

SEVENTH EUROPEAN ROTORCRAFT AND
POWERED LIFT AIRCRAFT FORUM

PAPER No. 64

ROTORBLADES FOR LARGE WIND TURBINES
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MUNICH, GERMANY

SEPTEMBER 8 - 11, 1981
GARMISCH-PARTENKIRCHEN
FEDERAL REPUBLIC OF GERMANY

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From the design and production work of 25 m long composite rotorblades detailed information is given on designers "tools", mold and tooling design, some manufacturing experience and final acceptance tests of blades.

1. INTRODUCTION:

Within the last 5 years some potential manufacturer have developed different Fibre-Composite-Rotorblades for Wind-mill-Power-Generation. The presented designs and manufacturing concepts are quite different. This report summarizes MBB's development work for production of large composite blades using an open mold concept and hot curing resin system.

The concept selection was based on four project requirements:

- maximum variability in structural design should be possible independent of tooling,
- minimum investment effort in the development phase was required by unknown size of commercial expansion possibilities,

- mechanisation of manufacturing should be possible for increase of production,
- most economical use of material properties and quantities was required to realize high fatigue resistance at all possible temperatures, close tolerance of natural frequencies, structural weight and geometrical dimensions.

The development includes the design and analysis of the blade structure, design of mold and toolings, manufacturing and qualification tests.

A general outline of this work was already given in /1/ and /2/. This paper will give some more detailed information about concepts in design of blade and mold, manufacturing experience and the final acceptance test of the first blade.

2. DESIGN OF BLADE:

Two different blades were designed and manufactured by MBB, following consequently the "integrated spar design".

Fig. 1 and 2 characterize the two Wind-Energy-programs for which the blades were developed.

2.1 Integrated spar design

Fig. 3 shows a rotorblade-section of a wind energy converter. The blade consists of two halves (upper and lower shell) which are bonded to each other. Caps on the leading and trailing edges complete the glass fibre skin to a torsion-box. The flanges are made of unidirectional carbon-fibre (T 300) laminate. They provide tensile strength and flexural stiffness.

The core, machined of PVC, does stabilize airfoil geometry uniformly and contributes to shear-load transfer.

The shear web reinforces the rear part of the foam core.

The analysis of such multi connected hybrid cross-sections cannot be done by manual calculations economically, so some computer programs were developed for the design

2.2 Analysis of multi connected hybrid sections

Basis of all design activities is the first blade layout by very few datas to meet the requirements of flexibility. The specification of the blade includes datas of the mass, center of gravity and the natural frequencies. The first layout of the stiffness and mass distributions is calculated by the program "BALKEN". The comparison of these results with the specification causes very often a change of the mass and stiffness distributions till the results meet the specification.

The blades profile, stiffness and mass are the input-datas for the layout of the sections.

The designer starts with the program "QDAT" using the input parameters, geometry of the materials and their properties.

The result of calculation is a complete analysis of the properties of all detail areas and the integral properties of the section. All geometric datas can be transfered directly to the "CADAM-System"*, for further design work and to create all drawings for manufacturing.

Additionally a preliminary easy calculation of the first natural frequencies can be done with the "BALKEN"- program. An analysis of the results and a comparison with the specification lead to a redesign of the blade-sections. The designer can change the materials, their thickness and positions.

A short action tree shown in Fig. 4 demonstrates the "designer's tools" and the information which is available for him when he startes creating all drawings by CADAM.

* CADAM: Computer Augmented Design And Manufacturing

2.3 Definition of blade surface

The costs of mold production are primarily influenced by the blade contour. MBB's goal was to produce a heat resistant mold without using a positiv model.

This is possible if bended steel plates can be used.

The task now was, to find a surface which can be developed to conical areas. The WEA-blade airfoil is defined by three different profils:

0.05 R	Circle	
0.25 R	FX-W 343	
0.40 R	FX-W 270 S	Wortman-Profils
0.70 R	FX-W 151 A	
1.0 R	FX-W 151 A	

This profils, including their twist position, are used in a 3D-Loftprogram named "GEOLAN" and a threedimensional geometry model was defined.

A special program was developed to analyse this model and to find a best approximation with developable areas and the according bending lines. The result is shown in Fig. 5.

3. MATERIALS:

The dynamic characteristics and the stresses of large rotor-blades are mainly dependent on their masses. For this reason, materials of high fatigue strength, high stiffness and low mass have to be selected.

