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QUALITY ASSURANCE FOR COMPOSITE STRUCTURES - AN INTEGRATED PROCESS

by

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Introduction

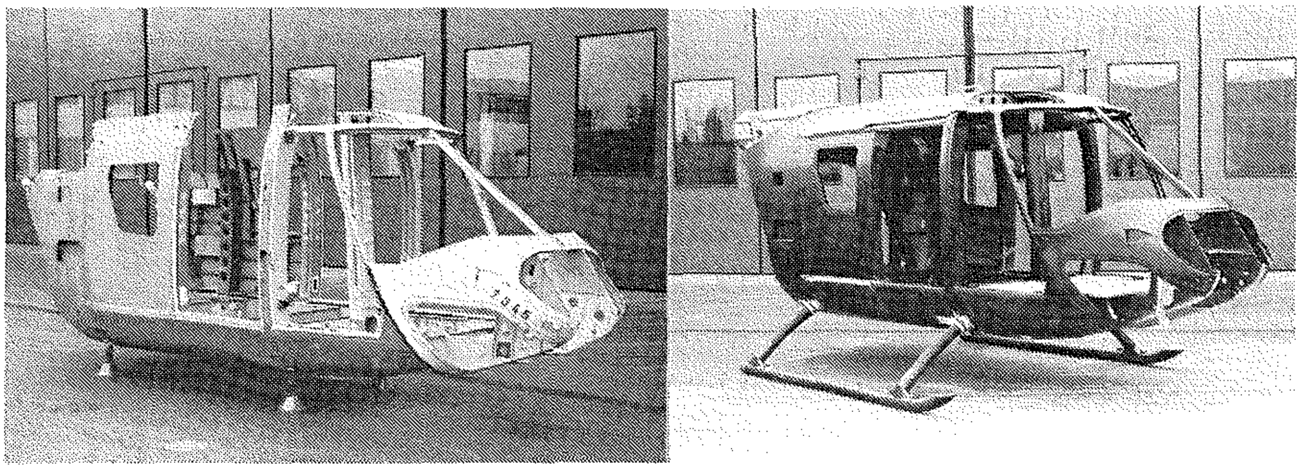
Pioneered in the laboratories and brought to flight initially in the early 60´s on the Bölkow Rotor System, Fibre Reinforced Composites have continuously increased their usage on nearly every production program of flight structure. This ambitious first introduction of new high performance plastics into flight hardware was followed and extended by several experimental hardware programs during the 70´s. The break through for series production application of composites for primary airframe structure was leaded by the avant-garde of these programs, the Airbus A310 Vertical Fin., 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 BK117 Faser Zelle utilises more than 50% of the total weight of advanced composites for the fuselage frame.

Weight reduction of 30% as well as performance increase are the gains of these experimental programs. Both of these development studies served as a conviction of the design for the new generation of helicopters.

Figure 1 BK117 Composite Air Frame

Today, modern designed helicopters like the French/German Tiger utilising nearly 100% of composites for the primary structures. The application of advanced composite materials changed the lay-out of structural and dynamical components completely. The use of FRP is not just a plain change of material, it is also a change of the design philosophy. Buckling stiffeners, attachment fittings, frames, girths and longerons are integrated components in a single part. Beside the weight savings, reductions of up to 80% of detail parts has been achieved due to the composite application.



	ALUMINIUM-DESIGN	FRP-DESIGN	REDUCTION
WEIGHT (kg)	103,4	69,0	33 %
SINGLE PARTS	721	150	79 %
CONNECTING ELEMENTS = DRILL - HOLES	12000	1500	87 %

Figure 2 Savings in Part Quantity

But, this change in design increased the complexity significantly. This leads me to the basic question for the future airframe manufacturing.

Are we able to take the responsibility for such complex designs and processes?
How can we ensure the reliability for our products?
And, what quality measures must we take to give our customers the confidence for our products?

To answer these questions we have to analyse the growth of a component from the first draft up to the series production. We have to indicate the quality measures applied in the development cycles.

Manufacturer of flight hardware are requested to carry special responsibility for their products and its quality. In any case of malfunction of a detail primary component human life may be involved and endangered. Therefore, for all parts and materials a quality standard is demanded, which requires an airtight tractability of each production step reaching from development to the entire service life. That means for the advanced composite materials, each of the basic ingredients of the composed material must be traceable, back to its manufacturer.

One of the peculiarities of Fibre Reinforced Plastic Manufacturing is, that the material and the component is produced at once in a single step. The designer is designing the material and the part simultaneously. Design method, raw material, manufacturing process and shop environment must be specified and superintend able.

To ensure these quality demands for the production of composite structure the quality assurance will consider four (4) main tasks. These tasks can only work efficiently in a tight and coordinated process (table 1).

