NASA/TM—2014-218497

An Overview of SBIR Phase 2 Airbreathing Propulsion Technologies

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November 2014

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Abstract

Technological innovation is the overall focus of NASA's Small Business Innovation Research (SBIR) program. The program invests in the development of innovative concepts and technologies to help NASA's mission directorates address critical research and development needs for agency projects.

This report highlights innovative SBIR Phase II projects from 2007-2012 specifically addressing areas in Airbreathing Propulsion which is one of six core competencies at NASA Glenn Research Center**.** There are twenty technologies featured with emphasis on a wide spectrum of applications such as with a Turbo-Brayton cryocooler for aircraft superconducting systems, braided composite rotorcraft structures, engine air brake, combustion control valve, flexible composite driveshaft, and much more. Each article in this booklet describes an innovation, technical objective, and highlights NASA commercial and industrial applications.

This report serves as an opportunity for NASA personnel including engineers, researchers, and program managers to learn of NASA SBIR's capabilities that might be crosscutting into this technology area. As the result, it would cause collaborations and partnerships between the small companies and NASA Programs and Projects resulting in benefit to both SBIR companies and NASA.

A Turbo-Brayton Cryocooler for Aircraft Superconducting Systems

Designed to lower aircraft emissions, fuel consumption, and noise

Hybrid turboelectric aircraft—with gas turbines driving electric generators connected to electric propulsion motors—have the potential to transform aircraft design. Decoupling power generation from propulsion enables innovative aircraft designs, such as blended-wing bodies, with distributed propulsion. These hybrid turboelectric aircraft have the potential to significantly reduce emissions, decrease fuel burn, and reduce noise, all of which are required to make air transportation growth projections sustainable. The power density requirements for these electric machines can only be achieved with superconductors, which in turn require lightweight, high-capacity cryocoolers.

Creare, Inc., designed, built, and tested two compact, lightweight, high-performance recuperators for the Cryoflight turbo-Brayton cryocooler. This will provide an enabling technology for the superconducting systems needed for hybrid turboelectric aircraft to be feasible.

Applications

NASA

The highly reliable and space-proven turbo-Brayton cryocooler is ideal for the following NASA applications:

- Aircraft demonstrations:
  - Design trade studies
  - System demonstrations
  - Superconducting aircraft demonstrations
- Cryogen liquefaction and storage for:
  - Planetary and extraterrestrial exploration missions
  - Crew exploration vehicles
  - Extended-life orbital transfer vehicles
  - Inspace propellant depots
  - Extraterrestrial bases
- Cooling for spaceport cryogen storage and transportation systems:
  - Demonstrations of hydrogen production and transportation systems

Commercial

The cryocooler is ideally suited for situations where high-temperature superconducting (HTS) materials are used, including:

- Power conditioning and power transmission systems
- Large-scale offshore wind turbines
- High-efficiency data centers
- Navy ship systems
- Turboelectric aircraft

Beyond HTS, this technology also can be used in the following applications:

- Cooling for laboratory and industrial-scale gas separation, liquefaction, cryogen storage, and cryogen transportation systems
- Liquid hydrogen fuel cell storage for the automotive industry
- Commercial orbital transfer vehicles and satellites


NASA photo

Phase II Objective

- Develop and demonstrate a compact, lightweight recuperator optimized for a turbo-Brayton cryocooler for hybrid turboelectric aircraft

Benefits

- Reduces CO_2 emissions
- Decreases fuel consumption
- Lowers noise

Firm Contact

Creare, Inc.
Anthony Dietz
P.O. Box 71
Hanover, NH 03755–3116
Phone: 603–643–3800
Fax: 603–643–4657

Proposal Number: 11-2: A2.01-9150

Braided Composite Technologies for Rotorcraft Structures

To reduce weight, noise, and vibration

A&P Technology has developed a braided material approach for fabricating lightweight, high-strength hybrid gears for aerospace drive systems. The conventional metallic web was replaced with a composite element made from A&P's quasi-isotropic braid. The 0°, +/–60° braid architecture was chosen so that inplane stiffness properties and strength would be nearly equal in all directions.

The test results from the Phase I Small Spur Gear program demonstrated satisfactory endurance and strength while providing a 20 percent weight savings. (Greater weight savings is anticipated with structural optimization.) The hybrid gears were subjected to a proof-of-concept test of 1 billion cycles in a gearbox at 10,000 revolutions per minute and 490 in-lb torque with no detectable damage to the gears. After this test the maximum torque capability was also tested, and the static strength capability of the gears was 7x the maximum operating condition. Additional proof-of-concept tests are in progress using a higher oil temperature, and a loss-of-oil test is planned.

The success of Phase I led to a Phase II program to develop, fabricate, and optimize full-scale gears, specifically Bull Gears. The design of these Bull Gears will be refined using topology optimization, and the full-scale Bull Gears will be tested in a full-scale gear rig. The testing will quantify benefits of weight savings, as well as noise and vibration reduction. The expectation is that vibration and noise will be reduced through the introduction of composite material in the vibration transmission path between the contacting gear teeth and the shaft-and-bearing system.

Applications

NASA

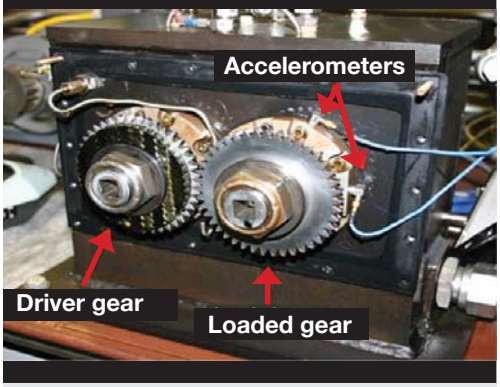
- Rotorcraft systems

Commercial

This technology could be applied to gears across many consumer industries, including:

- Aviation
- Industrial
- Automotive

A&P Technology photos



Phase II Objectives

- Determine operating conditions for a gear in a rotorcraft gearbox
- Develop, fabricate, and optimize full-scale composite/metal hybrid gears for full-scale validation testing
- Evolve analytical tools to enable design optimization

Benefits

- Decreased weight in rotorcraft gearboxes
- Reduced noise and vibration

Firm Contact

A&P Technology
Nathan Jessie
4595 East Tech Drive
Cincinnati, OH 45245–1055
Phone: 513–688–3200
Fax: 513–688–3201

Proposal Number: 11-2: A2.09-8194

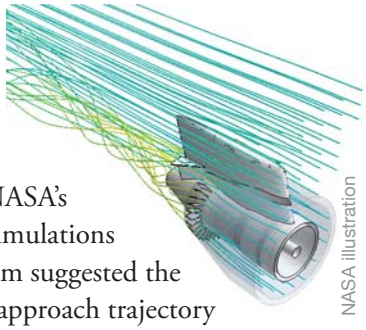
Deployable Engine Air Brake

For quiet drag management

On approach, next-generation aircraft are likely to have airframe noise levels that are comparable to or in excess of engine noise. ATA Engineering, Inc. (ATA) is developing a novel quiet engine air brake (EAB), a device that generates "equivalent drag" within the engine through stream thrust reduction by creating a swirling outflow in the turbofan exhaust nozzle. Two Phase II projects were conducted to mature this technology: (1) a concept development program (CDP) and (2) a system development program (SDP).

