Introduction

Structural analysis and design, whether static or dynamic, has its three foundations consisting of structural/solid mechanics, computational science and materials. The examples cited here are not intended to be inclusive but rather typical of where the profession stands and where it is heading. Solutions to many of these problems depend on concurrently developing efficient protocols for massively parallel computations.

Aging Aircraft and Structural Survivability

The goal of aging aircraft research studies is to reduce the cost burden of maintaining these aircraft while preserving its operational performance qualities and extend vehicle lifetime beyond its original design expectations. Concepts relating to nondestructive evaluation and the prediction and management of future occurrences of corrosion, stress corrosion cracking, widespread fatigue cracking, corrosion/fatigue, parts obsolescence, etc. are under active investigation at a large number of sites. Additional concerns include the ability to estimate the costs for future modifications, the economic impact of future mission changes (aeromedical evacuation, increased cargo, etc.) and the economic impact of maintaining aging USAF and commercial fleets.

Separate investigations by personnel at various jet engine manufacturers, Wright Patterson AFB and the National Center for Supercomputing Applications (NCSA) at the University of Illinois deal with flight vehicle structural survivability due to foreign object impact and time dependent failures due to creep.

GE Aircraft Engines is joining with the airframe community in an Air Force led program to assess the capability of designing, analyzing and manufacturing large composite fan cases for turbofan engines. Such engine fan cases must withstand high kinetic energy impacts and vibratory loads due to engine rotor imbalance.

NASA Langley Research Center tested material systems for the Hyper-X Mach 10 vehicle nose leading edge. Hf-based and Zr-based coatings on K321 5:1 C/C were evaluated in the arc-jet environment. Several leading-edge test articles survived multiple tests, providing the Hyper-X program with options for a passive leading edge meeting the 130 sec., single use, ~4000°F flight requirement.
Composite Structures

New manufacturing techniques at the Boeing Co. under a NASA Langley contract of stitched/resin film infused composite wing boxes has been validated by successful full scale experiments (Fig. 1) indicating failure at 97% of the design ultimate load requirement. Failure of the wing box initiated in the lower (tension) cover panel at an elliptical access door opening. Failure propagated across the lower cover into both spars and the upper (compression) cover panel.

Based on manufacturing of replicate cover panels and fabrication and assembly of the 42-ft-long S/RFI wing box, a projected cost reduction of 20-percent and a weight saving of 25-percent compared to today’s aluminum aircraft wing structures are envisioned. This technology has the potential to leapfrog state-of-the-art laminated prepreg tape fabrication technology currently used on the Boeing 777 composite empennage and on AirBus Industries aircraft.

At Arizona State University, research on smart structures and integrated systems is being performed, including vibration control and structural health monitoring. A coupled piezoelectric-mechanical-thermal theory that includes nonlinear piezoelectric effects has been developed. A general framework has also been formulated by integrating accurate analysis procedures and a multiobjective hybrid optimization technique for structural design. Results indicate the importance of incorporating both structural and control objectives simultaneously rather than sequentially.

A new form of carbon fiber based prepreg patented by Brigham Young University is being developed by Patterned Fiber Composites, Inc. with support from AFRL. This new material uses wavy fiber patterns to produce high levels of damping in composite structures while maintaining the stiffness, strength, and lightweight advantages of composites. Highly damped structures are achieved through the use of two (or more) opposing patterned composite face sheets causing high shear forces in the viscoelastic layer, which dissipates energy in the structure. The advantages of this new material in the construction of space based structures has been shown.

The University of Michigan, funded by AFOSR, has developed a robust well-tested non-empirical procedure to establish compressive strengths of multidirectional polymer matrix laminates.

