

IN SERVICE EXPERIENCE, REPAIR AND EVOLUTION OF EC135 M/R BLADE TOWARDS THE DMC BENCHMARK

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Abstract

Since decades now the EC 135 BMR (Bearingless Main Rotor) technology has proven its outstanding performance not only in service but also regarding low DMC (Direct Maintenance Cost) values. Although the first produced blades have shown some areas of improvement, the blade is now in an extremely mature and reliable state with still decreasing DMCs for customers. In addition small changes in manufacturing and design lead to important improvements regarding maintenance and inspection criteria for the customer, therefore an overview about trim tab design, sealing concepts, trailing edge and surface protection will be given. A further topic will be the various "In Service Evaluations", their results and final implementation in the manufacturing and / or maintenance of the main rotor blade and the valuable customer inputs. Additionally new repair and repair processes had to be implemented for the unique design of the rotor system and have further increased the Airbus Helicopters portfolio of repairs in quality, size and quantity. The paper will give an overview of the technical improvements performed to increase customer satisfaction and ease and reduce the DMCs spent on the main rotor blade, as the protection against erosion environment, like rain and sand, with a metallic erosion shield in connection with other protective measures against particle impacts.

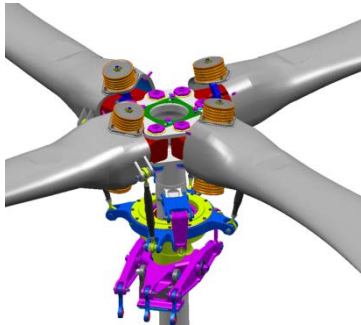


Figure 1: EC 135 BMR Rotor head assembly

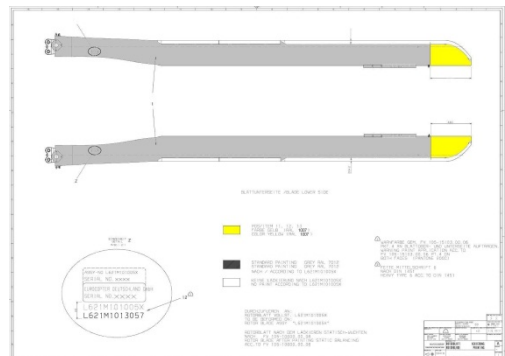


Figure 2: EC 135 Main rotor blade

NOMENCLATURE

BMR	Bearingless Main Rotor
DMC	Direct Maintenance Cost
DSC	Differential Scanning Calorimetry
FCM	Fibre Composite Material
Fh	Flight Hours
FVC	Fibre Volume Content
GFRP	Glass Fibre Reinforced Plastic
ILSS	Inter Laminar Shear Strength
L/E	Leading Edge
MRB	Main Rotor Blade
MTBF	Mean Time Between Failure
MTBUR	Mean Time Between Unscheduled Repair
NiCo	Nickel - Cobalt
PU	Polyurethane

QA	Quality Assurance
SLL	Service Life Limit
T/E	Trailing Edge
TT	Total Time
VP	Vacuum Process

1. EC 135 MAIN ROTOR BLADE DESCRIPTION

Introduction:

The main rotor blade is manufactured from Fibre Composite Materials (FCM, glass and carbon fibres). A flexible blade neck assumes the function of flapping and lead-lag hinges, and the blade angle bearing. This design has no mechanical joints and bearings, which are subject to wear and

sections and the leading edge of the control cuff.

A **balancing chamber** is integrated into the main rotor blade in the vicinity of the blade tip. It serves to accommodate the balancing weights required for static balancing (centre chamber) and chordwise balancing (both outer chambers) of the main rotor blade. Pre-setting are made by the manufacturer in the balancing chamber in order to ensure that individual blades can be replaced. These pre-setting must not be altered by the customer.

A **lightning protector** made of copper strip is integrated in the blade. In the event of a lightning strike on the blade tip, the electrical charge is conducted via the nickel erosion protection, a conductor in the blade skin and a ground cable from the main rotor blade cuff to the main rotor mast.

A **discharger** (Item 2, Fig. 4) is riveted to the trailing edge in the area of the blade tip.

Two **trim tabs** made of metal (Item 4 and Item 5, Fig. 4) are provided near the blade tip (see Fig. 4) and a trim strip (Item 3, Fig. 4) made of Fibre Composite Material (FCM) is bonded and additionally riveted to the blade trailing edge. The trim tabs permit adjustment of a uniform tracking for the main rotor blades.