Fibre composites open an extremely wide design field by the variability of their physical properties and their good fatigue resistance

For the first production line of only 3 blades the requirement of minimum investment cost was met by hand-lay-up of prepreg materials in open molds. Maximum laminate thickness of 90 mm needs a very long pot life of the resin system for material inspection, lay-up and vacuum bag set up.

Hot curing at 80 to 90°C was done under standard vacuum pressure. Fibre content of $61 \pm 1\%$ by weight were realized and the laminate properties for 90 mm thickness are still high in relation to test results within the material income inspection, measured on single-layer-specimens.

The properties of the actual laminate was precalculated with the program "VERBUND" using the properties of components and checked by tension test of the actual manufactured composite.

The calculated values of Joung's Modules had to be reduced by a factor depending on the weaving style of the fabric.

The problem of the exothermal reaction of the resin and the high temperatures within the thick laminate was checked by test specimens and no penalty was found.

The bearing stress analysis shows the following minimum factors of safety

bending load:	2.4
shear load:	8.3

In Fig. 6 the blade attachment configuration is shown.

Two requirements caused by thermal influences are to be met.

Difference of thermal expansion coefficients between FRC-blade and steel hub has to be a minimum for

- axial direction, to minimize variation in prestressing load of the studs, and
- circumferential direction to prevent fretting between FRC-blade root and steelring.

Thermal expansion coefficients of materials are:

T 300 - unidirectional:	0.77×10^{-6}	1/K
GRC $\pm 45^\circ$	0.34×10^{-4}	1/K
Steel	12×10^{-6}	1/K

From this properties a variation of preload of the studs is calculated to 153 N/K.

The load diagram, Fig. 7, shows that a load caused by 100 K temperature difference is uncritical.

4. TOOLINGS AND MOLDS:

Four tools are needed for production of two blade types:

- mold (each for different blade typ)
- milling jig (only one)
- cutting jig (only one)
- drilling jig (only one except drilling template)

4.1 The mold and milling jig

The blade is manufactured in two halves (upper and lower) which are joint by bonding a twisted area.

This joint area has to be milled on to the foam core of the blade in close tolerances to the outer geometry of the blade respectively to the mold geometry.

The molds are manufactured by plastic deformation of 8 mm thick steel plates in a free bending process.

The bending process is controlled by the plots of bending lines and contour of jointline and by two steel shablones for each shell part. One mold half is assembled from 5 shell parts positioned on a frame work.

The support in the leading edge area are free in axial direction and rigid in chord direction for thermal expansion. Those in the trailing edge area are free in chord-axial-plane. The vertical position (including twist position) is adjustable on each support, see Fig. 8.

The heating mat is manufactured from common carbon fabric with two layers in glass for isolation to the steel shell. Temperatures up to 130°C are possible at mold surface.

The inspection of the mold position and adjustment was done before implementation of heating system.

Fig. 9 shows the inspection devices

- shablones at each shell connection line
- laser beam used for definition of blade axis
- standard theodolit

In Fig. 8 the functional dependency of the mold geometry and the position of the milling jig is plotted. By this method very close tolerances were realized:

- axis position within a cylinder of 1 mm radius
- twist position of profiles within 0.1 degree
- other dimensions within 1 mm e.g. position of milling jig.

4.2 Milling of attachment plane

The interface to the rotorhub is a plane of a circle. After assembly of the two blade halves this plane has to be milled. Because of the size of the blades it was not possible to use standard milling machines, so a separate tool was to be developed. Fig. 10 shows the complete device. A plane steel ring is clamped on to the blade in close tolerances to the blade axis. This ring is support for a cradle on which a simple saw is mounted. The milling process is carried out in several turns of the total cradle and decreasing the cutting radius. The turn of cradle is actuated by hand till now.

4.3 Drilling of attachment holes

A serious problem was the drilling of holes up to 45 mm diameter and maximum lengths of 130 mm into the glass-carbon laminates.

The drill operation is carried out by a air actuated drill-chuck fixed on a drill template which is connected to the blade by auxiliary screws and clamps, s.Fig. 11. Cooling of the cutting edges of the drillers by liquid lubrication is not acceptable. Excellent results in geometry, surface accuracy and in abrasion resistance of cutting edges are possible by using a vacuum cleaning device within the drill shaft and the drill chuck. Cooling by air is sufficient and the removal of dust and cuttings substitutes any lubrication. Only one drill operation is necessary for final hole tolerances.

In Fig. 12 the design of the drill head is explained.

