

DESIGN and PROCESS GUIDELINES FOR HELICOPTER STRUCTURAL MODIFICATIONS

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Composite Parts or Composite Structure**

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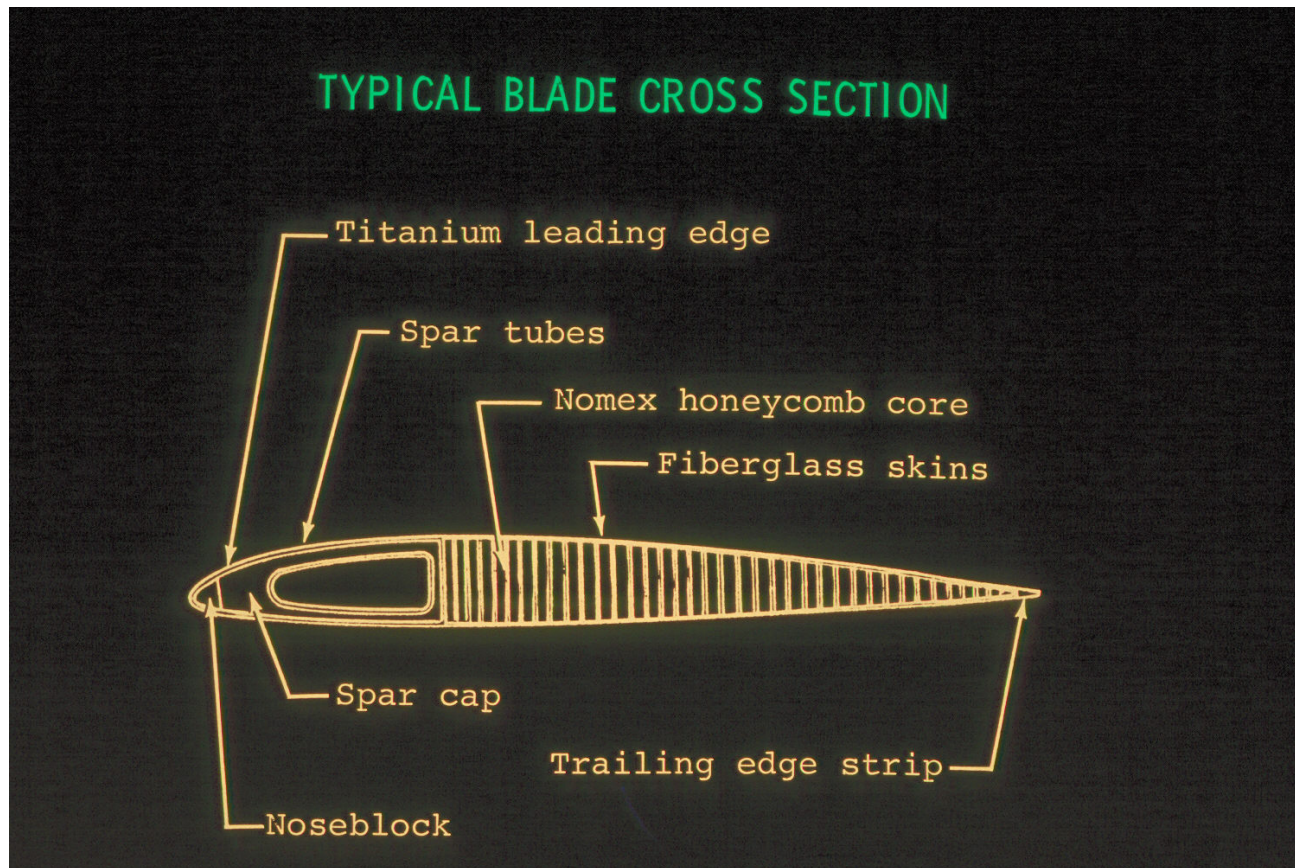
OUT LINE