Concept Development Program

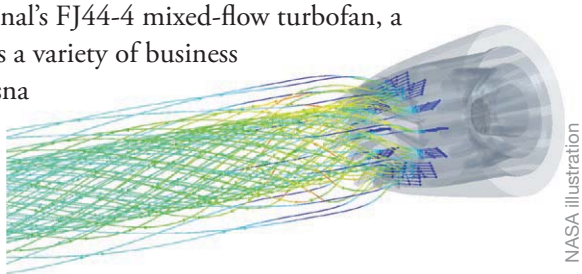
The CDP used computational fluid dynamics to quantify the relationship between flow, thrust, and equivalent drag for a number of EAB geometries designed by ATA. A model-scale prototype was designed and built for experimental aeroacoustics assessment in NASA's Aeroacoustic Propulsion Laboratory. Flyover simulations using NASA's Aircraft Noise Prediction Program suggested the technology could enable, for example, a steep approach trajectory (from a baseline 3.2° glideslope to 4.4°) for a 737-800-class aircraft, resulting in a peak tone-corrected perceived noise level reduction of up to 3.1 dB.



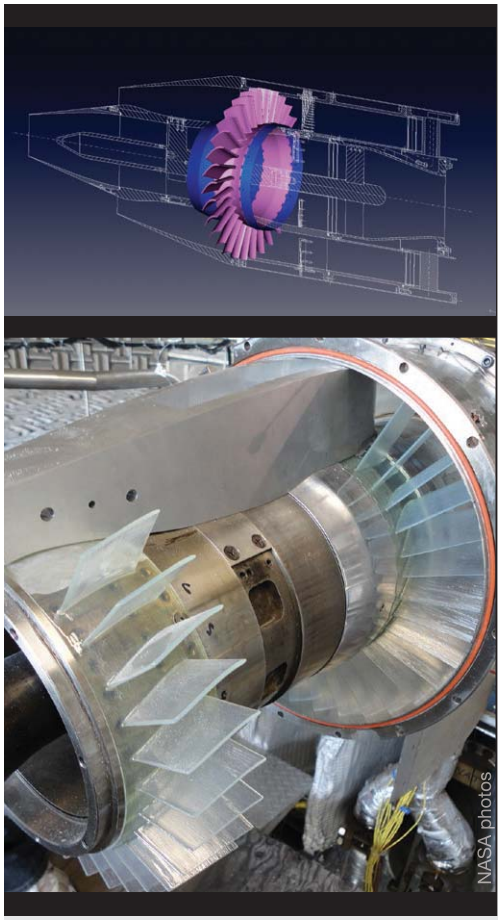
NASA illustration

System Demonstration Program

The system demonstration program (SDP) currently underway includes detailed design and fabrication of a mechanical EAB prototype to be used in demonstrating a system that can seamlessly switch between stowed and deployed modes while the engine outlet nozzle is charged with a high-pressure flow stream. That is, the system will include a mechanism to allow swirl-inducing vanes to be stowed within the engine structure, facilitating normal flow during cruise conditions and deployment on demand to reduce the engine's thrust while maintaining flow capacity. To demonstrate the technology on a relevant platform, the prototype is being designed to integrate with Williams International's FJ44-4 mixed-flow turbofan, a family of engines that supports a variety of business jet customers, such as the Cessna CJ4, Hawker 400XPR, and Pilatus PC-24.



NASA illustration



NASA photos

CDP Phase II Objectives

- Design and build a stationary model-scale EAB simulator for performance and noise testing
- Quantify relationship between swirl vane angle, equivalent drag, fan and core stream flow, and noise for a representative high bypass ratio engine
- Evaluate how the performance of an EAB is affected by deflection of the engine pylon trailing edge
- Assess system noise reduction potential via flyover simulation

Proposal Number: 07-2: A2.03-8606

Planned On-Engine Testing

The mechanical EAB prototype will be ground tested for functional, thrust reduction, and noise performance when installed on an FJ44-4 turbofan engine. The engine's operational parameters will also be measured over a range of throttle settings with the EAB at stowed, deployed, and intermediate points to ensure adequate surge margin at all operating conditions. Acoustic measurements will quantify the noise difference between the stowed and deployed states. Stresses, temperatures, and pressures within the engine will be monitored to validate normal operation. The operational test program is slated to be performed at Williams International's Outdoor Test Facility in mid-2015.

Applications

NASA

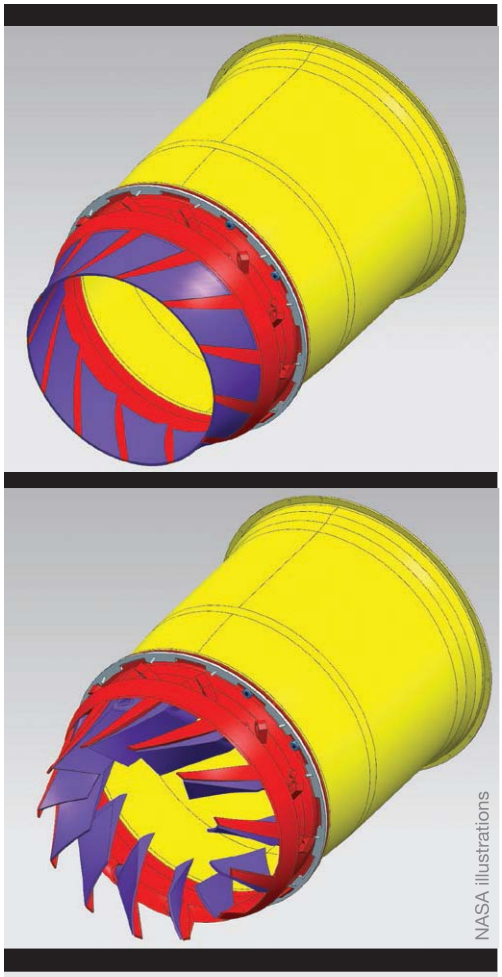
- Promote feasibility of next-generation quiet aircraft concepts:
  - Tube and wing (current generation +1)
  - Integrated airframe propulsion system configurations (current generation +2)

