

Technical Background

Background:

"Defining Resilient and Effective Space Order of Battle and Architectures" is the first of the Air and Space Force's operational imperatives, established by Secretary of the Air Force Frank Kendall. In this context, architectural resilience in the extreme environment of space is achieved through sound systems engineering and enabled by high performance materials. Currently, space platform materials and the engineering principles used to design them are primarily based on the observed performance of existing and legacy systems. This data-based approach leads to an extremely long and costly development cycle for new technology that is not sustainable. The Department of the Air Force (DAF) needs a reliable way to accelerate the development cycle for new space technologies, and to predict their performance in the space environment to achieve resilience of our assets in the contested space domain. The notion of space resiliency and the utility of proliferated satellite systems for communications or other critical DoD functions was highlighted to the world with the use of the Space X Starlink satellite cluster in Ukraine. Starlink operates in Low Earth Orbit (LEO), which is defined as an orbit of less than 128 minutes, with an eccentricity of less than .25, meaning most satellites in this range are below 2,000km in altitude. There are unique challenges in this environment, which combines Atomic Oxygen (AO), ultraviolet radiation (UV), ionizing radiation, ultra-high vacuum, thermal cycling, electrostatic discharge, and even micrometeoroids. These environmental effects, acting alone or in combination, degrade and compromise spacecraft and their operations.

This CoE aims at high-risk, high-reward basic research addressing the hardest challenges in testing and validation; insertion of new materials into space systems designed for LEO. We seek to accelerate material deployment in a cost-effective manner to enable rapid fielding of proliferated satellite systems for DoD and US Space Force requirements. While the theme of developing ground-based testing is necessary to enable space operations in all orbital environments, we constrain the problem to Low-Earth (LEO)—altitudes from 200km to 2000km. This Space Force relevant domain combines multiple effects, such as AO, UV, ionizing radiation, electrostatic discharge, ultra-high vacuum, and thermal cycling. NASA has studied some of these effects in their Long Duration Exposure Facility (LDEF), but this utilized experiments that were on-orbit at the International Space Station. This kind of testing is expensive and cost-prohibitive, especially when trying to develop materials for rapid insertion into new space systems, or to keep cost low to design, build and deploy proliferated space assets in mass. In addition, on-orbit testing delivers combined effects testing (exposure to UV, AO, radiation, thermal cycling, etc...) with no means to decouple the effects and understand which may be dominant, or how multiple effects together could enhance and/or accelerate materials degradation. Ground based testing has serious limits in this regard, as most testing only accounts for one variable at a time and assumes the effects of exposure to multiple environmental effects are additive in nature. Modeling of material response under the influence of multiple space environment factors has indicated the possibility of

complex, non-linear interactions such as the temperature dependence of the deleterious effects of radiation to polymers. Some efforts have been made to combine two-factors, such as exposure to UV and AO simultaneously, but these result in more costly ground-based test systems that are often over-subscribed creating long wait times for experiments. In addition, these systems, such as AFRL's STAR-lab provide some of this capability but represent millions of dollars in investment by large government entities. There is an active need to develop lab-based systems that can simulate space environments with multiple environmental factors to simply accelerate materials development for space. This will increase the number of researchers who can participate in meaningful experiments, teaches a new generation of scientists and engineers in space materials testing, and will provide a real framework to understand how multiple space environmental effects influence material performance on-orbit. Materials development will be accelerated by pre-screening materials so that only the most promising candidates make it into the test waiting list at the more exquisite materials testing facilities.

Through the execution of a research program aimed at the challenges described above, this FOA for a Center of Excellence (COE) will establish a long-lasting, multidisciplinary ecosystem to develop a cadre of new scientists and engineers at the convergence of these fields to accelerate fundamental research in data-driven discovery and design of optimized material systems.

Objectives:

This CoE will provide expertise in critical aspects of a wide-ranging, multi-disciplinary program aimed at developing the methodologies and tools for revolutionary advances in the design loop of future USAF material systems.

1. Space environment science
 - a. Holistic models of the complex environment in LEO
 - b. Laboratory capabilities to replicate or simulate multiple space environmental effects
 - c. Approaches to validate and quantify uncertainty in terrestrial representations of the space environment
2. Measurement science
 - a. In-situ measurement techniques to probe evolution of material properties during exposure to complex combinations of environmental factors.
 - b. Correlation of precision laboratory measurements with on-orbit observables
3. Performance forecasting
 - a. Quantification (through a combination of experiment and validated models) material response to multiple space environment factors
 - b. Methods, to include both physics-based modeling and data-driven analysis (ie, AI/ML), for predicting subsystem performance

The scientific challenges behind these questions are multi-fold and distill into a physics-based forecasting of the performance of materials subject to multiple environmental factors expected in the space environment. The proposed research requires an interdisciplinary workforce that crosses the

boundaries between materials testing, model development, and space systems engineers. Thus, this CoE seeks participation from the space weather community, the experimental test community, the data science community, as well as engineers, and scientists.