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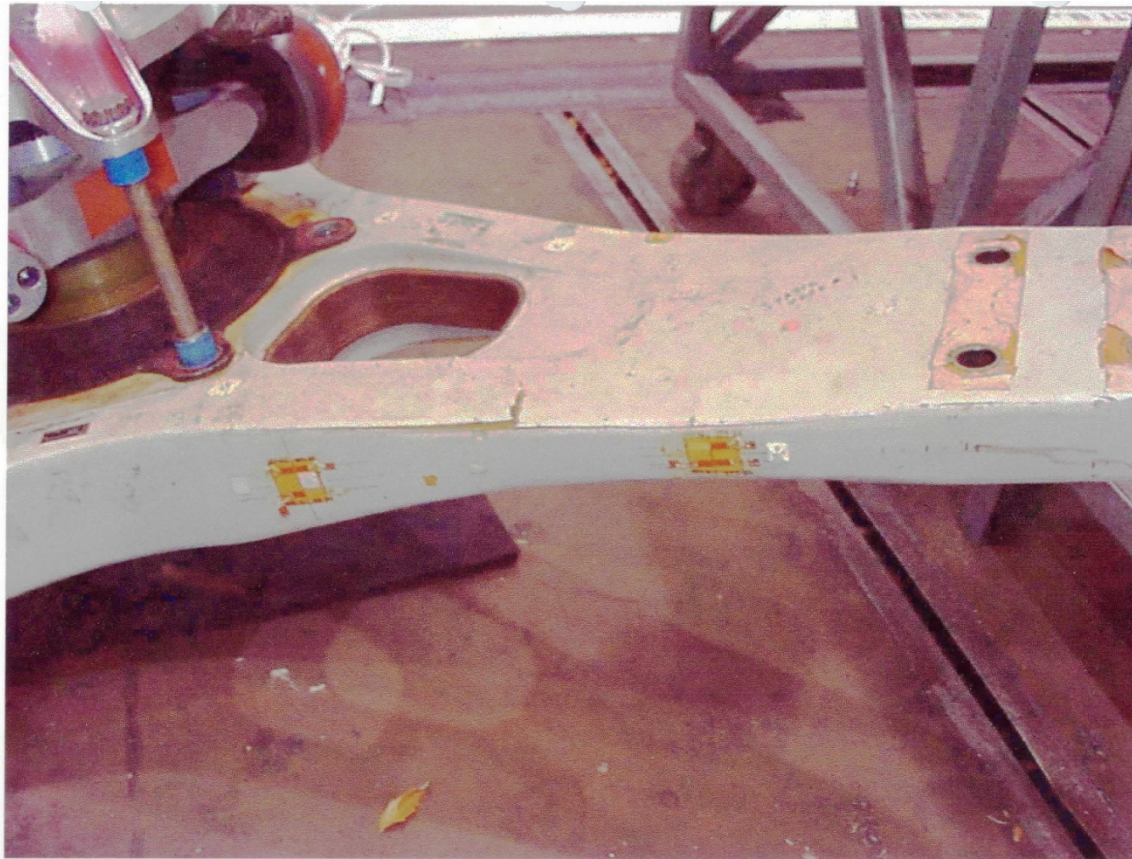
Historical background of Composites in Helicopter Industry

- Fiber reinforced composites have been used successfully in helicopter industry for more than 40 years in critical structure such as main and tail rotor blades and hubs
- Most of the Airframe is Metallic Structure
- Composite components in most of the rotor Hub and Blade operate in a tension dominated strain field and exhibit benign and non catastrophic failure modes, primarily delaminations or skin cracking which is non structural in most cases and easily repairable.
- Economic issue rather than a safety issue
- Almost all Major manufacturers are going with composite blades in the new designs, most of them also with composite hubs
- Failures are easily detectable (CVID) and do not degrade the performance of helicopter significantly and does not result in catastrophic failures

TYPICAL BLADE CROSS SECTION (REF 1)

