DESIGN OF COMPOSITE STRUCTURES:
DAMAGE/FAILURE MODES AND DEVELOPMENT OF
TESTING STANDARDS

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• Composite design: Design of a composite airframe for aircraft
• Crashworthiness of composites, High velocity impact

• State of design - Optimisation process

• Testing for Design/Simulation - input properties

• Damage mechanics: Calibration of input properties, validation of simulation tools

• Testing Design - Certification process

• Rate effects (High strain rates)

• Looking forward: Composites - Material or Material system?

• Testing standards
Bird strike on an aircraft leading edge (High velocity impact)

Issues for composites:
Energy absorption
Rate effects, adiabatic issues
Failure mechanisms- all leading to failures/erosion of elements in simulations
Standards for CDM- Continuum Damage Mechanics
Typically:
• fiber rupture in tension
• fiber buckling and kinking in compression
• matrix cracking under transverse tension and shearing and
• matrix crushing under transverse compression and shearing
• delamination

E.g., In Abaqus the onset of damage is determined by the initiation criteria proposed by Hashin and Rotem (1973)

Damage initiation
• Maximum strain
• Maximum stress
• Puck
• Hashin
• LaRc03
• LaRc04

Use of fracture toughness as a criteria for damage mechanics
• Going Beyond First-Ply-Failure (FPF) : Evaluate the load redistribution in a composite structure as the plies fail progressively
• Simulate delamination growth from initial flaw
• The concepts of damage tolerance and fail safe systems
• Study crack propagation to design for fail-safe structures
• Buckling
• — Standard tests are used to obtain these values.
High strain rates

Quasi static-low velocity impact-crash-bird strike-projectile impact

Complex physics: Adiabatic ?, Rheological ?, Fluid behaviour ? etc
Can composites be regarded as a material or is it actually a system?

With embedded sensors and ability for actuation, will its regulatory compliance philosophy change?

Would the certification of advanced composites of the future be through a “systems” worldview?

What are the kind of processes that can be envisaged when a change over from a material+structure approach to a functional system occurs?
The FAA Fail-Safe Design Concept

The fail-safe design concept considers the effects of failures and combinations of failures in defining a safe design.

a. The following basic objectives pertaining to failures apply:
   (1) In any system or subsystem, the failure of any single element, component, or connection during any one flight (brake release through ground deceleration to stop) should be assumed, regardless of its probability. Such single failures should not prevent continued safe flight and landing, or significantly reduce the capability of the airplane or the ability of the crew to cope with the resulting failure conditions.
   (2) Subsequent failures during the same flight, whether detected or latent, and combinations thereof, should also be assumed, unless their joint probability with the first failure is shown to be extremely improbable.

b. The fail-safe design concept uses the following design principles or techniques in order to insure a safe design. A combination of two or more is usually needed to provide a fail-safe design; i.e. to ensure that major failure conditions are improbable and that catastrophic failure conditions are extremely improbable.

   (1) Designed Integrity and Quality
   (2) Redundancy or Backup Systems
   (3) Isolation of Systems, Components, and Elements
   (4) Proven Reliability
   (5) Failure Warning and Indication
   (6) Flightcrew Procedures
   (7) Checkability
   (8) Designed Failure Effect Limits
   (9) Designed Failure Path
   (10) Margins/Factors of Safety
   (11) Error-Tolerance
Future of composites

Present approach:
Composites can be modelled using continuum theories

Buildup of laminates handled based on integration through thickness

Micro mechanics behaviour broadly integrated through averaging of multi-scale behaviour

Compliance for safety: Purely viewed as a structure, with static, dynamic and fatigue issues designed for using the damage tolerance approach

With new generation requirements, composite structures will require to be studied using a systems approach

Multi functional
Multi material
Nano infusions
Self monitoring and healing
Moving and actuating surfaces- Adapting to predetermined positions
Energy harvesting

All these are now systems, rather than just materials or structures alone
<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Test</th>
<th>Standard</th>
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<tr>
<td>1</td>
<td>Tensile</td>
<td>ASTM D3039</td>
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<tr>
<td>2</td>
<td>Open hole tensile</td>
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<td>Filed hole tensile</td>
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<td>4</td>
<td>Lap shear</td>
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<td>5</td>
<td>Flat wise tensile</td>
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<td>6</td>
<td>Bolt pull through</td>
<td>ASTM D7332</td>
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<td>7</td>
<td>Bearing (Single shear and double shear)</td>
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<td>8</td>
<td>In-plane shear</td>
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<td>9</td>
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<td>Inter laminar shear strength</td>
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<td>16</td>
<td>Flexure</td>
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<td>Double cantilever beam (Mode-1 fracture toughness test)</td>
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<td>End notched flexure (ENF) (Mode-2 fracture toughness test)</td>
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<td>Mixed mode bending test (for mixed mode fracture toughness)</td>
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<td>20</td>
<td>Compression after Impact (CAI)</td>
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Milk production at a dairy farm was low so the farmer wrote to the local university, asking help from academia. A multidisciplinary team of professors was assembled, headed by a theoretical physicist, and two weeks of intensive on-site investigation took place. The scholars then returned to the university, notebooks crammed with data, where the task of writing the report was left to the team leader. Shortly thereafter the farmer received the write-up, and opened it to read on the first line: "Consider a spherical cow in vacuum. . . ."[1]
Looking forward

Composites:

• Standards for failure models

• Fail safe/Damage tolerance concepts from a systems viewpoint

• Use of appropriate testing techniques-viability from cost perspectives-ROI

• Robust input to simulations to produce more optimum designs and better
  • predictive power in terms failures- leading to better inspection and maintenance
  philosophies

• Multi-physics optimisations now possible- extensive use to be a game changer

• Directionality ????