NASA SBIR 2021 Phase I Solicitation

Z4.06 Manufacturability Assessment as a Design Constraint for Advanced Tailorable Composites

Lead Center: LaRC

Participating Center(s): MSFC

Scope Title:

Manufacturability Assessment as a Design Constraint for Advanced Tailorable Composites

Scope Description:

While use of composite material systems in space vehicle structures is increasing, their broader implementation is still facing multiple challenges. One of these challenges, especially relevant in the context of advanced tailorable composites, is a manufacturability assessment that could be leveraged as a design constraint early in the development. Absence of a reliable and comprehensive manufacturability assessment often restricts exploitation of the full potential of the composite material system and promotes conservative fabrication approaches that can negate potential mass benefits of composites. Suboptimal designs such as quasi-isotropic lamination stacking sequence treat the material as “black aluminum,” failing to permit tailored load paths possible with composites. Consequently, a material system that can enable large reductions in system mass ends up being used in the design process in a way that results in structural components that are much heavier than necessary.

This solicitation seeks to advance the analytical predictive manufacturability assessment capabilities for layered composites. Such an assessment is required as a constraint in the structural design and optimization process. Layered pre-impregnated composite materials reinforced with either continuous or short fibers, and with a broad spectrum of ply thicknesses, are in the scope of this solicitation. For the continuous-fiber composites, the typical fiber areal weights range from approximately 30 grams per square meter (gsm) to just under 200 gsm. For short-fiber applications, the ultrathin plies in the single-digit gsm range are also of interest. Since a broad variety of composite material systems is within the scope of this solicitation, the scope of related manufacturability constraints can be tailored to the proposed material system. Consequently, the examples of manufacturability considerations provided in this solicitation are not all-inclusive, and parameters not listed below can be offered up for investigation when a compelling rationale is presented. The list of potential implementations of advanced tailorable composites is also provided to aid in the determination of manufacturing constraints of primary importance. The overarching approach should be based on recognizing that the more aggressive the tailoring of a composite material system, the greater the risk of developing defects in the manufacturing process. While avoiding any defects can be one countermeasure, quantifying the effects of defects can provide additional insights. Specifically, if the effect of defect can be quantified and it can be demonstrated that the benefits gained from the associated design tailoring can overcome the adverse effect of a small defect, then a rationale for the more aggressive tailoring can be justified. Examples of defects include, but are not limited to, tow gaps, overlaps, foldovers, or poor compaction/separation from the underlying plies. In cases where a placement imperfection can be subjected to restorative actions, analysis of how successful such actions can be is also of value.
The manufacturability assessment shall be based on analytical tools validated with experimentation/actual manufacturability trials. Examples of the performance-based manufacturing constraints for the continuous-fiber composites include, but are not limited to, determination of the minimum allowable steering radius, relative proximity of ply terminations such that no significant adverse interaction occurs, and minimizing thermal warping in the cure process when nonsymmetric lamination stacking sequence is present. For example, one of the important examples of the manufacturability assessment for short-fiber composites is determination of an initial preform thickness distribution that would produce a desired thickness distribution after forming that involves preform expansion and/or turning or steering (i.e., forming similar to deep-stamping or closed-cross-section forming with a clamshell tool and an expandable bladder). Similarly, estimation of the short-fiber orientation distortions in the forming process and predictive countermeasures to this behavior are also sought.

Subscale manufacturing demonstrations representative of the challenges that can be encountered in the full-scale applications are sought as the manufacturability predictive analysis validation cases. The full-scale structures of interest that can be scaled down for the manufacturing demonstrations include cryogenic tanks, crew modules, pressurized habitats, and other dry and unpressurized primary structural components or portions of thereof. Discrete features such as hatches, access and windows cutouts, and hard point attachments can be considered as manufacturability challenges to be encountered in the full-scale applications in addition to the general acreage considerations. Furthermore, manufacturability assessment for short-fiber composites is expanded to allow smaller size demonstrations, for example, those representative of hard point attachment brackets, hinges, clevises, etc.

**Expected TRL or TRL Range at completion of the Project:** 5 to 6

**Primary Technology Taxonomy:**
- Level 1: TX 12 Materials, Structures, Mechanical Systems, and Manufacturing
- Level 2: TX 12.4 Manufacturing

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

- Research
- Analysis
- Prototype
- Software

**Desired Deliverables Description:**

In Phase I, a comprehensive identification of manufacturability constraints shall be conducted for a selected material system and application. Analytical and experimental results shall be obtained for at least one selected aspect of the manufacturability assessment.

In Phase II, the analytical tool capabilities and related manufacturability trials shall be expanded to a more comprehensive and exhaustive list of manufacturability constraints identified in Phase I. A manufacturing demonstration article and the computational tool available for release shall be delivered at the conclusion of Phase II.

**State of the Art and Critical Gaps:**

Present composite designs are typically limited to straight fiber arrangements and lamination stacking sequences resulting in quasi-isotropic material properties. Apart from the lack of structural design and optimization tools, highly tailored fabrication of composites presents manufacturing challenges and is prone to introducing manufacturing defects. Manufacturability assessment is often performed via the trial-and-error approach, which is costly, time consuming, and very limited in scope. A validated computational manufacturability assessment tool would enable more rapid and comprehensive manufacturability assessment that can inform the design effort in its early stages.

**Relevance / Science Traceability:**
• Space Technology Mission Directorate (STMD), Artemis/HLS (human landing systems) programs, developers of air-launched systems, e.g., Generation Orbit Launch Services.
• Aeronautics Research Mission Directorate (ARMD), next-generation airframe technology beyond "tube and wing" configurations, e.g., hybrid/blended wing body.
• Developers of the in situ nondestructive evaluation inspection capabilities within both space and aeronautics programs.

References: