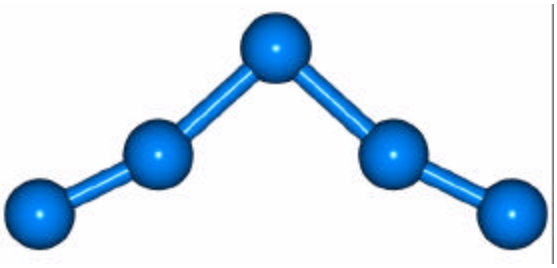
ACCOMPLISHMENT REPORT

PROPULSION DIRECTORATE
March 1999

BREAKTHROUGH IN POLYNITROGEN CHEMISTRY: Drs. Karl O. Christe and William W. Wilson, on-site contractors with the Propellants Branch (AFRL/PRSP), recently created a rare form of nitrogen that may allow future advances in high energy rocket propellants or explosives. The new compound, N_5+, is a positively charged ion consisting of five nitrogen atoms bonded in a V pattern, and it is believed to be one of the most explosive substances ever made. N_5+ was discovered as cation in the molecule N_5AsF_6. Though diatomic nitrogen (N_2) is a common element making up almost 80% of the atmosphere, molecules consisting only of nitrogen that have three or more atoms are quite rare. In fact, only one molecule of this type, an azide molecule (N_3), has ever been produced in bulk quantity. Experienced chemists considered the synthesis of N_5+ to be a virtual impossibility; however, Christe and Wilson beat the odds by devising a method to synthesize N_5+ and producing macroscopic quantities with high yield and purity. The scientists obtained proof of the substance's chemical composition using laser spectroscopy. Christe and Wilson made this discovery as part of the High Energy Density Matter (HEDM) team, a group devoted to finding and producing new high-powered rocket propellants or additives that exceed current capabilities for use in future AF systems. Though specific applications for this substance have not yet been identified, it is believed that N_5+ can be combined with an energetic anion to yield a highly energetic propellant or explosive ingredient. An article describing this achievement appeared in the science section of 2 February 1999 edition of *The New York Times*, and an Air Force press release is also available on the web (see below). (K. Christe, AFRL/PRSP, (805) 275-5194)



The N_5+ Cation

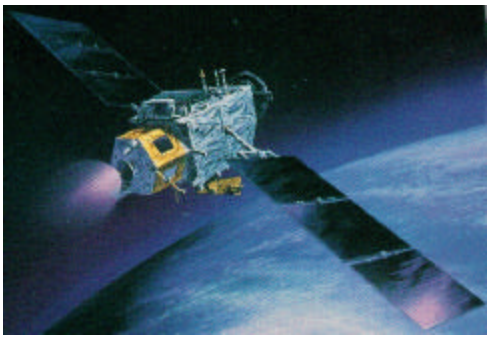
Drs. Christe and Wilson

[*NY Times* article at http://www.nytimes.com/library/national/science/020299sci-nitrogen.html]
[Air Force Press Release at http://www.ple.af.mil/public/articles/newpolyn.htm]

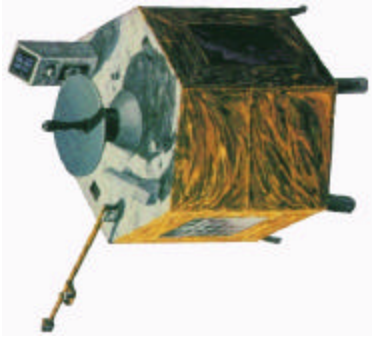
NEW SPACE PROPULSION SYSTEM LAUNCHED: On 23 February 1999, a new space propulsion experiment was launched from Vandenberg Air Force Base, California, aboard a Delta II rocket. The Electric Propulsion Space Experiment (ESEX) was launched as a payload of the Air Force Space and Missile Command's Advanced Research and Global Observation Satellite (ARGOS). An emerging technology produced by the Propulsion Directorate and TRW, the ESEX features an ammonia fueled arcjet propulsion system that is being demonstrated for the first time on orbit. Electric

