ACCOMPLISHMENT REPORT

PROPULSION DIRECTORATE
September 2000

RESEARCH UNDER SBIR PROGRAM LEADS TO R&D 100 AWARD: Research performed under a Propulsion Directorate sponsored SBIR program led to a 2000 R&D 100 Award for Picometrix, Inc of Ann Arbor MI. Since 1963, *R&D Magazine* has honored inventors by identifying the 100 most technologically significant products and advancements for each year and recognizing the winners with the R&D 100 Award. The Chicago Tribune has called these awards "The Oscars of Invention," and others have referred to them as the "Nobel Prizes of Applied Research." Working with researchers from PR's Combustion and High Speed Systems Branch (AFRL/PRSC), Picometrix developed technology for using terahertz radiation, or "T-rays," for the nondestructive characterization of combusting flowfields and advanced aviation fuels. T-rays, which were pioneered at Lucent Technologies, exhibit unique transmission properties as a result of their location in the electromagnetic spectrum between far-infrared and microwave radiation. T-rays can be utilized for a host of applications including imaging traces in semiconductor chips, inspecting packages and luggage, and even measuring the moisture content in Twinkies™. A prototype system based on a terahertz transmitter/receiver pair was recently installed at Wright-Patterson AFB for evaluation of its combustion and fuels diagnostics potential. Efforts are now under way to secure Phase II SBIR Enhancement funds to improve the bandwidth of the terahertz devices and increase their utility for propulsion applications. Picometrix has already lined up a number of commercial sponsors for their development of terahertz technology. (J. Gord, AFRL/PRSC, (937) 255-7431)

The Picometrix T-Ray System

[For more information on the R&D 100 Awards, see R&D Magazine's website at http://www.rdmag.com/scripts/100award.asp]

PR SCIENTISTS WIN AIR FORCE-LEVEL AWARDS: Three scientists in the Propulsion Directorate were recently selected as winners of prestigious Air Force-level Science and Technology awards. Two of these scientists were in the select group of four winners of the Air Force Science and Engineering (S&E) Award for the year 2000. Dr. W. Melvyn Roquemore won the S&E Award in the category of Research Management for his distinguished work as a laboratory technical manager in fundamental and applied combustion research in the Combustion and High Speed Systems Branch (AFRL/PRSC) at Wright-Patterson AFB, Ohio. Dr. Wesley

Hoffman won the S&E Award in the category of Manufacturing Technology for his pioneering work on microtubes and other high temperature materials as a member of the Propulsion Materials Applications Branch (AFRL/PRSM) at Edwards AFB, California. In addition, Capt Dustin Ziegler was selected as one of only three winners of the Air Force Research and Development (R&D) Award for 2000. Eligibility for the R&D Award is restricted to Air Force commissioned officers working in Exploratory or Advanced Technology Development. Capt Ziegler serves in the Aerophysics Branch (AFRL/PRSA) at Edwards AFB. Congratulations to the winners on this well-deserved recognition. (J. Pearce, AFRL/PRO (UTC), (937) 255-5451)