Commercial

- Existing aircraft:
  - Incorporate technology through retrofit (ejector) hush kits on older aircraft engines in order to meet current and future noise requirements
- Future aircraft:
  - Modify traditional engine exit guide vanes or bypass nozzles with a variable mechanism that generates a swirling outflow in drag management mode

Benefits

- Enables slower and/or steep approaches, thereby locating the noise source farther from affected communities below the flight path
- Reduces aircraft approach noise by creating "drag on demand," without the associated unsteady flow structures of devices such as flaps, slats, and undercarriage
- Can be rapidly stowed in a go-around event



NASA illustrations

SDP Phase II Objectives

- Development of a design specification for an FJ44-4 EAB
- Preliminary and detailed aero and mechanical design of a mechanical EAB prototype
- Hardware fabrication, assembly, and bench testing
- Operational testing of hardware on FJ44-4 engine

Firm Contact

ATA Engineering, Inc.
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San Diego, CA 92128
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Fax: 858–792–8932

Proposal Number: 11-2: A2.03-9148

High-Fidelity Simulation of Jet Noise From Rectangular Nozzles

Large eddy simulation (LES) model for noise reduction in advanced jet engines and automobiles

This Phase II project validated a state-of-the-art LES model, coupled with a Ffowcs Williams–Hawkings (FW-H) far-field acoustic solver, to support the development of advanced engine concepts. These concepts include innovative flow control strategies to attenuate jet noise emissions. The end-to-end LES/FW-H noise prediction model was demonstrated and validated by applying it to rectangular nozzle designs with a high aspect ratio. The model also was validated against acoustic and flow-field data from a realistic jet-pylon experiment, thereby significantly advancing the state of the art for LES.

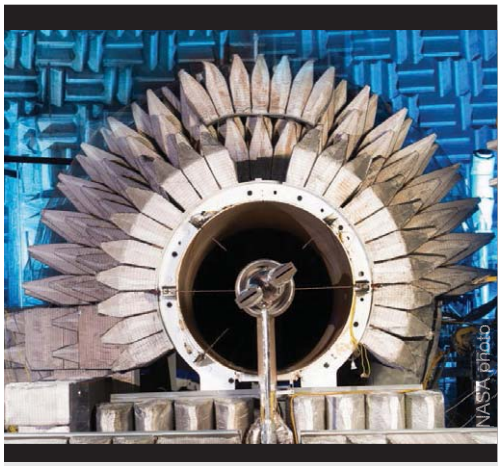
Applications

NASA

- Supersonic aircraft:
  - High-fidelity LES modeling for noise control
  - Testing of scale-model single or dual rectangular nozzles
  - Testing of nozzles with chevrons and bevels
- Subsonic fixed-wing aircraft:
  - Testing of high aspect ratio rectangular nozzles

Commercial

- U.S. Navy:
  - Noise suppression technology for the F/A-18E/F and Joint Strike Fighter F-35B programs
  - Retrofits for F414-400 engine, F404-400 engine, and F/A-18C/D aircraft
  - High-fidelity modeling for next-generation propulsion systems
- Automotive:
  - High-fidelity predictive tools for noise reduction caused by vortex shedding of side-view mirrors



Phase II Objectives

- Upgrade the LES for accurate interfacing with the nozzle internal flow field, including the effects of the nozzle boundary layer turbulence on initial shear layer growth
- Rectify overprediction of initial turbulent velocity statistics at the nozzle lipline
- Validate the LES/FW-H for performing flow-field predictions of high aspect ratio rectangular and bevel nozzle free jets using detailed flow-field and acoustic measurements
- Provide validation of the LES/FW-H model for predicting noise emissions for a real-world engine installation with effects of pylon on far-field noise

Benefits

- Provides highly predictive modeling
- Reduces noise in jet engines and automobiles

Firm Contact

Combustion Research and Flow Technology, Inc.
Neeraj Sinha
sinha@craft-tech.com
6210 Keller's Church Rd.
Pipersville, PA 18947–1020
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Proposal Number: 10-2: A2.03-9826

Microtextured Surfaces for Turbine Blade Impingement Cooling

Provides more effective internal impingement cooling

Gas turbine engine technology is constantly challenged to operate at higher combustor outlet temperatures. In a modern gas turbine engine, these temperatures can exceed the blade and disk material limits by 600 °F or more, necessitating both internal and film cooling schemes in addition to the use of thermal barrier coatings. Internal convective cooling is inadequate in many blade locations, and both internal and film cooling approaches can lead to significant performance penalties in the engine.

Micro Cooling Concepts, Inc., has developed a turbine blade cooling concept that provides enhanced internal impingement cooling effectiveness via the use of microstructured impingement surfaces. These surfaces significantly increase the cooling capability of the impinging flow, as compared to a conventional untextured surface. This approach can be combined with microchannel cooling and external film cooling to tailor the cooling capability per the external heating profile. The cooling system then can be optimized to minimize impact on engine performance.

Applications

NASA

- Turbine engine development
- Versatile Affordable Advanced Turbine Engine (VAATE) initiative
- Two-stage-to-orbit designs

Commercial

- Military and commercial aircraft:
  - Enables higher combustion temperatures with lower engine penalties
- Power generation plants:
  - Enables operation at higher temperatures and efficiencies
- Electronics
- Industrial processes
- Automotive
- Lasers

Phase II Objective

- Evaluate the suitability of high-temperature materials (e.g., from the Inconel® or HAYNES® series) in this application.

