NASA SBIR 2014 Phase I Solicitation

H5 Lightweight Spacecraft Materials and Structures

The SBIR topic area of Lightweight Spacecraft Materials and Structures centers on developing lightweight structures and advanced materials technologies for enabling launch vehicles and spacecraft for the Human Exploration Missions. Lightweight structures and advanced materials have been identified as a critical need since the reduction of structural mass translates directly to additional up and down mass capability in exploration missions. The technology drivers are:

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

Applications are expected to include space exploration vehicles including launch vehicles, crewed vehicles and habitat systems, and in-space transfer vehicles. The focus areas targeted in this topic are:

- Additive Manufacturing of Lightweight Metallic Structures.
- Deployable Structures.
- Advanced Fabrication and Manufacturing of Polymer Matrix Composite (PMC) Structures.Hot Structures.

Metallic additive manufacturing (AM) technology builds near-net shape components one layer at a time using metal powder bed or wire fed processes and data from 3-D CAD models. This technology enables the direct fabrication of net or near-net shape components without the need for tooling and with minimal or no machining thereby reducing component lead-time, manufacturing cost, and material waste. The purpose of the Additive Manufacturing of Lightweight Metallic Structures subtopic is to invest in mid- and long-term research to establish rigorous, systematic, scalable, and repeatable verification and validation methods for additive manufacturing (AM) using the EBF3 system. Nearly all spacecraft flown to date are powered by deployable solar arrays, having up to 100 m^2 of solar cell area and 25 kW of electrical power. NASA has a vital interest in developing much larger arrays over the next 20 years. The Deployable Structures subtopic seeks innovative structures and materials technologies and capabilities for the next generation of lightweight solar arrays beyond 50 kW. The subtopic area for Polymer Matrix Composite (PMC) Materials and Manufacturing concentrates on developing lightweight structures, using advanced materials technologies and new manufacturing processes. The objective of the subtopic is to advance technology readiness levels of PMC materials and manufacturing for launch vehicles and in-space applications resulting in structures having affordable, reliable and predictable performance. The subtopic will address two areas, manufacturing of structures and highly damage-tolerant materials for use in cryogenic environments. NASA has developed hot structure technology for several hypersonic vehicles. Significant reductions in vehicle weight can be achieved with the application of hot structures, which do not require parasitic thermal protection systems (TPS). The most significant technical issue that must be addressed in hot structure design is the development of cost effective, environmentally durable and manufacturable material systems capable of operating at temperatures from 1500 °C to 3000 °C, while maintaining structural integrity. The Hot Structures subtopic seeks to develop innovative low cost, mass and structurally efficient high temperature materials for hot structures applications. The metrics and specific needs of each of these focus areas of technology development are described in the subtopic descriptions. Research 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 Additive Manufacturing of Lightweight Metallic Structures

Lead Center: LaRC

Participating Center(s): GRC, JSC, MSFC

The objective of this subtopic is to advance technology readiness levels of lightweight metals and manufacturing techniques for launch vehicles and in-space applications resulting in structures having affordable, reliable, predictable performance with reduced costs. Technologies developed under this subtopic are of interest to NASA programs such as Space Launch System (SLS), Multi-Purpose Crew Vehicle (MPCV), Orion, and commercial launch providers.

Metallic additive manufacturing (AM) technology builds near-net shape components one layer at a time using metal powder bed or wire fed processes and data from 3-D CAD models. Metallic AM technologies like Selective Laser Melting (SLM), Direct Metal Laser Sintering (DMLS), Electron Beam Freeform Fabrication (EBF3), and Laser Engineered Net Shaping (LENS) are of interest to NASA for fabrication of advanced metallic aerospace components and in-space fabrication and repair. These technologies enable the direct fabrication of net or near-net shape components without the need for tooling and with minimal or no machining thereby reducing component lead time, manufacturing cost, and material waste. Metallic AM also has the potential to enable novel product designs that could not be fabricated using conventional subtractive machining processes and extends the life of in-service parts through innovative repair methodologies. Currently, some metallic AM systems use sensors for process control but not for in-situ quality assurance (QA) or flaw detection.

The purpose of this subtopic is to invest in mid- and long-term research to establish rigorous, systematic, and scalable verification and validation methods for metallic AM. Beam tracking errors, part distortion, feedstock nozzle stand-off distance variability, excessive heat build-up in the deposit, stuck or unmelted feedstock, etc. can contribute to build deposit geometric anomalies and discontinuities. The objective would be to achieve a capability to have in-situ assessment during the deposition process to provide immediate feedback to the operator or a closed loop control system to enable real-time process correction or remedial actions to correct for defects. Although the technologies developed may be specific to one metallic AM system, it is desired that they have cross cutting capabilities to other metallic AM technologies. Proposals are invited that:

- Explore new and improved sensors and sensor systems for monitoring of the metallic AM build deposit.
- Offer technologies to use the signals generated by the energy beam (either electron beam or laser) or beam / substrate emissions for in-situ process monitoring and quality assurance.
- Propose additional devices to support real-time geometric part inspection and identification of flaws (voids, cracks, lack of fusion defects or other discontinuities).