Dr. W. Melvyn Roquemore

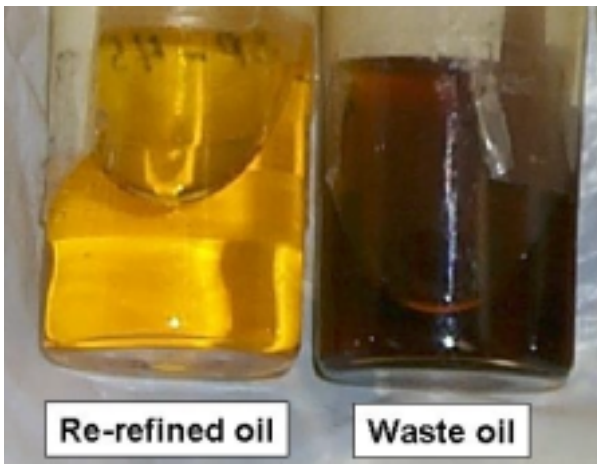
Capt Dustin Ziegler

NEW PUMP SURVIVES FOD - PROVES DURABILITY: Testing of the Variable Displacement Vane Pump (VDVP) for foreign object damage (FOD) tolerance has been successfully completed. Previous vane pumps, such as the one on F100 engines, suffered from poor durability. The purpose of this testing, performed under a Propulsion Directorate sponsored program, was to demonstrate the durability of the current vane pump design relative to gear pumps and previous vane pump designs. For these tests, FOD was injected into the pump at speeds corresponding to idle, maximum takeoff power, cruise power, and low power for descent. The FOD that was injected consisted of a variety of materials, including pieces of O-ring, lockwire, crushed quartz, and aluminum and steel chips. Some of the FOD materials used were added as a result of discussions with potential users and personnel familiar with the problems of the original F100 vane pump. Following FOD injection, no detectable adverse effects on pumping capacity or pump operation were observed for the VDVP. This is in sharp contrast to similar testing of a gear pump that was used as a comparison baseline. When tested with identical FOD slugs, the gear pump lost 30 percent of its pumping capacity due to heavy scoring of the pump housing. This demonstrated improvement in the durability of the vane pump will lead to safer, more robust turbine engines. (D. Tasch, AFRL/PRTA, (937) 255-6690)

Variable Displacement Vane Pump

FOD slug used in VDVP tests

NEW TECHNOLOGY ALLOWS REUSE OF WASTE OIL: Media and Process Technology, Inc (M&P) recently completed a Propulsion Directorate managed program titled "A Low Cost Environmentally Benign Waste Lubricants Recycling/Re-refining Technology." The purpose of this program was to utilize a membrane-based process to re-refine spent turbine oil to a near virgin state. Increasingly strict environmental regulations continue to limit disposal options for waste oil; thus, environmentally benign technologies for the recovery of waste lubricants are becoming increasingly attractive. Furthermore, a low cost and environmentally benign waste lubricant recycling process would improve US global competitiveness through cost reductions associated with waste lubricant disposal and also lower dependence on foreign oil supplies. During this effort, M&P successfully developed a pilot scale process that yields a re-refined product comparable to virgin synthetic material. In addition, a marketing agreement was established for marketing and sales of the re-refined lubricants. Construction of a full-scale process facility with a capacity to re-refine up to 5,000 gallons per month is now under way.



Samples of re-refined and waste oil

Tinker AFB is now a regular customer of M&P, and each month they sell about 1000 gallons of their waste lubricants to M&P at a price of $0.75 per gallon. This is three times the price they received in the past from selling waste oil to local power companies. M&P is currently working with other military installations and private airline companies to establish a waste lubricant collection program. If successful, 2 to 2.5 million gallons of spent MIL-L-7808 and MIL-L-23699 (or equivalent) turbine oils generated by the DoD and commercial airlines could be re-refined each year. (N. Dao, AFRL/PRSL, (937) 255-6765)

