Aerospace Structures Developments in 2007

Harry H. Hilton
University of Illinois at Urbana-Champaign (UIUC)

COMPOSITES

Science, engineering, and manufacturing advances are continuing to drive ‘nanocomposite’ research toward aerospace structural applications. The key idea of leveraging the exceptional mechanical and multifunctional (electrical, thermal conductivities, etc.) properties of nanoscale constituents into larger structures by creating new composites has not changed; what has changed is improvements in understanding and advances in synthesis and fabrication. Still receiving the most attention are carbon-based nanostructures, primarily nanotubes (Carbon NanoTubes, CNTs) and NanoFibers (CNFs). Many groups from across the world are working on modeling and large-scale synthesis of nanostructures, with particular interest in building the nano-scale constituents into existing advanced composite materials to create hybrids. Recent special nanomaterials technical sessions at the annual SDM conference highlight significant progress in realizing the potential of carbon nanostructures in composites, with new techniques for modeling, processing, and assessment of engineering properties being presented. From quantum and molecular simulations, to standard mechanical testing of nano-engineered composite laminates, the community is rapidly progressing towards realizing the benefits of nanotechnology. Recent advances in aligned-CNT thermosetting polymer composites (experimental M.I.T., theoretical M.T.U.) have established an understanding into the effects of long-range order on composite properties.

Tough, lightweight nano-hybrid structures for blast protection is an ongoing activity at the University of Michigan. Researchers have successfully designed and built polymer nanocomposites with remarkable stiffnesses and strengths using
the layer-by-layer (LBL) assembly technique. We have also recently demonstrated the ability to tailor the nanostructure of a polymer/nanoparticle system with LBL assembly to vary the toughness of nanocomposites from brittle elastic through anomalously high toughness. The finite element simulations of the nanocomposite systems allow us to predict the ductile to brittle transition as a function of nanostructural features in this system, providing a set of tools to design and build optimal structures for toughening of polymers.

The Composites Affordability Initiative (CAI) team consisting of the Air Force Research Laboratory, the Office of Naval Research, Bell Helicopter Textron, The Boeing Company, Lockheed Martin and Northrop Grumman has placed in the hands of the DoD supplier base a suite of tools and technologies that enable for the first time, the confident application and certification of bonded structures for primary load bearing applications.

An aggressive approach was taken by the CAI team to develop technologies to mitigate the risk of integrated and bonded primary aircraft structures in order to realize the potential benefits of lighter weight (10-20%), lower acquisition (15-30%) and maintenance costs (up to 75%) for airframe structures. Advanced structural analysis tools, which can more accurately predict the onset of failure as well as failure progression have been developed and transitioned to commercial vendors. These have been used to predict the results of testing including full-scale testing of wing carry through and a wing designed to DoD specifications, where the accuracy was shown to be within 5% of predictions. The adhesively bonded pi-joint design for structures has been shown to be very robust for manufacturing defects, tolerant of damage and provides a dual load-path approach increasing the confidence of satisfactory performance. Process controls have been implemented to improve the reliability of surface preparation, surface evaluation, adhesive mixing and dispensing as well as assembly.

These tools and technologies along with a sound certification plan of analysis supported by test provided DoD and FAA certification authorities with enough confidence that they believe that there are currently no technical barriers to certi-
fy bonded structures. Full-scale testing of integrated and bonded structures were performed to validate their capability for limit loads, ultimate loads, as well as two lifetimes of fatigue/w damage. All of the tools, technologies, methodologies and guidelines are in place to enable revolutionary advances in airframe structures through increased integration and bonding of primary as well as secondary structures.

At the University of Michigan Composite Structures Laboratory, a novel thermodynamically consistent framework for progressive failure analysis of laminated composite structures has been developed and experimentally verified. In particular, fiber direction failure modes have been properly captured along with the matrix dominated failures in a single unified mechanism based formulation which has been implemented through the commercial software ABAQUS.

