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

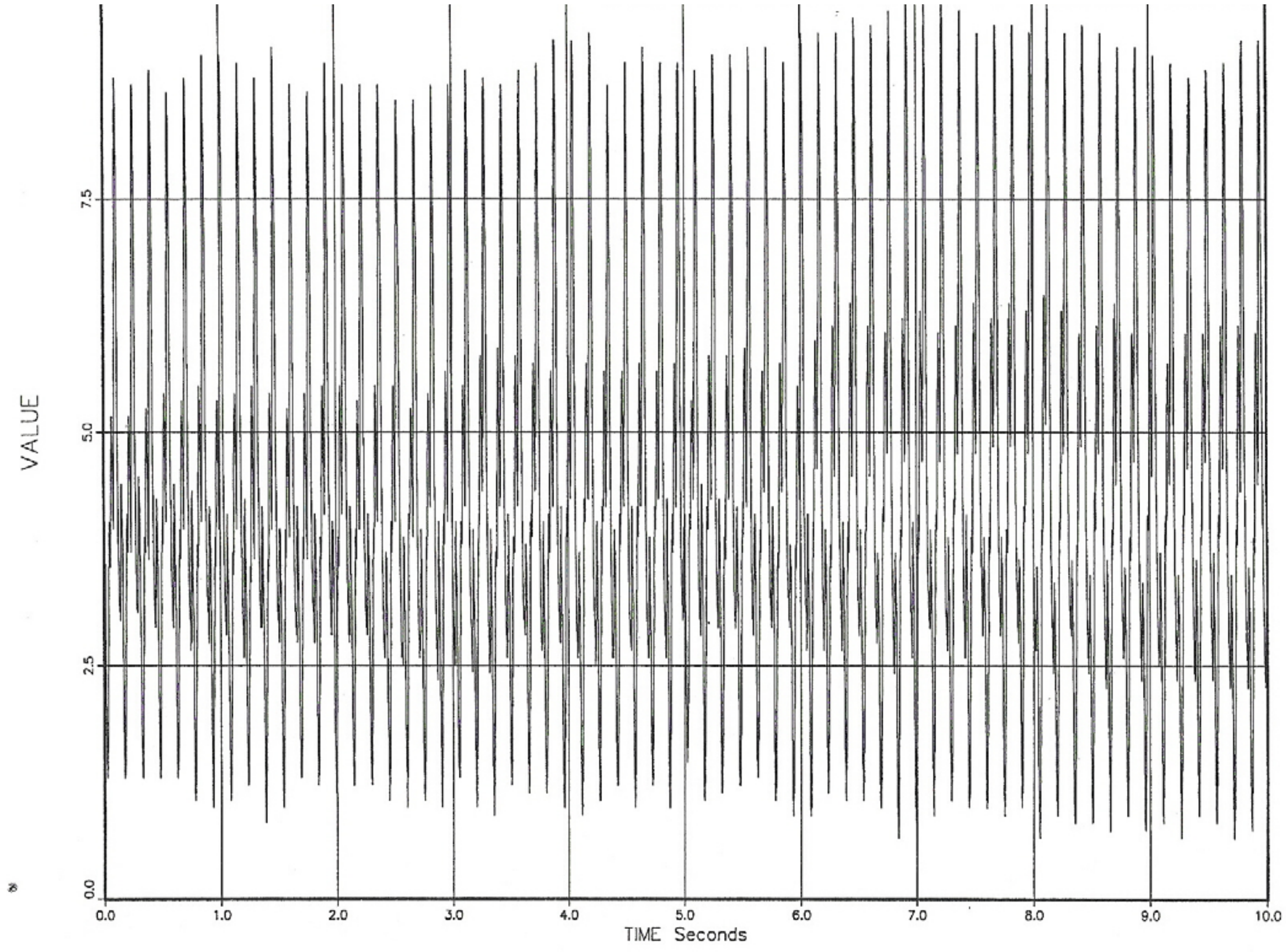
- Historically, helicopter rotor system components have been designed and qualified using safe-life approach
- Fiber reinforced composites have been used successfully in helicopter industry for more than 25 years in critical structure such as main and tail rotor blades and hubs
- Composite components 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 29.571requires 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, where as 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 where as 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

