RXC Structural Materials Open BAA

1. Statement of Objective / Needs:

Air Force Research Laboratory, Materials & Manufacturing Directorate is soliciting white papers and potentially technical and cost proposals under this announcement that support the needs of its Structural Materials and Applications mission. Structural Materials technologies that range from materials and scientific discovery through technology development and transition are of interest. Descriptors of Materials and Manufacturing Directorate technology interests are presented below in two contexts; that of structural materials science and engineering academic "competencies," and that of Air Force application area needs.

In all Directorate research, Integrated Computational Materials Science and Engineering (ICMSE) is used to couple processing, microstructure, and performance via validated computational methods to accelerate materials development, transform the engineering design optimization process, and unify design and manufacturing.

a. Structural Materials Competency Needs:

***<u>Ceramics and Ceramic Matrix Composites Materials and Processes</u>*: ** The objective of Ceramic Materials and Processes research is the development of advanced high-temperature constituents for fiber-reinforced ceramic-matrix composites (CMCs) and an understanding of their behavior in relevant service environments. Specific research that is underway in advanced constituents involves development of next-generation fiber reinforced structural ceramic materials and processing and process models for a range of air and space applications including turbine engine and scramjet engine hot-section components and thermal protection systems for hypersonic vehicles. Topics of interest include, but are not limited to: understanding of CMC behavior in service environments at the constituent level, maturing existing composite classes and their processes and discovering and validating new materials and process concepts, coatings and processes, characterization and property screening against temperature, environment, stress and time variables, and modeling and simulation used to advance ceramic materials technology.

<u>Polymer Matrix Composites Materials and Processes:</u> Polymer Matrix Composite Materials and Processing (PMC M&P) research involves the conceptualization, development, manufacturing and sustainment of polymer matrix composites in propulsion and structural applications for more "reach" from lighter-weight and higher-temperature structural components; more "affordability" from predictive, optimized, and agile processing methods; more "sustainability" from rapid insertion of robust materials with better as-manufactured performance baselines; and more "survivability" from electromagnetic energy and laser threats through multiscale functional materials. Areas of interest include, but are not limited to: the unique competencies of structure-processing-property modeling, high temperature polymer matrix composites, structural hardening, as well as nanomaterials and composites fabrication. Other topics of interest: 1) Development of computational tools to simulate and predict the processing and manufacturing of structural polymer matrix composite materials, 2) Development of new, emerging, disruptive processing methods with improved precision and processing flexibility to reduce the "design/build/test" development cycle, and 3) Development of processing methods for integration of multifunctional materials to expand the design space and meet specific Air Force needs, such as structural directed energy hardening.

Composite Performance Prediction: Due to the complex failure modes of composite materials, the prediction of their behavior in the often poorly characterized extreme environments of high performance systems is extremely challenging. Inherent material capabilities are not fully exploited due to the inability to predict performance of low probability, critical mechanical and environmental loading events. Rationalization of material and design knockdown factors associated with these events through the use of ICMSE modeling capabilities leads to optimized composite designs that fully exploit the material's capabilities. Computational and empirical methods within a digital framework that link characteristic material scale models to experiments for parameterization and validation to specific aspects of composite materials are needed. It is anticipated that research investment in this area will lead to risk reduction in high-temperature composites structures performance and impact emerging Air Force systems. The purpose of this research is to explore and expand frontier methods enhancing the fidelity and the reducing empiricism associated with predicting and representing materials performance.

The scope of the advanced structural airframe materials, process, and lifing tools to support composites certification covers exploratory through developmental research in understanding and prediction of composite behavior in representative Air Force system environments. The development of predictive, physics-based simulation tools for the prediction of damage evolution and behaviors across multiple scales is envisioned as a necessary step towards this goal. Constitutive models and the ability to analyze highly tailored composites at appropriate fidelity are needed.

Metallic Materials and Processes: Advanced propulsion concepts require metallic materials that withstand higher operating temperatures for longer times at higher stresses and in more aggressive environments relative to existing alloys. Further, many of the intended applications involve thin structural gauges and advanced heat-exchanger configurations. Future systems for access to space and hypersonic delivery are calling for the development of advanced metallic thermal protection systems (TPS) and high-temperature airframe structures. The high temperature metals sub-competency focuses on the Air Force's affordable mission & sustainment needs, leading critical-path development efforts needed to achieve "true" retirement for cause in rotating applications.

