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EIGHT YEARS OF FLIGHT OPERATIONS WITH COMPOSITE ROTORBLADES

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Abstract

In 1958, the Federal Armed Forces started helicopter flight operations. The first helicopter type was the Bell 47G light training helicopter, 36 EA of which were employed for the primary flying training of helicopter pilots in the German Air Force.

It was soon followed by the H-21 tandem-rotor helicopter or Vertol V 43, 32 EA of which were procured. There are just a few helicopter experts of the very first hour today who remember that these two models were equipped with wooden rotor blades.

In 1965, a technical problem arose regarding the wooden rotor blades of the H-21 helicopter which was caused by fungus growth in the critical areas. Operational readiness could only be maintained at that time because metal rotor blades for the H-21 had been developed shortly before; therefore, rapid procurement was possible.

From 1965 until today, the following helicopter types, all equipped with metal rotor blades, have been employed by the Federal Armed Forces in the Army, Air Force and Navy:

- Alouette II
- Vertol V 43 or H-21
- Sikorsky S-58 or H-34
- Bristol 171 Sycamore
- SO 1221 or Djinn
- Bell UH-1D
- Sea King
- Sea Lynx
- CH-53G

Because of the great bending stress resulting from the asymmetrical attack, the rotor blades fatigue after a comparatively short operating time.

Experience has shown that the actual operating time of metal rotor blades will be drastically shortened if the allowable bending stress is reduced in critical areas by minor prior damage such as small notches.

Depending upon the maximum takeoff weight and the rotor speed of the different helicopter types, the allowable and actual operating times range from 1,200 to 2,400 hours of operation.

The actual operating time can be considerably reduced if excessive flight velocity causes an excessive vibrational load on the metal rotor blades.

Due to the current flying hours programs, the metal rotor blades of all Federal Armed Forces helicopter types have to be replaced completely every five to 10 years. This replacement involves considerable maintenance costs for these high-value assemblies.

With the development, procurement and utilization of the

- liaison and observation helicopter and the
- 1st generation antitank helicopter

advanced rotor blades made of fiber-glass-reinforced plastic have been used by the German Army Aviation Forces since 1980.

After eight years of utilization now involving more than 1,200 rotor blades of this design and more than 1,000,000 hours of operation altogether, valid statements can be made on the essential advantages such rotor blades offer compared to the conventional metal rotor blades used before.

Obvious advantages are, above all:

- Considerable life cycle cost savings
- Greater safety in the case of contact with obstacles
- Substantially improved attack resistance
- Greater residual strength after repairs even in critical areas of strength
- Easy repairability with simple means and
- Extreme fatigue strength

1. The Helicopter, a Technical System Subjected to Dynamic Stress.

During conceptual design, definition, development, acquisition and the relatively long operational phase of helicopter systems, various forms of strong dynamic stress affecting almost every component are the most important problem. Particularly connecting elements and marginal zones of connected or integrated assemblies and components near the main rotor are subjected to extreme loads. This typical load on helicopters is caused by the asymmetrical attack of the rotor blades which has to be compensated by flapping and lead-lag movement. Controlled flight conditions can only be ensured by this propulsion system concept.

Thus, above all the rotors, but also the helicopter fuselage as well as almost every component and equipment, are subject to a large spectrum of driving-force frequencies. It is impossible to prevent the natural frequencies of various components and assemblies from being close to driving-force frequencies, which inevitably results in resonances with particularly unfavorable effects on fatigue strength.

Fatigue breakage, which can result in personal injury or loss of life if the primary structure or the propulsion system, e.g. the rotor, is affected, often occurs in every helicopter type.

Even if we succeed in avoiding a dangerous proximity of driving-force and natural frequencies by means of damping measures, the alternating stress caused by the blade forces alone will result in high stresses.

Static breaking strength is a material constant which can rather easily be determined for any material used for helicopter construction. Cyclic variations of the load imposed on components considerably increase the complexity of forecasting the breaking behavior. The fatigue strength of components used in helicopters - particularly in rotors - is no constant value.

The alternating stress which rotor components can endure for an infinite number of stress cycles is no constant value. It depends on the following factos:

- Influence of the material
- Component design
- Dimensions of the component
- Influence of combined stresses
- Influence of fretting corrosion and previous damage
- Helicopter flight mission profile, particularly within the range of high flying speeds exceeding 270 km/h.