Benefits

- Increases cooling capability of the impinging flow
- Enables tailored cooling capability

Firm Contact

Micro Cooling Concepts, Inc.
Jack Fryer
jayfryer@microcoolingconcepts.com
7522 Slater Avenue, #122
Huntington Beach, CA 92647–7738
Phone: 714–847–9945

Proposal Number: 10-2: A2.10-8672

Real-Time Aircraft Engine-Life Monitoring

For real-time health monitoring of aircraft engine components and systems

This project developed an inservice life-monitoring system capable of predicting the remaining component and system life of aircraft engines. The embedded system provides real-time, inflight monitoring of the engine's thrust, exhaust gas temperature, efficiency, and the speed and time of operation. Based upon this data, the life-estimation algorithm calculates the remaining life of the engine components and uses this data to predict the remaining life of the engine. The calculations are based on the statistical life distribution of the engine components and their relationship to load, speed, temperature, and time.

NASTEC photo

Applications

NASA

- Aircraft engine performance

Commercial

- Aviation and aerospace:
  - Inflight monitoring system analyzes remaining service life of aircraft engine

Phase II Objectives

- Acquire profiles of aircraft system engines
- Develop a complete embedded hardware/software system architecture
- Verify the system design in simulation
- Integrate the life monitor into a commercial or military aircraft

Benefits

- More accurately predicts remaining component and system life of aircraft engines
- Improves aviation safety, reliability, and maintenance
- Reduces life-cycle costs and maintenance costs
- Facilitates cost-effective design and manufacturing of new production engines

Firm Contact

Nastec, Inc.
Richard Klein, President & CEO
dickc123@earthlink.net
5310 W. 161st Street, Suite G
Brook Park, OK 44142–1601
Phone: 216–464–8388

Proposal Number: 09-2: A1.08-9406

Inflight and Preflight Detection of Pitot Tube Anomalies

Increases the safety of aircraft passengers and crew

The health and integrity of aircraft sensors play a critical role in aviation safety. Inaccurate or false readings from these sensors can lead to improper decision making, resulting in serious and sometimes fatal consequences. This project demonstrated the feasibility of using advanced data analysis techniques to identify anomalies in Pitot tubes resulting from blockage such as icing, moisture, or foreign objects.

The core technology used in this project is referred to as noise analysis because it relates sensors' response time to the dynamic component (noise) found in the signal of these same sensors. This analysis technique has used existing electrical signals of Pitot tube sensors that result from measured processes during inflight conditions and/or induced signals in preflight conditions to detect anomalies in the sensor readings.

Analysis and Measurement Services Corporation (AMS Corp.) has routinely used this technology to determine the health of pressure transmitters in nuclear power plants. The application of this technology for the detection of aircraft anomalies is innovative. Instead of determining the health of process monitoring at a steady-state condition, this technology will be used to quickly inform the pilot when an air-speed indication becomes faulty under any flight condition as well as during preflight preparation.

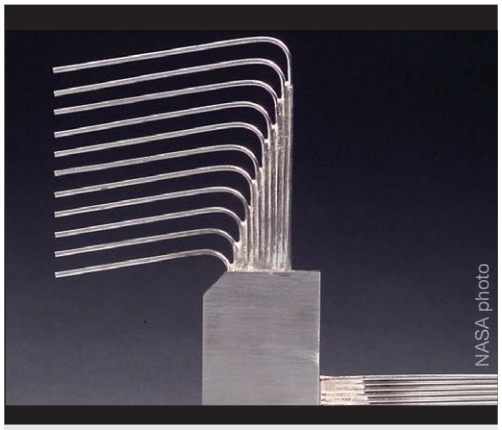
Applications

NASA

- Pitot tube/static system performance

Commercial

- Aviation and aerospace:
  - Detection of Pitot tube anomalies resulting from blockages during inflight or preflight conditions
  - Wide applications in commercial, private, and military aircraft industries
  - Applicable to new aircraft and existing aircraft with only minor modifications



Phase II Objectives

- Research and acquire existing air data systems and evaluate them for compatibility with the proposed signal analysis techniques
- Complete laboratory experiments to identify the signal analysis techniques that best distinguish Pitot tube blockage
- Develop and optimize the inflight blockage detection algorithm and software
- Develop and build inflight blockage detection prototype system
- Develop and build preflight blockage detection prototype system
- Demonstrate and validate prototype blockage detection system through inflight testing

Benefits

- Improves detection of inaccurate indications
- Increases safety of passengers and crew
- Reduces the potential for accidents

Firm Contact

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darrell@ams-corp.com
9119 Cross Park Drive
Knoxville, TN 37923–4510
Phone: 865–691–1756

Proposal Number: 09-2: A1.10-8957

Lightweight, Efficient Power Converters for Advanced Turboelectric Aircraft Propulsion Systems

Extremely efficient cryogenic power conversion technology

NASA is investigating advanced turboelectric aircraft propulsion systems that use superconducting motors to drive multiple distributed turbofans. Conventional electric motors are too large and heavy to be practical for this application; therefore, superconducting motors are required. In order to improve aircraft maneuverability, variable-speed power converters are required to throttle power to the turbofans. The low operating temperature and the need for lightweight components that place a minimum of additional heat load on the refrigeration system open the possibility of incorporating extremely efficient cryogenic power conversion technology. This Phase II project is developing critical components required to meet these goals.

Applications

NASA

- Turboelectric aircraft propulsion systems
- High-power drives for superconducting motors
- High-power and high-power-density cryogenic and wide temperature range power conversion systems:
  - Interplanetary and interstellar spacecraft
  - Satellites
  - Landers
  - Surface base stations on moons or planets

Commercial/Other Government

- Utility projects to develop superconducting power transmission
- Superconducting wind turbine generators
- Distribution systems for large buildings (e.g., data centers, manufacturing plants):
  - MTECH Laboratories is currently working toward a demonstration site of such a distribution system
- U.S. Navy:
  - Cryogenic motor drive system for the All-Electric Ship program
- U. S. Department of Energy (DOE):
  - Equipment for superconducting accelerators at DOE national accelerator labs

Phase II Objectives

- Design, fabricate, and test a cryogenic multichip module, which can be used in applications requiring very high power densities and efficiencies
- Design, fabricate, and test a cryogenic half-bridge inverter using these modules, demonstrating the potential reduction in size and weight for a given power level as well as ultrahigh efficiency

Benefit

- Offers small size, low weight, and high efficiency

Firm Contact

MTECH Laboratories, LLC
Michael J. Hennessy
mjhennessy@mtechlabs.com
831 Rte. 67, Bldg. 45C
Ballston Spa, NY 12020–0227
Phone: 518–885–6436

Proposal Number: 09-2: A2.01-9471

Novel Active Combustion Control Valve

For high-frequency modulation of atomized fuel flow

This project presents an innovative solution for active combustion control. Relative to the state of the art, this concept provides frequency modulation (greater than 1,000 Hz) in combination with high-amplitude modulation (in excess of 30 percent flow) and can be adapted to a large range of fuel injector sizes. Existing valves often have low flow modulation strength. To achieve higher flow modulation requires excessively large valves or too much electrical power to be practical. This active combustion control valve (ACCV) has high-frequency and -amplitude modulation, consumes low electrical power, is closely coupled with the fuel injector for modulation strength, and is practical in size and weight. By mitigating combustion instabilities at higher frequencies than have been previously achieved (~1,000 Hz), this new technology enables gas turbines to run at operating points that produce lower emissions and higher performance.

