



NASA SBIR 2016 Phase I Solicitation

H5 Lightweight Structures and Materials

The SBIR topic area of Lightweight Structures and Materials centers on developing lightweight structures and advanced materials technologies for space exploration vehicles including launch vehicles, crewed vehicles and habitat systems, and in-space transfer vehicles.

Lightweight structures and advance materials have been identified as a critical need since the reduction of structural mass translates directly to additional up and down mass capability that would facilitate additional logistics capacity and increased science return for all missions. The technology drivers for exploration missions are:

- Lower mass.
- Improve efficient packaging of launch volume.
- Improve performance to reduce risk and extend life.
- Improve manufacturing and processing to reduce costs.

Because this topic covers a broad area of interests, subtopics are chosen to enhance and or fill gaps in the exploration technology development programs. These subtopics can include but are not limited to:

- Manufacturing processes for materials.
- Material improvements for metals, composites, ceramics, and fabrics.
- Innovative lightweight structures.
- Deployable structures.
- Extreme environment materials and structures.
- Multifunctional/multipurpose materials and structures.

This year the lightweight spacecraft materials and structures topic is seeking innovative technology for large deployable structures for smallsats, multifunctional materials and structures for integrated structural health monitoring, extreme temperature structures and in-space structural assembly. The specific needs and metrics of each of the focus areas of technology chosen for development are described in the subtopic descriptions.

Research awarded under this topic should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a full-scale demonstration unit for functional and environmental testing at the completion of the Phase II contract.

Subtopics

H5.01 Large Deployable Structures for Smallsats

Lead Center: LaRC

Participating Center(s): GRC, MSFC

This subtopic seeks deployable structures innovations in two areas for proposed lunar and deep-space missions:

- Large solar sails with at least 85 m² of deployed surface area for 6U cubesats.
- Large solar arrays with at least 200 W of power for 6U-12U cubesats or 600 W for 50-100 kg microsats.

Design solutions must demonstrate high deployment reliability and predictability with minimum mass and launch volume and maximum strength, stiffness, stability, and durability.

Innovations are sought in the following areas for both capabilities (deployable solar sails and deployable solar arrays):

- Novel design, packaging, and deployment concepts.
- Lightweight, compact components including booms, substrates, and mechanisms.
- Validated modeling, analysis, and simulation techniques.
- Ground and in-space test methods.
- Load reduction, damping, and stiffening techniques.
- High-fidelity, functioning laboratory models.

Capability #1: Deployable Solar Sails

Solar sails provide propellant less in-space propulsion using reflected sunlight. Indefinite continuous thrust allows a wide range of advanced maneuvers including non-Keplerian orbits, efficient orbit changes, and extreme ultimate velocities. A near-term application of this technology is NASA's NEA Scout 6U cubesat missions. Larger and more capable solar sail systems are envisioned for future missions.

Square solar sails typically consist of four reflective triangular membranes supported by lightweight deployable booms, as well as mechanical sail actuation to assist attitude control. Specific innovations sought for 6U cubesat solar sails in this solicitation are: improved deployable boom technologies, novel sail designs and packaging concepts, and simpler or more-effective mechanical attitude control systems. Proposed improvements to the booms used on the LightSail mission (metallic Triangular Rollable and Collapsible (TRAC) booms) are of special interest.

Nominal solar sail requirements for 6U cubesats are:

- Deployed reflective surface area > 85 m² (>100 m² preferred).
- Stowed membrane volume < 10 cm x 10 cm x 20 cm.
- Sail membrane stress > 70 kPa.
- Minimum system deployed natural frequency > 0.1 Hz.
- Mission life > 3 years in deep space (< 2 AU from the Sun) including lunar vicinity.
- Deployed sail surface as flat as possible considering all thermal and mechanical loads and residual stresses.

Improvements to the deployable TRAC booms proposed for the NEA Scout solar sail should meet the following additional requirements:

- Deployed boom length: > 8 m (up to 10 m preferred).
- Stowed volume for all booms and deployment mechanisms < 5 cm x 10 cm x 20 cm.
- Boom buckling load > 3N.
- Mass of each boom < 0.25 kg (< 0.15 kg preferred).