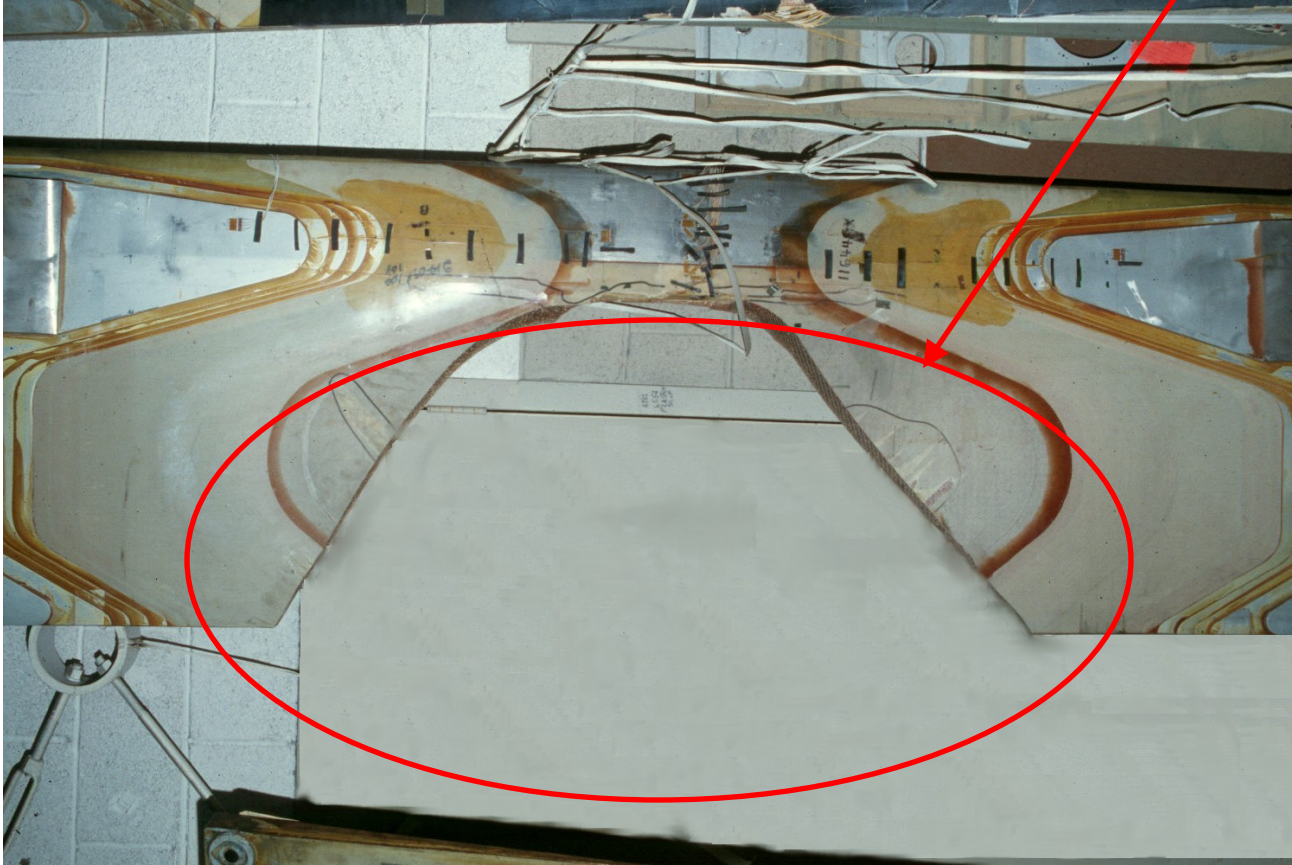


Typical Yoke Failure (Ref 2)



Damage Tolerance Test of a Blade (Ref 1)

Blade Afterbody Removed



Contrast between Fixed Wing vs. Rotary wing Loading

- In Airplanes significant Fatigue loading occurs from Takeoff back to Landing (G-A-G) with few smaller loading cycles in flight
- In Helicopters significant fatigue loading occurs during every rotor revolution on dynamic components 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 on main rotors and in less than an two hours on tail rotors
- Most of the Helicopter Airframe has very low fatigue loading except for main rotor/pylon attach area, tail rotor attach area, vertical tail, tail boom and elevator. These areas are subjected both G-A-G Cycles and significant high frequency loading resulting in fatigue and durability issues
- Landing Gear and Landing Gear attach area is only subjected to landing loads

