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REPAIRABILITY OF COMPOSITE AIRFRAMES

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ABSTRACT

Due to their well known advantages in terms of mass, resistance and environmental behavior, Composite Materials are more and more selected in the new helicopters design. It is the case of the TIGER and NH90 helicopters, presently in development, which have composite airframes. Their design take into account the results of research work conducted in France and Germany by EUROCOPTER.

This research work was extensively conducted in view to explore all the aspects which can be met in service. One of the most important for the user is the composite fuselage repair after an accident or a battlefield damage.

The author presents in this paper the repairing processes for primary composite airframe which have been developed and qualified by EUROCOPTER.

Two types of repairs are presented:
- temporary repairs on field,
- definitive repairs in workshop.

Both types of process have been developed with the aim to get repairs so easy as for metal fuselage and to minimize the quantity of tools and ingredients.

1. INTRODUCTION

The increasing number of composite items in the aircraft structure raises the problem of damage and repair.

The damage and repair problem is taken into account at the design phase, by the substantiation of the parts with damage tolerance concept, the definition of a repair assessment table, and the qualification of the different repairs.

The inspection means and the size of defects to be detected are optimized with the aim to simplify on field inspection.

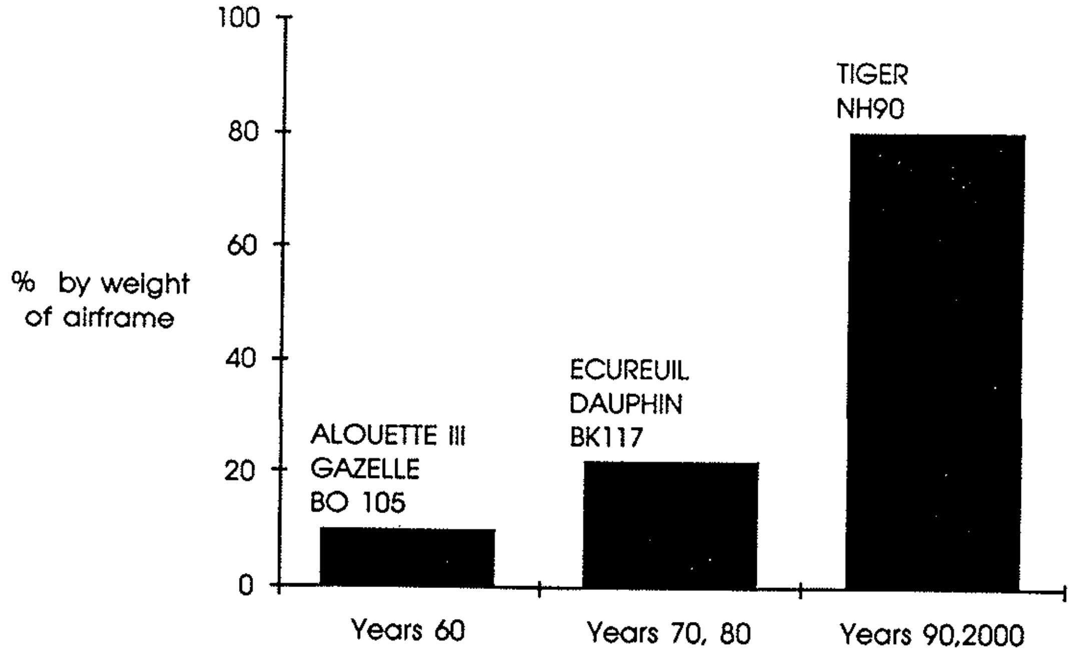
Two levels of repair techniques are developed: temporary and permanent.

Manufacturing aspects are also addressed, showing that the repairs have been designed with the aim to get repairs as simple as possible.

2. COMPOSITE IN HELICOPTER AIRFRAMES

2.1. HISTORY, FACTS AND FIGURES

The composite have been introduced progressively on secondary structures. With the experience so gained and the support of specific research programs, the composite technology has been extended to primary structures and represents now up to 85 % of the structure weight for the TIGER or NH90 (sketch 1).



Sketch 1: Composite materials evolution on Eurocopter's helicopter airframes.

The following table sums up Eurocopter's experience in composite primary structure. A very significant example is the Dauphin fenestron and empennage, certificated in 1982, which has accumulated more than 650 000 FH.

SERIAL PRODUCTION	DEVELOPMENT	RESEARCH
Dauphin: Fin, Stabilizer Certif. 1982 650000 FH	TIGER: complete fuselage	BK117: fuselage flight tested
BK 117 : Stabilizer	EC135: canopy, lower shell, tail boom, fenestron	Research central structure NH90 type : DEFC static and crash tests
Super Puma MKII: Intermediate structure Certif. 1992	NH90: complete fuselage	350 Z fenestron flight tested
	EC120: canopy, fenestron	

2.2. MAIN CHARACTERISTICS OF COMPOSITE AIRFRAMES REGARDING MAINTAINABILITY

It exists big differences between composites and metallic materials which induce important advantages in terms of operation and maintenance :

- The stress - strain diagram of a composite material has no plastic region. The parts are sized to avoid failure at ultimate load, so they are able to withstand an overload up to 50 % of the limit load without plastic deformation.

