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36th ERF
Session: Aircraft Design
Requirements on Advanced Airframes for Commercial Transport H/C

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1.Introduction

Commercial transport helicopters are used worldwide for a large variety of missions like “Gas & Oil”, “VIP or Corporate Transport”, “Parapublic” and “EMS” etc.
The airframe as the subsystem which contains all the other subsystems has to offer certain features, which enable the helicopter to provide maximum benefit for its various roles, to provide to customers an attractive product.
The presentation deals with requirements on advanced helicopter airframes starting with architecture- and other aspects like
general layout, i.e. e.g. cabin layout, like passenger accommodation taking into account studies of various seat rows and seat per row investigations in different view directions linked with comfortable in- and egress and emergency evacuation requirements. This will finally result in selecting appropriate door configurations, hinged- and sliding ones. Comfortable loading and unloading of luggage or cargo has to be investigated and thereof defined cargo door arrangements. Possible landing gear arrangements like e.g. tricycle landing gears, rectractable vs. non retractable ones have to be investigated and rear fuselage/ tailboom architectures like e.g. fishtail- vs. rear clampshell door-design have to be compared to each other and the right choice has to be made based on engineering selection criteria.
Aerodynamic drag drives the design lay out and influences also the freedom on styling aspects which has to be considered during the predesign/architecture phase.

A review of the current technologies from standard aluminium alloy sheet metal to composites is displayed in the presentation.
Main parameters such as weight, cost, fatigue, corrosion, repairability have to be addressed for these ‘reference’ technologies.
In the meantime new aluminium alloys, like e.g. aluminium lithium alloys and new joining methods, like friction steer welding have evolved, which provide either higher strength/stiffness values and/or lower densities or less assembly efforts resp.. In conjunction with modern surface treatment methods, like the different electrophoresis methods, these technologies become attractive for airframe parts. In addition advanced composite technologies like e.g. fibre placement and several infusion techniques have been developed and allow highly integrated design/manufacturing approaches for subassemblies. Composites allow lowest weight design, they behave superior in fatigue and corrosion and they are suitable for all kind of surfaces. However their production process is complex and electrical bonding and lightning strike protection needs special care as well as qualified repair procedures.
Both, the advanced metal- as well as the advanced composite technologies enable weight- and manufacturing cost savings.
In addition engineering judgement is to be applied by selecting appropriate technologies for certain subassemblies of the fuselage to respect smart integration of necessary equipments as well as worldwide customizations.
So in fact a smart mixture of several technologies seems to provide the best results.

2.General Requirements

- Minimum Weight
- Production rate - Quantity/RC
- Civil certification rules e.g. FAR/CS 29
- Maximum strength
- Crash behaviour
- Resistance to the corrosion
- Maximum reliability
- Safety ⇨ « Fail Safe » aspects
- Reliability
- Adaptation to the missions - versatility
- Dynamic qualities
- Maintainability (control, repair ability)

Table 2.1: Listing of most relevant general requirements

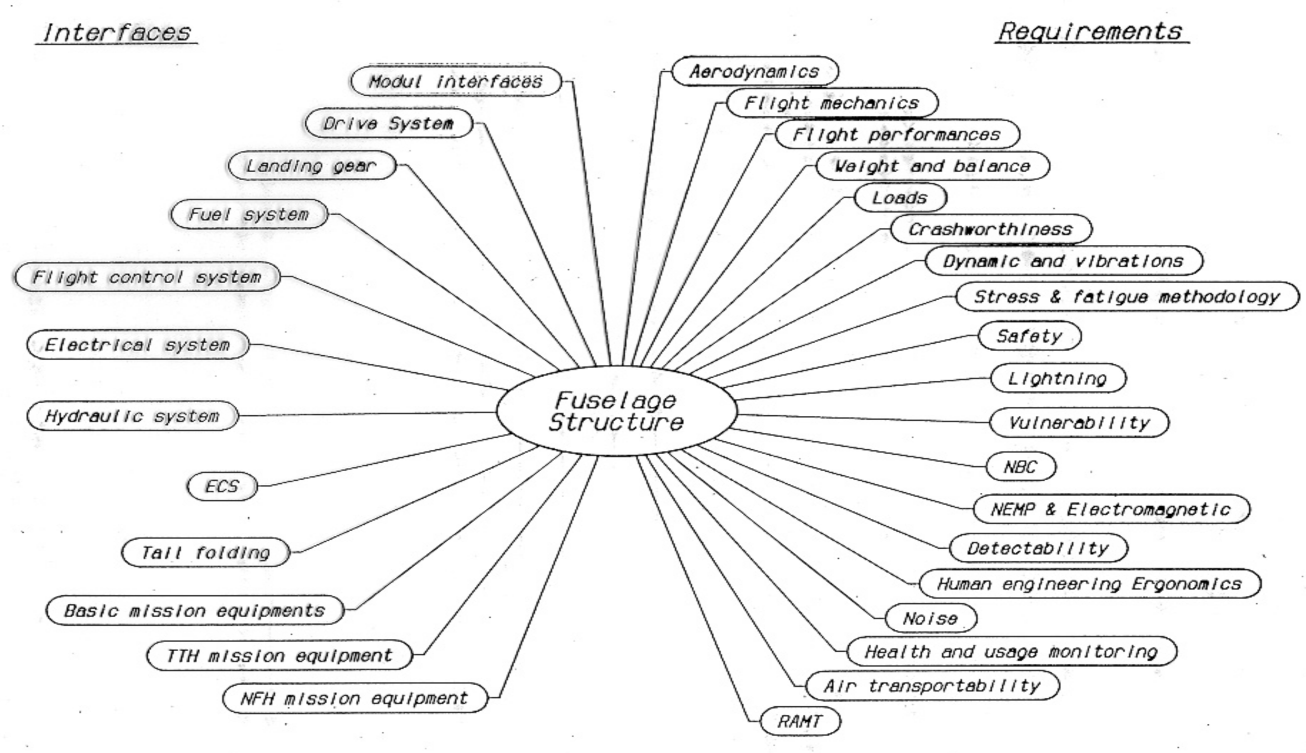


Fig. 2.2: Example interfaces and requirements on fuselage structure,

3.Architectures

Some main drivers for airframe architecture are examined hereafter :

3.1 Cabin layouts:

Organization of passengers seating leads to cabin length & width.

Seat organization i.e. number of rows vs nb of pax per row has a direct impact on the fuselage length.
A 'long and narrow' fuselage with cantilever cockpit and nose landing gear will have a structural flexibility and static ground stability more difficult to manage than a compact concept .
On the other hand the compact solution leads to a greater wetted surface with inconvenience for drag.

