Inflatable Softgoods for Next Generation Habitation Systems: Testing and Structural Health Monitoring

A key enabling technology for future crewed habitation systems is the development of inflatable softgoods materials and structures. In the past, habitat structures have typically consisted of metal alloys, but larger habitable volumes with lower structural mass will be required for long-duration, exploration-class missions. This subtopic seeks activities to mature inflatable softgoods through integration of sensing capabilities for structural health monitoring (SHM) and development of accelerated testing techniques.

Activities that may be undertaken under a Phase I effort include:

- Development of approaches for accelerated materials creep testing, specifically for high-strength materials in inflatable softgoods such as webbings and cords. In implementing these materials in habitation structures, one long-term risk is failure of the structural material due to creep (deformation under sustained loading). Real-time creep testing at the component and subscale levels can take years and new test methods need to be developed to help certify softgoods for flight in their intended use environment. Approaches may include novel test methods to reduce the duration of the test (while still generating meaningful data relative to long term use of a material system in its environment) and/or a combination of test methods and modeling approaches to accelerate generation and capture of relevant lifetime material data. Development of new approaches will help to increase testing throughput and mitigate potentially catastrophic risks in failure of inflatable materials.

Scope of work includes:

- Develop a methodology and test approach that can be validated to produce accurate predicted lifetime creep strain data and time-to-failure (TTF) for high-strength softgoods over a range of percent creep loads (50-90% nominally) within a year. (Within 1 to 3 months would be preferable).
  - "High strength" refers to webbings and cordage of strength nominally in the range 5,000 to 20,000 lbs/in.
- Produce master creep curves for each percent load and failure points.

The second focus area is integrated SHM. Integrated sensing capabilities in inflatable softgoods material systems are needed to monitor the structural performance of the material in situ, measure load/strain on softgoods components, detect damage, and predict further degradation/potential failures. The ability to acquire, process, and
make use of this data in real time is an important risk mitigation for potential structural failure modes. The current state of the art in this field are instrumentation systems such as high-resolution strain gauges, fiber optics, accelerometers, and acoustic sensors using flexible electronics. However, there is a technology gap in developing a proven system that can integrate into a softgoods material system and continually monitor performance through its life. For this activity, integration of a system as a proof of concept and preliminary testing on an integrated inflatable softgoods structure are expected as part of the Phase I.

Scope of work includes:

- Develop robust/repeatable integration approach with high-strength softgoods during manufacture or afterwards, that minimizes impact on the performance of the softgoods.
- Develop sensor(s) that are robust to packaging/deployment/handling of the softgoods they are integrated into.
- Repeatable performance and high-accuracy strain measurement (creep strain is typically 0.1 ~ 0.5%) once deployed and over the lifespan of the inflatable module.
- Sensor(s) are inherently able to (or have a defined path to) survive the extreme environment of space.

**Expected TRL or TRL Range at completion of the Project**

3 to 4

**Primary Technology Taxonomy**

**Level 1**

TX 12 Materials, Structures, Mechanical Systems, and Manufacturing

**Level 2**

TX 12.2 Structures

**Desired Deliverables of Phase I and Phase II**

- Research
- Analysis
- Prototype
- Hardware

**Desired Deliverables Description**

Phase I: Depending on the activity the proposer chooses to focus on, a Phase I effort would result in:

1. Development of accelerated creep test methods for inflatable softgoods at the component level and a laboratory proof of concept.
2. Approach to SHM for inflatable softgoods, a laboratory proof of concept of efficacy of approach, and/or preliminary design, which integrates the SHM approach into test articles.

Phase II: Depending on the activity the proposer chooses to focus on, a Phase II effort would result in:

1. Implementation of accelerated testing methods for evaluation of material creep and comparison with traditional (real-time) testing approaches at the component level.
2. Integration of SHM approach into inflatable softgoods components or subscale inflatable softgoods prototype and preliminary testing under load.

**State of the Art and Critical Gaps**
Development of approaches for accelerated materials creep testing. Current state of the art for testing uses straps for real-time creep testing at the component level and subscale (or full-scale) inflatable softgoods test articles for (a) burst and (b) creep-to-burst testing. These tests are needed to understand the behavior of the inflatable softgoods over the mission lifetime and predict failure due to creep, which represents a catastrophic risk. Real-time testing takes months to years to collect data (depending on load level) and predictions require extrapolation from a limited number of data points. Accelerated testing techniques would enable higher fidelity characterization of the performance of the inflatable softgoods system over the entire mission scenario prior to flight and reduce risk.

Integrated SHM. Approaches for SHM in inflatable softgoods are needed to track the performance of the material system in real-time and identify when the structure has incurred damage or is at risk of failure. SHM typically uses strain gauges, digital image correlation, or accelerometers. SHM for inflatable softgoods requires novel approaches, as the material system is multilayer and fundamentally different from many other habitat structures. New techniques, such as flexile electronics, wireless systems, and fiber optics, are also generally unproven in a flight scenario for SHM.

Relevance / Science Traceability

Technology for inflatable softgoods has historically been developed under Human Exploration Operations Mission Directorate (HEOMD) and Advanced Exploration Systems (AES). Current work on inflatable softgoods is under NASA's Next Space Technologies for Exploration Partnerships (NextSTEP) A: Habitation Systems Broad Agency Announcement opportunity, which has been ongoing since 2016 and focuses on design of next-generation habitat systems for cislunar space, the lunar surface, and Mars transit scenarios. The work under this subtopic will strongly complement ongoing work under the NextSTEP habitat project and increase the potential for the infusion of inflatable softgoods into future habitation concepts by reducing risk associated with understanding and predicting material behavior.

References