- The effects of temperature and moisture (extreme environment conditions) are taken into account during sizing by environmental reducing factors applied on new material characteristics, that lead to have a higher safety margin for most of the life of the average aircraft.

- Composite materials are not so sensitive to fatigue as metallic, that makes fatigue failures unlikely on a composite airframe.

- Composite materials do not corrode. Cautions are only necessary were metallic parts are in contact with composite.

All these advantages lead to a large saving on inspection , repair or replacement of parts, reducing the operating costs.

Delaminations are nevertheless a potential problem of composites. They are due to local, high, out of the plane loads, coming from high energy impact. Due to the relative thinness of the helicopter structures, the result of the impact is usually a surface failure or puncture. It is taken into account during design by the damage tolerance approach, and by the inspection and repair manual, as described in this paper.

2.3. MAIN PARTS AND RELATED TECHNOLOGIES

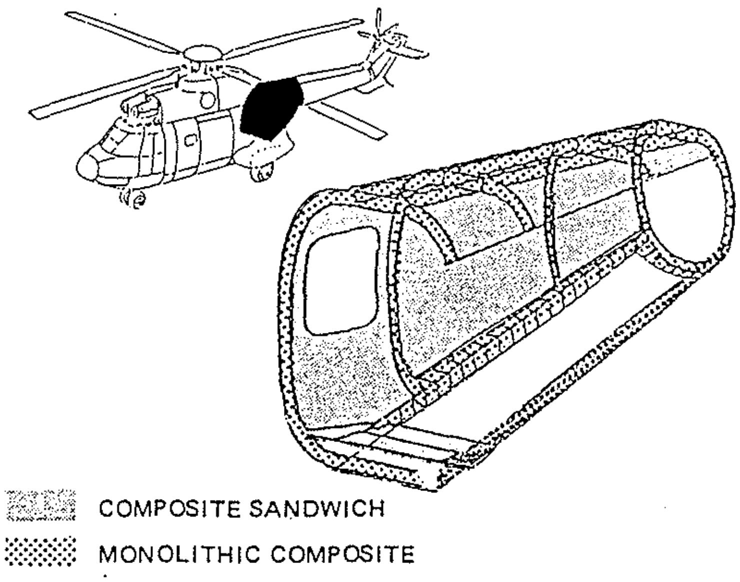
The most efficient technology for moderately loaded shell structure is the sandwich structure, as used on:

- 332 MKII intermediate structure skins (Sketch 2)
- TIGER skins and internal frames (Sketch 3)
- NH90 skins and bottom structure frames
- EC135 lower shell, tail boom and fenestron.

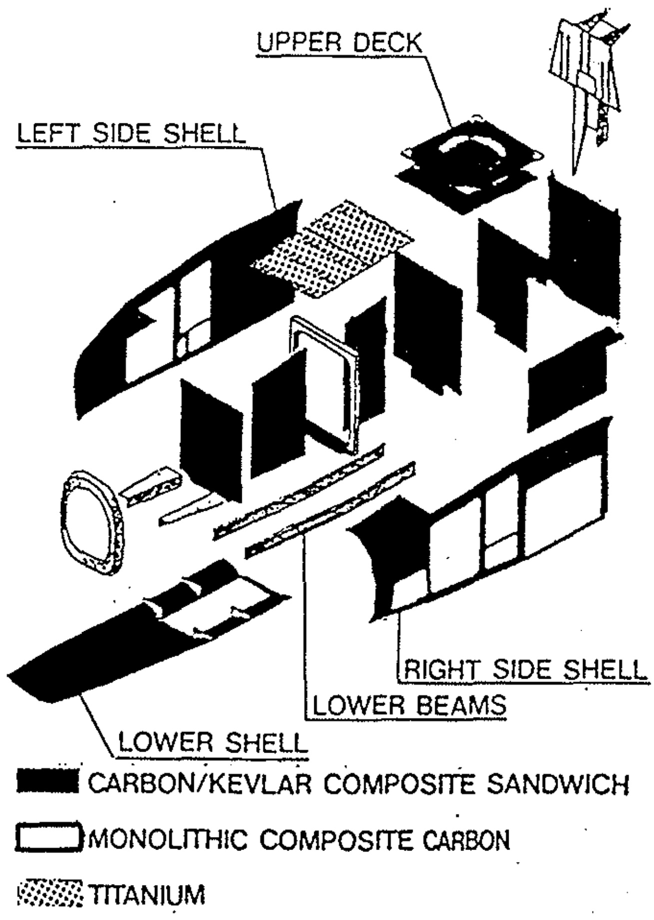
Beams, frames and stiffening elements are mainly made of monolithic as used on:

- 332 MKII intermediate structure internal frames
- NH90 main beams and frames.

The repair principles developed consider these two technologies. The sandwich parts being however in majority, and more exposed to impact (outer surface), we will speak in particular about repair of sandwich parts.