2. Rotor Loads Caused by Flight Mission Profiles

Helicopter tests performed in the speed range between 0 km/h and 310 km/h show that the allowable alternating stress of components made of aluminum alloys or magnesium alloys is exceeded at a speed of approximately 270 km/h. High alternating stress occurs also within the speed range between 50 km/h and 80 km/h if a helicopter is abruptly slowed down from a high-speed forward flight. Particularly in case of a high takeoff weight and low external temperatures, such flight conditions may result in excessive rotor loads. Components with inherently high stress concentrations are prone to sudden cracks which rather quickly spread in aluminum components.

3. Short Review of Rotor Blade Utilization

Today, there are only a few helicopter experts of the German Army Aviation Forces who remember that the helicopter models Bell 47G and Boeing Vertol H-21 - also referred to as the "Flying Banana" - were equipped with wooden rotor blades. In 1965, the wooden rotor blades of the H-21 helicopter had to be discarded because they were damaged by fungus growth to an extent beyond repair.

Since 1965, only rotor blades with aluminum spars have been used in the Federal Armed Forces.

Only since the procurement of the liaison and observation helicopter as well as the 1st generation antitank helicopter in 1980 have rotor blades made of fiber-reinforced plastic been used for flight operations. Numerous flying hours with rotor blades made of aluminum alloys as well as fiber-reinforced plastic blades have provided the basis for a comparative evaluation. In the following discourse, I am going to compare the rotor blades of the BO 105 M/P and Alouette II helicopters.

This comparison is appropriate for the following reasons:

- Both rotor blade types have completed more than 1,000,000 hours of operation in the Federal Armed Forces. This great number provides the basis for valid statistical statements.

- Both helicopter types are subjected to similar rotor blade loads. Thus, differences in fatigue strength may plausibly be explained by the different materials.

- The structures of both rotor blade types are of similar design. The only significant differences are in the skin material and the different production methods for metal and fiber-reinforced plastic.

- Blade chord and blade thickness of both rotor blade types differ only slightly.

- The blade sections differ only slightly. Thus, significant load differences can be excluded.

- The most significant difference is in the connection between rotor blades and hub. Whereas the Alouette II helicopter is provided with flapping and drag hinges, the BO 105 M/P helicopter is equipped with a rigid rotor. It is evident that the blade base of the BO 105 M/P helicopter is subjected to higher loads since moments have to be absorbed in addition to the forces.

4. Rotor Blade Structure of the BO 105 M/P and Alouette II Helicopters

A. BO 105 M/P

Technical Characteristics

- Weight: 31 kp
- Length: 4,610 mm
- Chord length: 270 mm
- Blade section: NACA 23012
- Blade twist: 1° 36'/m
- Pitch angle: 16°

1 Blade root end fitting
2 Sleeve
3 Leading-edge fairing
4 Cover strip
5 Erosion protection
6 Tip plate
7 Rovings (blade spar)
8 Lead insert
9 Rotor blade core
10 GRP skin
11 Trim tab
12 Neck fairing