Cutters and inserts can be exchanged if they are worn down. One set of cutters resist about five holes.

5. FINAL TESTS ON BLADES (WEC BLADES):

The final acceptance of the blade is based on a static test where the flexibility of the blade is checked by magnitude of load and deflection and a dynamic test evaluating the natural frequencies in bending and torsion.

5.1 Static bending test

The blade was loaded up to 30% of safe load $F = 17,5$ kN and the deviations and strains were measured through out the blade length. The decision to test only up to 30% of safe load was based on no risk at cross load introduction points within the airfoil. The 100% test was applied at an 11m-test blade and the results are published in ref./2/.

5.2 Dynamic test

In Fig. 13 the positions of acceleration pick up and of accelerometers are shown. The measured natural frequencies of the WEC-rotorblade are listed in table 3.

	Bending		Torsion
	flapwise	chordwise	
1.mode	1.22	1.87	21.5
2.mode	3.14	5.71	32.79
3.mode	6.51	12.52	/1/sec/
4.mode	10.98		

6. SUMMARY:

From a running prototype production of rotorblades of wind energy generators the most interesting details in design work and manufacturing are described. This type of production is one of the most potential alternatives to the filament-winding process. Depending on the low number of produced blades no mechanisation was introduced till now. For further production of blades from 10 to 25 m length or more a mechanisation is planned.

7. REFERENCES:

- /1/ M.Hahn, P.M.Wackerle, "Development and Design of a large Wind-Turbine-Blade", 3. Internat.Symposium on Wind Energy Systems, Copenhagen, Denmark, Aug. 1980
- /2/ H.Bansemir, K.Pfeifer, "Stress Analysis and Test Philosophy for Wind Energy Converter Blades", 4. Meeting of Experts-Rotor Blade Technology, Stockholm, Sweden, April 1980

