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The Development of an Innovative Composite Tailboom

A. Engleder / S. Görlich / D. Strobel

alexander.engleder@eurocopter.com

Airframe Design & Stress

EUROCOPTER DEUTSCHLAND GmbH

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0 ABSTRACT

This article describes the development of an innovative tail boom structure incl. the strength substantiation approach for this highly integrated composite part. The design targeted at competitive weights, -manufacturing costs and service friendliness e.g. in terms of integration of electrical systems like antennas. The loft of the parts makes the effective use of composites interesting. A comparison of part count of several tail boom designs of EC fleet is shown to demonstrate the evolution in terms of qualitative Recurring Costs (RC) savings by such high degree of integration.

1 INTRODUCTION

Tail boom structures on conventional helicopters act as supporting structures for the anti-torque system and they comprise as well the empennages to ensure longitudinal-, pitch and yaw stability.

EUROCOPTERs Fenestron® Anti-Torque-System is widely used in its product range up to the 5 ton All Up Weight, AUW class.

The presentation deals with the development of an innovative composite tail boom with Fenestron® shroud for the EC145 T2.

2 DESIGN REQUIREMENTS AND FEATURES

This innovative design targeted at competitive weights, competitive manufacturing costs and service friendliness in terms of integration of electrical systems like several antennas and reparability in case of accidental in service damages.

The loft of the Fenestron® shroud as well as the loft of the tail boom structure itself make the effective use of composites interesting in terms of manufacturing costs, due to the fact that almost all surfaces of both assemblies are non developable.

It is generally known by the helicopter community that the tail booms are subjected to fatigue.

The fatigue behaviour of composites (e.g. Carbon Fibre Reinforced Plastic, CFRP) compared to conventional aluminium alloys is much better in terms of the endurance limits of both materials, see Fig.2.1.

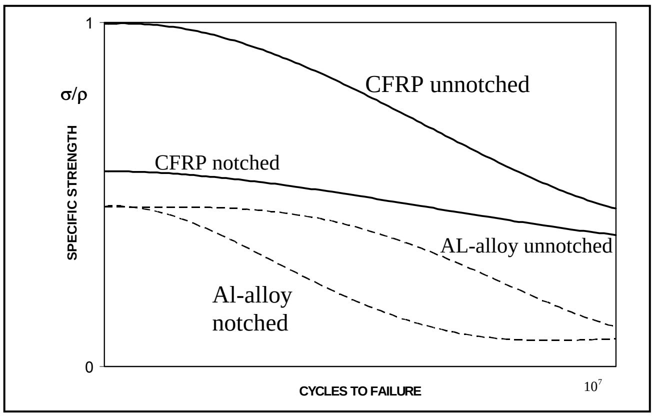

Fig. 2.0-1 - Comparison of S/N curves from notched and un-notched specimen made out of CFRP and Aluminium.

That is one reason why almost all helicopter manufacturers use nowadays composite material for their main- and tail-rotor blades.

In addition composites, compared to conventional aluminium alloys provide a much better resistance to all terms of corrosion.

2.1 COMPATIBILITY WITH EXISTING HELICOPTER ARCHITECTURE

One of the design targets for the new composite tail boom is the system compatibility with the existing EC145. This requirement leads to several restrictions in the design. The upper constraint of the tail boom is defined by the axis of the tail drive shaft. The lower limit is given by the existing geometry of the fuselage with its clamshell doors and the avionic deck. Lateral constraints are given by the loft of the engine cowling and the engine exhaust openings on both sides of this cowling.

The new interface flange has the same height as the previous one and has only a minor increase in width.

These geometrical changes allow an unchanged basic tail drive shaft layout on the EC145 T2 with a sub-critical shaft and a small clearance to boom.