Missions analysis lead to cabin height.
Doors and transparencies have to account for accessibility and emergency egress.
Then framing is selected from examination of :

- outer constraints from dynamic components & engine locations
- inner constraints from cabin layouts

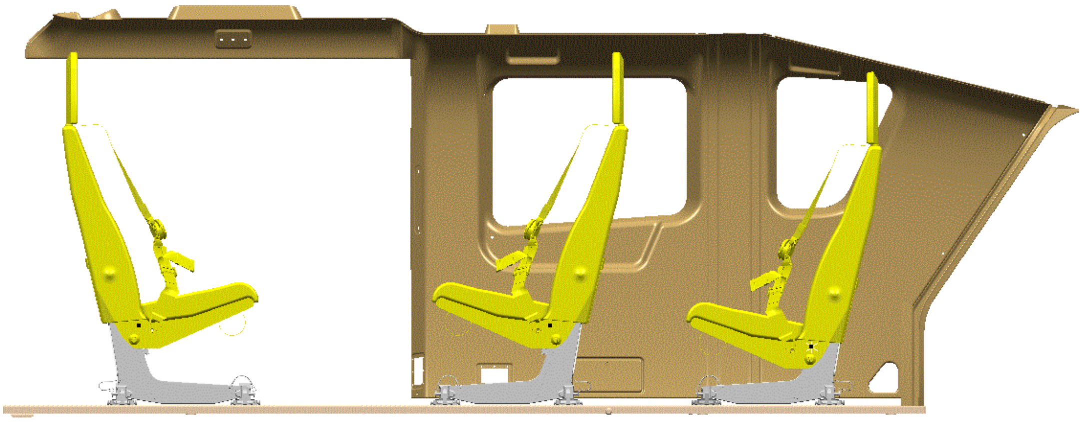


Fig. 3.1.1: Seat arrangement on EC145, Clubseating

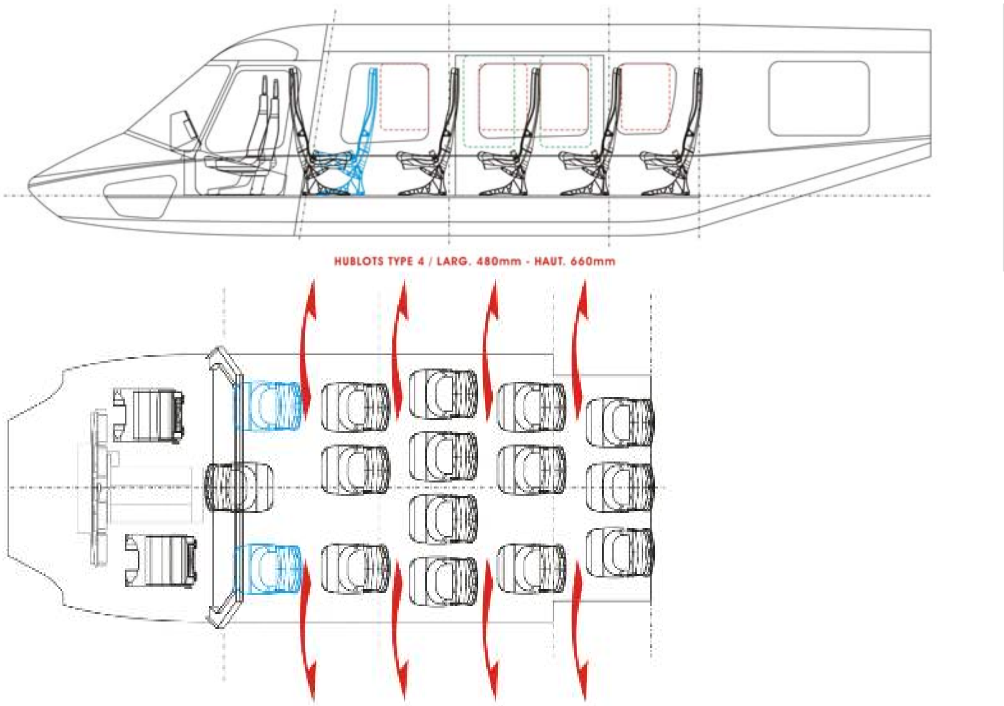


Fig. 3.1.2: Seat arrangement EC175, 16 Pax layout

Technology for main frames is selected through their aptitude for the better optimisation of :

- Dimensions vs strength & stiffness criteria .

  To this respect high resistance fibres aligned with loads are very efficient .
- Capability to attenuate the impact accelerations transmitted from cabin floor to heavy mass items above the cabin. Capability to absorb kinetic energy while maintaining cabin integrity

  To this respect ductile materials are recommended.

3.2 Landing gears:

Integration of landing gear onto fuselage needs to account for:
- specified performances (civil, army, navy,..)
- static stability
- ground resonance
- contribution to survivability in crash
- influence on HC drag
- compatibility with HC accessibility

Fig.:3.2.1 MLG Dauphin

Fig.:3.2.2 MLG Super Puma

3.3 Fuel System:

Two main possibilities are offered

- Fuel under floor.
  This allows for a good balancing of fuel weight under main rotor. It also allows for sufficient fuel volume installation to fulfil the missions (particularly very demanding offshore transportation), as it occupies a volume located under a big surface (volume otherwise partially unused).
  It also leads to a design of the bottom structure capable of energy absorption in case of crash.

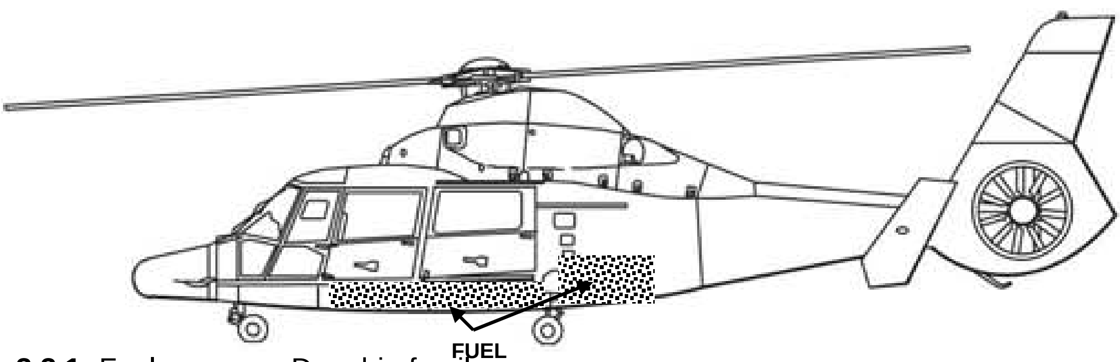


Fig. 3.3.1: Fuel space on Dauphin family

- Fuel after the cabin.
  This permits to reduce the bottom structure thickness and therefore the cabin floor height w.r.t. the ground and could limit the necessity for an

access step.
Nevertheless, this increases the CG range envelope .
Then the C.G. management may become difficult for medium size helicopters .
This architecture reduces the number of fuel cells and therefore simplify the fuel circuit.
For a given cabin height this solution leads to a lower fuselage height compared to the fuel located under the floor and then a reduced wetted surface .
On the other hand cabin length becomes longer .

3.4 Luggage compartment:

For the luggage hold, usual possibilities are lateral or rear access.
Lateral access allows for an aerodynamic "fish tail" shape, optimizing the drag, favourable for speed and fuel consumption.

