REPAIR PROCEDURES FOR ADVANCED COMPOSITES FOR HELICOPTERS

by
Hermann Eschbaumer
Production Engineering
Experimental Shop
Messerschmitt Bölkow Blohm GmbH
Helicopter Division, Munich, Germany

ABSTRACT

The application of composites introduced a significant change in the structural design for aeronautical engineering. Weight savings, performance increase and reduction in life cycle costs are the achievements for both, operator and manufacturer. Now, airframes are manufactured utilizing nearly 100% of composites as the structural material. Differential construction was replaced by large, highly integrated FRP - components. In case of any damage, large and very expensive parts will be involved. Replacement of the damaged pieces, as it used to be the repair method for conventional constructions, has become fairly difficult and very costly too. The way how to deal with new materials and technologies made aircraft users and services hesitating. Development of repair procedures as well as their approval was essential.

The aim of this paper is to discuss standard repair procedures and the various solutions, which have been determined for structural repairs. Repairs on load introduction areas and extensive damages have been rated to require specific repairs and therefore assistance of stress design. Specific repairs will not be discussed hereinafter.

This presentation will refer to standard repairs applicable for primary and secondary structures. It will distinguish between "In House Repairs", "Depot and On Aircraft Repairs" and "Field Repairs.

It will also refer to suitable NDT - techniques for non-stationary inspection and will discuss aspects to transfer the required standard repair procedures to maintenance personnel.

INTRODUCTION

Pioneered in the laboratories and brought to flight initially in the 60's on the Bölkow Rotor System, Fiber Reinforced Composites have continiously increased their usage on nearly every production program of flight structure. This ambitious first introduction of new high performance plastics into flight structure was followed and extended by several experimental hardware programs and replacements of secondary pieces like covers for weight saving reasons during the 70's. The breake through for series production application of composites for primary airframe structure was leaded by the avant gard of these programs, the Airbus A310 Vertical Fin, also driven by MBB, or the USAF F-16 and US Navy F/A-18A in the 80's.

On the helicopter side of the business, programs like the USA ACAP introduced composites to the primary structure of helicopters. Dwarfed but not neither sophisticated the so called "Poor Mans ACAP",the German BK 117 Faser Zelle, utilizes more than 50% of the total weight of advanced composites for the fuselage frame.

Weight reductions of 30% as well as performance increase are the gains of these development studies served for convincement of design for the new generation of helicopters.

MBB Deutsche Aerospace

COMPOSTIE AIRFRAME OF BK 117

HE512 91 03

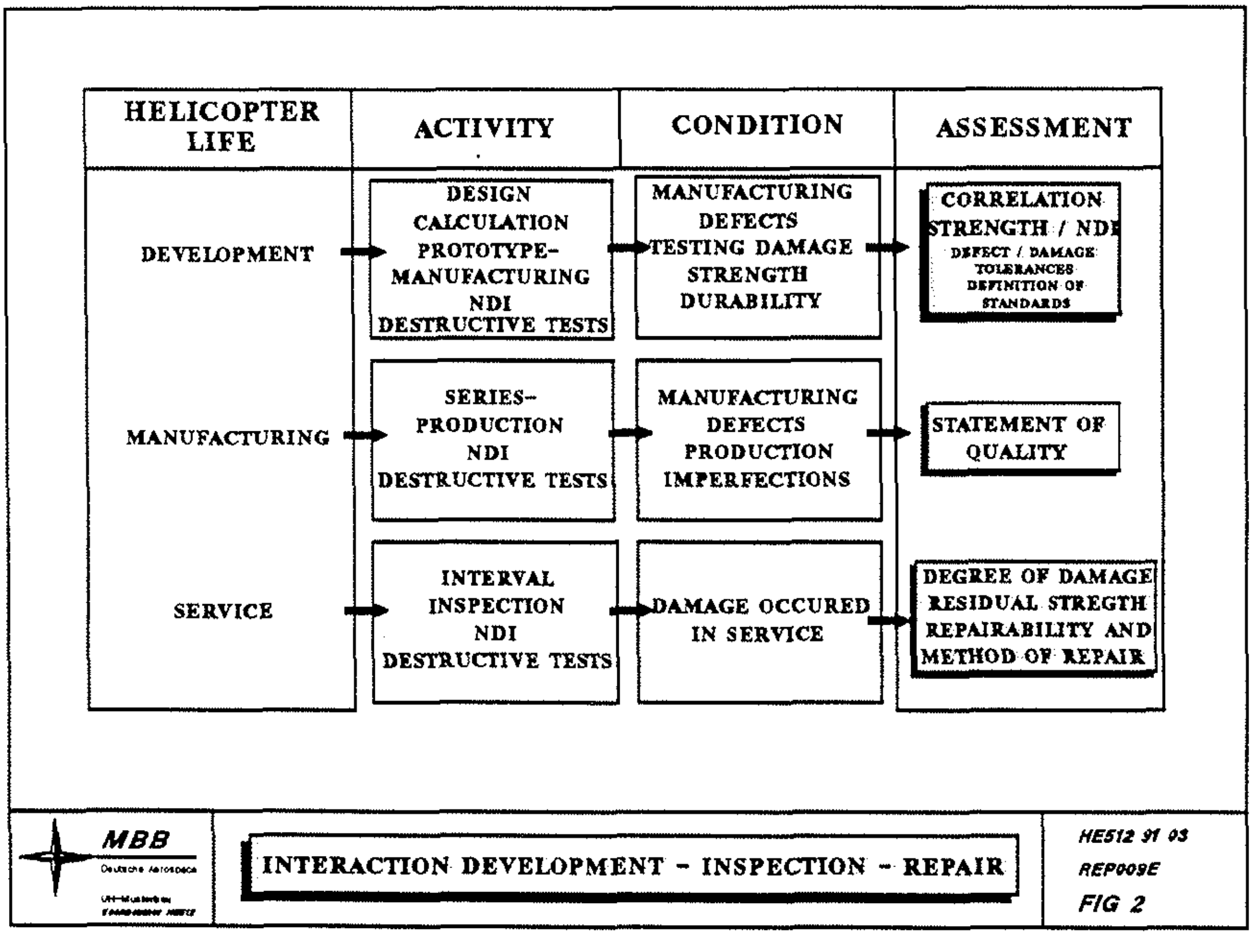
REP001E

FIG 1

Today, modern designed helicopters like the French / German Tiger or the US Army UH-60A utilizing nearly 100% of composites for the primary structure. Repair capabilities for these airframes have become a requirement for manufacturing and operation. Repair procedures capable for advanced composites must ensure a complete functional restore of the damaged component.

Therefore, a complete understanding of the composite design procedures and knowledge of the manufacturing technology apears to be a must for composite repair.

This leads me to the basic question on future application of composites for primary structure.
Who or what is going to be the future repair shop?



Will it be high payed specialists, who combine all the necessary know how?

Will it be a licenced repair shop, equipped with autoclave and NDI facilities or just a regular operators hangar with hand tools?

To answer these questions, we have to analyse the composite development process, the manufacturing techniques, the most endangered structures and the possible repair solutions considering following aspects:

- **Reserve factors, quality standards and damage tolerances**
- **Classification of parts**
- **Detection of damages, NDI methods and most damage exposed areas on aircraft**
- **Available repair methods and requirements for thermoset materials**
- **Transfer of repair procedures to the operator**

TECHNOLOGICAL BACKGROUND

As sayed, complete functional restore is a must for repairs. Regarding this requirement, we have to know, how the defected part was designed, what was the initial material and what are the design procedures for composite materials. Defects, manufacturing imperfections and damages are interruptions in the homogeneity of all materials. Repair of these flaws will be certainly an improvement, but will not restore the materials steadiness. These reductions are considered already in the design procedure as reserve factors.

Associated to these reserve factors the NDI, the destructive testing and the failure interpretation of development test articles will deliver a correlation of strength and quality. The derivative of these results are quality standards.
Taking samples from the series production for destructive inspection and testing of already flown hardware for determination of residual strength will provide damage tolerances and information of allowable defects. These are the minimum provisions to be considered in design.

INPUT: VALUES OF UNIDIRECTIONAL RESPECTIVELY WOVEN FABRIC PREPREGS FOR AR / RT AND H / W CONDITION
(AR = AS RECEIVED)

CALCULATION:
STIFFNESS
THERMAL EXPANSION
MECHANICAL STRENGTH
STABILITY
BEARING AND NOTCH TOUGHNESS
MATING INTERACTION
STRUCTURAL COMPONENTS (BUCKLING STIFFENERS, SANDWICH....)

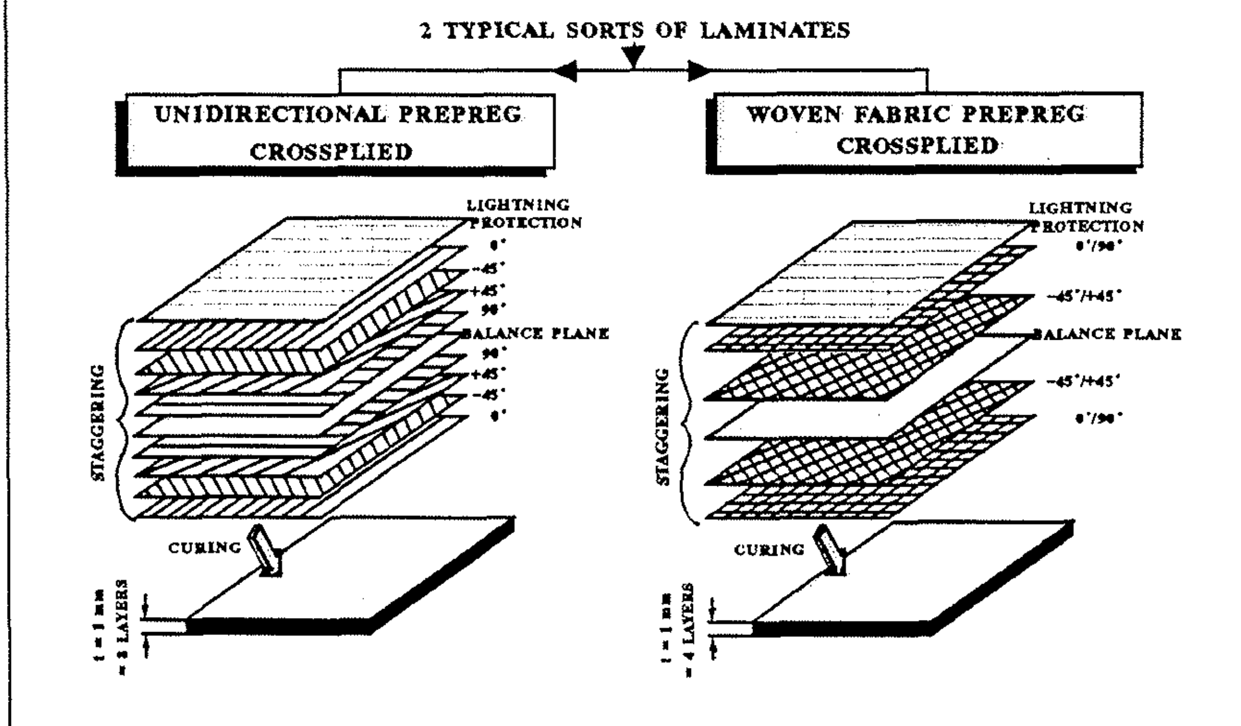
OUTPUT: RESERVE FACTORS

MBB | DESIGN PROCEDURES FOR ADVANCED COMPOSITES | HE512 91 01 REP006E FIG 3

Fiber reinforced plastics are unisotropic materials. This unisotropic behavior is one of the advantages of these materials. Staggering of layers in various fiber orientations will allow a design, corresponding to the actual load pathes. That means, by designing the composite components, we are designing also the material, spefically for the part itself. Each component could have its very layup sequence, which includes local reinforcements, tension girths or buckling stiffeners. Even mixtures of different fiber materials are possible, such as Glass, Aramid and Carbon. We call that a hybrid construction.

Typical airframe structures are reinforced by honeycomb cores or buckling stiffeners. Extensive drawings and process specifications are necessary to ensure proper manufacturing of such components.

Each single layer, each piece of core and adhesive must be addressed in the process sheets according its succession to build for production and documentation reasons.