TITLE	TASK	TOOLS
Quality measures for predesign and design	Predesign examination checking of drawings on class 1 parts, preparation of manufacturing and inspection specifications	Material data sheet design standards
Quality measures for materials	Material selection material qualification, qualification of supplier, material income inspection	Delivery specification storage specification technical conditions for delivery
Quality measures for manufacturing	Development and qualification of manufacturing processes, checking of production steps, final control environmental control	Lay up scheme, cure cycle chart, manufacturing specification, qualification of manufacturing equipment
Inspection oriented QA	Measuring technique destructive inspection non destructive inspection	X-Ray, Ultrasonic, Computer tomography

Table 1 Main Tasks for Quality Assurance

Quality Measures for Predesign and Design

Highly integrated FRP-components are complex technical systems. They can only be designed in a complicated, iterative development process. Load predictions made during predesign must be specified and verified too. The **QA** ensures that only secured data banks, qualified characteristic values and realistic requirements are used.

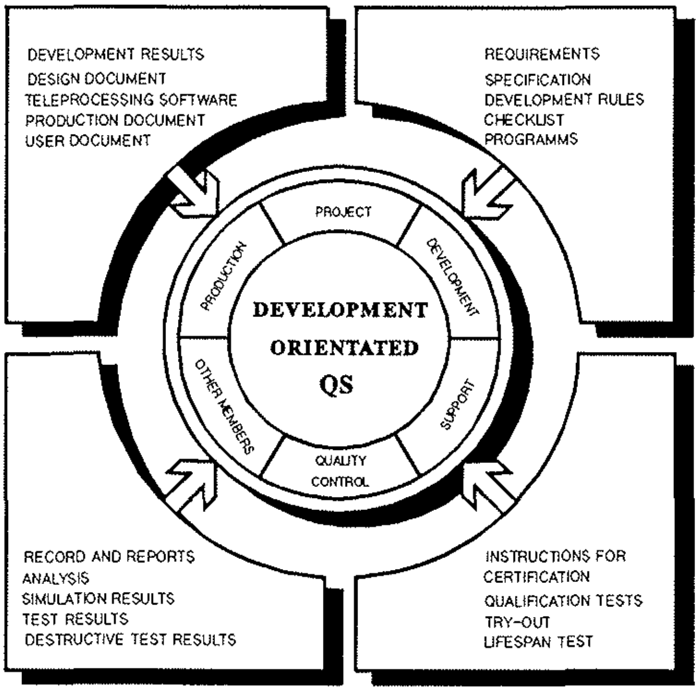


Figure 3 Design Oriented Quality Assurance

One of the main fields for the design oriented **QA** is the safety classification of parts. Malfunction of vital or safety class 1 parts may cause the loss of the aircraft and therewith jeopardize human life. Such parts can only be produced using qualified materials and secured processes. Drawings for such components must be approved, tolerances and quality grades clearly indicated.

The key element during the development process is the definition of design criteria with safety and reserve factors. The design oriented QA supports the design office with material data which are qualified according to the relevant aircraft standards. Since the composite becomes increasingly **the airframe material**, there is a continuos improvement of these material to recognise. That means, each of new designed products will employ the newest generation of composite material with the best performances. That means also, material specifications, such as design values, income inspection procedures e.g. are not available at the beginning of predesign. The actions being taken from a design oriented **QA** are to develop secure material specifications and reliable design values. Tightened costframes in the aeronautic industry require very short development cycles. Parallel proceedings instead of sequential operations of the involved departments is badly needed. That means, predesign must proceed until material selection and qualification takes place. Close cooperation of design office, material and process office and QA-office is the only possibility to be successful. This early QA-actions for predesign are not only a duty of QA-department, these task are being accomplished of anyone involved at that early stages.

From the first draft up to the delivery of drawings to the production shop quality measures will accompany the development cycle.

The application of composites opened an unimaginable degree of freedom for the designer's creativity. Looking at the variety of composite parts designers created we will find light and delicate structures as a canopy frame or heavy and high loaded components like a rotor hub. This variety indicates the differences in design methods as well as in the production technology necessary. In order to use the advantages composites offer, we must allow completely new construction methods. This requires new manufacturing processes which aren't specified during predesign and design phases. A design oriented QA must analyse and qualify these processes and abandon risky approaches already in the beginning of development.