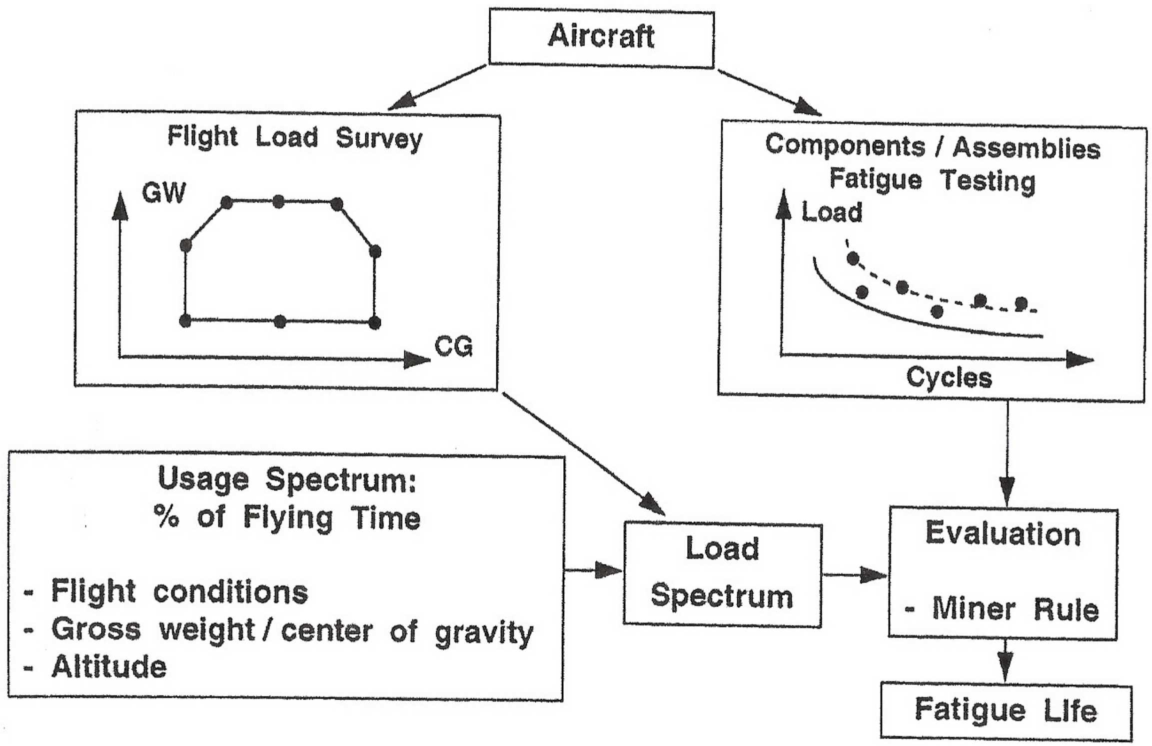
Typical loading on Helicopter Blade



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



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 requirments

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 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

