Aviation Fuel," co-authored by Jim Gord, Chris Bunker, and Keith Grinstead, to an international audience at the annual Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy (PittCon). During her brief stay with PRSC, Ms. Hirt invested her efforts in the study of water determination in aviation fuel. Water in fuel creates icing issues, and JP-8+100 exacerbates some water-related concerns. Ms. Hirt, working with Dr. Jim Gord, studied the effects of the +100 additive on Aqua-Glo measurements of water in fuel. Aqua-Glo is a commercial device based on an American Society of Testing and Materials (ASTM) standard method for water measurement. Her results revealed important new details regarding water-fuel-additive interactions. Her paper was very well accepted and the session chairman indicated that Ms. Hirt's paper was the best he had ever seen presented by a high-school student. This success demonstrates that the summer intern program provides benefits to both the Air Force and the participating students. (J. Gord, AFRL/PRSC, (937) 255-7431)

IHPTET COMBUSTORS GO SUPERCRITICAL: Under the auspices of the Integrated High Performance Turbine Engine Technology (IHPTET) Program, Pratt & Whitney has achieved a major milestone. For the first time, JP-8+100 fuel was successfully vaporized, endothermically cracked, and burned in a combustor rig. These tests were focused on fuel injector performance and primary combustion zone characteristics. The tests also provided validation of an engine prototype heat exchanger. In these tests, JP-8+100 fuel vapor was introduced at 800° to 1000°F, and there was no evidence of coking anywhere in the fuel system. The test plan included points that represented maximum design fuel-air ratio conditions and design vapor/liquid fuel flow splits. Preliminary results indicate that as vapor fraction increased, combustion efficiency increased and smoke characteristics decreased. The test was a complete success in terms of both the aero combustor performance and the posttest condition of the fuel system hardware. This technology is essential for future advanced military aircraft to counter the ever-increasing fuel heat load resulting from subsystem cooling throughout the aircraft. (C. Arana, AFRL/PRTC, (937) 255-5974)

IHPRPT BOOST DEMO PROGRAM UNDERWAY: The kickoff meeting for the Integrated High Payoff Rocket Propulsion Technology (IHPRPT) Phase I Solid Boost Demonstration was recently held at Thiokol's facility in Wasatch, Utah. The objective of this Rocket Propulsion Division (AFRL/PRR) sponsored program is to demonstrate Phase I IHPRPT goals for a space launch solid propellant booster. The program will integrate mature and innovative technology from IHPRPT and other contracted technology programs, including Thiokol Independent Research and Development (IR&D). The two-year program will culminate in the static test of a 92-inch diameter large demonstration motor. (L. Quinn, AFRL/PRR, (661) 275-5630)

UNIQUE MEASUREMENT CAPABILITY DEMONSTRATED: The first ever simultaneous high-quality measurements of turbine stage aerodynamic performance and surface heat transfer have been made at the Propulsion Directorate's Turbine Research Facility (TRF). These results were obtained during the Advanced High-Work Turbine (AHWT) test. Previous tests of turbine stages in other short duration facilities have been able to demonstrate heat transfer and pressure loading data, but were unable to make acceptable aerodynamic efficiency measurements. With both the aerodynamic and heat transfer data from the same test, it is now possible to conduct energy audits to confirm the accuracy of the results and to provide estimates of the heat transfer where no instrumentation exists. This ability to make accurate aerodynamic and heat transfer measurements is a critical milestone in the DoD/NASA Integrated High Performance Turbine Engine Technology (IHPTET) Program. (D. Hoying, AFRL/PRTE, (937) 255-6802)

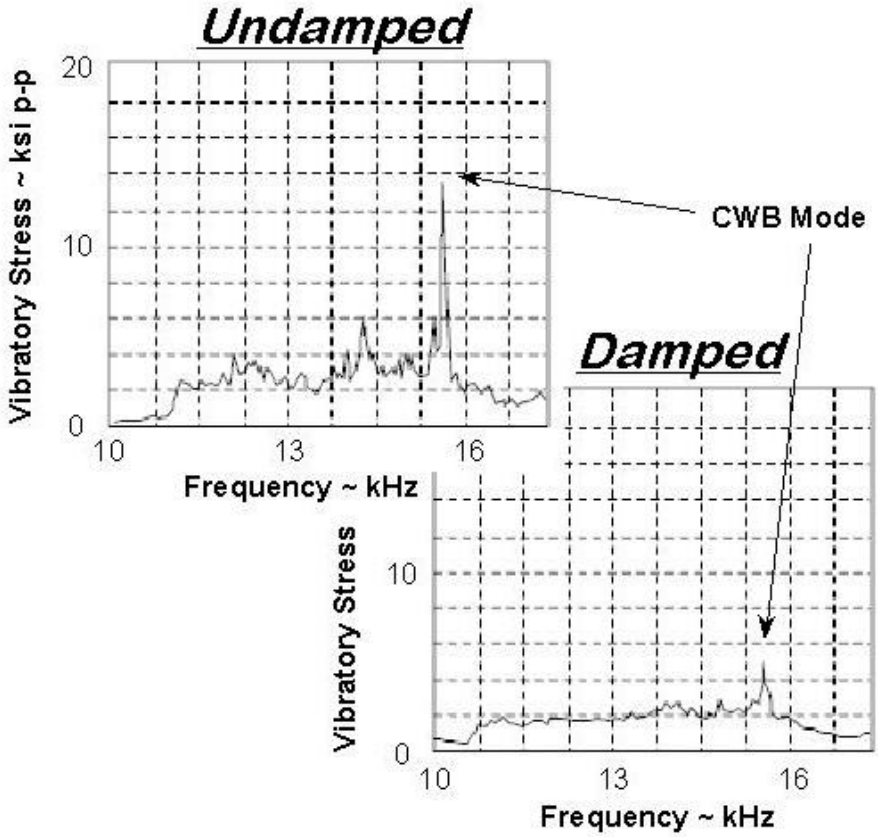
FORSTER NOMINATED FOR STLE FELLOWSHIP: Dr. Nelson Forster of the Lubrication Branch (AFRL/PRSL) has been nominated for fellowship in the Society of Tribologists and Lubrication Engineers (STLE). Dr. Hooshang Heshmat, a senior fellow of STLE, nominated him for his role in advancing basic understanding and technology in high temperature lubrication. The Propulsion Directorate's Chief Scientist, Dr. Alan Garscadden, also sent a letter to Dr. Heshmat supporting Dr. Forster's nomination. If the nomination is successful, Dr. Forster will be given fellowship status at the upcoming STLE annual meeting in May 1999. (R. Wright, AFRL/PRSL, (937) 255-5568)