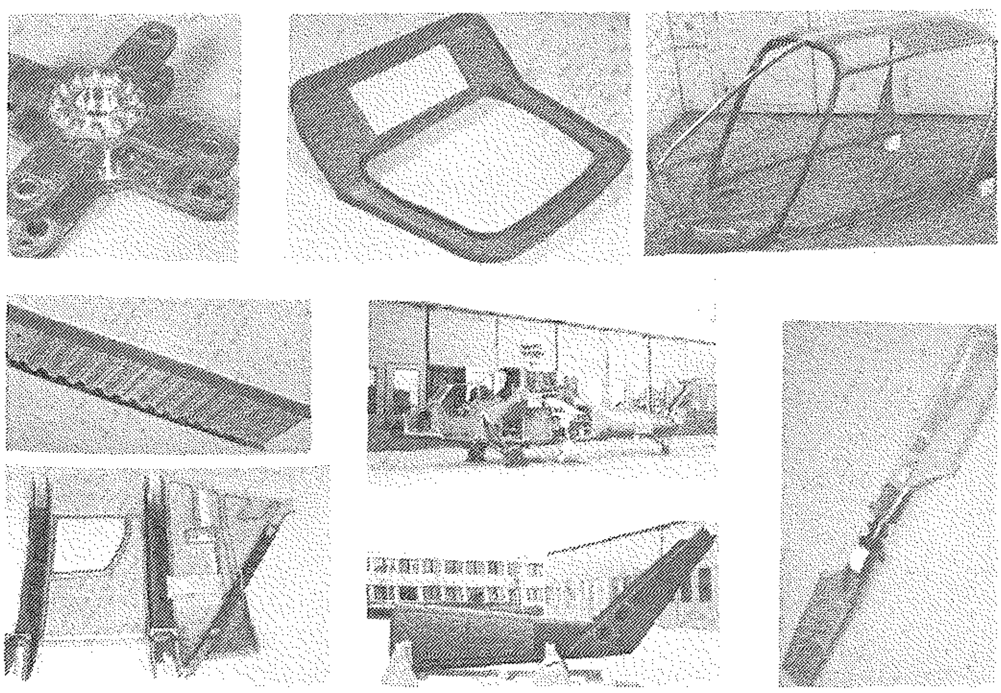


Figure 4 Variety of Structural Design

Regarding the responsibility, airframe manufacturer have to take, production of vital parts, class 1 or highly loaded components require specific manufacturing and inspection specifications. The **QA** ensures and coordinates, that equivalent specifications and standards will be prepared and verified during predesign phases. Additionally, existing technical reference documents and specifications will be analysed if quality relevant demands are definite and completely defined. If we tend to apply new technological products, these existing rules may not fit. Updates and revisions shall be made prior to production start.

Quality Measures for Materials

Material selection and qualification has always been a key task in the aeronautic industry. In order to manage this complicated task most airframe manufactures have put that responsibility into a materials and process office. The M&P office initiates all safety relevant measures already during material selection. Qualification of materials and suppliers as well as procedures for incoming inspection, storage and transportation are handled and organised from these offices. Materials may only be employed when all quality demands, established by M&P, are met. In a pristine sense, the tasks of the materials and process office is clearly a quality assurance assignment.

As we said before in composite design we are designing the material and the part at once. This complicates qualification of composite materials significantly. Composites are unisotropic materials, staggering of layers in different orientation will provide different values. On top of that composites offer a tremendous variety of different materials. Each type of fibre and each type of matrix resin has its one behaviour. These peculiarities must be considered for any qualification program.