Under the support of the National Science Foundation, Utah State University (USU) has developed a new framework, namely, variational asymptotic method for unit cell homogenization (VAMUCH), for thermoelastic and diffusive micromechanical modeling VAMUCH not only accurately predicts the effective properties but also the local fields within the microstructures. VAMUCH has been assessed using other well-known micromechanics approaches and its advantages have been clearly demonstrated. USU has also developed a semi-analytical approach to predict the post buckling and mode jumping in buckled composite laminates. The variety of possible modal interactions is expressed in an explicit and concise form by transforming the coupled nonlinear governing equations into a system of nonlinear ordinary differential equations (ODEs). While the FEA may lose its convergence when solution comes close to the secondary bifurcation point, the analytic approach has the capability of exploring deeply into the post-secondary buckling realm and capture the mode jumping phenomenon for various combinations of plate configurations and in-plane boundary conditions. Qualitatively different propagations of buckling pattern are observed before and after mode
jumping. Free vibration along the stable primary postbuckling and the jumped equilibrium paths are also studied.

Researchers at Virginia Tech are developing fiber-reinforced composite material tailoring schemes to mitigate structural performance losses, relative to circular cylindrical structures, of non-circular cylindrical structures. The tailoring scheme is based on continuous angle variations with circumferential location designed so as to off-set effects of radius of curvature varying continuously with circumferential location. Results to date indicate that for an axially loaded cylinder, significant improvements in buckling load can be achieved. The buckling load of the non-circular cylinder is about 40% less than that of the circular cylinder while the buckling load of the tailored one is closer to that of the circular cylinder.

AIR FORCE ACTIVITIES

AFIT is working on the evaluation of the amount of wear created by experimental sleigh movement down a rail at speeds of Mach 10. The AFOSR sponsored research has just begun. AFIT was successful in overcoming the gouging problem for this Air Force facility at Holloman AFB. Work is also beginning in the Micro air vehicle scenario especially in nonliner structural dynamics. A third area of research is for the Structural Center of excellence in conjunction with the University of Illinois. This work is related to the investigation of impact of functionally graded plates. A fourth area of investigation is into the nonlinear damping characteristics of coatings used on a turbine blade.

FAILURE INVESTIGATIONS

The Multidisciplinary Optimization Group at the University of Florida has been exploring how to use more effectively structural element testing. It has been
found that it is safer to apply explicit knockdown factors rather than use worst-case scenarios in structural element testing because it reduces the effect of chance.

UAVs AND MAVs

Research at AFRL is focusing on advanced structures for small/mini/micro UAV’s. As we march along this path from large-scale aircraft albeit manned or unmanned and migrate to small scale vehicle systems the size of birds, we encounter new challenges and complexities associated with such mini micro systems. The demands for multifunctional systems capabilities becomes essential at such small scales thus necessitating that a design for primary function capability will be expected to provide at least one additional function or adapt performance in accordance with changes in the operating environment. Structural materials such as nanostructured composites offer potential new possibilities for enhanced multifunctional and functionally adaptive structures where multifunctionality can be achieved through the interaction of mechanical, electromagnetic, thermal and other field effects. These latter field effects open up new dimensions in multifunctionality not heretofore explored and appear on the cusp of providing new design opportunities for such mini and micro air systems opportunities for such mini and micro air systems.

**Figures**

Figure 1a Aligned carbon nanotube (CNT) and polymer composite compression specimen (courtesy B.L. Wardle, MIT)

Figure 1b Molecular model of hexagonal representative volume elements of an aligned CNT/polyimide composite material (courtesy G.M. Odegard, MTU).

Figure 2a Buckling deformations of a quasi-isotropic circular cylinder

Figure 2b Buckling deformations a non-circular cylinder with the same laminate, circumference, and length
Figure 2c Buckling deformations of a tailored non-circular cylinder (Curtesy M. W. Hyer, VPI)