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EXPERIMENTS IN SUPERPLASTIC FORMING OF HELICOPTER COMPONENTS

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EXPERIMENTS IN SUPERPLASTIC FORMING OF HELICOPTER COMPONENTS

FRANCO PERSIANI - RODOLFO TRIPPODO

ABSTRACT

- This work contains an analysis on the convenience of applying superplasticity for helicopter construction to achieve lighter and stiffer components without cost increase.
The impact of the new technology on helicopters designers is also considered.

It was chosen to involve designers in experimental work, to make them familiar with this new technique and to have a quick feed-back on practical applications.

The authors describe an experimental device for realization of prototype components in superplastic alloys, which allows a wide range of forming temperatures and pressures and an accurate environment control.

A highly stressed tail boom rib was realized using different process parameters and materials. High structural efficiency, i.e. high stiffness to weight ratio, was achieved with a new design, based on two bonded sheets.

1. INTRODUCTION

- Superplasticity is a property of some metal alloys, which under specific temperature and strain rate conditions, exhibit high elongation.

Owing to the low flow stresses, superplastic material sheets can be formed into complex shapes, utilizing gas under pressure as usually done in forming plastic materials (1) (2).

Superplasticity is generally present in alloys featuring a stable structure with very small-size grains (5 to 20 μm) at a temperature of about 0,4 times their absolute melting temperature.

The application of superplastic forming technology requires a new approach to the structural components design. This technique is suitable to obtain an optimum solution of some helicopter design problems. The reduction in the number of parts and joints leads to a lower risk of vibration induced damage. In addition superplastic alloys for aerospace use (namely Ti-6Al 4V or 2000-7000 Aluminum Alloys) exhibit acceptable or good mechanical properties (3) (4).

Hereinafter is a description of the activity and experimental equipment required for the development of a helicopter component.

The final objective pursued was:

- to assess the impact of a superplastic alloy type (Tl-6Al-4V or Series 2000 Aluminum Alloy) on the complexity of the technological process and on the achievable geometric features;
- to assess to what extent the structural design is conditioned by the adoption of the superplastic forming process with respect to alternate technologies, and by the necessary conversion process of the design mentality.

2. TEST EQUIPMENT

- The test facilities (fig. 1) have been set up at the Aeronautical Constructions Institute c/o the University of Bologna and consist of a press which, by way of two opposed columns provided with an adequate cooling system, could exert a thrust action inside the chamber of a modified electric muffle furnace. The thrust action could be used either to exert pressure directly on a moving mold and as well to keep united the two halves of a stationary mold inside which the metal sheets are formed by the differential pressure exerted by inert gas (fig. 2a and 2b).

In this latter case the construction solution adopted shows the following benefits:

a) relative to a hot-plate press: the possibility of reaching very high temperatures in a controlled environment (furnace chamber) with better temperature uniformity inside the mold, no heat dispersion problems from the mold sides, safety and energy saving as a result of the insulation provided by the furnace walls;

b) relative to a mold closed by wedges or bolts in a conventional furnace: the rapidity of the assembly operation and lack of creep problems with the closing elements as well as a reduction in mold deformation due to the fact that the closing action is distributed over the widest exterior surfaces of the mold instead of being concentrated in the proximity of the joining elements of the two halves;

