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An Overview of In-Space Propulsion and Cryogenics Fluids Management Efforts for 2014 SBIR Phases I and II

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Abstract

NASA's Small Business Innovation Research (SBIR) program focuses on technological innovation by investing in the development of innovative concepts and technologies to help NASA's mission directorates address critical research and development needs for Agency programs.

This report highlights 11 of the innovative SBIR 2014 Phase I and II projects from 2010 to 2012 that focus on one of NASA Glenn Research Center's six core competencies—In-Space Propulsion and Cryogenic Fluids Management. The technologies cover a wide spectrum of applications such as divergent field annular ion engines, miniature nontoxic nitrous oxide-propane propulsion, noncatalytic ignition systems for high-performance advanced monopropellant thrusters, nontoxic storable liquid propulsion, and superconducting electric boost pumps for nuclear thermal propulsion. Each article describes an innovation and technical objective and highlights NASA commercial and industrial applications.

This report provides an opportunity for NASA engineers, researchers, and program managers to learn how NASA SBIR technologies could help their programs and projects, and lead to collaborations and partnerships between the small SBIR companies and NASA that would benefit both.

Divergent Field Annular Ion Engine—Phase I

ElectroDynamic Applications, Inc.

Achieves the projected high current densities necessary for high thrust, high power applications

The proposed work investigates an approach that would allow an annular ion engine geometry to achieve ion beam currents approaching the Child-Langmuir limit. In this respect, the annular engine, whose design inherently allows for significant increases in perveance by resolving the span-to-gap problem, can achieve the projected high current densities necessary for high thrust, high power applications. The case for high power gridded ion thrusters is compelling if not only for risk reduction in contrast to lower TRL Hall thruster variants such as the nested channel systems. This point cannot be over emphasized as there is now significant effort and resources applied to Hall engine development. Yet there still remains some uncertainty as to how high power variants or magnetically insulated variants will actually perform in space. Interpretation of high power Hall engine operation in ground test facilities is also not completely well understood. This is in contrast with gridded ion technology whose facility corrections are well understood. The current investment in high power gridded ion thruster technology is minimal. This effort seeks to address this gap in technology development and in the process continue the advancement of a credible risk reducing technology for high power mission applications.

Applications

NASA

- Electric propulsion
- Supporting those current and future NASA missions with high power requirements.

Commercial

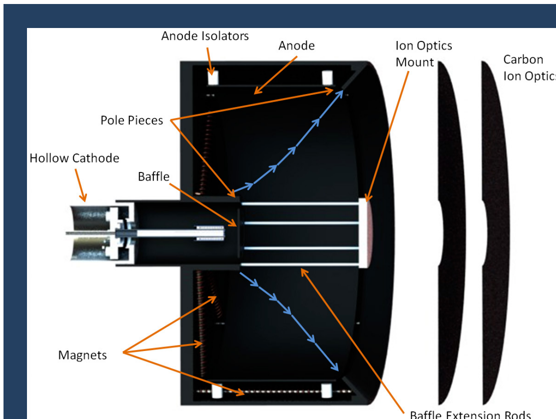
- Commercial satellite interests for orbital transfer applications
- Materials processing and neutral beam injectors (fusion)

Phase I Objectives

- Design a divergent field annular ion engine with:
  - The capacity for geometric growth thus supporting high power architectures
  - High discharge efficiency design
  - High discharge currents at high ionization efficiency.

Benefits

- To increase the availability of anode surface area to electron flow
- Maintaining low discharge losses.



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Proposal number: 14-1 H2.01-8814

Miniature Nontoxic Nitrous Oxide-Propane (MINNOP) Propulsion—Phase I

Orbital Technologies Corporation

Providing a nontoxic propellant alternative which simplifies development work and ground operations.

ORBITEC developed the Miniature Nontoxic Nitrous Oxide-Propane (MINNOP) propulsion system, a small bipropellant propulsion system which we offer as an alternative to miniature hydrazine monopropellant thrusters for CubeSat-class spacecraft. As compared to state-of-the-art hydrazine systems, MINNOP propulsion provides significant increases in specific impulse (in bipropellant mode) and comparable levels of minimum impulse bit (in cold gas mode), and it does so with a nontoxic, environmentally benign, self-pressurizing set of propellants. In Phase I, we focused on demonstrating the operation of the bipropellant thrust chamber, and ignition of that chamber within appropriate weight constraints. Our propulsion system occupies 1U of a 3U-size CubeSat.