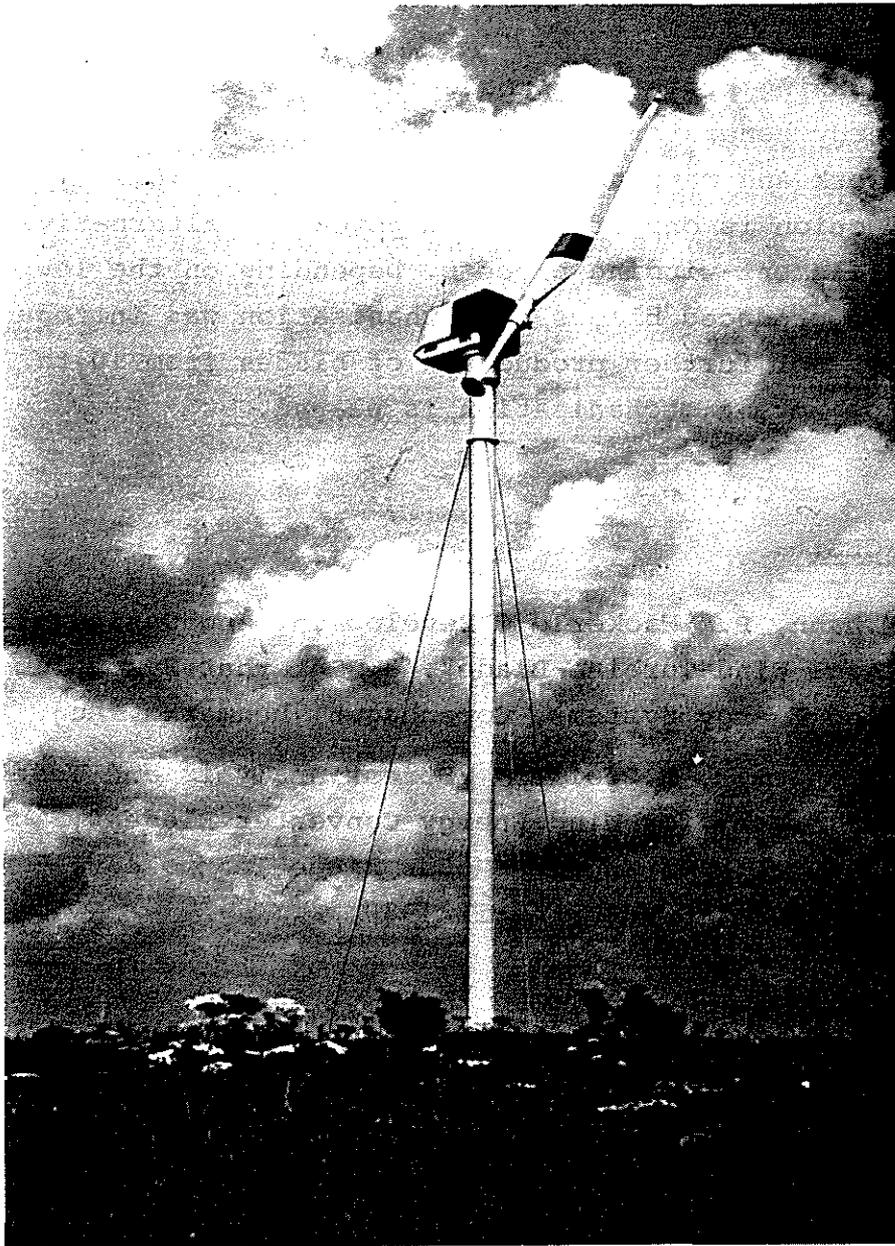


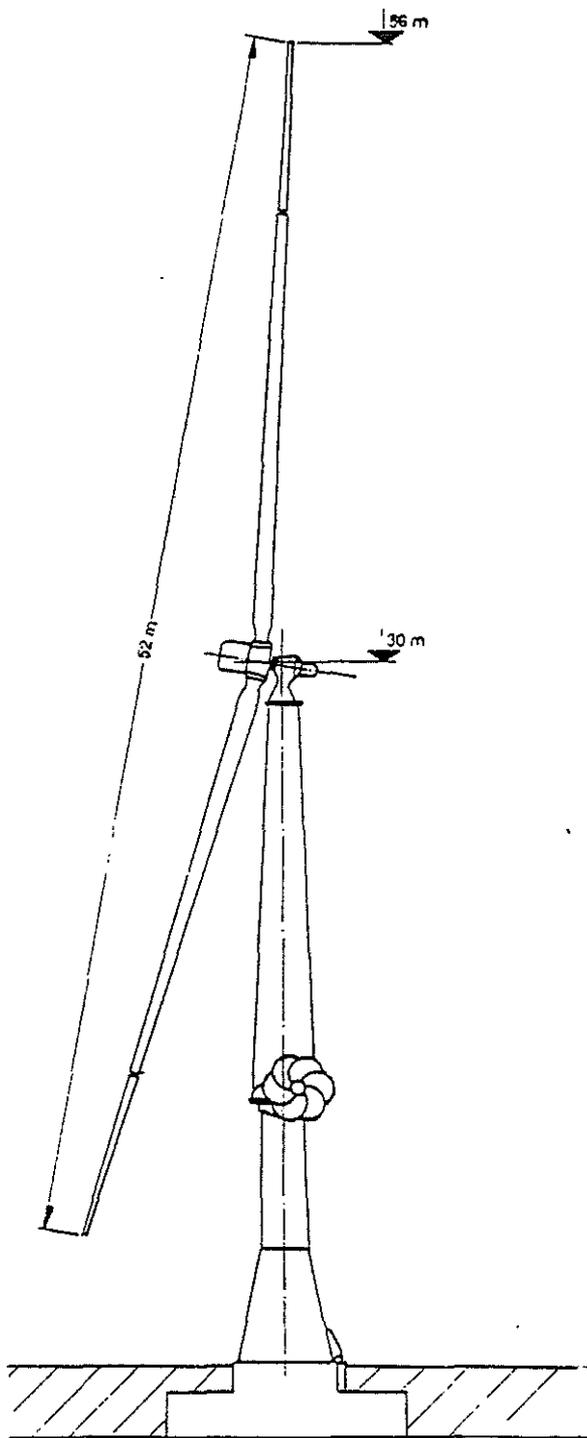
Figure 1 Wind-Energie-Anlage 300

WEA-DEMO-System

Power 370 kW

Rotordia 48 m

Hubheight 50 m



