NASA SBIR 2021 Phase I Solicitation

H5.02 Hot Structure Technology for Aerospace Vehicles

Lead Center: MSFC

Participating Center(s): AFRC, JSC, LaRC

Scope Title:

Hot Structures Technology for Aerospace Vehicles

Scope Description:

This subtopic deals with the development of reusable nonmetallic hot structure technology for structural components exposed to extreme heating environments on aerospace vehicles. Desired hot structure systems encompass multifunctional structures that can reduce or eliminate the need for active cooling or separate thermal protection system (TPS) materials. The potential advantages of using hot structure systems in place of actively cooled structures or a TPS with underlying cool structure include reduced mass, increased mission performance (such as reusability), improved aerodynamics for aeroshell components, improved structural efficiency, and increased ability for nondestructive inspections. Hot structure is an enabling technology for reusability between missions or mission phases, such as advanced propulsion systems requiring multiple engine firings and vehicles requiring aerocapture/aerobraking followed by entry, descent, and landing. The development of hot structure technology for (a) combustion-device liquid rocket engine propulsion systems and (b) aerodynamic structures for aeroshells, control surfaces, wing leading edges, and heatshields is of great interest. Examples of prior flight-proven hot structures include: (a) the nozzle extension for the Centaur RL10B-2 upper-stage rocket engine, and (b) wing leading edges and control surfaces for the Space Shuttle Orbiter, Hyper-X (X-43A), and/or X-37B.

This subtopic seeks to develop innovative, low-cost, damage-tolerant, reusable, and lightweight fiber-reinforced hot structure technology applicable to aerospace vehicles and components exposed to extreme temperatures. At a minimum, materials developed under this subtopic should be capable of operating at a temperature of at least 1,371 °C (2,500 °F)—higher temperatures are of even greater interest, such as up to 2,204+ °C (4,000+ °F). These aerospace vehicle applications are unique in requiring the hot structure to carry primary structure vehicle loads and to be reusable after exposure to extreme temperatures during liquid rocket engine firings and/or atmospheric entry. The material systems of interest for use in developing hot structure technology include advanced carbon-carbon (C-C) and ceramic matrix composite (CMC) materials. Potential applications of interest for hot structure technology include: (a) propulsion system components (hot-gas valves, combustion chambers, and nozzle extensions), and (b) primary load-carrying aeroshell structures, control surfaces, leading edges, and heatshields.

Proposals should present approaches to address the current need for improvements in operating temperature capability, toughness/durability, reusability, and material system properties, as well as the need to reduce cost and manufacturing time requirements. Focus areas should address one or more of the following:

- Improvements in manufacturing processes and/or material designs to achieve repeatable uniform material properties, while minimizing data scatter, that are representative of actual vehicle components: specifically, material property data obtained from flat-panel test coupons should correlate directly to the properties of prototype and flight test articles.
- Material/structural architectures and multifunctional systems providing significant toughness and/or durability improvements over typical 2D interlaminar mechanical properties while maintaining in-plane and thermal properties when compared to state-of-the-art C-C or CMC materials. Examples include incorporating through-the-thickness stitching, braiding, or 3D woven preforms. Advancements in oxidation protection that enhance durability are also of interest: matrix inhibition, oxidation resistant matrices, exterior environmental coatings, etc.
- Manufacturing process methods that enable a significant reduction in the cost and time required to fabricate materials and components. There is a great need to reduce cost and processing time for hot structure materials and components – current state-of-the-art materials are typically expensive and have fabrication times often in the range of 6 to 12 months, which can limit or exclude the use of such materials. Approaches enabling reduced costs and manufacturing times should not lead, however, to significant reductions in material properties. Advanced manufacturing methods may include but are not limited to the following: (a) rapid densification cycles, (b) high char-yield resins, (c) additive manufacturing (AM), and (d) automated weaving, braiding, layup, etc.

Expected TRL or TRL Range at completion of the Project: 2 to 4
Primary Technology Taxonomy:
Level 1: TX 12 Materials, Structures, Mechanical Systems, and Manufacturing
Level 2: TX 12.1 Materials
Desired Deliverables of Phase I and Phase II:

- Prototype
- Hardware
- Research
- Analysis

Desired Deliverables Description:

Research, testing, and analysis should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware demonstrations. Phase I feasibility studies should also address cost and the risks associated with the hot structures technology.

