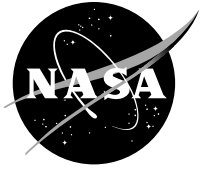


NASA/TM—2017-219461



An Overview of Materials Structures for Extreme Environments Efforts for 2015 SBIR Phases I and II

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An Overview of Materials Structures for Extreme Environments Efforts for 2015 SBIR Phases I and II

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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 2015 Phase I and II projects that specifically address areas in Materials and Structures for Extreme Environments, one of six core competencies at NASA Glenn Research Center. Each article describes an innovation, defines its technical objective, and highlights NASA applications as well as commercial and industrial applications.

Ten technologies are featured: metamaterials-inspired aerospace structures, metallic joining to advanced ceramic composites, multifunctional polyolefin matrix composite structures, integrated reacting fluid dynamics and predictive materials degradation models for propulsion system conditions, lightweight inflatable structural airlock (LISA), copolymer materials for fused deposition modeling 3-D printing of nonstandard plastics, Type II strained layer superlattice materials development for space-based focal plane array applications, hydrogenous polymer-regolith composites for radiation-shielding materials, a ceramic matrix composite environmental barrier coating durability model, and advanced composite truss printing for large solar array structures.

This report serves as an opportunity for NASA engineers, researchers, program managers, and other personnel to learn about innovations in this technology area as well as possibilities for collaboration with innovative small businesses that could benefit NASA programs and projects.

Metamaterials-Inspired Aerospace Structures (MIAS)

Concepts to Systems, Inc.

The vibroacoustic characteristics of structures are vital in determining the operational envelope and mission feasibilities. The sources of vibroacoustic excitation are mainly due to noise generated by the launcher during ignition, lift-off, and atmospheric flight. Typically, foam or fiberglass claddings and cores or acoustic liners which incorporate resonating chambers are used to prevent the transmission of sound through such structural locations. However, this approach is found to be ineffective for vibroacoustic sources with dominant frequency content below 400 Hz. It is proposed to develop a metamaterial-inspired composite structure incorporating low-frequency vibro-impact resonating elements coupled with conventional high-frequency acoustic absorbers. The idea is to employ structurally integral tuned resonators to pick up energy from incident low-frequency sound waves and, utilizing the mechanism of frequency up-conversion via impacts, transfer the energy to higher modes in the sandwich primary structure for subsequent dissipation with conventional acoustic absorbers. The advantage of the proposed structure would be in reducing the transmitted pressure of low-frequency waves, for which conventional methods are ineffective. Successful completion of Phase I work will result in a “proof-of-concept” MIAS unit cell. In Phase II, detailed design and fabrication of the MIAS prototype panel will be completed.

Applications

NASA

Launch vehicles: The proposed solution can be used in primary and supporting structures to reduce the transmission of vibroacoustic energy to subsystems and payloads.

Manned flights: The transmission of acoustic and vibrational energy to modules accommodating astronauts has to be minimized. MIAS panels directly integrated into module structure is highly desirable as long as weight and size constraints are satisfied. Aeronautical structures designed to increase fatigue life and quieten the internal space are aggressively pursued by NASA.

Commercialization

Commercial and general aviation applications to increase fatigue life and reduce internal noise level have the largest potential for commercializing the technology. The defense aerospace applications will also benefit from the technology. Ground and ship transportation market sectors will experience limitless applications as the cost of the technology is reduced.

Structural cladding for protective packaging systems and civil infrastructural partitions where low-frequency acoustic insulation is critical can be the next potential market.



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Metallic Joining to Advanced Ceramic Composites

Plasma Processes, LLC

The Orion Launch Abort System (LAS) utilizes attitude control motors (ACM) with advanced ceramic composite components that function as a valve control system to allow for safe maneuverability away from danger. This system is made steerable due to the valve controlled thrusters which utilize advanced ceramic pintles made of 4D C/C-SiC that are attached to metallic structures and actuated.

During the Phase I effort, an innovative technique to join metallics with the advanced ceramic composites was demonstrated. Detailed characterization confirmed the deposited metal (Inconel 625) produced during this investigation had good adherence to C-C/SiC pintles, and no interfacial reactions occurred during deposition or elevated temperature exposure. In Phase II, the joining interface will be optimized and pindle assemblies will be produced for hot fire testing with Orbital ATK. Additional CMC materials and components will also be developed.

