PROPULSION DIRECTORATE

Monthly Accomplishment Report
November 2000

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MORE-ELECTRIC TECHNOLOGIES TAKE FLIGHT ON AFTI F-16: On 24 October 2000, the JSF/Integrated Subsystem Technology (J/IST) Program successfully completed the first flight of the Advanced Fighter Technology Integration F-16 (AFTI F-16) modified for electric-powered actuation. This AFTI flight test is significant in that all primary flight control surfaces were driven by electrically-powered actuators, without hydraulic actuator backup. This demonstration was also the first to fully integrate a 270VDC electric power distribution system for power transmission to the flight control actuators, and this integration is representative of the More Electric Aircraft (MEA) configuration pursued by AFRL under the More Electric Initiative (MEI). Further desired was that the 270VDC power and actuation system remain transparent in terms of basic aircraft flight performance. Data obtained from this demonstration will be used to validate numerous supplier models, thereby lowering future JSF Engineering & Manufacturing Development (E&MD) risks. The key technologies matured under this program include: 1) an electric actuation system of five self-contained dual-redundant 270VDC electrohydrostatic actuators and control electronics to drive the primary flight control surfaces, 2) a dual-channel 270VDC switched reluctance starter/generator (S/G) as the electrical power source, 3) an upgraded emergency power unit (EPU) to provide emergency electrical power and cooling, 4) a new 270VDC, 15-kW generator (driven by the EPU) as back-up to the main S/G, and 5) a new 270VDC battery to provide uninterruptible flight control system power. The first demonstration flight lasted 78 minutes and successfully completed all planned test points. Flying qualities were evaluated at altitudes of 5k, 10k, 15k, 20k, and 30k feet. The test pilot reported that the aircraft felt very solid and handled like a basic F-16. (B. Hager, AFRL/PRP, (937) 255-4853 & J. Nairus, AFRL/PRPE, (937) 255-9392)


The AFTI F-16 in flight

DoE, AIR FORCE JOIN FORCES TO REDUCE EMISSIONS: On 6 October 2000, the Department of Energy (DoE) and the Air Force took a major step towards providing cleaner aviation fuels for the future. On this date, Dr. Fred Brown, Associate Director for the Office of Fuels and Energy Efficiency at the DoE's National Energy Technology Laboratory (NETL) and Brig Gen Paul D. Nielsen, AFRL Commander, signed a Memorandum of Understanding (MOU) to collaborate on research, development, and demonstrations of clean aviation fuel technology. This five-year, cost-shared effort supports the DoE's Ultra Clean Transportation Fuel Initiative managed by NETL, which is focused on providing the nation with affordable, clean transportation fuels from petroleum, natural gas, coal, and other energy sources. One of the initial efforts under this MOU involves the Propulsion Directorate's Fuels Branch (AFRL/PRTG) in studies focused on understanding how sulfur compounds in fuels, particularly jet fuels, impact engines and pollutant emissions. Sulfur compounds are of particular concern because sulfur-containing emissions are pollutants that contribute to poor air quality and increased levels of smoke and soot. Furthermore, when jet fuel is used as a single fuel for the battlefield in Army ground equipment, sulfur compounds can poison catalytic converters used to remove other pollutants. Jet fuels currently contain far more sulfur (specification limit 3,000 ppm) than transportation fuels such as diesel fuel. Diesel fuels currently contain about 500 ppm and pending EPA mandates that will reduce the level to 15 ppm. The ultimate goal of this research task is to develop technologies to dramatically reduce pollutant emissions generated by jet aircraft. (W. Harrison, AFRL/PRTG, (937) 255-6601)

Brig Gen Nielsen (left) and Dr. Fred Brown (right) shake hands after signing the MOU to collaborate on efforts to develop clean aviation fuel technology

