Composites in rotorcraft Industry & Damage Tolerance Requirements

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Objectives

• Historical background of composites in rotorcraft industry
• Positive attributes of composites in rotorcraft industry
• FAA efforts to address rotorcraft Industry
• Fixed Wing vs. Rotary Wing
• Typical failure modes in composites
• Certification Requirements and Approach
• Typical Repairs
Back Ground

- Historically, helicopter rotor system components have been designed and qualified using safe-life approach.
- Fiber reinforced composites have been used successfully in helicopter industry for more than 25 years in critical structure such as main and tail rotor blades and hubs.
- Composite components in most of the rotor system operate in a tension dominated strain field and exhibit benign and non catastrophic failure modes, primarily resin dominated delaminations or skin cracking which is non structural in most cases and easily reparable.
- Most of the failure modes are an economic issue rather than a safety issue.
- Since 1989 amendment 28 to 29.571 requires damage tolerance (DT) substantiation has become a requirement and all composite rotor system components designed since that time have to meet the DT requirements.
Fixed Wing vs. Rotary wing

- In Airplanes significant Fatigue loading occurs from Takeoff back to Landing with few smaller loading cycles in flight.
- Practically significant fatigue loading occurs during every rotor revolution in Helicopter Rotors and some areas of airframe structure.
- Typical Number of fatigue cycles in a life time for Airplane are usually 200,000, whereas on rotors can accumulate 200,000 cycles in less than 10 hours.
- Most of the rotor components operate in tension dominated field due to Centrifugal Force whereas typical Wing sees both tension and compression.
- A delamination type or fiber buckling type of failure mode in compression can result in a catastrophic failure of the wing.
Fixed Wing vs. Rotary wing

Typical loading on Helicopter Blade
Safe- Life Methodology

- Historically, helicopter components have been designed and certified using safe life approach (fatigue)- does not account for failures due to presence of defects.
- Since 1990’s certifying agencies are also requiring damage tolerance in addition to safe life to improve safety
- Fatigue test 4-6 Full scale components of each critical assembly to define the fatigue strength curve (20 to 40 components)
- Measure flight loads/stresses in these critical parts (100 to 400 gages).
- Measure loads for 100 to 200 flight conditions, 6-12 gross weight , c.g and 3 to 4 altitudes (1800 to 9600 flight conditions)
- Determine Fatigue life using strength curve, flight loads and expected severe operational usage of the aircraft
SAFE- LIFE METHODOLOGY

Flight Load Survey
GW
CG

Components / Assemblies
Fatigue Testing
Load
Cycles

Usage Spectrum:
% of Flying Time
- Flight conditions
- Gross weight / center of gravity
- Altitude

Load Spectrum
Evaluation
- Miner Rule
Fatigue Life
FAA Composite Rotorcraft Fatigue and D.T. Efforts

• Lack of uniform requirements for certification of composites resulted in ARAC activity (2000 thru 2002) for a new rule and advisory material for part 27 and 29 rotorcraft certification requirements
  – Team of technical specialists from industry and regulatory agencies from Europe and U.S.A worked to formulate new rule and advisory material for composite structures certification
  – Rule and AC material were developed based on the insights derived from the previous twenty years of use of composites in the rotorcraft industry
  – Harmonized the requirements considering various certifying agencies
  – Developed several acceptable means of compliance
  – Considered a range of dynamic and airframe components
FAA Composite Rotorcraft Fatigue and D.T. Efforts

- Significant areas of emphasis of AC
  - Manufacturing processes and acceptance criteria
  - Environmental Effects
  - Static Strength requirement (effect of repeated loads on static strength)
  - Building Block Test approach for certification
  - Fatigue and Damage Tolerance evaluation
    - Characterize the sensitivity of damage level on fatigue and static behavior of the structure
    - Threat assessment
    - Various compliance approaches
  - Special Repairs and Continued airworthiness requirements
Damage Tolerance Requirements

• Demonstrate Static Strength
• Demonstrate durability of the structure considering acceptable manufacturing defects and expected in-service damage (un repaired) for the required life.
• Demonstrate Damage Tolerance of the structure for clearly detectable damage or at maximum cutoff energy level whichever occurs first and establish appropriate inspections and repairs
• Demonstrate safe continuance of flight after discrete source damage such as bird strike or uncontained high energy impact
• Characterize the sensitivity of damage level on fatigue and static behavior of the structure
Damage Tolerance Requirements

- **Static Strength Demonstration** should consider the following:
  - Acceptable manufacturing defects (acceptance criteria)
  - Expected in-service damage (un-repaired) limited by threat, detectability or a maximum cut-off energy whichever occurs first (Comprehensive Threat analysis is required to establish threat levels)
  - Manufacturing and Process variability
  - Effects of environment on static strength
  - Effects of repeated loading on static strength
Damage Tolerance Requirements

• **Durability Demonstration** should consider following
  – Acceptable manufacturing defects (acceptance criteria)
  – Expected in-service damage (un repaired) limited by threat, detectability or a maximum cut-off energy (Comprehensive Threat analysis is required to establish threat levels) whichever occurs first
  – Manufacturing and Process variability
  – Effects of environment on fatigue
  – Effects of scatter on durability life

• **Demonstrate ultimate load capability after the repeated load tests**
Damage Tolerance Requirements