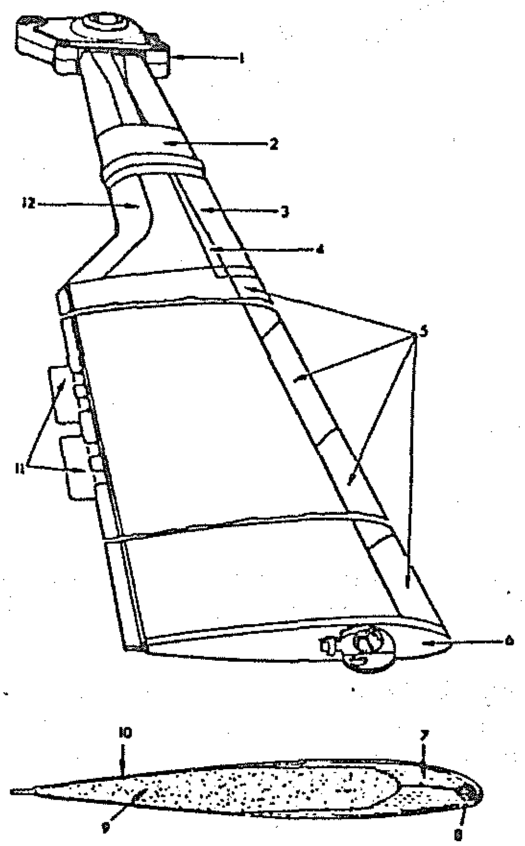
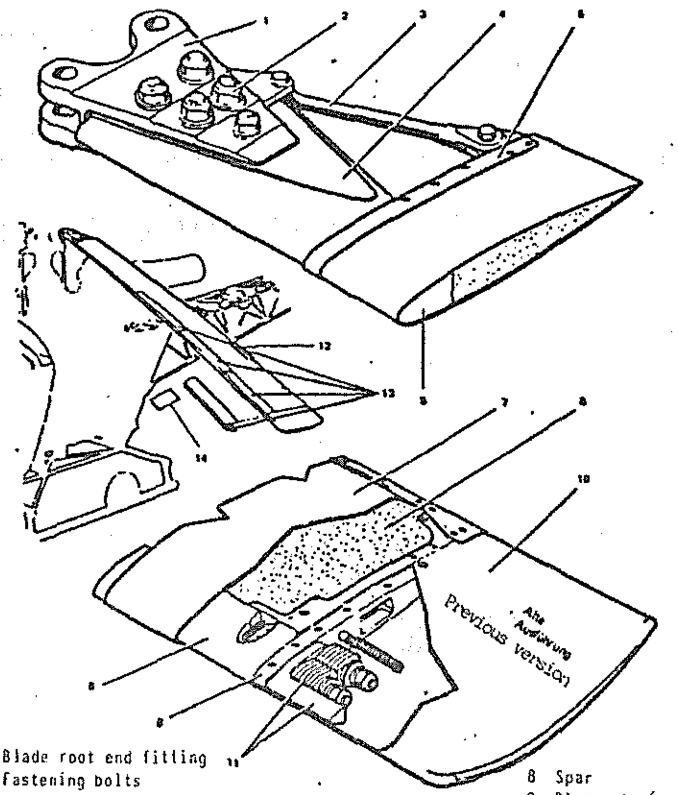


Illustration of the BO 105 M/P rotor blade structure

B. Alouette II

Technical Characteristics

- Weight: 28.9 kp
- Length: 4,250 mm
- Chord length: 280 mm
- Blade section: NACA 0012
- Blade twist: 1° 36'/m
- Pitch angle: 14°



1 Blade root end fitting
2 Fastening bolts
3 Strut
4 Reinforcement bracket
5 Blade rib (root rib)
6 Moltopren
7 Skin
8 Spar
9 Blade rib (end rib)
10 Tip plate
11 Balance weights
12 Trim tabs
13 Protective fairing (Inox)
14 Butt cover (Inox)

Main rotor blade

5. Comparative Evaluation

Rotor blades made of fiber-reinforced plastic (BO 105 M/P rotor blades) offer significant advantages owing to the following factors:

- Long allowable and actual operating time amounting to 10,000 hours as compared to metal rotor blades with a maximum operating time of 2,500 hours.

- Considerably lower susceptibility to malfunctions.

Repair cost and effort for metal rotor blades are increased above all by corrosion of various joints which requires extensive repair.

- Life cycle cost savings.

Metal rotor blades have to be completely replaced twice or three times during the service life of a helicopter. Owing to the high susceptibility to malfunctions, the maintenance float required for metal rotor blades is twice or three times as big. Because of unpredictable repair requirements, helicopters with metal rotor blades have longer downtimes due to a lack of spare rotor blades than helicopters with rotor blades made of fiber-reinforced plastic.

- Greater flight safety.

Contacts with obstacles, and above all with power transmission lines, have shown that rotor blades made of fiber-reinforced plastic cut cables without suffering damage which could result in disastrous accidents. Metal rotor blades for light helicopters - as used in the Alouette II helicopter - are particularly susceptible to damage in case of such flight incidents. This susceptibility to damage often caused disastrous flight accidents.

- Easy repairability of rotor blades made of fiber-reinforced plastic.