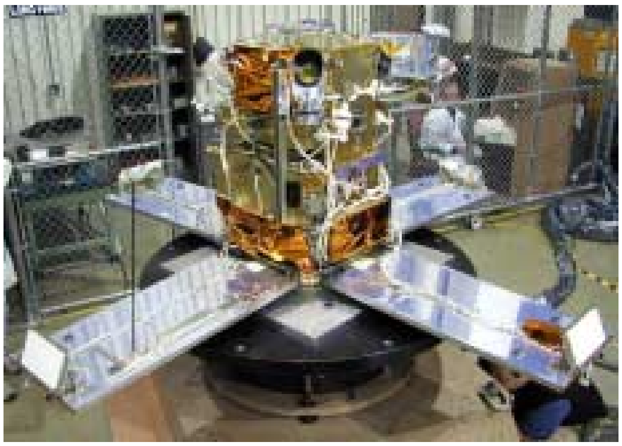
Want more information?

- ❖ A NETL Press Release on the signing of the MOU is available at http://www.netl.doe.gov/publications/press/2000/tl_wrightpat.html.
- ❖ More information on the Ultra Clean Transportation Fuels Initiative is available at http://www.fe.doe.gov/coal_power/fuels/fuels_ultraclean.shtml.

RISK ASSESSMENT AIDS MIT SATELLITE LAUNCH: A risk assessment performed by the Propulsion Directorate's Motor Branch (AFRL/PRSB) played a key role in the recent launch of a research satellite. On 9 October 2000, the HETE-2 satellite (HETE = High Energy Transient Explorer) was successfully launched on a Pegasus launch vehicle. Prior to this success, the Massachusetts Institute of Technology (MIT) enlisted the help of PRSB to evaluate the potential risks of using aged Stage I and II Pegasus solid rocket motors. These motors were beyond their normal service life; however, MIT was interested in them because they were available at a reduced cost. Propellant formulation and test data provided by the motor manufacturer were reviewed by PRSB personnel, and a determination was made that the motors would operate safely and meet the needs of the mission. Having concluded that propellant aging should not be an issue of concern, PRSB recommended using the motors, and MIT concurred. The value of this recommendation was proven with the successful launch of the HETE-2 satellite, and it was reported that the rocket motors performed perfectly. The HETE-2 is a small research satellite designed to detect galactic gamma ray bursts and rapidly relay the coordinates to the Earth to support ground observation. The HETE Program is an international collaboration led by MIT's Center for Space Research. (S. Bridges, AFRL/PRSB, (661) 275-5406)

Want more information?

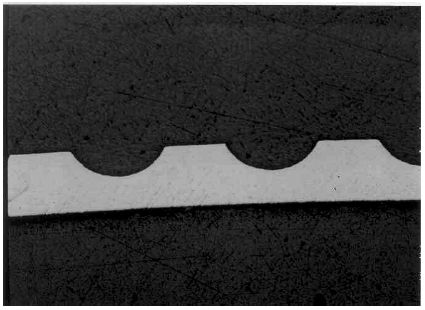
- ❖ Additional information on the HETE-2 can be found at http://space.mit.edu/HETE/.
- ❖ A replay of the launch can be found at http://science.ksc.nasa.gov/payload/missions/hete-2/.