Fig. 3.4.1: Luggage compartment outside view, Dauphin family

On the other hand, rear access allows for installation of clamshell doors on small helicopters and is very appreciated in EMS missions

Fig.3.4.2: rear clamshell doors EC135

Fig.3.4.3 Rear cargo ramp NH90

On large transport helicopters rear access allows for integration of a ramp providing rapid ingress/egress for troops or access for light automotive vehicle, but the size of this helicopter prevent it from both these applications.

4.Current Airframe Technologies

There are mainly 4 different design principles for H/C fuselages currently applied at EC-Group.

Sheet/Stringer Design, e.g. on EC120-, EC130-, EC135-, EC145-, EC155-, EC175-, AS332-Fuselages

Aluminium/Nomex Sandwich Design, e.g. on EC120-, EC155-, EC175-Tailbooms

Prepreg CFRP/Nomex Sandwich-, e.g. on NH90 Center Fuselage Skins, EC135 tailboom, bottom shell, roof structure and doors, EC 145 bottomshell, doors and roof structure, Tiger fuselage skins and tailboom.

CFRP/Monolithic – Design, e.g.on NH90 Frames, Tiger Frames, EC135 & EC145 Canopy.

4.1 Sheet/ Stringer Design:

Characteristics: well known technology, well known repairability, sensitive in fatigue and corrosion, needs special care to cope with that, heavier than composite design, mainly suitable for developable surfaces.

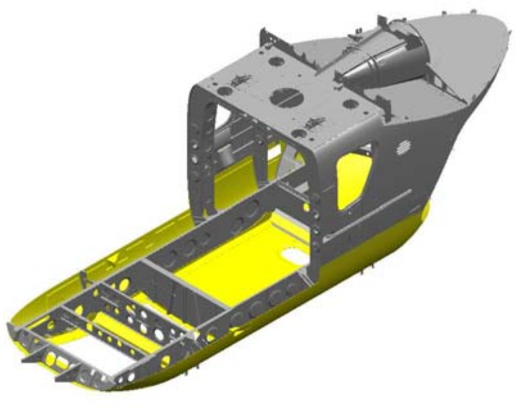


Fig. 4.1.1. :Sheet-Stringer Design (e.g. EC135 Center Fuselage)

4.2 Aluminium – Nomex Sandwich Design
Characteristics: Lower weight than sheet/stringer design, bettering fatigue than sheet/stringer design, special process in production required and sensitive in corrosion, both need special care, mainly for developable surfaces.

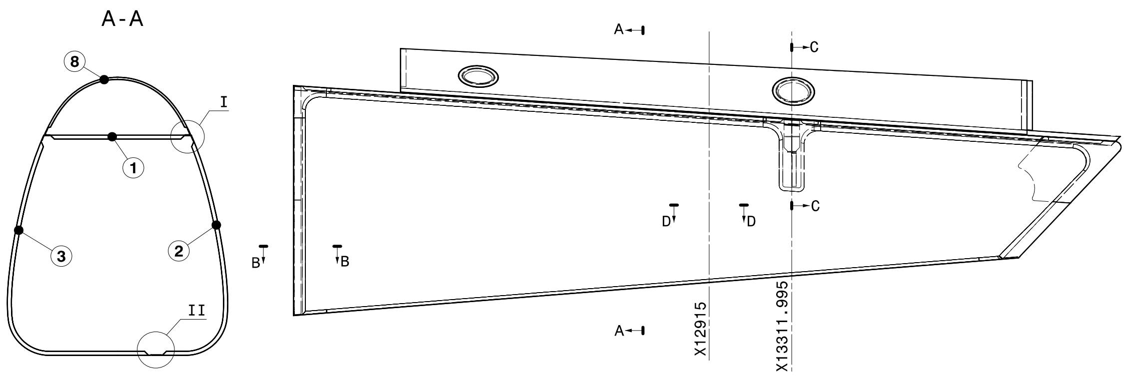


Fig. 4.2.1.: Aluminium – Nomex Sandwich Design (e.g. EC175 Tailboom)

4.3 Prepreg CFRP – Sandwich Design, CFRP – Monolithic Design
Characteristics: Low weight design, good in fatigue, good in corrosion, suitable for all kind of surfaces, special process required, repairability more complex than in sheet/stringer design.

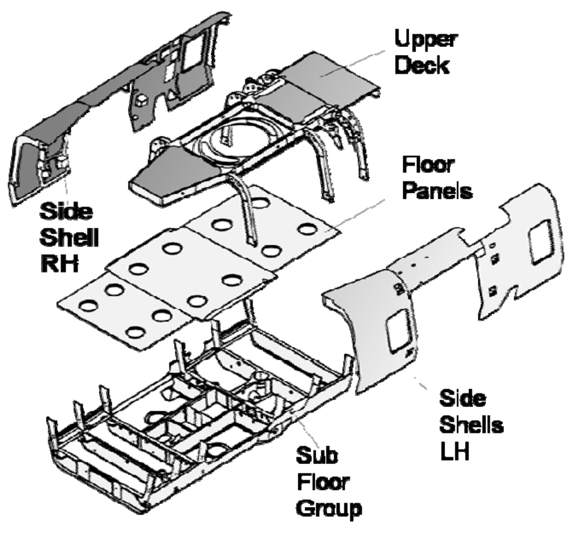


Fig 4.3.1.: Prepreg CFRP Sandwich (skins), CFRP Monolithic design (frames), (e.g. NH90 Center Fuselage)

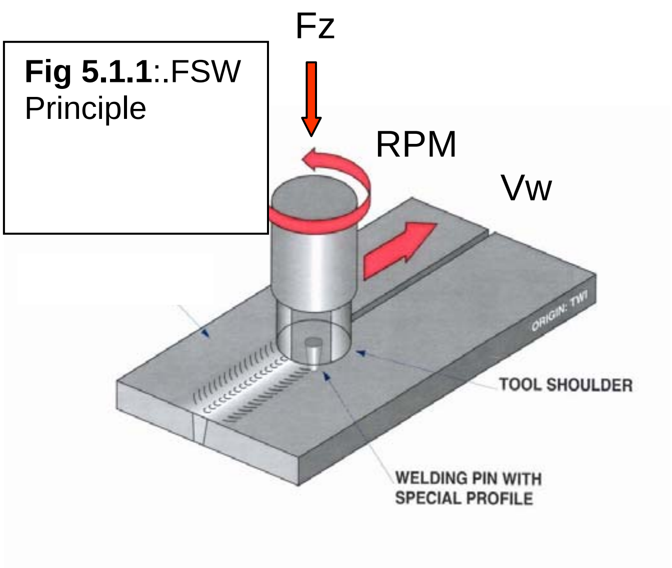
5.Advanced Metals/Joining Technologies

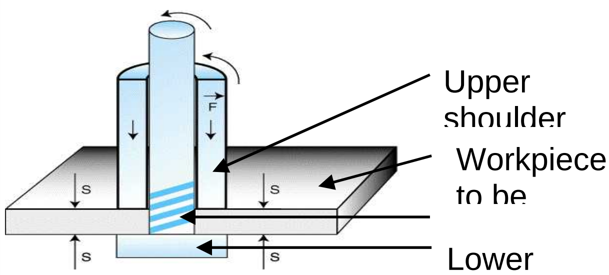
5.1 Friction stir welding

Friction-stir welding (**FSW**) is a solid-state joining process in which the metal is not melted during the process.

