NASA SBIR 2021 Phase I Solicitation

Z4.05  Nondestructive Evaluation (NDE) Sensors, Modeling, and Analysis

Lead Center: LaRC

Participating Center(s): ARC, GSFC

Scope Title:
Nondestructive Evaluation (NDE) Sensors, Modeling, and Analysis

Scope Description:

NASA’s NDE SBIR subtopic will address a wide variety of NDE disciplines. These disciplines include but are not limited to structural health monitoring (SHM), novel NDE sensor development, and NDE modeling and analysis. All three of these disciplines can be used on aerospace structures and materials systems, including but not limited to Inconel, titanium, aluminum, carbon fiber, Avcoat, ATB-8, Phenolic Impregnated Carbon Ablator (PICA), and thermal blanket structures. Sensor systems, SHM, and modeling can target any set of these materials in common aerospace configurations, such as micrometeoroid and orbital debris (MMOD) shielding, truss structures, and stiffened structures. In addition, NDE can target material and material systems in a wrought state in process, and NDE techniques that could be used to inspect additively manufactured components post production would be favored. Current NDE computational tools do not have sufficient resolution to provide representation on the order of finite-element models (FEMs) allowing for a digital twin. Depending on the size of the critical flaw in the material system/structure, this resolution can range from 500 nm to 100 cm realistically. As NDE tool resolution grows, larger volumes of data are created, and thus new computational tools are required. At the same time, low-cost emerging computational hardware, such as graphics processing units (GPUs), is enabling the growing use of advanced physics-based models for improved NDE inspection and for advanced data analysis methods such as machine learning. In addition, as NASA strives to go deeper and longer, new tools need to be developed in order to support long-duration spaceflight.

NDE Sensors and Data Analysis
Technologies enabling the ability to perform inspections on large complex structures will be encouraged. Technologies should provide reliable assessments of the location and extent of damage. Methods are desired to perform inspections in areas with difficult access in pressurized habitable compartments and external environments for flight hardware. Many applications require the ability to see through assembled conductive and/or thermal insulating materials without contacting the surface.

Techniques that can dynamically and accurately determine position and orientation of the NDE sensor are needed to automatically register NDE results to precise locations on the structure. Advanced processing and displays are needed to reduce the complexity of operations for astronaut crews who need to make important assessments quickly. NDE inspection sensors are needed for potential use on free-flying inspection platforms. Integration of wireless systems with NDE may be of significant utility. It is strongly encouraged that proposals provide an explanation of how the proposed techniques and sensors will be applied to a complex structure. Examples of structural components include but are not limited to multiwall pressure vessels, batteries, tile, thermal blankets, micrometeoroid shielding, International Space Station (ISS) radiators, or aerospace structural components.

Additionally, techniques for quantitative data analysis of sensor data are desired. It is also considered highly desirable to develop tools for automating detection of material foreign object debris (FOD) and/or defects and evaluation of bondline and in-depth integrity for lightweight rigid and/or flexible ablative materials. Typical internal void volume detection requirements for ablative materials are on the order of less than 6 mm, and bondline defect detection requirements are less than 25 mm.

Additive manufacturing is rapidly becoming a manufacturing method targeting fracture-critical components; as such, NDE requirements will become more stringent. Additively manufactured components represent a novel challenge for NDE due to the layering nature of the process and its effect on diffracting energy sources. Development of NDE techniques, sensors, and methods addressing these issues would be highly desired, but techniques addressing weld inspection will also be considered. Most of the aerospace components will be metallic in nature, and critical flaws are on the range of 1 mm or smaller and can be volumetric or fracturelike in nature.

**Structural Health Monitoring (SHM)**

Future manned space missions will require spacecraft and launch vehicles that are capable of monitoring the structural health of the vehicle and diagnosing and reporting any degradation in vehicle capability. This subtopic seeks new and innovative technologies in SHM and integrated vehicle health management (IVHM) systems and analysis tools.

Techniques sought include modular/low mass-volume systems; low-power, low-maintenance systems; and systems that reduce or eliminate wiring, as well as standalone smart-sensor systems that provide processed data as close to the sensor as practical and systems that are flexible in their applicability. Examples of possible systems include surface-acoustic-wave- (SAW-) based sensors, passive wireless sensor tags, flexible sensors for highly curved surfaces, and direct-write film sensors. Damage detection modes include leak detection, ammonia detection, micrometeoroid impact, and others. Reduction in the complexity of standard wires and connectors and enabling sensing functions in locations not normally accessible with previous technologies is also desirable. Proposed techniques should be capable of long-term service with little or no intervention. Sensor systems should be capable of identifying material state awareness and distinguishing aging-related phenomena and damage-related conditions. It is considered advantageous that these systems perform characterization of age-related degradation in complex composite and metallic materials. Measurement techniques and analysis methods related to quantifying material thermal properties, elastic properties, density, microcrack formation, fiber buckling and breakage, etc., in complex composite material systems and in adhesively bonded/built-up and/or polymer-matrix
composite sandwich structures are of particular interest. Some consideration will be given to the IVHM/SHM ability to survive in on-orbit and deep space conditions, allow for additions or changes in instrumentation late in the design/development process, and enable relocation or upgrade on orbit. The system should allow NASA to gain insight into performance and safety of NASA vehicles as well as commercial launchers, vehicles, and payloads supporting NASA missions.