HETE-2 with solar panels deployed

HETE-2 mounted on the Pegasus launch vehicle

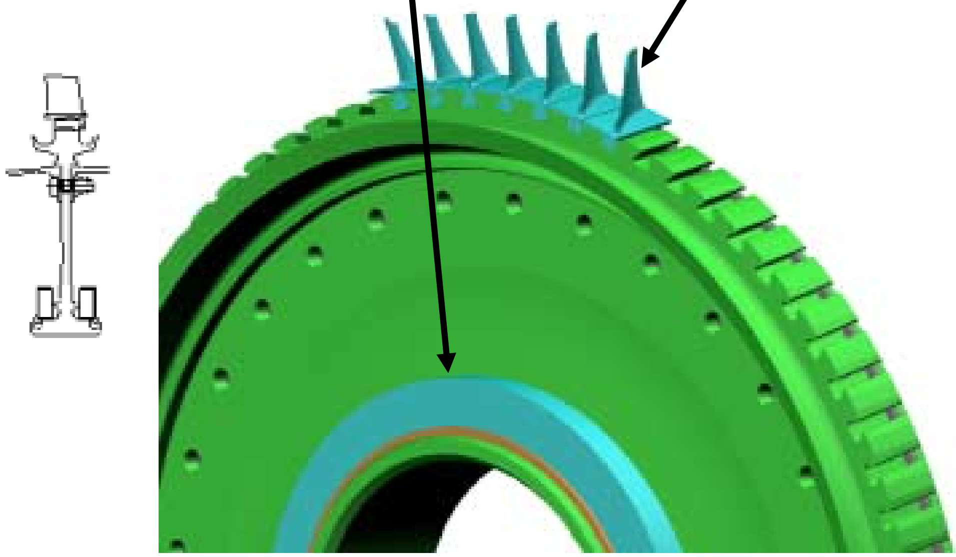
ORTHORHOMBIC MMC REMOTE RING COMPRESSOR ROTOR DEVELOPMENT: Allison Advanced Development Company (AADC) and Textron have successfully made the first orthorhombic high temperature Metal Matrix Composite (MMC) rings capable of meeting Integrated High Performance Turbine Engine Technology (IHPTET) Phase II compressor T_3 requirements. Remote ring reinforced MMC compressor rotors allow designers to reduce rotor disk weight by 28 percent while meeting high rotational speed and temperature requirements. To date, three rings have been successfully made using orthorhombic foil that is machine grooved, and one additional ring is in process bringing the total to four rings. X-ray and ultrasonic inspection results of these new rings show them to be greatly superior to rings where the foil was etched. A comprehensive spin pit program is in place to ensure that the ring and compressor rotor assembly designs can be demonstrated in the core engine at reduced risk. A number of tests of these rings are planned over the coming months. All four MMC rings will be individually proof tested at maximum temperature and load conditions. A ring will be burst to compare maximum load capability to analytical predictions and compare actual ring material properties to NDE inspection results. The compressor rotor will be spin pit tested as an assembly to test ring attachment features and disk bore loading, and a ring cyclic spin pit test is also scheduled. Both AADC and Textron have developed cost efficient manufacturing processes for foil manufacturing and automated fiber placements. Core engine demonstration is scheduled to commence in June 2001. (M. Barga, AFRL/PRTP, (937) 255-2767)



Orthorhombic 7 mil foil with
90 machined grooves per inch

MMC Remote Ring with
Orthorhombic Ti Matrix, 5 mil
diameter Ultra SCS Fibers

Gamma Ti Blade



MMC Remote Ring reinforced Orthorhombic Rotors meet the
Phase II weight and compressor exit temperature objectives

CARBON-CARBON COMPOSITE BEARING CAGES SCALED-UP: The technology for carbon-carbon (C-C) composite bearing cages was recently scaled-up to a diameter of over 7 inches for the auxiliary bearing concept being pursued by the Propulsion Directorate's Mechanical Systems Branch (AFRL/PRTM). This concept is being considered as a back-up for the magnetically supported turbine engine rotor in the Allison/General Electric Aircraft Engines (GEAE) Advanced Turbine Engine Gas Generator (ATEGG). Due to their low density, high-specific strength, excellent heat transfer and thermal properties, and good wear resistance, C-C composite materials are ideal for high-speed, high-temperature bearing applications. Analyses performed by PRTM show that bearings fitted with C-C cages generate significantly less internal