DESIGNING THE MATERIAL BY STAGGERING OF LAYERS

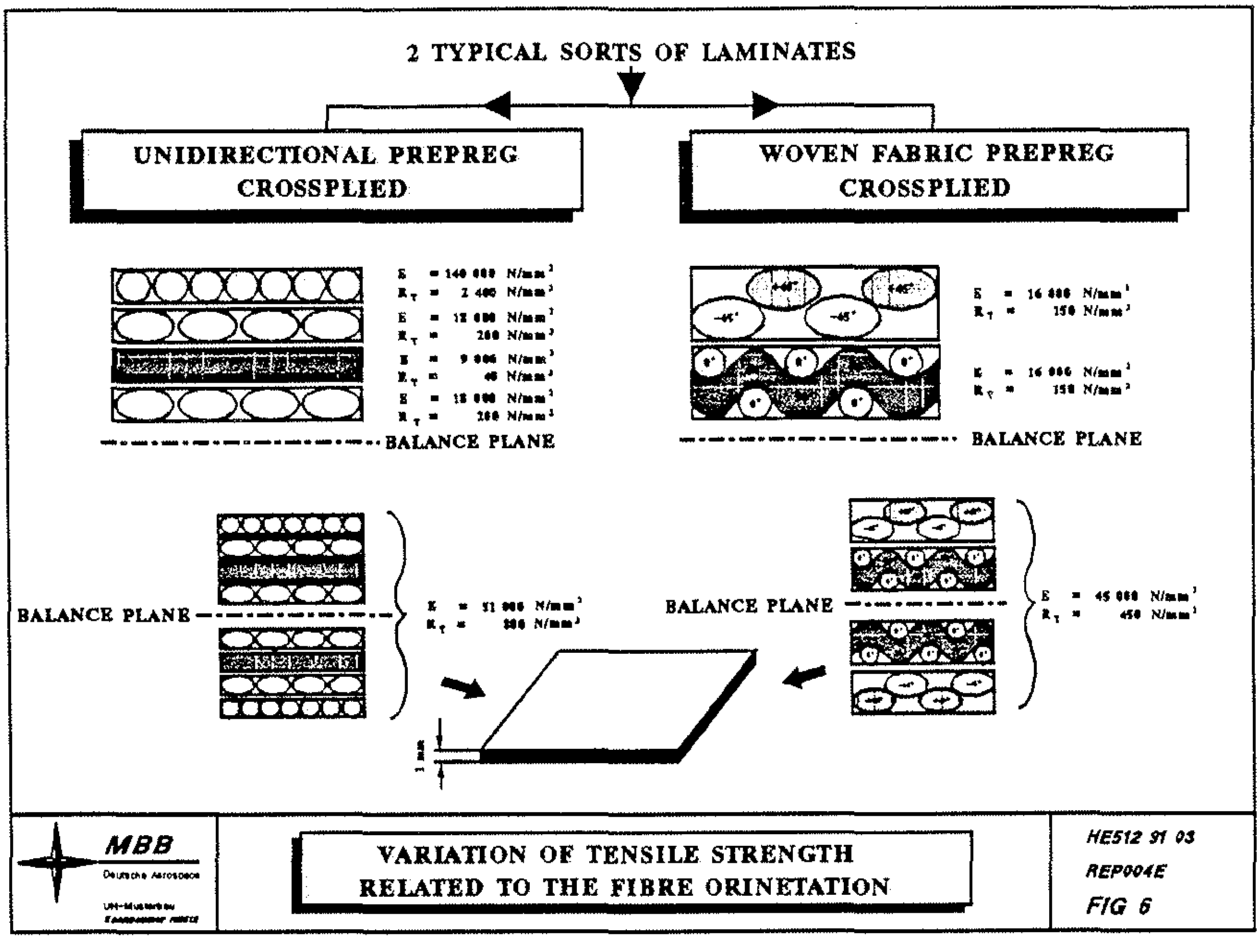
HE512 91 03
REP005E
FIG 5

Today, we are able to handle and process nearly any combination of different materials such as fibers, resins, pregregs, honeycombs and adhesives. We are able to manufacture large and highly integrated structures comprising the total composite know how in one single component.

Within the repairs of composites we have to restore the component and therewith the layup in its detail and all integrated structural elements. In order to continue load pathes, fibers must be replaced in the same directions as determined in the original design. For preparing any repairs, we have to be aware of what has to be replaced.

Looking at the different fiber materials and their various orientations within the laminate, there is a wide difference in the mechanical strength of each layer.

Figure 6 indicates the variation in tensile strength related to the fiber orientation, even within a monolitic laminate. Composite components for helicopters often are designed using a mixture of Carbon-, Aramid- and Glass Fibers. In order to increase stiffeness, laminates are reinforced by honeycombs and foam sandwiches. These hybrid constructions would even complicate the strength determination. Additionally, there is also a remarkable difference in the mechanical properties amongst the type of fibers as well as their style. As shown on figure 6 it differs between 450 N/mm^2 on a quasi isotropic laminate of T300 carbon fabric and 800 N/mm^2 on a T800 carbon unidirectional prepreg.
That means for the repairs, a restore of the component may only be possible by replacing materials as determined in the original design.



Additional to that variety of fibers, there is also a wide difference in the matrix materials as well. Up to now, the most common matrixes on helicopter composites are thermoset materials. Fiber reinforced thermoplastics are more or less in an introduction phase and will not be discussed within this paper.
However, the thermosets differ basically in their temperature resistance and shear strength. Both measures are an indicator for their processability and curing temperatures. Differences in resin viscosity, moister absorbtion, shelf life time e.g. are influence factors for the manufacturing technology.
Several provisions must be made for storage, handling and processing of these materials. Cold stores up to -18°C and environmental controlled workshops with aircondition and dustcontrol are requested to store and handle uncured thermosets. Vacuum pumps, autoclaves, ovens and heated presses are the minimum facilities needed for processing.

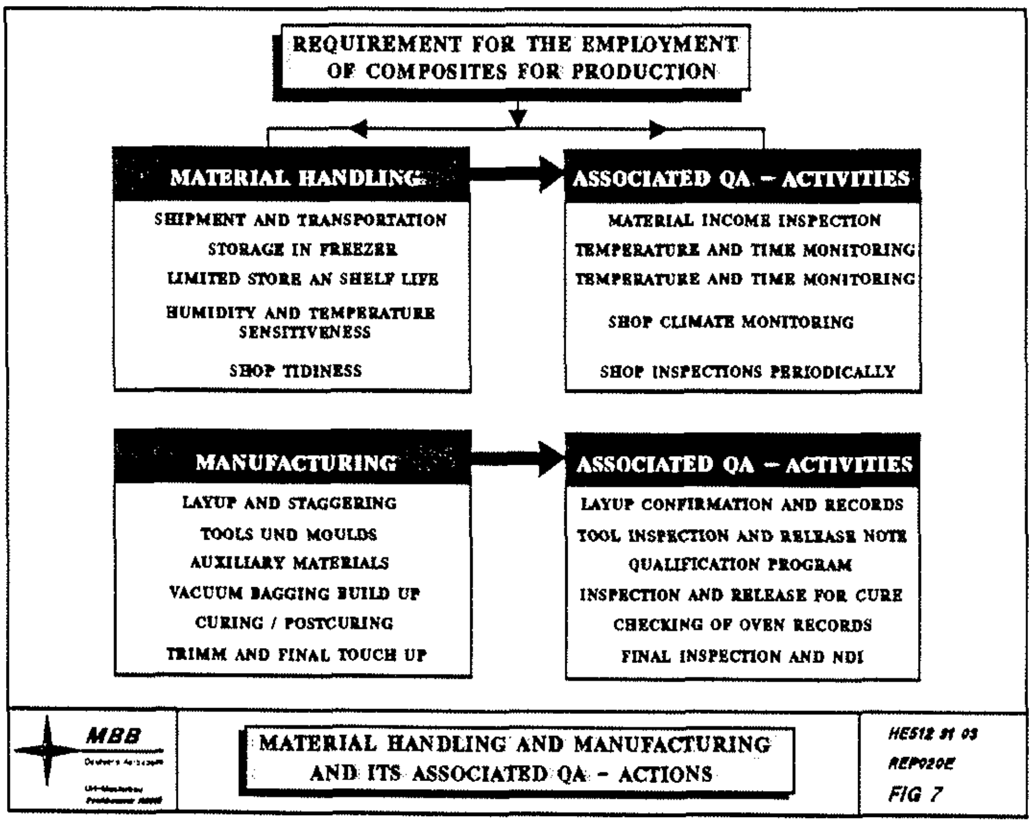
Coherent to the process technology are the auxiliary materials, necessary for debulking, bagging and curing. The quality achieved in manufacturing of composites will depend on these auxiliary materials. Therefore, peel plies, release films, breathers and vacuum bags are carefully selected and tested prior their application.
As one can see, concernig the design procedures as well as the manufacturing technology there is no limitation in complexity neither on the expenses for facility investments of the composite shop.

The core operation of repair on composites would need similar facilities and an equal variety of auxiliary materials if we tend to restore the defected part according its initial design. Furthermore the skill of the composite workmates and of the facility operators would be a minimum requirement.
This is defenitely not the way to sell composite productes and to introduce repair procedures to the operators.

STATEMENT OF QUALITY AND QUALITY ASSURANCE

Since we produce simultaneously to the component manufacturing the material, the part values will differ from the material values used for design. Temperature, humidity, shelf life time, shop tidiness as well as manufacturing imperfections, process divergences and tolerances will influence the quality. Uncured thermosets are characterized by their thermal instability, their sensitiveness for humidity and their limited shelf and store life time. The manufacturing process requires spefically developed debulk operations, precompaction cycles, cure and postcure cycles, where temperature, vacuum and pressure is applied following an especially defined cycle chart.

This requested a completely new shop and store environment as well as a new shop management too.
In the intent to produce quality products, these handling and manufacturing influences are carefully observed and monitored by quality control measures.
To emphhasize, even simple things as shop tidiness may influence the part quality drastically.
In order to ascertain the product quality manufacturing and storage monitoring, quality control, non destructive inspection and destructive testing of process traveller specimens were the measures taken for QA.



One of the peculiarities of composites are unvisible defects due to their impact sensitiveness. Damages occured during handling or operation may mark on the surface, but their extent can't be visually recognized. Detection and determination of defect sizes is essential prior to any repair activity. This is only possible by non destructive inspection techniques. During the feasibility phases for composites very efficient NDI - methods were developed and approved for detection of such flaws. Specimens and test components, built with artifical defects gave a correlation of NDI - results to strength and therewith a statemant of quality.

Today, there are various NDI - techniques available which are:

* **Visual Inspection**
* **Coin tapping**
* **Fokker Bond Testing**
* **Ultrasonic Inspection where we distinguish between:**
  + **Through Transmission**
  + **Squirter Technique**
  + **Impuls Echo**
* **X - Ray**
* **Holography**
* **Computer Tomography**

Each of these methods will provide sufficient evidence for quality, but require high trained personnel. The invest expenses for X-Ray, Holography and Computer Tomography are tremendous and will not be adaptable to all inspection tasks.
Thin laminates of glass fiber may be inspected visually using a luminous source. Delaminations, voids and bonding separations can be seen easily.
Coin tappping may be sufficient for the inspection of thin laminates of Aramid, carbon and glass. Small defects like voids may not be identified clearly. High skilled personnel is required.
Fokker Bond Testing was originally designed for inspection of metal bonds. Its application to composites is limited and rarely used.

The most common NDI - technique for composites is the Ultrasonic Inspection. The invest expenses depend upon the equipment used and its purpose. However there are portable devices available for reasonable expenses, which are adaptable to almost any NDI - task. These devices are in particular suitable for non stationary service and therefore well appropriate for repairs and field repairs.
The Ultrasonic inspection offers in basic three (3) different techniques.

* ***Through Transmission***

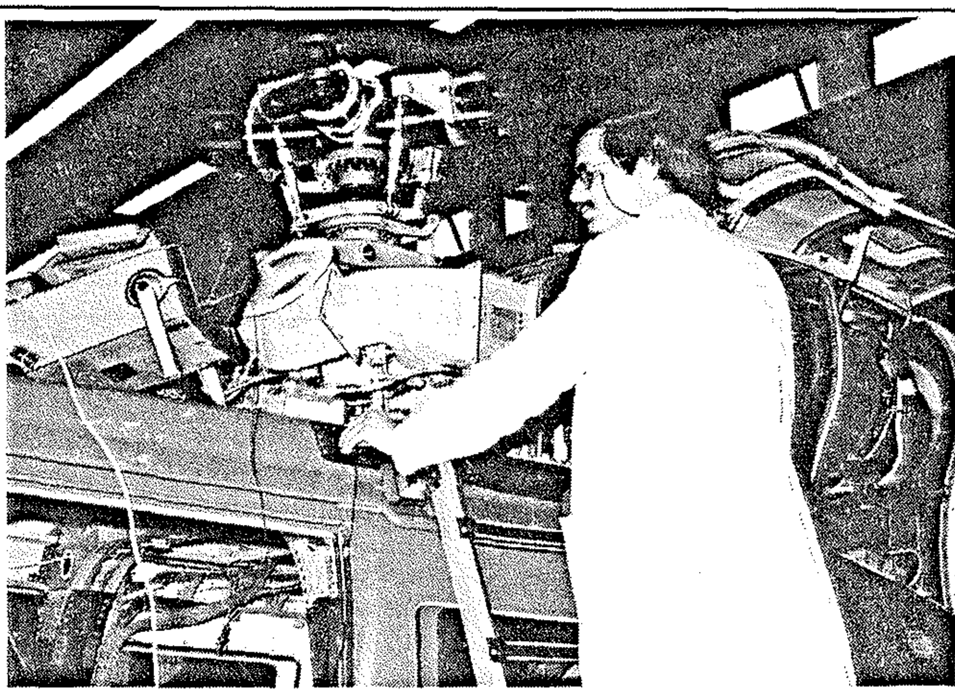
The component must be placed in a water basin between transmiter and receiver. This technique is not suitable for field repairs.