Since metal rotor blades are produced as composite structures, their repair requires extensive expenditure and effort. In case of internal corrosion, rotor blades of this design normally have to be discarded, whereas rotor blades made of fiber-reinforced plastic can be repaired with simple means, even near the spar.

6. Repair Procedures

In 1980, rotor blades made of fiber-reinforced plastic have been used by the German Army Aviation Forces for the first time. In the beginning, general uncertainty predominated among the engineering personnel due to a lack of experience regarding the behavior of this new material in components which are important for flight safety. After eight years of flight operations comprising tough mission profiles of the

- 1st generation antitank helicopter as well as the
- liaison and observation helicopter

and involving more than 1,200 rotor blades, the experience may be considered favorable. Particularly regarding the repair of damage caused by improper handling and maintenance as well as during flight operations, rotor blades made of fiber-reinforced plastic offer essential advantages as compared to metal rotor blades.

Only 28 items of ground equipment, test equipment, and special tools are required for repair of the BO 105 M/P rotor blades. The list of consumable materials comprises 40 items. 13 visual inspections and measurements are required.

Metal rotor blades, which have been used and will still be used for a long time by the Federal Armed Forces for the helicopter types

- Alouette II,
- Vertol V 43 or H-21,
- Sikorsky S-58 or H-34,
- Bristol 171 Sycamore,
- SO 1221 or Djinn,
- Bell UH-1D,
- Sea King or MK 41,

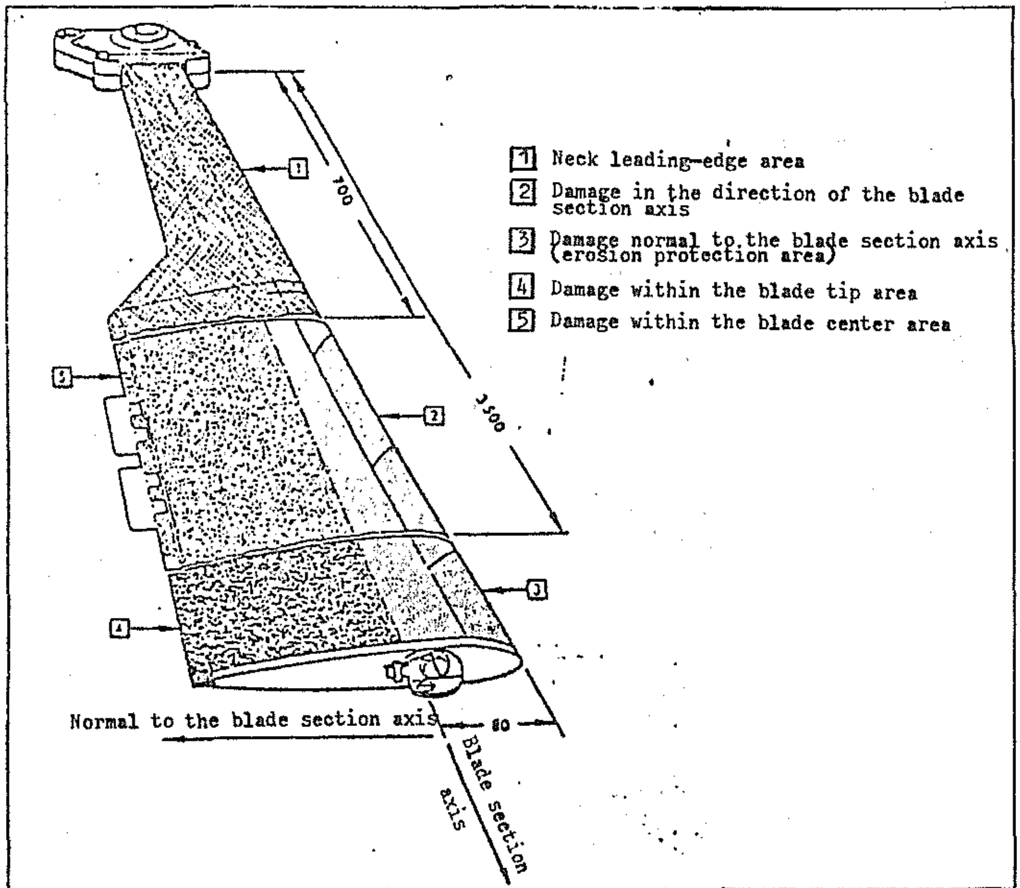
- Sea Lynx or MK 88, and
- CH-53G,

can not be repaired at unit level.