Smart and Damping Materials, Structural Health Monitoring and Control

NCSA and AFRL are cooperating in analytical research to reduce probabilities of failure and extend lifetimes of viscoelastic flight structures through control by linear and nonlinear piezoelectric viscoelastic devices. Problems that have been considered are delamination, buckling of columns and plates, torsional divergence, flutter and control surface effectiveness and it was shown that the desired effects can be achieved in all cases.
Over past several years, a major emphasis of ARO’s Structures and Dynamics Program has been on the theoretical, computational, and experimental analysis of smart structures and structural dynamics, damping, active control, and health monitoring as applied to rotorcraft, electromagnetic antenna structures, missiles, land vehicles, and weapon systems. A number of research projects are currently active under the sponsorship of this program that incorporate the concepts of smart materials and structural damping.

Stanford University is pursuing research efforts to develop integrated composite structures with a built-in self-diagnosis system for monitoring the health condition of a variety of structures in service. The approach used includes hardware development with distributed piezoelectric sensors and actuators, and software development of intelligent diagnostic. At Arizona State University a new theory has developed for composite box beams of arbitrary wall thickness to model the principal load carrying member in a helicopter rotor blade.

At Pennsylvania State University an integrated approach is being developed which relates to active-passive hybrid smart structures for dual-functional multidirectional vibration controls. The main advantage of these types of structures is that they generally require less power than the purely active systems. University of Michigan researchers have been collaborating with Auburn to develop a balanced active rotor blade flap system using piezo-ceramic C-block actuators, which would be insensitive to gust loads and will experience no performance degradation with increasing rotor speed. At the University of Washington, two types of innovative surface damping treatments are being developed which can potentially increase the capacity of existing systems by a factor of 5 to 10. Specifically, these are the collapsed-bubble and active-standoff constrained layer treatments.

Ohio State University is concentrating on the design, modeling, and testing of adaptive materials based smart antenna structures and electromagnetic devices. A major objective of this research program is to develop conformal multi-functional smart electromagnetic antennas that have the ability to replace several antennas either on aircraft or satellites.

The University of Nevada at Reno is developing a novel magneto-rheological (MR) fluid shock absorber that could be integrated in the suspension system of an off-highway, high-payload vehicle. This controllable shock absorber reduces the mechanical complexity encountered in currently used servo-hydraulic shock absorbers since components such as reservoirs, heat exchangers, pumps, and external systems are not required when using the MR fluid technology.

In a collaborative research project, North Carolina A & T University, the University of Missouri (Columbia) and Virginia Polytechnic Institute & State University are investigating a novel structural damping technique using PZT patches as actuators/sensors and the internal resonance and saturation phenomena to suppress transient and steady-state vibrations of flexible isotropic and composite structures. This technique exploits modal interactions and saturation phenomenon arising from internal resonance to transfer energy from a vibrating structure to one or more electronic circuits.
In the non-linear modeling of repolarizing piezoelectric composites, MIT has developed efficient computational methods (finite element techniques) for complex electro-mechanical systems. This approach has included linear piezoelectric materials, non-linear electrostrictive materials, non-linear behavior and repolarization of piezoelectric materials, and antiferroelectric-ferroelectric phase transitions of shape memory ceramics. Reduction in acoustic radiation has been successfully demonstrated with the use of a panel incorporating accelerometers and piezoceramic fiber composites.

Although significant progress has already been made in multi-disciplinary areas of active materials, composite structures and control, a number of challenges still remain to be met. These include information and communication coordination and control of embedded devices, structural identification and optimization, developing a thorough understanding of and designing active micro- and nano-scale active sensors and actuators, biologically inspired devices, distributed transducers, active materials for high authority actuators, evolving knowledge-based systems for design, optimizing sensor/actuator performance, integrating concurrent design and control tools to include active materials in adaptive structures and for devising accurate constitutive models.

Visit the STRC web page [http://jafar.ncsa.uiuc.edu/aiaa/](http://jafar.ncsa.uiuc.edu/aiaa/)

Fig. 1 Full scale load test of Advanced Subsonic Technology Composite Wing

Fig. 2 Viscoelastic layer shown between two layers of wavy composite (exploded view).
Figure 2: Viscoelastic layer shown between two layers of wavy composite (exploded view).