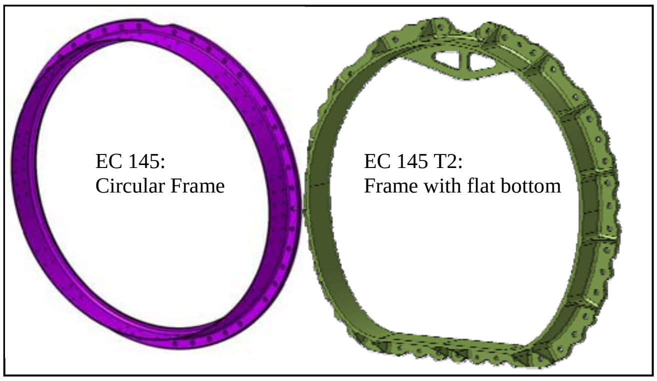

Figure 2.1-1 - comparison between existing interface on EC145 and new interface at the EC145 T2

The clearance of the tail for the landing slope was selected to be 10°. This was achieved with a specific design of the lower vertical surface of the Fenestron®.

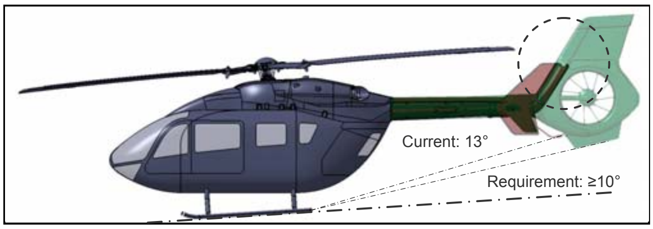

Figure 2.1-2 - Comparison of the side view between EC145 and the EC145 T2 aircraft

2.2 Increased tail rotor thrust, growth potential for main rotor

Due to the integration of new engines a more powerful anti-torque system was necessary. The requirements regarding stiffness and dynamic behaviour are similar to the existing tail boom of the EC145, whereas the materials used is changed from Aluminium sheet/stringer to carbon composite sandwich design. The prepreg material was selected because of its low weight and the suitability for complex geometry. Besides the composite layup can be tailored and optimized to the asymmetric loads.

2.3 Integration of internal and external equipment

Tail booms provide locations for antenna integration as well as installation of other equipment. The new composite tail boom has the capability to mount all these antennas without specific antenna consoles. The antennas shall be installed either direct on the structure or on dedicated plates that are part of the structure.

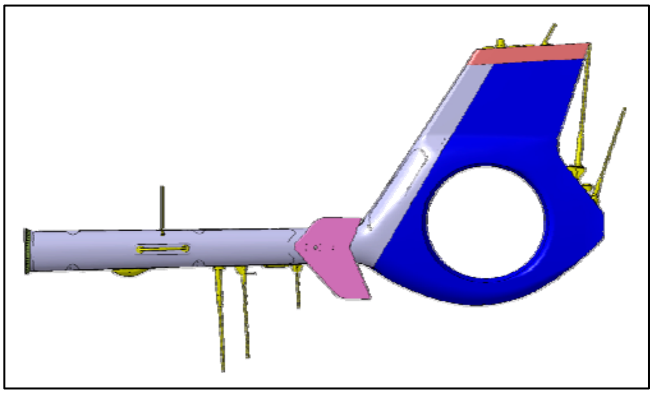

Figure 2.3-1 - maximum configuration of all antennas at the tail unit

The harnesses to these antennas and to equipments inside the tail boom are configured and pre-installed on cable rails outside the tail boom. This allows flexible changes in the configuration during final assembly as well as easy customization of green helicopters in subsidiaries

2.4 Competitive Recurring Costs

The new composite tail boom is designed for competitive recurring costs. The focus for the tail unit itself is on a reduced number of individual parts and because of this also on a reduced number of rivet joints. This results in a high integration level of structural parts:

- The boom with integral fin leading edge is manufactured in one shot using tube technology (co-curing of two half shells).
- The Fenestron® housing and the fin is made of only two shells, the Fenestron® duct is integrated into LH shell.
- The boom, the shells and the spar are assembled by riveted joints.

Due to this high level of integration of parts also the assembly costs and equipment installation costs were made competitive. As already described in the previous section, the harnesses can be customized and pre-assembled outside the boom in a parallel step. The antennas can also be individually pre-assembled on the specific antenna plates. This increase of parallel work cuts down the necessary time during final assembly of the helicopter.

3 Manufacturing Concept

This innovative tail boom design, see Fig.3.0-1, shows a not yet seen level of integration, compared to its predecessors.