Blades made of glass-reinforced plastic, on the other hand, allow the following extensive repair work to be performed:

- Replacing erosion protection,
- replacing tip plates,
- attaching trim tabs,
- repairing skin and core damage,
- repairing erosion damage,
- reworking the blade root end fitting,
- resining the blade root end fitting,
- inspecting the antierosion fairing.

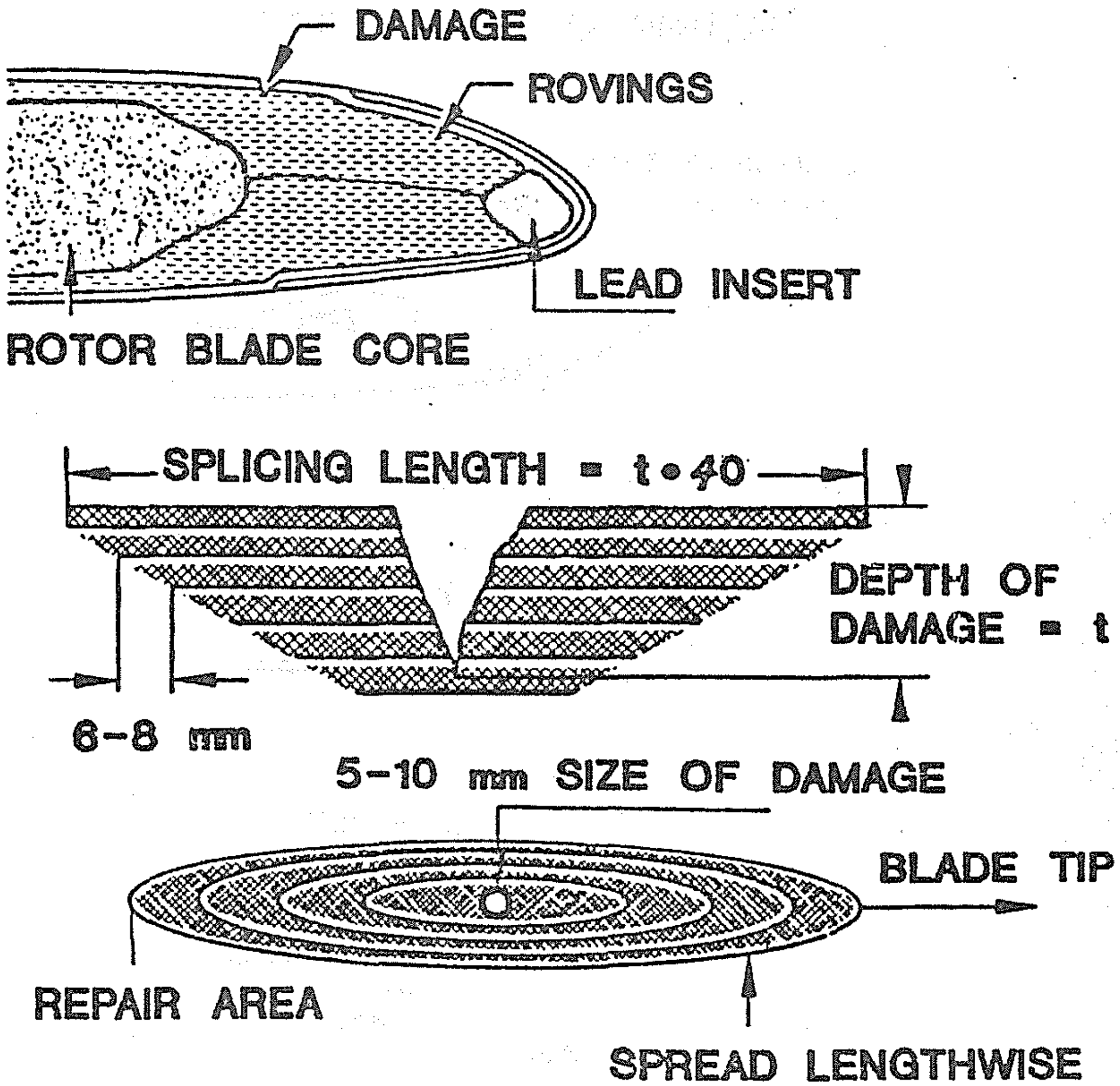
The repair of skin and core damage is the most difficult task as it deeply affects the rotor blade structure. Therefore, five allowable repair areas have been defined. A damage catalog prescribes type, size, and spacing of the defects which may be repaired within these five areas.