- **Damage Tolerance Demonstration should consider following**
  - Acceptable manufacturing defects (acceptance criteria)
  - Expected in-service damage (un repaired) limited by threat, detectability or a maximum cut-off energy (Comprehensive Threat analysis is required to establish threat levels) whichever occurs first
  - Manufacturing and Process variability
  - Effects of environment on fatigue
  - Effects of scatter on durability life
  - Clearly detectable damage or at maximum cut-off energy level whichever occurs first and establish appropriate inspections and repairs or retirement life

- **Demonstrate required residual strength** (minimum of limit load)
Damage Tolerance Requirements

• Demonstrate safe continuance of flight after discrete source damage such as bird strike or uncontained high energy impact
  – All the factors considered for damage tolerance demonstration
  – Discrete source damage

• Demonstrate static residual strength required for the expected flight envelop after discrete source damage
Certification Approach

- Review existing data base to define critical parameters that effect the static and fatigue behavior of similar composite structure
- Define the test program appropriate to the design and manufacturing features of the structure
- Building Block Approach to certification is desirable to avoid costly design errors
  - Material Characterization
  - Coupon Tests(Point Design Tests) –Laminate Configurations
  - Element Tests- Design Details
  - Sub component Tests
  - Component (Full Scale) tests
Figure A. Schematic diagram of building block tests.
Certification Approach

• Material Characterization
• Purpose
  – A & B Basis allowable strength values using small coupons
  – Should consider effects of moisture and temperature
  – Establish Glass transition temperature
  – Establish basic design values considering batch variations
Certification Approach

• **Coupon Tests (Point Design Coupons)**
  Laminate configurations

• **Purpose**
  – To develop design allowables for various laminate configurations used in the structure
  – To quantify effects of temperature, moisture and repeated loads
  – Types of coupons: No Hole, Open Hole, an Filled Hole, Load Transfer etc.
  – Types of Tests: Static, Fatigue at various ‘R’ Ratios, Static after Fatigue, Spectrum Fatigue Tests
Certification Approach

• Element Tests
• Purpose

  – To quantify effects of temperature, moisture and repeated loads
  – To determine durability, damage tolerance and static strength behavior of structural details (Sensitivity to damage level and sensitivity to spectrum elevation (load))
  – Types of Tests: Static, Spectrum Fatigue Tests at various elevations (sensitivity to spectrum) and various damage levels, Static after Spectrum Fatigue
Certification Approach

- Sub component Tests
- Purpose
  - Validate the design details for static and fatigue under complex loading
  - Evaluate sensitivity to damage (manufacturing and in-service)
- Examples of sub component
  - A simulated blade section or scaled yoke flexure
  - A simulated Wing Torque box
  - Should simulate manufacturing and inspection processes
- Loading
  - Simulate complex loading such as beam, chord, torsion and CF (if applicable) to subject the structure to representative strains in all directions
Certification Approach

• **Component (Full Scale) tests**

• **Static Test**
  – Demonstrate Static strength with acceptable manufacturing flaws, expected in-service damage (un repaired) accounting for environment

• **Durability and Damage Tolerance Test**
  – Durability test for required life with acceptable manufacturing and expected in-service damage limited by threat, detectability or cut-off energy level whichever occurs first
  – Ultimate load tests
  – Damage Tolerance Test: Apply clearly detectable damage or cutoff energy level damage, apply anticipated repairs at appropriate locations, develop inspection intervals, procedures and validate repairs
  – Residual Strength Test
  – Damage tolerance test for safe continuance of flight after discrete source damage
Rotorcraft Industry experience with composite structures

- Rotorcraft industry has excellent experience for past 25 plus years with composite structures in rotors (Bell, Eurocopter, Agusta, Sykorsky)
- All most all manufacturers are going with composite blades in the new designs, most of them also with composite hubs
- Primarily operate in tension-dominated strain field
- Benign failure modes: primarily skin cracking or delaminations (ILS failures)
- Failures are easily detectable and donot degrade the performance of helicopter significantly and does not result in catastrophic failures
TYPICAL BLADE CROSS SECTION

- Titanium leading edge
- Spar tubes
- Nomex honeycomb core
- Fiberglass skins
- Spar cap
- Trailing edge strip
- Noseblock
Damage Tolerance Test of a blade
Typical Yoke Failure
Typical Yoke Failure
Typical Repairs

- Matching Skin Patching on Rotor blades
- Core Replacement
- Trailing Edge Splicing
- Replacement of Abrasion Strip of the blade
- Bushing Replacements at Blade Attach
- Surface Ply removal and replacement on Yokes
- Buffer Pad replacement on blades and yokes at attachment areas

- All non standard repairs have to be approved by DER (FAA approval required)
Conclusions

• Composites have been used extensively in the Rotorcraft Industry since 1970’s very successfully
• Eliminated all catastrophic failures associated with metallic hub and blades
• All most all failure modes associated with hubs and blades are benign and non-catastrophic and do not degrade performance significantly
• All New designs at Bell have composite Hubs and Blades
• Bell never had an serious incident related to composite yoke or blade
• Significant advantage of composite in rotors is, primarily they operate in tension strain/stress field
References

- Ugo Mariani, Luigi Candiani, “AGUSTA Experience on Damage Tolerance evaluation of Helicopter Components”, presented at RTO Specialists meeting, Corfu, Greece, 21-22 April, 1999