Sketch 2: 332 MKII Intermediate structure



Sketch 3 : TIGER center structure

3. DAMAGES AND REPAIRABILITY IN DESIGN PHASE

3.1. DAMAGE TOLERANCE DESIGN

Since 1989, FAR 29, Amend.28, and AC 20.107 require damage tolerance on composite structures.

The aim of the Fatigue / Damage Tolerance evaluation is to demonstrate that catastrophic failure due to fatigue, environmental effects, intrinsic manufacturing flaws or accidental impact damages is extremely remote during the design life or the service time of the helicopter. Maintenance will be carried out on condition.

For each critical part of primary structure the following substantiation approach is carried out :

The maximum damage size to be considered is determined:

- **a** - Selection of the maximum impact damage size based on a probability assessment of impacts in assembly, maintenance and in-service. The maximum damage size is determined according to the results of this probability assessment and the specified visual inspection programme.

- **b** - The maximum size of damages is determined according to the permissible delaminations and disbonds usually fixed in Quality Assurance NDT document.

Damage sizes resulting from these two points are considered on both static and dynamic dimensioning.

Then for each critical part, following procedure is adopted :

- Determination of the effect of damages on the static strength of the structure (by analysis or by tests).
- Fatigue tests of critical areas on component articles including artificial damages.

Fatigue tests are concluded with a static test showing the residual strength.

3.2. DAMAGE ASSESSMENT AND REPAIR CHOICE

To help the customer to choose the adapted repair, a repair assessment table is defined by the design office, the different parameters are:

- the type of damage
- the size of the damage
- the location of the damage. Each part is broken down into different areas depending of the stress margins, the temperatures in operation, the geometry:
    - Area 1: reserved area, no structural repair allowed without consulting manufacturer.
    - Area 2: Hot area
    - Area 3: Curved hot area
    - Area 4: Cold area
    - Area 5: Specific area.

For each situation, if repair is allowed, a reference to a catalogue repair is identified (see para 5.2 and 5.3).

Limits for number of repairs are also stated, for example, on a sandwich panel (1 m2), are allowed :

- 3 repairs of damages dia <20 mm
- 1 repair of damage 20 < dia < 200 mm

For defects out of the range, specific repairs can be defined in accordance with EUROCOPTER.

3.3. QUALIFICATION OF REPAIRS

Different sample tests are made to qualify the repairs. For each type of repair, it is demonstrated that design ultimate loads capability is reseted.

Finally a test structure including many repairs of different types is submitted to a low load cycle fatigue test, and then the residual static strength is shown by a static test up to ultimate loads.

4. INSPECTION MEANS

An important aspect of the decision is the damage assessment. It is made through a proper inspection technique to maintain the airframe structure.

As described in para 3.1., the structure has been qualified with damage tolerance, that is to say that defects and damages are implemented into the structure prior to static and fatigue tests and qualified with these defects. The inspection techniques will be related to the size of defects to be detected.

The choice have been made during design and qualification of the sandwich parts to admit a defect easily detectable by simple means, in a daily inspection.

4.1. ON FIELD

Only **visual daily inspections** (walk around inspection) is required to assess the general condition of the airframe, looking for:

- external signs of impacts, such as scratches, notches, chipping, dents.
- looseness of rivets

This visual inspection is completed by **Coin-tapping** where a damage is suspected.

4.2. IN THE WORKSHOP

To the two basic inspection means used in field, **Ultrasonic test equipment for bond testing** can be added to carry out inspection of specific areas during major servicing, such as some highly stressed frames bonds, load introduction areas.

This equipment is easy to operate.

5. REPAIR TECHNIQUES

5.1. GENERAL

The driving factors for the choice of the repair technique were:

- restore sufficient structural integrity and satisfy design requirements (electrical bonding, fire resistance, ...)

- repair must be possible in situ without removing the part of the aircraft

- the number of different ingredients must be minimized, especially short shelf live products,

- the tools and process must be as simple and standard as possible.

Different types of repair operations have been developed:

- Cosmetic repair:
The mechanical strength is not altered by the damage, the tightness and the cosmetic aspect of the area must be restored. Temporary or permanent repairs have been designed.

- Temporary structural repair on field:
The mechanical strength is altered by the damage, it is restored by quickly implemented means. The aim of this kind of repair is to put the helicopter back to service quickly and with limited means. The materials and tools must be standard, the repairs must be simple and call only standard practices, the time to repair must be short.

- Final structural repair (Permanent repair):
The mechanical strength, altered by the damage is restored finally. This repair is done in an agreed workshop, referring to a catalogue of definitive repairs.

5.2. COSMETIC REPAIRS

In general, there is no worry of stress raisers due to scratches or small radiuses introduced by a damage.

Damage can be left on a temporary basis, but it is necessary to apply a protective treatment to prevent water ingress which might cause further degradations.