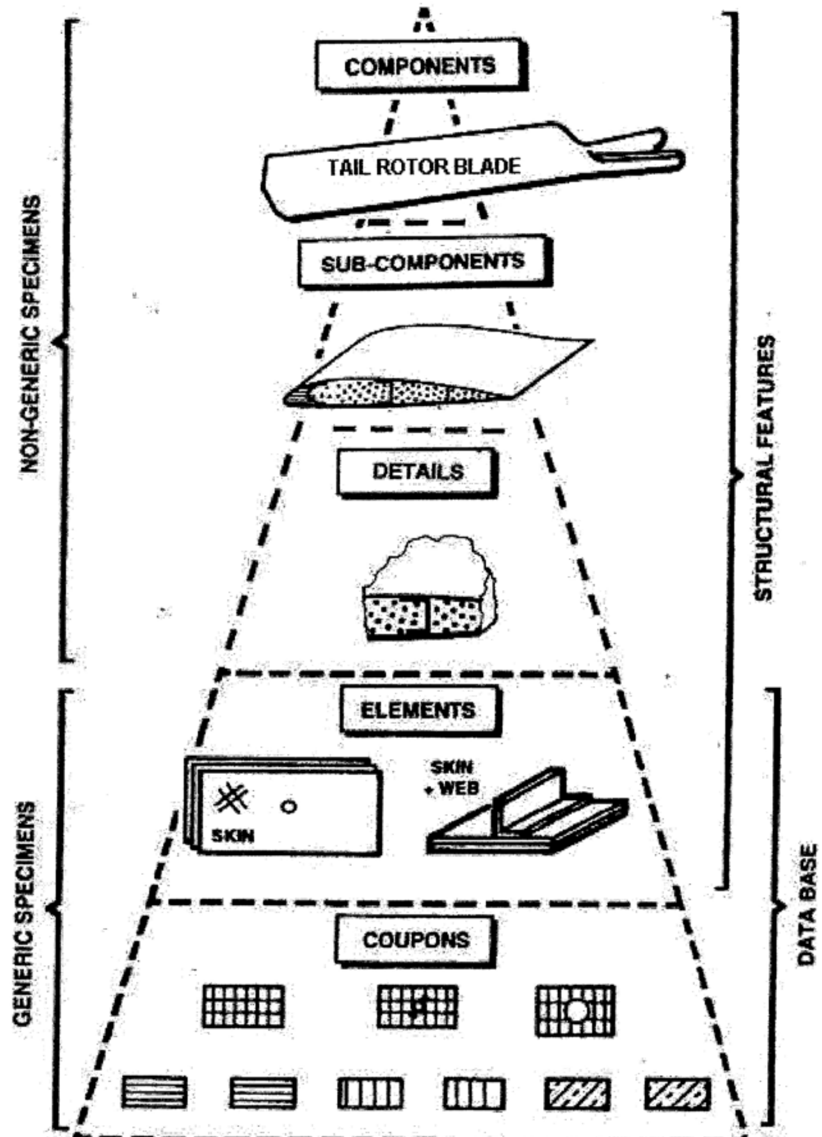


Figure A. Schematic diagram of building block tests.