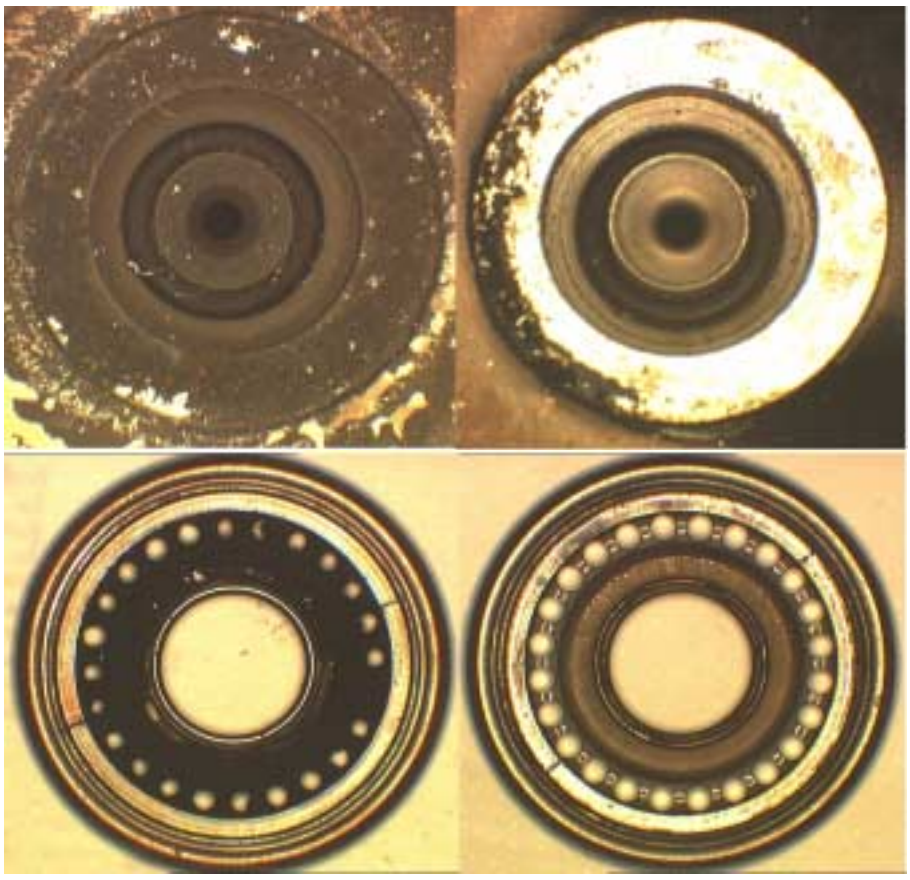
SOLAR THERMAL PROPULSION TESTING SUCCESSFUL: The Propulsion Directorate is developing a space propulsion system based on solar thermal rocket technology which can double the capability of current orbit transfer systems. This system is based on a large inflatable concentrator system concept that collects sunlight and harnesses its energy for propulsion. This technology will directly benefit the Air Force by enabling much greater mobility for inter-orbit vehicles while providing a significant reduction in propulsion system weights. Successful deployment tests of the Solar Thermal Propulsion system's 4 x 6-meter concentrator took place in August. A number of key objectives were achieved as a result of this testing. Objectives achieved include: (1) a tangle-free low-stress packaging method was proven, (2) low pressure valves to reduce weight and increase venting were developed and fabricated, (3) system weight was reduced by about 61 pounds, (4) integrated deployment of struts, torus, and lenticular concentrator demonstrated, (5) deployment accuracy of struts, lenticular, and torus and surface accuracy of lenticular measured, and (6) technique to simulate low-g conditions developed. Based on these successes, the system is ready for vacuum deployment tests in the Space Propulsion Environmental Facility this fall at Edwards AFB, California. (L. Quinn, AFRL/PRR, (661) 275-5630)

Artist's concept of a deployed solar thermal propulsion system

SUMMER FACULTY CONTRIBUTE TO SUPERCONDUCTIVITY RESEARCH: Dr. P. Terri Murray of the University of Dayton Research Institute and Dr. Sharmila Mukopadhyay of Wright State University are supporting the Propulsion Directorate's Power Systems Branch (AFRL/PRPS) under special faculty assistance programs. Under the National Research Council (NRC) Summer Faculty Program, Dr. Murray has assisted the Superconductivity Group (which includes PRPS) in developing a new pulsed laser deposition (PLD) facility for depositing high temperature superconducting (HTS) samples of YBCO (yttrium barium copper oxide). He also is conducting experimentation on the creation of nano-particles using PLD. These particles can be deposited in-situ with the HTS YBCO to act as flux pinning sites for enhancement of the current carrying properties of the HTS material. Dr. Mukopadhyay, via the Propulsion Directorate's Summer Faculty Program, is using a unique, high resolution X-Ray Photoelectron Spectroscopy (XPS) system to examine a coated sample from YBCO to buffers and to substrate. This detailed study of the sample will reveal inter-diffusion of material in the coated conductor as well as chemical states of the material to help determine reactions at the interfaces. This information has not been previously collected to this level of detail, and will reveal new information on the epitaxial growth processes of buffers and YBCO. HTS coated conductors are important for the development of compact coil windings and magnets needed for such applications as directed energy weapons and high speed systems. (P. Barnes, AFRL/PRPS, (937) 255-2923)