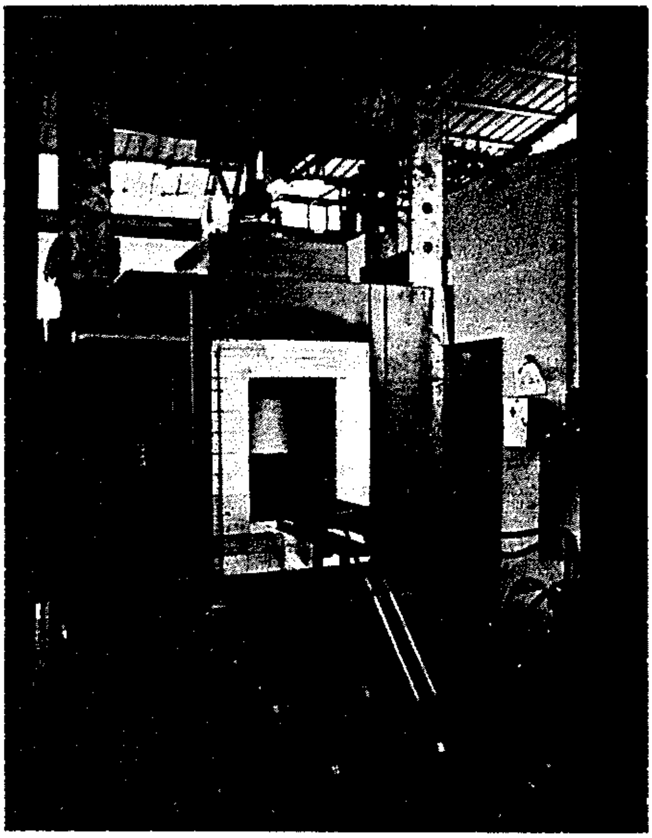

Fig. 1

Equipment used for testing superplastic forming

c) relative to an induction heating system: a much lower cost.

The temperature is controlled by a thermocouple housed inside a deep dead hole drilled on the lower side of the mold. The inert gas pressure is controlled by a control valve.

The system also comprises an hydraulic power unit, a cooling system for the thrust columns and relating seals and provisions for the rapid loading and unloading of the molds into the furnace chamber.

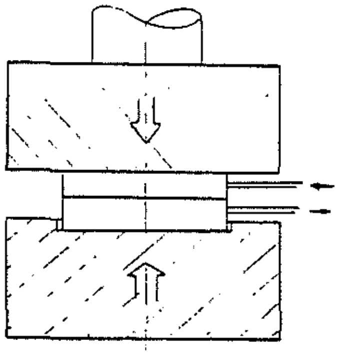

Fig 2a

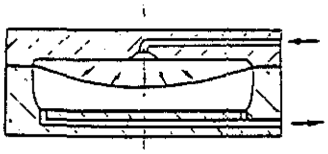

Fig 2b

3. THE DESIGN OF A SUPERPLASTIC COMPONENT

- It is important to think developing a structural component resorting to superplasticity rather than thinking developing it by conventional means and then study it in superplastic version.

In this latter case it is unlikely that the superplastic features will be fully exploited.

An optimum utilization of superplastic forming may however be achieved by substituting a simpler and more efficient component in respect of cost (5) (2), weight and/or performance, for a multiple-piece component.

The experimentation conducted for the adoption of this new technology, has implied from the outset the involvement of the designers, who have identified in the A 109 helicopter tail boom rib, a critical component on which to evaluate possible technological alternatives.

This rib is a very important item, for it supports the tail rotor drive system and is subject to stringent weight limitations.

The original version was built in multiple pressed sheet metal pieces assembled by riveting, and its upper portion - consisting of 7 pieces and about 75 rivets - has evidenced fatigue problems in the area of Fig. 3 marked with an arrow.

Figure 4 shows an alternate solution, whereby the upper portion of the rib is made by forging, to which the remaining portion manufactured in a conventional way, will be subsequently riveted.

This solution which features a monolithic (one-piece) design of the upper portion of the rib, has contributed to the solution of the fatigue problem, but it implies a weight penalty and in addition it requires to be machine processed.

This solution constitutes the version currently adopted for it was designed and developed in a much shorter time and with many less unknowns than other versions which have also been studied. If the same item is made by precision casting, this would imply an overall rib weight exceeding by about 200 grams the weight of the forged solution. The cost for an average production output would be competitive relative to forged versions.

Following the thorough investigation conducted into the item , it was decided to test the superplastic forming process.

This component has proved particularly suited for the assessment of:

- the influence of geometric complexity (double curvature points) on wall thickness uniformity;
- the impact of material selection on cost, weight, duration of the cycle in relation to geometric complexity;
- the possibility of obtaining draft angles and minimum corner radii.