Contrast between Fixed Wing vs. Rotary wing Loading (cont,d)

- Generally Airplane loads are high at low altitude and high 'G' Maneuvers and Loads go down as the wing stalls
- In helicopter main rotor hub & blades loads increase rapidly as the rotor stalls. This generally occurs at high altitude conditions
- Tail Rotor Loads are high in high speed forward flight at low altitudes and sideward flight conditions.
- Most of the Critical Airframe structure is loaded by the Tail Rotor or Main Rotor and in a constant displacement environment

Types of Structural Modification in Helicopters

- Structural Modifications to address Fatigue and Durability -Vertical Fin Spar Tail Boom, Weapons Pylon Lugs
- Structural Modifications to add Auxiliary Equipment (External tanks, Rescue Hoist, Cameras, Radars, Fire Fighting Equipment Etc)
- Structural Modifications to incorporate New Improved Components (New Tail Boom, New Composite or Metal Blades)

Design and Process Guidelines for Structural Modifications to address Fatigue and Durability in Helicopter Structure

- In Most Airplanes Structures, Fatigue and Durability can be enhanced by increasing the load carrying capability of the structure by adding doublers or increasing the size.
- In Helicopter airframe this approach specially in tail boom, Vertical Fin Spar and Elevators does not work due to the fact these operate in a displacement driven environment
- Increasing the stiffness of the tail boom or Vertical Fin may change the dynamic characteristics of the helicopter and may even increase the loading and change loading in other components.
- Most of the Helicopter airframe Fatigue and durability issues are solved enhancing the fatigue capability without changing the structural stiffness
- **If significant structural changes are implemented- Verification of loads/strains in all critical components is a must in Helicopters. Additional Analyses may be required**

Examples of Modifications to Improve Fatigue and Durability

- Vertical Fin Spars in Model 214 B – Cold Working the Critical Holes- Verified by the Element Tests
- Vertical Fin spars on Models 212/412- Cold working the Critical Holes
- AH-1W Weapons Pylon Lugs- Use Force-Mate Process
- **All the above modifications have no effect on stiffness of the structure or loads**
- AH-1W Vertical Fin Spar- Changing the material from Aluminum to Titanium- **Verified by Element Tests and Flight Test**
- **Cold Working and Force-Mate Processes Improve Fatigue strength of Aluminum Structure Significantly in the high cycle region and is highly effective way of solving high cycle fatigue issues . These processes significantly improve crack growth capability in the slow growth region. (References 3 and 4)**

Design & Process Guidelines-Structural Modifications to add Auxiliary Equipment

- Adding any new External device such as rescue hoist, cameras, radars, litter or water bucket to helicopter structure can have significant impact on main rotor, tail rotor and critical airframe loads
- In addition to analyses of the local areas, a limited flight test program (Critical Conditions) with instrumented main and tail rotor and airframe with and without the auxiliary equipment is a must.
- If the loads are in excess of baseline- special operational limitations such as airspeed etc., have to be developed for the auxiliary equipment, so that the loads on any of the critical structure does not exceed baseline
- If limitations are not acceptable, a new type certification process has to be accomplished

Design and Process Guidelines to incorporate New Improved Components

- Any significant new component development for an existing Helicopter is a major effort and would require to meet latest regulations such as damage tolerance.
- Would require complete set of analyses (Dynamic, Flutter, Static and Fatigue, Performance etc)
- Would require Fatigue and Damage Tolerance Testing
- Comprehensive Flight Test Program with all critical components instrumented with original component and modified component
- As long as loads are equal to or less than the base line configuration on existing components with new component . New component is acceptable
- If loads are greater, it will be difficult to evaluate the other components unless you are the OEM
- The probability of success is higher if you can match the stiffness distribution of the new component to the old component- good example replacement composite blade for Bell 214B