This process creates a continuous link between two pieces to join under solid-state condition with a continuous dynamic recristallization characterized by a very fine and equiaxed
grain structure (typical grain size of 10 microns).
The thermal input is mainly generated by friction, on and between the pieces to assemble, of a rotating cylindrical welding tool, equipped with a shoulder and a threaded pin.
The heating generated by friction brings the material to a pasty condition.
Then the increased temperature allows the progress of the tool (translation and rotation motions) along the joint line

Fig 5.1.1:.FSW Principle





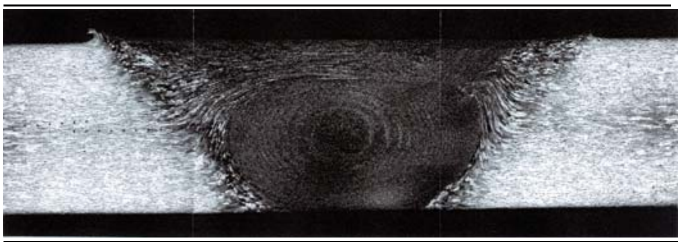


Fig5.1.2 : Photomicrogragh of welded zone

The FSW technique acting in solid-state condition will allow to join most of light alloys, even the materials qualified as unweldable, ie some of 20xx (ex 2024) and 70xx alloys.

Gantries with several axis and robot can be used for this assembly technique.

Fig 5.1.3 Gantry

Fig.5.1.4.: FSW Robot

The main operational parameters of the process are :
- Vertical position of the welding tool (ie position of the pin top with respect to the lower surface)
- Welding velocity
- Rotation velocity
- Vertical downforce

Beyond these operational parameters, the control mode selected is also a key parameter of this technique.
Indeed the technique can be controlled by the position of the welding tool or by the vertical downforce.
Lastly, the clamping strategy is also a significant process parameter.

FSW allows to go for rivet-free assembly for thin sheet metal technology .
- Stiffeners to skin
- Skin to skin
- Frames to skin

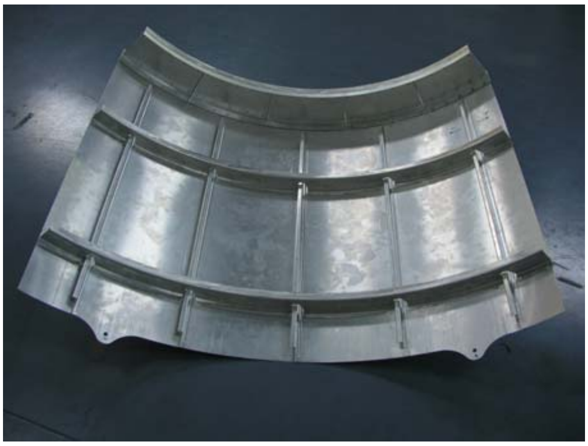


Fig 5.1.5: Generic FSW sheet stringer and frame assembly

FSW allows also to reduced scrapped material when machining a large blank by welding semi-products of much lower dimension.

5.2 Alloys suitable for FSW

Pushed by AIRBUS and BOEING interests, over the past few years, the aluminium alloys were strongly improved from chemical composition and tempers point of view. The objective was to optimize the properties regarding the related zones and loadings and to improve the processing capability of the materials for new technologies introduction (welding, forming..)

2000 serie alloys

Some candidates, similar to the 2024 baseline, are currently available. Their development has been mainly motivated by the research of damage tolerance improvement for aircraft with equivalent or higher static level than the 2024:

- purified 2024: 2056 T3 sheet, 2524 from ALCOA.
- 2022 alloy: improved damage tolerance , corrosion resistance

Within the research of weight reduction, the last five years have strongly contributed to the development of
Aluminium-Copper-Lithium alloys offering the best level of specific rigidity (density from 2,62 up to 2,7).
These alloys are currently available in sheet and extrusion profile products.

- High static alloys, Li content < 1

o 2198 T8 alloy: sheet, higher static strength & improved corrosion resistance

- High damage tolerant alloys, Li content > 1

o 2199 T8 alloy: sheet, improved rigidity & corrosion . Better candidate in fracture toughness and fatigue crack propagation

6000 serie alloys

The new 6000 serie aluminium alloy candidates have been promoted by the development of the welded aircraft fuselage concept (laser beam technology) since 1997 and the global research of corrosion resistance improvement.
Beyond that, the current new candidates offer static and fatigue savings with respect to the 6061 reference.

- 6x56 (sheet and extruded profile) with both weldable alloys, 6056 and 6156:

o The 6056 in its T78 is un-sensitive to intergranular corrosion
o The 6156, purified 6056

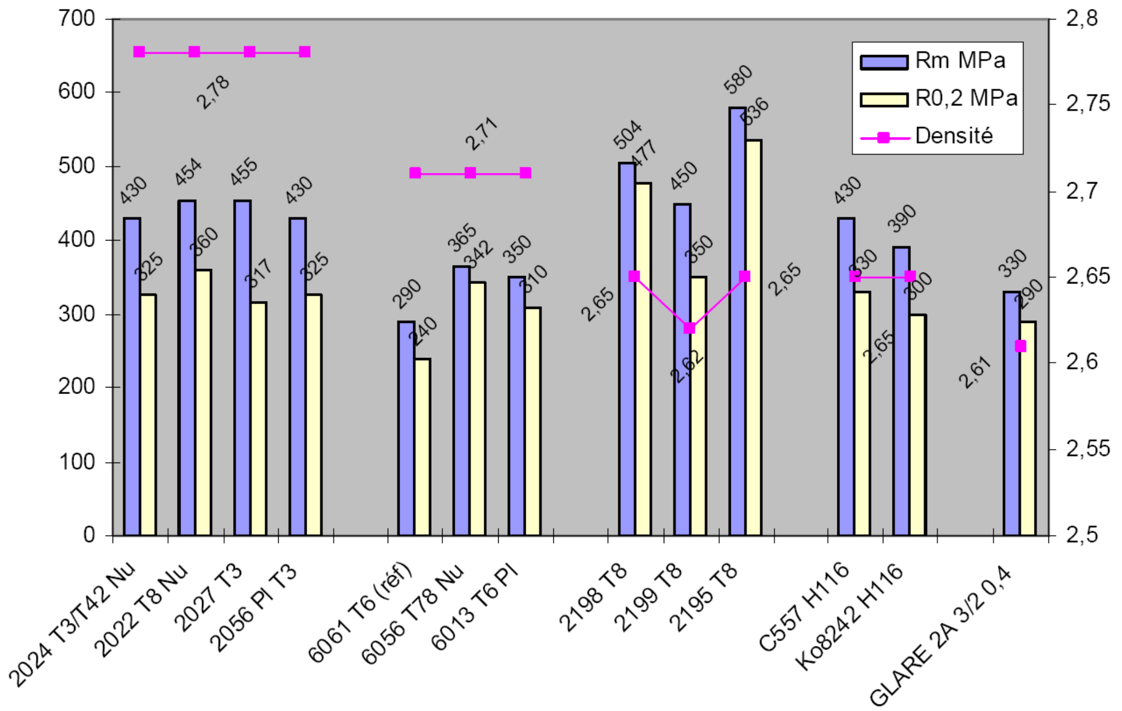


Fig 5.2.1:. Typical strength and density values of new Aluminium Alloys (thin skins)