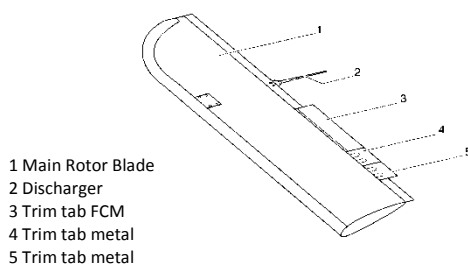


Figure 4: Main rotor blade segment

The **weight washers** for dynamic fine tuning are mounted on the control cuff under a cover.

Lead-Lag damper and **support** form a function unit. The Lead-Lag damper consists of several damping elastomer plies with steel washers embedded between them. The steel washers increase the axial stiffness of the Lead-Lag damper. The package of elastomer plies and steel

washers is vulcanised between a lower aluminium panel and an upper steel panel. The Lead-Lag dampers are bolted to the lower aluminium panels at the damper attachment of the control cuff. The upper steel panels are fixed to the ends of the support with nuts and hence connected together. The two Lead-Lag dampers are connected to the support in a pre-stressed condition. This ensures that tensile stresses are avoided in the elastomer material when control inputs are received and the main rotor blade is subject to flapping movements. Tensile stresses would significantly reduce the service life of the Lead-Lag damper.

The support is positioned to be rotatable and tiltable via a spherical joint bearing in the blade attachment. Lead-Lag dampers and support align the open side of the control cuff to the blade attachment and centre it to the spar.

In the existing prepreg process the quality of the final part is ensured by the incoming inspection, check of the material properties by standard test specimen to ensure e.g. fibre-volume ratio, DSC measurements as well as mechanical properties such as tensile strength and ILSS values. Those have to correlate to the originally qualified material properties (incl. tolerances) that have been defined and certified during the material qualification. In production the correlation to drawings and manufacturing instruction has to be ensured and checked by QA signature. The curing process is validated by graphical correlation verifying the temperature curve corner points. In case of doubt or printer failure it can be alternatively checked by DSC measurements, following the necessary authorisation via quality notification. The final part is then verified via computer tomography for production flaws like cavities, waves, or misalignments.

2. GENERAL CALCULATION OF DMC

The overall drivers for our customer are first "Safety" and directly linked as well the cost of the safe operation of our blades. This is tightly linked to the direct maintenance cost per flight hour.

General formula:

$$(1) \quad DMC = \frac{Cost}{Flight\ hours}, \quad [DMC] = \frac{\text{€}}{Fh}$$

3. DMC DISTRIBUTION OF EC 135 MRB

For the achieved data see figure 5 below.

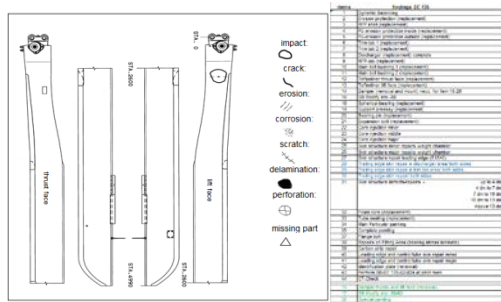


Figure 5: Repair-packages of EC 135 MRB

For each rotor blade passing through the repair shop, the basic package is, simplified, the incoming inspection and standard cleaning and rework procedures. It per se is the biggest part of the DMC as every blade received in the shop has to be checked according to the inspection instructions. Damper, paint, PU erosion protection and identification plate are subject to wear and tear. The surface protection has been improved by an added erosion resistant lacquer. For the PU erosion protection an easy to exchange material has been applied and for the identification plate an erosion and UV resistant patch is currently in certification. These improvements were mandatory but in the context of DMC we will concentrate on the pure design related subject.

To assist our customer we have concentrated on the following topics to reduce the time and money spent per flight hour.

- Optimising the fibre volume content of the trailing edge
- Enhancing the TT of the dampers
- Improvement of the C-Profile
- Balancing chamber sealing
- NiCo erosion shell
- PU erosion protection (added)
- Sand erosion paint
- Trim tab service evaluation

4. DMC REDUCTION ACHIEVEMENTS

4.1 Optimising the fibre volume content of the trailing edge

The trailing edge cracks or "45°-Cracks" are a known phenomenon on the EC 135 Main rotor blades. As this area is highly loaded, 9 layers of fabric have been placed in this area to strengthen this specific region. Finally the achieved FVC was too

close to the maximum acceptable value, see figure 6.