Applications

NASA

- CubeSat in LEO
- Larger systems for orbital insertion and planetary maneuvering.

Commercial

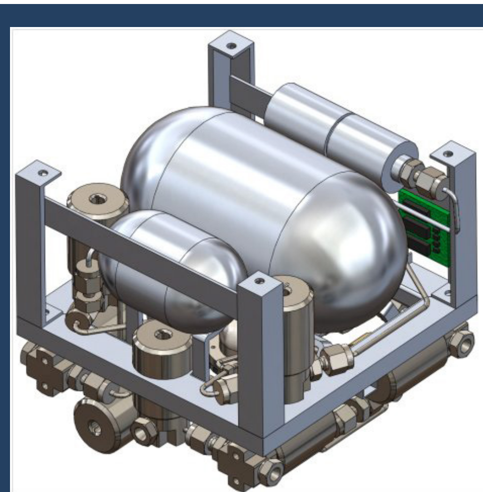
- DoD
- Commercial spacecraft

Phase I Objectives

- Demonstrate operation of a bipropellant nitrous oxide-propane thrust chamber at an appropriate thrust level
- Demonstrate ignition of these gaseous propellants with an igniter suitable for use on a miniature spaceflight propulsion system.
- Establish the feasibility of the MINNOP propulsion concept

Benefits

- Replaces toxic hydrazine with green propellants
- Provides increase in specific impulse (in bipropellant mode) and comparable levels of minimum impulse bit (in cold gas mode)



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Proposal number: 14-2 S3.02-9823

Non-Catalytic Ignition System for High Performance Advanced Monopropellant Thrusters—Phase I

Systima Technologies, Inc.

A non-catalytic ignition technology for advanced green ionic salt monopropellants

Systima Technologies, Inc. is developing a non-catalytic ignition technology for advanced green ionic salt monopropellants such as HAN-based monopropellant AF-M315E. Green (non-hazardous, low toxicity) monopropellants such as AF-M315E offer significant advantages in performance and reduced handling infrastructure for vehicles and payloads compared to traditional hydrazine systems. Systima's innovative ignition technology does not require a catalyst bed, thus avoiding the need to pre-heat the thruster chamber, is light weight, and operates with very low power. This approach is well suited for applications that require a lower system weight, less power consumption and increased thruster lifetime, and is also well suited for auxiliary power units (APU's). The Phase I program will establish parameters for non-catalytic ignition of AF-M315E. In Phase II we will conduct extended life hot-fire testing, evaluate system performance, and identify paths to flight demonstration in collaboration with Aerojet Rocketdyne.

Applications

NASA

- In-space propulsion systems such as:
  - Axial propulsion, trajectory correction maneuvers (TCM)
  - Orbit insertion
  - Mars sample return missions
  - Launch propulsion systems.

Commercial

- Launch propulsion systems
- Missile system divert and attitude control systems
- Commercial launch vehicles
- Auxiliary power units.

Phase I Objectives

- Demonstrate ignition of AF-M315E in a workhorse thruster
- Establish a preliminary set of parameters for reliable ignition
- Develop thruster concept designs.

Benefits

- Provides increased performance and new operating regimes for future NASA missions
- Eliminates the need for a pre-heated catalyst bed and overcomes the performance limitations of catalytic thrusters
- Very low power requirements
- Eliminates catalyst bed/pre-heater to provide dramatic weight savings

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Low Cost Nanolauncher—Phase I

Orbital Technologies Corporation

Low Cost Nanolauncher (LCN) sounding rocket to lower small payload launch costs

The Low Cost Nanolauncher (LCN) is an upper stage using a new, inexpensive propulsion system. The Phase I program combined several technologies with a simple design strategy to produce a flight-weight propulsion system that is easy to fabricate and operate. Self-pressurizing propellants minimize complexity of the propulsion system and vortex cold-wall technology simplifies the combustion chamber. Commercially available components were used where possible to further reduce costs.

The Phase I LNC demonstrated these technologies through ground testing of a flight-like propulsion system. A small launch vehicle second stage was designed based on the experimental performance characteristics. This work forms the foundation for the design of a family of vehicle stages from small upper stages to main booster stages. The low cost technologies and design methods employed in the LNC will reduce the cost of launching nanosatellites into orbit.

Applications

NASA

- Applicable to many vehicle sizes
- Small rockets with small budgets
- Launch Services Enabling eXploration and Technology (NEXT) program.