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

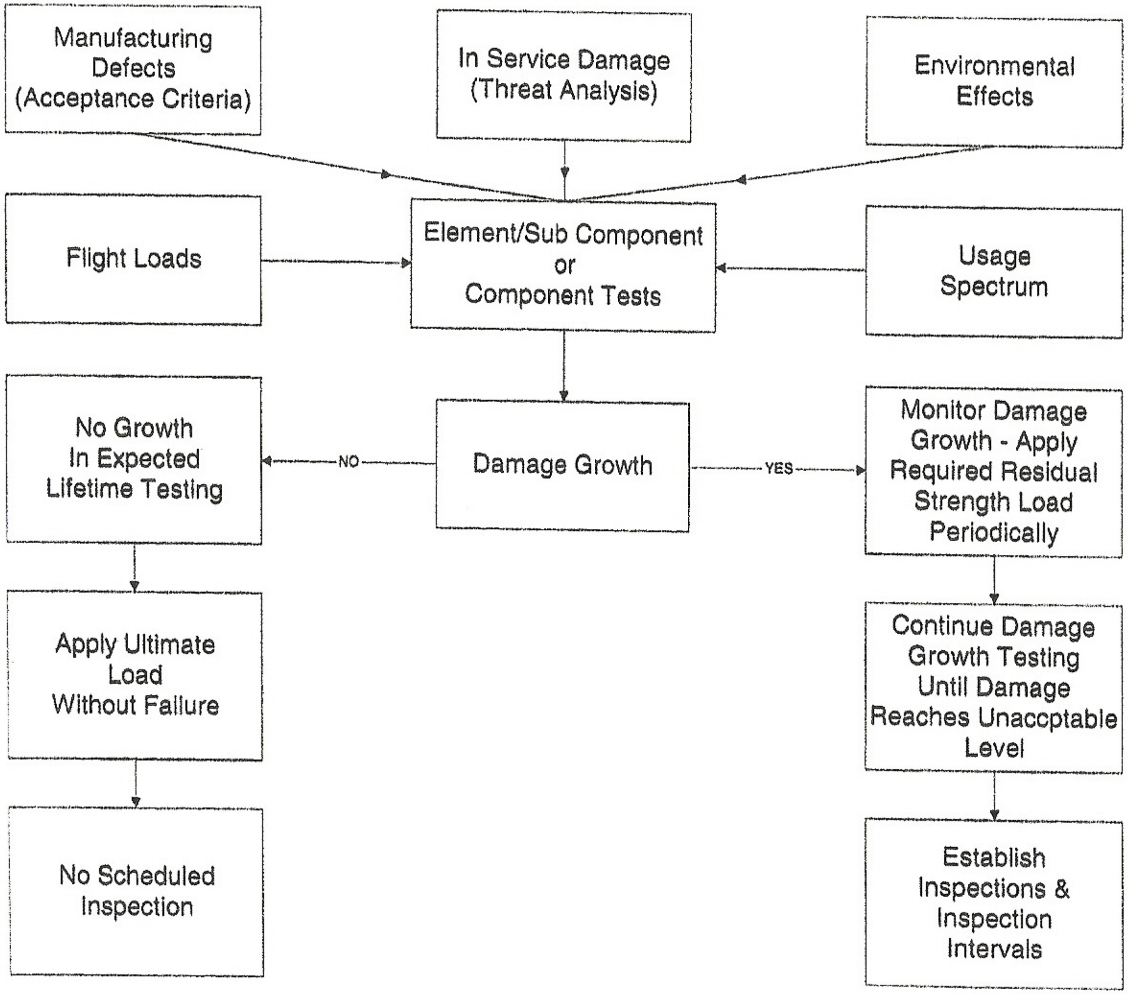
Certification Approach