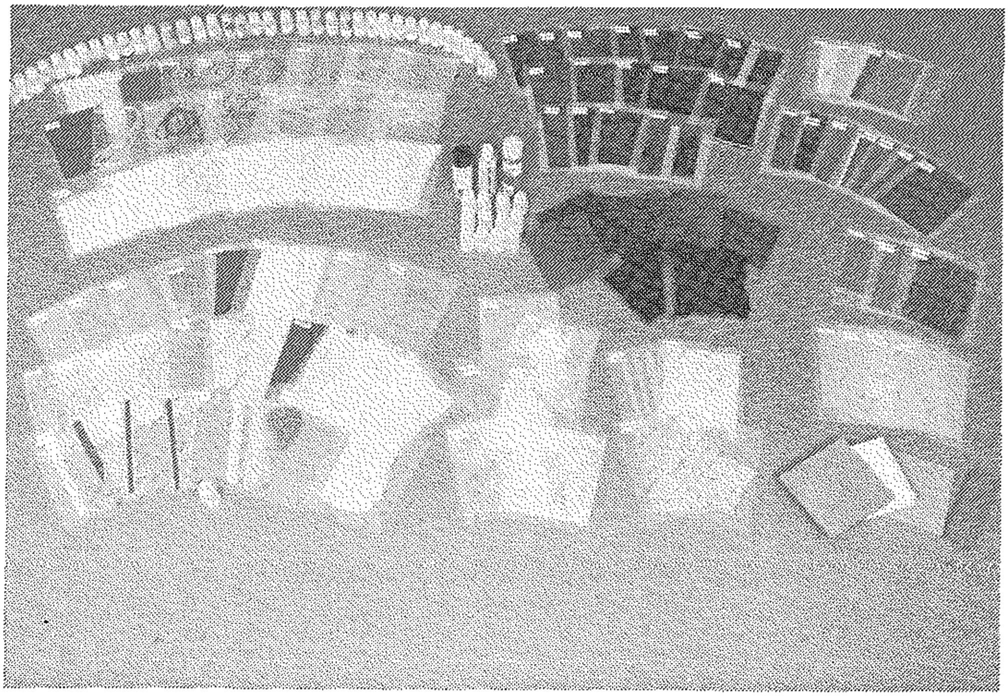
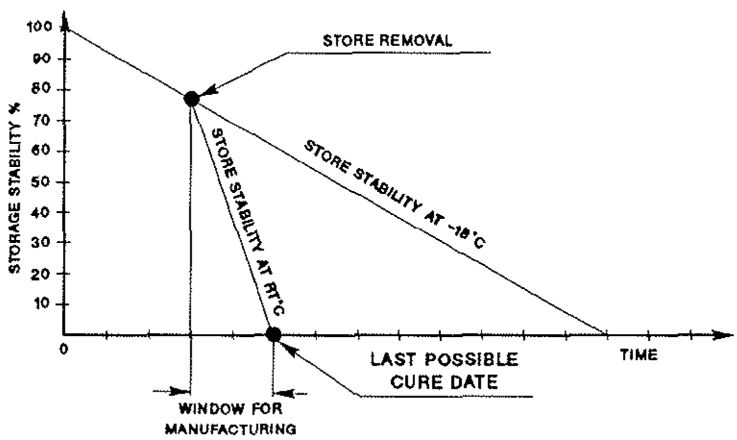


Figure 5 Variety of Materials

Quality assurance for materials starts with a specimen program which will provide the specific data for the lay-out of FRP's. To allow a comparison of different materials engineers have created an international harmonised specimen catalogue. Tension modul, tension strength, bending modul and strength, interlaminiar shear strength, flatwise tension, α-therm and many others more will be ascertained. These data received will be recorded in material data sheets, which indicates the level of performance of each material and each supplier.

Quality assurance and M&P office will select and assess suppliers. Only qualified supplier are allowed to deliver materials for aircrafts. The qualification of these suppliers includes quality audits held at the suppliers plant. They must fulfill all technical delivery conditions which are stated at the material data sheet.

STORAGE STABILITY OF COMPOSITES



TYPICAL STORAGE STABILITY OF COMPOSITE MATERIAL

	STORE STABILITY AT - 18°C	STORE STABILITY AT ROOMTEMP.
V913 PREPREG	2 YEAR	60 DAY
SYNCORE SYNTACTICAL CORE	6 MONTH	10 DAY
SPLICE ADHESIVE	6 MONTH	10 DAY
ADHESVIE FILM	6 MONTH	10 DAY
CONTACT ADHESIVE	3 MONTH	5 DAY
PASTE ADHESIVE	---------	6 MONTH
BONDING PRIMER	6 MONTH	30 DAY
GREEN CORE HONEYCOMB	---------	1 YEAR

Table 2 Storage Stability of Composites

Each type of material must have its own material income specification. Most of the composites we are using are reactive chemicals with limited life. The income inspection procedures will proof that transportation was unharmed. In spite of contractual secured delivery conditions material data such as tension modul and strength, strain and ILS will be checked. Beside that resin flow, fibre/resin content, density of fibres, chemical reaction enthalpy and others more are carefully determined and recorded.

Beside corrosion metal materials have an unlimited store life whereas composites contain reactive ingredients, which are depended on climatical influences. Temperature, humidity and light may influence the reactivity behaviour of the materials. Therefore store life and climatical conditions must be specified and superintendable.

Quality assurance and M&P offices together have created efficient and save working procedures which guaranties a supply of material appropriate to the high quality demands for airframe manufactures.

Quality Measures for Manufacturing

The introduction of composite initiated a significant change on the manufacturing floors. The former sheet metal shop with its machines and forming presses was replaced by ovens, autoclaves, heated presses, vacuum pumps and environmental controlled working areas. The handling of shelf life limited materials occasioned a totally different production management. Since we manufacture the material and the part concurrently the manufacturing process became a key-element. Little things like shop tidiness or an elevated humidity in the production shop may entail fatal failure of the component. Most of such defects are not visible and often difficult to detect. Easy to grasp detail part drawings for conventional sheet metal parts have changed into large and complicated drawings with lay-up schemes and detail sections. Composites increased the complexity on the shop floor drastically. In order to handle this complexity quality assurances has become of major importance.