propulsion has been used for many years to control satellite positioning in space. However, this propulsion system offers the potential to not only control the satellite's position in space, but also to insert the satellite into various orbits or move the satellite efficiently from one position to another. The arcjet system's long lifetime and fuel efficiency extend the useful lifetime of the satellite that it propels. The electric propulsion system is far more efficient than chemical rockets, though the net thrust generated is less than chemical rockets. During the course of the experiment, electric propulsion researchers will gather data and control the arcjet demonstration from three different Air Force ground sites. (L. Quinn, AFRL/PRR, (805) 275-5630)
[Air Force Press Release at http://www.ple.af.mil/public/articles/esex991a.htm]

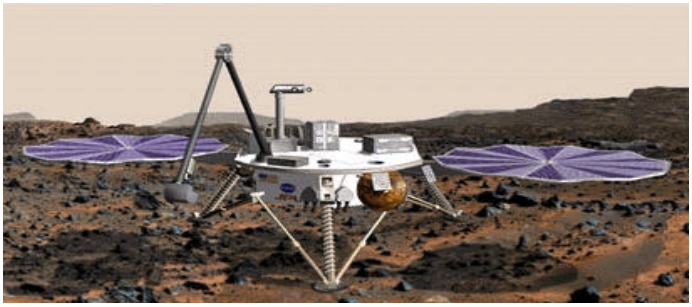
The ESEX Arcjet



The ARGOS Satellite



The ARGOS Arcjet Assembly



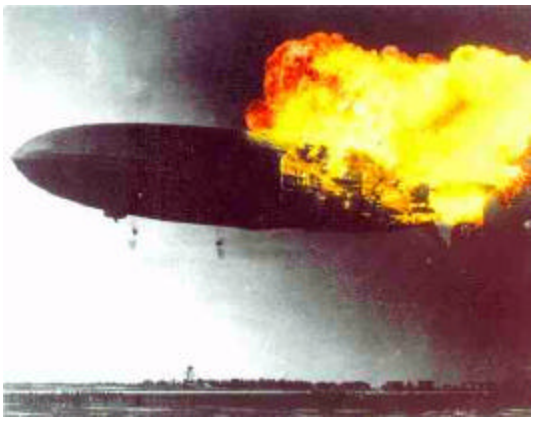
Mars 2001 Lander

LITHIUM-ION BATTERIES GOING TO MARS: Two contracts awarded under the joint DoD/NASA Lithium-Ion Battery Initiative are producing candidate cells for the NASA/Jet Propulsion Laboratory (JPL) Mars 2001 Lander Mission. Under contracts managed by the Power Division's Battery Branch (AFRL/PRPB), Yardney Technical Products and BlueStar Advanced Technology Corp are fabricating rechargeable lithium-ion cells sized for the next NASA/JPL Mars exploration mission. Alliant Techsystems, under contract to Lockheed, is also being considered. Lockheed Martin Astronautics, prime contractor for the Lander vehicle, is conducting design reviews of each contractor's technology during March and April in conjunction with JPL, NASA, and PRPB. Selection of a final cell supplier is scheduled for May 1999. The Lander design requires two 25 ampere-hour, 8-cell batteries capable of

operating over a temperature range of -20°C to 40°C (-4°F to 104°F) for 200 cycles. The batteries, which will be used to power the Lander's onboard computer and several experiment modules on the surface of Mars, must have this capability after completing the 9-month flight to Mars. Due to attractive performance characteristics, lithium-ion was identified as a favored battery technology. After careful consideration and consultation with the battery community, Lockheed was confident in baselining rechargeable lithium-ion batteries for this historic mission. The Mars 2001 Lander mission, scheduled to launch in April 2001, may represent the first spaceflight of lithium-ion technology. To learn more about the mission, see the website referenced below. (S. Vukson, AFRL/PRPB, (937) 255-7770)
[For more info on the Mars 2001 Mission, see http://mars.jpl.nasa.gov/2001/index.html]

FEASIBILITY OF NEW COOLING CONCEPT DEMONSTRATED: Coffinberry and Associates recently completed a successful Phase I SBIR for the Fuels Branch (AFRL/PRSF) titled "Indirect Cooling System." In this program, Coffinberry and Associates showed the feasibility of generating cooled cooling air (CCA) for turbine blades by using supercritical steam as an intermediate heat transfer fluid. This system is controllable, maintainable, and is inherently safe, as high temperature air does not come into direct contact with fuel. Previous studies of the CCA concept performed by the Turbine Engine Division (AFRL/PRT) indicated the potential for significantly reducing cooling flow and turbine material temperatures, thereby improving engine performance and increasing component life. Furthermore, the steam to fuel heat exchanger can be easily removed for periodic cleaning if necessary. This system is estimated to have a weight penalty of less than 30 lbs over a direct fan air/fuel heat exchanger, and the benefits of the system are believed to far outweigh this penalty. When applied to an Integrated High Performance Turbine Engine Technology (IHPTET) Phase III-like engine, this system would be required to operate only two to four percent of the time. The extra cooling would be necessary only for a small portion of the flight envelope where existing turbine materials technology cannot cope with the temperatures. (G. Tibbs, AFRL/PRSF, (937) 255-6935)

AFRL RESEARCHER REWRITING HISTORY: Dr. Claude Merrill, a researcher with the Propellants Branch (AFRL/PRSP) at Edwards Air Force Base, is involved in amending the history of one of the world's great air tragedies--the 1937 Hindenburg disaster. A retired NASA engineer, Addison Bain, has published an article theorizing that the Hindenburg fire was not caused by the hydrogen which buoyed the airship, but rather by the flammability of the airship skin. Merrill met Bain at a recent technical conference and obtained the compositions for the Hindenburg skin that he used to calculate probable flame temperatures. Applying expertise gained from conducting electrostatic discharge (ESD) studies on solid propellants, Dr. Merrill concluded that the Hindenburg's aluminized paint is a prime candidate for ESD ignition. Writing his findings in a short article, Merrill sent it to Bain suggesting that they publish the work as co-authors. The British Broadcasting Company (BBC) contacted Bain about making a documentary on the Hindenburg disaster for broadcast first in Europe and later on PBS



The Hindenburg in Flames

in the US. The BBC plans to interview Dr. Merrill for the piece and possibly obtain footage of Propulsion Directorate (PR) facilities. In addition, the BBC has interviewed personnel in the Power Division (AFRL/PRP) at Wright-Patterson Air Force Base who have expertise in static charge buildup. As well as being an excellent opportunity to gain favorable public exposure of PR's mission and capabilities, this work demonstrates the synergy between the expertise at PR-East and PR-West. (C. Merrill, AFRL/PRSP, (805) 275-5169)

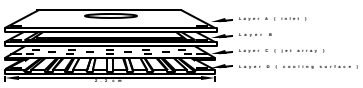
TRAPPED VORTEX COMBUSTOR SINGLE-CAVITY TESTS: A study is in progress to investigate the feasibility of a single-cavity trapped vortex combustor (TVC) design using the 6" atmospheric TVC rig. The TVC is an innovative Integrated High Performance Turbine Engine Technology (IHPTET) Phase III combustor concept conceived to improve flame stability and reduce undesirable emissions (e.g., NO_x, volatile organic compounds, and carbon monoxide). The existing TVC design is a double-cavity with recirculation zones above (outer cavity) and below (inner cavity) the main combustor. By eliminating the inner cavity, significant reductions in weight, complexity, and cost could be achieved. To investigate this new concept, three configurations will be evaluated over the next two months: baseline (both inner and outer cavities), passive inner-cavity (no fuel to the inner cavity), and single-cavity (no inner cavity at all). An additional set of tests will be performed afterwards with a multi-hole-cooled design TVC. The 6" TVC is currently being refitted with newer, thicker cavity boxes as the old boxes were damaged during tests performed in January 1999. (Lt I. Vihinen, AFRL/PRSC, (937) 255-8623)