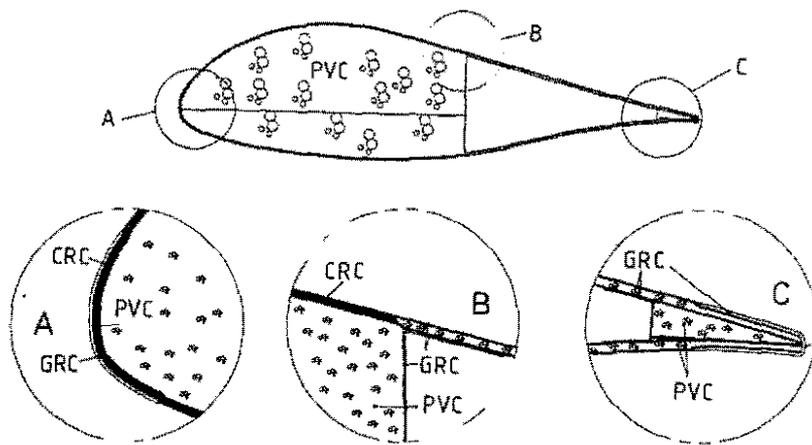
WEC-System of Voith-Co.

Power 285 kW

Rotordiameter 52 m

Hubheight 30 m

Figure 2 Wind Energy Converter 285 kW