* **Squirter Technique**

This is also a through transmission technique, the accustic coupling is made by a pre_enable distance of water. Dismantling of the component is required.

* **Impulse Echo Technique**

The component can be inspected accessible from one side.
Up to now, the Ulrasonic inspection, in particular the interpretation of the signals requires highly skilled personnel as all NDI - methods do.



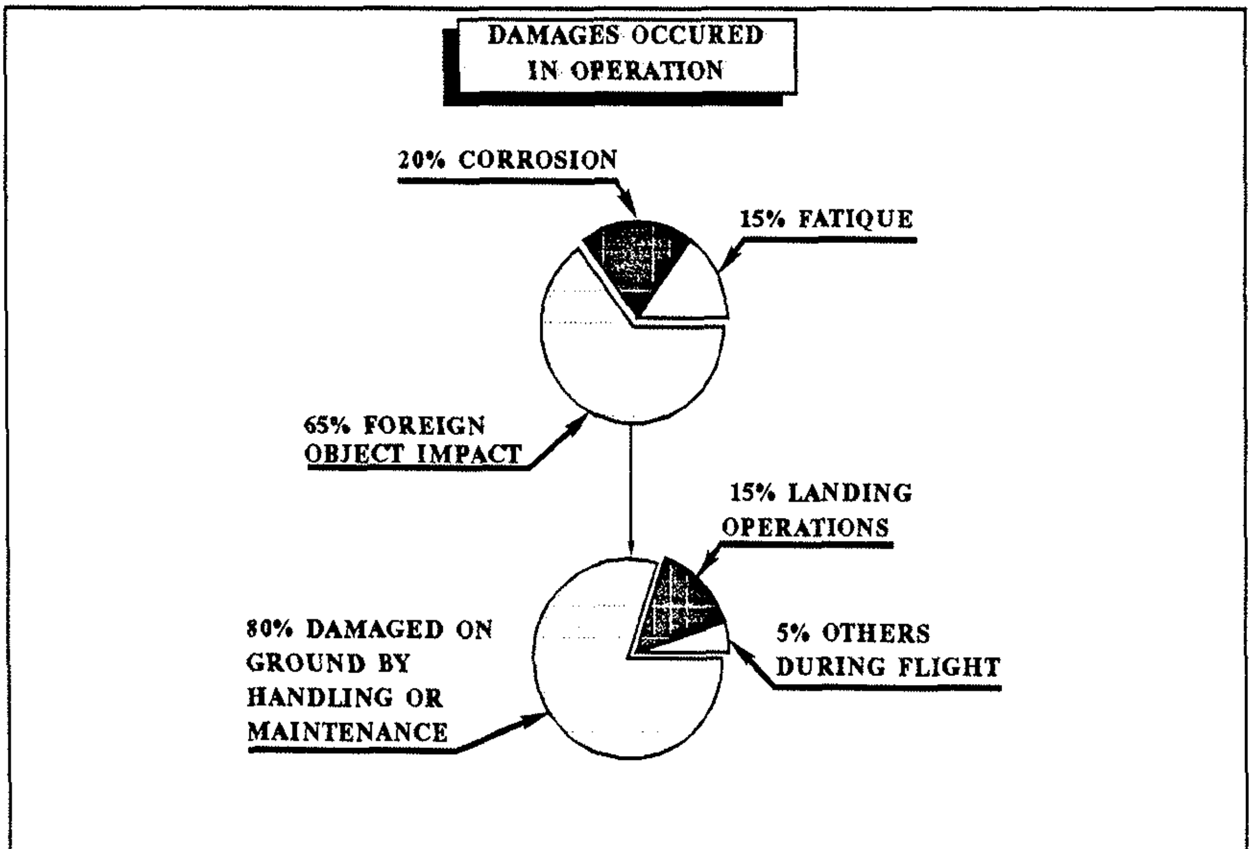
MBB | ULTRASONIC INSPECTION ON A BK 117 HELICOPTER | HE512 31 03 REP029E FIG 8

The ultrasonic inspection, in particular the Impuls Echo Technique appears to be the most appropriate NDI - method for repair purposes. For some time there are portable equipments available, which offer conversion of the sound echo to a multi color screen as well storage of these data on computer disk. The different sound attenuations measured will indicate as varying colors on the screen. The former very difficult interpretation of signal amplitudes on the monitor is now reduced to the comparison of colors. The advantage of this equipment is definiteley the employment of a PC and the storage of datas on disk. Due to mailing of computer disk to the manufacturer mistakable results can now be efficiently analysed by a specialist. To allow such services the composite manufacturer should provide calibration gauges to repair shops and operators comprising its complete variety of composite materials used on its helicopter with artifical defects. Additionally, the repair handbook should indicate beside the damage tolerances a compartison list of ultrasonic attenuation to color images.

DAMAGE CLASSIFICATION

Associated to the detection of defects and damages is their assessment. In order to define the suitable method for the defect determination and an appropriate repair solution, it is important to know the damage occasion. According to the **Structural Composite Working Group Report, IDA Record Doc. D 31, 1983,** the main damage causes on airframe structures are fatique, corrosion and impact.

As reported, 65 % off al damages are initiated by impacts of foreign objects. Far and away the most impact damages are caused during on ground handling like maintenance e.g. fall down of tools, hitting during transport or by ground support equipment, fall down during assembly. Impact damages during operation as bird-, stone - or hailstrike has been reported fairly seldom .



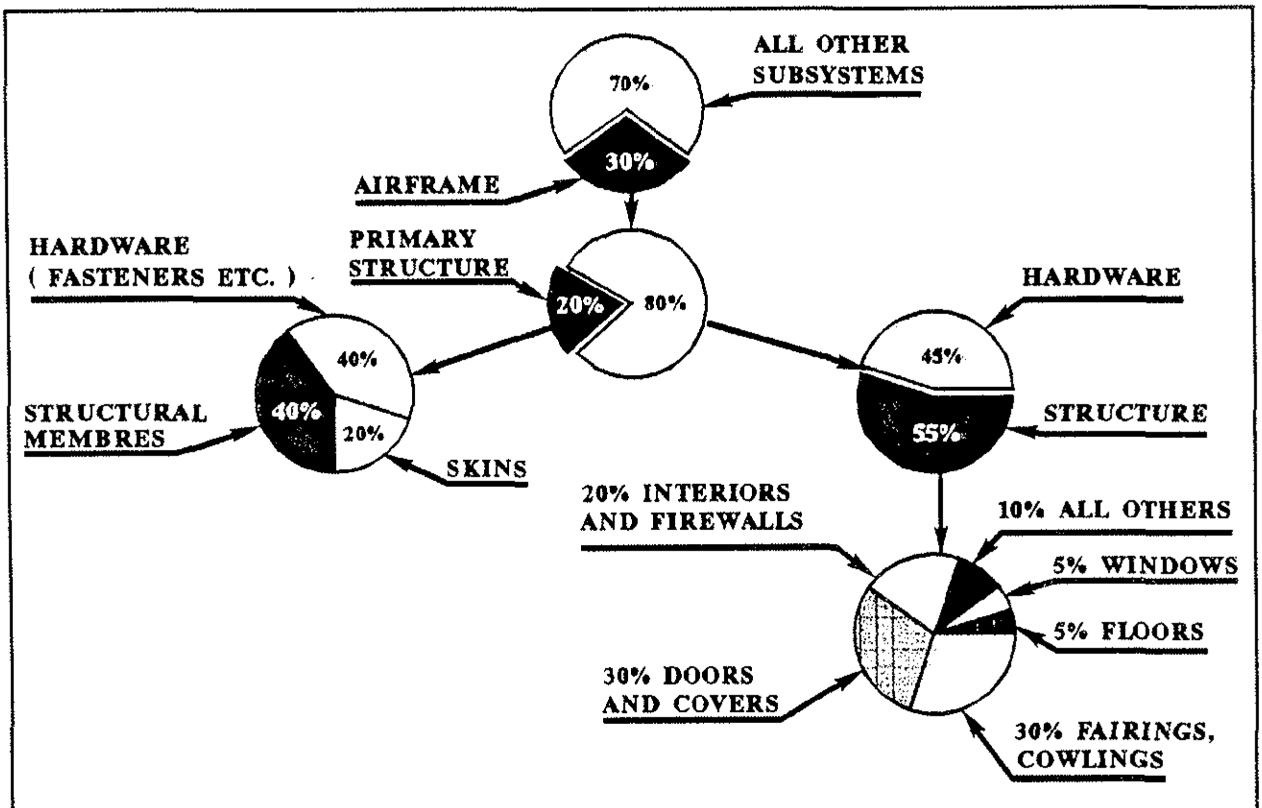
MBB

DAMAGE OCCASIONS ON HELICOPTERS AND ITS FREQUENCY

HE512 91 03
REP028E
FIG 9

In order to define suitable repair techniques, it is important to know what needs to be repaired. Evaluating the records of damages we establish impact endangered areas on the airframe structures. According to the **IDA / OSD Reliability and Maintainability Study Vol. 6, Steering Group Report 1983** only 30% of the total amount of repairs is related to the helicopters airframe.

Analyzing of this 30% indicates, 80 % of these repairs were required on secondary structures and only 20% related to primary structure. The study distinguishes also between hardware and structure, whereas 55% of secondary and 40% of primary structure was involved in repairs. Considering this, we should focus on repair techniques applicable for secondary structures.



MBB

AIRFRAME CONTRIBUTION OF HELICOPTERS TO REPAIRS

HE512 91 03 REP02/E FIG 10

Derived from the damage occasion we can define the damge impact and its appropriate inspection method. For instance, damages initiated by overloading may require dismantling of the component and a 100% inspection. Whereas a stone impact may need just a local inspection and a suitable repair. The follwing figures will show the most common damage causes and its related impacts.

The damage impact differs dependent on the design. Monolithic construction may show different destruction than sandwich components do with the same type of impact. Since we found foreign object impact during ground handling as the most severe damage causation, the impact sensitiveness of composites has become of major importance.

	DAMAGE CAUSATION	DAMAGE IMPACT
IMPACT DAMAGES	HANDLING AND ASSEMBLY DEFECTS BATTLE DAMAGE LIGHTNING STRIKE RUNWAYSTONE - / HAILSTRIKE BIRDSTRIKE	DELAMINATIONS EDGE DEFECTS PEELED LAYERS PENETRATIONS
PRODUCTION FLAWS	MANUFACTURING DEFECTS HANDLING AND ASSEMBLY DEFECTS	VOIDS POROSITY DRILLING FLAWS
FLIGHT DAMAGES	OVERHEATING / FIRE DAMAGE EROSION OVERLOADING	EDGE DEFECTS DELAMINATIONS DISBONDS

MBB — DAMAGE OCCASION AND ITS IMPACT — HE512 91 03 REP007E FIG 11

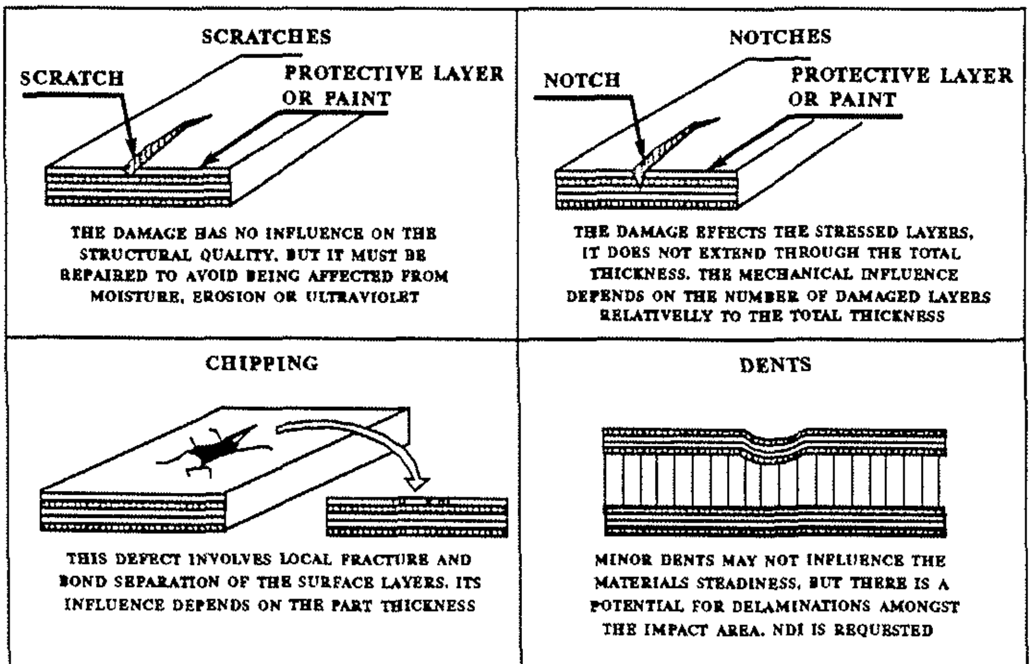
Since we have found the foreign object impact as the most probable cause for damages, the extent of destruction depends on the energy involved.Therefore we can distinguish between:

* **Low energy impact as**
  + handling incidents
  + dropping a tool
* **High energy impacts such as**
  + bird-, hail-, stone strikes
  + combat damages, ballistic impact
  + crash
* **Crack initiation and propagation**
  caused either by impact, fatique or overloading

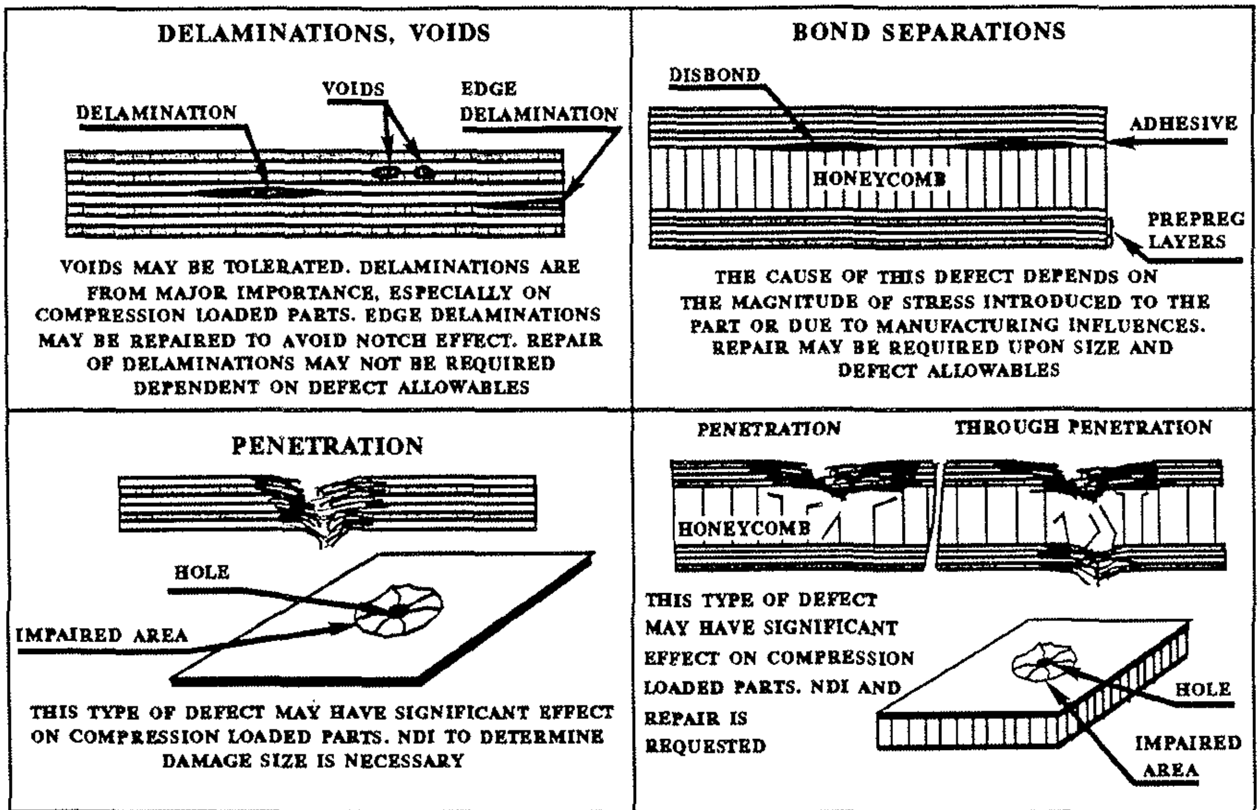
Considering this, the follwing damage categories may be identified:

* **Scratches, notches, chippings, dents**
  (which are surface flaws)
* **Disbonds, delaminations, voids**
  (which are interlaminar defects)
* **Perforations, penetration**
  (ballistic impact damages)

These typical damages may be combined to **Minor Damages** with non or limited influence on the structural integrity and into **Limited and Major Damages** where approved repairs are requested.



MBB — DEFECT / DAMAGE CLASSIFICATION MINOR DAMAGES — HE512 91 03 REP017E FIG 12



MBB

DEFECT / DAMAGE CLASSIFICATION
LIMITED DAMAGE SIZE

HE512 91 03
REP018E
FIG 13

PART CLASSIFICATION

Structural components of airframes may be classified into three categories, which are:

* Vital Parts

These are critical components whose failure or malfunction could result in loss of the aircraft.

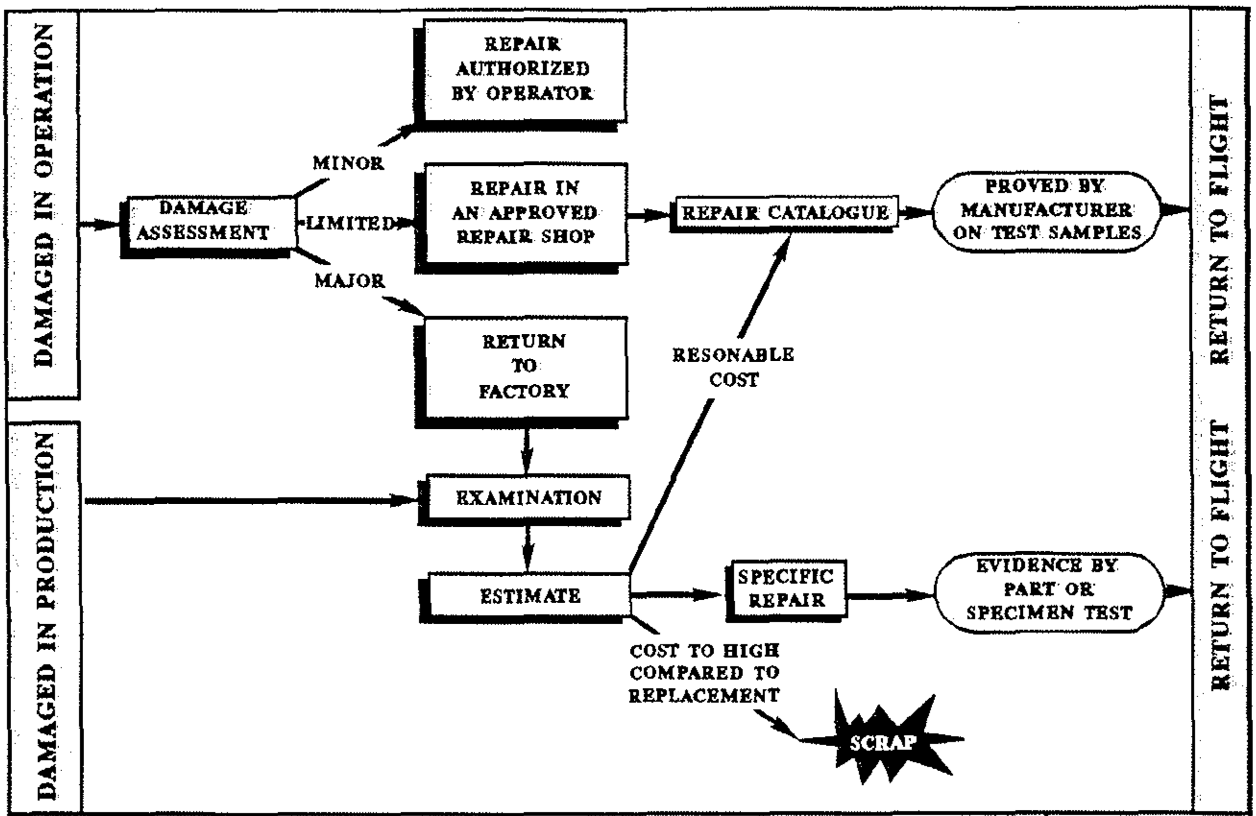
* Primary Structure Components

Failure of these parts may have serious consequences on the aircraft operation or may jeopardize the fatigue strength of vital part requiring subsequently major maintenance.

* Secondary Structural Components

Failure of these parts has no direct influence on the aircraft operating safety.

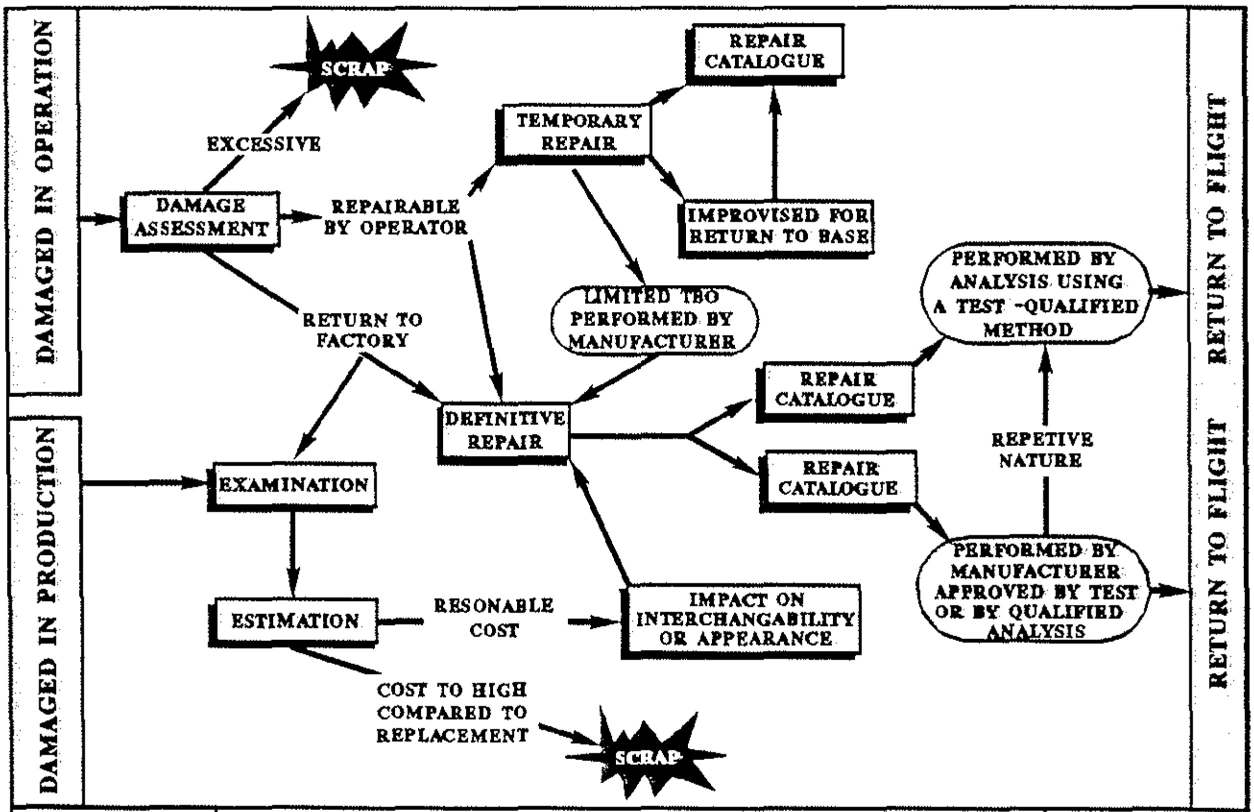
The application of composites for primary structures opened many possibilties for the layout and design of airframes. Covers, doors, main frames and bulkheads, even bearingless rotorblades or fuselage skins are now made from advanced composites. Large, single sectioned components comprising secondary structure as well as high loaded primary sections like load introduction zones within a detail part. That means, one single part could contain all three part classifications. The classification of parts must now include a mapping of safety areas. This mapping should be shown in the maintenance handbook.
Consecutive to the damage assessment is the determination of the defect location related to the part or area classification. Dependent on this classification there are several ways to proceed for repair. Vital parts may be differentely treated than structural components (see Fig.s 14 and 15)



