FOURTEENTH EUROPEAN ROTORCRAFT FORUM

Paper No. 98

EH-101 MAIN ROTOR HUB APPLICATION OF THICK CARBON FIBER UNIDIRECTIONAL TENSION BANDS

L. CARONI-G.ACAMPORA-F.BORGNOLO-O.ROSSI-M. FARIOLI

COSTR.AERON.GIOVANNI AGUSTA SpA
ELICOTTERI MERIDIONALI SpA

20-23 September, 1988
MILANO, ITALY

ASSOCIAZIONE INDUSTRIE AEROSPAZIALI
ASSOCIAZIONE ITALIANA DI AERONAUTICA ED ASTRONAUTICA

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ABSTRACT

The EH 101 main rotor hub is a typical application of unidirectional tension band in helicopter dynamical components. The criticity of the component emphasises the need of a deep investigation concerning the defects recognition and their behaviour characterisation under static and cyclic loading. Non Destructive Testing play a primary role in the development phase of the project allowing design and manufacturing optimization. Moreover NDT must be improved in order to give the needed reliability of the inspection techniques which assures the aircraft safety.

The defect acceptance limits have been preliminary determined by the theoretical analysis based on the results of tests on similar structural elements. These limits will be updated and validated by the test program performed on actual structures characterised from the defect standpoint.

INTRODUCTION

The "Gruppo Agusta", in a joint effort with the British Westland Helicopter company is working on the medium weight EH 101 helicopter which will be produced in both military an civil versions. Thanks to its tri-engine formula the EH 101 will provide complete autonomy and transport capacity as well as high safety levels. The military version was initially planned to meet the antisubmarine requirements of the Italian Marina Militare and of the Royal Navy. After that, a further version, for land forces, has been developed. The EH 101 is also being developed as a valuable commercial aircraft carrying up to 30 passengers or 5 tons of cargo with a range of over 900 kilometers. This helicopter will be particularly suitable for off-shore operations.

In the EH 101 (see fig. 1), composites are widely utilized both in airframe and rotors and represent an important percentage of the total weight of airframe, flight controls and rotors (see fig. 2).

The major composite components under Agusta design and manufacturing responsibility are:

- Tail unit, including the tail cone, the fin and the tailplane
- Tail rotor
- Fixed flight control rods
- Main rotor hub

EH 101 MAIN ROTOR HEAD

The main rotor head is articulated with elastomeric bearings carrying blade tension loads while allowing flap, lag and torsional movements (see fig. 3 & 5).

The centrifugal load from the elastomeric bearings is carried by the hub, which is a composite structure plate shaped and fitted to the mast by a splined metallic core; the articulation system, which consists of centering and spherical elastomeric bearings, is arranged in such a way that, in flight, the majority of the shear loads pass directly into the core via the hub centre arm.
A tension link incorporating the blade folding system attaches the blades to the hub.

The main rotor hub of EH 101 helicopter consists of a steel core which connects to the mast and a composite portion, which basically comprises a number of graphite loop windings and external wraps of glass/epoxy.

HUB ASSEMBLY

The loop windings are the main subcomponents of the hub assy.
They are closed structures either flat or having complex double contoured shapes.
They are made by graphite tape wound and cured in the press.
Because of the relevant thickness of the part, a special compaction technique was developed during tape winding to get a low void component.

In the first assembly stage, windings are fitted and bonded together and to the steel core; epoxy molded compound fillers are used to get a monolothic structure (see fig. 4).

The second fabricating stage consists of the wrapping of the outer case; extensive vacuum compaction is used in this phase to improve the quality of the laminate.
Finally the metal attachements are bonded to the hub.

DEFECTOLOGY AND N.D.T.

Loop Windings

Defectology of loop windings is that tipycal of thick laminates, complicated by the shape and the closed loop structure, and may be summed up in:

- sharp deviations of fibers from lay-up direction (Marcels).
- Thin elongated voids following fiber orientation (porosity).
- lack of compaction between adiacent plies (voids).

Radiographic inspection of loop windings is capable of detecting such defects.
Due to the nature the material and size of the parts a number of testing parameters have been tried in the course of the development stage to get the highest possible resolution.
It can be concluded that the best conditions are: fine focus, high contrast film, low voltage (in the range of 30 to 40 KV).

To reach a confidence in the discrimination of defects such as voids or porosity which may appare identical in the radiography, extensive destructive testing, associated with cross inspection by means of contact ultrasonics, was conducted.

It is important to remark that this effort was very useful not only in the development of the inspection procedure, but also as a feed back for the set up of the manufacturing process.

To improve the characteristics of the parts in order to meet the established requirements, the whole manufacturing process has been optimized. Tooling has played a major role toghether with compaction pressure and tension and lay-up of the material.