In addition to the final report, delivery of a representative sample(s) of the material and/or technology addressed by the Phase I project should be provided at the conclusion of the Phase I contract—for example: (a) coupons appropriate for thermal and/or mechanical material property tests, or (b) arc-jet test specimens. Plans for potential

Phase II contracts should include the delivery of manufacturing demonstration units to NASA or a Commercial Space industry partner during Phase II. Testing of such test articles should be a part of the anticipated Phase II effort. Depending upon the emphasis of the Phase II work, such test articles may include subscale nozzle-extension test articles or arc-jet test specimens/hot structure components.

State of the Art and Critical Gaps:

The current state of the art for composite hot structure components is limited primarily to applications with maximum use temperatures in the 1,093 to 1,593 °C (2,000 to 2,900 °F) range. While short excursions to higher temperatures are possible, considerable degradation may occur. Reusability is limited and may require considerable inspection before reuse. Critical gaps or technology needs include:(a) increasing operating temperatures to 1,649 to 2,204+ °C (3,000 to 4,000+ °F); (b) increasing resistance to environmental attack (primarily oxidation); (c) increasing manufacturing technology capabilities to improve reliability, repeatability, and quality control; (d) increasing durability/toughness and interlaminar mechanical properties (or introducing 3D architectures); (e) decreasing cost, and (f) decreasing overall manufacturing time required.

Relevance / Science Traceability:

Hot structure technology is relevant to the Human Exploration and Operations Mission Directorate (HEOMD), where the technology can be infused into spacecraft and launch vehicle applications. Such technology should provide either improved performance or enable advanced missions requiring reusability, increased damage tolerance, and the durability to withstand long-duration space exploration missions. The ability to allow for delivery and/or return of larger payloads to various space destinations, such as the lunar South Pole, is also of great interest.

The Advanced Exploration Systems (AES) Program would be ideal for further funding a prototype hot structure system and technology demonstration effort. Commercial Space programs, such as Commercial Orbital Transportation Services (COTS), Commercial Lunar Payload Services (CLPS), and Next Space Technologies for Exploration Partnerships (NextSTEP), are also interested in this technology for flight vehicles. Additionally, NASA HEOMD programs that could use this technology include the Space Launch System (SLS) and the Human Landing System (HLS) for propulsion applications.

Potential NASA users of this technology exist for a variety of propulsion systems, including the following:

- Upper-stage engine systems, such as those for the Artemis SLS.
- In-space propulsion systems, including nuclear thermal propulsion systems.
- Lunar/Mars lander descent/ascent propulsion systems.
- Propulsion systems for the Commercial Space industry, which is partnering with and supporting NASA efforts.

Finally, the U.S. Air Force is interested in such technology for its National Security Space Launch (NSSL), ballistic missile, and hypersonic vehicle programs. Other non-NASA users include the U.S. Navy, the U.S. Army, the Missile Defense Agency (MDA) and the Defense Advanced Research Projects Agency (DARPA). The subject technology can be both enhancing to systems already in use or under development, as well as enabling for applications that may not be feasible without further advancements in high temperature composites technology.

References:

Liquid Rocket Propulsion Systems:

- “Carbon-Carbon Nozzle Extension Development in Support of In-Space and

Upper-Stage Liquid Rocket Engines;" Paul R. Gradl and Peter G. Valentine; 53rd AIAA/SAE/ASEE Joint Propulsion Conference, Atlanta, GA; AIAA-2017-5064; July 2017; https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170008949.pdf

- "Extreme-Temperature Carbon- and Ceramic-Matrix Composite Nozzle Extensions for Liquid Rocket Engines;" Peter G. Valentine and Paul R. Gradl; 70th International Astronautical Congress (IAC), Washington DC; IAC-19-C2.4.9; October 2019; https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20190033315.pdf

Hypersonic Hot Structures:

- "Ceramic Matrix Composite (CMC) Thermal Protection Systems (TPS) and Hot Structures for Hypersonic Vehicles;" David E. Glass; 15th AIAA International Space Planes and Hypersonic Systems and Technologies Conference, Dayton, OH; AIAA-2008-2682; April-May 2008; https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080017096.pdf
- "A Multifunctional Hot Structure Heatshield Concept for Planetary Entry;" Sandra P. Walker, Kamran Daryabeigi, Jamshid A. Samareh, Robert Wagner, and Allen Waters; 20th AIAA International Space Planes and Hypersonic Systems and Technologies Conference, Glasgow, Scotland; AIAA 2015-3530; July 2015; https://arc.aiaa.org/doi/pdf/10.2514/6.2015-3530

Note: The above references are open literature references. Other references exist regarding this technology, but they are International Traffic in Arms Regulations (ITAR) restricted. Numerous online references exist for the subject technology and projects/applications noted, both foreign and domestic.