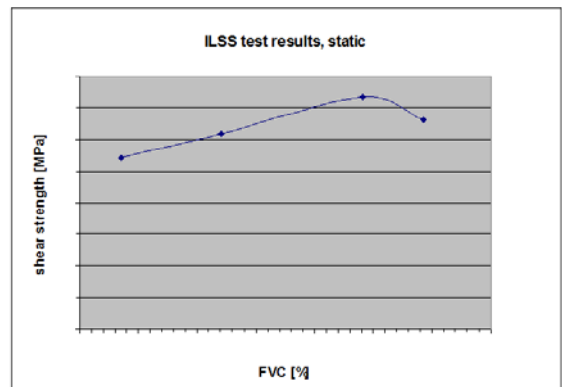


Figure 6: FVC corresponding to ILSS values

Due to the high FVC, already small production deviations could weaken the trailing edge in the most highly loaded area resulting in light delamination in the trailing edge.

By reducing the FVC with using 8 instead of 9 fabric layers, a FVC between 45% and 53% was reached including all production deviations. Thus the delaminations were completely banned and customer satisfaction measurably enhanced, see figure 7.

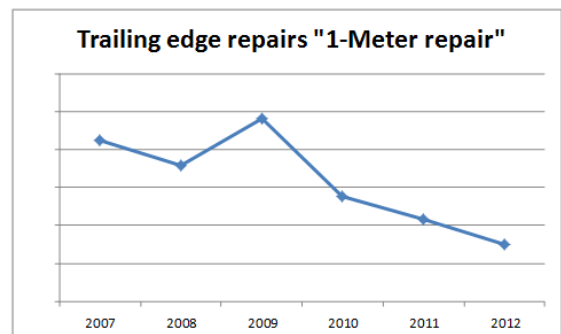


Figure 7: Reduction of repair number due to optimised fibre volume content

The delaminations in the trailing edge were a major inconvenience for our customers and had a measurable impact on our DMC values. Delaminations have, up to now, never been found on blades with the new design, so a DMC reduction to zero would be calculable. As the repairs of all blades in the fleet has dropped to 50%, to use this value is the more conservative approach. Therefore the impact on the overall DMC is a reduction of 17%.

4.2 Enhancing the Total Time of the dampers

During years the reported DMC impact on the dampers has been located at the corrosion of the attachment plate and the requested service life limit of 6 years. These two impacts have especially been taken into account and due to tests finally the SLL could be enhanced from 6 to 8 years and the material of the attachment plate was exchanged by corrosion resistant aluminium that has still the bonding capability to the elastomeric body. So now the door is opened for changing the replacement philosophy to an "on condition" approach with an inspection interval. The impact on the customer DMC for dampers is considered to be 25% reduction for the already implemented 8 year solution and 35-50% for the on condition approach. The overall DMC impact will be in the range of 3-5% on the blade.

4.3 Change of the C-Profile

The C-profile has two major effects on DMC for the customer. First, if the sealing capability is not fully intact due to water ingress, the customer faces difficulties in balancing the blades leading to continued increased balancing efforts.

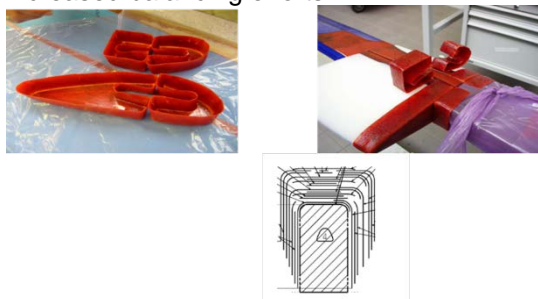


Figure 8: C-Profile design change

The second impact is the degraded support function with the same unbalanceability effects that in some cases might lead to removing the blade from service. The solution for both cases was the increased flexibility of the C-profile for relative movements spar - cuff. Explain the figure and remove the different modification and history and the scale for the water

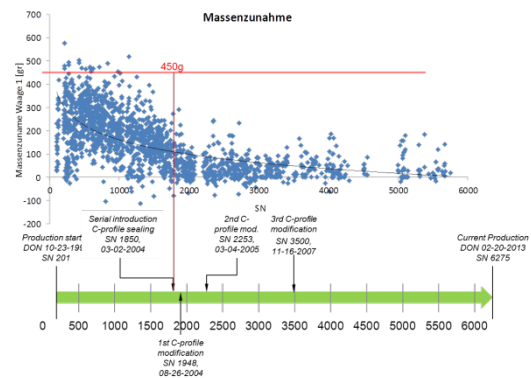


Figure 9: Reduced water accumulation due to C-profile design change

DMC impact for water ingress is approximately 6% of the blade DMC and in the second case up to 8%.