- 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

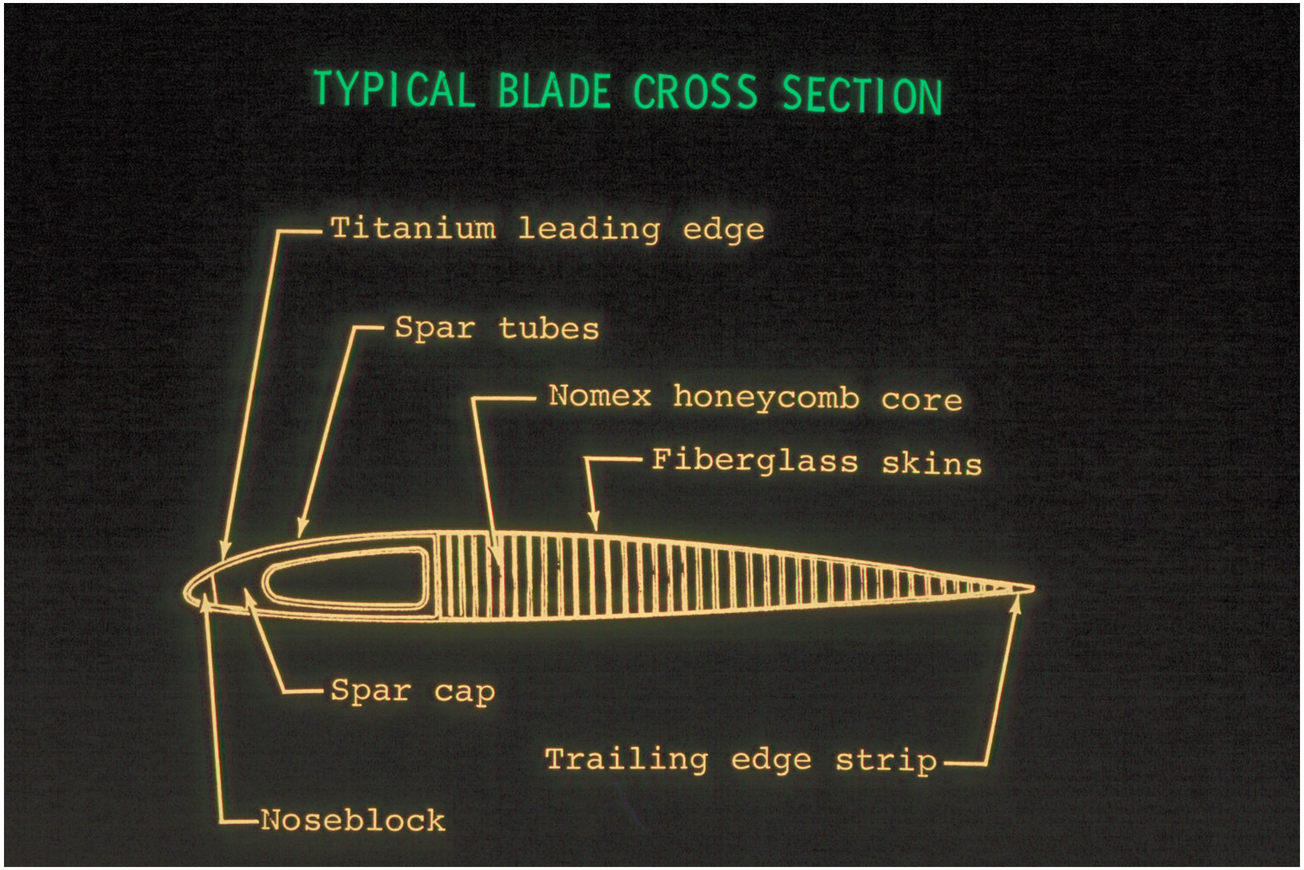