ROTORBLADE - SECTION OF
WINDENERGY CONVERTER

Figure 3

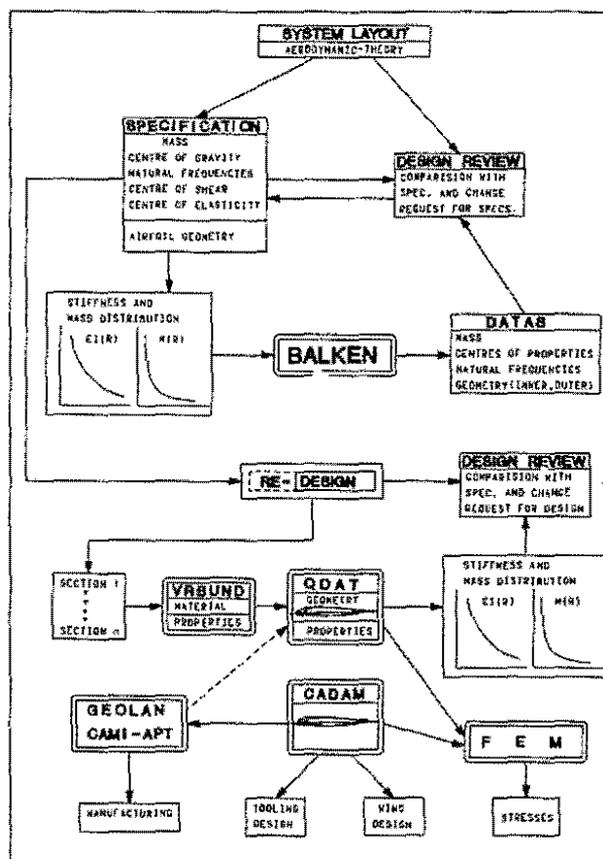
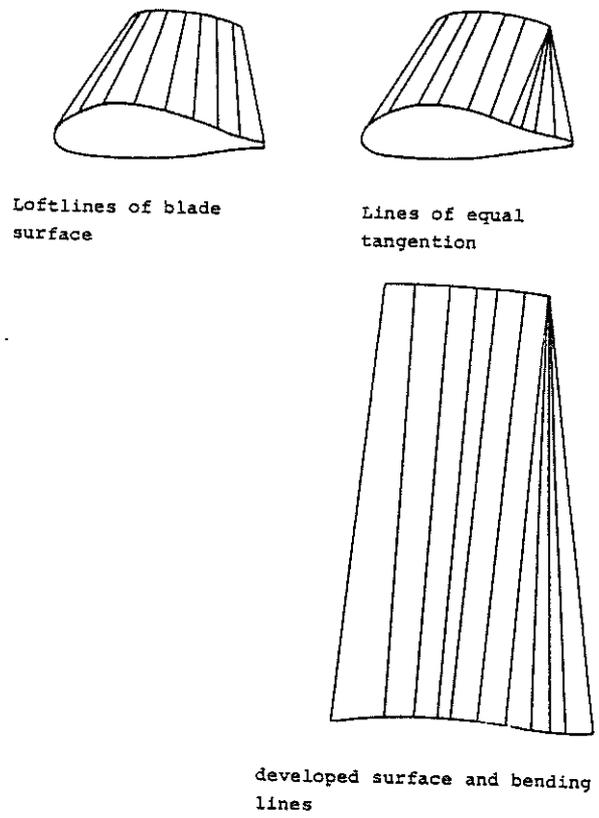
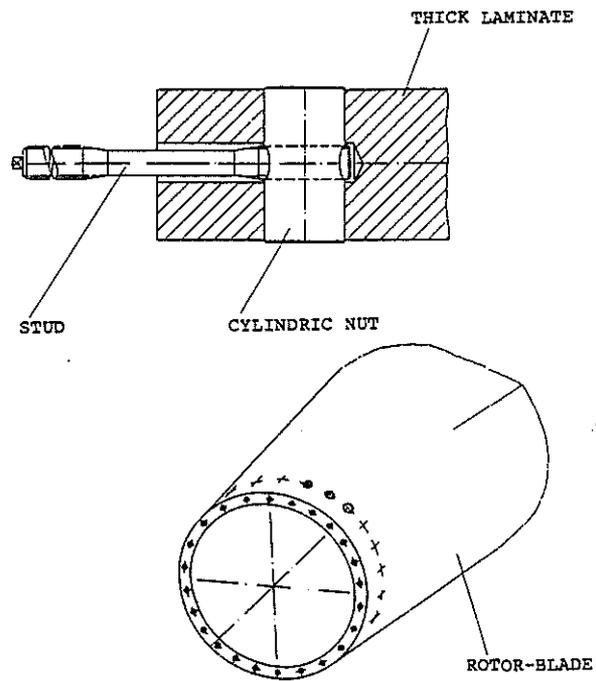