4.4 Balancing chamber sealing

In especially rainy environment, at various customers, water was found in the balancing chamber. The path of the water was located to be in the degrading sealing compound (by sunlight) together with the high start-stop cycles to lead to movements of the inner insert. In a first step, the sealing was enhanced by implementing a first sealant, to secure the insert and a second one to seal the whole area of the cover. This reduced the number of cases drastically but still some cases remained. The final step was to fix the insert with adhesive and also the cover to prevent any relative movement. This finally solved the issue when the sealing is performed properly.

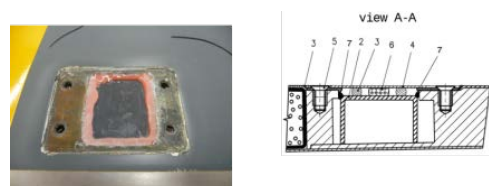


Figure 10: Improved balancing chamber sealing

The DMC impact of this improvement is hardly calculable, as the additional amount of balancing trials differs widely. But the inconvenience for the customer has remarkably been reduced.

4.5 NiCo erosion shell

The electrolytically deposited Nickel Cobalt metallic erosion shield was a tremendous improvement. The new manufacturing concept allows for new design and weight distribution freedoms and at the same time enhances the MTBF/MTBUR in comparable environments by two.

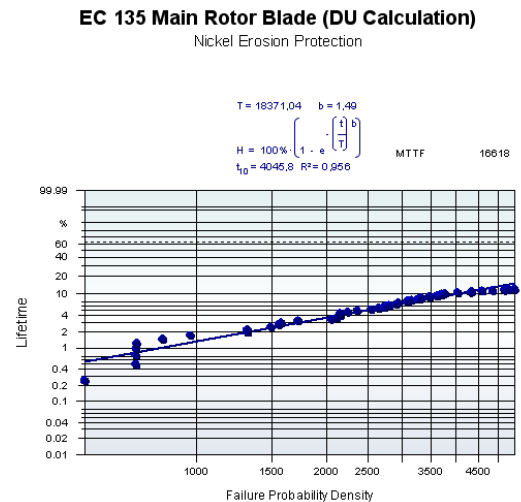


Figure 11: MTBF calculation for NiCo material erosion

As on the EC 135, except at the very beginning an aluminium shell, no other material was used, a calculated DMC reduction is hard to estimate but based on the doubled MTBUR it can be expected to be in the range of 4%.

4.6 PU erosion protection (added)

In the original design on the inner area of the leading edge, instead of a metallic shield a PU strip is attached to protect the blade against erosion. As this PU is bonded to the blade via a pasty adhesive, which is demanding to achieve proper adherence, many customers preferred to have this application performed by qualified repair shops. It is obvious that this has impacts on the availability of the blade and the DMC of the customer. An additional PU film has been introduced to be applied on top of the PU film between R 1490 and R 2990 in conformity with Figure 12.

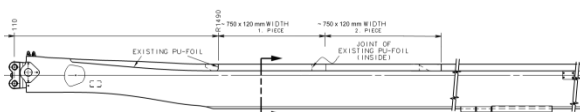


Figure 12: Application of additional PU-film

The additional PU-film can be applied in one or two parts. The length is 1500 mm measured from R1490. The PU strip can be applied as 1500 mm long and 120 mm wide or as 2 x 750 mm long and 120 mm wide PU strip. With the introduction of the PU foils, which are equipped with a self-adhesive layer, this task is now easily performed by the customer while the blade is still attached to the helicopter. This simple change is so successful that nearly all blades nowadays are delivered with this additional PU. The cost reduction can be regarded to be in the range of 7%, not including the time and cost for the easy removal and application of the foils.

4.7 Sand erosion painting

The structure of rotor blades is exposed to the effects of erosion caused by water, sand, and dust particles which impact the blade with high velocity in hover (rotational speed) or forward flight (forward speed + rotational speed). The leading edge and specifically the blade tip are affected the most. To avoid damage by that effect to the structure the leading edge of the rotor blade profile is covered with a metallic shell and the rotor blade skin surface is protected by paint. For missions in sandy regions the blade structure in the area of the blade tip can be equipped with a sand kit based on self-adhesive PU tapes which are bonded onto the blade and cover the sensitive blade structure areas. Under very extreme operational conditions, as is present in deserts, the reliability time of the existing protection is reduced to a level which should be improved to be in line with the customers' expectations.