Certification Approach



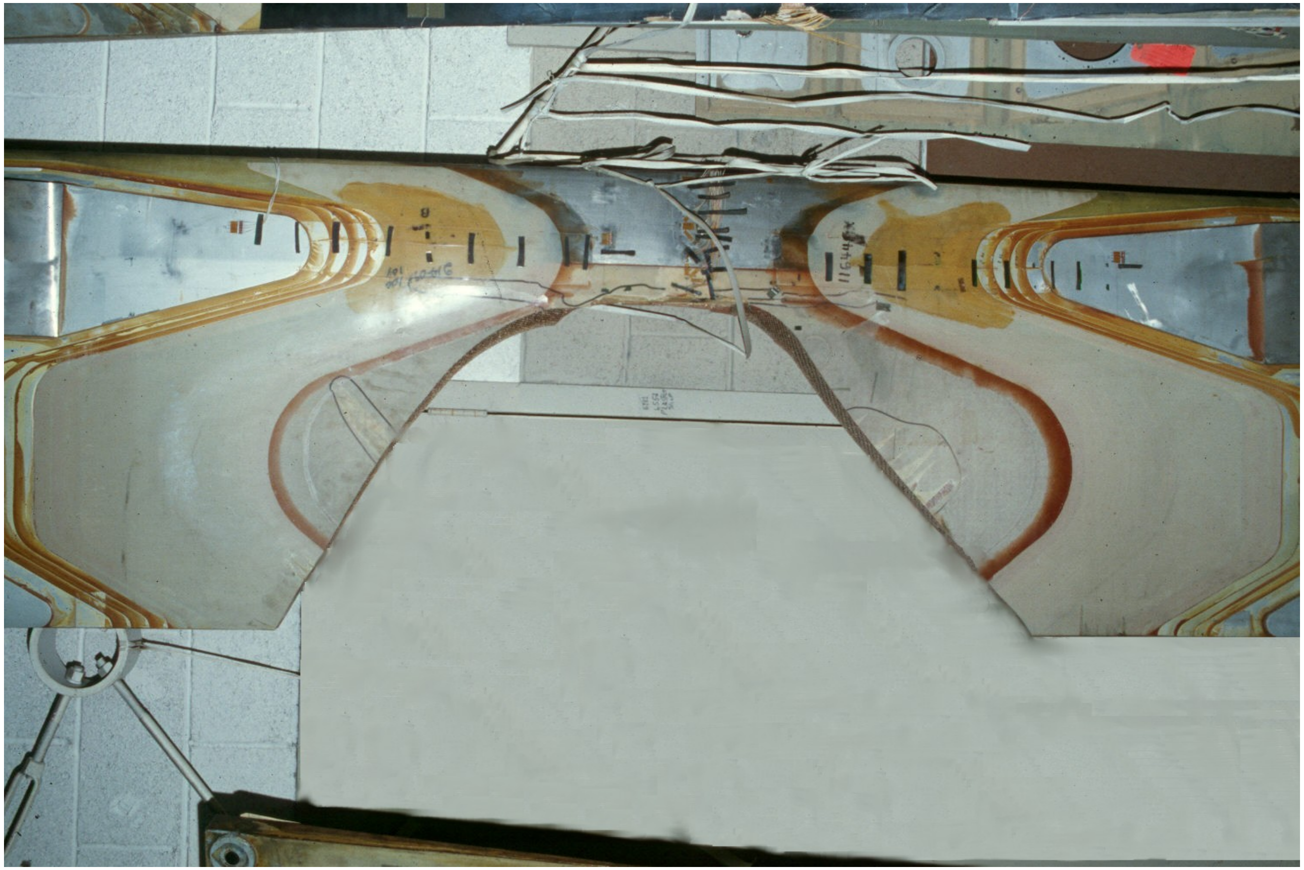
Rotorcraft Industry experience with composite structures