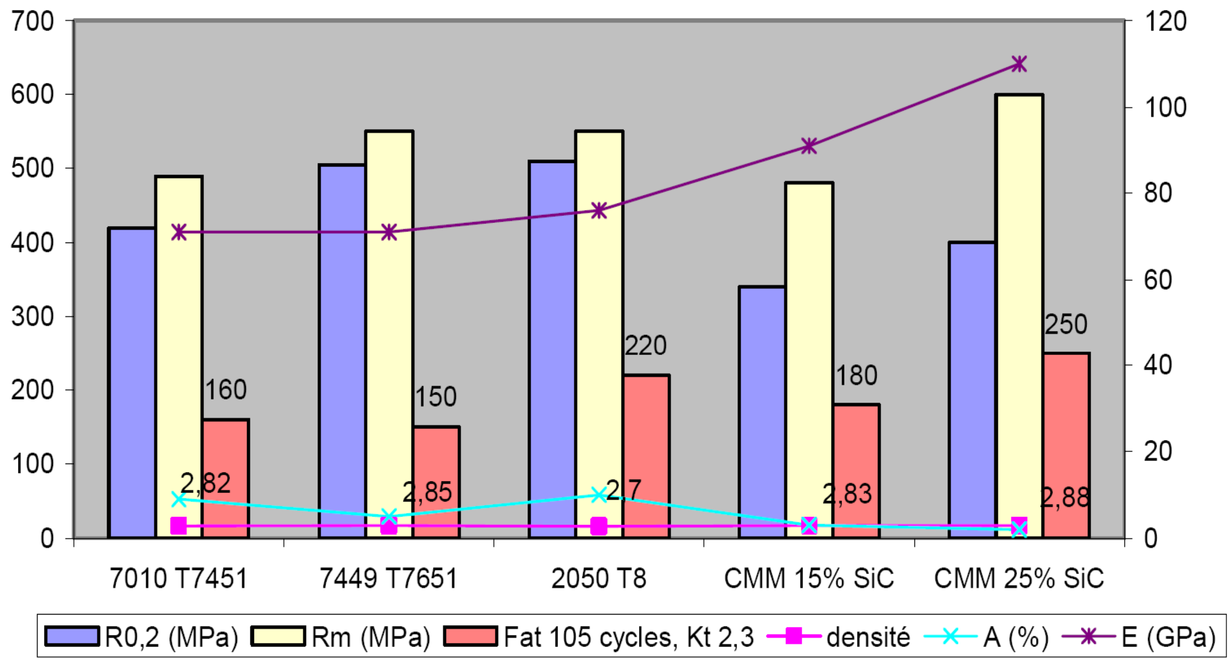


Fig 5.2.2: Alu Alloys & MMC Tensile Characteristics for frames

6. Advanced Composite Technologies

Future helicopter concepts will be based on advanced composite technologies, which have to lower production costs compared to today's technologies. Low cost production technologies are the key factor, when up-scaling for future helicopter specifications.
The experience gathered with the manufacturing of EC135, NH90 and Tiger parts – mainly prepreg hand-lay-up technologies supported with overhead laser-projections and autoclave curing – is the benchmark.

To exploit further cost and weight reduction potentials, further research programmes are pursued.
Promising new technologies seem to be so called Resin Transfer Moulding (RTM) in combination with advanced pre-form developments for more thick walled monolithic parts like e.g. frames and so called Fibre Placement (FP) for more thin walled monolithic/or sandwich parts like e.g. skins.

Existing out-of-autoclave Infusion technologies, e.g. RTM, VAP, VARTM etc. and Fibre Placement Technologies will help to improve the current manufacturing process in terms of cost, design freedom and performance. Further advancements in e.g. preform technologies (manufacturing of the dry fibre architecture) will play an important role for the selection of future production routines. Regarding complexity and size, as well as required performances, future helicopter will exceed today's specifications. As a consequence, highly reproducible and automatable composite production technologies have to be developed in order to minimize this overall risk. An on-line quality control technology for the step-wise control of part generation is mandatory.
Labour cost is a significant factor in helicopter production; hence it is clear that automation will play an important role. However, a main focus has to be set also on the flexibility of such technologies, since a large range of different parts have to be addressed (frames, skins, assemblies, etc.).

6.1 Infusion technologies with advanced preforms:

To automate composite technologies for thick walled H/C parts like e.g. frames (here: generation of the fibre architecture - preforming), basic requirements regarding the material and process selection are identified. New material families have to be developed in order to reach technological maturity in due time.

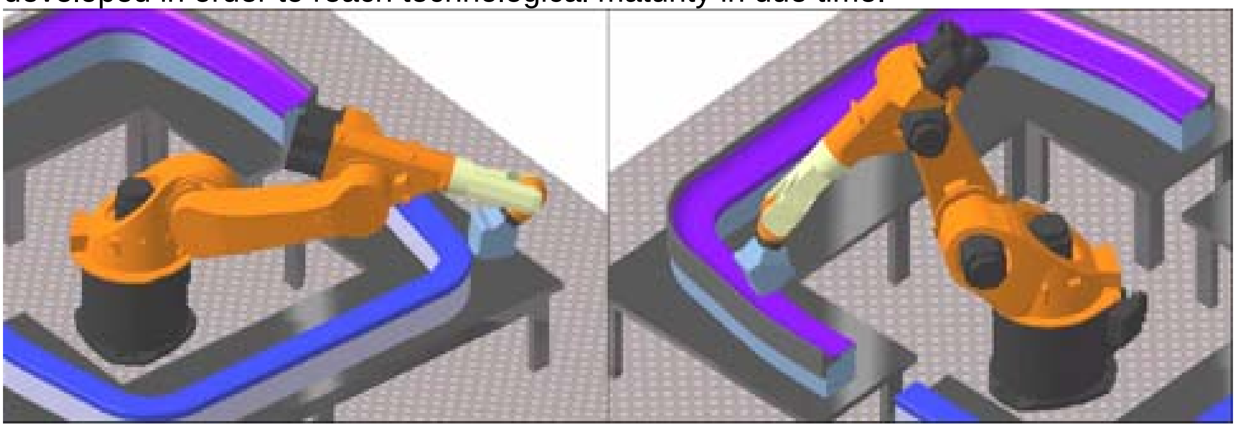


Fig. 6.1.1: automated laying of performs, CATIA simulation

As a first approach, automated manufacturing of dry preforms can be considered. For this process it is mandatory to find and to develop semi-finished products, which are capable of being draped as multi-stacks at room temperature to avoid costly and time consuming heating and bindering cycles.