Capability #2: Deployable Solar Arrays

Smallsats promise cost-effective solutions for diverse human spaceflight precursor missions using fuel-efficient solar electric propulsion (SEP). SEP thrust increases with electrical power, so larger solar arrays can shorten travel times and allow higher-power science and communications equipment. This subtopic seeks structures innovations for the next generation of smallsat solar arrays with at least 5x larger area than basic body-mounted solar cells or hinged pop-out panels. Scaling up electrical power for smallsats by > 5x will require game changing innovations. In particular, novel flexible-substrate solar array designs are sought that minimize structural mass and packaging volume while maximizing deployment reliability and deployed area, stiffness, strength, and longevity.

Nominal solar array requirements are:

- Beginning-of-life (BOL) power at 1 AU > 200 W for cubesats or > 600 W for microsats.
- Packaging efficiency > 50 kW/m³ BOL.
- Recurring cost < \$500/W.
- Deployment reliability > 0.999.
- Deployed stiffness > 0.5 Hz.
- Deployed strength > 0.05 g (all directions).
- Lifetime > 2 yrs.

Proposals should emphasize structural design innovations, not materials or photovoltaic innovations. Solar array designs that can be rapidly commercialized are of special interest.

For both capabilities, contractors should prove the feasibility of proposed innovations with suitable analyses and tests in Phase I. Significant hardware or software capabilities should be developed and demonstrated in Phase II. A Technology Readiness Level (TRL) at the end of Phase II of 3-4 or higher is desired.

References:

- (http://www.nasa.gov/sites/default/files/files/Small_Spacecraft_Technology_State_of_the_Art_2014.pdf).
- (<http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140012882.pdf>).
- (<http://www.planetary.org/blogs/jason-davis/2014/20140610-lightsail-update-boom.html>).

H5.02 Extreme Temperature Structures

Lead Center: LaRC

Participating Center(s): AFRC, MSFC

This subtopic seeks to develop innovative low cost and lightweight structures for cryogenic and elevated temperature environments. The storage of cryogenic propellants and the high temperature environment during atmospheric entry require advanced materials to provide low mass, affordable, and reliable solutions. The development of durable and affordable material systems is critical to technology advances and to enabling future launch and atmospheric entry vehicles. The subtopic focuses on two main areas: highly damage-tolerant composite materials for use in cryogenic storage applications and high temperature composite materials for hot structures applications. Proposals to each area will be considered separately.

Cryogenic Storage Applications

The focus of this area is to yield material polymeric composite systems and manufacturing processes which enable the capability to store and transfer cryogenic propellants (liquid oxygen and liquid hydrogen) to orbit. Operating temperature ranges for these fluids are -183° C to -253° C. Material systems and processes proposed should be sensitive to eventual scale up and manufacturability of end use hardware. Specific areas of interest include:

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- Polymeric composite systems for applications in extreme cold environments such as storage vessels and ductwork for cryogenic fluids. Performance metrics for cryogenic applications include: temperature dependent properties (fracture toughness, strength, coefficient of thermal expansion), resistance to permeability and micro-cracking under cryogenic thermal and biaxial stress state cycling.
 - Reliable hatch or access door sealing technique/mechanism for cryogenic polymeric composite structures. Concepts must address seal systems for both composite to composite and composite to metal applications.

Hot Structures

The focus of this area is the development of cost effective, environmentally durable and manufacturable material systems capable of operating at temperatures from 1200° C to 2000° C, while maintaining structural integrity. Significant reductions in vehicle weight can be achieved with the application of hot structures, which do not require structurally parasitic thermal protection systems. The desired material systems are lightweight structural composites that include continuous fibers. This area seeks innovative technologies in one or more of the following:

- Material systems with significant improvements of in-plane and thru the thickness mechanical properties, compared to current high temperature laminated composites, such as stitched or 3D woven fibrous preforms.
- Decreased processing time and increased consistency for high temperature composite materials.
- Improvement in potential reusability for multiple missions.