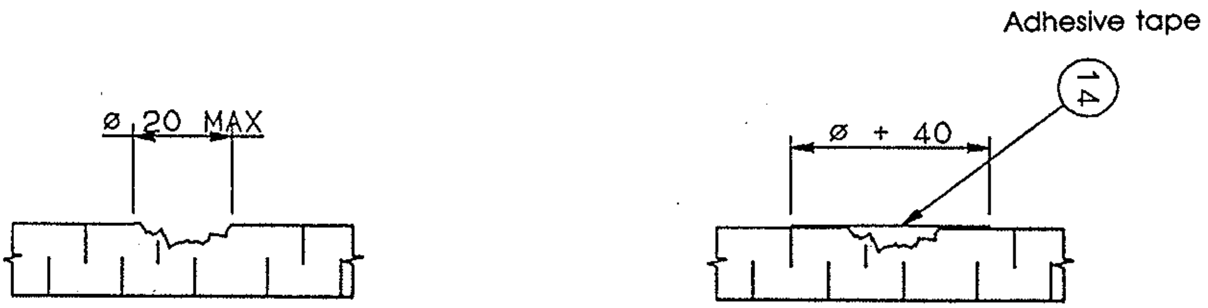
The following table presents an abstract of the repair assessment table of 332 MKII intermediate structure, showing areas and type of damages concerned by cosmetic repairs.

Type of damage	Dimension of repairable damage	Area	Type of repair		
			Temporary	Final	
				Flat element	Curved element
Impact, honeycomb sinking	Visible dia. ≤ 20 Real dia. ≤ 25	2-3-4	1 T	1 P	1 P
Impact perforating internal skin and/or honeycomb damage	Visible dia. ≤ 20 Real dia. ≤ 25	2-3-4	1 T	1 P	1 P

The proposed repairs are:

- **Temporary repair** (Sketch 4, Repair type 1T):

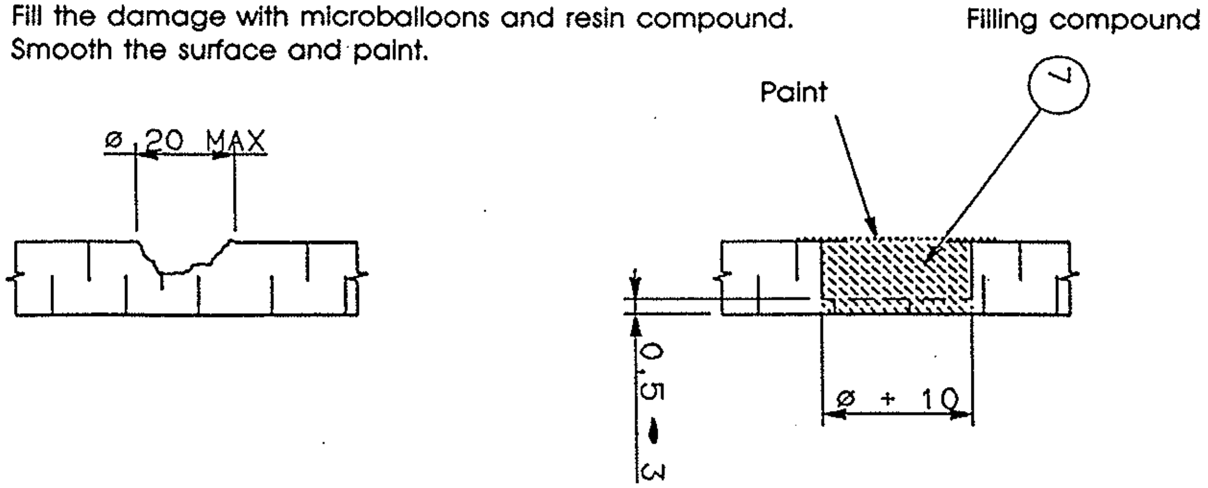
The small size damage is protected by a water proof patch: adhesive tape.



Sketch 4 : Repair type 1T, Temporary cosmetic repair.

- **Permanent repair** (Sketch 5, Repair type 1P):

Fill the damage with microballoons and resin compound.
Smooth the surface and paint.



Sketch 5: Repair type 1P, Permanent cosmetic repair.

5.3. STRUCTURAL REPAIRS

The following table presents an abstract of the repair assessment table of 332 MKII intermediate structure, showing areas and type of damages concerned by structural repairs.

Type of damage	Dimension of repairable damage	Area	Type of repair		
			Temporary (provisional)	Final	
				Flat element	Curved element
Impact perforating internal skin and/or honeycomb damaged	20 $\leq$ dia. $\leq$ 200	2-3-4	2 T	3P	3P
external skin and/or honeycomb damaged External skin Internal skin	20 $\leq$ dia. $\leq$ 150 20 $\leq$ dia. $\leq$ 200	2-3-4	2 T or 13T	5	5-5F

The table shows that repairable damages with catalogue repairs, in most areas of the structure, can have a size up to diameter 150 mm on external skins or 200 mm on internal skins. A big effort has been made to increase the size of damages considered to allow the customer to repair without referring to EUROCOPTER for a majority of damages.

Here again, two different types of repairs are considered : Temporary and Permanent.

The different repairs must be adapted to flat or curved (single curvature) elements.

If necessary, a flush repair is proposed (5F).