MBB Deutsche Aerospace

DECISION FLOW CHART FOR REPAIR OF CLASS 1 COMPONENTS AND VITAL PARTS

HE512 91 03
REP011E
FIG 14



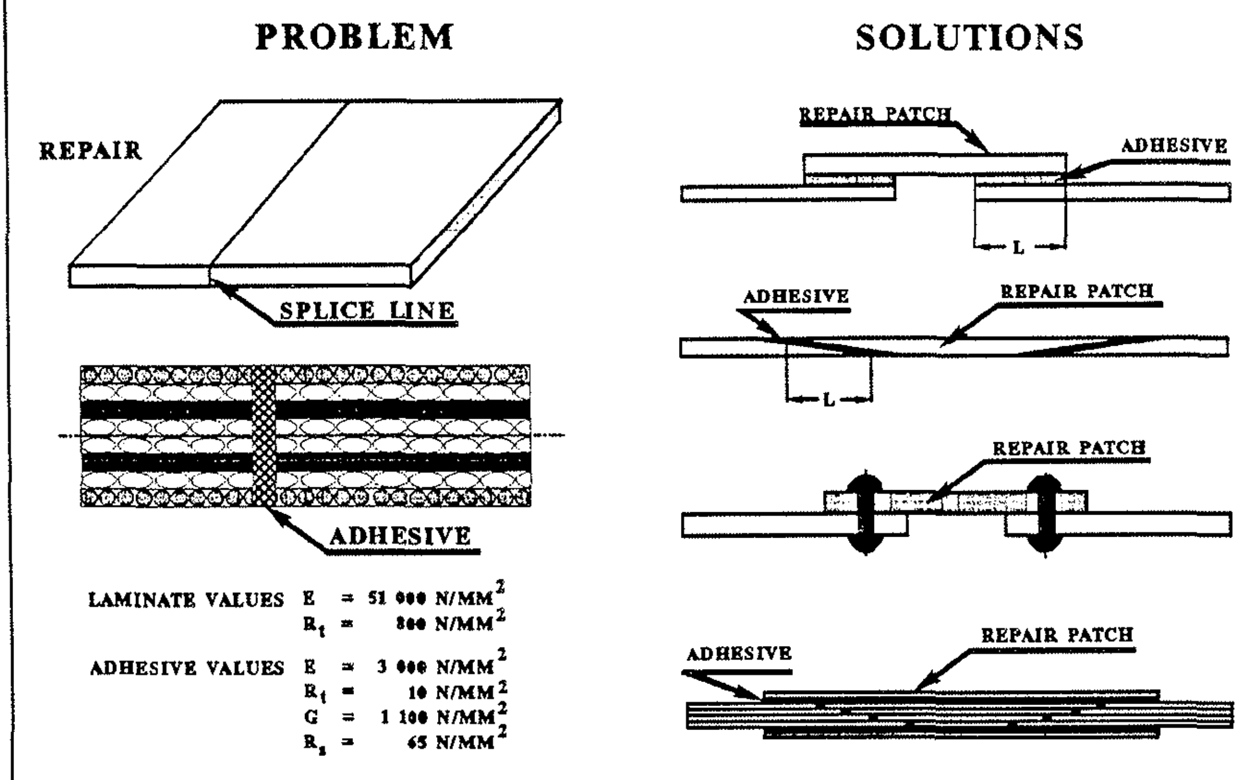
MBB Deutsche Aerospace

DECISION FLOW CHART FOR REPAIR OF STRUCTURAL COMPONENTS

HE512 91 03
REP024E
FIG 15

REPAIR PRINCIPLES

According to the FAA regulations of the United States or any other official aviation authority, repairs of airframe structures must restore the ultimate design strength and properties of the part for its remaining service life. For the composites, where the material and component is processed simultaneously, the repairs must restore the local strength and the materials steadiness as well. This can be done by applying metal or composite reinforcement patches, which could be either bonded or riveted to the part.



MBB Deutsche Aerospace

PRINCIPLE REPAIR SOLUTION FOR ADVANCED COMPOSITES

HE512 91 01
REP008E
FIG 16

The aeronautic engineering devide the repair methods into four categories:

* **Strengthwise Uncritical Repairs**
* **In house Repairs**
* **On Aircraft or Depot Repairs**
* **Field or Battle Damage Repairs**

Dependent on the damage extent and the equipment available we also distinguish in:

* **Cosmetic Repairs**
* **Temporary Repairs**
* **Permanent Repairs.**

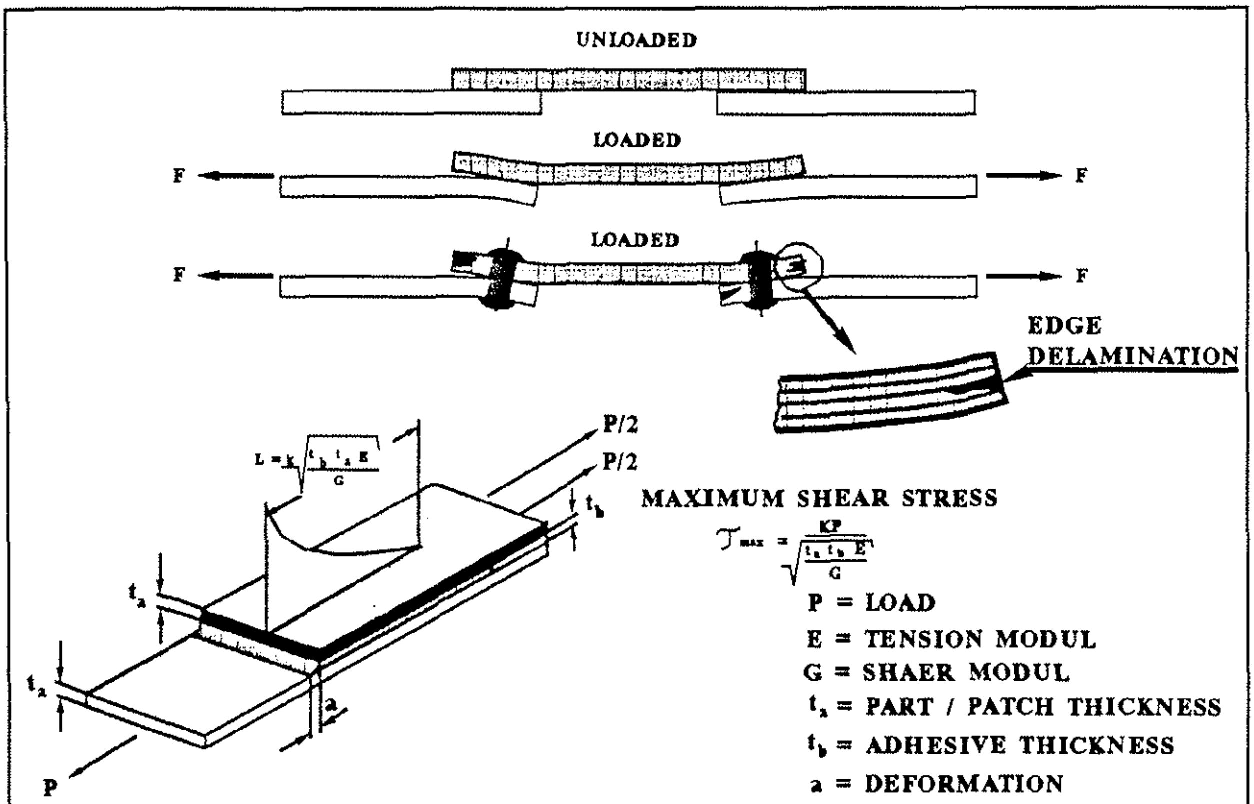
Cosmetic repairs are designed to restore the aerodynamical surface and for leaktight sealing of minor damages. They are applicable only to minor defects with no influence on the structural integrity of the part.

The temporary repair consists of provisionally restoring the mechanical strength, required to permit aircraft operation until a definitive repair can be carried out. It should be considered only in order to allow the aircraft complete its mission or for return to base.

Permanent repairs should ensure restoration of all component properties for the remaining service life. They could by either cosmetic or structural.

As we have mentioned before the most common damages are amongst secondary structures, their occasion is mostly impact during ground handling. Considering this, the repair procedures to be presented and transfered to the operators should primarly focus on such repairs. Damages on primary structure, in particular on load introduction areas will require specifically defined repairs and the assistance of stress design (refer to Fig.14/15). The way how to proceed in such cases is identical on conventional metal structures and composites too. The repair procedures discussed within this presentation will not consider restauration of such damages.

This paper will refer to standard repair methods applicable for the most common repair cases, concerning primary and secondary structures without load introduction zones.
For these repairs, we apply additional material and patch the damage. The least difficult approach would be mounting on a plain doppler. Beside the aerodynamical tolerances regarding steps there are also technical constrains. Dependent upon the magnitude of stress and the allowable deformation we must select either a stepped or chamfered repair patch. As indicated on figure 17 the edge peeling may be the design criteria.



MBB | PRINCIPLE DEFORMATION OF LOADED REPAIRS | HE512 91 01 REP033E FIG 17

The type of component and the type of defect will require a different repair solution. For the selection of any kind of repair we should consider the technical requirements and the available equipment and facilities. Several repair solutions are possible which can be adapted to most of the damages. Figure 18 shows the most appropriate repair solutions and compares them. Metal patches as shown in label R1 and R2 are the least difficult repairs to perform, but their application is limited.

Complex shapes and corrosion may restrict its deployment.
Composite repair patches, as indicated on label R3 - R6 will meet the demands for FRP's. But the manufacturing of such patches requires a process technology as used for production of parts. If we tend to do " On Aircraft Repairs" or similar, the facilities needed, as autoclave, moulds e.g. are not available. The use of original material as used for the component manufacturing may not be possible.

REPAIR MATERIAL	METAL PATCH		COMPOSITE PATCH			
REPAIR PRINCIPLE	PLATE	SHEET METAL	COBONDING	BONDING	COCURING	BOLTED
DESCRIPTION	BOLTED REPAIR 	BONDED CHAMFERED REPAIR 	UNCURED PATCH SPLICED WITH FILM ADHESIVE PREPREG PATCH	CURED PATCH SPLICED WITH FILM ADHESIVE PREPREG PATCH	UNCURED PATCH SPLICED WITH EXCESS RESIN WET LAMINATED PATCH	CURED PATCH SPLICED WITH BOLTS OR RIVTES PREPREG OR WET LAMINATED PATCH
ADVANTAGE	FAST TO PERFORM	GOOD LOAD TRANSMISSION SLIGHT CURVATURES POSSIBLE	* REPAIR HAS SIMILAR CHARACTERISTICS AS THE REPAIRED COMPONENT (STIFFENESS, THERMAL EXPANSION) * GOOD AERODYNAMICAL SURFACE * DOUBLE CURVATURE SURFACE POSSIBLE			
DISADVANTAGES	NO DOUBLE CURVATURES POSSIBLE	EXTENSIVE SURFACE PREPARATION REQUIRED	REDUCED MATERIAL VALUES	CURETOOL FOR THE PATCH REQUIRED	POOR MATERIAL VALUES	CURETOOL FOR THE PATCH REQUIRED
LABEL	R1	R2	R3	R4	R5	R6

MBB Deutsche Aerospace

COMPARISON OF PRINCIPLE REPAIR METHODS

HE512 91 03
REP032E
FIG 18

As we know, these original materials require temperature, pressure and vacuum for processing. At least for field repairs we may not be able to process under such conditions. Temperatures up to 125°C / 175°C applied during "On Aircraft Repairs" may seriously endanger the substructure. Local vacuum bags are the maximum which can be applied for debulking . If we use structure materials for repairs this will result in reduced material values. Therefore it is essential to select repair resin materials for room temperature and just vacuum cure.
We also discussed the huge variety of fiber materials used in composite design. If we tend to replace the original materials during repairs, the repair shops and the operators must keep the whole variety in their stores. The expenses of storage, material documentation and handling complexity may become unaffordable. To minimize this, the repair fiber material should be limited to just one fiber type of the highest material quality possible.