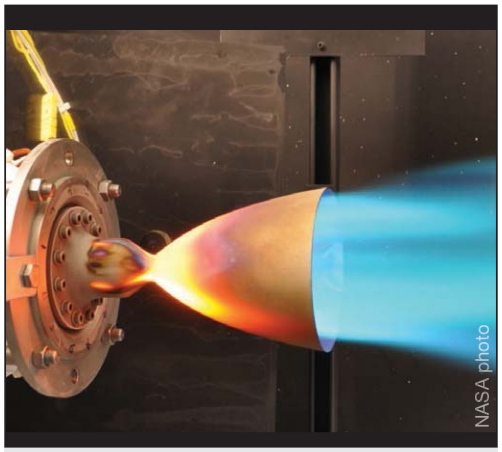
Applications

NASA

- This technology can be used in engine designs for higher performance and lower exhaust emissions for:
  - Prime propulsion
  - Auxiliary power
  - Power generation

Commercial

- Large-frame power generating gas turbine manufacturers
- Low-emission combustion systems



Phase II Objectives

- Use analysis and design tools to refine and optimize the ACCV and its associated components, including the motor, electronic controller, and proportional solenoid
- Finalize the design and generate hardware drawings
- Manufacture the ACCV components and assemble the various components into working prototype units
- Test the ACCV to validate its fuel flow modulation strength and frequency response up to 1,000 Hz
- Reduce the test data and determine the effectiveness of the ACCV at modulating fuel flow at 1,000 Hz
- Validate analysis models

Benefits

- Mitigates combustion instabilities at higher frequencies
- Can be close-coupled to the atomizer for high-modulation strength
- Consumes low electrical power
- Offers compact and lightweight design

Firm Contact

Jansen's Aircraft Systems Controls Inc.
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Proposal Number: 09-2: A2.02-9291

Ultrahigh Temperature Capacitive Pressure Sensor

To monitor engine health and improve aircraft safety

Robust, miniaturized sensing systems are needed to improve performance, increase efficiency, and track system health status and failure modes of advanced propulsion systems. Because microsensors must operate in extremely harsh environments, there are many technical challenges involved in developing reliable systems. In addition to high temperatures and pressures, sensing systems are exposed to oxidation, corrosion, thermal shock, fatigue, fouling, and abrasive wear. In these harsh conditions, sensors must be able to withstand high flow rates, vibration, jet fuel, and exhaust. In order for existing and future aeropropulsion turbine engines to improve safety and reduce cost and emissions while controlling engine instabilities, more accurate and complete sensor information is necessary. High-temperature (300 to 1,350 °C) capacitive pressure sensors are of particular interest due to their high measurement bandwidth and inherent suitability for wireless readout schemes.

The objective of this project is to develop a capacitive pressure sensor based on silicon carbon nitride (SiCN), a new class of high-temperature ceramic materials, which possesses excellent mechanical and electric properties at temperatures up to 1,600 °C.

Applications

NASA

- Planetary exploration mission to Venus
- Integrated vehicle health management and control for onboard systems:
  - Propulsion systems, including launch and station-keeping, turbo pump assemblies, thrust chamber assemblies in liquid rocket motors, and nuclear thermal propulsion
- Energy generation systems, such as fuel cells, Stirling engines, and nuclear reactors
- *In situ* resource utilization systems

Commercial

- Commercial and military jets
- Fossil fuel (coal and natural gas) power generation
- Nuclear power generation
- Concentrating solar thermal power generation

Phase II Objectives

- Optimize SiCN formulations to create materials with optimized dielectric and loss tangent properties
- Develop an SiCN device fabrication process to realize air/electrode gap sizes of less than 5 μm
- Fabricate improved prototype SiCN sensor devices, prototype packaging hardware, and signal conditioning electronics
- Perform laboratory-scale performance testing
- Based on results of initial integrated hardware testing, redesign and rebuild prototype hardware for relevant environment testing in NASA and/or partner test systems to achieve a technology readiness level (TRL) 5–6

Benefits

- Significantly reduces payload weight and volume
- Enables enhanced health monitoring via a noninvasive, on-engine system
- Does not require cooling

Firm Contact

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515 Courtney Way, Suite B
Lafayette, CO 80026–8821
Phone: 303–516–9075 ext. 12

Proposal Number: 09-2: A2.02-9410

Simulation Tool for Dielectric Barrier Discharge Plasma Actuators

Can be used at atmospheric and subatmospheric pressures

Traditional approaches for active flow separation control using dielectric barrier discharge (DBD) plasma actuators are limited to relatively low speed flows and atmospheric conditions. This results in low feasibility of the DBDs for aerospace applications. For active flow control at turbine blades, fixed wings, and rotary wings and on hypersonic vehicles, DBD plasma actuators must perform at a wide range of conditions, including rarified flows and combustion mixtures. An efficient, comprehensive, physically based DBD simulation tool can optimize DBD plasma actuators for different operation conditions.

Researchers are developing a DBD plasma actuator simulation tool for a wide range of ambient gas pressures. The tool will treat DBD using either kinetic, fluid, or hybrid models, depending on the DBD operational condition.

