1. **Research Title:** Multiscale Simulation Methods for the Design of Performance-Optimized Composite Material Architectures
2. **Individual Sponsor:**

Dr. Michael Keith Ballard, AFRL/RXNP
AFRL/RXNP, Building 655 Room 013
2941 Hobson Way
Wright-Patterson AFB, OH 45433-7750
michael.ballard.28@us.af.mil

3. **Academic Area/Field and Education Level:** Materials Engineering, Mechanical Engineering, Aerospace Engineering, Applied Mathematics, Computer Science or related disciplines (BA/BS, MS or PhD level)

4. **Objectives:** The objective of the research is to develop novel computational approaches that advance one or more of the following:
   - Multiscale techniques to model the progression of damage as it evolves across length scales and propagate uncertainty,
   - Simulation of dry-fiber mechanics during weaving and braiding processes,
   - Robust mesh generation approaches for complex geometries,
   - Numerical methods for efficiently solving nonlinear equations that emerge in damage and multiscale simulations, and/or
   - Sustainable frameworks for development of computational tools for modern and emerging high-performance computing systems.

5. **Description:** The concurrent design of structures and material architectures at multiple intermediate length scales promises transformative capabilities for the future Air Force, ranging from integrated structural antennae to materials capable of sensing damage in real-time to performant joints for vehicles composed of complex components made of dissimilar materials. However, key challenges stand as barriers to this vision.

   Though homogenization methods have long existed to bridge length scales with sufficient separation, methods to efficiently predict the behavior of material structures that defy length scale separations do not exist. Furthermore, damage tends to localize at a small scale and evolve into critical features at larger scales, which remains a seminal challenge for multiscale modeling to capture. Simulations are needed for the most extreme environments, ranging from hypersonic to space, requiring the incorporation of multiple physics at relevant scales. Additionally, multiscale predictions must quantify uncertainty across length scales, but new methods are required beyond the prohibitive Monte Carlo methods used today. Topology optimization algorithms offer a path to superior design, but algorithms must begin to be constrained by the manufacturing process. A key pillar of multiscale methods is varying approximations at each scale to capture pertinent phenomena, but robust methods to adaptively create suitable meshes and finite element approximations in the presence of complex topologies, geometric artifacts from preceding process simulations, and networks of cracks still need advancing. Finally, the high-performance computing hardware on which large-scale simulations rely is evolving rapidly, prompted by the opportunities created by the rise of machine learning, and demands methods to develop future-proof performance portable computational tools for emerging novel processing units. The research project will focus on addressing some of these barriers in collaboration with a team of experts in the fields.

6. **Research Classification/Restrictions:** US Citizenship required.
7. **Eligible Research Institutions:** This is open to all accredited academic institutions.

PA Approval #: AFRL-2024-0911