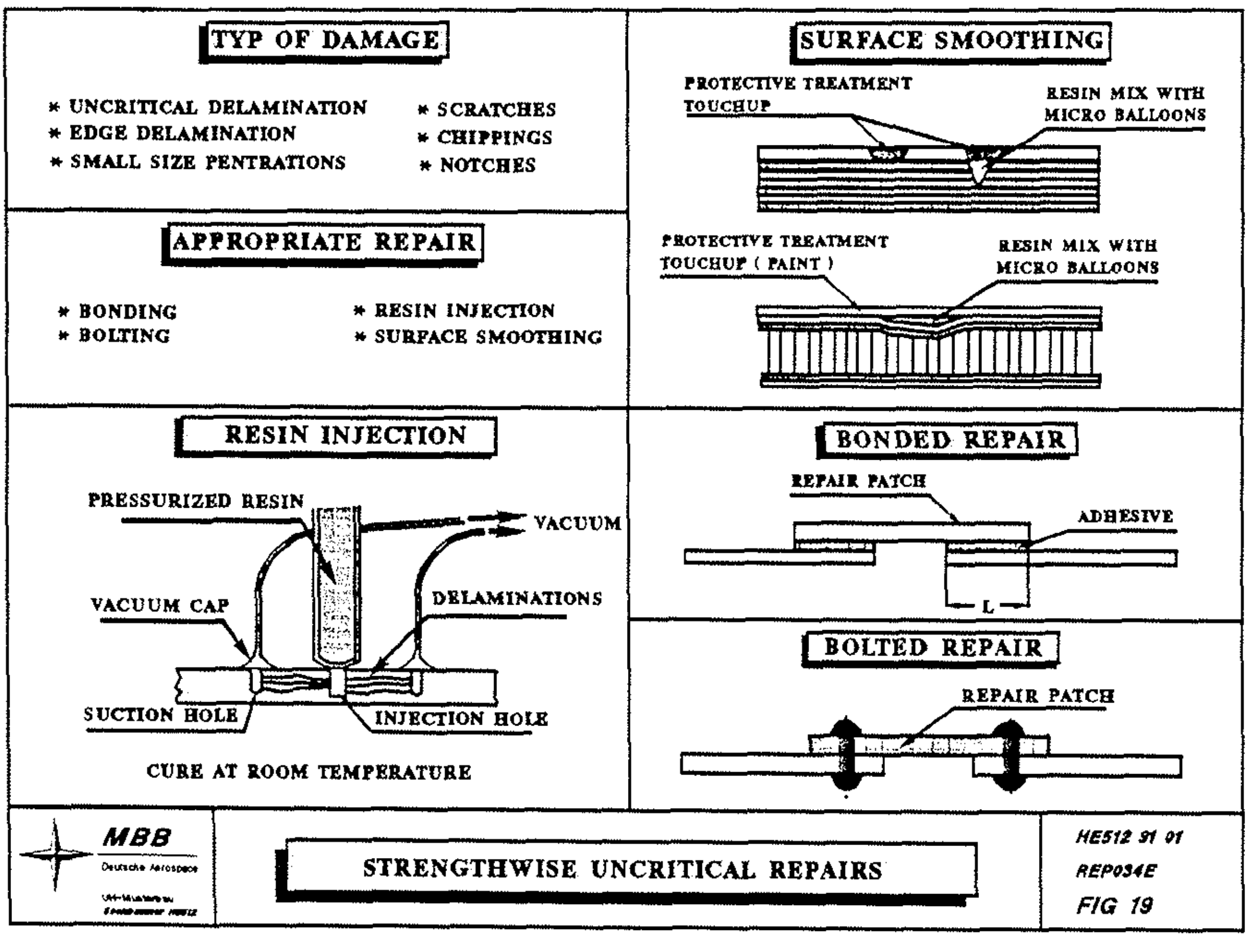
To condense the information for selection of composite repair materials we may summarize:

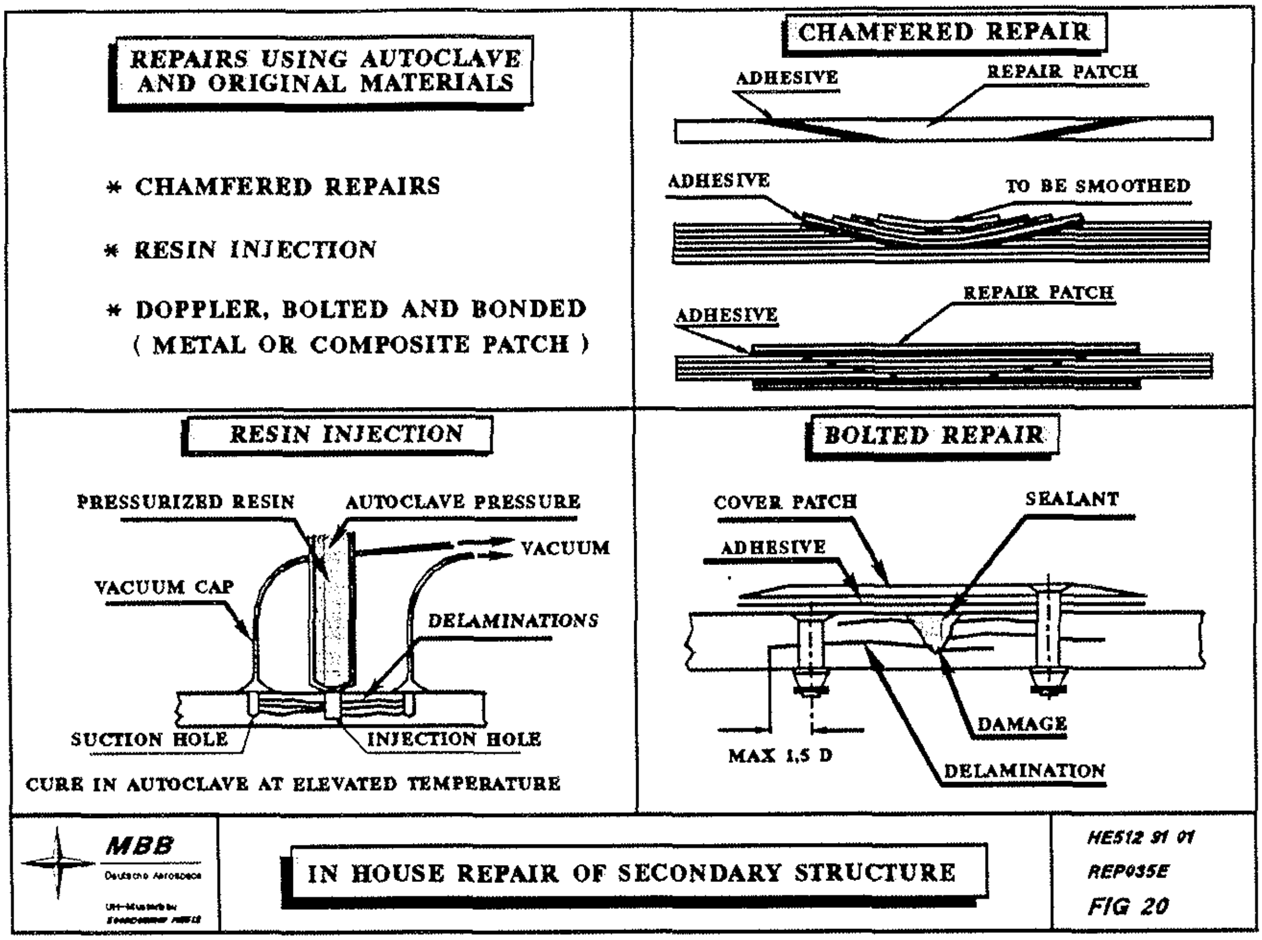
- **For In House Repairs, we use original materials**
- **For On Aircraft or Depot Repair, we use room temperature curing resins and adhesives, highest fiber quality possible and apply if requested a postcure up to 100°C using heat lamps or similar. Alternatively we use precured standard patches.**
- **For Field Repairs, we use room temperature curing resins and adhesives and highest fiber quality possible, if elevated temperatures above 70°C are required, the repair will be temporary only**

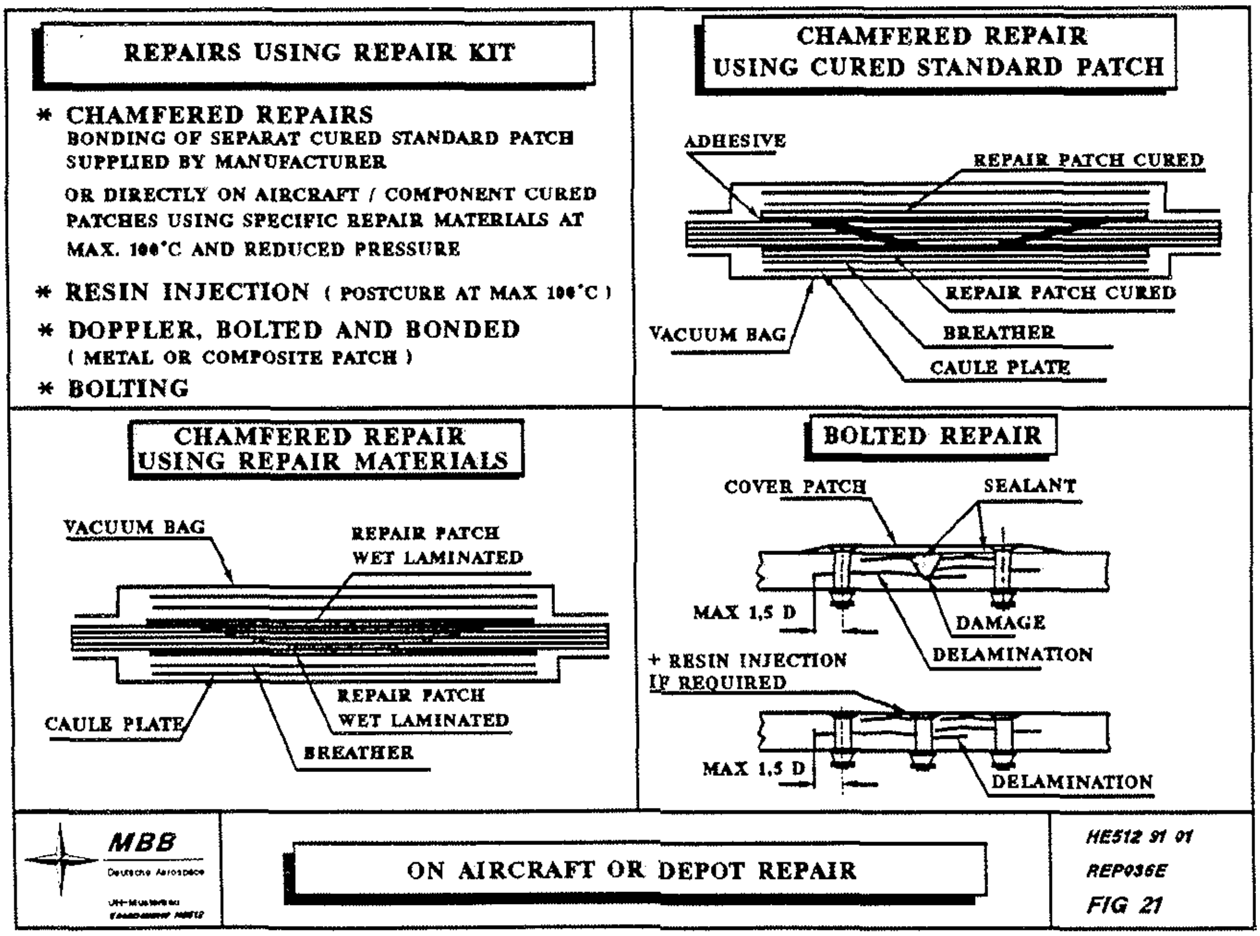
REPAIR SOLUTIONS

Considering above described principles we may find only a few but effective repair solutions. The key element for repairs is the selection of a suitable material combination which meets the demands of the composite material system used for production. For 125°C and 175°C curing epxoy thermoset matrixes the Hysol EA 956 may be a very promising candidate. It features room temperature cure, the capability for low, medium and high temperature post cures dependent on the glass transition temperature requested and offers a low viscosity to allow for low porosity laminates and resin injection. MBB uses Carbon, Aramid and Glass fibers for structure manufacturing. Since we recognized, that each repair patch increases the thickness, the stiffness will increase as well due to the higher moment of inertia.

Helicopter structures are basically designed for stiffness. Therefore the dry fiber material for repair may be selected for high stress values rather for stiffeness. The standard fiber material, which is T300 at MBB, may be well appropriate. If we summarize this, we could offer to the customer a repair kit which includes just one type of resin and one type of fiber.
With that limited amount materials the standard repair procedures may be differentiated for "In House Repairs", where original materials like prepregs are used as far as possible, and "On Aircraft and Field Repairs", where the above discribed material combination is recommended.
The follwing figures show the various repair solutions, separated according their repair depth.