Applications

NASA

- Active flow separation control:
  - Subsonic and hypersonic flights
- Optimize gas discharges at different ambient pressures (e.g., plasma-assisted combustion for the reduction of carbon emissions)

Commercial

- Active flow separation control for subsonic and hypersonic programs:
  - Flow separation control for commercial airplanes during takeoff or landing
  - Active flow control for hypersonic vehicles
  - Increase in lift for tiltrotor aircraft
  - Improvement of engine performance
- Plasma aerodynamics applications:
  - Plasma-assisted combustion
  - Flow control using different types of discharges
  - Reduction of carbon emission
  - Optimization of air vehicle operation
  - Magnetohydrodynamic (MHD) and electrohydrodynamic (EHD) applications
  - Plasma processing and plasma medicine

Phase II Objectives

- Extend chemical and physical discharge model in VORPAL® software application
- Extend hybrid capabilities of the proposed model
- Enhance computational speed of the proposed DBD simulation tool
- Demonstrate the DBD simulation tool through validation against experimental data at a wide range of DBD operational conditions

Benefits

- Provides an efficient and effective simulation tool for DBD plasma actuators
- Is optimized for a wide range of ambient gas pressures

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Proposal Number: 09-2: A2.05-9058

Design Environment for Multifidelity and Multidisciplinary Components

An integrated framework for turbomachinery analysis

One of the greatest challenges when developing propulsion systems is predicting the interacting effects between the fluid loads, thermal loads, and structural deflection. The interactions between technical disciplines often are not fully analyzed, and the analysis in one discipline often uses a simplified representation of other disciplines as an input or boundary condition. For example, the fluid forces in an engine generate static and dynamic rotor deflection, but the forces themselves are dependent on the rotor position and its orbit. It is important to consider the interaction between the physical phenomena where the outcome of each analysis is heavily dependent on the inputs (e.g., changes in flow due to deflection, changes in deflection due to fluid forces). A rigid design process also lacks the flexibility to employ multiple levels of fidelity in the analysis of each of the components.

This project developed and validated an innovative design environment that has the flexibility to simultaneously analyze multiple disciplines and multiple components with multiple levels of model fidelity. Using NASA's open-source multidisciplinary design analysis and optimization (OpenMDAO) framework, this multifaceted system will provide substantially superior capabilities to current design tools.

Applications

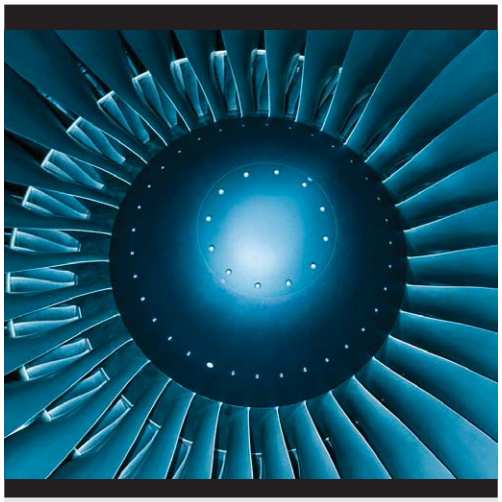
NASA

- Integrated framework for turbomachinery analysis
- Multifidelity physics-based tools
- Numeric zoom functions in numerical propulsion system simulation (NPSS):
  - Fluid-structure interaction capability
  - High-fidelity analysis and optimization in OpenMDAO

Commercial/Military

Enhanced design and development of:

- Gas turbine engines
- High-performance turbomachinery



Phase II Objectives

- Develop and validate the modeling architectures for fluid structure interaction (FSI) analysis
- Develop FSI capability in NASA computational fluid dynamics solver and commercially available solver
- Verify and validate the functions for numeric zoom, FSI, multidisciplinary, and multifidelity analysis

Benefits

- Improves design analysis process of a wide range of high-performance turbomachinery (gas turbine and chemical propulsion, power generation, oil and gas)
- Reduces failure rate and development cost of turbo-machinery systems
- Reduces time and complexity of multiphysics analysis (e.g., job setup, solution control, pre- and postprocessing)

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Proposal Number: 09-2: A2.08-8224

Embedded Data Acquisition Tools for Rotorcraft Diagnostic Sensors

To monitor and diagnose harmful vibration effects inherent to flight operation

Rotorcraft drive trains must withstand enormous pressure while operating continuously in extreme temperature and vibration environments. Captive components, such as planetary and spiral bevel gears, see enormous strain but are not accessible to fixed instrumentation, such as a piezoelectric transducer. Thus, it is difficult to directly monitor components that are most susceptible to damage.

This innovation is a self-contained data processing unit within a specialized fixture that installs directly inside the rotating pinion gear in the gearbox. From this location, it detects and transmits high-resolution prognostic data to a fixed transceiver. The sensor is based on microelectromechanical systems (MEMS) technology and uses innovative circuit designs to capture high-bandwidth data and transmit it wirelessly from inside an operational helicopter transmission.

With Ridgetop's advanced MEMS-based sensor, researchers have, for the first time, been able to extract high-resolution acoustic signatures wirelessly from sensors within the transmission that would otherwise be muffled by background gear noises. Ridgetop's innovative instrument will help researchers perform dynamic analysis of gear interaction and develop improved designs for gear components. In addition, data from this instrument can be used to validate new algorithms that detect and predict faults based on external acoustic signatures, for prognostic purposes. The result of this work will be an improvement in safety, performance, and cost for future generations of rotating components.

Applications

NASA

- Subsonic Rotary Wing Project:
  - Improved vibration sensors to help monitor and diagnose harmful vibration effects

Commercial

- Rotorcraft operators:
  - Real-time, efficient analysis of critical diagnostic data and routines
- Rotorcraft manufacturers:
  - Field testing measurements of vibration and accumulated stress
- Railway abnormal condition detection
- Real-time monitoring of downhole drill vibration in oil and gas exploration
- Sensing tool wear, chatter, or spindle balance in computer numerical control applications

Phase II Objectives

- Build and demonstrate module and acquisition system
- Tie in data collection with prognostics and advanced diagnostic approaches, and show an improvement in failure detection horizon times
- Develop a data interface between the wireless sensor port and a standard health and usage monitoring systems (HUMS) communication bus
- Demonstrate the technology with airframe manufacturers

Benefits

- Monitors structural and electronic stress due to vibration during flight
- Detects wear in the drive gears inside helicopter gearboxes
- Provides IoT (Internet of Things)-compatible wireless technology
- Supports hundreds of nodes in a sensor network
- Downloads data quickly

Firm Contact

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Proposal Number: 09-2: A2.09-9940

Design Concepts for Cooled Ceramic Matrix Composite Turbine Vanes

To reduce emissions and improve fuel consumption in gas turbine engines

This project demonstrated that higher temperature capabilities of ceramic matrix composites (CMCs) can be used to reduce emissions and improve fuel consumption in gas turbine engines. The work involved closely coupling aerothermal and structural analyses for the first-stage vane of a high-pressure turbine (HPT). These vanes are actively cooled, typically using film cooling. Ceramic materials have structural and thermal properties different from conventional metals used for the first-stage HPT vane. This project identified vane configurations that satisfy CMC structural strength and life constraints while maintaining vane aerodynamic efficiency and reducing vane cooling to improve engine performance and reduce emissions. The project examined modifications to vane internal configurations to achieve the desired objectives. Thermal and pressure stresses are equally important, and both were analyzed using an ANSYS® structural analysis. Three-dimensional fluid and heat transfer analyses were used to determine vane aerodynamic performance and heat load distributions.