Figure 4
Action-tree of Computer
program



Figur 5
 Definition of blade surface



Figur 6
 Blade attachment configuration

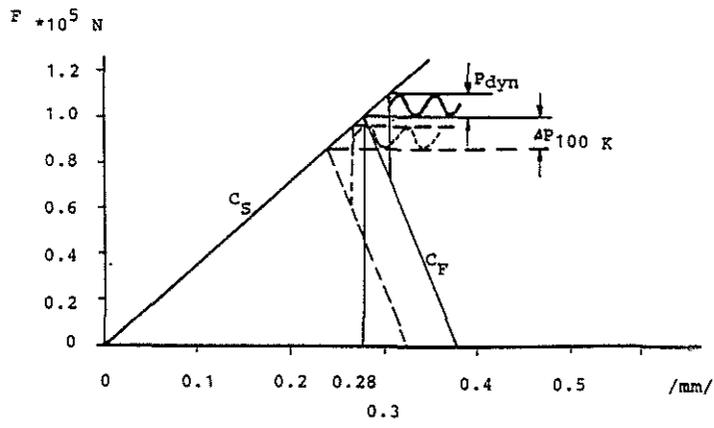


Figure 7
Preload-diagram of studs (WEA-DEMO)

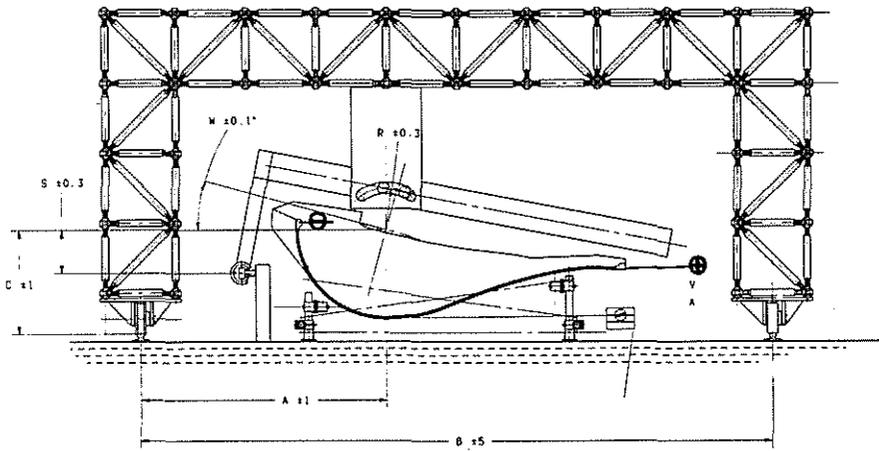


Figure 8
Mold and milling jig

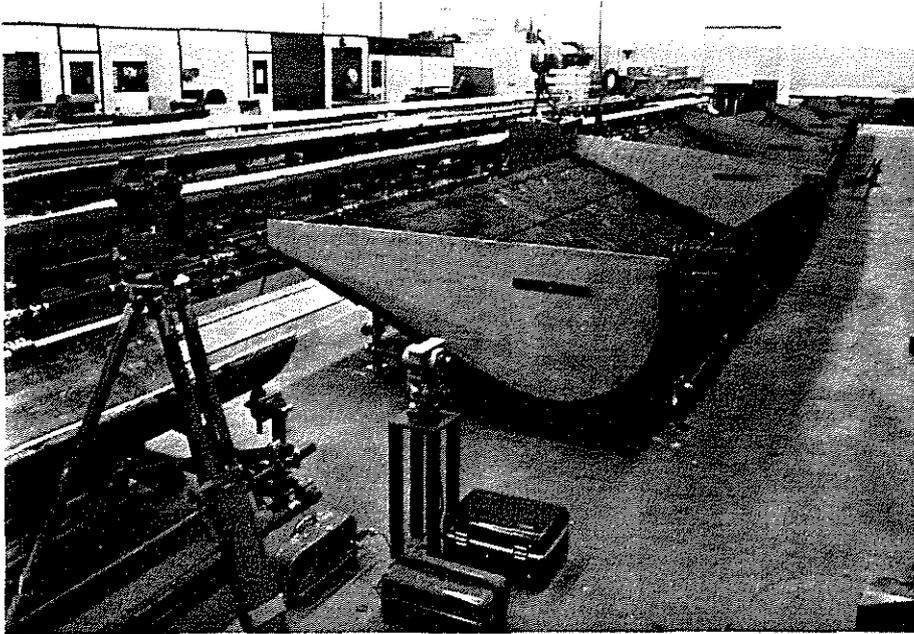


Figure 9