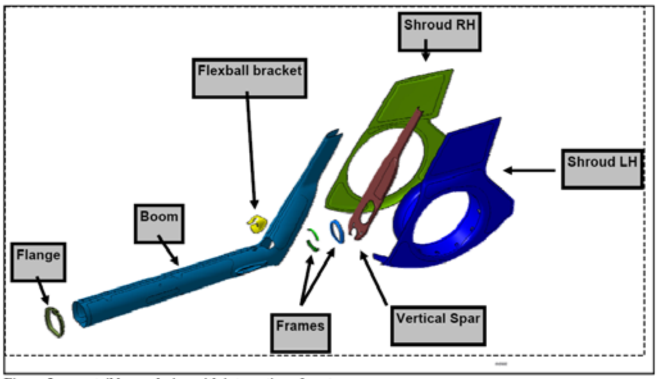

Fig.3.0-1 - Structural Lay Out of tail boom

A comparison of part count between the several designs of Fenestron® tail booms, see Fig. 3.0-2 demonstrates the recent achievements on terms of qualitative RC savings by ensuring such high level of integration.

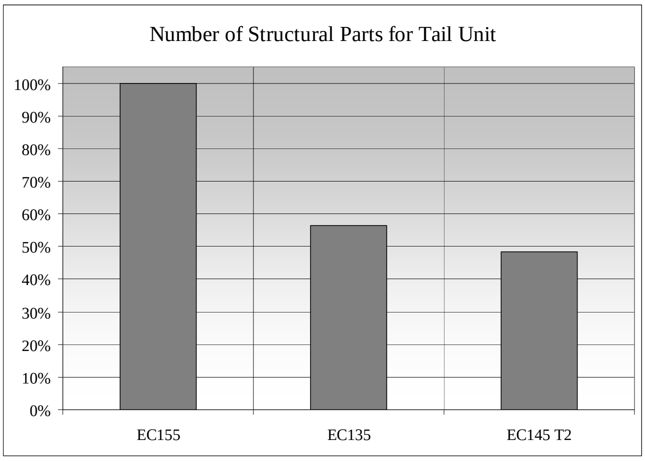

Fig 3.0-2 - Part count of different generations of Fenestrons®

The main design features of the presented tail boom structure and its associated Fenestron® shrouds consist out of CFRP/Nomex® sandwich shell structures (Nomex®: Du Pont's aramid fiber paper treated with phenolic resin, used for sandwich cores), whereas some other areas are in monolithic CFRP Design. The used CFRP prepreg material comprises an epoxy resin which is to be cured at 180°C.
The few parts remaining are joined together by riveting, a well established joining method at EUROCOPTER for composite parts. Riveting of composites is a proven joining method, the joints can be reliably controlled by Non Destructive Testing, NDT methods and their fatigue behaviour is of good nature.
In addition, replacement of parts in case of accidental damage in service is similar than on metallic sheet/stringer design.

3.1 One-shot composite tail boom in co-curing-technology

The tail boom is designed as a "one-shot" tube; the widely used so called "tube technology" at Eurocopter has been extended to a big sandwich part of the primary structure. The layup of the composite material is made in two halves of a closed tooling; the final consolidation is achieved in the autoclave after closing of the tool.

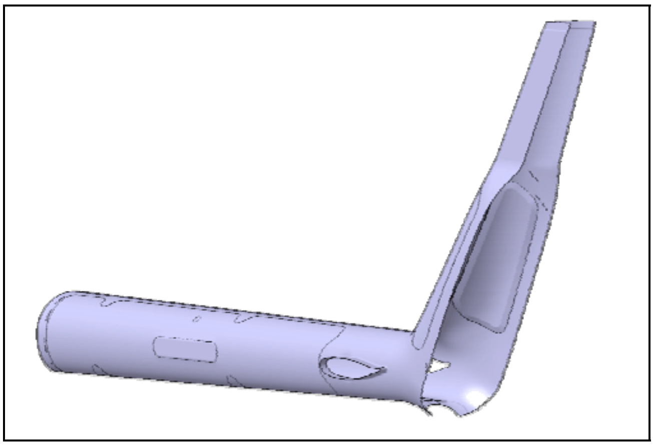

Figure 3.1-1 - one shot tail boom part

The lower area is full flat to ease the integration of antennas. To cope with compression loads, stringers and local reinforcements have been installed there to stiffen it with its cut outs, to prevent stress concentrations as well as local instabilities. It includes also the attachment flange for the horizontal stabilizer.