Specially designed seams and stitches, with special thread materials have been developed to match with these requirements. Different process chain studies have shown, that the preform stitching routine, in-plane preparation of preforms combined with draping and 3D-assembly processes can resolve the problem of automation while staying within a flexible production environment.
This multi-stack dry draping (2D to 3D operation) approach is a key element to save production/labor cost compared to single prepreg ply draping. The draping process has to be designed in a way to prevent cuttings. If cuts would be needed, staggering and overlaps would have to be introduced again and the cost reduction potential compared to standard prepreg lay up processes is lowered. Following the process chain of dry preforming, different dry-assembly steps (3D) will follow the multi-stack room temperature draping. For this assembly process, again preform stitching or bonding operations are being developed. First results show applicability and proof the cost saving potential.

The unidirectional reinforcements needed in highly loaded and curved areas also require special technologies in order to be used in future helicopter programs. Looking at dry fiber materials, “unidirectional” woven fabrics or tapes have to be developed which can be automatically placed to generate the desired fibre architecture. These materials need to be adaptive to the performing process chain described before. The equipments needed for complex helicopter structures are tested today with different development partners.

Fig. 6.1.2: Dry preform on tool

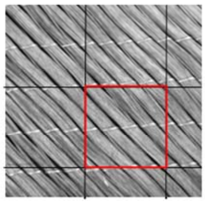
Fig. 6.1.3: Cured RTM Part

A fully dry process based on stitching technology is followed in parallel to a binder-activation technique. Especially an easy binder activation routine offers additional automation potential. However, the flexibility of such processes for different types of parts has to be assessed. In addition, the materials themselves need to be adaptive for high complex shapes. A transfer from aircraft (AC) unidirectional binder materials is not easily possible, since the shape complexity of a helicopter airframe exceeds fixed wing structures.

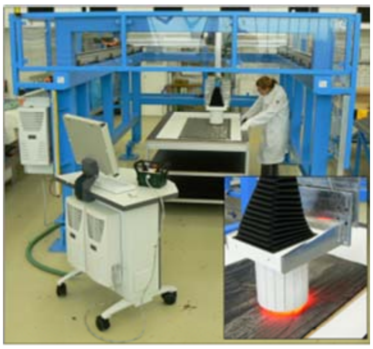
In order to investigate dry preform lay-up technologies, different studies have been carried out at Eurocopter. E.g., a frame structure of the NH90 upper-deck has been designed applying the multi-stack draping process.

The preform was impregnated and cured applying a special infusion and oven curing process. The results gave confidence in the process. Compaction or infiltration problems have not been found. The static tests performed are very promising in terms of future optimization potentials – no cuttings of fibers in highly loaded part sections. No cut through fibers lead to optimized stress and load transfer. As a consequence load carrying capacities rise – one key item for future helicopter structure optimization. The cost saving potential could be shown and especially the potential for further cost reductions is demonstrated as another important factor for an economically producible composite airframe.

On-line process control techniques are addressed in several projects today. One major milestone has been achieved with the introduction of a surface scanning technology combined with specific analysis software. This software allows the inspection of fiber architectures with respect to fiber angles, distortion, seam position and foreign objects in-line the process chain. This basic processing element will be developed further to inspect 3D-aspects of preforms. A calibration of the on-line process control elements is done with experimental scanning equipment. An industrial implementation plan is already scheduled.



Optical inspection of fibre architecture



Experimental Equipment for Qualification

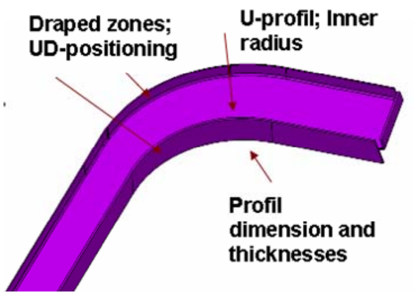


Fig. 6.1.4:. Quality control of preforms

6.2 Prepreg Fibre Placement Technology/Tape Laying:

To automate the manufacture of thin walled H/C parts like e.g. skins, automated fibre layup processes have to be developed esp. for sandwich skins.
Currently there are two manufacturing principles possible for an automated laying of CFRP tapes, slit tapes resp.

Tape Laying: Fibre Placement:

Fig.6.2.1: Tape layer

Fig.6.2.2: Fibre placement robot

Both technologies allow high lay-down rates. Tape laying is more suitable for large, flat or slightly curved parts, whereas Fibre Placement is more suited for smaller, complex geometries, often found on H/C airframe parts.

The expected advantages are:

- High manufacturing process stability,
- Potential NDT effort reduction
- Reduction of manual labour cost
- Reduced cutting waste compared to hand lay up(ca.2-3%for FP, compared to 35% for hand lay up)

The following pictures illustrate the working principle of fibre placement technology:

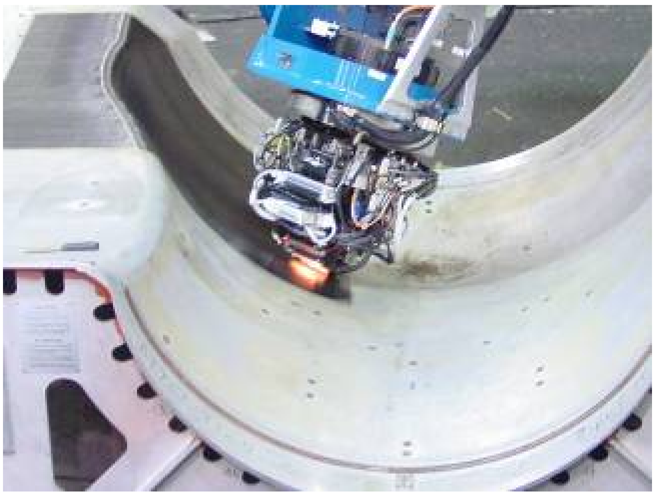


Fig. 6.2.3: FPRobot at work

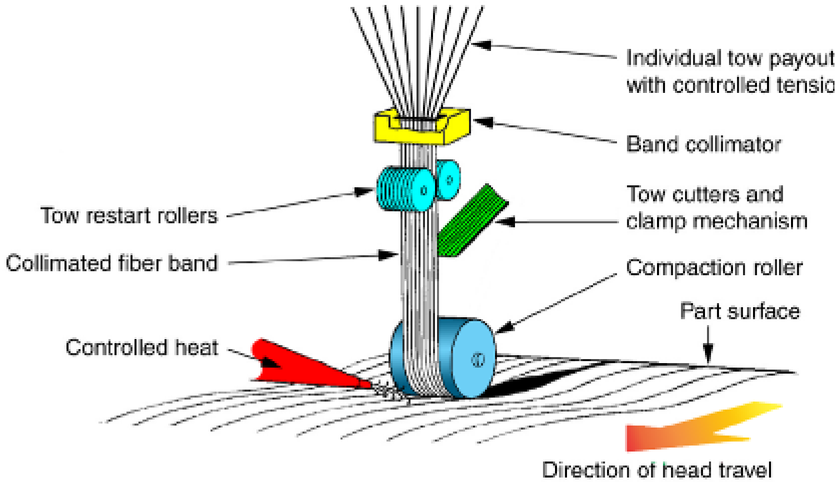


Fig. 6.2.4: Fibre Placement Schematic

By investing in future research work, Eurocopter expects good potentials w.r.t. RC reduction for manufacturing following H/C parts in fibre placement technology for new upcoming programs.