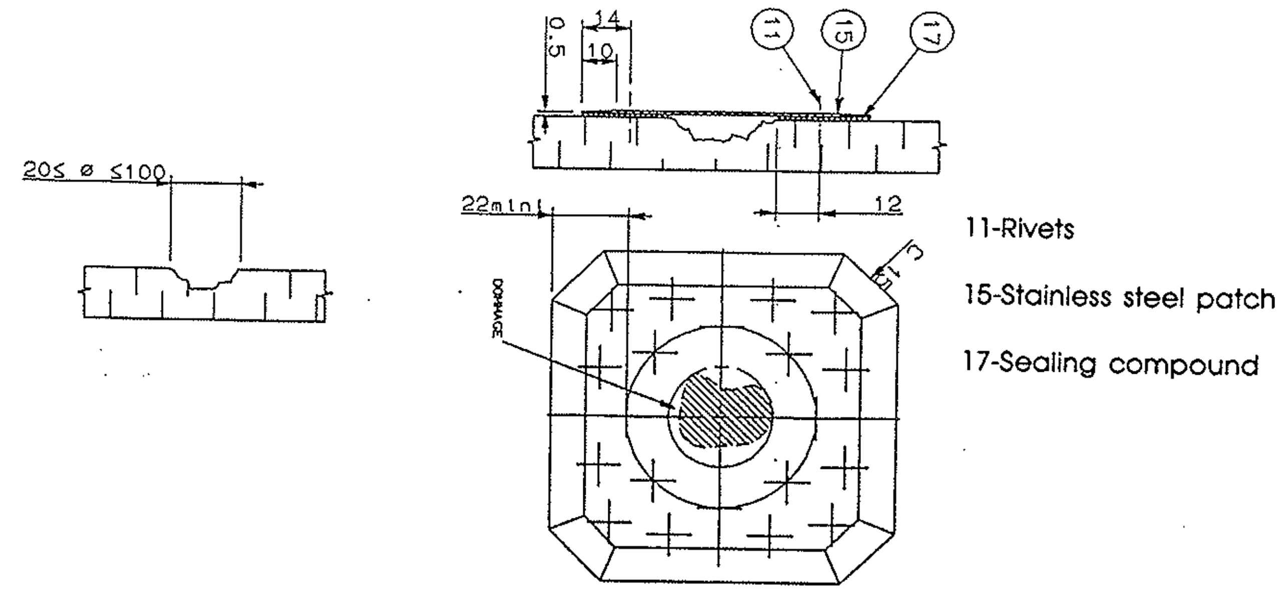
5.3.1. TEMPORARY REPAIRS

Eurocopter has developed a simple and rapid temporary riveted repair concepts for composite structures, that are compatible with existing repair concepts for metallic structures.

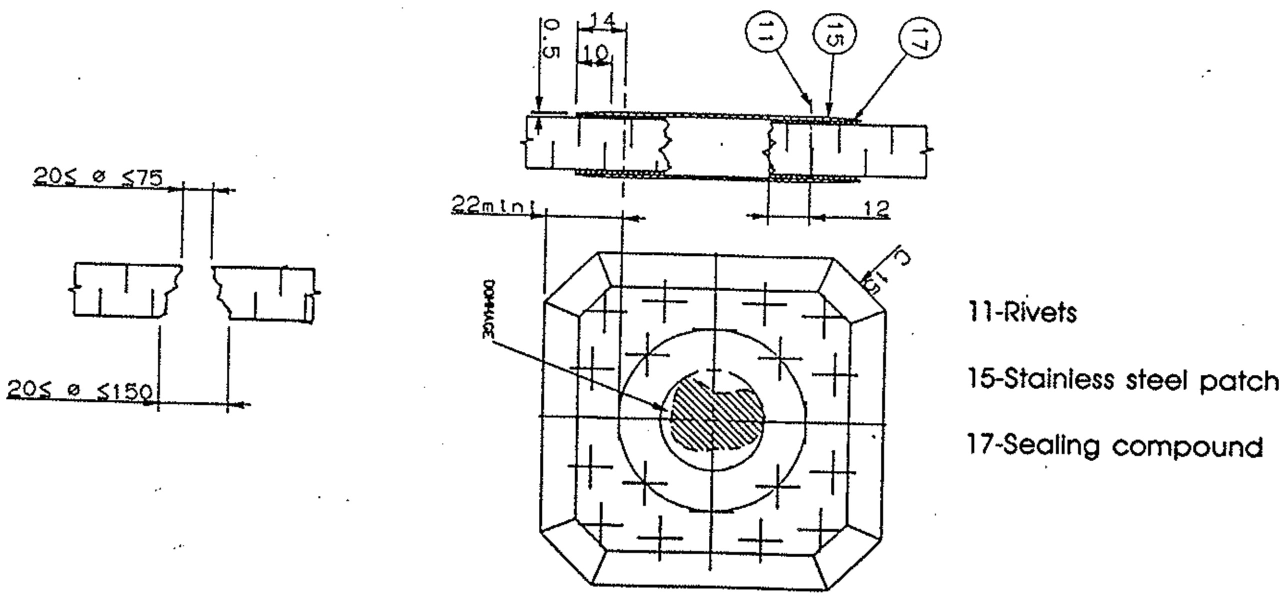
The repair consists of the mechanical attachment of metallic doubler plates directly over the damage area.

