

Structures

Mississippi State University is investigating key elements in the development of a damage tolerance plan for multifunctional composites that accounts for loss of structural integrity as well as degradations in multifunctionality. While the effect of in-service or discrete source damage on composite structural integrity is relatively well understood, the effect of damage on safety-of-flight aspects of multifunctionality remains to be explored. A crucial consideration is for cases where loss of mission-critical composite functionality occurs while structural integrity is preserved. Such issues must be addressed if the full weight-saving potential of multifunctional structural composites is to be realized.

The Air Force Institute of Technology continues to work on the biological characteristics of a *Manduca sexta* for application to a flapping-wing micro air vehicle. The team has dissected the species and studied the thorax to evaluate the dorsal ventral muscle and determine its lifting power. This tiny creature, appropriately 1.5 g in mass, can produce a lifting power of 73 W/kg. Its thorax/wing structure can be modeled as a mechanical spring system. Loads applied to the thorax by the flight muscles cause compression, which in turn moves the wings through hinges on either side of the thorax.

Carbon nanotube, graphene, oxide nanoparticle, and nanoclay-reinforced polymer nanocomposites research continues at Michigan Technological University (MTU) and MIT, which are collaborating on model-experiment comparison and correlation across length scales for next-generation composites for NASA applications. MIT is working on large-scale bulk structured materials that have nanoscale reinforcement and take advantage of nanoscale physics. MIT and Metis Design (MDC) have collaborated on Air Force and Navy programs to leverage multifunctional nanoengineered laminate properties for ice protection systems and structural health monitoring. Nanomaterials are literally getting bigger as evidenced by the recent MIT-MDC full-scale test of a nanoengineered composite.

Arizona State researchers are synthesizing novel multifunctional core-shell composite particles, composed of a polymeric core and an inorganic shell, which are responsive to environmental damages. The

new matrix system that uses poly (ionic liquids) will replace the traditional epoxy, bringing additional sensing and healing benefits to composite structures under service conditions.

At NASA Glenn, 'smart materials' are being used to achieve performance improvements. Studies have shown that substantial gains in engine noise, fuel efficiency, and emissions can be achieved not just by increasing material properties but also by individually optimizing different components for different portions of a flight's mission cycle. Thus the main structural components could remain as those of today, but could then be used in configurations that take advantage of properties optimized to specific environments. Analytical and experimental methods on piezoelectric blade vibration damping have produced the first successful demonstration of vibration damping on GE's GENx engine composite fan blades. The damping levels achieved lead to reduced dynamic stresses. New compositions have been developed to extend the temperature capability of high-performance piezoelectrics to near 400 C.

The Structures and Materials Division at Glenn has established the NASA Multiscale Analysis Center of Excellence, to develop, integrate, and validate physics-based models and the associated multiscale computational design, analysis, and optimization tools required to make these models accessible to the engineering and materials science communities. Working with industry (GE Aircraft Engines, HyperSizer, Firehole Composites) and academia (University of Michigan, Mississippi State, University of Alabama, Miami University, Clarkson), NASA is developing methods and tools for advanced composites (PMCs, CMCs), high-temperature metallic alloys, and smart (piezoelectric, shape memory alloy) materials that link microstructure-scale mechanisms to structural performance. Projects include modeling of lightning damage on PMCs, deformation and fatigue life prediction for hot engine component CMCs, efficient multiscale microstructural modeling of nickel-based superalloys, and development of nano-informed damage models for polymer matrix materials. **A**

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Anticing was demonstrated on unmanned air system aerosurface. Left: Aerosurface (white) with GFR-modified regions. Right: Delicing during ice tunnel testing. Courtesy: MIT and NDC.