Inclusion of a plan for detailed technical operation and deployment is highly favored.

**NDE Modeling**

Technologies sought under this SBIR include near real-time realistic NDE and SHM simulations and automated data reduction/analysis methods for large datasets. Simulation techniques will seek to expand NASA’s use of physics-based models to predict inspection coverage for complex aerospace components and structures and to utilize inverse methods for improved defect characterization. Analysis techniques should include optimized automated reduction of NDE/SHM data for enhanced interpretation appropriate for detection/characterization of critical flaws in space-flight structures and components, and may involve methods such as machine learning and domain transformation. NASA’s interest area is lightweight structural materials for spaceflight, such as composites and thin metals. Future purposes will include application to long-duration space vehicles as well as validation of SHM systems.

Techniques sought include advanced material-energy interaction (i.e., NDE) simulations for high-strength lightweight material systems and include energy interaction with realistic damage in complex 3D component geometries (such as bonded/built-up structures). Primary material systems can include metals, but it is highly desirable to target composite structures. NDE/SHM techniques for simulation can include ultrasonic, laser, microwave, terahertz, infrared, x-ray, x-ray computed tomography, fiber optic, backscatter x-ray, and eddy current. It is assumed that any data analysis methods will be focused on NDE techniques with high-resolution, high-volume data. Modeling efforts should be physics-based, and it is desired that they can account for material aging characteristics and induced damage, such as micrometeoroid impact. Examples of damage states of interest include delamination, microcracking, porosity, and fiber breakage. Techniques sought for data reduction/interpretation will yield automated and accurate results to improve quantitative data interpretation to reduce large amounts of NDE/SHM data into a meaningful characterization of the structure. It is advantageous to use coprocessor/accelerator-based hardware (e.g., field-programmable gate arrays (FPGAs) and GPUs) for simulation and data reduction. Combined simulation and data reduction/interpretation techniques should demonstrate ability to guide the development of optimized NDE/SHM techniques, lead to improved inspection coverage predictions, and yield quantitative data interpretation for damage characterization.

**Expected TRL or TRL Range at completion of the Project:** 1 to 6

**Primary Technology Taxonomy:**

- Level 1: TX 08 Sensors and Instruments
- Level 2: TX 08.X Other Sensors and Instruments

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

- Research
- Analysis
- Prototype
- Hardware
- Software

**Desired Deliverables Description:**

Phase I Deliverables: For proposals focusing on NDE sensors: Lab prototype and feasibility study or software package, including applicable data or observation of a measurable phenomenon on which the prototype will be built. For proposals focusing on NDE modeling: Feasibility study, including demonstration simulations and data interpretation algorithms, proving the proposed approach to develop a given product (Technology Readiness Level (TRL) 2 to 4). Inclusion of a proposed approach to develop a given methodology to a TRL of 2 to 4. All Phase I proposals will include minimum of short description for Phase II prototype/software. It will be highly favorable to
include a description of how the Phase II prototype or methodology will be applied to structures.

Phase II Deliverables: Working prototype or software of proposed product, along with full report of development, validation, and test results. Prototype or software of proposed product should be of TRL 5 to 6. Proposal should include plan of how to apply prototype or software on applicable structure or material system. Opportunities and plans should also be identified and summarized for potential commercialization.

State of the Art and Critical Gaps:

NDE tools for flight still do not have sufficient resolution to provide representation on the order of finite-element models (FEMs) allowing for a digital twin. Also, as NDE tools grow and sensors get faster, larger volumes of data are created and thus new computational tools are required. At the same time, low-cost emerging computational hardware, such as GPUs, is enabling the growing use of advanced physics-based models for improved NDE inspection and for advanced data analysis methods such as machine learning. Development of new techniques are enabling Orion to meet its 100% inspected mission directive. In addition, as NASA strives to go deeper and longer, new tools need to be developed in order to support long-duration spaceflight.

Relevance / Science Traceability:

Several missions could benefit from technology developed in the area of NDE. Currently, NASA is returning to manned spaceflight. The Artemis program's Orion spacecraft and Space Launch System have had inspection difficulties, and continued development and implementation of NDE tools will serve to keep our missions flying safely. Currently, Orion is using several techniques and prototypes that have been produced under the NDE SBIR topic. The Space Launch System is NASA’s next heavy-lift system, capable of sending hundreds of metric tons into orbit. Inspection of the various systems is ongoing and will continue to have challenges, such as verification of the friction stir weld on the fuel tanks. As NASA continues to push into deeper space, smart structures that are instrumented with SHM systems can provide real-time mission-critical information on the status of the structure.

References:


Cramer, K. E.; and Klaassen, R.: Developments in Advanced Inspection Methods for Composites Under the NASA