MINIATURE HEAT PIPES TO COOL MICROELECTRONICS: The Power Division (AFRL/PRP) is working with Florida International University to develop prototype miniature heat pipes to provide thermal management solutions for ceramic multichip module (MCM-C) packaging. The multichip module (MCM) is a microelectronic packaging assembly that offers higher speed, smaller size, and higher reliability than competing packaging technologies. However, due to power dissipation within the MCM, thermal management is a concern. To address this concern, MCM-Cs have been fabricated that incorporate miniature heat pipes as an integral part of the substrate. The heat pipes enhance cooling because they are much more effective at transferring heat than the alumina substrate material. Testing of the miniature heat pipes has demonstrated that they have an effective thermal conductivity of 10,000 W/m-K, which is more than 300 times the conductivity of the alumina material which they replace. The necessity for this technology continues to grow as the power dissipated in MCMs is projected to increase over the next decade. This work will be presented at the Society of Automotive Engineers (SAE) Aerospace Power Systems Conference in April 1999. (B. Donovan, AFRL/PRP, (937) 255-6241)

CATALYTIC COMBUSTOR DEVELOPMENT TOOL: The Fuels Branch (AFRL/PRSF) is working with Precision Combustion, Inc (PCI) to improve models for catalytic combustion. Catalytic combustion is a technology that yields both fuel savings from more efficient engine operation and reduced emissions of undesirable compounds such as nitrogen oxides (NO_x), carbon monoxide, and unburned hydrocarbons. Unfortunately, the design of practical catalytic combustion devices is hindered by the lack of affordable, accurate modeling tools. The goal of this effort is to develop a computational model to accurately predict catalyst surface temperature and the temperature and composition of the

gas leaving the catalytic reactor over a wide range of operating parameters. By achieving this goal, accurate assessments of combustor performance can be made enabling the design of practical catalytic combustion systems. The synergy achieved by combining the Air Force's experience with military engines and PCI's experience with commercial systems positions this project for success. Results of this effort are expected to have wide application, with results being pertinent to both aerospace propulsion and ground-based gas turbine engines. Presently, the rig to assess the effects of various catalysts on pollutant emissions has been constructed, and experiments are under way. A preliminary kinetic model has been assembled and is being evaluated. Results are to be presented at the 4th International Workshop on Catalytic Combustion in April 1999. (L. Maurice, AFRL/PRSF, (937) 255-5345)

MICRO-JET IMPINGEMENT COOLING FOR ELECTRONICS DEVICES: The inverter/converter electronic units of future More Electric Aircraft (MEA) power systems will be difficult to cool because of the increased power density from these volume and mass constrained devices. It is desirable to cool these devices with air to avoid the complexity associated with using liquid coolants. To address this issue, the Power Generation and Thermal Management Branch (AFRL/PRPG) is developing arrayed micro-jet impingement coolers that are fabricated through microelectromechanical systems (MEMS) techniques. Jet impingement of air is usually easy to implement and can provide high surface heat transfer rates. An experimental cooler was built-up with multiple silicon wafers fabricated with the MEMS process of deep reactive ion etching (DRIE). The layer with the micro-jet array has 221 jet ports each with a diameter of 0.277 mm (~1/100 in). Tests have demonstrated heat transfer flux rates up to 15 W/cm^2 from a surface heated to 85°C (185°F) which is impressive in relation to the volume of the micro-cooler. These promising test results demonstrate cooling performance comparable to liquid cooling of plate surfaces. Alternate designs are now being considered to address problems encountered in this design with respect to the airflow paths within the device. Also, an improved heat transfer correlation is being developed to account for variable air properties. (J. Leland, R. Ponnapan, and K. Yerkes, AFRL/PRPG, (937) 255-6241)

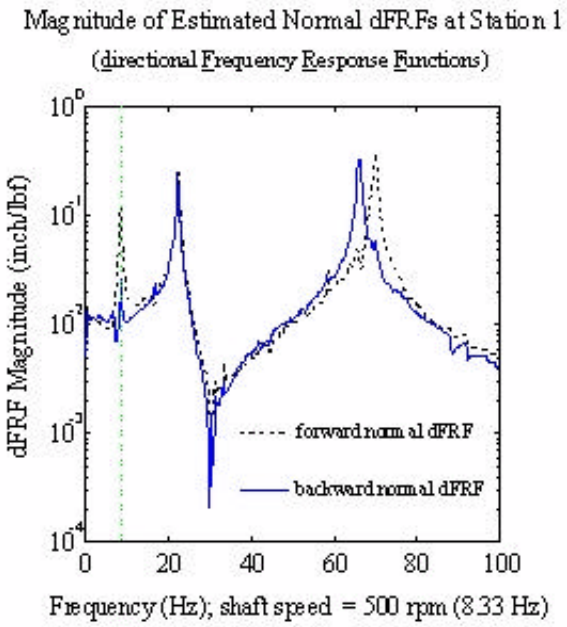


Layered View of Micro-Jet Cooler

SBIR SUPPORTS HIGH TEMPERATURE SUPERCONDUCTING RESEARCH: A recently awarded Ballistic Missile Defense Organization (BMDO) funded SBIR contract will support the efforts of the High Temperature Superconductivity (HTS) Group in AFRL/PRPS. PRPS assisted BMDO with the evaluation of SBIRs, and this proposal was among PRPS' highest-rated proposals. The contract is a collaboration between Applied Thin Films, American Superconductor Corp, and the AFRL's Superconductivity Group (a joint group involving PRPS, MLPO, and MLMR) on conductive buffers. Current buffer layers such as yttria stabilized zirconia (YSZ) and CeO_2 must be carefully deposited to avoid excessive oxygenation of the substrate. The use of conductive buffer layers being developed for the yttrium barium copper oxide (YBCO) coated conductor has the potential to resolve several major problems. Buffers that are conductive, both electrically and thermally, will allow use of the existing substrate for quench protection and thermal dissipation. The special coating can also alleviate problems of interface surface oxygenation and offer compositional variations to enable strain matching at both interfaces. Successful research will result in a coated conductor to be used in high current density coil windings for a superconducting power generator. The research will benefit the Air Force with the

development of lightweight, compact, high power generators for space and directed energy applications. (P. Barnes, AFRL/PRPS, (937) 255-2923)