Applications

NASA

Joining advanced composites to metal structures is applicable to existing and future NASA programs, including the ACM motors of Orion MPCV's LAS, human lunar ascent/descent, Commercial Crew motors, and nozzle extensions of upper stage engines for nanosatellite launch (e.g., ORBITEC's vortex liquid rocket engine) and International Space Station resupply (e.g., SpaceX's Merlin Vacuum liquid rocket engines).

Commercialization

Commercial applications for metallic joining to advanced ceramic composites include upper stage nozzle extensions; nosetips, leading edges, and control surfaces for hypersonic vehicles; and turbine engine components, exit cones, and control vanes for tactical missiles.



Proprietary Pindle

DM-1 Valve 1

Vacuum plasma sprayed Inconel 625 deposited metallic structure onto 4D C/C-SiC pindle shaft.

Vacuum plasma sprayed Inconel 625 deposited onto 4D C/C-SiC showing CMC voids are filled by dense Inconel metal.

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Multifunctional Polyolefin Matrix Composite Structures

TDA Research, Inc.

Polyethylene, and ultra high molecular weight polyethylene (UHMWPE) in particular, is an outstanding material for radiation shielding in the sense that its extraordinarily high hydrogen content both minimizes the production of secondary ions during exposure to energetic radiation and captures neutrons. Its low density and high wear resistance also make it attractive for the structures of manned spacecraft and extraterrestrial habitats. However, its use in structures is limited by its flammability and poor mechanical properties under load compared to other structural materials. While carbon fiber/UHMWPE composites are an obvious solution, to date they have not proved useful because load is not easily transferred to or from UHMWPE, and because its melt state is too viscous to infiltrate fiber preforms. In this Phase II project, TDA will apply its recent advances in composite manufacturing to create a UHMWPE-matrix composite that has good load transfer to a creep-mitigating continuous fiber reinforcement. Such a composite will not only have outstanding radiation shielding properties but will also have sufficient mechanical properties to be useful as a structural material.

Applications

NASA

Multifunctional radiation shielding was identified as the top technical challenge in NASA's Materials, Structures, Mechanical Systems, and Manufacturing (MSMM) draft Roadmap (Technical Area 12), and the technology proposed herein offers a solution. The composites proposed herein should be key components of the structural materials used in extraterrestrial human habits, whether they are in space, on the Moon, on Mars, or in any other location subject to high energy galactic cosmic rays and/or solar particle events. The light weight and high strength of the proposed materials will enable their use in efficient structures, providing true multifunctionality from a radiation shield and minimizing the parasitic weight of the shielding.

Commercialization

The Cf/UHMWPE composites should be commercially useful in other wear-resistant structures, including mining equipment and ballistic threat protection. Self-reinforced UHMWPE composites dominate the market for lightweight armor, and the composites proposed herein should provide a complementary but similarly outstanding set of properties for mitigating a broad spectrum of ballistic threats. UHMWPE is widely used in the bed liners of mining equipment, and the composite materials proposed herein should extend the use of UHMWPE into other hard rock handling structures.



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Integrated Reacting Fluid Dynamics and Predictive Materials Degradation Models for Propulsion System Conditions

CFD Research Corporation

Computational fluid dynamics (CFD) simulations are routinely used by NASA to optimize the design of propulsion systems. Current methods for CFD modeling rely on general materials properties to determine fluid structure interactions. Closer integration of material properties would extend the applicability of CFD to assist in the selection and incorporation of materials for extreme temperature and flow conditions where rate of material degradation and probability of failure set performance limits. During Phase I, the team demonstrated a mesoscale materials model based on peridynamics, a theory of continuum mechanics that can describe fracture and defect progression at the level of the microstructure. The modeling scheme uses CFD methods to establish the thermal loads and mechanical stresses imposed at the boundaries of the structure. Multiscale peridynamics simulations are used to determine the macroscale properties and surface recession rates as a function of microstructure, damage, and boundary conditions. The model was demonstrated with simulations of erosion and degradation of a ceramic matrix composite material subjected to high temperature, high velocity flow conditions.