The fibre placement technology allows also manufacturing complex sandwich skins:

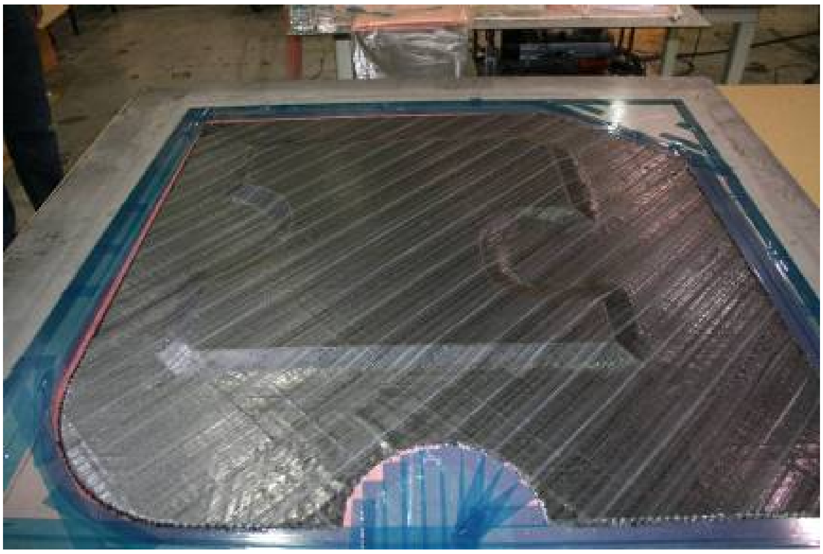


Fig. 6.2.5: Generic Sandwich panel made with FP

Fig.: 6.2.6 H/C Side Shell made in FP

7.Selection Criteria for Advanced Technologies

To select for a component or subassembly of an airframe the “right” technology, means to take a prudent decision, which might have far reaching consequences on the market success. Such technology decision needs to take into account industrial aspects like recurring costs inclusive the eventually necessary efforts for rework; non recurring costs for R&D and industrialisation, and the possibility to respect eventual offset necessities.
Furthermore the selected technology has to enable a professional integration of optional- and customized equipments at subsidiaries/ completion centers worldwide.
Most important for the market success are however , despite the price, which is more driven by the competition than by internal costs, customer value requirements like e.g. weight, survivability in case of crash (crashworthiness), excellent behaviour in fatigue (no cracks), superior behaviour against environmental degradation (e.g.no corrosion) and the possibility to perform quick and reliable repairs worldwide.
One possibility to try to find the “right choice” for the subassemblies of a certain airframe made possibly in several technologies, is to create some sort of decision matrix, which lists all requirements shown above and giving them a certain weight in percent in such a way, that the sum of all of them does not exceed 100%.
In a next step all possible technologies are listed according to the requirements in parallel and certain grades or marks are given for each possible technology by comparing them among each other, how good they can fulfil this specific requirement.
We found that grades from 1, i.e. the requirements is just fulfilled up to 4, i.e. the technology is the best choice available for this specific requirement, provides at the end a transparent and quantitative result, if finally those grades or marks are multiplied with the weighing factor of the requirement and then summed up per technology variant.

Figure 7.1 shows the result for such a technology comparison as example.

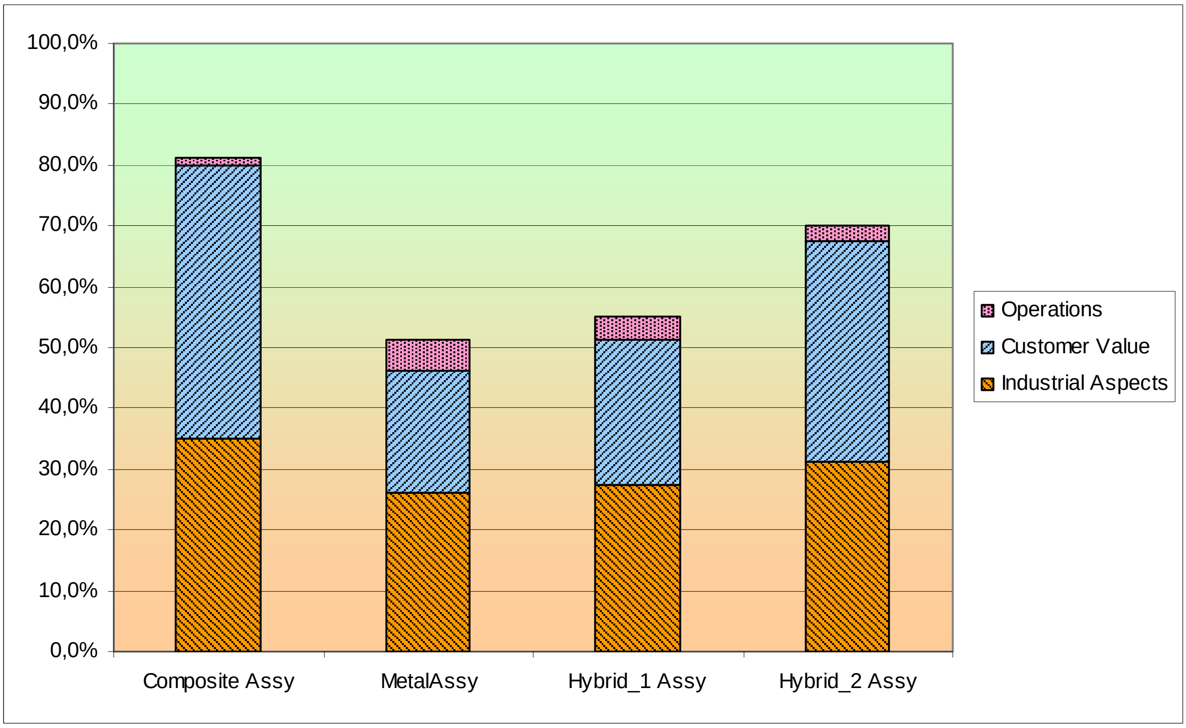


Fig. 7.1: Example: Technology selection on a component assembly

8.Substantiation Criteria

The design- and substantiation philosophy of metal- as well as of composite airframe parts follows mostly the same logic, except some specific considerations based on the different material behaviours.

8.1Substantiation Philosophy Metal Parts:

- Analytical static strength substantiation acc. to appl. CS/FAR 27 or 29 requirements supported by a static test with representative structural parts/subassemblies.