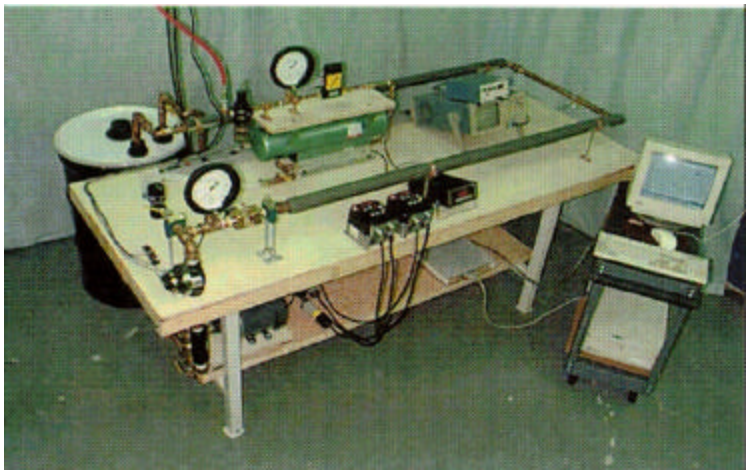
ROTOR DYNAMICS DISSERTATION SUPPORTS ELECTROMACHINE RESEARCH: Chuck Kessler (AFRL/PRPG) successfully defended his PhD dissertation, "Complex Modal Analysis of Rotating Machinery," on 29 January 1999 at the University of Cincinnati. Modal analysis deals with understanding contributions of system modes to the dynamic relationship between particular system inputs and outputs. The relevance of this rotor dynamics research topic is to improve the understanding of applied rotor forces due to electromachine power generation, magnetic/foil bearing control strategies, stability in turbines and flywheels, and other related subjects. The dissertation research involved modal analysis in which system inputs and outputs are complex (as opposed to real) variables; one representing the excitation at a rotor station (input) and one representing the response at a rotor station (output). A novel analytical concept was developed and successfully verified through experimental impact tests on a test rotor rig. Kessler presented two papers related to this complex modal analysis and its experimental verification at the International Modal Analysis Conference in February 1999. The material was of particular interest to TECO-Westinghouse Motor Company (Round Rock, Texas) which manufactures and rebuilds multi-megawatt machines. They had experienced shaft vibrations that they had not been able to explain until presented with the concepts in Kessler's papers. (C. Kessler, AFRL/PRPG, (937) 255-6241)



NEW DIAGNOSTIC CAPABILITY AIDS SUPERCONDUCTING RESEARCH: The ability to generate "pole figures" was recently established at the Propulsion Directorate by the High Temperature Superconductivity Group (AFRL/PRPS). Pole figures are a diagnostic that gives a detailed account of the surface texture of a material in a short time period. PRPS is able to generate pole figures by using x-ray texture data from a Philips defractometer located in the Materials Directorate (AFRL/ML) in conjunction with commercial plotting software (TECPLOT). Pole figures are an important diagnostic used in the evaluation of the yttrium barium copper oxide (YBCO) coated conductor being developed for use in lightweight, compact high temperature superconducting (HTS) generators. Pole figure data is important in evaluating the quality of texture in the metallic substrate, buffer layers, and the superconductor at each stage of processing so screening of specimen quality can be done at each stage. The pole figures that are generated presently do not correct for background and defocusing errors (due to tilt and rotation of the specimen). A software program to account for these special aberrations was acquired from Los Alamos and will also be integrated into the data plotting. This new diagnostic

capability will aid in the development of HTS generators that are needed for high power directed energy and space applications. (P. Barnes, AFRL/PRPS, (937) 255-2923)

PROGRESS IN MULTI-PHASE FLOW MEASUREMENT: Foster-Miller recently bench tested a non-intrusive flow measurement technique capable of resolving high temperature gas, liquid, and multiple phase flow characteristics. The concept differs from the state of the art, largely heuristic based techniques by employing a non-contacting piezoelectric (ultrasonic) transducer and smart-sensing algorithm. In the prototype measurement system, signature analysis and mode selection logic is carried out using a neural network algorithm. Switching between data collection strategies and identifying statistically significant flow events are key to success of the technique. This new measurement capability offers significant benefits for advanced fuel systems in addition to the ability to measure multi-phase flows. These benefits include cost reduction over competing approaches, greater flow measurement accuracy, and capability to measure flow parameters at high (> 600°F) temperatures. The technique can potentially be used as a diagnostic sensor for determining fuel byproduct deposition (coking) rates, fuel pump health/performance, and system safety. Non-Intrusive Multi-Phase Flowmeter development was accomplished under a SBIR Phase I effort funded by the Propulsion Directorate. Successful completion of flow testing represents the first step in demonstrating an operational device. Future work by Foster-Miller on a commercial contract will result in development of a high temperature transducer. Suitability for the military environment will require testing in a high temperature fuel system rig. (K. Semega, AFRL/PRTA, (937) 255-6690)



Multi-Phase Flow Measurement Rig