H5.02  Hot Structure Technology for Aerospace Vehicles

Lead Center: MSFC

Participating Center(s): AFRC, JSC, LaRC

Scope Title

Hot Structure Technology for Aerospace Vehicles

Scope Description

This subtopic deals with the development of hot structure technology for aerospace vehicle structural components that are exposed to extreme heating environments. The hot structure technologies proposed for development must be for reusable, nonmetallic, oxidation-resistant, fiber-reinforced composite structures. Hot structure is an enabling technology for reusability, thus facilitating the development of 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. Desired hot structure systems encompass multifunctional structures that can reduce or eliminate the need for active cooling, and in the case of aerodynamic structures, 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 and greater thermal efficiency), improved aerodynamics for aeroshell components, improved structural efficiency, and increased ability for nondestructive inspections. 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. Examples of prior flight-proven hot structures include: (a) the composite nozzle extensions for the Centaur RL10 family of upper-stage rocket engines, and (b) the 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, lightweight fiber-reinforced composite hot structure technology adhering to the following:

- At a minimum, the subject hot structures must be capable of operating at temperatures of at least 1,510 °C (2,750 °F)—higher temperatures are of even greater interest, such as up to 2,204+ °C (4,000+ °F).
- Constructed from composite fiber-reinforced materials, such as 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, nozzles, 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. Technology focus areas for submitted proposals should address one or more of the following:

- **Repeatable materials properties**: 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.
- **Improved toughness/durability**: 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 resistance that enhance durability are also of interest, and may include: matrix inhibition, oxidation resistant matrices, functionally graded material systems, and exterior environmental coatings. The goals here are to eliminate/reduce discontinuities in material properties and to provide robust material systems.
- **Reduced cost and/or delivery time**: 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 (or longer), 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 or prototype demonstrations. Phase I feasibility studies should also address cost and the risks associated with the hot structure technology.

In addition to delivery of a Phase I final report, 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. Examples of representative Phase I sample deliverables include:
- Coupons appropriate for thermal and/or mechanical material property tests.
- Arc-jet test specimens.
- Subelement or subcomponent structures.

Plans for potential follow-on 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 demonstration articles should be a part of the anticipated Phase II effort. Depending upon the primary application addressed by the Phase II contract, such test articles may include subscale nozzle-extensions, arc-jet specimens, or other representative hot structure components. Opportunities and plans should also be identified and summarized for potential commercialization with at least one aerospace company. Vehicle integration issues (attachment, joining, etc.) should be addressed.

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 potential reuse. Critical gaps or technology needs include:

- Increasing operating temperatures to 1,649 to 2,204+ °C (3,000 to 4,000+ °F).
- Increasing resistance to environmental attack (primarily through oxidation).
- Increasing manufacturing technology capabilities to improve reliability, repeatability, and quality control.
- Increasing durability/toughness and interlaminar mechanical properties (for 2D reinforcement) or introducing 3D architectures.
- Decreasing manufacturing cost.
- Decreasing overall manufacturing time requirements.

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 (andcrewed vehicles) to various space destinations, such as the lunar South Pole and Mars, is also of great interest.

The Advanced Exploration Systems (AES) Program (https://www.nasa.gov/directorates/heo/aes/index.html) would be ideal for further funding a prototype hot structure system and technology demonstration effort. Commercial space programs, such as the Commercial Resupply Services (CRS) Program, the Commercial Crew Program (CCP), the Commercial Lunar Payload Services (CLPS) Program, 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 for propulsion upgrades or block changes in the future include the Artemis Space Launch System (SLS), Orion, and Human Landing System (HLS). Hot structure technology is also highly relevant to the NASA Aeronautics Research Mission Directorate’s (ARMD’s) Hypersonic Technology (HT) Project (https://www.nasa.gov/aeroresearch/programs/aavp/ht). Other relevant efforts include the work done by NASA and the Defense Advanced Research Projects Agency (DARPA) in developing nuclear thermal propulsion (NTP) systems, both for reactor materials and nozzle extensions.

Potential NASA users of this technology exist for a variety of propulsion systems and other applications requiring the use of similar materials, 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.
- Atmospheric entry vehicle aeroshells, such as those for use at Earth, Mars, or other planets and their moons.
Related applications include the structures required for hypersonic flight vehicles.

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. Army, the U.S. Navy, the U.S. Space Force, the Missile Defense Agency (MDA), and 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:


Hypersonic Flight Vehicle Structures:


Note: The above references are all 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 presented here, both foreign and domestic.