Repair areas of the BO 105 main rotor blade

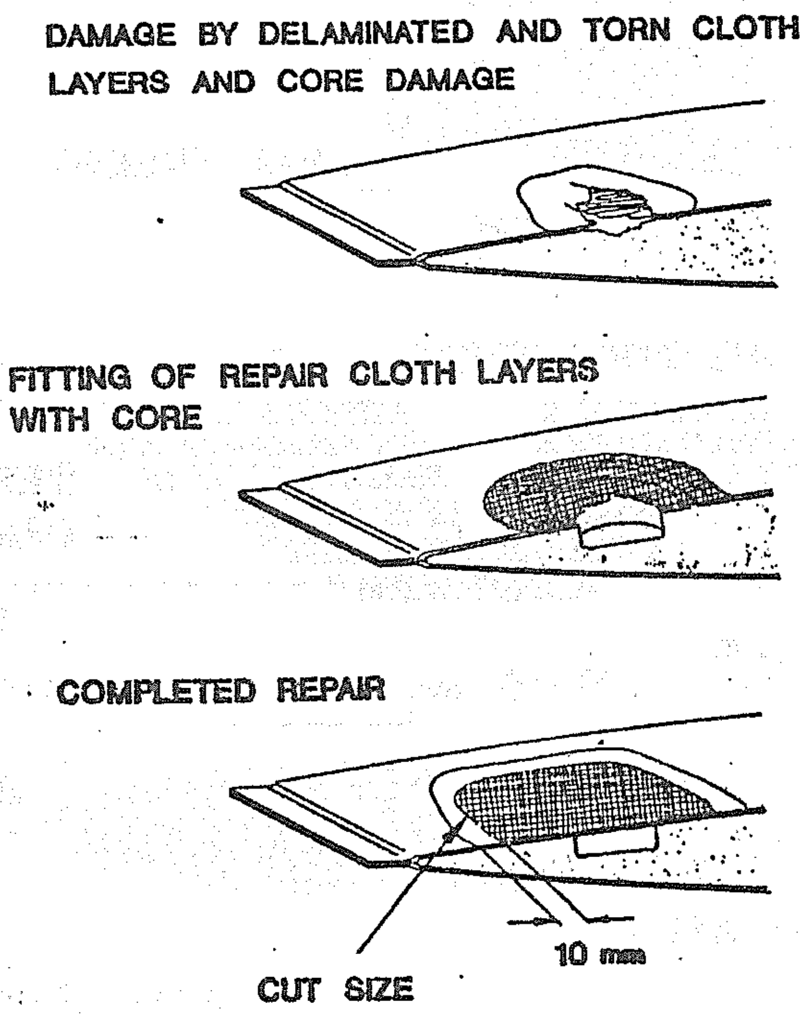
Precise splicing the extent of which has to be determined exactly in accordance with size and depth of damage is important for the repair of rotor blades made of fiber-reinforced plastic.