Fig. 3

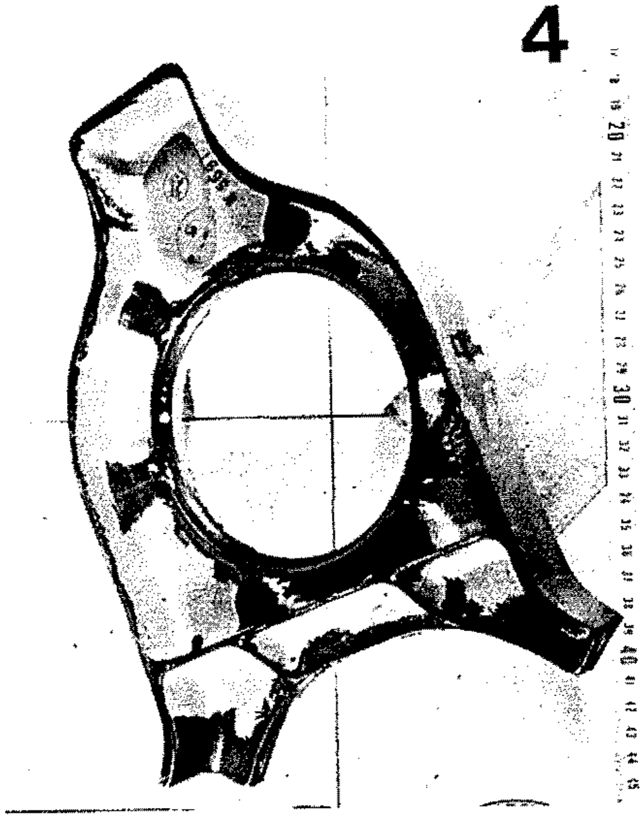

Fig. 4

4. SUPERPLASTIC FORMING OF Ti6Al4V COMPONENTS

- The selection of Titanium Alloy Ti-6Al-4V as a material for the construction of the component under examination, presents some beneficial aspects as regards the solution of the fatigue problem evidenced during operation.

This alloy is superplastic in a temperature range of between 850 to 950°C, with its optimum value at about 930°C. In this temperature range the alloy oxidation speed is so fast as to become incompatible with the duration of the forming process.

In the areas of contact against the mold may be experienced diffusion welding phenomena between sheet and mold walls.

These problems had therefore to be solved with the adoption of the following technological solutions:

a) adoption of a knife edge sealing between mold and sheet;

b) coating of the sheet and mold with a special diffusion inhibiting and at the same time heavily reducing agent;

c) utilization of Argon (by pressure differential) on both sides of the sheet.

Fig. 5 shows typical pressure and temperature trends during a forming cycle.

Fig. 6 shows a formed component.