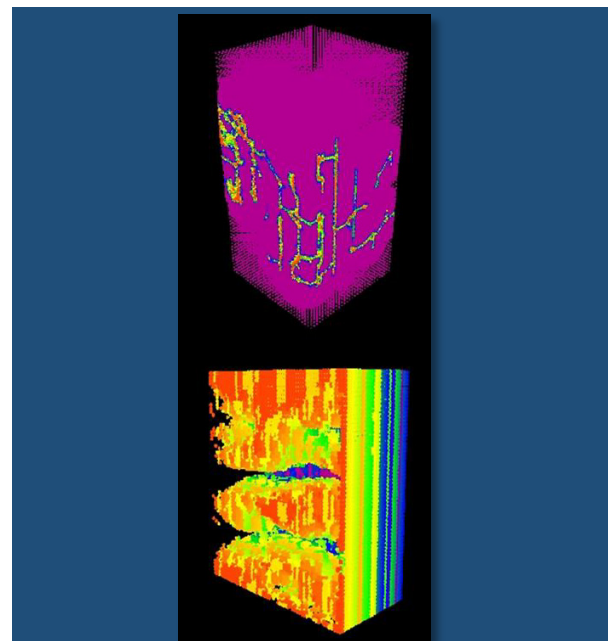
Applications

NASA

Integrated computational materials engineering (ICME) has been identified as an enabling technology both to advance the development of new materials and to accelerate their incorporation into commercial systems. The proposed modeling product falls within the scope of ICME as a means to link material features to product performance. This work product can be transferred as a modeling tool to assist material selection in any application where mechanical degradation limits performance, such as ablative and high temperature materials for hypersonic environments.

Commercialization

The work established in this project can be transitioned to support other applications in government and industry. Programs supported by the Department of Defense, such as the development of hypersonic systems, involve the selection and incorporation of materials for extreme environments. Performance of energy systems for power generation and fossil energy extraction involve applications where material degradation limits the performance. A reasonable extension of this model would be to model accumulated damage in cyclic fatigue applications, which could substantially reduce maintenance cost of aircraft.



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Lightweight Inflatable Structural Airlock (LISA)

CFD Research Corporation and Thin Red Line Aerospace

Innovative low-cost, lightweight airlock technologies are required to integrate with deep space and surface platforms hosting Extra-Vehicular Activity. The CFD Research Corporation and Thin Red Line Aerospace team propose an inflatable airlock structure that employs unique fabric architecture capable of delivering the lowest mass and greatest versatility of any competing design. The proposed design features a highly innovative integrated structure to generate the wall stiffness required for airlock depressurization without the mass and bulk of metallic pressure hulls or the complexity of multistructure adaptations associated with competing inflatable habitat architectures. The Lightweight Inflatable Structural Airlock (LISA) stows compactly for transport on the habitat surface, further reducing logistic costs. The Phase I SBIR effort focused on conceptual design and characterization of the airlock system as well as identification and evaluation of candidate materials. The Phase II effort focuses on design refinement, testing, analysis, and an integration plan that will culminate in the fabrication of a full-scale prototype inflatable airlock demonstrator.

Applications

NASA

This system will have immediate application in expanding the utility of any human space exploration architecture while benefiting from system cost and payload volume reduction. The proposed technology will find direct application within many NASA missions, programs, and projects, including projects associated with the Evolvable Mars Campaign, the STMD Minimalistic Advanced SoftGoods Hatch (MASH) project, the Exploration Augmentation Module (EAM), and Deep Space Habitat. Other NASA applications include planetary surface habitats and large-scale space hangars for on-orbit assembly, design, and analysis of space-based inflatable structures such as telescopes, inflatable aerodynamic decelerators, antenna reflectors, cryogenic propellant tanks, debris shields, rescue vehicles, and barometric chambers.

Commercialization

Non-NASA commercial applications include many potential venues, including pressurized habitation architecture for high altitude commercial and military applications, underwater habitats, deep sea emergency escape systems (submarine), portable storage tanks for oil transport, high-altitude air ships, aerostats, compressed air energy storage, remote fuel depot stations, remote water storage tanks for forest fire control, deep space antenna reflectors for ground stations, antenna radomes, emergency shelters, and troop shelters with integrated ballistic protection.