Inspection of the mold

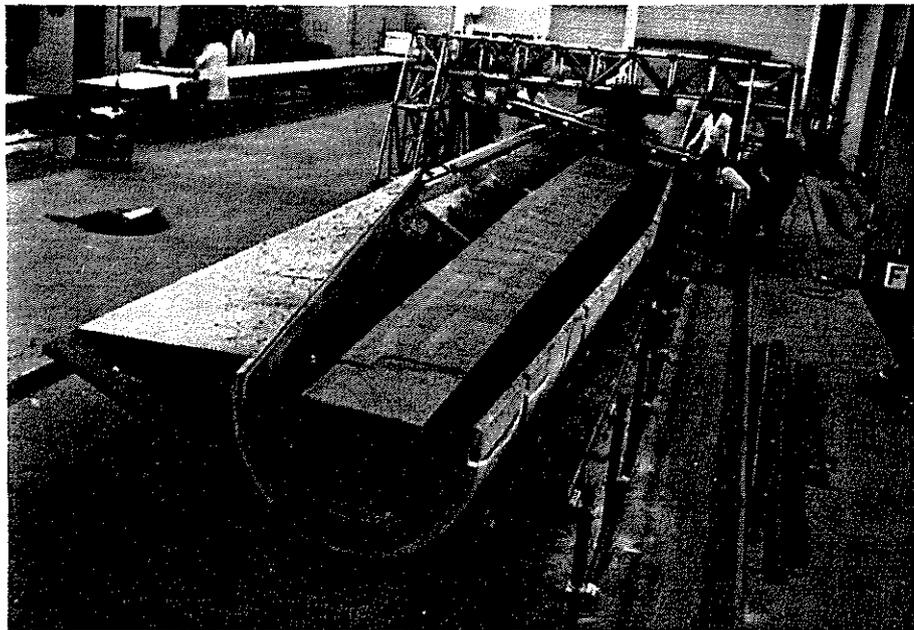


Figure 10
Milling of the blade

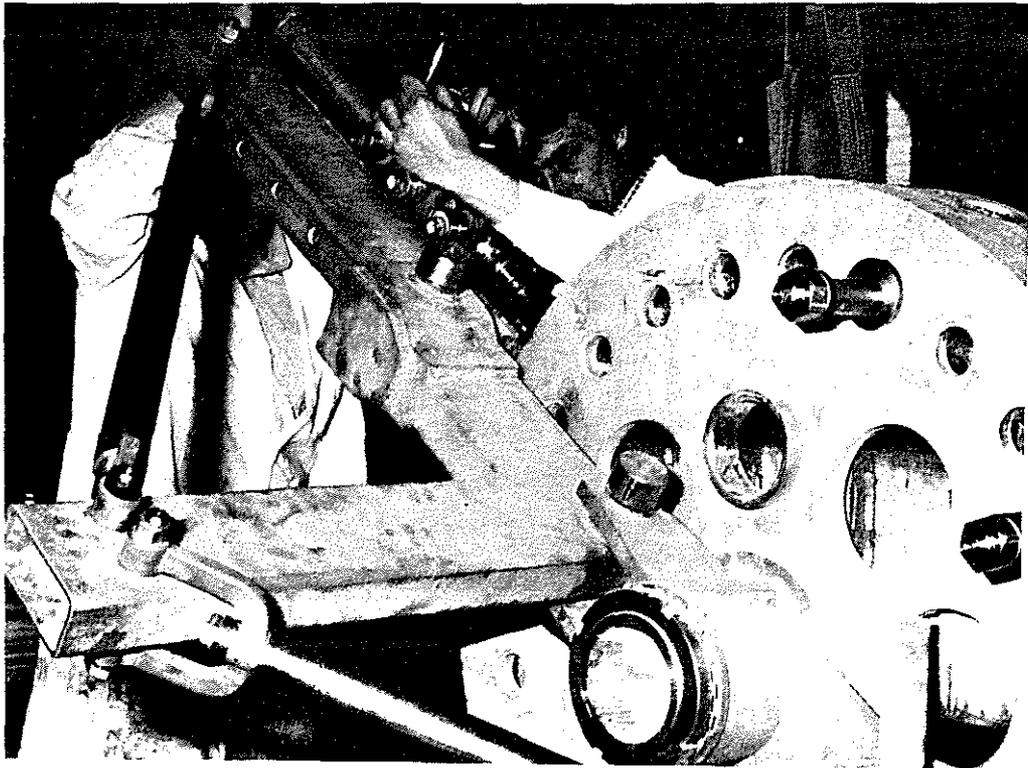
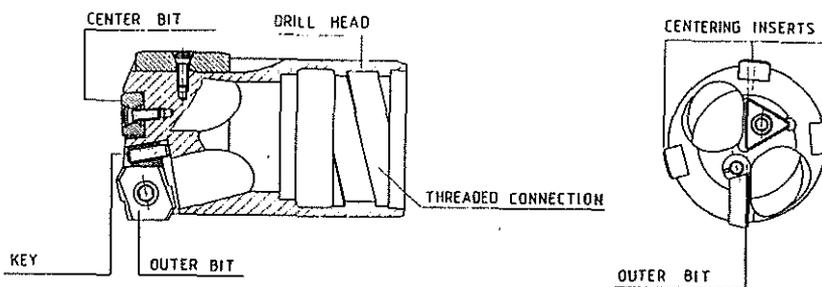


Figure 11
Drilling device



DRILL TOOL

Figure 12
Design of the drill head

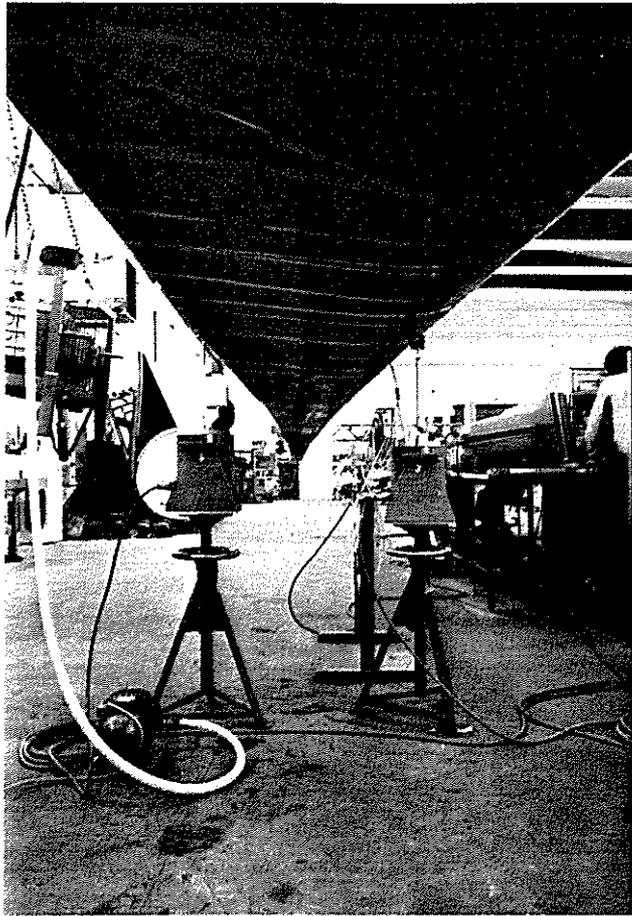


Figure 13
Testing of the blade