For all above technologies, research, testing, and analysis should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware demonstration. Emphasis should be on the delivery of a manufacturing demonstration unit for NASA testing at the completion of the Phase II contract.

Phase I Deliverables - Test coupons and characterization samples for demonstrating the proposed material product. Matrix of verification/characterization testing to be performed at the end of Phase II.

Phase II Deliverables - Test coupons and manufacturing demonstration unit for proposed material product. A full report of the material development process will be provided along with the results of the conducted verification matrix from Phase I. Opportunities and plans should also be identified and summarized for potential commercialization.

References:

- Anon, "Final Report of the X-33 Liquid Hydrogen Tank Test Investigation Team," National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Alabama 35812, May 2000.
- Glass, D. E. "Ceramic Matrix Composites (CMC) Thermal Protection Systems (TPS) and Hot Structures for Hypersonic Vehicles," 15th AIAA International Space Planes and Hypersonic Systems and Technologies Conference, Dayton, Ohio, AIAA-2008-2682, April 2008.
(<http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080017096.pdf>).

H5.03 Multifunctional Materials and Structures: Integrated Structural Health Monitoring for Long Duration Habitats

Lead Center: LaRC

Participating Center(s): GRC, JSC, MSFC

Multifunctional and lightweight are critical attributes and technology themes required by deep space mission architectures. Multifunctional materials and structural systems will provide reductions in mass and volume for next generation vehicles. The NASA Technology Roadmap TA12, "Materials, Structures, Mechanical Systems, and Manufacturing"

(http://www.nasa.gov/sites/default/files/atoms/files/2015_nasa_technology_roadmaps_ta_12_materials_structures_final.pdf), proposed Multifunctional Structures as one of their top 5 technical challenges, and the NRC review of the roadmap recommended it as the top priority in this area stating: "... To the extent that a structure can

simultaneously perform additional functions, mission capability can be increased with decreased mass. Such multifunctional materials and structures will require new design analysis tools and might exhibit new failure modes; these should be understood for use in systems design and space systems operations.”

Some functional capabilities beyond structural that are in this multifunctional theme are insulating (thermal, acoustic, etc.), inflatable, protective (radiation and micrometeoroids and orbital debris), sensing, healing, in-situ inspectable (e.g., IVHM), actuating, integral cooling/heating, power generating (thermal-electric, photovoltaic, etc.), and so on.

Because of the broad scope possible in this SBIR subtopic, the intent is to vary its focus each year to address specific areas of multi-functionality:

- That have high payoff for a specific mission.
- That are broadly applicable to many missions.
- That could find broader applications outside of NASA which would allow for partnerships to leverage the development of these technologies.

For FY16, this SBIR subtopic seeks innovative, multifunctional approaches to integrating long-duration health monitoring capabilities within the range of candidate materials currently being investigated for space habitat long-duration mission concepts. These materials include, but are not limited to, thin-ply composites as well as the materials comprising the multiple soft-goods layers utilized in expandable space habitats, including the bladder, restraint and MMOD layers. Soft-goods materials, used in expandable habitats, may be packaged in an unloaded state for long periods of time prior to deployment, and then maintained at pressure for several years during a mission, while also being subjected to varying levels of thermal cycling. This creates a challenging set of conditions from which to predict the mechanical behavior of these structures over their operational life. NASA seeks the integration of robust, long-term sensing capabilities into the flexible materials (e.g., webbing, cordage, and woven fabrics) used in long-duration habitats, to provide health monitoring and evaluation of the structural integrity and properties of the multi-layer habitat structure throughout its mission life. The integration of the sensors would ideally be performed directly during manufacture; however, robust integration, post-fabrication, via non-destructive application, is also of interest. Ideally, the innovative sensing technology and integration approach should maintain the load-carrying capability or some other structural design requirement, and those technologies that enable weight reduction with similar or better structural performance when compared to traditional approaches will be considered. Sensing capabilities can include both the direct measurement of properties (strain, displacement, and load for example) and sensor fusion using multiple sensors to predict and locate critical damage areas and probable failure zones. The goal for long-duration space habitat design is fail-safe operation; providing monitoring and early prediction of failure onset via structural health monitoring and a benign, progressive failure architecture that allows for safe evacuation even at or after the first failure point.