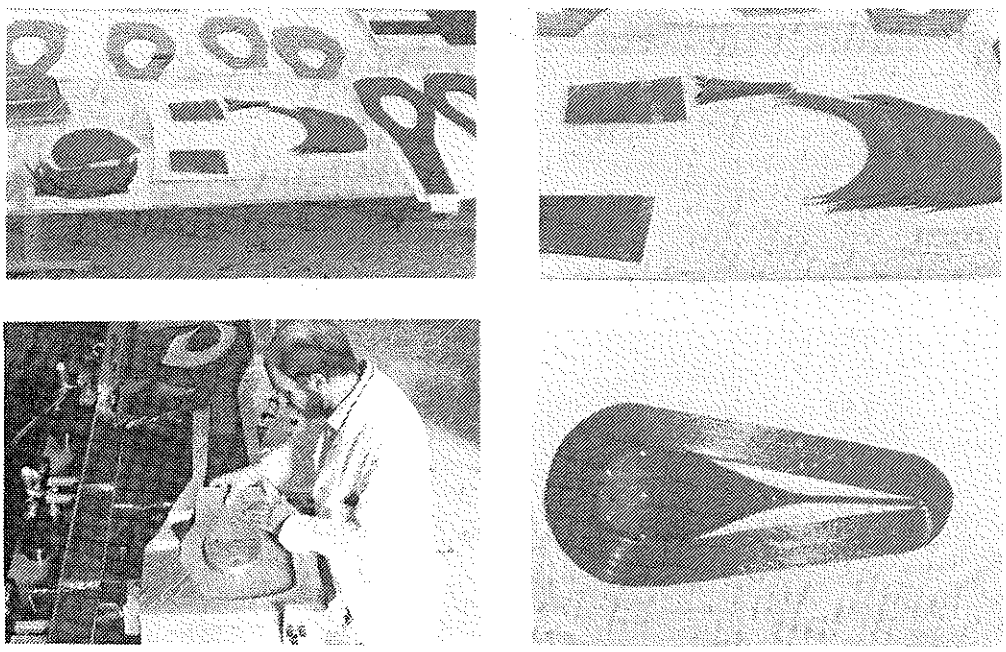


Figure 6 Detail Layers of a Rotor blade

In the intent to manufacture quality instead of inspecting it, QA measures we consider, reaching from the kind of drawing prepare up to the qualification of auxiliary materials. It is an integrated task for the designer, the production engineers, the workman itself and quality inspector. A manufacturing oriented QA is accompanying the production of a component from the out of store date of material up to the final release for flight. These cost intensive features are a requirement, aircraft authorities demanding of each aviation manufacturer.

Quality assurance for production must consider preventive, inspective and corrective measures to avoid failures, recognise them premature and forestall repetition. Therefore the QA checks all technical documents and ensures that only qualified manufacturing and inspection aids are used for production. The same is for the applied processes. QA measures will take notice that qualified processes and facilities are employed in manufacturing. It will superintend the process and machine precision of ovens, presses and autoclaves, analyses process records and performs "On-line" readings of equipment. Additionally, all manufacturing facilities may be calibrated periodically and cross-check by specimen examinations.

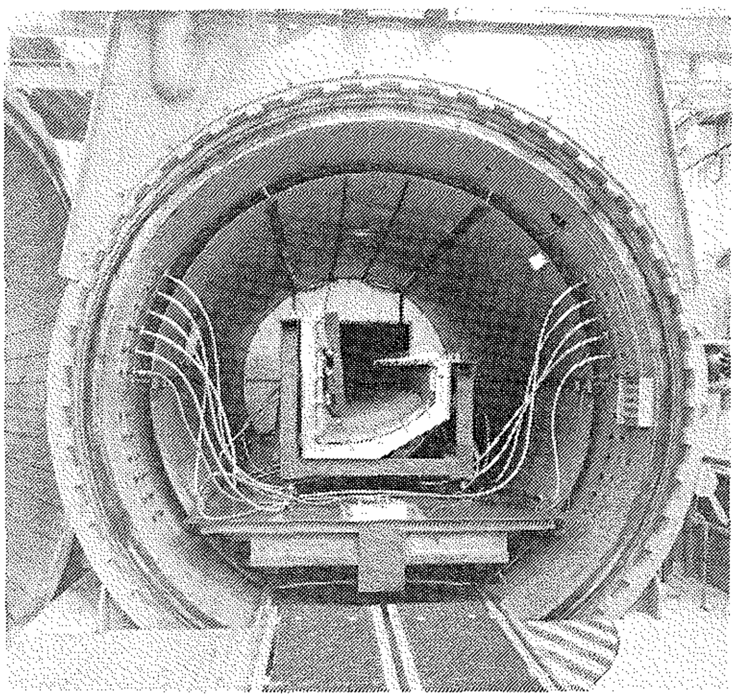


Figure 7 Autoclave

The production of composites requires uncountable different auxiliary materials such as release films, peel plies, bleeders, breather, vacuum bags and many others more. Curing of composites is a chemical reaction which needs controlled conditions to produce quality. Auxiliary materials may interfere this processing. As an example a moisture peel ply in direct contact to a epoxy material during the cure process may initiate a totally different chemical reaction and destroys the part. Therefore qualification of such materials is urgently demanded. QA secures that only qualified auxiliary materials will be employed and superintends their application.