3.2 Composite shroud in two shells with spar

The tunnel of the Fenestron® was integrated to the Left Hand, LH shell, as well as the closing plate in the lower and rear section of the Fenestron®.
This is done with a separate layup of the shell and the tunnel on two tools. These tools are joined before the autoclave cycle, and the result is a high integrated structural part.

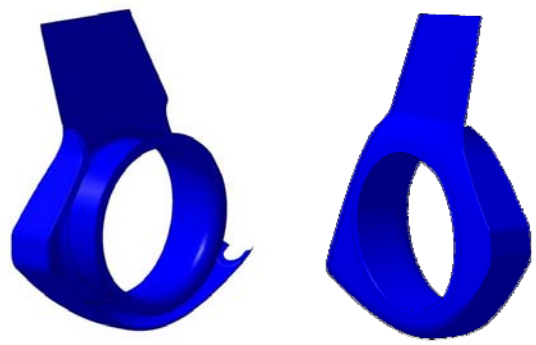

Figure 3.2-1 - LH Fenestron® shell

The Right Hand, RH shell remains simple; it is a closure panel for the Fenestron® shroud and has less complexity for the tool and the layup than the LH shell.

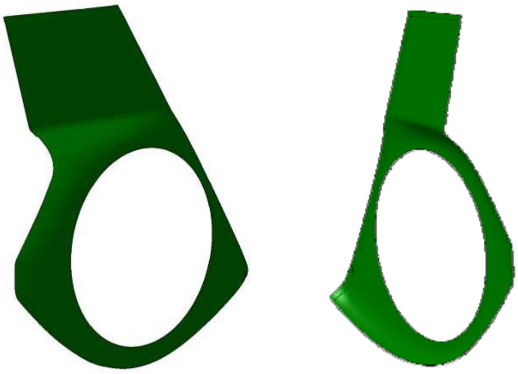

Figure 3.2-2 - RH Fenestron® shell

The joint to the tail boom is no longer with a splice frame but with a spar. Three parts are joined with a single rivet line. The rivet line is located in a low stressed area with a good load distribution on the rivets.

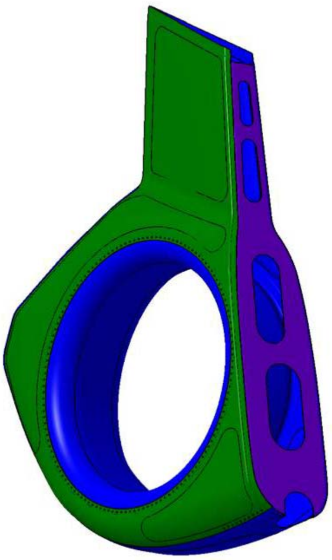

Figure 3.2-3 - assembled Fenestron® shroud

3.3 ANTENNA INTEGRATION CONCEPT

The layout of antenna configuration is chosen to be similar to EC145 layout (see Fig. 2.3-1). Most of the antennas are attached to aluminium plates; some are mounted direct on a ground plane on the composite structure. The global electrical bonding and the ground planes are provided by additional copper mesh and copper strips on the carbon fibre laminate. The electrical bonding of antenna plates to the structure is performed with conductive gaskets in between.

3.4 INTEGRATION OF HARNESSES

The electrical harnesses are pre-equipped outside on rails. These rails are mounted inside the tail boom on the vertical Y shaped -stiffeners with a dedicated locking provision and are secured by one screw per attachment point. The bulkhead at the front end of the tail boom is used for the attachment of the electrical connectors.