Hub

Fabrication of the hub takes places in three steps as mentioned earlier.

Visual inspection of first stage suffices inspection of parts fit-up as the assembly is totally visible from the outside.

On the first manufactured part it was decided to take X Rays at all the three stages to inspect for delaminations in the rings.

Radiographs of the part at the 2nd level of assembly showed in some areas thin hair-like lines that could be assumed to be tight cracks in the rings running along the circumference. At this stage one cannot determine if the cracks are in the top or bottom ring as the radiograph is taken in the plan view. Comparison of this radiographs with those of the rings which had been used to make the assembly showed that the indication found belonged to the hub. The defects were mapped and the hub taken through the 3rd bonding stage and radiographed; again no increase in size or number of delaminations was detected.

The hub was then sectioned for mechanical testing and visual examination.

It was found that the cracks in the rings were more numerous than what appeared in the X ray. This was due to the fact that their plane was not only vertical (in the plane of the lay-up of the rings) but also inclined as much as 45^ degrees.

In fact it became clear that X Rays only could not be used to detect all the delaminations unless one would go to the expenses of taking an unduly large number of radiographs at different angles. At this point we decided to resort to ultrasonics to check whether this method could spot all the defects as they appeared in the sections. We are fortunate enough to have some beautiful natural occurring delaminations and thus calibration specimens. Therefore it was not too difficult to determine the right probe and parameters for the inspection. Briefly the technique can be described as one that uses the back wall reflections of each ring as an indication of a sound part in a pulse-echo method, taking advantage of the fact that the bondline of two rings or that of rings to fillers is in our case very reflective and shows up as a sharp line in the CRT. Testing is done manually by circling the inner and outer rings spanning the height of the vertical surface of the hub. So, lack of this echo is a strong indication of presence of delamination. Moreover their location and direction can be determined in case they are aligned perpendicular to the sound wave. Presence of delamination is indicated either by loss of what can be reffered to as backwall echo and concurrent appearance of a defect echo in case where this lies perpendicular or slightly inclined to the direction of the beam, or by mere loss of back-wall echo in case the angle of tilt is higher. Also in this case the experienced inspector by probing from the corner surfaces will positively identify and locate the delamination. High power beam is necessary to get a good bottom echo. This will cause a lengthening of the dead zone but this will do no harm as it will be confined in the glass cover case.

As a series of tests and considerations have excluded the possibility of delaminations lying in different positions from those described, the method described suffices our inspection needs to check for delaminations, which we found is the only occurring defect in the hub.

Trials using a squirter system to investigate the possibility of going to numerically controlled automated scanning and recording have not been too promising so far with the existing equipment due to the attending loss of signal in such a technique.
We expect improvement of results with the new equipment.

Manufacture improvement

Of course recognition of defect such as described spurred investigation as to causes and ways to minimize them.
It was found that defects were associated to areas of deficient compaction and sometimes started at a site of a large porosity (a few tens of a millimeters in cross section).
Such a finding brought two immediate responses:

1) Review of all the radiographs of built rings in light of more stringent acceptance standards.

2) Improvement of manufacturing system of the rings from the fabrication stand-point and from the design one.
This two actions did away with the cracks as a number of hubs built so far, ultrasonically tested, showed and as desctruct tests have proved.

ACCEPTANCE LIMITS

The acceptance limits of the defectology indicated above are the result of the development tests which are conducted throughout the whole prototype phase.
Therefore such limits are subject to an evolution toward values which become more reliable as the tests build up greater confidence.
The first tests have been concluded on a representative model of the hub whose configuration is indicated in fig. 6.

Main goals of the composite hub model lead-in tests were:

1) Feasibility of a composite modular structure, providing an investigation of the manufacturing problems and their effect on the features of the item.

2) Study of load distribution and correlation with the analytical results obtained with finite element models.

3) Study of loading capability and of the type of failure of the structure, from which information about the failure of the structure, should result.

4) Evaluation of the outcoming of the defects contained in the assemblies as detected by the NDT.

The specimens to be tested comprised of three hubs, the first one made from glass-epoxy material, the second one made from graphite-epoxy following the same manufacturing procedures as the previous one and the third one made of graphite - epoxy too but with a different manufacturing procedure.

The constraints were equivalent to the real ones: the hub in fact was fitted and a flange fixed at the top of the mast constraints the hub vertically.

The loading procedures are equivalent to the real ones.
The major task of static testing is to validate the stiffness properties of the M/R hub, namely the in-plane stiffness which reacts against centrifugal load and the out-of plane one which reacts against ground shear loads entering at the droop-stops; an additional task is to locate stress concentration areas and consequently assess the maximum load capacity.

The results, evaluated in a conservative way, allowed the first preliminary definition of acceptance limits.