In summary NASA seeks innovations in integrating structural health monitoring into materials for long-duration deep space habitats, including, but not limited to, state-of-the art thin-ply composites and soft-goods materials for expandable habitat structural concepts, during or after fabrication, to enable evaluation of structural properties and failure prediction over the duration of the habitat's operational life.

Contractors should prove the feasibility of proposed innovations using suitable analyses and small scale tests in Phase I. In Phase II, significant testing/fabrication or software capabilities should be developed and demonstrated. A Technology Readiness Level (TRL) at the end of Phase II of 3-4 or higher is desired.

H5.04 In-Space Structural Assembly

Lead Center: LaRC

Participating Center(s): ARC, JSC, KSC, MSFC

In-space assembly (ISA) of spacecraft systems has been proposed and demonstrated several times as way of assembling systems too large to fit into a single launch vehicle and enabling installation of orbital replacement units. The International Space Station and the repair missions of the Hubble Space Telescope are two good examples.

Efficient structural assembly in space, namely structures with low-mass and high-stiffness and strength, can be achieved by system level design that takes advantage of robotic assembly. For deep-space exploration, the key technology gaps for a robust ISA capability are the joining and unjoining technology (mechanical and electrical), design modularity, and the reuse of components. These technologies will enable a capability that makes future long duration vehicle systems more affordable than the current single-launch, single-use approach to space vehicle design.

The need for on-orbit repair/assembly/servicing are well documented Ref. 1-3. This subtopic seeks in-space assembly and structures manufacturing innovations in two areas of special interest for proposed deep-space space exploration missions:

- Reversible joining technology for structural components and modules.
- In-space and surface systems that recycle spent metallic and composite components to produce additive manufacturing feedstock. Design solutions must minimize mass, power, and complexity while meeting all other mission requirements including contamination control, load bearing strength and stiffness of the assemblage.

Capability #1: Reversible Joining Technology

The ability to join structural and spacecraft components in-space allows for the assembly of vehicles (perhaps aggregated from multiple launches) and for re-use of vehicle subsystems. The joining technology should be reversible for maximum flexibility and utilize simple approaches (electro-mechanical or other) amenable to robotic assembly and disassembly. In addition, the joining technology must provide for mechanical, electrical and optionally thermal load transfer.

This subtopic capability seeks innovative joining technologies and capabilities for in-space assembly, disassembly, and re-use of deep-space exploration vehicle subsystems such as cargo tugs that use solar electric power for propulsion. Joining in-space of structural trusses that support multiple solar arrays for solar electric propulsion is one class of needed joining technology. The assembled truss must provide power connections either integral to the structural joint or as a non-mechanical load bearing harness with connectors. The second class of in-space joining is for modular subsystems nominally three-dimensional shapes (square or rectangular) with power, data, and mechanical load carrying connections. While these modules could represent orbital replacement units (ORUs), the modules could serve to construct an entire space vehicle.

In particular, novel reversible joining systems for robotic operations are needed that minimize mass, energy and complexity while maximizing assembled stiffness, strength and stability.

Nominal joining applications are:

- Class 1: Structural Truss Joints.
 - Strength: > 0.4 g (Mars Extensible) in all degrees of freedom assuming a fixed joint with 1 meter rigid offset of a 100Kg point mass.
 - Power Transmission: > 5 kW.
 - Operating Temperature: -100° C to +100° C.
 - Assembly/Disassembly: > 20 times.
- Class 2: Module Joints.
 - Strength: > 0.4 g (Mars Extensible) with 0.25 meter cubic module connected on one face with uniform density of 640 Kg/m³.
 - Power Transmission: > 5 kW.
 - Data Transmission: 25 low voltage lines.
 - Temperature: -100° C to +100° C.
 - Assembly/Disassembly: > 20 times.

In Phase I, contractors should prove the feasibility of proposed innovations using suitable analyses and prototype tests. In Phase II, operational joining hardware for assembly and disassembly. Technology Readiness Level (TRL) at the end of Phase II is expected to be 3-4 or higher.