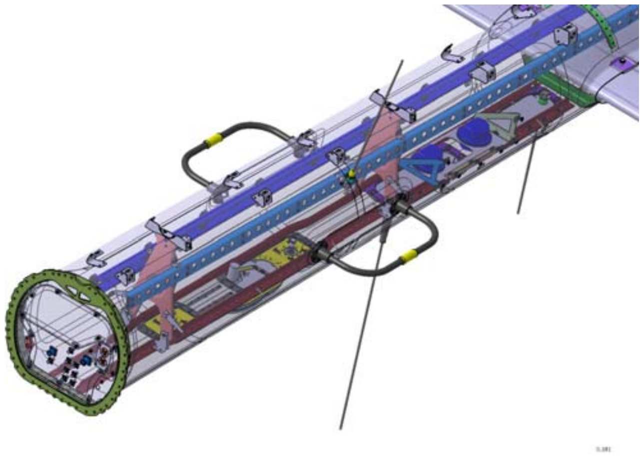

Figure 3.4-1 - harness installation rails inside the tail boom

4 STRENGTH SUBSTANTIATION

4.1 SUBSTANTIATION PHILOSOPHY

EUROCOPTER's substantiation methods are based on analytical tools which are supported by test evidence. According to the building block approach the chosen material is based on a material qualification which was already established on previous programmes and is consequently updated.

The strength substantiation is accomplished by applying the state of the art approach, i.e. demonstration of limit load capability without detrimental deformations and ultimate load capability without collapsing of the structure, both under consideration of environmental effects by applying a certain Load Enhancement Factor, LEF.

Principal Structural Elements, PSE are identified. Manufacturing and typical in-service damages are considered. Allowable manufacturing- and Barely Visible Impact Damages, BVID which can be realistically expected during production and in service are not allowed to grow under repeated loading to such an extent that the structural strength would be reduced below Design Ultimate Load, DUL, i.e. no damage growth. Visible Damages resulting from obvious discrete sources shall not reduce the structural strength below Design Limit Load, DLL and impact damages that could reduce the strength below DUL have to be detectable.

4.2 STRESS WORK AND STRUCTURAL TESTING

4.2.1 STRESS WORK (SIZING)

A Finite Element Model was created, see Fig 4.2.1-1 to simulate the tail booms behaviour under relevant flight- and ground load conditions, considering also the effects of local and global instabilities.

Typical sandwich failure modes in terms of instability such as face wrinkling and shear crimping have been investigated theoretically and coupon tests have been performed.
Those results were used to verify the failure theory.
Finally full scale static tests were performed to verify the analytical tools.

Fig.4.2.1-1 - Finite Element Model

4.2.2 STATIC TESTS ON COUPON LEVEL

The geometry of the tail boom tube and the loading which is mainly bending and torsion leads to a compression and tension loading in the tail boom structure. Sandwich panels under compression are prone for different instability modes, such as shear crimping and face wrinkling of the skin.
Coupons were tested (see Fig. 4.2.2-1) at Room Temperature, RT and realistic environmental condition, to verify the failure modes.

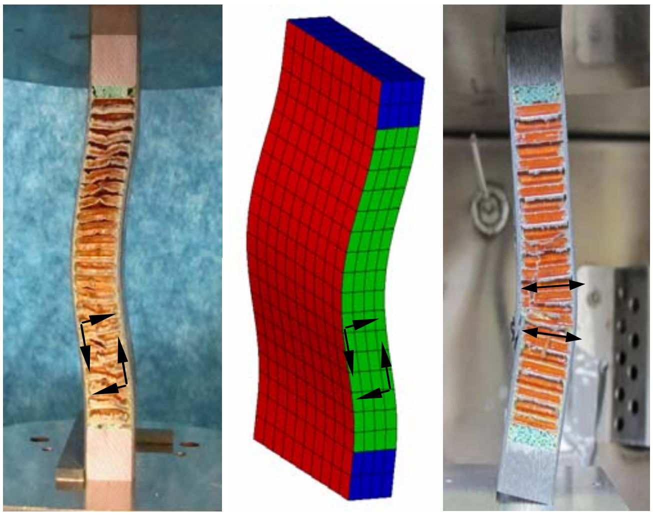

Fig. 4.2.2-1 - Coupon test samples,
LH Shear Crimping, RH-Face Wrinkling

Description of Shear Crimping and Face Wrinkling acc. to [1]:

*"**Shear crimping** failure appears to be a local mode of failure, but is often a general form of overall buckling in which the wavelength of the buckles becomes very small because of low core shear modulus. The crimping of the sandwich occurs very suddenly and usually causes the core to fail in shear at the crimp. Crimping may also occur in conjunction with overall buckling of the sandwich. In such cases, the overall buckle begins to appear and the crimp occurs suddenly because of severe local shear stresses at the end of the overall buckle. As soon as the crimp appears, the overall buckle may disappear."*
[1]

*"**Face Wrinkling** may occur if a sandwich facing subjected to compression buckles as a plate on a elastic foundation. The facing may buckle inward or outward, depending on the flatwise compressive strength of the core relative to the flatwise tensile strength of the bond between the facing and core. If the bond between facing and core is strong, facings can wrinkle and cause tension failure in the core. Thus, the wrinkling load depends upon the elasticity and strength of the foundation system, namely the core and the bond between facing and core."*
[1]

Both local instability modes face winkling and shear crimping can lead to a global failure of the structure.

4.2.3 FULL SCALE TESTING

Finally static tests have been performed on the complete tail boom structure to verify all analytical methods. Fig 4.2.3-1 shows the static test set up.

Fig.4.2.3-1: Test set up for static tests

To simulate realistically the support of the tail boom, an aluminium adapter tube based on the EC145 tail cone design was used. State of the art measurement methods were utilized for test monitoring, i.e. strain gauges, load cells, photogrammetry and even 3Dimensional-correlation.
3D-correlation is an optical, non-contact measuring instrument analysing displacements and strain on surfaces under loading condition. Figure 4.2.3-2 shows a comparison between the expected strain (FE analysis, left picture) and the measured strain (3D-correlation, right picture) at the middle of tail tube structure under yawing condition.

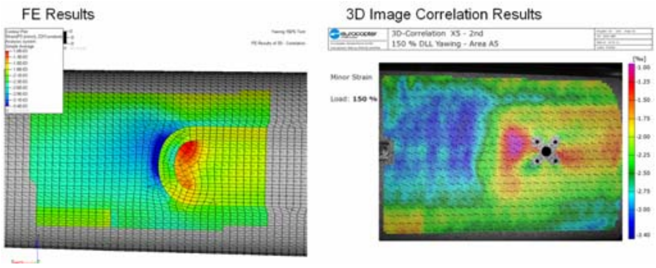

Fig.4.2.3-2 - 3D correlation of tail boom RH side

The demonstration of fatigue and damage tolerance is done by showing no growth behaviour of Barely Visible Impact Damages (BVID) at Design Limit Load. The applied energy level of those Impact Damages is determined by impact tests on representative structural parts. Then maximum allowable strain limits are defined, derived from S/N curves with impacted specimen. These strain levels are used as allowables for sizing the structure.

5 Conclusion

The design targets with respect to weight and recurring costs for the composite tail boom were achieved by a not yet seen high level of integration. The material selection allows the smart manufacturing of non developable surfaces and the applied design concept results in exceptional size accuracy. The achieved small manufacturing tolerances of the integrated parts allow a precise assembly.

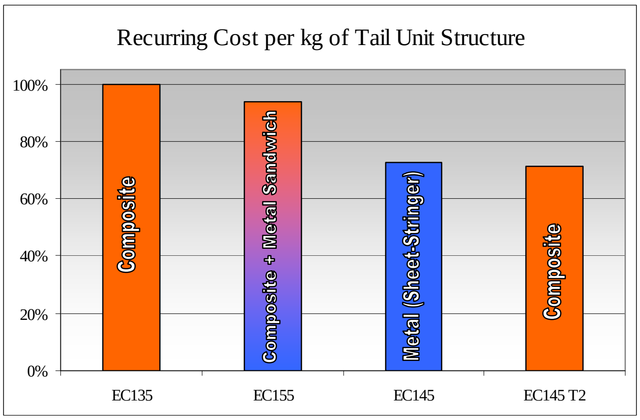

Fig 5.0-1 – Recurring Cost per kg Mass of several EC tail booms

List of References:

[1] Bruhn "Analysis and Design of Flight Vehicle Structures"
Chapter 12 "Sandwich Construction and Design"