After that, the prototype hubs, manufactured in the final design configuration, and containing defects mapped with great detail, have been submitted to the following test campain:

a) static tests for substantiation of the structural integrity of the assembly under the following conditions:
   - Shear loads corresponding to the "ground case"
   - centrifugal forces applied simultaneously at the five arms to simulated overspeed condition
   - out of plane loads
   - centrifugal loads factorised to take in account the humidity and temperature effect on composite parts.

   At this moment the results of static tests conducted under this programme are considered to be representative because the data are correspondent to those coming out from analytical calculation. Moreover no failure nor cracks growth have been noted.

b) Fatigue tests at high frequency.

c) Fatigue tests at low frequency ("start-stop") to simulate transient ground conditions.

The follow-up on all such tests has allowed the official issue of the specification containing the acceptance limits. This specification has been submitted to the CIVIL and MILITARY AUTHORITIES and is the base for the acceptance of the prototype assemblies used for ground and flight functional tests. Such acceptance limits are strictly connected with materials, parts configurations and the required performance of the assembly. Therefore their quantitative definition is subjected to restrictions of industrial information.
Anyhow the parameters which have been taken in account are listed in the following:

- marcels evaluation as a function of the individual length and deviation radius and of their numbers

- delaminations evaluation as a function of the individual length and height, of their number and of their density.

- porosity evaluation as a function of individual dimensions , of their number and of their density,

- debondig evaluation as a function of their individual extension, their number and of their density

- simultaneous presence of the above defects on same item.