FAA APPROVES +100 FUEL ADDITIVE: The Federal Aviation Administration (FAA) recently approved the use of the Betz 8Q462 fuel additive for all Pratt & Whitney commercial

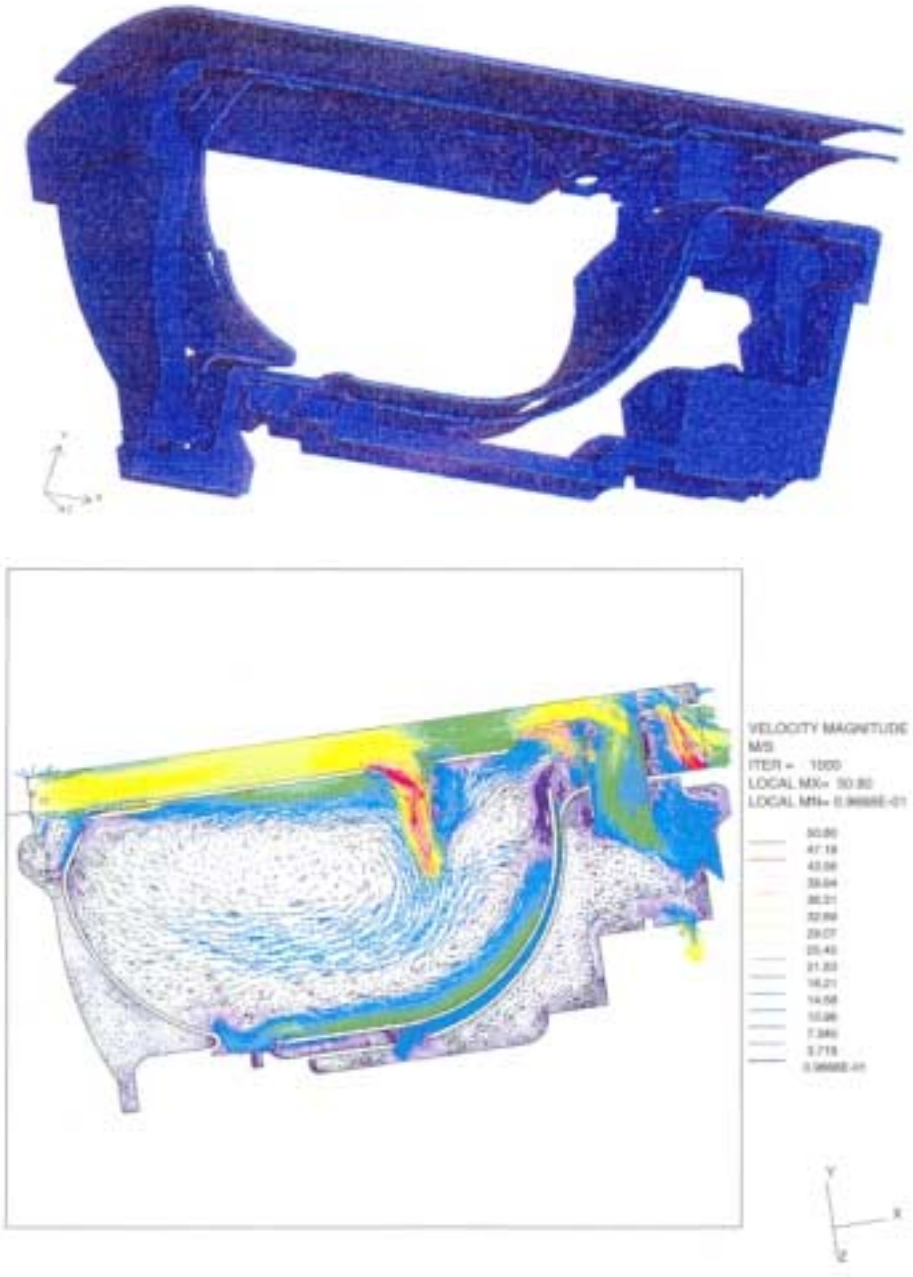
aircraft turbine engines. The Betz 8Q462 additive is known in Air Force parlance as the +100 Thermal Stability Improver Additive. This additive was developed under a program sponsored by the Propulsion Directorate's Fuels Branch (AFRL/PRSF). The goal of the program was to develop an additive that would extend the useful operating temperature of JP-8 fuel by 100°F (thus the +100 name) through the addition of a low-cost additive package. JP-8+100, the new fuel featuring the additive, has been extremely well received by users because of its outstanding performance in cleaning up fuel related deposits in aviation turbine engines. To date, JP-8+100 has been successfully used by thousands of Air Force aircraft as well as numerous aircraft of allied nations. The FAA's approval of the additive for use in commercial engines is a huge step towards getting the additive into wide use in the commercial aviation industry. (P. Pearce, AFRL/PRSF, (937) 255-6918)