An essential challenge of alloy and process development is finding the best overall balance of properties using chemistry, thermodynamics, and processing to tailor the microstructure. Moving away from a uniform property set over an entire component and toward utilization of point-specific properties allows tailoring to location requirements. As such, microstructure-sensitive design is one of many topics of interest. Additional topics include, but are not limited to: models for the formation of deformation, recrystallization, and transformation texture during processing of single-and multi-phase alloys, crystal plasticity, finite element methods (FEM), advanced fracture mechanics and crack growth analyses.

Characterization, Sensing, and Analytics: The mission of Characterization, Sensing, and Analytics is to lead, discover, develop, and deliver material and damage characterization technologies that assure maximum reliability, availability and safety of Air Force systems. This includes research and development addressing needs in the areas of nondestructive evaluation/inspection (NDE/I) and characterization of materials of interest to the aircraft structures, turbine engine, and low observables communities within the Air Force. The characterization, sensing, and analytics (CSA) team develops next generation sensing technologies for materials and damage state characterization to enable future sustainment and maintenance strategies such as Condition-based Maintenance plus Prognosis (CBM+). Developments enable validation and augmentation of life prediction for multiple material classes (existing and new structural materials) by characterizing their structure, sensing pre-cursors to damage, and assessing damage evolution. Success and full implementation of these future strategies will only be successful if damage and material state can be quantified.

The objectives of the research efforts in CSA includes using physics-based and numerical models addressing the primary NDE sensing modalities of electromagnetic (e.g. eddy current, THz, microwave), mechanical waves (e.g. modal analysis, ultrasound), and thermal (e.g. thermography), plus innovative coupling of multiple sensing modalities to augment the detection of changing material states. Computational models coupled with estimation theory are being investigated to solve the ill-posed inverse problem to tackle the challenges of a complex and cluttered sensing environment.

Integrated Computational Materials Science and Engineering (ICMSE):
Continued Air Force dominance in aerospace warfare is predicated on the continuous advancement of warfighting platforms and the materials that make them possible. Incorporating new materials or even evolutionary changes in materials into critical, performance-limiting components is a high risk and expensive process. Integrated Computational Materials Science and Engineering is an emerging approach that digitally integrates the results of experiments and modeling methods in order to simultaneously optimize material and component design for optimum performance. The approach significantly reduces the cost and risk of incorporating evolutionary and revolutionary materials advances into propulsion, airframe and conventional structural applications. Advances to the approach require infrastructure improvements that include but are not limited to advancing finite element modeling methods and constitutive descriptions for macroscopic and microscopic deformation (static loading and processing), testing,

modeling includes thermo-mechanical processing, thermo-kinetics, microstructural evolution, casting, elastic-viscoplastic deformation over a wide range of stress, strain rates and temperatures, and multi-scale (space and time) verification, validation and uncertainty quantification of simulated behavior. Methods should also address representation and simulation of microstructure and its evolution, damage accumulation, extreme and anomalous features, and life-time prediction.

b. AIR FORCE Application Needs:

***Propulsion*:** Advanced materials technologies are sought that enable higher operating efficiencies, enhanced performance, increased range, affordable manufacturability, and sustainability. In order to achieve improved efficiency and performance, materials technologies are required to enable higher operating temperatures, resulting in higher thermodynamic efficiency. Additional enhancement in efficiency is achieved through materials solutions that reduce engine weight, without reducing thrust. Activities are therefore sought to develop novel materials technologies with higher temperature capability and/or reduced weight for applications such as ducts, rotors, blades and airfoils, integrated rotating structures, vanes, shrouds, nozzles, and combustor liners. Developmental technologies could target advancements in polymer matrix composites (PMC), metals, ceramic and CMC, and coatings.

Space: Spaceframe concepts demand complex, lightweight, load-bearing three-dimensional structures that can withstand launch loads. Similarly, space vehicle propulsion systems seek to identify component (impellers, cryo-pumps, nozzles, bearings) materials that reduce weight while fully meeting operational needs. Often space structural components do more than carry load and are multifunctional, requiring the optimization and consideration of non-structural properties as part of materials invention and development. Activities to develop novel, lightweight materials and/or manufacturing processes that address such needs are sought.

***Hypersonics and Thermal Protection*:** Existing materials must be evaluated to validate performance in the extreme environment and new materials developed to fill technical gaps. The materials need to be robust, reproducible, and affordable. High temperatures ranging from 1100 degree F to over 2400 degree F, limit the material options that can be considered. The materials and process (M&P) technology options are needed to reduce the risks associated with M&P acquisition decisions for future hypersonic vehicles. Vehicle concepts span the spectrum from expendable to reusable, boost glide to air-breathing propulsion; all placing different demands on the materials selected. All material systems are of interest as well as hybrid concepts. Joining, attachments, integration, insulation and seals are also areas of interest.