Commercial

- Nanosatellite launch vehicle
- Orbital Nanolauncher

Phase I Objectives

- Demonstrate their viability in a sounding rocket
- Design and Fabrication of Prototype Engine
- Design and Fabrication of Prototype Electronics
- Ground Test of Prototype Engine
- Design of Sounding Rocket

Benefits

- Lower small payload launch costs
- Reduces the complexity of the vehicle and using commercial grade components.
- Eliminates the need for pumps or separate pressurization tanks
- Produces a vehicle with modest performance, but much lower design, fabrication, and operational costs than conventional liquid rockets able to perform the same task

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Proposal number: 14-1 T1.01-9949

Physics-Based Modeling Tools for Life Prediction and Durability Assessment of Advanced Materials—Phase I

Elder Research, Inc.

Improving the current ability to simulate and avoid corrosion fatigue failure of engine disks or metallic structural components

The technical objectives of this program are: (1) to develop a set of physics-based modeling tools to predict the initiation of hot corrosion and to address pit and fatigue crack formation in Ni-based alloys subjected to corrosive environments, (2) to implement this set of physics-based modeling tools into the DARWIN probabilistic life-prediction code, and (3) to demonstrate corrosion fatigue crack initiation and growth life prediction for turbine disks subjected to low-cycle and high-cycle fatigue loading in extreme environments. This technology will significantly improve the current ability to simulate and avoid corrosion fatigue failure of engine disks or metallic structural components due to prolonged exposure to extreme environments at elevated temperatures. Completion of the proposed program will provide probabilistic corrosion fatigue crack growth life assessment software tools for structural components subjected to aggressive hot corrosion environments. Such a suite of software tools is unique and is urgently needed for designing and improving the performance of critical structures used in the space structure and propulsion systems in commercial and military gas turbine engines, and oil and gas industries. This generic technology can also be used to provide guidance for developing new alloys or improving current Ni-based alloy designs for hot-section applications.

Applications

NASA

- Aerospace gas turbine engine sector and in the space structure, rocket and propulsion sectors

Commercial

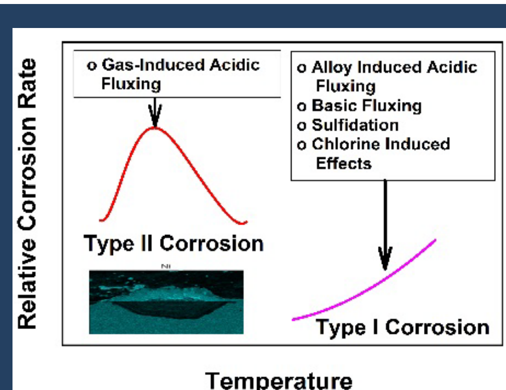
- Military gas turbine engine sector
- Industrial gas turbine engine sector
- Oil and gas industries
- Nuclear power industries

Phase I Objectives

- Develop Physics-based Hot Corrosion Prediction Methodology
- Develop Physics-based Hot Corrosion Algorithms
- Demonstrate Hot Corrosion Prediction Methodology

Benefits

- Provides accurate life prediction and reliability assessment of Ni-based superalloy components used in hot corrosion environments.
- Provides guidance for developing new alloys or improving current Ni-based alloy designs for hot-section applications



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Proposal number: 14-1 T12.02-9930

100-lbf Non-Toxic Storable Liquid Propulsion—Phase II

Plasma Processes, LLC

Hydrazine replacements, including nontoxic HAN- and ADN-monopropellants, combust at higher temperatures

NASA's Road Maps for both Launch and In Space Propulsion call for the development of non-toxic, monopropellant reaction control systems to replace the current toxic hydrazine based systems. The Orion Multi-Purpose Crew Vehicle capsule with twelve 160 pound force (lbf) hydrazine monopropellant thrusters and the Orion Service Module with eight 100 lbf NTO/MMH auxiliary propulsion thrusters are obvious insertion candidates. Additionally, the Commercial Crew and Cargo spacecraft have also demonstrated the need for 100lbf class attitude control thrusters with quantities comparable to Orion. Hydrazine replacements, including non-toxic HAN- and ADN-monopropellants, combust at higher temperatures making them incompatible with current Inconel 625 thrusters used in 100lbf engines. With an emphasis on hydrazine replacement increased performance, ease of manufacturing and cost reduction, a "green" 100 lbf flight-weight thruster is being developed.

Applications

NASA

- Reaction control thrusters for the Orion MPCV capsule and service module;
- 100 lbf thrusters in support of Commercial Crew and Cargo spacecraft
- Reaction Control Systems for Space Launch System

Commercial

- Commercial Access to Space programs including:
  - Lift/space craft programs for SpaceX Falcon/Dragon and Orbital Antares/Cygnus;
  - Satellite insertion and positioning
  - Tactical missile divert and attitude control
  - Auxiliary power generators
  - Jet engine restarters

Phase II Objectives

- Demonstrate the design, manufacture and testing of a long-life, high-temperature 100lbf thrust chamber for advanced non-toxic monopropellant reaction control systems
- Evaluate electrolytic augmentation to improve thruster response
- Fabricate the flight weight thrust chamber and catalyst
- Ignite 100 lbf thruster at sea level conditions
- Commercialize the 100 lbf green thruster technology

Benefits

- Increased performance
- Ease of manufacturing
- Cost reduction

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Proposal number: 14-2 H2.02-9347

Superconducting Electric Boost Pump for Nuclear Thermal Propulsion—Phase II

Florida Turbine Technologies, Inc.

Significant performance and operability benefits to future nuclear thermal

Design, fabrication, assembly and test of the Florida Turbine Technologies, Inc. (FTT) concept for a submersible, superconducting electric boost pump during Phase II will transition the pairing of superconducting motor and high performance pump technology for use in liquid hydrogen (LH2) from TRL 3 to TRL 6. This innovative solution offers significant performance and operability benefits to future nuclear thermal and conventional chemical propulsion powered cryogenic in-space and upper stage systems. FTT's submersible superconducting electric motor driven liquid hydrogen (LH2) boost pump combines a high performance hydrogen pump inducer along with an electric motor drive using active speed modulation to maintain constant discharge pressure with up to 55% vapor at the inlet. The LH2 environment enables an energy dense superconducting motor that is precisely controlled.

Applications

NASA

- Low heat leak cryogenic circulators and transfer pumps for propellant depot, upper stage engine recirculation pumps, and cryogenic stage boost pumps
- Small, light-weight, cryogenic; Hydrogen, Methane, Oxygen propellant boost pumps for chemical rocket engine

Commercial

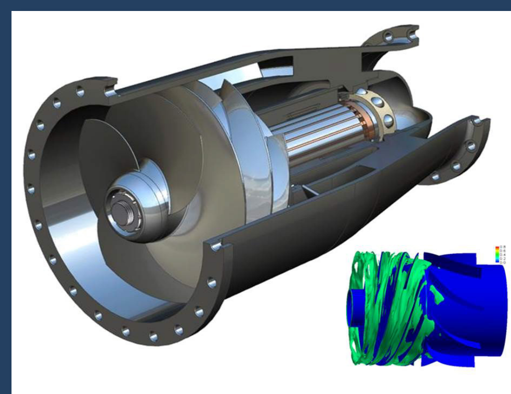
- Boost pump application for cryogenic upper
- Ground based refueling station applications to transfer liquid natural gas from the storage tank to the vehicle tank.

Phase II Objectives

- Demonstrate a 1/3 flow (1/2 scale size) scaled prototype version of the electric boost pump in LH2 during Phase II
- Demonstration of the superconducting motor performance and motor insulation material to survive the effects of continuous operation while submerged in LH2
- Demonstrate the concept to a technical readiness level (TRL) of 6, testing in a relevant environment (LH2).

Benefits

- Reduces the risk of cavitation in the main pump
- Enables the downstream high speed turbopump to be operated at optimum efficiency with much reduced pressures in the propellant tank.
- Considerable tank weight savings
- Significant operability and vehicle performance advantages for new cryogenic upperstage vehicles



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Proposal number: 14-2 H2.03-9718

Integrated Propulsion and Primary Structure Module for Small Satellite and CubeSat Applications—Phase II

Planetary Resources Development Corporation

Significantly reduce required resources by seamlessly integrating propulsion with another critical resource-intensive subsystem

Planetary Resources Development Corporation (PRDC) proposes to significantly reduce required resources by seamlessly integrating propulsion with another critical resource-intensive subsystem: the spacecraft's primary structure. PRDC will integrate high-reliability COTS components from the medical consumer products industries into an additively-manufactured two-module primary structural element that includes integrated tank, plenum, and manifold geometries for a hybrid green monopropellant / cold-gas propulsion implementation, as well as the spacecraft's launch interface. The resulting system, called the Integrated Propulsion and Primary Structure Module (IPPSM), provides a standard interface, serving as the strongback for simple integration of other Cubesat subsystems and payloads within the 6U and 12U size regimes. During Phase II, PRDC will continue the IPPSM development initiated during Phase I, culminating in the fabrication, assembly, performance evaluation, and environmental test of a full-scale 12U IPPSM prototype with integrated RCS and high-thrust, high delta-V capability.