Samples of engine parts operated with (right) and without (left) the +100 additive

PR ENGINEERS ASSIST WITH REDESIGN OF LOCAAS COMBUSTOR: Propulsion Directorate engineers are helping to refine the propulsion system for the Low Cost Autonomous Attack System (LOCAAS). LOCAAS is an air launched weapon system that is being developed under a government-industry partnership between the Air Force and Lockheed-Martin. LOCAAS is much smaller and less expensive than current missiles used for theater missile defense. A scaled down engine design had exhibited combustion-related instability. The Component Branch's (AFRL/PRTC) in-house combustor team was called in by LOCAAS managers at Eglin

AFB to assist in resolving this instability problem. PRTC carried out computational fluid dynamics (CFD) analyses to find a solution to the instability problem in a timely and cost-effective manner. Results of the calculations have been obtained, and potential problems with the design were identified. As a result of these predictions, a new combustor liner design to eliminate the pressure fluctuation was made and is currently being analyzed by detailed CFD. (B. Sekar, AFRL/PRTC, (937) 255-5974)



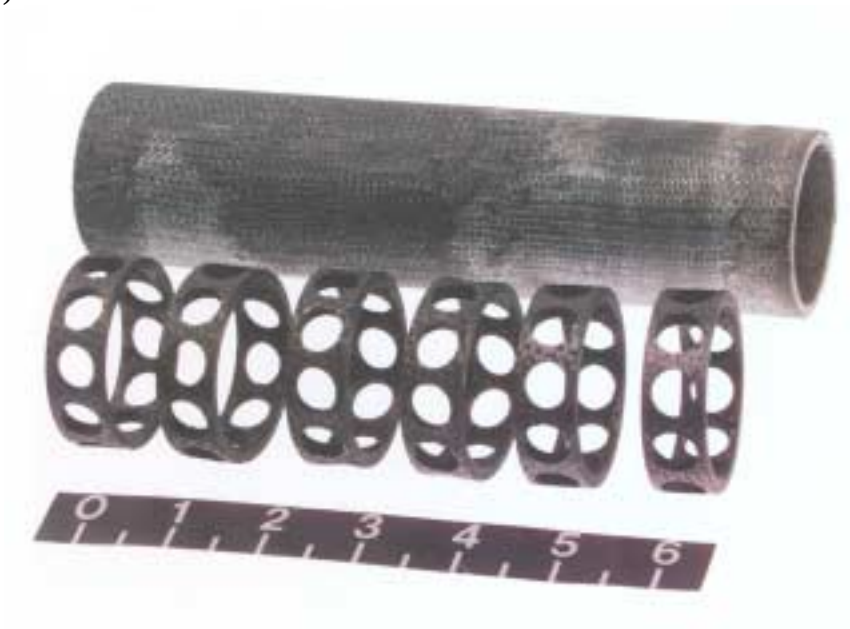
LOCAAS combustor sector (top) and computed velocities (bottom)