Material of the doubler is stainless steel to avoid galvanic corrosion. A sealant is applied between the doubler and the skin. The repair plates are installed externally, to simplify the repair. Typically blind fasteners are used to attach the repair plates. Fastener diameters are standardized at 3.2 and 4 mm that simplify logistics (number of drills and fasteners limited). To minimize the time to repair, and simplify fabrication, simple plate shapes such as rectangles or hexagons are selected. The edges of the plates may be beveled to improve aspect but it is not mandatory. The stainless steel plate can be easily formed to the shape (single curvature) of the structure to repair.

The following sketches show two types of temporary repairs, type 2T, sketch 6 were only internal skin is damaged, and type 13T, sketch 7, were both skins are damaged.



Sketch 6:Repair type 2T, Temporary structural repair.



Sketch 7: Repair type 13T, Temporary structural repair.

5.3.2. PERMANENT REPAIRS

Eurocopter has developed and qualified a simple permanent repair concept for composite structures, which is close to existing repair concepts for metallic structures. This repair applied to selected areas, with a certain size allows to reconstitute the strength necessary to the repaired part, to allow flight without any limitation.

The repair, derived from the bonded repair principles, consists of a stack of thin composite hard precured patches bonded and riveted directly over the damage area. If the honeycomb is damaged, it is reconstituted with new honeycomb, bonded on the edges to the honeycomb of the part.

Material of the hard patches is the original carbon prepreg of the parts, or equivalent. The hard patches are manufactured by Eurocopter following the same manufacturing process than the original parts, and delivered in big plates as a semi finished product to the customer. No particular storage precautions are necessary. There are two different patches, with different orientations of fibres, the orientation being marked to ensure a correct positioning .These two different patches allow to realize all necessary combination of orientations of plies, and all necessary thicknesses .

The plates are cut to the necessary size, shape, and orientation in the repair workshop. The total thickness being made by a stack of patches, it is possible to minimize stress concentration by a staggered edge of the repair doubler, made by decreasing sizes of patches.

The patches are very thin and can be bent to the shape of the part (single curvature or very small double curvature) to be repaired without any difficulty. The final bonding makes the shape definitive

The patches are assembled together and to the part by bonding and riveting. The main load transfer is made by the bonding, rivets are used as tools to apply the pressure on the adhesive. In case of failure of the adhesive, or debonding, rivets are able to take a percentage of ultimate load, that allows to add a fail-safe aspect to the repair.

As qualified for the SUPER PUMA MKII intermediate structure, adhesive is a 110°C cure supported adhesive film, for bonding composite on composite, or nomex on composite. The materials of the parts (180°C class) allow to cure the adhesive in situ without degradation of the parts.

Rivets are stainless steel blind fasteners, which ensure enough installed tension during riveting.

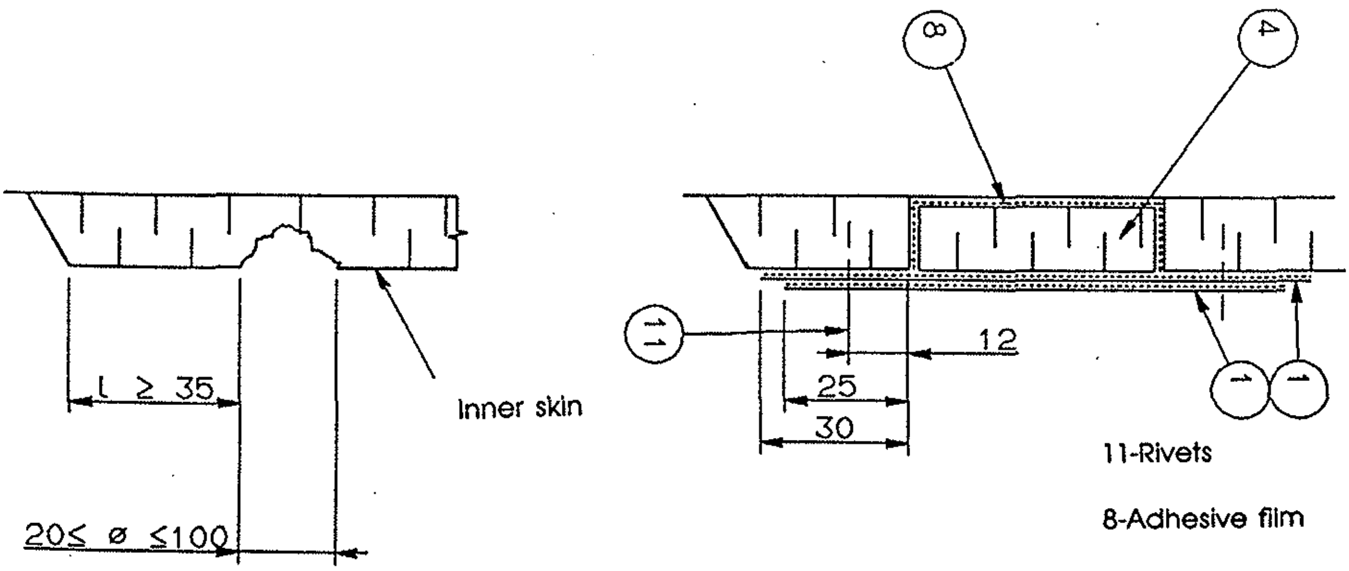
The main advantages of this kind of repairs are:

- Use of qualified materials, and qualified process and inspection, for the manufacturing of the parts in EUROCOPTER facilities ensures quality and performance of the patches.
- The bonding and riveting technique allows to make a fail safe repair.
- The repair concept is very similar to repair of metallic parts, and doesn't need specially trained workers, the techniques involved are classical, except the curing of the adhesive.
- The number of materials necessary is very limited, and the only material with a shelf life, to be stored in a freezer is the adhesive film.
- The tools are standard, except the heating device.
- This repair can be used on the different parts of the helicopter, without removing the parts.
- This repair concept allows to realize repairs on curved parts without any mould

EUROCOPTER is involved in an European research program on repairs, and is working in particular on the qualification of new structural bi-component adhesives for this kind of repair, curing at room temperature, and which have good characteristics at high temperature. This new adhesive will allow to simplify again the repair process by avoiding the storage of an adhesive film, and the use of an heating device.

The following sketches show three types of permanent structural repairs:

- type 3P, sketch 8 were only internal skin is damaged,
- type 5P, sketch 9, were both skins are damaged, the repair is shown on a curved surface, but of course is similar on a flat surface,
- type 5F, sketch 10, which allows a flush repair.



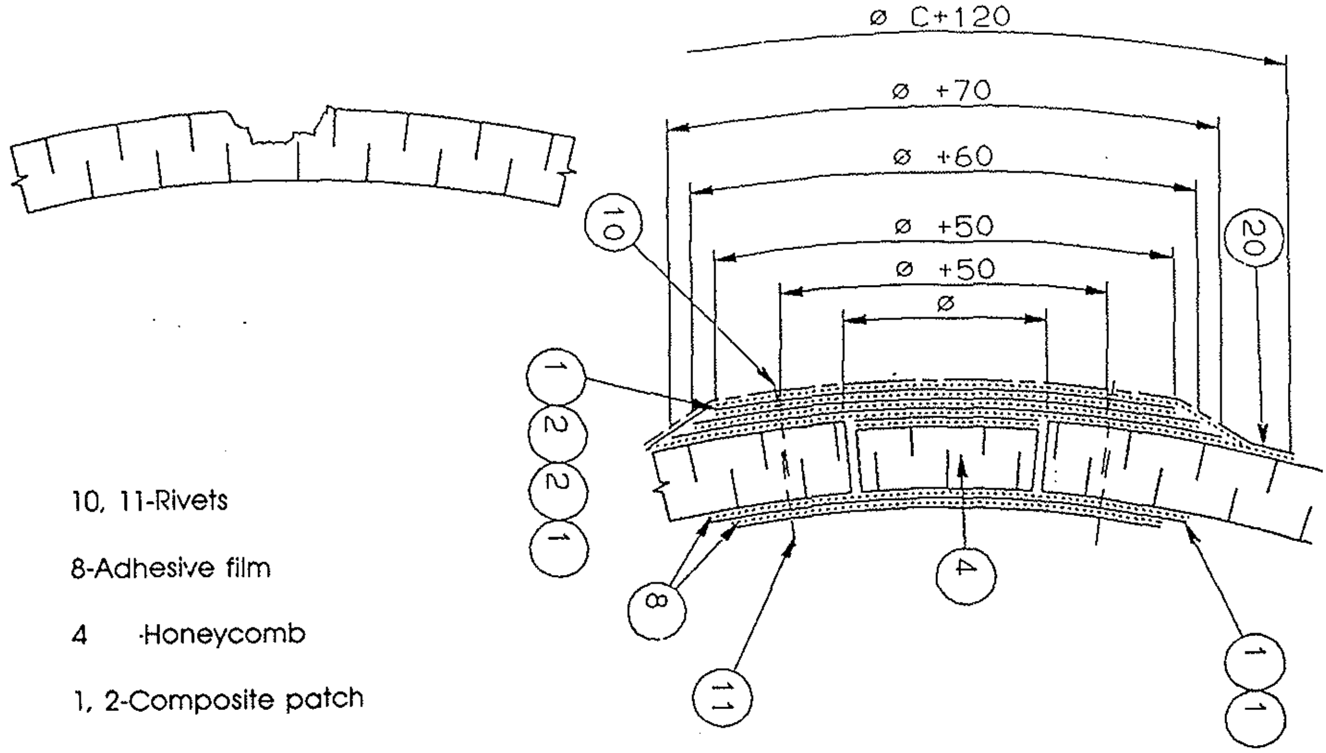
11-Rivets

8-Adhesive film

4-Honeycomb

1-Composite patch

Sketch 8:Repair type 3P, Permanent structural repair.