Thin Red Line Aerospace's patented Ultra High Performance Vessel forms the architectural basis for the Lightweight Inflatable Structural Airlock (LISA).

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Copolymer Materials for FDM 3-D Printing of Nonstandard Plastics

Cornerstone Research Group, Inc. (CRG)

CRG offers NASA the ability to reprocess space mission waste packaging plastics into replacement tools, parts, and devices via 3-D printing. The innovation combines CRG's additives with a plastic recycling, blending, and extrusion process to allow current and future packaging materials to be processed into a filament suited for a Fused Deposition Modeling (FDM) type 3-D printing system. This approach offers two implementation routes, including (1) an additive that can be combined with existing waste packaging to produce 3-D printer filament and (2) a replacement polymer packaging material that can be directly reclaimed into a 3-D printer filament. The material properties of a reclaimed packaging-based 3-D printer filament can be tuned for mechanical performance by adjusting additive blend ratios. This will provide NASA with a means to generate 3-D printer feedstocks with varying mechanical performance from on-hand waste packaging plastics without the need for separate 3-D printer material payloads. In the Phase I effort, CRG demonstrated the efficacy of this approach by successfully 3-D printing a part from a reclaimed packaging filament. CRG's proposed approach to reclaim NASA's waste packaging will provide a material and processing technology readiness level (TRL) of 5 at the conclusion of the Phase II effort.

Applications

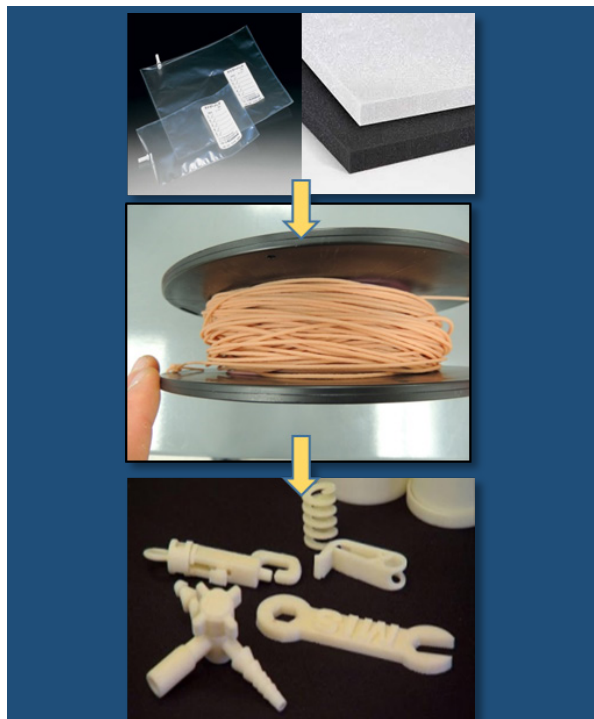
NASA

Supporting NASA's Human Exploration and Operations Mission Directorate (HEOMD) and the Marshall Space Flight Center, this project's technologies directly address requirements for solutions to recycling on-board plastics materials into 3-D printable formats for low-Earth orbit and space flight additive manufacturing systems. This project's technologies offer a means to take on-board noncritical plastics, such as packaging materials, and reclaim these objects for 3-D printing of needed custom parts without requiring an additional mission payload of 3-D printing feedstock.

Commercialization

Department of Defense systems would derive benefits from this technology, including rapid prototyping and additive manufacturing of complex, low-run number, and advanced design parts. Prime defense contractors could derive benefits from the new and exotic polymeric materials or polymeric composites previously thought incompatible with FDM-type 3-D printing processes. Human-systems-focused solutions would have the ability to additively manufacture custom components for personnel equipment, such as softer elastomeric materials for integral user custom equipment.

This technology's attributes for improving the compatibility of polymers to 3-D printing systems would yield a high potential for private sector commercialization for 3-D printer manufacturers, significantly increasing the materials properties available in the feedstock. Such companies could dramatically expand the thermoplastic raw materials available to consumers and would potentially be able to produce materials with custom mechanical performance on-demand.