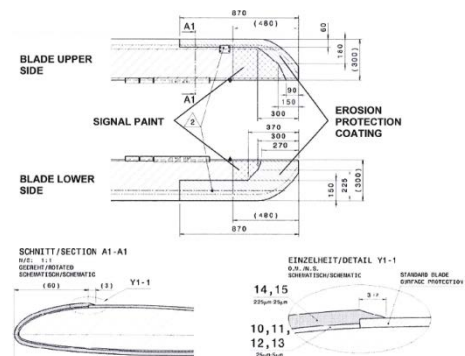


Figure 13: Erosion paint design shape

The consequence was the development of an erosion resistant sprayable “paint” solution. After a successful service evaluation in a combined, sand and rain erosion area, as well as hovers over water,

the following data were received. At that time the blades were still in a state where they are still serviceable, but the erosion shell were already exposed at the tip to sand and rain environment:

The following rough estimations on sand and rain endurance before a repair process has to be performed can be made.

Sand landings approx.	80
Rain endurance	2h
Hovers over water (10 min per hover):	45

4.8 Trim tab service evaluation

Due to high stresses in the trailing edge of the blade because of the high centrifugal loads, cracks have been discovered at the trim tabs' outer areas, see figure 14.



Figure 14: Standard trim tab design

As a first customer satisfaction measure a limit of 7 mm for such cracks has been established and a redesign started. The final concept has been verified via FEM analysis and a Service Evaluation (SE) has been launched.

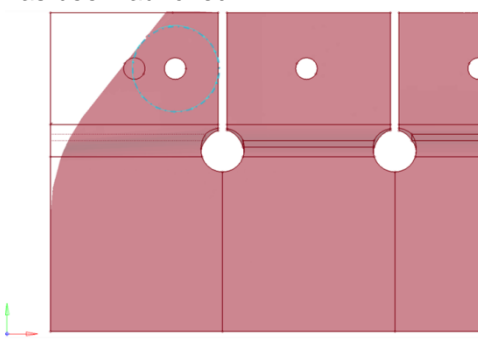


Figure 15: Trim tab design change

During the shape optimisation a lot of different geometries were calculated and the one providing the highest reduction of the maximum v. Mises stress was chosen. The chosen geometry provided a reduction of the maximum stress of 40%. Due to this reduction of the loads a significant increase in lifetime is to be expected.

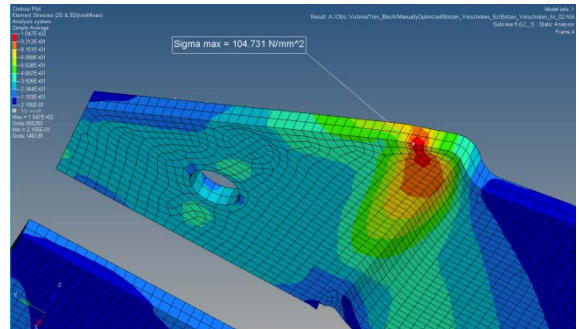


Figure 15: FEM analysis on new design

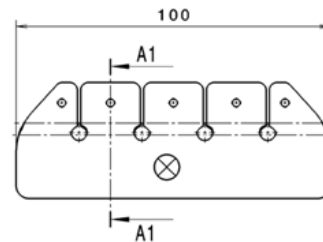


Figure 16: New design for SE campaign

The current feedback from the 5 starting customers is the absence of any crack so far. The DMC impact of this improvement can be estimated in the range of 1% if the cracks area completely banned.

5. SUMMARY

Introduction of the Main Rotor BMR concept in the mid 90ths was already a fundamental improvement in rotor systems regarding DMC. Nevertheless additional benefits could be accomplished during the years to fully support our customers and reduce the burden of maintenance, scheduled as well as unscheduled. If the DMC reduction for all individual parts is combined, the value of 43% over the years from 2007 to 2015 is reached. Especially remarkably, for our customer, is the improvement of MTBF and MTBUR values that have more than doubled over this time period. This means, that the events with the most negative impact on helicopter availability have been cut by half. Finally it has to be mentioned that, especially in the area of the DMC reduction, future designs will be measured and decisions taken on basis of estimated costs per flight hours for the customers. For the BMR technology the current design of the EC 135 Main rotor blades is the current benchmark for such an evaluation.

6. ACKNOWLEDGEMENTS

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