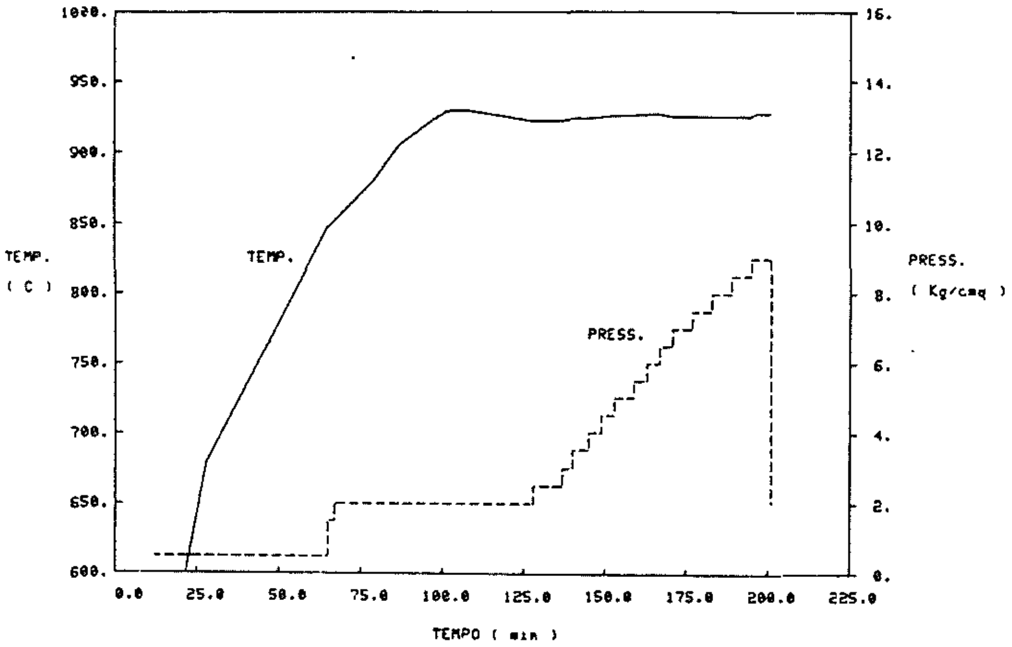

Fig. 5 - Forming cycle of a Ti-6AL-4V component

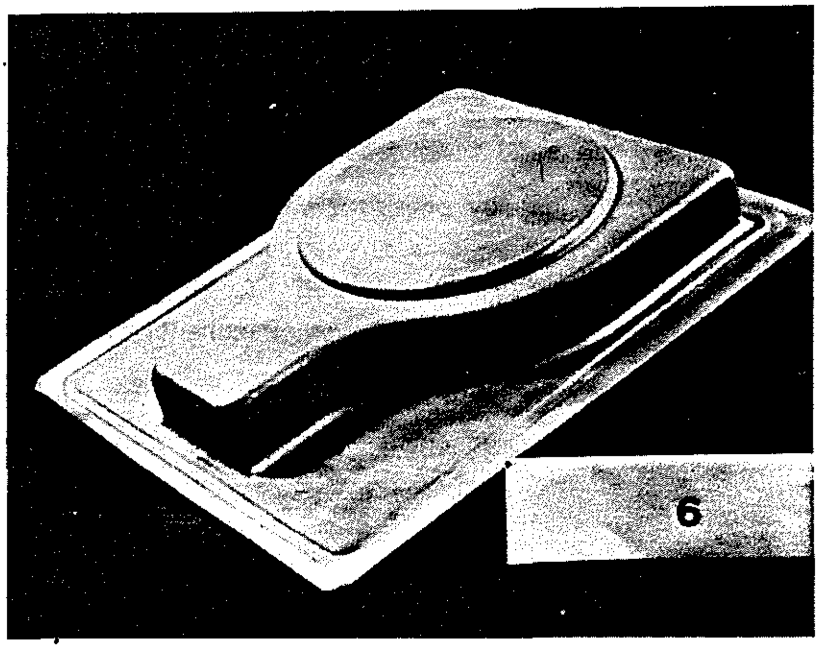

fig. 6 - Superplastically formed component in Ti-6Al-4V alloy

5. SUPERPLASTIC FORMING OF ALUMINUM ALLOY COMPONENTS

- During testing, have been developed some superplastic aluminum alloy components, based on two different manufacturing solutions:

a) thin sheets with high-stiffness features provided by stiffening ribs or box-type assembling;

b) single, but relatively high-thickness sheets.

As regards the components destined to solution a), sheets have been used which had previously been superplastically stretched, with a 50% deformation. As regards type b) components a 2mm thick and unstretched sheet was used.

The enclosed graph per Fig. 7 shows the temperature and pressure trend during testing.

The temperature during forming was held in a narrow range around 460°C. During this phase the pressure has been subjected to progressive increases as necessary to maintain about constant the membrane strains of the sheet portions which were not yet in contact with the mold and which were being subject to a steady decrease in bending radii.

This has implied that the strain rate (linked to the flow stress by the law $\sigma = K\dot{\varepsilon}^m$) was held in a range of values at which the strain sensitivity factor was at its maximum value.

The stiffening ribs system was achieved through the incorporation of simple inserts into the base mold.

Photo 8a shows a formed item without stiffening ribs (the exterior shape is identical in either the case with low-thickness sheets or high thickness sheets).

Photo 8b and 8c show the item provided with stiffening ribs and destined to be incorporated into a component of the type per Fig. 8a, namely thin sheets bonded together.

In this case a box-type structure is developed, which is particularly light, stiff and with crack-arrest capability, i.e. a fail safe solution.