Carbon-carbon composite bearing cages

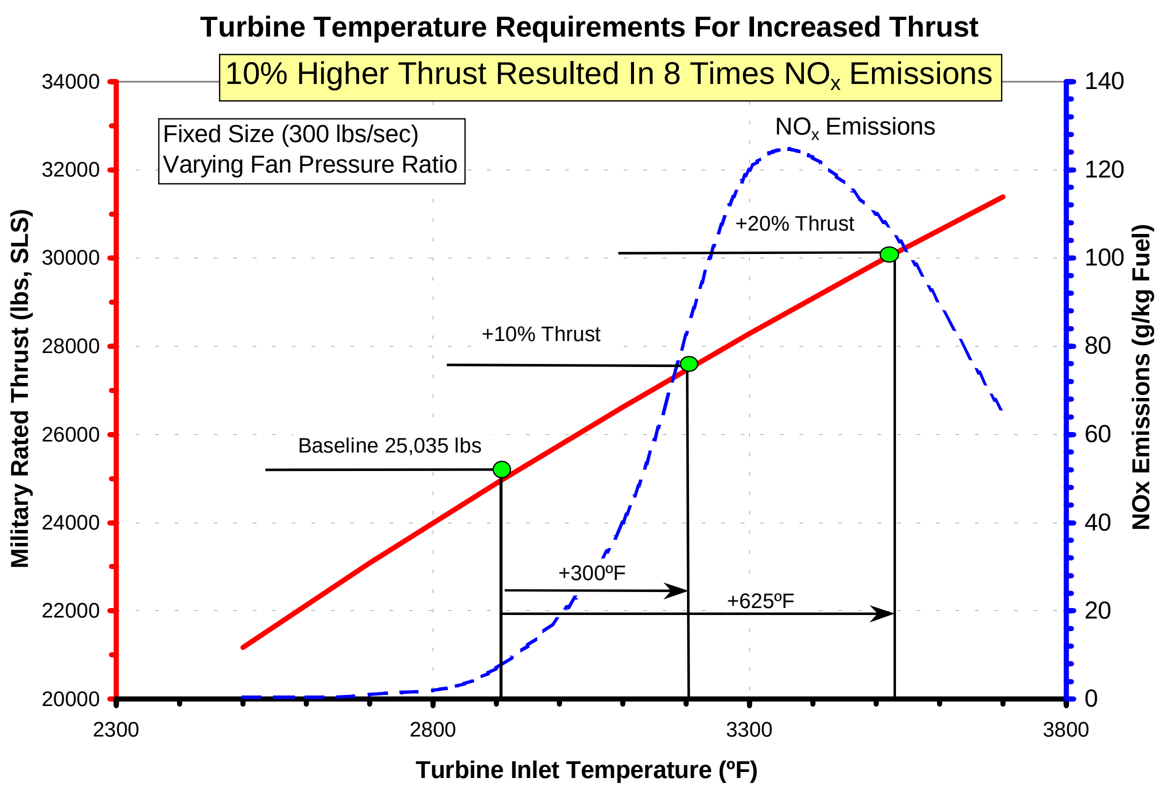
heat than those fitted with steel cages, with the heat reduction being particularly remarkable at high speeds. The lower heat generation, in turn, allows the bearings to be lubricated with non-traditional methods (e.g., oil mist, fuel lube, vapor phase lubrication, etc.) which do not require a complex recirculating system. The excellent experimental results obtained thus far on small cages (2.0 inch OD) have prompted turbine engine, aerospace, and bearing companies to seriously consider C-C cages for various bearing applications including limited life turbine engines, flywheels for space, medical x-ray scanners, tool spindles, and dental drills. The patent for this technology was granted to PRTM in 1998, who jointly developed the concept with BFGoodrich. Development of the scaled-up bearing cage was achieved by enlisting the expertise of the Propulsion Materials Applications Branch (AFRL/PRSM), BFGoodrich, SRJ, and Allcomp, Inc. In addition, Allcomp has requested to exclusively license this technology from the Air Force. This effort demonstrates for the first time that C-C cages can be made in the size required for large fighter-class turbine engine bearings. The cages will be incorporated into 150 mm-bore auxiliary bearings for testing in PRTM's auxiliary bearing rig later this year. (L. Rosado, AFRL/PRTM, (937) 255-6519)