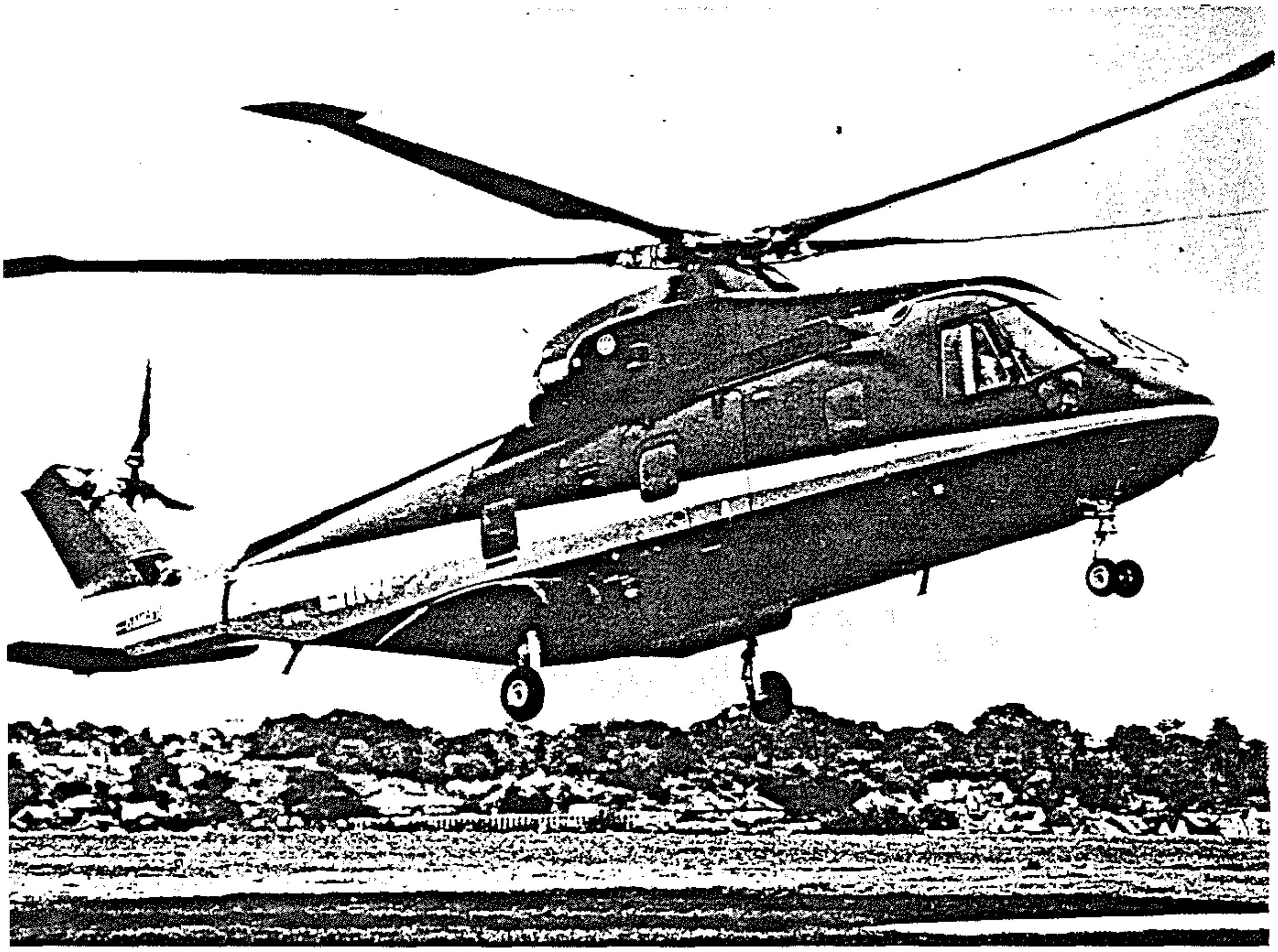


Fig. 1

COMPOSITES IN EH101

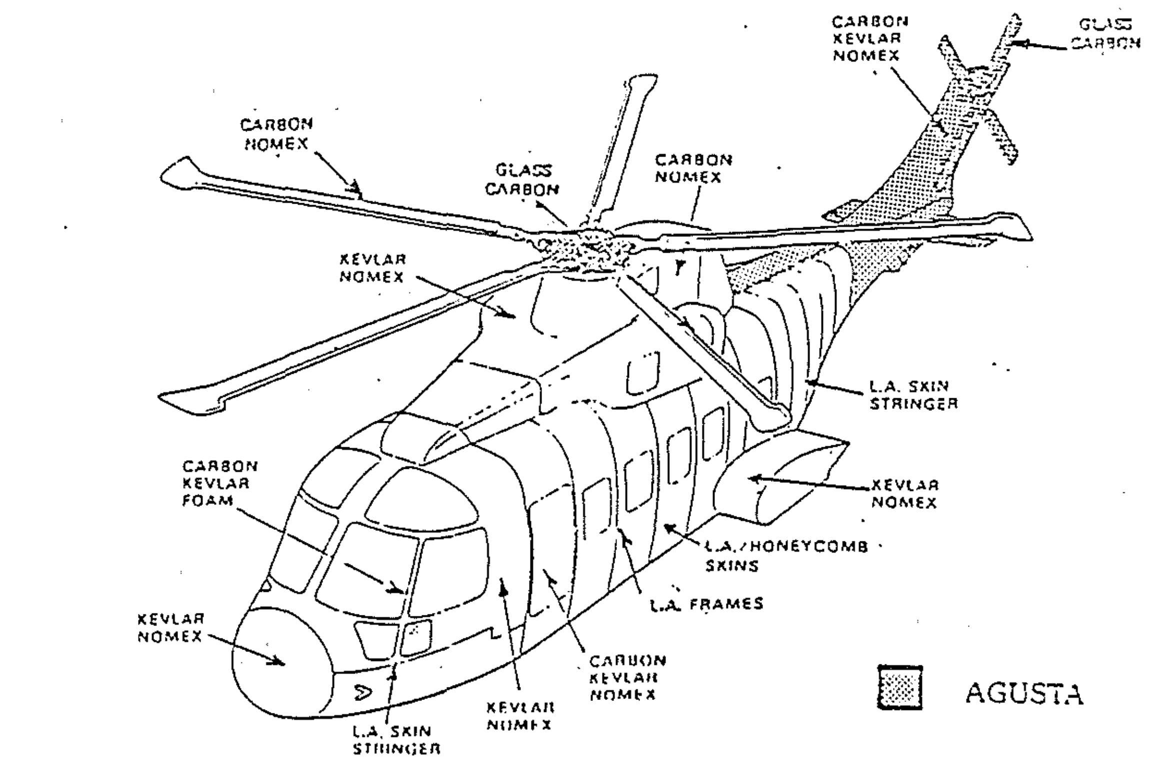