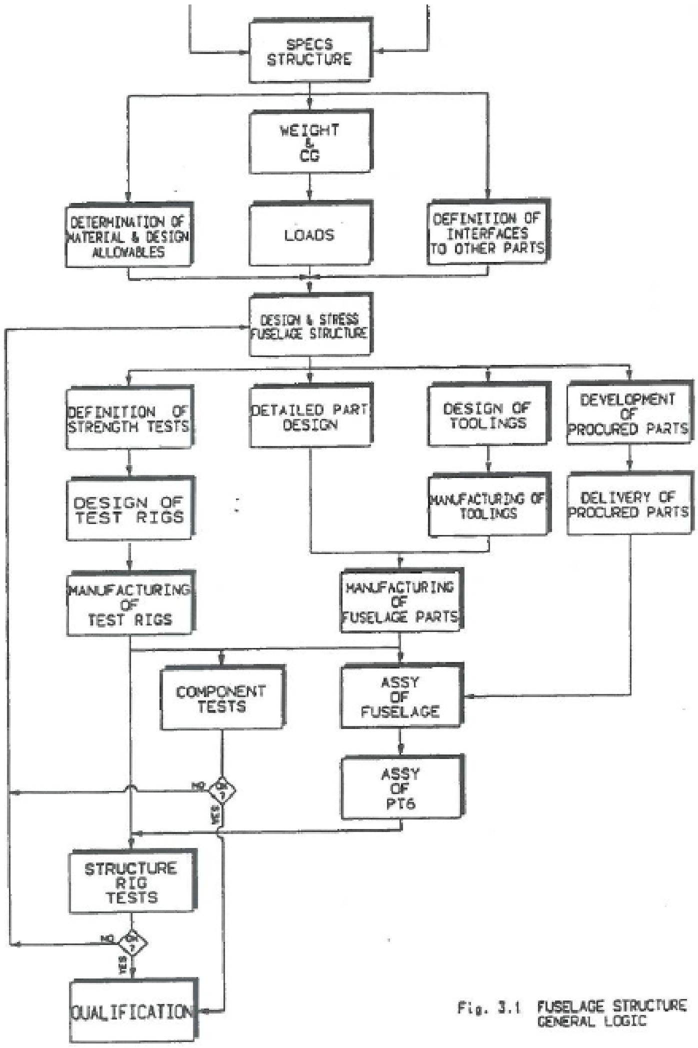


Fig.8.1.1: Example Design/Substantiation Logic Fuselage Structure

- Analytical fatigue analysis acc. to appl. CS/FAR 27 or 29 requirements, supported by fatigue tests on coupon and subcomponent level

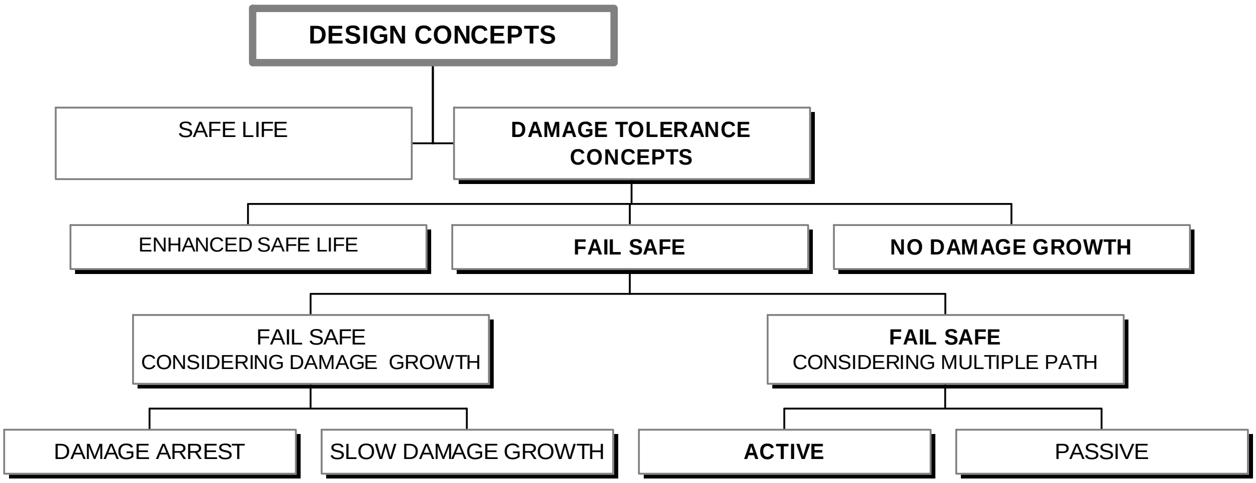


Fig.8.1.2: Flow chart Damage Tolerance Concept

8.2 Substantiation Philosophy Composite Parts:

- Analytical strength substantiation acc. to appl. CS/FAR 27 or 29 requirements, supported by tests with relevant parts and structures.
- All these parts are designed according to the damage tolerance approach taking into account allowable manufacturing and in-service defects and no-growth of allowable defects under repeated loading

- Identification of principal structural elements
- Consideration of manufacturing and in-service damages
- Allowable manufacturing and barely visible impact damages (BVID) which can realistically be expected from production and during operational service shall not grow under repeated loading to such an extent that the structural strength will be reduced below Design Ultimate Load (DUL) (no damage growth).
- Size and location of these damages is selected with respect to the quality assurance and inspection program.
- Visible damage resulting from obvious discrete sources shall not reduce the structural strength below Design Limit Load level.
- Impact damages that could reduce the strength below Design Ultimate Load have to be detectable.

Test Philosophy for Composite Structure

- Coupon and element tests to determine material allowables
- Damage size at BVIDs (barely visible impact damages)
- Strain limits with & without BVID
- Environmental conditions: RT/ambient, hot/wet
- Load enhancement factor approach in test

No-Growth“-Concept
To ensure the no-growth of various damages under repeated loading a certain strain limit at Ultimate Load is applied. Its suitability has been demonstrated on coupon level and on a full scale tests.

9.Conclusion

The presentation showed how EC group is investigating advanced technologies for possible applications on airframes for new products.
To select the “right choice” in terms of technology is a difficult task and requires much more than applying fundamental rules like: If it is a skin and the surface is not developable, than better make it in composites, like it is done meanwhile on engine cowlings of most helicopters worldwide.
A considerable amount of in-house knowledge up to at least TRL 6 is necessary, to apply a process as was described in chapter 8, which needs the active involvement of design-, production- and service-engineers.

Special emphasis has also taken on likely future requirements concerning the substantiation of damage tolerance and fatigue evaluation on helicopter airframe structures including the substantiation of qualified repair processes for both, metallic and composite designs.

To build a sound product which satisfies all customer needs, requires from airframe designers to cope with all aforementioned requirements which are to some extent contradicting, e.g. light weight design vs. crashworthiness.
Visions and knowledge, skill and experience, courage for innovations and the ability and willingness to listen to customers and their needs are necessary to provide outstanding solutions for the market and to the satisfaction of our customers.