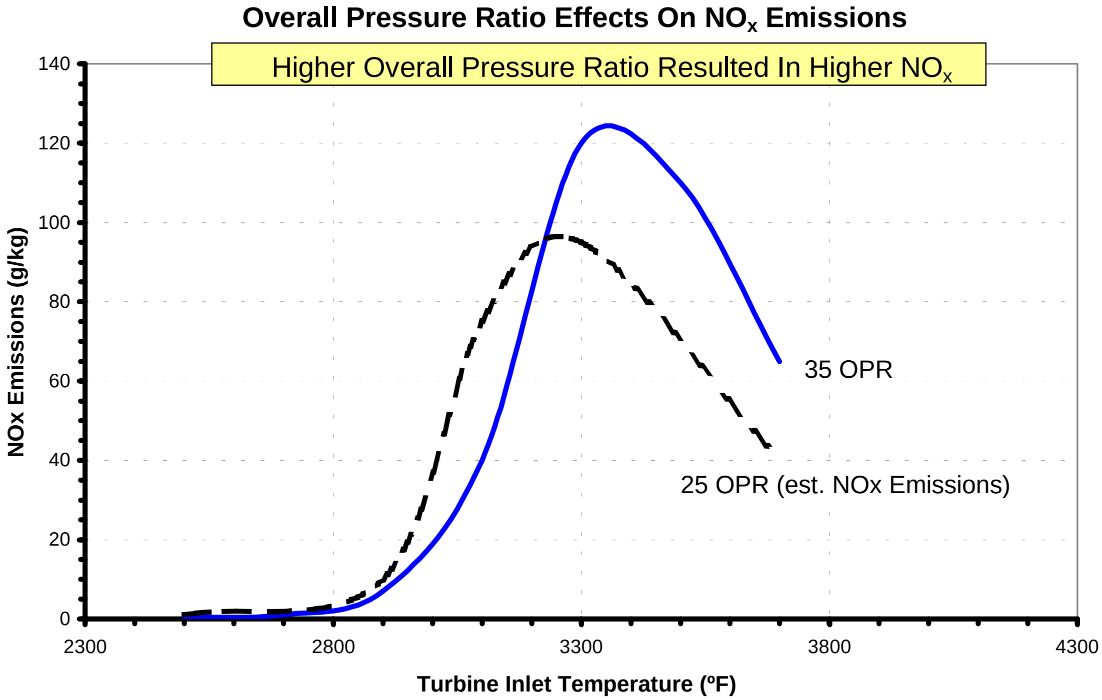
A developmental RS-68 engine being fired at Edwards AFB

<u>RS-68 ENGINE INSTALLED AT EDWARDS AFB</u>: The latest RS-68 developmental rocket engine was recently installed at the Propulsion Directorate's Test Stand 1-A at Edwards AFB, CA. This motor was installed in anticipation of a series of test firings that will continue the development of this new booster engine. The RS-68 is the first large liquid-fueled rocket developed in the US since the Space Shuttle Main Engine (SSME), and it will power the new Delta IV/Evolved Expendable Launch Vehicle (EELV). The EELV Program has a goal of reducing space launch costs by more than 25 percent, and achievement of this goal would make the RS-68 the lowest-cost American rocket engine ever produced in terms of dollars per pound of thrust. In recent testing at Edwards AFB, the RS-68 set a record for the most thrust ever attained for a liquid oxygen/liquid hydrogen engine at more than 650,000 pounds. This test effort is being performed under a joint

program with Boeing and the Air Force Flight Test Center (AFFTC). The first RS-68 powered Delta IV launches are scheduled for FY02. (R. Drake, AFRL/PRSO, (661) 275-5542)

NO_x EMISSIONS SENSITIVITY TO CYCLE PARAMETERS DETERMINED: The Propulsion Directorate recently investigated the relative sensitivity of NO_x emissions to engine cycle parameters at the request of the Office of the Under Secretary of Defense (Science & Technology)/Weapons Systems. The effects of turbine inlet temperature and overall pressure ratio were of primary interest since these are key technology parameters for improving engine performance. Based on work accomplished by Dr. G. Sturgess of Innovative Scientific Solutions, Inc (ISSI), the Engine Integration and Assessment Branch (AFRL/PRTA) was able to correlate turbine inlet temperature and overall pressure ratio to NO_x emissions. It was found that both parameters significantly increased the NO_x emissions compared to a baseline engine. The analysis demonstrated that as progress is made in technology to increase engine performance, emissions becomes more of a challenge. Reducing NO_x is important because it is a key participant in ozone-depletion, acid-rain formation, and the creation of photochemical smog. Furthermore, environmental legislation limits allowable NO_x emissions, and these limits are expected to become more restrictive in the future. The data was provided to ODUSD (S&T)/Weapons Systems to aid in developing a technology plan to address emission reduction. (C. Norden, AFRL/PRTA, (937) 255-2121)