Fig. 2

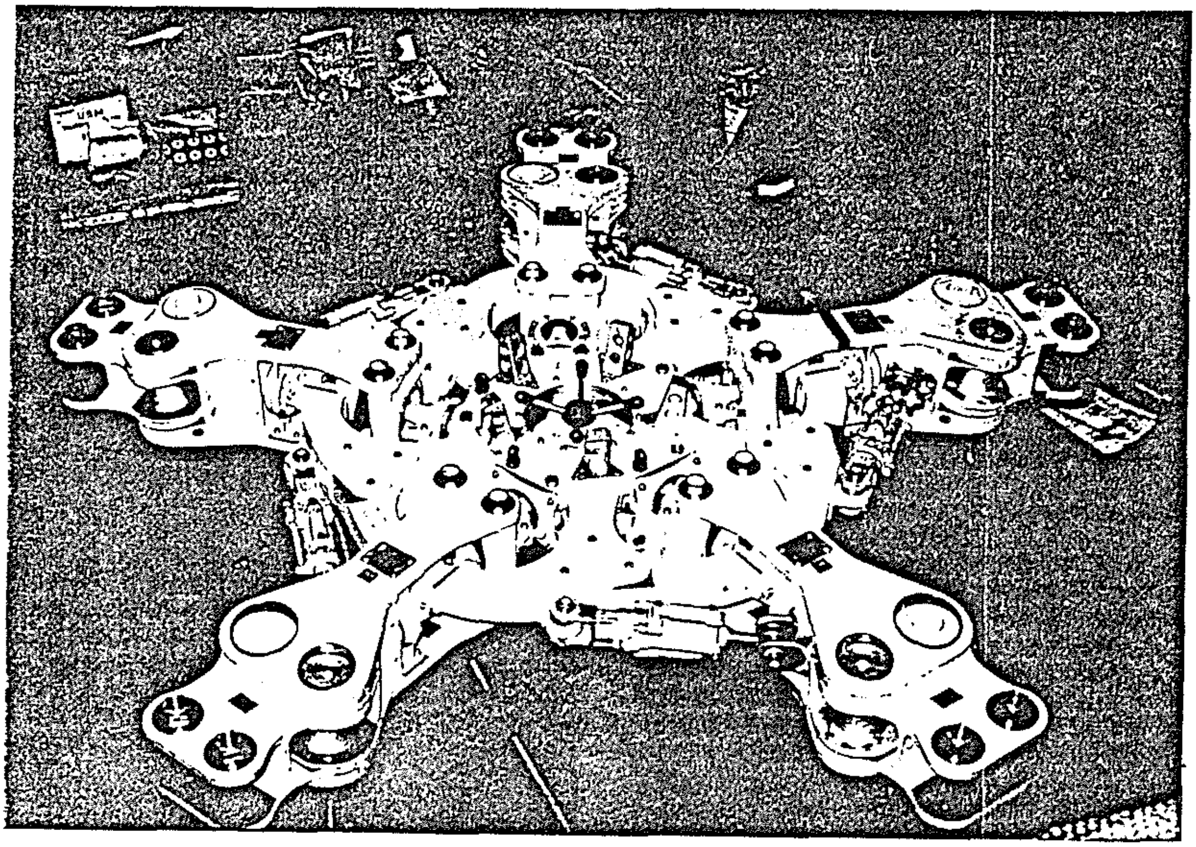
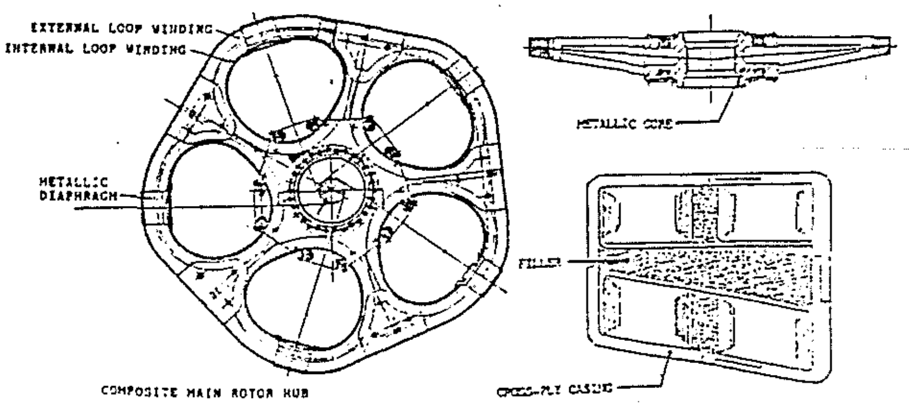