Strength and stiffness of FRP-parts and therefore also the material characteristics are defined by the type of fibre and its orientation. As one can see below, the rotor blade, shown in fig. 8, is composed out of 2200 different layers of prepreg materials. Drawings and lay-up schemes define fibre orientation and staggering sequence explicitly.

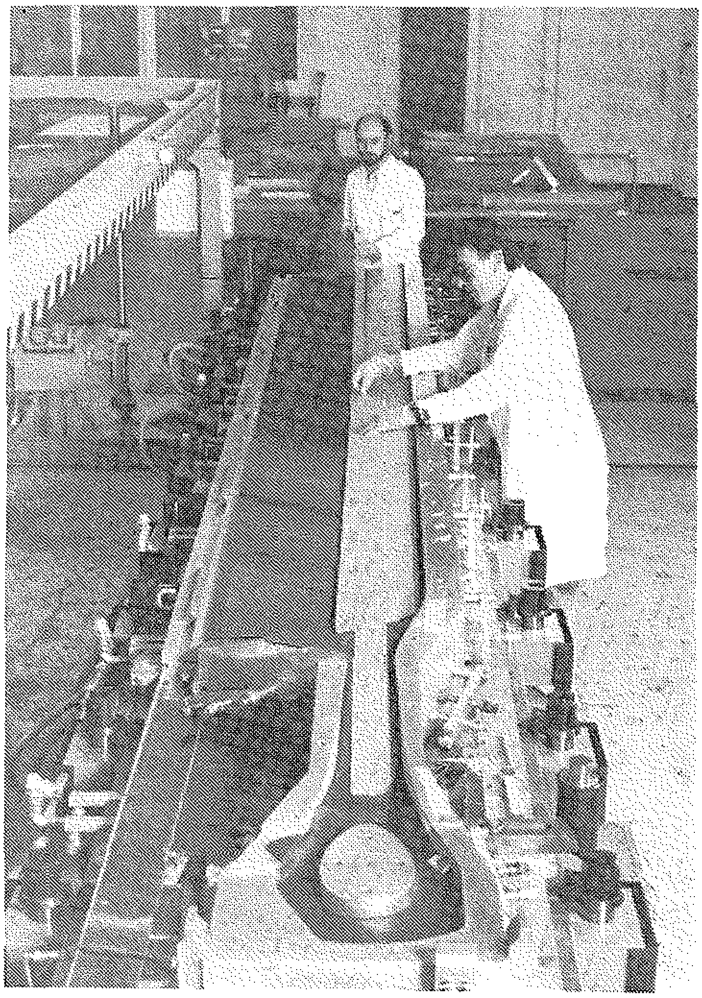


Figure 8 Tiger Rotor blade Manufacturing

Deviations of these staggering and orientation sequence will influence the part quality, they may only be detectable by destructive measures or extensive inspection methods. Documentation and super intention of the manufacturing process is indispensable necessary.

The manufacturing of composites requires production steps as hot forming operation, debulking cycles or prereactive compacting. Elevated temperatures are necessary for such processes. Since the FRP´s we are using are temperature reactants such production steps will influence the material integrity. Documentation of these cycle is necessary too.