Damage Tolerance Requirements

- Demonstrate Static Strength
- Demonstrate Damage Tolerance and durability of the structure considering acceptable manufacturing defects and expected in-service damage (un repaired) for the required life or inspection interval.
- Demonstrate safe continuance of flight after discrete source damage such as bird strike or uncontained high energy impact

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

- **Damage Tolerance and Durability Demonstration shall consider following**
 - Acceptable manufacturing defects(acceptance criteria)
 - Expected in-service damage (un repaired) limited by threat, detectability or a maximum cut-off energy (1200 In.Lbs) (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
- **IF No Growth occurs in required life times of Testing:
Demonstrate ultimate load capability after the repeated load tests**
- **IF Growth occurs, establish appropriate inspections with demonstration of required residual strength**

Damage Tolerance Requirements (Discrete Source Damage)

- **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**

Attributes of Thick Composite Components

- Composite components in the rotor system are relatively thick (upto 4 inches in yokes)
- In general 3 D FEM model is necessary to understand all the different strains
- It is better to test thick composites after environmental conditioning- **Applying a factor to loads based on the coupon data is very conservative.**
- ILS Failure modes seen on yokes and Skin cracking on the blades have no degradation due to environment as these are displacement driven rather than load driven.
- Thick composites also are more susceptible to Fiber Waviness (Marcel).
- Any Fiber waviness in the longitudinal (Load direction) results in significant increase in all strains (Tension/compression, ILS and ILT)

Attributes of Thick Composite Components

- Thermal incompatibility between Aluminum and Carbon/Epoxy is a significant issue in Joints with multiple fasteners
- In Aluminum/Carbon/Epoxy joints with similar stiffnesses, each degree of temperature change can result in internal strain of 7 micro in/in (70 psi)
- This can be very significant when range of operational temperatures can go from 120 deg . F (ground Condition) to -50 deg . F (high Altitude)
- These type of joints need to consider operational temperature range in addition to flight loading in analysis and testing.
- Titanium is the most compatible material with Carbon/Epoxy material to minimize the strains due to operational temperature range

Typical Repairs on Helicopter Composite Components

- 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)

Summary

- Loading in Helicopter Airframe Critical structure is displacement driven and also high frequency, conventional approach of Stiffening the structure may not work well and may even cause other problems
- Most of the Helicopter airframe Fatigue and durability issues are solved by enhancing the fatigue capability without changing structural stiffness by using processes such as cold working and ForceMate
- If significant stiffness changes are implemented- Verification of loads/strains in the entire system is required, which is an expensive effort
- Adding external Auxiliary equipment or new components requires comprehensive load /strain verification and can be expensive effort and also would have to meet latest regulations

Lessons Learned in using Composites

- Simple load paths- No discontinuities
- Composite designs for Complex loaded structures are difficult and are better off using metallic designs
- Thermal incompatibility in hybrid multiple fastened joints (aluminum/carbon epoxy) should be considered (significant strains due to temperature variation)
- Titanium and Carbon/epoxy have best thermal compatibility
- Titanium abrasion strips are preferable in fiber glass composite blades (more strain compatible)
- If radical new designs are considered, sufficient development testing and analysis should be conducted to verify the viability of the design
- Closed cavity tooling can result in Marcells in the component (need good process control)
- Marcells can result in significant increase in local strains and cause failures

Lessons Learned in using Composites

- In blades, failure modes are usually in the skin and are benign. Failure modes seldom occur in the unidirectional spars or trailing edges
- Failure modes in yoke are generally interlaminar shear (Mid plane delaminations) or surface ply delaminations
- Composites should not be tested at elevated (S/N testing) load testing, should be tested with a spectrum type tests. Elevated load testing can result in non representative failures
- It is advantageous to qualify thick composite components by testing in the appropriate environment- since environmental factors based on small coupons are conservative
- Eliminated all catastrophic failures associated with metallic hub and blades
- Composites in rotors have significant advantage since they primarily operate in tension field and have benign failure modes
- Almost all manufacturers are going with composite blades in the new designs, most of them also with composite hubs
- Failures are easily detectable and do not degrade the performance of helicopter significantly and does not result in catastrophic failures

References

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