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Type II SLS Materials Development for Space-Based FPA Applications

IntelliEPI IR, Inc.

This Phase II SBIR proposes to further develop high-performance (low dark current, high quantum efficiency (QE), and low NEdT) infrared epitaxy materials based on Type II Strained Layer Superlattice (SLS) for large-format space-based sensor applications. The epitaxy materials will be grown with the Sb-capable multiwafer production Molecular Beam Epitaxy (MBE) reactor at IntelliEPI IR. The initial goal includes achieving QE of at least 40% with long wavelength infrared (LWIR) spectral wavelength band near 12 μm . The SLS detector design will be developed in consultation with the infrared detector group at the Jet Propulsion Laboratory (JPL) to ensure that this effort addresses NASA needs. In the engineered SLS detector structures, many properties are already determined once epitaxial growth is completed. The technical approach will be to develop improved epitaxial stack design with a goal to dramatically improve detector properties. This is based on existing high-performance GaSb-based Type II SLS detector growth technology, with novel design, development of MBE growth to implement the design, and fabrication and characterization of devices from the epitaxy grown material. The objective is to dramatically improve QE in the detector structure. The Phase II effort will focus on focal plane array (FPA) demonstration.

Applications

NASA

Type II SLS technology can serve as a platform for the next generation of space-based high-performance and large-format infrared FPAs. This will be a materials evolution of the ongoing SLS technology being developed at JPL. This SLS technology offers a unified platform for high-performance 5–14 μm detection wavelengths. Substrate size scaling will support large-format infrared imaging NASA needs with high sensitivity and high operating temperature sensors for space-based applications.

Commercialization

Improved Type II SLS technology offers thermal imagers at higher operating temperature, uniformity, and sensitivity from mid wave to long wavelength infrared based on scalable GaSb substrates. This opens the door for more military vehicles and platforms to be outfitted with these high-performance cameras. Commercially, environmental or gas sensing can benefit from competitive cost scaling.



Thermal image taken by a prototype Long Wavelength Infrared (LWIR) Focal Plane Array (FPA) using advanced SLS detector epitaxy materials produced by MBE.

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Hydrogenous Polymer-Regolith Composites for Radiation-Shielding Materials

International Scientific Technologies, Inc.

NASA has identified a need in subtopic H11.01 for advanced radiation-shielding technologies using in situ resources, e.g., regolith, to protect humans from the hazards of galactic cosmic radiation during extraterrestrial missions. The radiation species of greatest interest are light ions (particularly protons), heavy ions (such as iron-56), and neutrons. International Scientific Technologies, Inc., in conjunction with the College of William and Mary, proposes the use of regolith combined with hydrogenous polymers to develop radiation-shielding structural materials for habitats. The program Technical Objectives include analysis of polymer-regolith specimens to supplement the empirical results of the Phase I program, fabrication of polymer-regolith materials and structures for use as radiation shields, acquisition of families of test data to determine key parameters of polymer-regolith structures for stopping galactic cosmic radiation on the Mars surface, and design of polymer-regolith bricks for habitat construction of the Mars surface. The innovation is the development of polymer-regolith composites and their efficient fabrication for structural radiation-shielding materials to protect humans on deep-space missions. The anticipated result is composite materials that combine in situ resource utilization (ISRU), e.g., regolith, with a hydrogenous polymeric matrix. Additives, such as boron, could be included to enhance absorption of neutrons generated by interactions of galactic cosmic radiation and solar particle event with the shielding materials. The proposed composites have multifunctional properties of radiation shielding against galactic cosmic radiation, neutrons, and electromagnetic radiation, and structural integrity to permit use in habitats.

Applications

NASA

The proposed multifunctional high-performance polymers will find application in NASA missions in protecting astronauts and sensitive optical, electronic, thermal, and acoustic components from space hazards, including radiation, dust, and thermal transients, while at the same time providing structural components for habitats. It is expected that these polymer-regolith composite systems will provide a high-performance-to-weight radiation shield that can be used for human habitats.

Commercialization

Multifunctional radiation shielding will find application in the commercial sector in reducing collateral damage from charged particles, emerging as a therapeutic approach in nuclear medicine. The Department of Defense and the Department of Homeland Security will find applications that include protection of soldiers, first responders, and emergency medical personnel against high-energy gamma radiation and neutrons resulting from so-called dirty bombs as well as from hazards brought about through accidental release of radiological materials.