Capability #2: In-situ Surface Manufacturing

Sustainable extraterrestrial presence will require innovative approaches to lightweighting launch masses. The ability to manufacture structures onsite affords an alternative to carrying components of surface systems as part of the launch mass and volume. Additive manufacturing (AM) offers the flexibility to achieve this objective since it enables the conversion of various feedstocks into functional components, especially. Maximum benefits can be realized if the AM method can take advantage of resources available onsite, including both ISRU extracted planetary metals and discarded materials.

State of the art AM techniques can process material classes ranging from metals to plastics and ceramics. Typically, AM equipment use pristine forms of these material feedstocks. This manufacturing capability will permit the construction of various surface systems using feedstock carried as part of the launch and taking advantage of AM in this manner can contribute to the reduction of volume required to carry partly or fully assembled surface systems during launch. However, the impact of AM can be maximized if it is also able to utilize a broader suite of materials, especially those generated from repurposing objects/components required only for launch and transport to the exploration destination, in-space and surface presence. For example, metallic or composite parts from vehicles needed only for transit to the planetary surface, can be recycled to construct pressure vessels for life support and propulsion. The ability to repurpose what would otherwise be discarded materials and/or fabricate with processed extracted planetary materials (such as iron, aluminum, and silicon) takes full advantage of limited resources available to make sustained presence affordable. Further, automated AM offers a means to construct surface systems ahead of the arrival of humans.

Proposals are sought for additive manufacturing concepts that can enable manufacturing from extracted planetary materials and/or the recycling/repurposing of structural components from space vehicles to produce pressure vessels. This does not include the process of ISRU to extract the materials, just the use of the extracted materials in AM. (See H1.01 In-Situ Resource Utilization for processes to extract materials.) Of interest are the following:

Design concepts for AM approaches to accommodate feedstocks that are composites of various material types including but not limited to:

- Processing techniques to recycle and repurpose structural composites having thermoset matrices and carbon fiber reinforcement to yield AM feedstocks.
- Processing techniques to recycle and repurpose structural metallic vehicle components to yield AM feedstocks.
- Approaches to join additively manufactured components from disparate materials.
- Approaches to use minimal power in the manufacture of components.
- Mobile AM methods that operate on power generated from planetary surface resources.

Nominal manufacturing applications are:

- Class 1: Pressure vessels.
 - Size: > 0.25 m³.
 - Strength: > 14.7 psi.
 - Operating Temperature: -100° C to +100° C.
- Class 2: Two-Dimensional Platform for Mobile Carrier.
 - Size: > 3 meter X 2 meter with thickness based on strength.
 - Strength: > 0.4 g (Mars) with 300 Kg mass uniformly distributed.
 - Operating Temperature: -100° C to +100° C.

In Phase I, contractors should prove the feasibility of proposed innovations using suitable analyses and prototype tests. In Phase II, prototype manufacturing systems capable of processing multiple material classes. Technology Readiness Level (TRL) at the end of Phase II is expected to be 3-4 or higher.

References:

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- Barnhart, David; Will, Peter; Sullivan, Brook; Hunter, Roger; and Hill, Lisa: "Creating a Sustainable Assembly Architecture for Next-Gen Space: The Phoenix Effect," 30th Space Symposium, May 2014, Colorado Springs CO.
 - Erkorkmaz, Catherine; Nimelman, Menachem; and Ogilvie, Andrew: "Spacecraft Payload Modularization for Operationally Responsive Space," 6th Responsive Space Conference, April 28-May 1, 2008, Los Angeles, CA.
 - Troutman, Patrick A.; Krizan, Shawn A; Mazanek, Daniel D.; Stillwagen, Frederic H.; Antol, Jeffrey; Sarver-Verhey Timothy R.; Chato, David J.; Saucillo, Rudolf J.; Blue, Douglas R.; and Carey, David: "Orbital Aggregation and Space Infrastructure Systems (OASIS)", IAC-02-IAA.13.2.06, 53rd International Astronautical Congress, 10-19 Oct. 2002, Houston Texas.