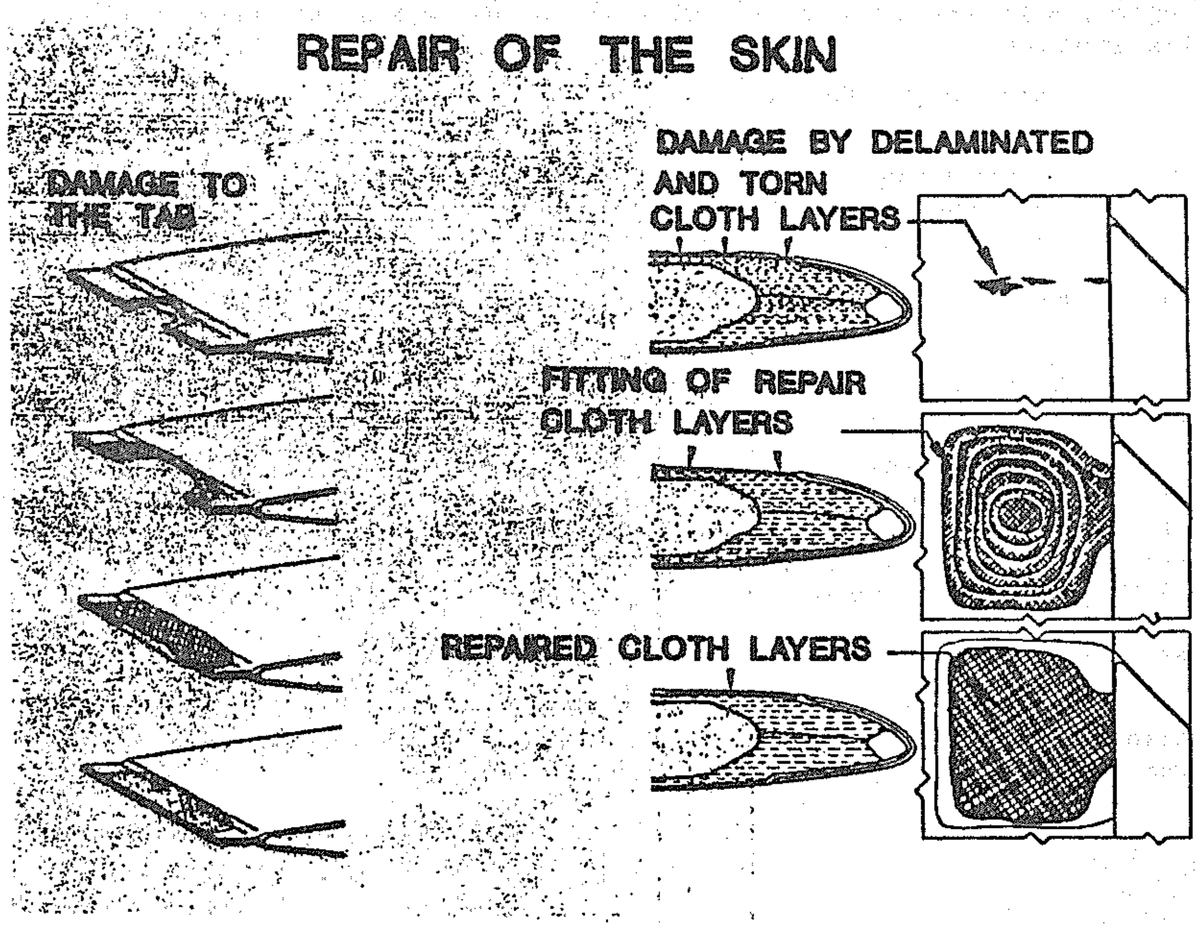
The following figure shows a standard splicing of a rotor blade damage.



The following figure shows repair work within repair area 4, the blade tip area, and repair area 5, the rotor blade center area. These types of repair can be executed with simple means even though an additional core damage has to be repaired within repair area 5.

REPAIR OF THE CORE





The repair within repair area 5 includes a standard repair of the skin.

The right side of the figure shows the repair of damage to the skin at the upper surface of the leading edge.

7. Concluding Remarks

According to the repair manual for Alouette II metal rotor blades, only a Moltopren plug may be glued to the end rib at the organizational maintenance level.

Any other repair as

- repairing corrosion damage at the leading edge,
- replacing corroded, cracked or loose rivets,
- replacing the protective fairing (Inox) at the leading edge,
- repairing a perforated skin,

has to be performed at the commercial maintenance level.

Since rotor blades are subjected to considerable wear and are often damaged, frequent repair is required.

It is of utmost importance to simplify the unavoidable repair work in order to minimize the restrictions imposed on operational readiness. This objective has been achieved by the utilization of rotor blades made of fiber-reinforced plastic. Many years of favorable experience have induced the Federal Armed Forces to procure rotor blades of this design for the UH-1D and MK 41 helicopters as well. Since the rotor blades of every helicopter type are very expensive, we hope for a favorable influence on life cycle cost.

We do not regard the development of fiber-reinforced plastic rotor blades as completed. Extensive effort is still required in this field as far as heavy helicopters are concerned.