SECOND GENERATION PDE SUCCESSFULLY OPERATED: The second generation in-house pulsed detonation engine (PDE) was successfully fired on the first attempt in August 2000. The new engine was built by researchers in the Propulsion Directorate's Combustion and High Speed Systems Branch (AFRL/PRSC) at a cost of only $300. The new in-house PDE, which required 3 weeks to build, replaces the record setting first generation engine that was recently destroyed during testing. The Quad-4 cylinder head based engine design operates premixed like its predecessor and incorporates numerous design improvements. This new engine has a 30 percent higher operating frequency limit, which results in a 30 percent increase in thrust. The increased "red-line" also provides higher stability margins through improved valve sealing and control, and improved lubrication systems should enhance durability. The new engine has been operated on propane fuel which is a significant technological stride towards the development of practical PDE propulsion systems because propane detonates much like kerosene based jet fuels. Other enhancements include a redesigned detonator tube mount that eliminates the hardware which produced the first engine's demise and makes for quick-hardware changeovers. Other components showing signs of fatigue damage during testing have been replaced with redesigned components, and the new engine incorporates improved instrumentation. The research engine will produce benchmark PDE data and serve as a test bed for developing this revolutionary propulsion technology. (F. Schauer and J. Stutrud, AFRL/PRSC, (937) 255-6462)

PDE rig (top) and view of partially disassembled rig showing valves (bottom)

CARBON-CARBON BEARING CAGES UNDERGO TESTING: The Propulsion Directorate's Lubrication Branch (AFRL/PRSL) has developed carbon-carbon (C-C) composite bearing cages for use in fuel lubricated bearings. These bearing cages were developed to support Williams International's efforts to investigate the benefits of C-C cages in fuel lubricated bearings. Fuel lubricated bearings with 1000 hours of life are required for application in the Integrated High Performance Turbine Engine Technology (IHPTET) Joint Expendable Turbine Engine Concept (JETEC) Phase III demonstrator engine. Cage friction has been the primary obstacle to extended operation. C-C cages have previously been developed in-house by PRSL for use in marginal lubrication applications, such as vapor phase lubrication, but this is the first time they have been used with fuel lubrication. PRSL provided Williams with two test bearings featuring T15 steel races, silicon-nitride balls, and C-C cages. Both bearings are run in the test rig simultaneously and are lubricated by ambient JP-8 fuel. As of 5 June 2000, 212 hours of C-C cage life had been accumulated, already far surpassing the life limitations of previously tested cage materials. At that time, testing was suspended due to lack of funds. Funding has now been restored and testing

toward the 1000-hour goal is scheduled to resume in October 2000. (M. Wagner, AFRL/PRSL, (937) 255-7406)