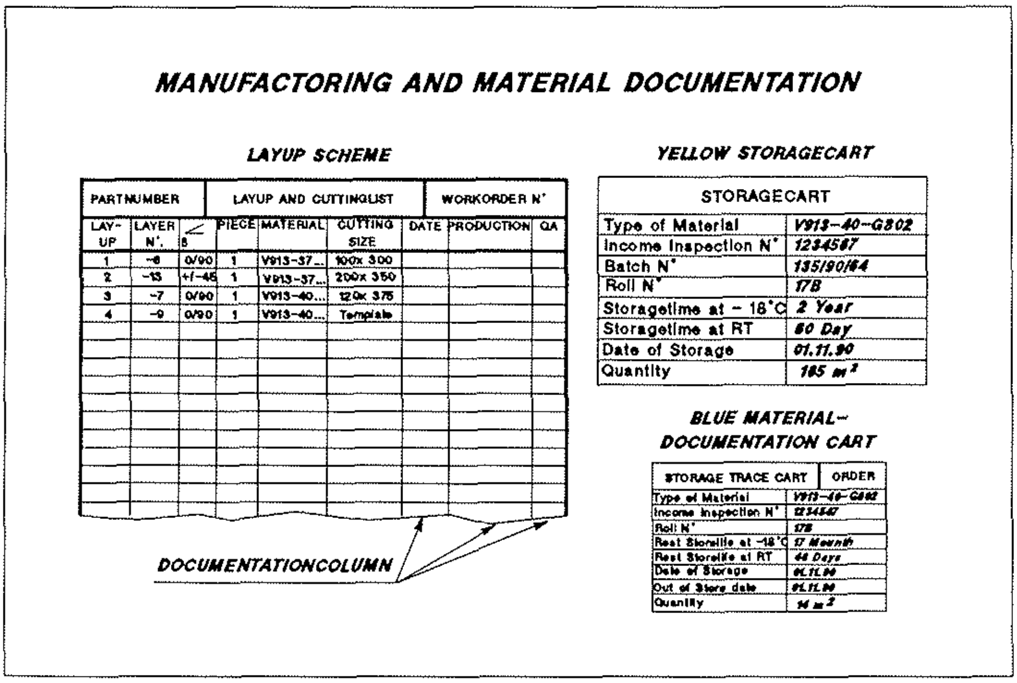


Table 3 Manufacturing and Material Documentation

The key operation in FRP manufacturing is the cure. A production oriented QA will finalise with the inspection of the curing records of ovens or autoclaves. Any deviation of the requested process will be reported. Depended on the valuation of the deviation either a discrepancy report or a scrap order will be given.

The final inspection of any manufactured component includes a cross-check of all documentation steps. Objected deviations must be approved with a concession.

Inspection Oriented Quality Assurance

An inspection oriented quality assurance can be divided into three (3) chapters. These are:

- **Plain Measurement Technique**
- **Destructive Inspection**
- **Non Destructive Inspection**

The plain measurement technique will inspect all processing and functional dimensions. This includes dimensional check of aerodynamical profiles or surface roughness e.g. Most of the time FRP components are manufactured using a mould. It has become a common to inspect such tools with the final dimensional check of the first manufactured component. After checking of such a first part the mould will be released for series production if all dimensional precision is achieved.

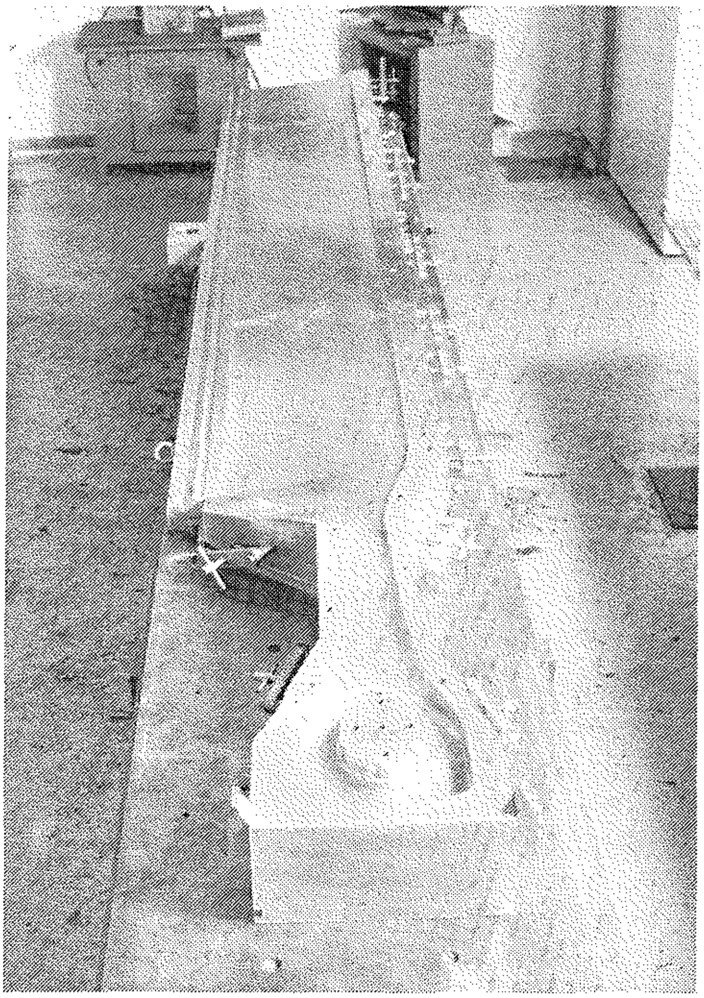


Figure 9 Rotor blade Mould

Critical aerodynamical surfaces such as rotor blades may be measured in spite of this tool release procedure. Measurements will be taken until a consolidated and reproducible databases of the manufacturing precision is achieved. Subsequently to that inspections will be made following the rules of the "Gausschen Statistic" procedure.