Technologies should enable determination of the boundaries of the molten pool within 0.001” (in order to define the size and shape), measurement of temperature over the range from 700 °F to 3000 °F (representative of the molten pool and surrounding regions) to within 25 °F, measurement of geometric features to within +0.005”, detect flaws in the range of 0.010 - 0.001”, and determine chemical composition within 1 weight percent. Technologies should be compatible with standard high speed computer communication protocols and sensors should be able to update at frequencies on the order of 10 Hz. Highly desirable attributes are that technologies enable non-contact sensing and measurement, are vacuum compatible, and are relatively insensitive to contamination. Desirable attributes include that technologies are non-hazardous, do not require the use of additional consumables, and do not introduce contaminants into the process.

Research should be conducted to demonstrate technical feasibility in Phase I and show a path toward demonstration in Phase II of in-situ process monitoring and quality assurance. Phase II proposals should include delivery of a prototype system for test and evaluation in environments representative of NASA's metallic AM systems. Expected Technology Readiness Levels (TRL) at the completion of Phase I projects are 2-3 and 4-5 at the end of Phase II projects.

Links to information about NASA's additive manufacturing development projects can be found at:

- Selective Laser Melting (SLM) and Direct Metal Laser Sintering (DMLS).
    - (http://www.nasa.gov/exploration/systems/sls/3dprinting.html).
- Electron Beam Freeform Fabrication (EBF3)
    - (http://www.sciencedaily.com/releases/2009/11/091110071535.htm).
    - (http://www.nmc.ctc.com/useruploads/file/events/PA_Karen_Taminger.pdf).
- Laser Engineered Net Shaping (LENS).
    - (http://www.sandia.gov/mst/pdf/LENS.pdf).

H5.02 Deployable Structures

Lead Center: LaRC

Participating Center(s): GRC, JPL

Nearly all spacecraft flown to date are powered by deployable solar arrays, having up to 100 m^2 of solar cell area and 25 kW of electrical power. NASA has a vital interest in developing much larger arrays over the next 20 years with up to 4000 m^2 of deployed area (1 MW) for exploration missions using solar electric propulsion (SEP). Scaling up solar array deployed surface area by more than an order-of-magnitude will require game changing innovations. In particular, novel flexible-substrate designs are needed that minimize structural mass and packaging volume while maximizing deployment reliability, deployed stiffness, deployed strength, and longevity. Most of the mass savings in these very large future arrays will probably come from improvements to solar array supporting structures, not from improvements in the solar cells mounted on the arrays.

NASA is currently developing solar array systems for SEP in the 30-50 kW power range. This SBIR subtopic seeks innovative structures and materials technologies and capabilities for the next generation of lightweight solar arrays beyond 50 kW. Technologies are needed for the design and verification of large deployable solar arrays with:

- 200-400 m^2 of deployed area (50-100 kW) in 3-5 years.
- 400-1200 m^2 of deployed area (100-300 kW) in 5-10 years.
- 1200-4000 m^2 of deployed area (300-1000 kW) in 10-20 years.

These deployed areas are typically divided between two solar array wings, with each wing requiring half of the specified area.

This subtopic seeks innovations in the following areas for future large solar array structures:

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

Nominal solar array requirements for large-scale SEP applications are:

- Mass specific power > 120 W/kg at beginning of life (BOL).
- Stowed volume specific power > 40 kW/m^3 BOL.
- Deployment reliability > 0.999.
- Deployed stiffness > 0.1 Hz.
- Deployed strength > 0.2 g (all directions).
- Lifetime > 5 years.

Variations of NASA's in-house large solar array concept referred to as the Government Reference Array (GRA) could be used for design, analysis, and hardware studies. Improved packaging, joints, deployment methods, etc. to enable GRA-type solar arrays up to 4000 m^2 in size (1 MW) with up to 250 W/kg and 60 kW/m3 BOL are of special interest. The GRA is described in Reference 2.

In Phase I, contractors should prove the feasibility of proposed innovations using suitable analyses and tests. In Phase II, significant hardware or software capabilities should be developed and demonstrated to advance their Technology Readiness Level (TRL). TRLs at the end of Phase II of 3-4 or higher are desired.

References:

- "Concept Design of High Power Solar Electric Propulsion Vehicles for Human Exploration"

(http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120000068_2011025608.pdf).

- Pappa, R. S. et al., "Solar Array Structures for 300 kW-Class Spacecraft," Presented at the Space Power Workshop, April 24, 2013.