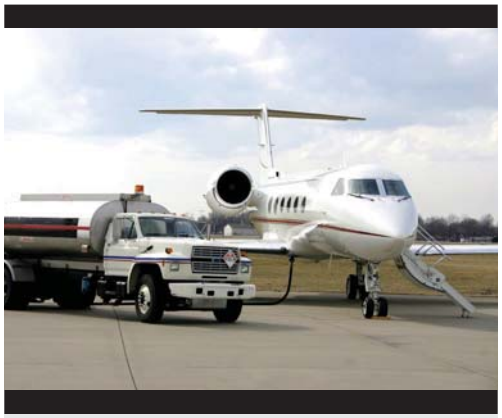
Applications

NASA

- Gas turbine engine applications:
  - Develop new materials to increase turbine inlet temperatures
  - Reduce vane cooling to lower combustor outlet temperature without decreasing rotor inlet temperature
  - Reduce specific fuel consumption and carbon dioxide (CO_2) emissions

Commercial/Military

- Transport aircraft:
  - Improve specific fuel consumption in gas turbine engines
- Power:
  - Reduce fuel consumption and CO_2 emissions of gas turbines



Phase II Objectives

- Perform aerothermal analyses for the first-stage vane of the high-pressure turbine of the energy-efficient engine (EEE)
- Identify benefits of reduced specific fuel consumption and nitric oxide emissions due to CMC vanes and blades
- Evaluate thickness, hoop, and radial component stresses for EEE vane
- Evaluate stresses due to pressure, thermal, and combined loads
- Evaluate significance of film cooling holes on stresses
- Evaluate stresses due to the presence of trailing-edge ejection cooling tubes
- Evaluate sensitivity of component stresses to variations in material properties and boundary conditions
- Evaluate radial cooling concepts for small engine application

Benefit

- Reduces emissions and improves fuel consumption in gas turbine engines

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Proposal Number: 09-2: A2.10-9062

Blade Vibration Measurement System for Unducted Fans

Provides noncontacting measurements to characterize unducted fan blade dynamics

With propulsion research programs focused on new levels of efficiency and noise reduction, two avenues for advanced gas turbine technology are emerging: the geared turbofan and ultrahigh bypass ratio fan engines. Both of these candidates are being pursued as collaborative research projects between NASA and the engine manufacturers. The high bypass concept from GE Aviation is an unducted fan that features a bypass ratio of over 30 along with the accompanying benefits in fuel efficiency. This project improved the test and measurement capabilities of the unducted fan blade dynamic response. In the course of this project, Mechanical Solutions, Inc. (MSI) collaborated with GE Aviation to (1) define the requirements for fan blade measurements; (2) leverage MSI's radar-based system for compressor and turbine blade monitoring; and (3) develop, validate, and deliver a noncontacting blade vibration measurement system for unducted fans.

Applications

NASA

- Innovative, nonintrusive unducted fan blade dynamics measurement system
- Wind tunnel facilities

Commercial/Military

- Turbofan and turboprop engines
- Blade health management for wind turbines and rotorcraft

Phase II Objectives

- Develop and validate a noncontacting measurement system for unducted fans
- Integrate system with existing technology at GE Aviation
- Deliver a working system to NASA

Benefits

- Offers resolution capable of characterizing fan blade dynamic modes
- Improves test and measurement technology
- Improves measurement capability

Firm Contact

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Proposal Number: 09-2: A4.01-8214

Fast Response Shape Memory Effect Titanium Nickel (TiNi) Foam Torque Tubes

High-speed, high-torque torsional actuators for aerospace applications

Shape Change Technologies has developed a process to manufacture net-shaped TiNi foam torque tubes that demonstrate the shape memory effect. The torque tubes dramatically reduce response time by a factor of 10. This Phase II project matured the actuator technology by rigorously characterizing the process to optimize the quality of the TiNi and developing a set of metrics to provide ISO 9002 quality assurance. A laboratory virtual instrument engineering workbench (LabVIEW™)-based, real-time control of the torsional actuators was developed. These actuators were developed with The Boeing Company for aerospace applications.

Applications

NASA

- "Morphing" unmanned aerial vehicles (UAVs)
- Concept vehicles:
  - Using wing twist to control flexible wing structures
- Deployment of booms:
  - Deploying sensors in aircraft and/or in spacecraft where the lightweight, minimal part count actuators could be heated electrically
- Next-generation shuttles (actuators must also be space qualified):
  - Controlling wing twist, nacelle structures, or ancillary aircraft structures

Commercial

- Aviation:
  - Controlling variable nacelle structures
- Windmills and turbines:
  - Generating energy more efficiently
- Health care:
  - Assisting the disabled as a lift device (similar to hydraulic actuators but with less bulk)

Phase II Objectives

- With Boeing:
  - Optimize materials to reduce contamination
  - Develop ISO 9002 production standards
  - Develop high-speed, high-torque torsional actuators
- Fully characterize the materials mechanically and chemically during production to minimize oxide/hydride contamination
- Develop LabVIEW-based computer-controlled actuation for on-off and proportional control
- Develop infrastructure to support batch production of actuators
- Test actuators (Boeing provides in its testbed facility)

Benefits

- Large torque
- Fast response
- More aerodynamically efficient structures

Firm Contact

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Proposal Number: 08-2: A2.01-8646

LabVIEW is a trademark of National Instruments.

Integrated Multidisciplinary Optimization Objects

Integrated modules for constructing and solving multidisciplinary design analysis and optimization (MDAO) problems

OpenMDAO is an open-source MDAO framework. It is used to develop an integrated analysis and design environment for engineering challenges. This Phase II project integrated additional modules and design tools into OpenMDAO to perform discipline-specific analysis across multiple flight regimes at varying levels of fidelity. It also showcased a refined system architecture that allows the system to be less customized to a specific configuration (i.e., system and configuration separation). By delivering a capable and validated MDAO system along with a set of example applications to be used as a template for future users, this work greatly expands NASA's high-fidelity, physics-based MDAO capabilities and enables the design of revolutionary vehicles in a cost-effective manner. This proposed work complements M4 Engineering's expertise in developing modeling and simulation toolsets that solve relevant subsonic, supersonic, and hypersonic demonstration applications.