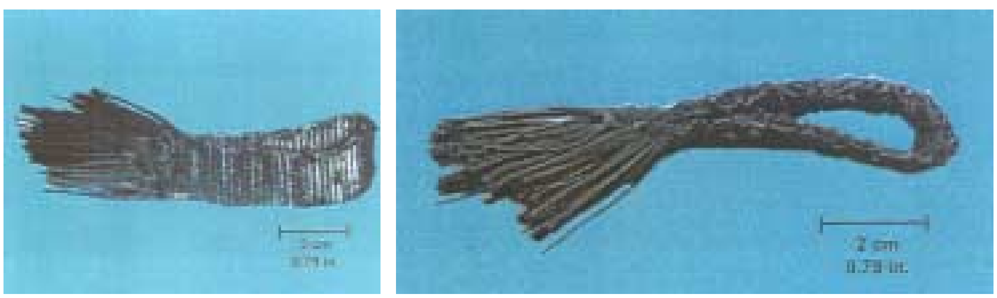


NEW FUEL TEST METHOD ACCEPTED AS STANDARD: In a joint program, the Propulsion Directorate's Fuels Branch (AFRL/PRTG) and the University of Dayton Research Institute (UDRI) have developed a new commercial test method for aviation turbine fuels. This new method determines the hydrogen peroxide content of the fuel. The hydrogen peroxide content is important because it is an indicator of fuel degradation during storage, and hydrogen peroxides also adversely affect certain elastomeric materials in fuel systems. The new test method was standardized in an Air Force run round robin test program, and in September 1999, it was accepted by the American Society for Testing and Materials (ASTM) as ASTM D6447, "Standard Test Method for Hydroperoxide Number of Aviation Turbine Fuels by Voltammetric Analysis." This test method was recently published in the *2000 Annual Book of ASTM Standards*.

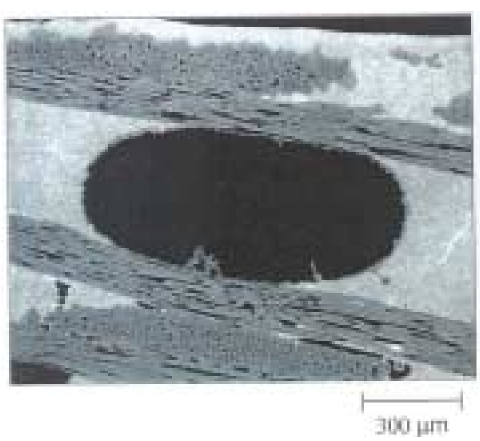
A new standard test method is available for determining the hydrogen peroxide content of jet fuel

The previously used commercial standard, ASTM D3703, had several drawbacks. The old method used ozone depleting chemicals (ODCs) and large samples, which resulted in a large amount of waste products. In addition, the method was very time consuming. In contrast, the new test method (ASTM D6447) does not use ODCs, it reduces posttest waste by 95 percent, and it can be used to analyze a sample twelve times faster than the old ASTM method. Furthermore, the substantial advantages of this new method will not only be reaped by the military, but also by commercial aviation fuel suppliers and users. (P. Pearce, AFRL/PRTG, (937) 255-6918)