10, 11-Rivets

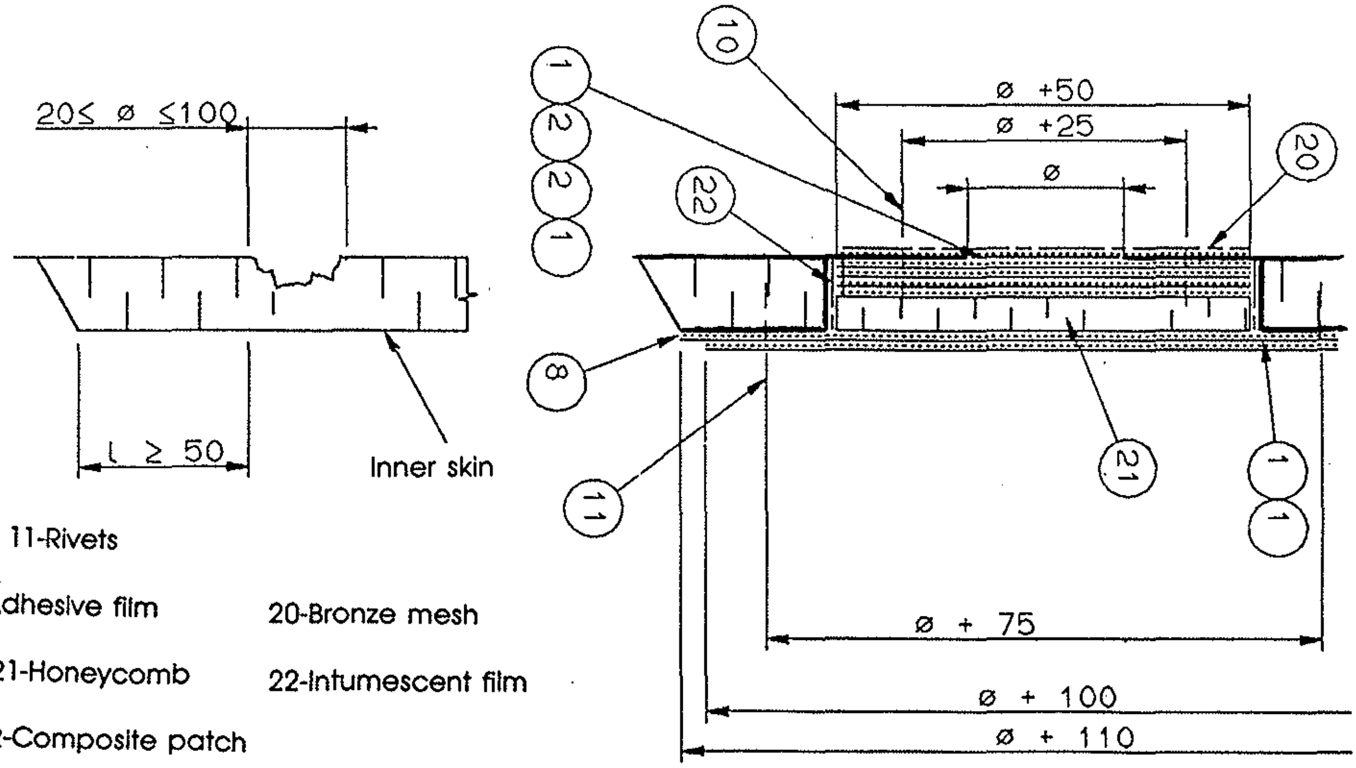
8-Adhesive film

4 -Honeycomb

1, 2-Composite patch

20-Bronze mesh

Sketch 9:Repair type 5P, Permanent structural repair.



10, 11-Rivets

8-Adhesive film

4, 21-Honeycomb

1, 2-Composite patch

20-Bronze mesh

22-Intumescent film

Sketch 10:Repair type 5F, Permanent structural flush repair.

6. MANUFACTURING

The manufacturing process for temporary repairs is very classical, special tools or means and highly trained people are not necessary. They can be easily realized on field.

For permanent structural repairs, the main phases of the manufacturing process are:

- Machining of the damaged area.
- Cutting of the patches.
- Surface preparation of the part and the patches. The surface preparation of the patches is reduced to nearly nothing, because the patches come with a peeling ply, that protects the patch and allows a good bonding.
- Installation of patches, adhesive, and rivets. Blind fasteners are used.
- Curing. No vacuum is needed, the pressure being applied by the rivets. Until cold curing adhesive is qualified, an heating device is necessary, based on heating blankets.

The curing operation excepted, this process is close to classical metallic repairs.

7. CONCLUSION

With the extensive use of composite in airframes, Eurocopter has made an important work on repair of composite structures in order to be able to propose to the customer simple and efficient repair methods.

Depending of the part, the area of the part, the type and size of defects, temporary and permanent repairs are proposed, to satisfy both the immediate and long term needs.

Temporary structural repairs are based on metallic doublers riveted to the parts, very similar to metallic repairs.

Permanent structural repairs are made of precured composite hard patches, made of a stack of thin precured plates, bonded and riveted to the part. The tools and the number of ingredients are minimized, the means necessary are limited to a heating device.

These repairs can be easily done by workers used to metallic structure repairs.

Eurocopter is still working to improve the methods, and is on the way to qualify a cold curing adhesive for repair, in replacement of the adhesive film.

All this makes maintainability of composite parts, nearly as easy as metallic parts.