Fig. 3



EH101 MAIN ROTOR HEAD

Fig. 4

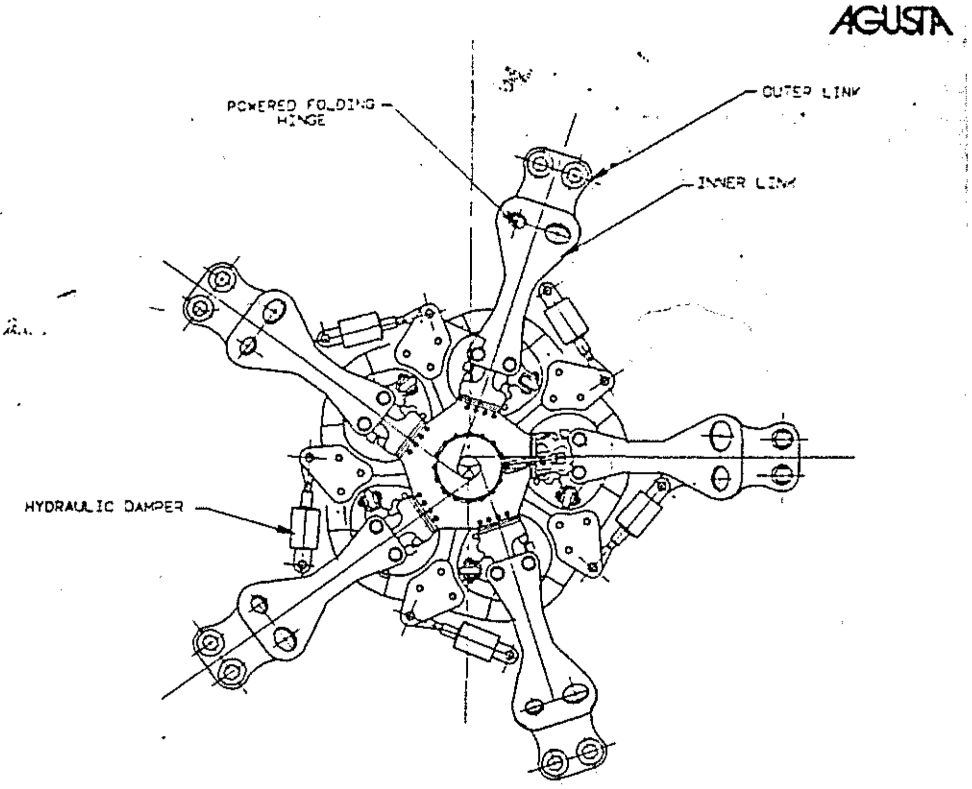


Fig. 5