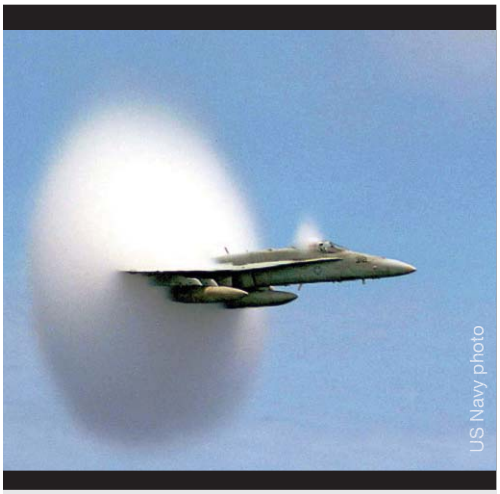
Applications

NASA

- MDAO:
  - Exchange information between multiple analysis codes at multiple levels of fidelity to create models of complex systems
  - Apply state-of-the-art MDAO algorithms designed to solve highly coupled problems that arise when multiple analysis tools are combined
  - Quickly implement new tools and methods for handling complex design problems

Commercial

- Subsonic, supersonic, and hypersonic demonstration



Phase II Objectives

- Establish system design
- Integrate framework-neutral software library
- Implement additional analysis modules
- Implement general-purpose modules
- Validate system with example problems

Benefits

- Enables a much higher degree of code sharing and reuse among the MDAO community
- Provides a baseline set of modules for constructing and solving MDAO problems
- Integrates discipline-specific and common-object modules into OpenMDAO, including propulsion, noise, mission, and stability and control
- Increases the commercialization potential for sub/super/hypersonic modules and other associated products

Firm Contact

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Proposal Number: 08-2: A2.08-8438

Blade Vibration Measurement System

For characterization of closely spaced modes and mistuning

The Phase I project successfully demonstrated that an advanced noncontacting stress measurement system (NSMS) could improve classification of blade vibration response in terms of mistuning and closely spaced modes. The Phase II work confirmed the microwave sensor design process, modified the sensor so it is compatible as an upgrade to existing NSMS, and improved and finalized the NSMS software. The result will be stand-alone radar/tip timing radar signal conditioning for current conventional NSMS users (as an upgrade) and new users. The hybrid system will use frequency data and relative mode vibration levels from the radar sensor to provide substantially superior capabilities over current blade-vibration measurement technology. This frequency data, coupled with a reduced number of tip timing probes, will result in a system capable of detecting complex blade vibrations that would confound traditional NSMS systems.

The hardware and software package was validated on a compressor rig at Mechanical Solutions, Inc. (MSI). Finally, the hybrid radar/tip timing NSMS software package and associated sensor hardware will be installed for use in the NASA Glenn spin pit test facility.

Applications

NASA

- Gas turbine propulsion engines
- Turbomachinery for liquid propulsion engines
- Steam turbines for power generation

Commercial

- Aircraft engines
- Industrial gas turbines
- Steam turbines in power generation and/or oil and gas
- Predictive health management for aerospace and industrial machines

Phase II Objectives

- Develop and demonstrate improvements in sensors and data acquisition
- Validate prototype work using instrumented compressor rig
- Characterize mistuning, mode shapes, and frequencies in test article
- Develop prototype software
- Perform rig tests, with synchronous and nonsynchronous blade excitation
- Compare strain gage data to noncontacting measurements

Benefits

- Improves blade vibration measurement capability
- Reduces cost and risk of developing and operating gas turbine engines

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Proposal Number: 07-2: A2.04-8395

Fully Integral, Flexible Composite Driveshaft

All-composite driveshaft technology for improved performance

An all-composite driveshaft incorporating integral flexible diaphragms was developed for prime contractor testing. This new approach makes obsolete the split lines required to attach metallic flex elements and either metallic or composite spacing tubes in current solutions. Subcritical driveshaft weights can be achieved that are half that of incumbent technology for typical rotary wing shaft lengths. Spacing tubes compose an integral part of the initial tooling but remain part of the finished shaft and control natural frequencies and torsional stability. A concurrently engineered manufacturing process and design for performance competes with incumbent solutions at significantly lower weight and with the probability of improved damage tolerance and fatigue life.

Applications

NASA

- Rotary wings:
  - Tail rotor drives
  - Tilt-rotor crossover drives
  - Tandem rotor connection shafts

Commercial/Military

- Rotary wing programs
- Weight-sensitive driveshaft applications
  - Joint Strike Fighter (JSF) lift fan flexible shafts
  - Navy hovercraft/air cushion landing craft
- Industrial applications
  - Very high speed turbomachinery that relies on long titanium spacing tubes

Phase II Objectives

- Build tooling and prototypes for larger diameter applications
- Build prototypes for JSF, hovercraft, tandem rotor helicopters
- Produce additional test articles for prime contractor fatigue test and support qualification plan

Benefits

- Improves driveshaft torque
- Provides higher operational speed
- Improves fatigue performance (resistance and damage tolerance)
- Reduces part count and weight

Firm Contact

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Proposal Number: 07-2: A2.10-8919

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14. ABSTRACT
Technological innovation is the overall focus of NASA's Small Business Innovation Research (SBIR) program. The program invests in the development of innovative concepts and technologies to help NASA's mission directorates address critical research and development needs for agency projects. This report highlights innovative SBIR Phase II projects from 2007-2012 specifically addressing areas in Airbreathing Propulsion which is one of six core competencies at NASA Glenn Research Center. There are twenty technologies featured with emphasis on a wide spectrum of applications such as with a Turbo-Brayton cryocooler for aircraft superconducting systems, braided composite rotorcraft structures, engine air brake, combustion control valve, flexible composite driveshaft, and much more. Each article in this booklet describes an innovation, technical objective, and highlights NASA commercial and industrial applications. This report serves as an opportunity for NASA personnel including engineers, researchers, and program managers to learn of NASA SBIR's capabilities that might be crosscutting into this technology area. As the result, it would cause collaborations and partnerships between the small companies and NASA Programs and Projects resulting in benefit to both SBIR companies and NASA.

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