Applications

NASA

- CubeSat Launch Initiative
- CubeSat flight opportunities
- Other future small satellite missions for deep space or Earth observation

Commercial

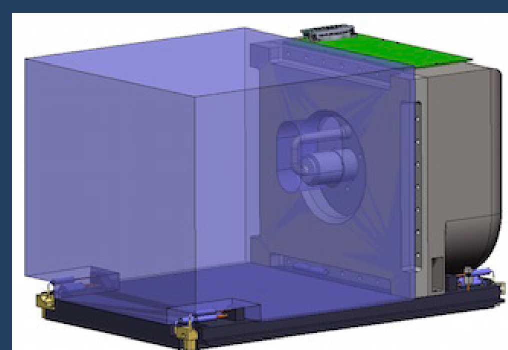
- Current university and non-profit nanosatellite and Cubesat programs
- Commercial nano-satellite developers
- Low-cost commercial telecommunications and Earth observation companies.

Phase II Objectives

- Assembly, and checkout of IPPSM prototype
- Integration of HPGP and ammonia propellants into a functional IPPSM system
- Full environmental and system functional testing of an IPPSM prototype in a relevant environment

Benefits

- A standard interface, serving as the strongback for simple integration of other Cubesat subsystems and payloads within the 6U and 12U size regimes
- Provide high thrust-to-weight capability
- Enable both impulsive maneuvers and RCS on a 6U or 12U CubeSat



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Proposal number: 14-2 S3.02-8682

Additive Manufacturing of Ion Thruster Optics—Phase II

Plasma Controls, LLC

Creating novel/complex geometry with better performance

Plasma Controls will manufacture and test several sets of ion optics for electric propulsion ion thrusters using additive manufacturing technology, also known as 3D printing. Additive manufacturing can potentially produce optics with novel or complex geometry that have better performance compared to those made traditionally, while also giving cost and mass savings.

Applications

NASA

- High power, nuclear-scale or multi-thruster spacecraft
- Low power small/micro/nano-scale spacecraft and satellites
- Use on large diameter annular-geometry ion engines

Commercial

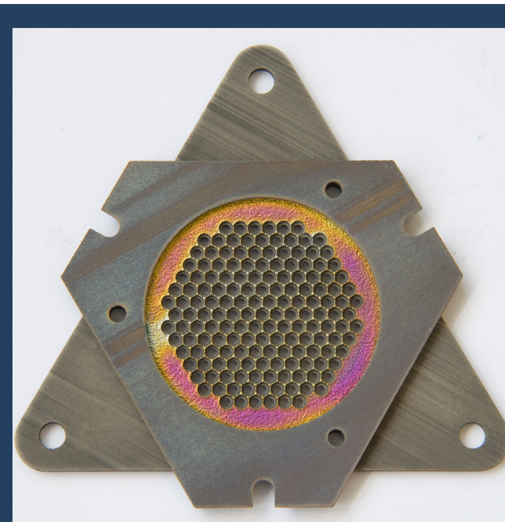
- Semiconductor and electro-optical manufacturing industry in etching (sputtering and reactive ion) and physical vapor deposition processes.

Phase II Objectives

- Scaled-up versions of optics, and implement modifications to the grid geometry to enable higher current capability and/or improved beam collimation
- Determine the optics' ion extraction capabilities in vacuum using an ion source
- Collect beam profile information using a current density probe
- Correlate the collected data to literature data, analytical models, and ffx numerical simulation

Benefits

- Potentially gives cost and mass savings while simultaneously creating novel/complex geometry with better performance compared to optics made traditionally.



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Proposal number: 14-2 S3.02-9208

Laser-Directed CVD 3D Printing System for Refractory Metal Propulsion Hardware—Phase II

Ultramet

Unconstrained complex build geometries, reduced cost, reduced lead time, and reduced material usage

Ultramet is developing a three-dimensional (3D) laser-directed chemical vapor deposition (CVD) additive manufacturing system to build free-form refractory metal components for liquid rocket propulsion systems. By combining Ultramet's experience in refractory metal fabrication by CVD with computer control of directed laser energy, nearly unlimited expression of part shape and metal composition can be realized for component fabrication. 3D additive manufacturing is revolutionizing many industries by offering unconstrained complex build geometries and reduced cost, lead time, and material usage compared with conventional manufacturing techniques. By developing laser-directed CVD technology for refractory metals, Ultramet will bring these inherent benefits to a class of materials that are notoriously difficult to form and thus are expensive to implement. In Phase II, Ultramet will design and build a new high-power, high-speed reactor with *z*-axis control to enable layering for 3D geometries at high deposition rates. Software and hardware integration will provide automated layering control to enable fully automatic additive manufacturing from 3D models.