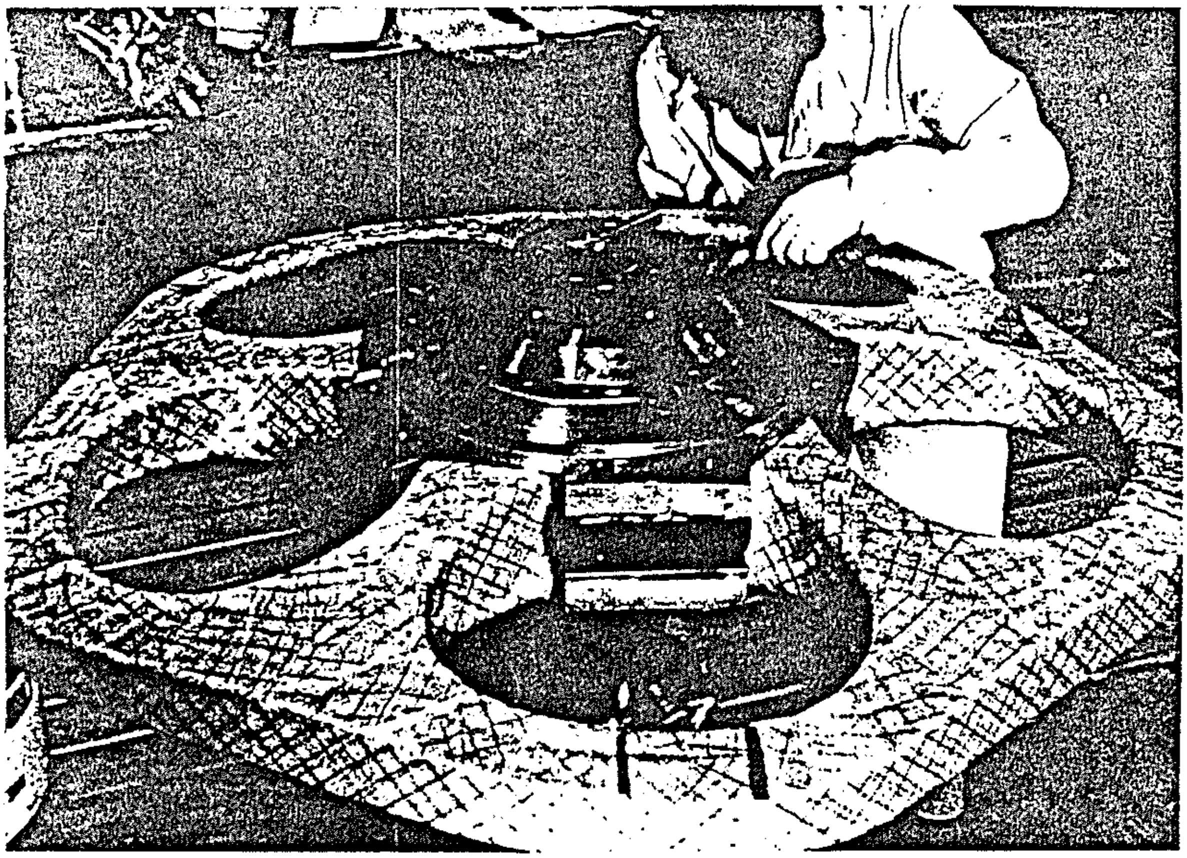


Fig. 6

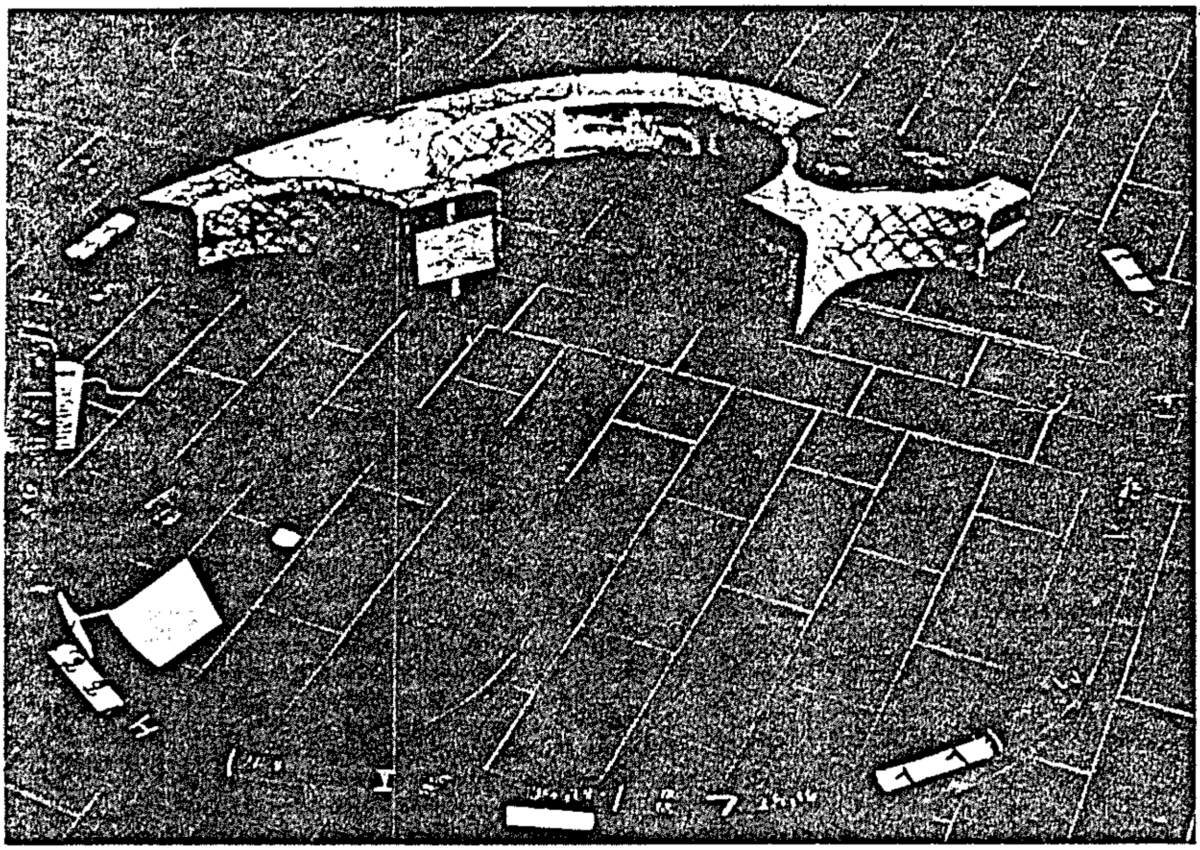


Fig. 7