H5.03 Advanced Fabrication and Manufacturing of Polymer Matrix Composite (PMC) Structures

Lead Center: MSFC

Participating Center(s): LaRC

The subtopic area for Polymer Matrix Composite (PMC) Materials and Manufacturing concentrates on developing lightweight structures, using advanced materials technologies and new manufacturing processes. The objective of the subtopic is to advance technology readiness levels of PMC materials and manufacturing for launch vehicles and in-space applications resulting in structures having affordable, reliable and predictable performance. The subtopic will address two areas, manufacturing of structures and highly damage-tolerant materials for use in cryogenic environments. Proposals to each area will be considered separately. Areas of interest include: advances in PMC materials for large-scale structures and for in-space applications; innovative automated manufacturing processes (e.g., fiber placement); advanced non-autoclave curing; damage-tolerant/repairable structures; low-cost, durable tooling; high temperature PMC materials for high performance composite structures (high temperature applications); and materials with high resistance to micro cracking at cryogenic temperatures. Reliable, affordable, and practical joining techniques for large segmented composite structures are desired.

Lightweight structures and PMC materials have been identified as a critical need for launch vehicles since the reduction of structural mass translates directly to vehicle additional performance, reduced cost, and increased payload mass capacity. Reliable large-scale (approximately 8 meters or greater in diameter) PMC structures will be critical to the "heavy lift" of America's next-generation space fleet. The capability to transfer and store for long-term propellant, particularly cryogenic propellants in orbit, can significantly increase the nation's ability to conduct complex and extended exploration missions beyond Earth's orbit. The use of PMC materials for cryotanks offers the potential of significant weight savings. Applications include storage of cryogenic propellants on an Earth Departure Stage, a lunar or asteroid descent vehicle, long-term cryogen storage on the Moon, and propellant tanks for a heavy lift launch vehicle. Consideration shall be made for manufacturability in the sense of either using out of autoclave cure or autoclave cure and, in made in sections, novel and reliable approaches to join sections of composite structures to take advantage of the high strength to weight properties so that the joining methods do not significantly increase the complexity or weight of the overall structure. Novel approaches from cradle to grave will be considered in the sense that these very large structures required robust and lightweight tooling and transportation methods for minimal modifications to existing facilities and use of existing transportation or minimal modifications to such infrastructures.

Performance metrics for manufacturing structures include: achieving adequate structural and weight performance; manufacturing and life cycle affordability analysis; verifiable practices for scale-up; validation of confidence in design, materials performance, and manufacturing processes; low-cost, durable tooling; and quantitative risk reduction capability. Research should be conducted to demonstrate novel approaches, technical feasibility, and basic performance characterization for polymer matrix composite structures or low-cost, durable tooling during Phase I, and show a path toward a Phase II design allowables and prototype demonstration. Emphasis should be on demonstrable manufacturing technology that can be scaled up for very large structures.

Performance metrics for materials developed for cryotanks are: temperature-dependent material properties including strength, modulus, CTE, and fracture toughness; and demonstrated improved resistance over present SOA of multi-directional laminates to microcracking under cryogenic temperature cycling. Initial property characterization would be done at the coupon level in Phase I. Generation of design allowables, characterization of long-term material durability, and fabrication of larger panels would be part of follow-on efforts.

High temperature polymer matrices for high performance composite structures (high temperature applications) with ease of manufacturing using the current composite manufacturing techniques.

H5.04 Hot Structures

Lead Center: LaRC

This subtopic seeks to develop innovative low cost, mass and structurally efficient high temperature materials for hot structures applications.

The National Aeronautics and Space Administration (NASA) has developed hot structure technology for several hypersonic vehicles. Significant reductions in vehicle weight can be achieved with the application of hot structures, which do not require parasitic thermal protection systems (TPS). The most significant technical issue that must be addressed in hot structure design is the development of cost effective, environmentally durable and manufacturable material systems capable of operating at temperatures from 1500 °C to 3000 °C, while maintaining structural integrity. The development of these durable and affordable material systems is critical to technology advances and to enabling future economical hypersonic vehicles. Atmospheric re-entry from cis-lunar space will push the boundaries of thermal structures system technical capabilities. Advanced hot structures are required to enable these future missions.

This subtopic seeks innovative technologies in the following areas:

- Light-weight, low-cost, composite material systems that include continuous fibers.
- Significant improvements of in-plane and thru the thickness mechanical properties, compared to current high temperature laminated composites.
- Decreased processing time and increased consistency for high temperature materials.
- Low conductivity, low thermal expansion, high impact resistance.
- High temperature performance improved with oxidation resistant coatings.

Overall looking for 20% or greater reduction in mass and an order of magnitude reduction in cost.

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 with 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 approach to develop the hot structure material product (TRL 2-3). Matrix of verification/characterization testing to be performed at the end of Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

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 (TRL 3-4). Opportunities and plans should also be identified and summarized for potential commercialization.