REPAIRS USING AUTOCLAVE AND ORIGINAL MATERIALS
* CHAMFERED REPAIRS
* RESIN INJECTION
* DOPPLER, BOLTED AND BONDED (METAL OR COMPOSITE PATCH)
CHAMFERED REPAIR
ADHESIVE
REPAIR PATCH
ADHESIVE
TO BE SMOOTHED
ADHESIVE
REPAIR PATCH
RESIN INJECTION
PRESSURIZED RESIN
AUTOCLAVE PRESSURE
VACUUM
VACUUM CAP
DELAMINATIONS
SUCTION HOLE
INJECTION HOLE
CURE IN AUTOCLAVE AT ELEVATED TEMPERATURE
BOLTED REPAIR
COVER PATCH
SEALANT
ADHESIVE
DAMAGE
MAX 1,5 D
DELAMINATION
MBB
IN HOUSE REPAIR OF SECONDARY STRUCTURE
HE512 91 01
REP035E
FIG 20


REPAIRS USING REPAIR KIT
* CHAMFERED REPAIRS
BONDING OF SEPARAT CURED STANDARD PATCH SUPPLIED BY MANUFACTURER
OR DIRECTLY ON AIRCRAFT / COMPONENT CURED PATCHES USING SPECIFIC REPAIR MATERIALS AT MAX. 100°C AND REDUCED PRESSURE
* RESIN INJECTION (POSTCURE AT MAX 100°C)
* DOPPLER, BOLTED AND BONDED (METAL OR COMPOSITE PATCH)
* BOLTING
CHAMFERED REPAIR USING CURED STANDARD PATCH
ADHESIVE
REPAIR PATCH CURED
REPAIR PATCH CURED
VACUUM BAG
BREATHER
CAULE PLATE
CHAMFERED REPAIR USING REPAIR MATERIALS
VACUUM BAG
REPAIR PATCH WET LAMINATED
REPAIR PATCH WET LAMINATED
CAULE PLATE
BREATHER
BOLTED REPAIR
COVER PATCH
SEALANT
MAX 1,5 D
DAMAGE
DELAMINATION
+ RESIN INJECTION IF REQUIRED
MAX 1,5 D
DELAMINATION
MBB
ON AIRCRAFT OR DEPOT REPAIR
HE512 91 01
REP036E
FIG 21

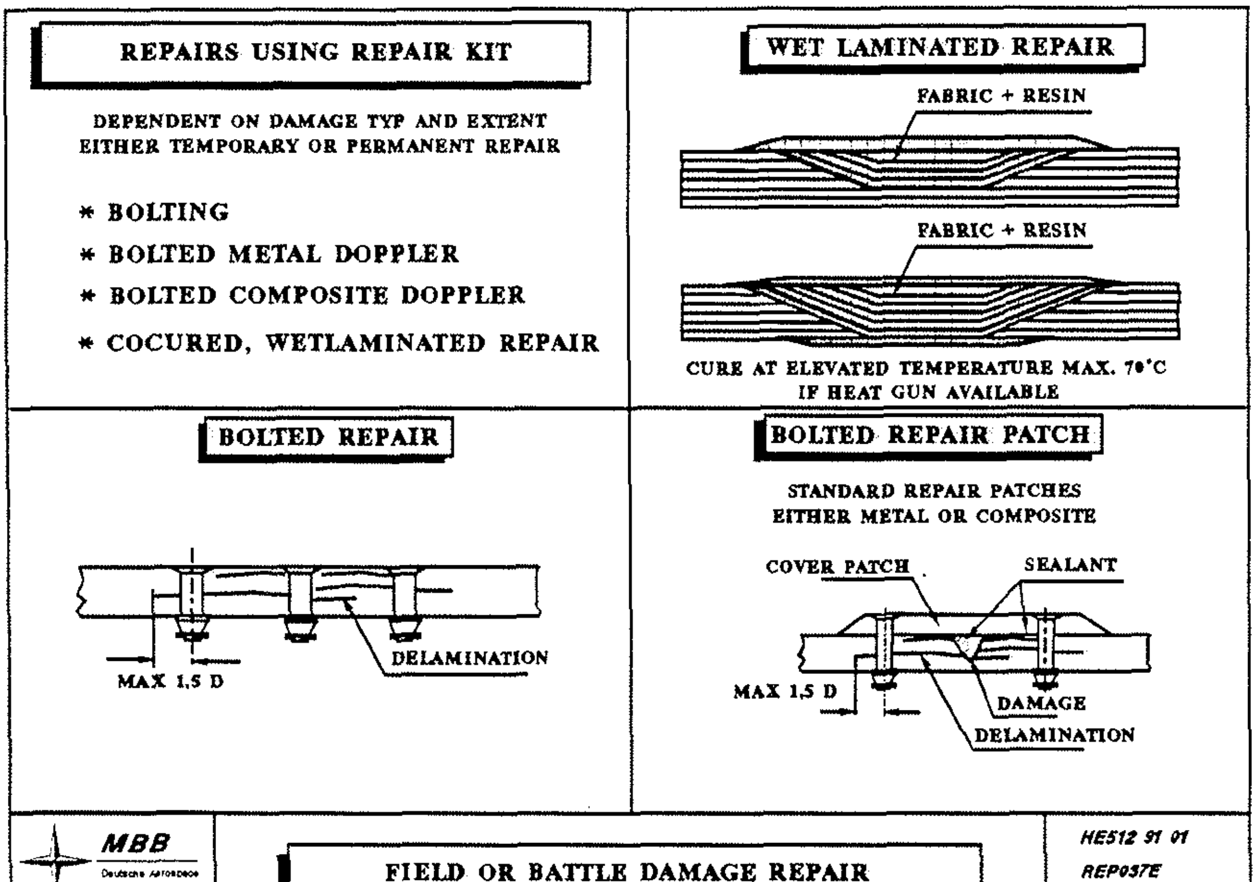
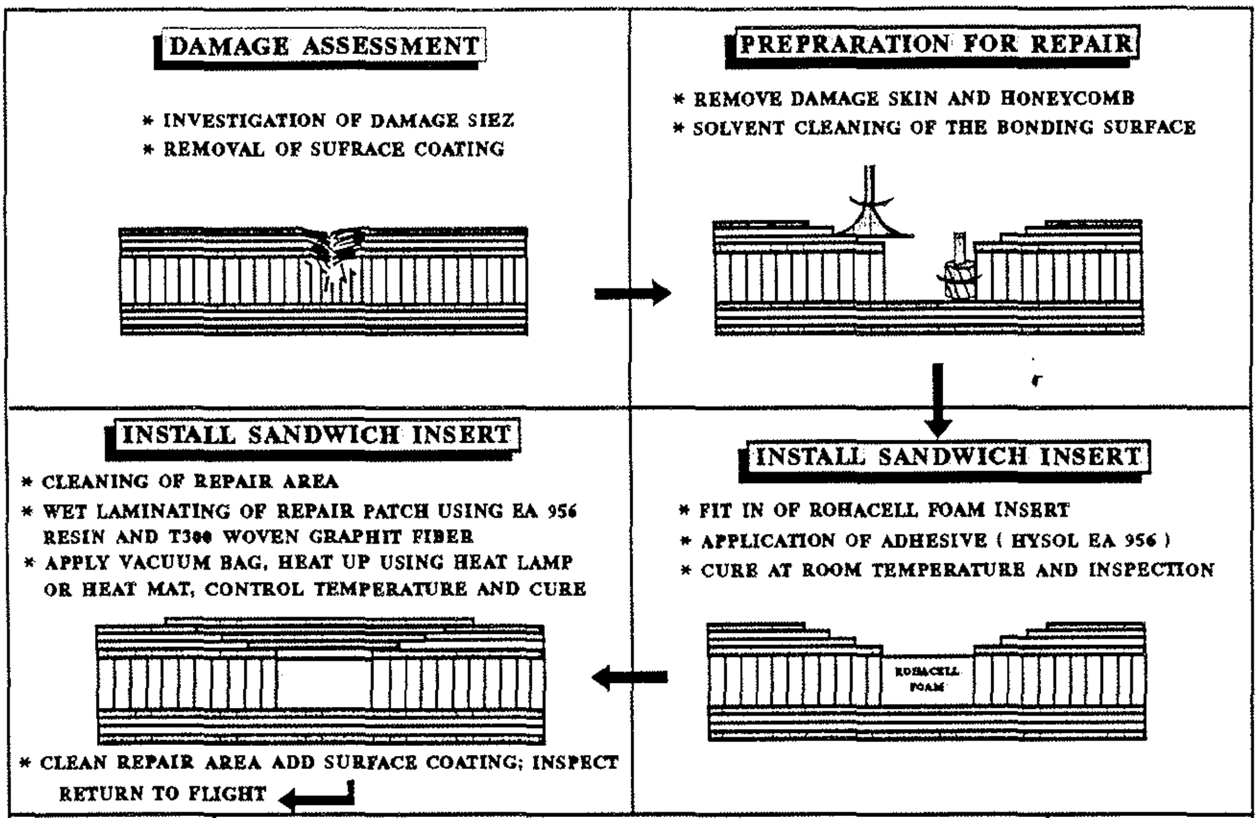


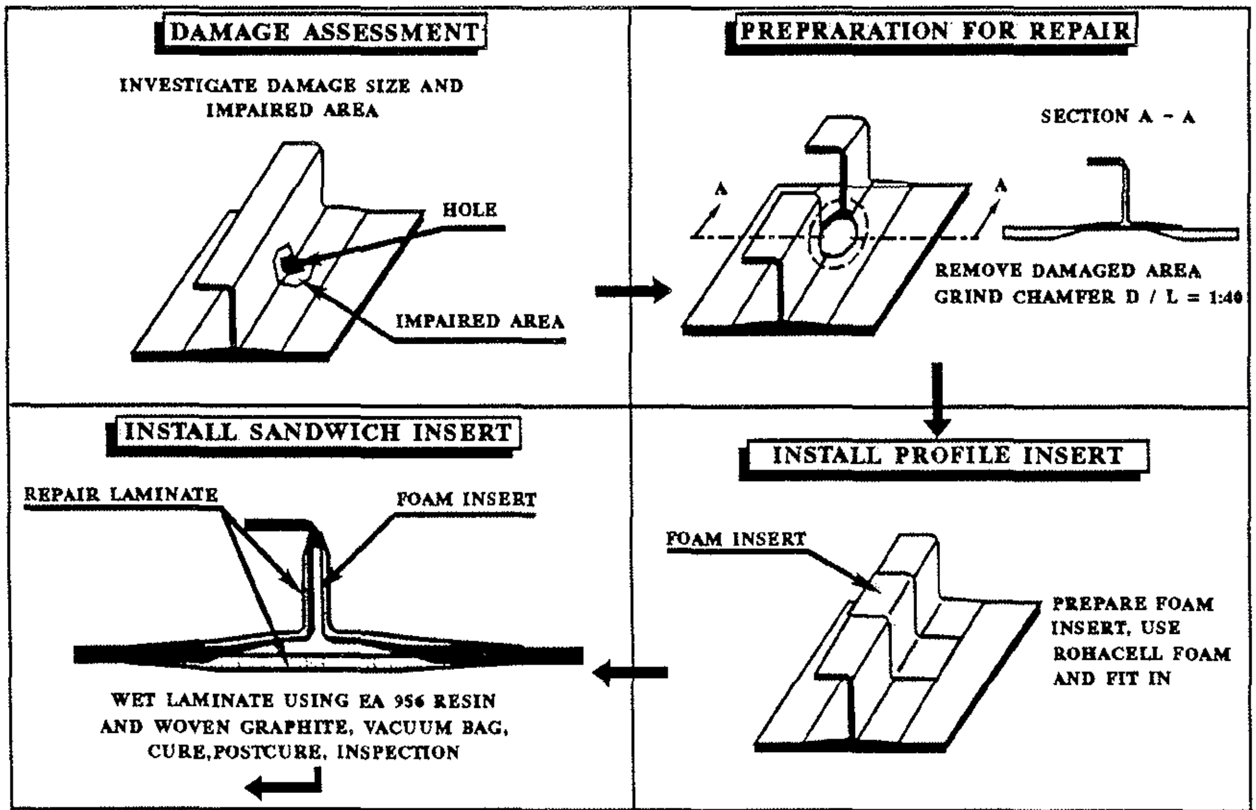
FIG 22

Each of these repair solutions requires an appropriate manufacturing cycle. The figures 23 and 24 will show the manufacturing sequences for an "On Aircraft or Depot Repair". Many of the damages on secondary structure may be repairable follwing these roughly depicted repair procedures. In some cases, we won't be able to repair according to this low tech approach. If we have to restore the structure using the original material, moulds may be requested to cure a repair patch. Airframes often have complex shape. Making such tools has always been one reason for a drawback in repairs.
At the present time we are working on a simple method to produce such tools using the aircraft or the damaged component as the master model. This would offer the oportunity to use original materials for depot repairs or to produce cured patches for complex shape. Thus, if these materials require autoclave cures, it may be to "no avail".