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Ceramic Matrix Composite Environmental Barrier Coating Durability Model

Materials Research and Design, Inc. (MR&D)

As the power density of advanced engines increases, the need for new materials that are capable of higher operating temperatures, such as ceramic matrix composites (CMCs), is critical for turbine hot-section static and rotating components. MR&D is proposing to perform a combined analytical and experimental program to develop a durability model for CMC Environmental Barrier Coatings (EBC). This program will be the first step in developing a tool to accurately evaluate the life of the EBC for a CMC turbine blade, helping to facilitate their inclusion in future engine designs. This will be done by developing a custom, user-defined element formulation for finite element modeling to simulate the kinetic reactions of the EBC with the turbine exhaust. It will be built on the back of earlier work, developing such an element to model the oxidation of carbon fiber in reentry environments.

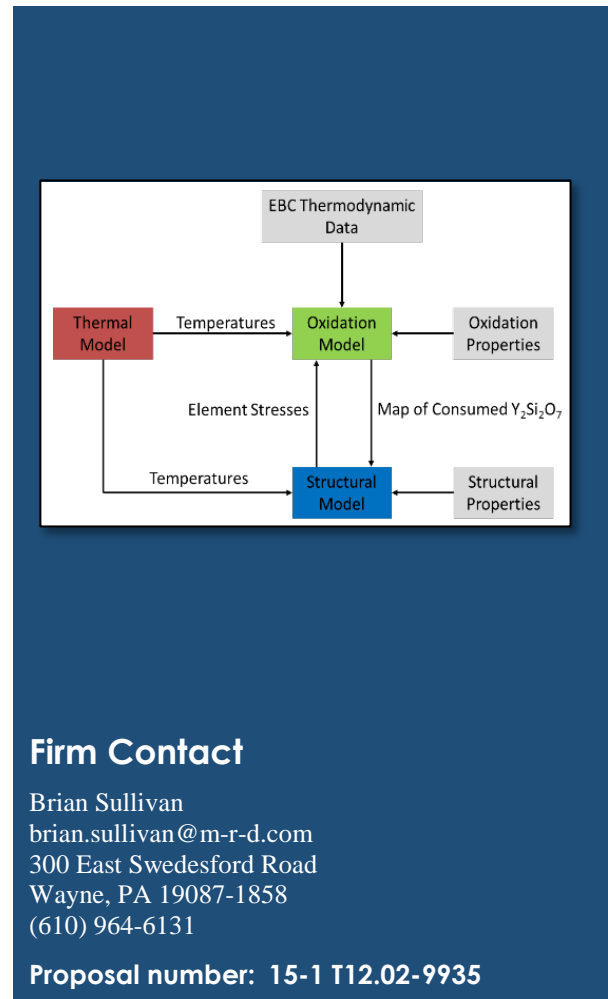
Applications

NASA

NASA Glenn has been directly involved in the effort to bring these materials to turbine hot-section components. The NASA Ultra Efficient Engine Technology (UEET) program is focused on driving the next generation of turbine engine technology. One of the major thrusts is the development and demonstration of advanced high-temperature materials which are capable of surviving the extreme environments of turbine combustion and exhaust.

Commercialization

In the commercial sector, the Rolls Royce Trent 1000 and Trent XWB engines are being developed for the Boeing 787 and Airbus A350 XWB aircraft, respectively. There are currently 1030 Boeing 787s on order or flying and 814 Airbus A350 XWBs on order. The Trent 1000 was the launch engine for the Boeing 787. These are large markets where the benefit of this technology will have a lasting impact in efficiency and cost. The aerospace industry is not the only potential beneficiary of this technology. The Department of Energy (DOE) is working hard to improve the efficiency of power generators. Just as with aircraft engines, power turbines' efficiency improves with higher operating temperatures. As an example, current turbines operate at 2600 °F, which provided a large improvement in efficiency over earlier models operating at 2300 °F. CMC turbine blades and stators will allow even higher temperature operation and is a topic the DOE is currently investigating.



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