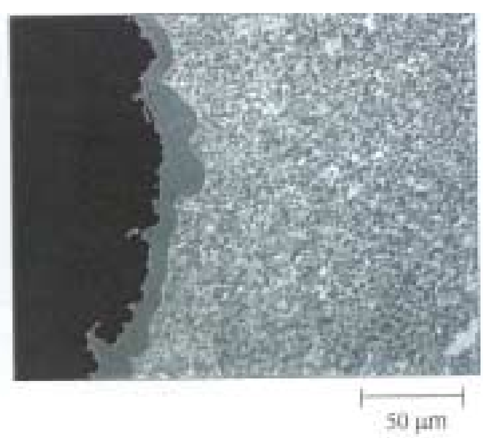
WEAVING STRAW INTO GOLD: The Propulsion Directorate is sponsoring a program with Pratt & Whitney titled "Materials and Cooling for Turbine Airfoils – MACTA II." The objective of this program is to initiate design and fabrication process development for constructing a ceramic matrix composite (CMC), low pressure turbine (LPT) vane for an Integrated High Performance Turbine Engine Technology (IHPTET) Phase III demonstrator engine. Fabricating the LPT vanes out of CMC will reduce the LPT cooling flow by 50 to 60 percent or increase the LPT inlet temperature capability by 900°F, and this translates into about a 1 to 3 percent increase in engine thrust-to-weight. Attaining the ability to weave the high modulus silicon carbide (SiC) fibers into realistic vane shapes is the major technology barrier faced by this program. To date, significant progress has been made in developing a test procedure to gauge the weavability of various fibers. A constant cross-section LPT airfoil preform has been weaved using Hi-Nicalon Type S fiber, and a method for incorporating cooling channels in the melt infiltrate SiC/SiC composites without causing too much breakage in the surrounding fibers has been developed. This is the first successful fabrication of a 3-D woven LPT airfoil preform. Although this is a significant accomplishment, many challenges remain including the problem of weaving an aerodynamic trailing edge. A monolithic ceramic insert may have to be used to provide the right trailing edge shape. In addition, the cooling holes have only been made in a flat panel, and weaving them into a vane shape will not be a trivial task. (R. Sikorski, AFRL/PRTC, (937) 255-5974)



Hi-Nicalon Type S fibers



40 mil x 18 mil racetrack shaped hole



Edge of the hole with SiC coating

FLUIDIC NOZZLE TEST MODELS DELIVERED TO GLENN RESEARCH CENTER: Scale model test hardware has been delivered to NASA Glenn Research Center (GRC) for testing under an AFRL-NASA Interagency Agreement. The hardware simulates an axisymmetric, fixed aperture, ejector nozzle design that employs fluidic thrust vectoring. The design and fabrication of the hardware were performed under the "Nozzle Technology" contract with Pratt & Whitney. Data from these tests are needed in order to assess the aerodynamic performance of this nozzle design that employs mechanical throat actuation, a throat ejector, and a fixed exit aperture. The testing will also be used to analyze an advanced flow diagnostic capability at NASA GRC and will be used to expand the database for fluidic injection. To date, the database for fluidic nozzle control includes data that either concentrates on throat area control or thrust vectoring. Additional data is needed to include ejector nozzle concepts. Fluidic thrust vectoring is a critical technology for tailless vehicle designs and offers significant weight, complexity, and cost saving potential compared to existing mechanical thrust vectoring nozzle designs. Testing in the NASA GRC Engine Research Building, CE-22 test facility, should be completed by the end of the calendar year. Upon conclusion of the tests, NASA GRC will be permitted to use the test hardware for future experimental testing. (A. Giese, AFRL/PRTA, (937) 255-1443)

Fluidic nozzle test models

"PLASMA MAGIC" EXAMINED IN SCIENTIFIC MAGAZINE ARTICLE: In the 28 October 2000 issue of *New Scientist* magazine, an article was published that describes new technological developments in supersonic and hypersonic flight vehicle design using air plasma based drag reduction. This article, titled “Plasma Magic,” cites work performed at several Russian institutions, the Defence Evaluation and Research Agency (DERA) and BAe in England, NASA Langley Research Center, and the Propulsion Directorate’s Power Systems Branch (AFRL/PRPS). The article contains excerpts of interviews with some plasma researchers including PRPS’s Dr. Biswa Ganguly. The controversy over thermal versus nonthermal plasma based drag reduction is discussed in the article, as is the tremendous potential of this technology as a drag reduction strategy. (B. Ganguly, AFRL/PRPS, (937) 255-2923)