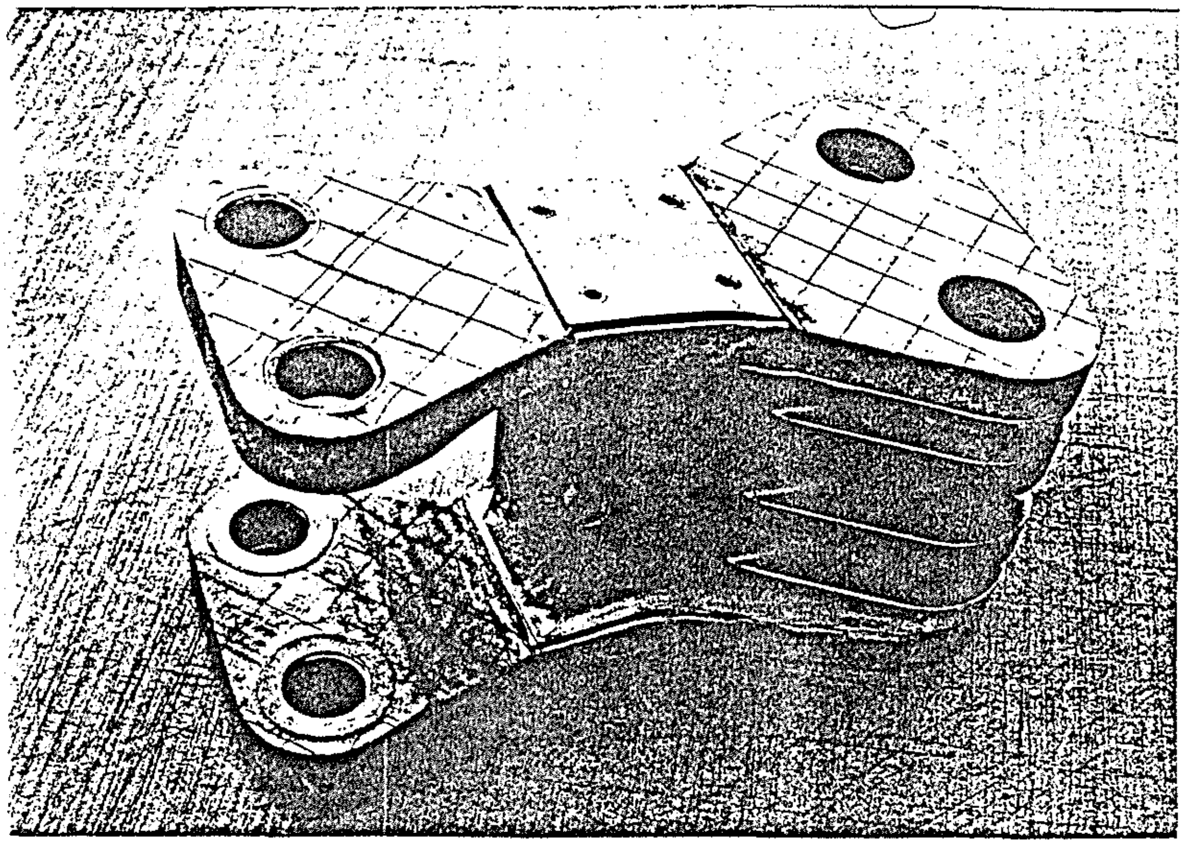


Fig. 8

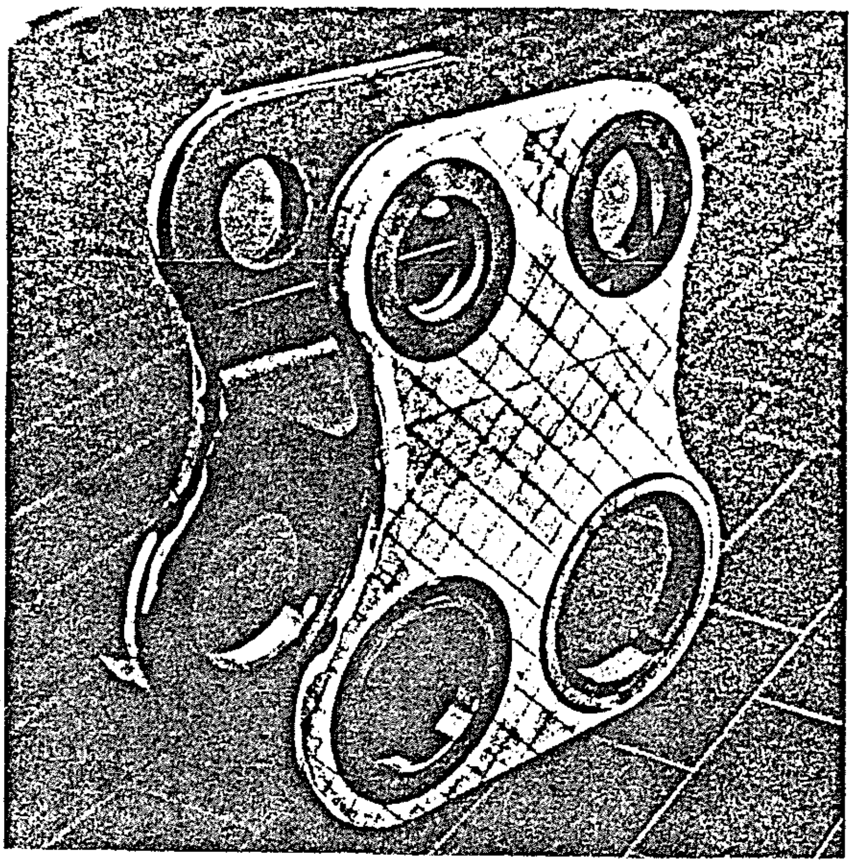


Fig. 9