- **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**

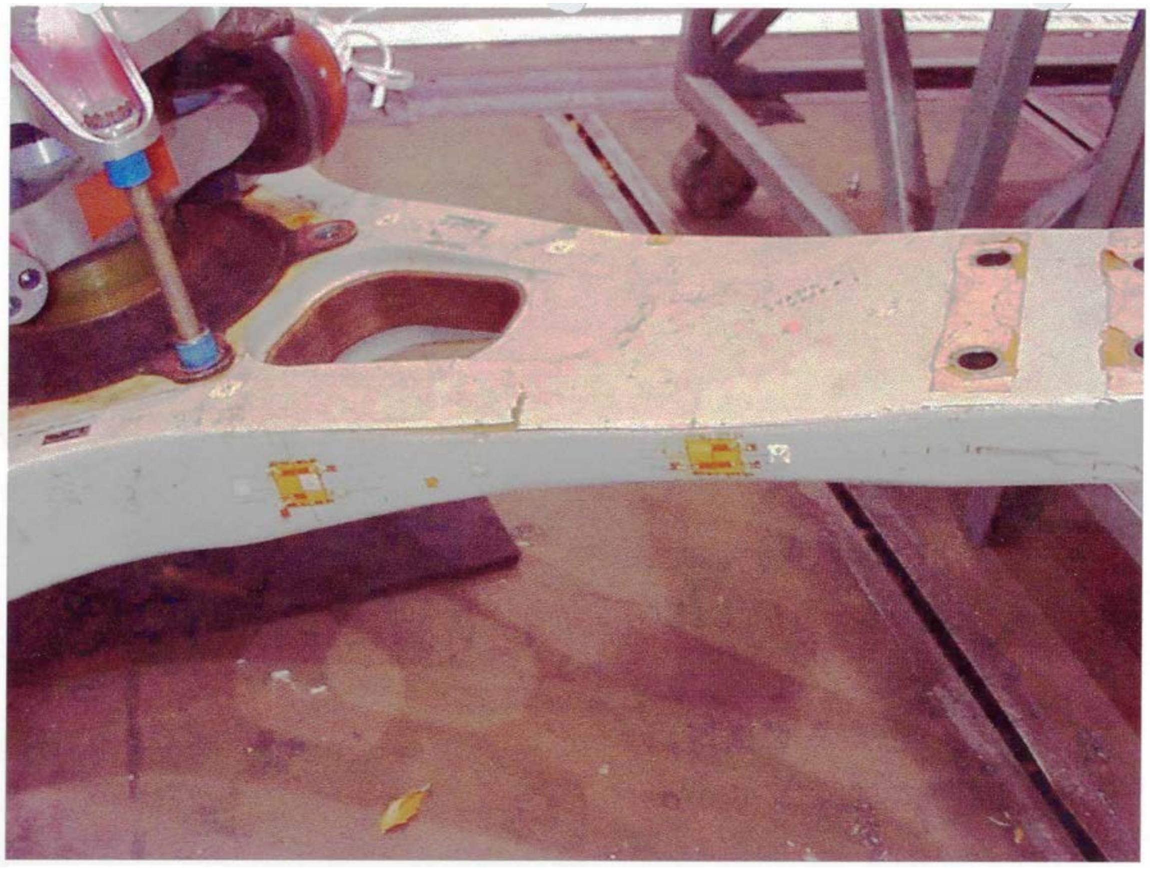
TYPICAL
BLADE CROSS SECTION



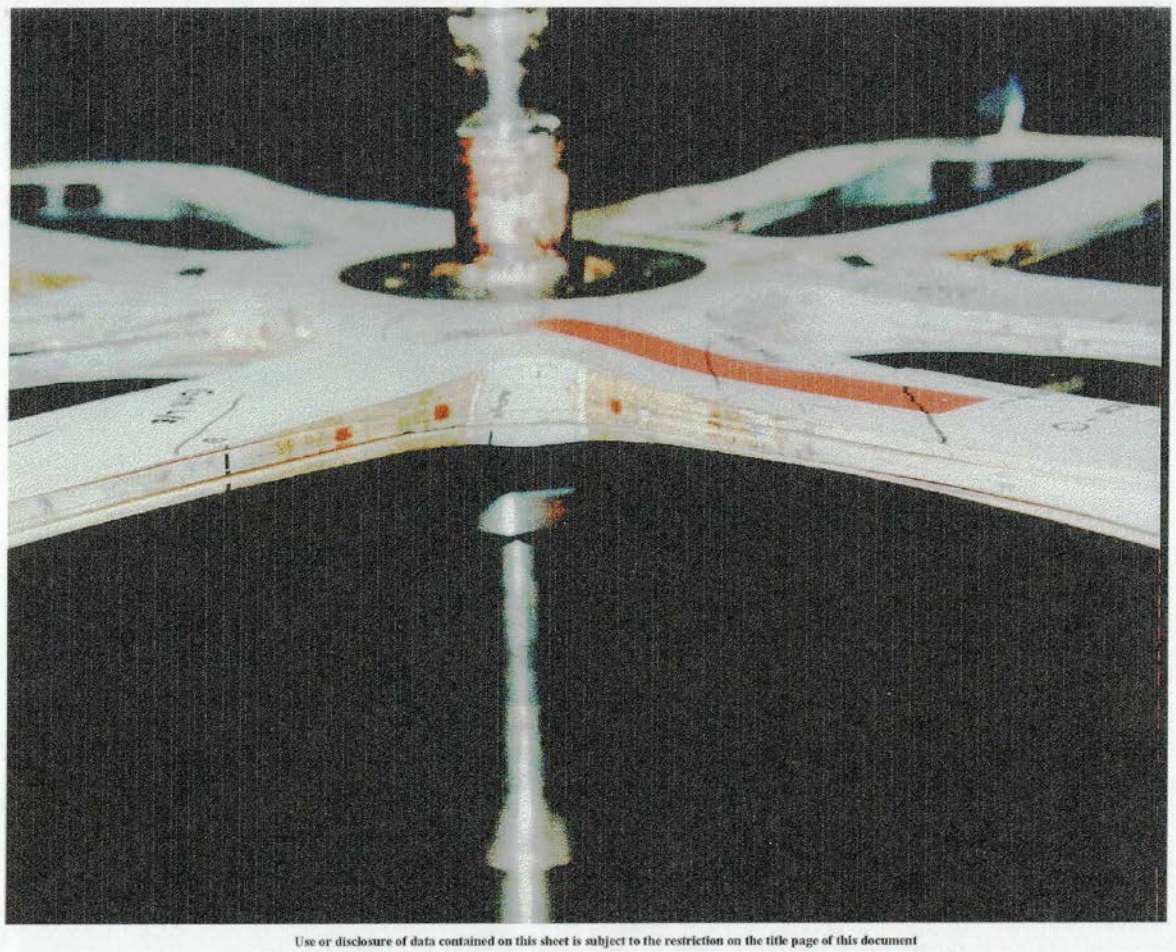
Damage Tolerance Test of a blade



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

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