NASA SBIR 2020 Phase I Solicitation

H5.02 Hot Structure Technology for Aerospace Vehicles

Lead Center: MSFC

Participating Center(s): AFRC, JSC, LaRC

Technology Area: TA12 Materials, Structures, Mechanical Systems and Manufacturing

Scope Title
Hot Structure Technology for Aerospace Vehicles

Scope Description

This subtopic encompasses the development of reusable hot structure technology for structural components exposed to extreme heating environments on aerospace vehicles. A hot structure system is a multi-functional structure that can reduce or eliminate the need for a separate thermal protection system (TPS) or active cooling system. The potential advantages of using a hot structure system in place of a TPS with underlying cool structure are: reduced mass, increased mission capability, such as reusability, improved aerodynamics, improved structural efficiency and increased ability to inspect the structure. Hot structure is an enabling technology for reusability between missions or mission phases, such as aerocapture followed by entry, and has been used in prior NASA programs (Space Shuttle Orbiter, Hyper-X, and X-37) on control surfaces and wing leading edges, as well as in Department of Defense programs. Additionally, the development of hot structure technology for combustion-device liquid rocket engine propulsion systems is of great interest.

This subtopic seeks to develop innovative low-cost, damage tolerant, reusable and lightweight hot structure technology applicable to aerospace vehicles exposed to extreme temperatures between 1093° to 2204°C (2000° to 4000°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 atmospheric entry and/or liquid rocket engine firings. The material systems of interest for use in developing hot structure technology include: advanced carbon-carbon (C-C) materials, ceramic matrix composites (CMC's), or advanced high-temperature refractory metals. Potential applications of hot structure technology include: primary load-carrying aeroshell structures, control surfaces, leading edges, and propulsion system components (such as hot gas valves, combustion chambers, and passively- or actively-cooled nozzle extensions).

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

- Improvements in manufacturing processes and/or material designs to achieve repeatable and uniform material properties that should be scalable to actual vehicle components: specifically, material property data obtained from flat-panel test coupons should represent the properties of prototype and flight test articles.
- Material/structural architectures and multifunctional systems providing significant improvements over typical

2D inter-laminar 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.
- Functionally-graded manufacturing approaches to optimize oxidation protection, damage tolerance and structural efficiency, in an integrated hot structure concept that extends performance for multiple cycles up to 2204°C (4000°F).
- Manufacturing process methods that enable a significant reduction in the time required to fabricate materials and components. There is a great need to reduce processing time for hot structure materials and components -- current state-of-the-art fabrication times are often in the range of 6 to 12 months, which can limit the use of such materials. Approaches enabling reduced manufacturing times should not, however, lead to significant reductions in material properties.

Under this subtopic, 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 risk associated with the hot structures technology. At the completion of the Phase I project, in addition to the final report, deliverables should include at least one of the following to aid assessment of technical feasibility: (a) coupons appropriate for thermal and/or mechanical material property tests, (b) arc-jet test specimens, or (c) a subscale nozzle extension test article or analog component. Emphasis should be placed on the delivery of manufacturing demonstration units for NASA testing at the completion of the Phase II contract. In addition, Phase II studies should address scale-up and integration with vehicles that could make use of the developed technology.

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 re-usability, increased damage tolerance and the durability to withstand long-term space exploration missions. The ability to allow for delivery 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 Space Launch System,
- In-space propulsion systems, including nuclear thermal propulsion systems,
- Lunar/Mars lander descent/ascent propulsion systems,
- Solid motor systems, including those for primary propulsion, hot gas valve applications, and small separation and/or attitude-control systems, and
- Propulsion systems for the Commercial Space industry, which is supporting NASA efforts.

Finally, the U.S. Air Force is interested in such technology for its Evolved Expendable Launch Vehicle (EELV), 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 composite technology.

References

Hypersonic Hot Structures:

Glass, David. "Ceramic matrix composite (CMC) thermal protection systems (TPS) and hot structures for hypersonic vehicles." 15th AIAA International Space Planes and Hypersonic Systems and Technologies Conference. 2008.

Walker, Sandra P., et al. "A Multifunctional Hot Structure Heat Shield Concept for Planetary Entry." 20th AIAA

International Space Planes and Hypersonic Systems and Technologies Conference. 2015.

Liquid Rocket Propulsion systems:

"Carbon-Carbon Nozzle Extension Development in Support of In-Space and Upper-Stage Liquid Rocket Engines" paper; 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.

"Carbon-Carbon Nozzle Extension Development in Support of In-Space and Upper Stage Liquid Rocket Engines" presentation charts; 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/20170008945.pdf.

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.

Expected TRL or TRL range at completion of the project: 2 to 4

Desired Deliverables of Phase II

Prototypes or components suitable for testing by NASA or Commercial Space partners.

Desired Deliverables Description

At the completion of Phase I project deliverables should include at least one of the following: coupons appropriate for thermal/mechanical material property tests, arc-jet test specimens, or a subscale nozzle extension test article. Emphasis should be on the delivery of manufacturing demonstration units, with representative structural features, for NASA testing at the completion of the Phase II contract.

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 1093° – 1600°C (2000° – 2912°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 1700° – 2204+°C (3092° – 4000+°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); and (e) decreasing overall manufacturing time required.

As an alternative to composites, metallic hot structures may reduce operating temperature requirements to near 1000°C (1832°F) in some applications, while offering greater structural reliability, and should also be pursued. Unfortunately advancements in high temperature metals have been a significant gap.

Relevance / Science Traceability

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