The destructive inspection reaches from testing of simple tension specimens over to determination of thermal or sound conductivity of helicopter doors up to the EMC test or lightning strike testing. Destructive tests are being accomplished to verify design methods and stress analysis, to simulate load cases and to determine quality of series production. Vital parts and safety class 1 must be inspected destructive to get flight admissions. It serves to provide sufficient material data concerning static and dynamic strength and to certificate production methods. The destructive inspection is usually organised by design and engineering office but it is a clear quality assurance task.

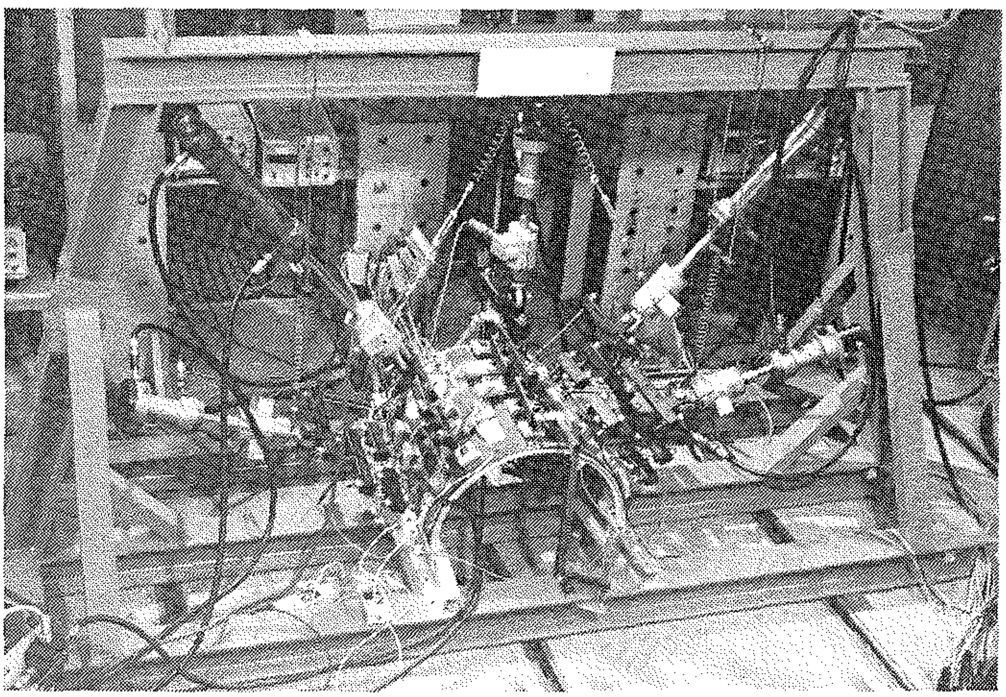


Figure 10 Component Test

Fibre Reinforced Plastic allow for the production of large and highly integrated components comprising aerodynamical cover, fittings, load introduction areas within a single part. The employment of such complicated structure contains an increased risk compare to differential constructions. Inspection methods which indicate the state of quality clearly are a must for the application of these designs. Non destructive inspection methods have been developed in the past years which provide definite statement of quality produced.

Several non destructive inspection techniques are available, these are:

Tapping Test

Ultrasonic Inspection

- **Through Transmission**
- **Impulse Echo**
- **Squirter Technique**

Fokker Bond Test

X-Ray Inspection

- **Classical**
- **Computer Tomograghy**

The investment expenses for the non destructive inspection equipment are tremendous. They differ from approximately 60.000 DM for a portable ultrasonic device up to some millions for a computer tomogragh. Each non destructive method requires high skilled personnel, the airframe manufacturer spending in education for that are very high. Most common inspection methods are ultrasonic inspection or X-Ray for structural parts. Computer tomograghy is increasingly applied for the inspection of vital parts such as rotor blades with its high demand for quality.

Conclusions

Quality assurance proceedings in the aeronautic industry differ from the QA measures applied in regular industry. The high quality standards on aircraft passenger demands, are requiring measures which are confirmed due to the low number of accidents.

The fast increasing application of Fibre Reinforced Plastics requested a concentrated and integrated cooperation of all involved disciplines. Design, M&P engineers, manufacturing and quality assurance personnel have found efficient ways for a successful concurrent engineering. A complete understanding of the peculiarities composites contain is a must which is managed in the aeronautic industry by a quality assurance control system.

We have developed and verified methods to handle that complex designs and processes. The QA measures ensure a tractability of materials and processes. The inspection methods such as monitoring of production, measurements, destructive and non destructive inspection are providing reliability in our products.