TRF FEATURES NEW CAPABILITIES: The measurement of the design operating point condition for the Integrated High Performance Turbine Engine Technology (IHPTET) Advanced High-Work Turbine (AHWT) has been completed. In the process of obtaining this measurement, several new facility capabilities were demonstrated simultaneously in the Propulsion Directorate's Turbine Research Facility (TRF). First of all, the operation of a redesigned drive system was verified up to 10,500 rpm. The new drive system includes an improved bearing design to minimize vibration and a more powerful starting motor to significantly reduce the spin-up time to reduce wear on the bearings and minimize time spent at critical speeds. Additionally, the operation of an active speed control system has been verified throughout the speed range of the TRF. The speed control system has allowed an order of magnitude improvement (± 0.25 percent) in the ability to set and hold a corrected speed during a test. Finally, the ability to make high quality aerodynamic measurements in a transient facility has been successfully demonstrated. (M. Kobelak, AFRL/PRTX, (937) 255-1931)

FUELS BRANCH SUMMER INTERN WINS SCHOLARSHIP: Mr. Craig Isgro, a summer intern with the Fuels Branch (AFRL/PRSF) in 1998, placed first in a recent American Institute of Aeronautics and Astronautics (AIAA) scholarship competition. The Dayton-Cincinnati Section of AIAA offers this $2,000 scholarship, and the competition attracted more than 90 applicants. A student at Stebbins High School, Mr. Isgro, was chosen as one of five finalists in the competition. He was clearly the most outstanding applicant, as he proceeded to capture 8 of 10 first place votes in the final voting. He told the interviewing committee that his wonderful experiences at PRSF helped him decide on engineering as a career path. During his brief experience with PRSF, Mr. Isgro contributed to some important projects. He performed experiments on a device called the ellipsometer that PRSF is striving to have adopted into an American Society of Testing and Materials (ASTM) test method. He also assisted with the JP-8+100 demonstration program at the Springfield (Ohio) Air National Guard unit. Mr. Isgro will be formally recognized at the AIAA awards banquet to be held on 26 May 1999. He plans to attend the University of Dayton in the fall and may again be an intern with PRSF this summer. (P. Liberio, AFRL/PRSF, (937) 255-6918)

INTERNAL DAMPERS CRITICAL TO VANELESS OPERATION: One solution to meeting the Integrated High Performance Turbine Engine Technology (IHPTET) thrust-to-weight and cost reduction goals is a highly loaded single stage high pressure turbine (HPT) followed by a vaneless counter-rotating low pressure turbine (LPT). The resulting design has potentially two fewer airfoil rows in the HPT and one fewer in the LPT allowing significant weight and cost savings. However, this solution presents unique challenges in that high frequency shocks are produced which provide potential excitation sources for the first stage LPT blade. A damper program to assess the effectiveness of a fully integrated internal damper is part of the Navy Enhanced Turbine Blade Damping Program. This program has shown that integrated internal dampers can effectively damp high frequency modes of vibration. Vibratory stress reductions up to 80 percent have been achieved on higher frequency modes that cannot be damped using conventional blade-to-blade or blade-to-ground dampers. Pratt & Whitney will continue to generate data to be used to calibrate the microslip design system for internal dampers and to establish the effects of wear on this damper configuration. This higher frequency data allows assessment of the engine forcing functions and provides data for future vaneless turbine designs such as those being

considered for the Joint Strike Fighter. Demonstration of these dampers will be conducted in the IHPTET engine XTE66/1. (D. Thomson, AFRL/PRTC, (937) 255-2081)



Comparison of Damped and Undamped Vibratory Stresses