Carbon-carbon composite bearing cages

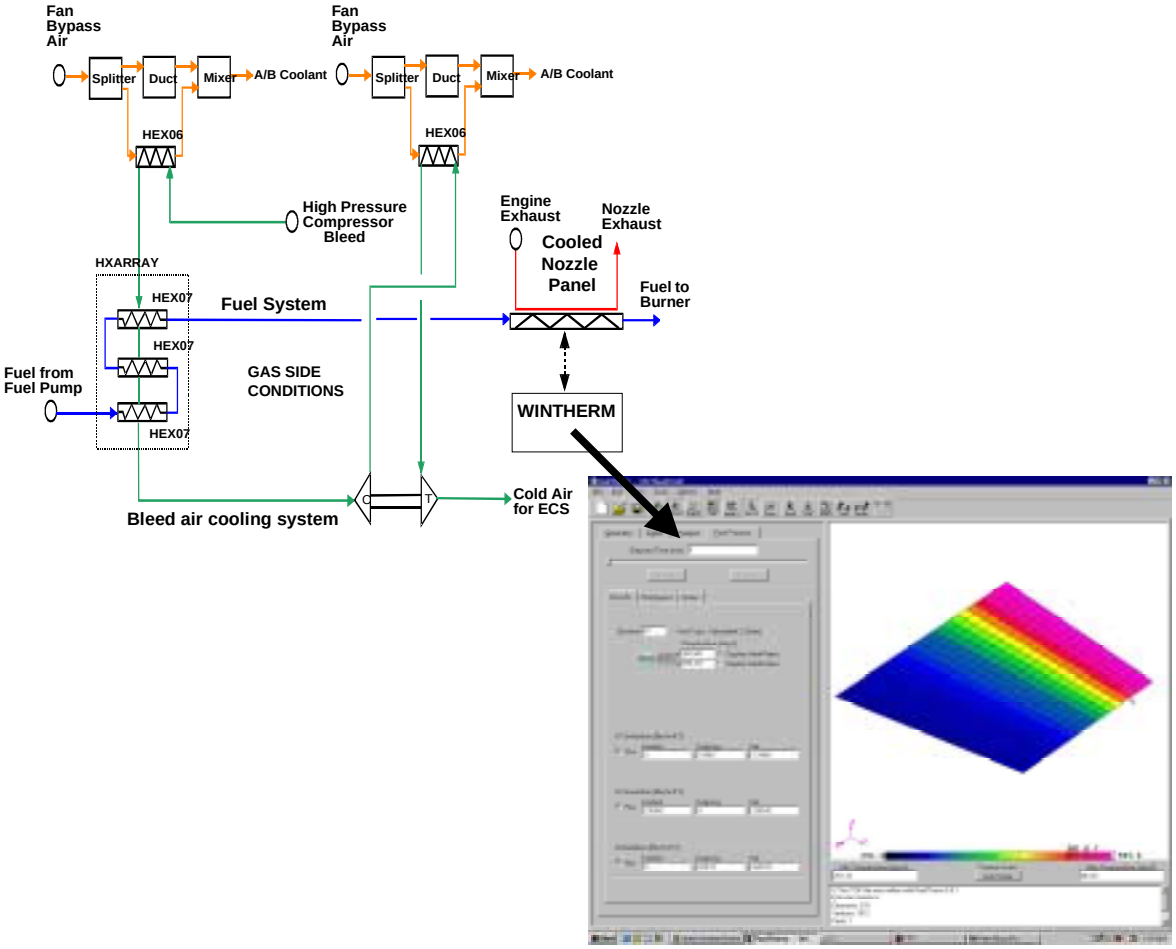
PR/NASA BEGIN COLLABORATION ON FUELS FOR SPACE ACCESS: Researchers in the Propulsion Directorate are working with NASA on hydrocarbon fuels for space access. In July 2000, the Fuels Branch (AFRL/PRSF) shipped fuels including JP-7, JP-8, and JP-8+100 to NASA Glenn Research Center (GRC) for testing. Researchers at GRC will utilize these fuels in testing in the Heated Tube Facility, a high heat flux simulation of rocket thrust chamber regenerative cooling. This testing is one of the initial stages of the PR/NASA collaboration on the study of liquid hydrocarbon fuels for space access. It is anticipated that several of the high energy hydrocarbons being developed by the Propellants Branch (AFRL/PRSP) at Edwards AFB, California, will also be tested in this NASA facility as sufficient quantities become available. Much of this activity is to be funded under the NASA Advanced High Performance Propellants project of Spaceliner 100. The Spaceliner 100 Program has the goal of developing and demonstrating the technologies required for a third-generation reusable launch system. Among the goals of this system is to reduce launch costs to the level of hundreds of dollars per pound. (T. Edwards, AFRL/PRSF, (937) 255-3524)