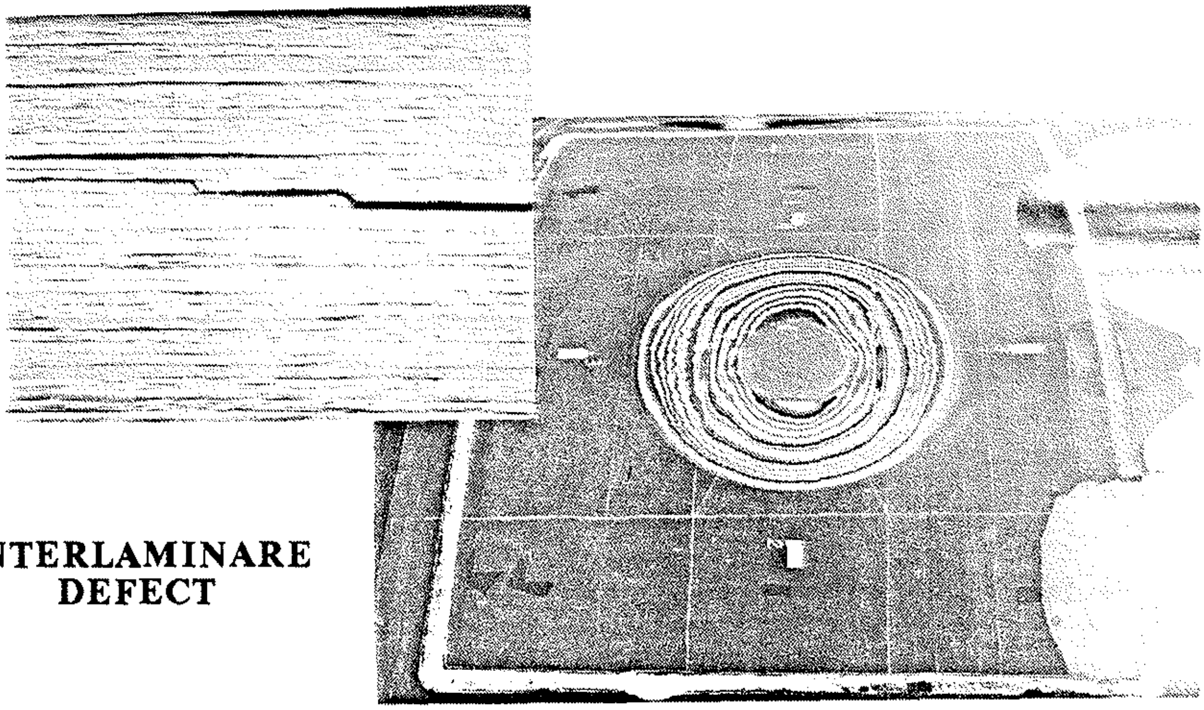
Therefore it is essential to develop and qualify materials for non autoclave cures. As we know, material values as received from autoclave cured composites can't be achieved by non autoclave cures. A reasonable reduction of strength values should be considered already in design in our reserve factors to allow for in service repairs.
In order to prove the above depicted repair solutions and their associated manufacturing process several test articles have been produced and tested.
These trials were carried out simulating conditions as applicable for "Depot and On Aircraft Repairs" as well as for "Field repairs". The results of this study delivered promising data. For both repair conditions it was possible to restore the components and their initial strength values.
It is not intended to present data of this study within this paper.



MBB Deutsche Aerospace UH-Musterbau	REPAIR SEQUENCE ON A SANDWICH STRUCTURE	HE512 91 01 REP038E FIG 23

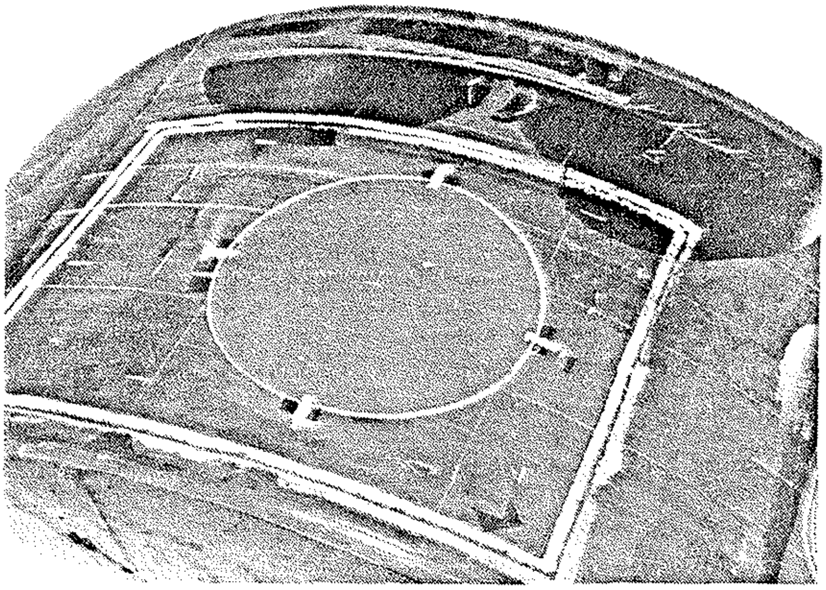


MBB Deutsche Aerospace UH-Musterbau	REPAIR SEQUENCE ON A MONOLITHIC STRUCTURE	HE512 91 01 REP039E FIG 24



INTERLAMINARE DEFECT

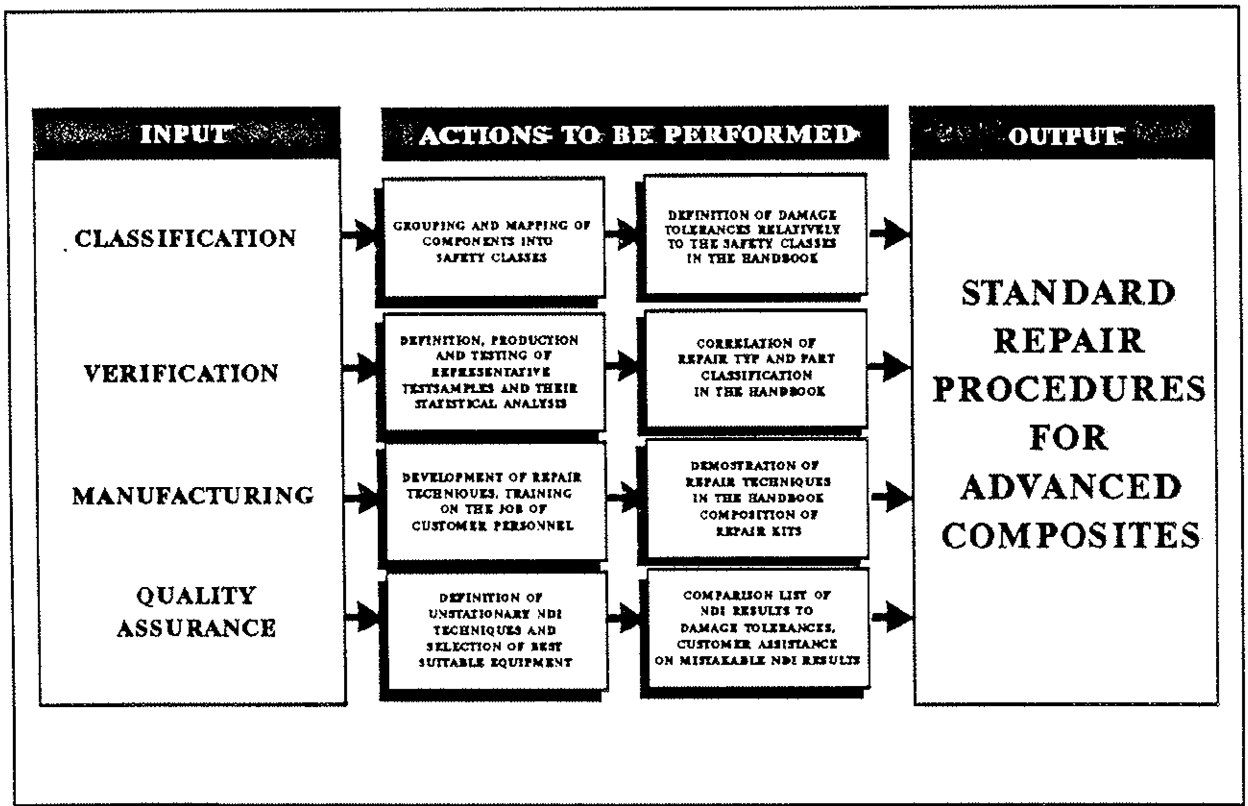
DAMAGED AND IMPAIRED MATERIAL REMOVED AND CHAMFERED FOR REPAIR



REPAIRED AREA ON A FUSELAGE SKIN

MBB Deutsche Aerospace UH-Musterbau Eschbaumer HE512	UNVISIBLE IMPACT DAMAGE AND ITS PREPARATION FOR REPAIR	HE512 91 03 REP040E FIG 25

Figure 25 shows samples of this study. However, to release standard repair procedures for advanced composites it is necessary to manufacture and test specimen, considering each of the materials and each material combination used on the relevant aircraft. The complete variation in design (e.g. sandwich, monolithic and integrally stiffened) must be simulated for such a qualification program. Thus, there is a huge amount of work to be accomblished, which can be done only in closed cooperation of all involved, design, manufacturing, quality assurance, product support and last but not least the relevant inputs of operators too.



MBB Deutsche Aerospace

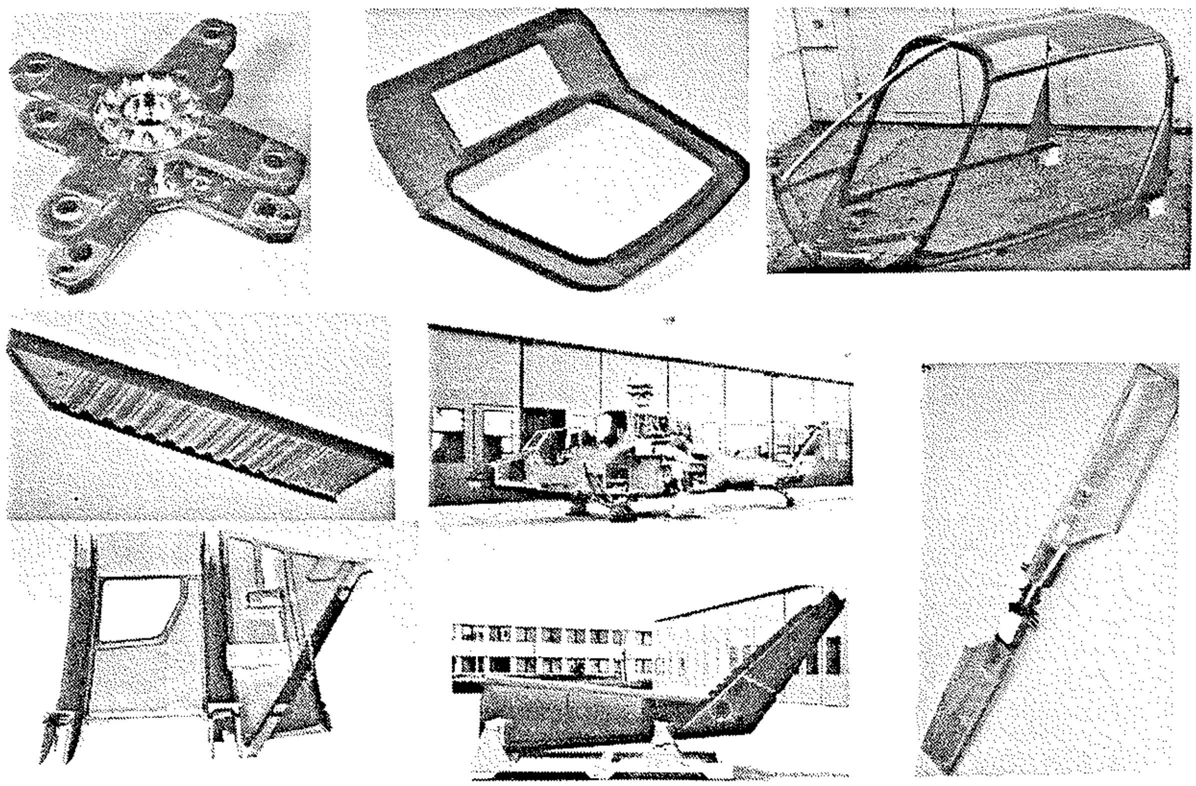
COOPERATION OF EXPERT TEAMS FOR EFFECTIVE STANDARD REPAIR PROCEDURES

HE512 91 03
REP042E
FIG 27

To conclude this presentation, let me briefly come back to the opening question of the future repair shop for composites. The advances in composites opened nearly unlimited possibilities in the design of lightweight structures. The variety of today's aerospace structures reflects the degree of freedom in design which was offered to engineers due to the employment of these materials. Beside the technical benefits we all expect significant savings for the series production as well as for the overall life cycle costs too. But the application of composites also reflects the degree of complexity and expenses for facilities we have to deal with.

To make composites be an extraordinary material for everyone around the heli business, we, the fellows from development must consider all aspects. Beside our thinking in high tech we must scale down the daily operation complexity to a feasible value.

One of the approaches to do so are the standard repair procedures. Repairs, where all the fancy high tech is requested will always be limited for airframe manufacturers and won't sell the product. Handy repair solutions will be one link to make composite realy an extraordinary material for the future.



MBB
Deutsche Aerospace

VARIATY OF COMPOSITE COMPONENTS
FOR HELICOPTERS

HE512 91 03
REP031E
FIG 4