Munitions: Advanced munitions require new materials, processes, and performance understanding to support structural design in both the conventional and hypersonic regimes. Structural component performance in the areas of penetrating capability, enhanced fragmentation, weight reduction (cases and control surfaces), and propulsion efficiency drive future munitions capability. Solutions incorporating the following are of interest: novel metals, ceramics, and polymer matrix composite manufacturing process development, hybridization and location specific tailoring of the properties of parts to optimize for function, NDI methods for quality inspection after manufacture, and the development and validation (using novel test techniques) of predictive performance models/simulations for munitions' unique, high strain rate performance environments.

Advanced Material Characterization: The development of novel microstructure and properties characterization tools and research methodologies is necessary to advance the state of the art in materials science. Tools and techniques that support integrated computational materials science and engineering such as automated data acquisition, multiscale structural performance characterization techniques and apparatus, microstructural (chemistry, orientation, shape, residual stress), characterization techniques and apparatus (destructive and nondestructive), remote testing, and data analytics/management are therefore sought. Both research laboratory and/or industrial setting/application environments are of interest.

Sustainment: Emerging technologies and methods to inspect aging and diverse structures are of interest, as well as innovative sensor manipulation methods to place inspection probes on or within aircraft structures to aid inspectors in their inspection task. Tools and techniques that support airframe sustainment such as advanced sensor development, automated data acquisition/processing, inspection reliability, remote sensing/testing, and data analysis/management are of strong interest. Technology development and advancement shall be derived with the Air Force depot and field application environment in mind.

Airframe: Hardened and Multifunctional Structures:

Hardened Structures: Exploration and development of polymer and inpolymer matrix composite materials and processes that meet current and future Air Force system needs is of interest, including Ultra-High Temperature Ceramics (UHTCs). This includes matrix materials, fibers, preforms, and other reinforcement materials, interfaces, processes, and the supporting computational tools. The research would include structure-process-property relationship development, processing science development, concept and feasibility exploratory studies, anticipated weapons material vulnerability assessment, and development of modeling and simulation capability in these areas. Processing science that enables tailoring of extremely dissimilar constituents is critical to development, design and structural integration.

Multifunctional Structures: The Air Force is continuously challenged with developing capabilities to better design, develop, fabricate, characterize, and assess the performance of new and emerging multifunctional materials. Therefore, the development of novel design tools; advanced sensing technologies; advanced data collection, fusion, processing and analysis techniques; advanced evaluation and validation methods; as well as the development of inspection protocols and procedures for these materials require further investment in research and development. Modeling and simulation tools to design, characterize and optimize sensor response to the materials of interest are also highly desirable.

Advanced Electromagnetic and DE Structures: Electromagnetic (EM) protection materials are required for aircraft, spacecraft, ground support systems, and personnel. Threats to systems and personnel include high power microwave (HPM) weapons, various electromagnetic pulse (EMP) sources, lightning strikes, and high voltage electrostatic discharges from space charge build-up (spacecraft).

Lighter weight carbon fiber composites and higher temperature systems such as ceramics require development and system validation of electromagnetic shielding materials for aircraft, spacecraft, or ground support systems that include vehicle structures and electronics enclosures against electromagnetic pulse, nuclear burst products, and high power microwave sources.

Materials enabling passive agile filtering of high power microwave energy directed at antenna apertures are a second area of focus. These materials must enable continuous operation of the underlying sensor or receive/transmit module by only blocking narrow bands associated with high power RF events. The materials should respond intelligently to high RF field strengths and develop surfaces to block out only the undesired RF frequency. In addition, this ability to develop a surface should be over as broad a frequency range as possible, with a narrow notch width. Finally, materials that enable intrinsically high power RF hardened electronics such as conformal antennas are desired.

2. Operations Security (OPSEC) Requirements: All contractors shall follow appropriate OPSEC measures required for this particular contract. This is required in an effort to reduce program vulnerability from successful adversary collection of possible sensitive unclassified and/or proprietary information, and violations of export control requirements. The prime contractor will ensure that all subcontractors, if applicable, conform to these requirements as required by the prime contractor. Guidance can be provided by AFRL/RX Security as needed.

Program Protection Plan (PPP): Any potential critical program information (CPI) generated as part of this effort will be reviewed to determine the need for a PPP.