A Spaceliner 100 launch concept

PROGRESS CONTINUES TOWARDS SOLID BOOST DEMO TEST: The Integrated High Payoff Rocket Propulsion Technology (IHPRPT) Phase I Solid Boost Demonstration Program continues to make progress toward a November 2000 test date. The goal of this program is to demonstrate new and improved materials in the case, propellant, nozzle, and thrust vector control in a Castor 120® size rocket motor. These improvements will yield 23 percent more payload at a 32 percent lower cost for medium space lift applications. Recent progress towards this demonstration includes completion of the nozzle assembly, with the exception of final contouring of the nozzle throat and installation of instrumentation required for the static test. The igniter component has been fabricated and is awaiting the application closure insulation. In addition, mix and cast of the propellant was completed. Propellant mix acceptance testing was conducted on 19 mix batch samples, and ballistic and mechanical property testing were both accomplished. A 3-month data chart shows that this propellant ages well, and bondline test results show that ambient aging and accelerated aging do not result in any deterioration of the bondline for this system. Final assembly will commence in September 2000, and the static test firing of the demonstrator is scheduled for 16 November 2000. (L. Quinn, AFRL/PRR, (661) 275-5630)

NEW THERMAL SYSTEMS ANALYSIS TOOL PROVEN: An analytical tool combining detailed three-dimensional thermal analysis with one-dimensional system level analysis has been successfully developed and demonstrated. This analytical tool was developed under the Thermal Systems Analysis Tool (TSAT) Dual-Use Science & Technology (DUS&T) Program managed by the Propulsion Directorate. The product of this effort was successfully demonstrated during a recent working team meeting. This capability was achieved through the creation of a Component Object Model (COM) component wrapper of the three-dimensional thermal analyzer, WinTherm, and directly integrating it into a TSAT/Model Engineer model. In the near-term, this capability paves the way for increasing system model accuracy by including detailed temperature distributions of components and/or subsystems in critical thermal environments to aid in determining impacts on the overall system. In the long-term, this ability provides a pathway for linking system level assessments with structural, aerodynamic, computational fluid dynamics (CFD) and other models. (V. Van Griethuysen, AFRL/PRTA, (937) 255-2121)
[*see image next page*]

RECENT PLASMA JOURNAL PUBLICATIONS: Two technical papers were published in the August 2000 issue of *Plasma Sources and Sciences Technology Journal*. One paper describes two-photon laser-induced fluorescence measurement of atomic nitrogen losses in volume and surface reactions, and is co-authored by Dr. Steve Adams of the Propulsion Directorate and Terry Miller of Ohio State University. The data presented in this paper is important for the design of a high-flux atomic nitrogen source. The second paper reports the measurements of plasma sheath electric fields using Rydberg-atom Stark spectroscopy by both laser-induced fluorescence and optogalvanic spectroscopy. This paper is co-authored by Dr. Bish Ganguly of the Propulsion Directorate and Dave Dolson of Wright State University. The sheath electric field values determine the ion energy distribution in a plasma-etching source, and also determine the electron kinetics in a low “pd” (pressure x gap distance) parallel plate plasma source. These measurement techniques are very useful for the validation of nonequilibrium plasma model and ion-assisted etching process development. (B. Ganguly, AFRL/PRPS, (937) 255-2923)



A sample application of the new thermal systems analysis tool -
The thermal circuit of a turbine engine with fuel and bleed air cooling loops (upper left) is linked to a cooled nozzle panel modeled in WinTherm (lower right)

NEW FUELS LABORATORY ESTABLISHED: Propulsion Directorate researchers have begun initial efforts to establish a laboratory dedicated to the development and characterization of novel, state-of-the-art fuels and fuel additives. Researchers in the Fuels (AFRL/PRSF) and Combustion and High Speed Systems (AFRL/PRSC) Branches are spearheading development of the laboratory. The laboratory will combine classical organic and inorganic synthesis capabilities with advanced laser-based diagnostic methods and computational modeling. These capabilities will maximize PRSF exploitation of emerging technologies such as nanomaterials, advanced polymers, and dendrimers. Members of PRSF and PRSC along with researchers from on-site contractors Innovative Scientific Solutions, Inc and the University of Dayton Research Institute will perform research in the new laboratory. (C. Bunker, AFRL/PRSF, (937) 255-1945)