Applications

NASA

- Revolutionize the fabrication of engine and hot gas path components for liquid and solid rocket propulsion
- Applicable to the fabrication of prototype and production propulsion components

Commercial

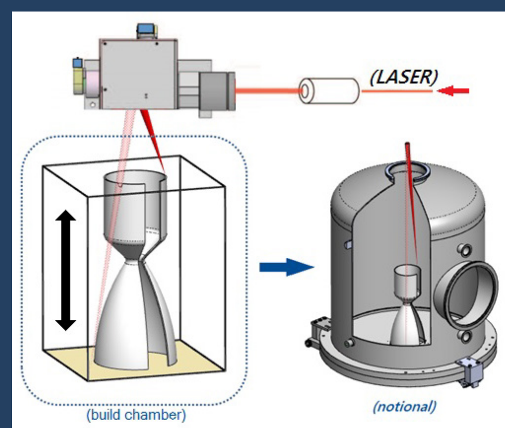
- Applicable to the fabrication of propulsion components for attitude control and apogee engines for commercial and government satellites
- Refractory metal crucible market
- Tungsten components for the fusion research community and future power plants

Phase II Objectives

- Develop a fully integrated and mature 3D LCVD additive manufacturing system for the production of fully dense rhenium propulsion hardware
- Perform LCVD deposition with the high-speed reactor to explore the deposit morphology of the operating envelopes identified by modeling.
- Explore layering and cross-sectional changes by printing mechanical tensile test specimens to characterize the mechanical and microstructural properties of the favorable operating conditions identified.

Benefits

- Unconstrained complex build geometries and reduced cost, lead time, and material usage
- Build components from rhenium, tungsten, molybdenum, tantalum, niobium, and their alloys with complex internal features and reduced assembly part count



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Proposal number: 14-2 H5.01-9108

In-Situ EBCs for High Performance Composite Propulsion Components—Phase II

Physical Sciences, Inc.

Potential to fundamentally change the design and manufacture of aeronautical and space propulsion systems to significantly increase performance

Silicon Carbide based ceramic matrix composites (CMCs) offer the potential to fundamentally change the design and manufacture of aeronautical and space propulsion systems to significantly increase performance and fuel efficiency over current metal-based designs. Physical Sciences Inc. (PSI) and our team members at the University of California Santa Barbara (UCSB) are developing, designing and fabricating enhanced SiC-based matrices capable of long term operation at 2750 °F to 3000 °F in the combustion environment. Our approach is successfully building upon PSI’s and UCSB’s previous work in incorporating refractory and rare earth species into the SiC matrix to increase the CMC use temperatures and life-time capabilities by improving the protective oxide passivation layer that forms during use. As part of this work we are creating physics based-materials and process models that qualitatively define methods of improving matrix properties and the interaction of the fibers, interphases and matrix with each other.

Applications

NASA

- Higher temperature operation of turbine engines in subsonic, supersonic, and hypersonic aircraft

Commercial

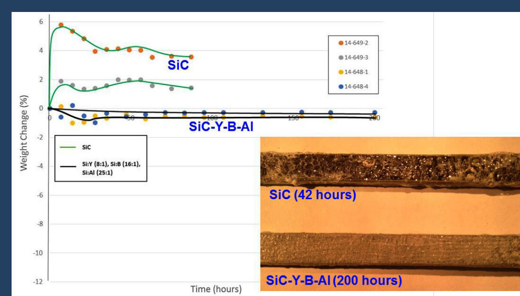
- Commercial aircraft engines, both large and small
- Ground-based gas turbines for power generation

Phase II Objectives

- Develop and demonstrate SiC based CMCs for demonstrated long term operation at 2700 °F
- Demonstrate non-brittle failure of the CMC
- Define physical differences between rapid (1000 °F/min) and slow heating,
- Demonstrate no material degradation after 300-500 hours burner test rig exposure

Benefits

- Increases performance and fuel efficiency over current metal-based designs
- Increase performance and fuel efficiency



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Proposal number: 14-2 T12.02-9894