From a comparison of these results with those achieved during the forming of Titanium alloy components, it becomes promptly evident how the test conditions are extremely less severe as regards temperature, pressure and time; in particular the forming process takes place in a slower and more gradual way in the case of Titanium alloys than in the case with Aluminum sheets, for which the process has almost completely concentrated in the early phase of the tests.

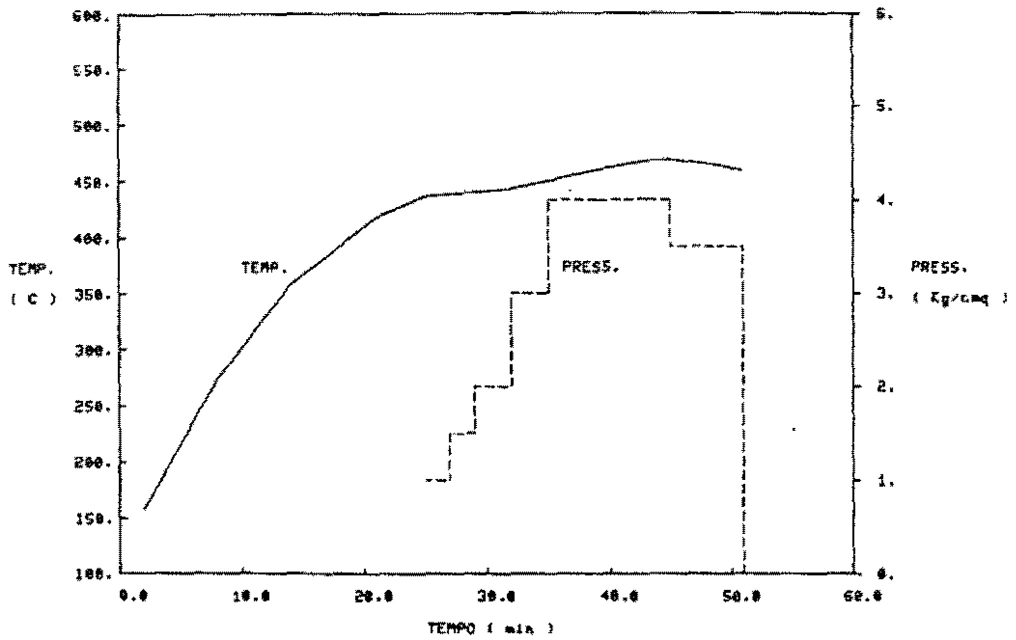

Fig. 7 - Forming cycle of an Aluminum Alloy component

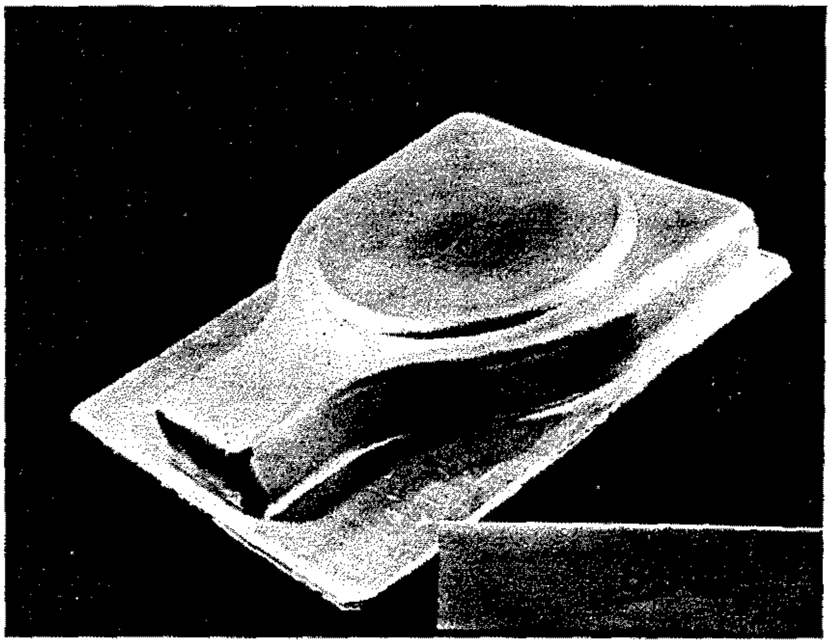

Fig. 8a

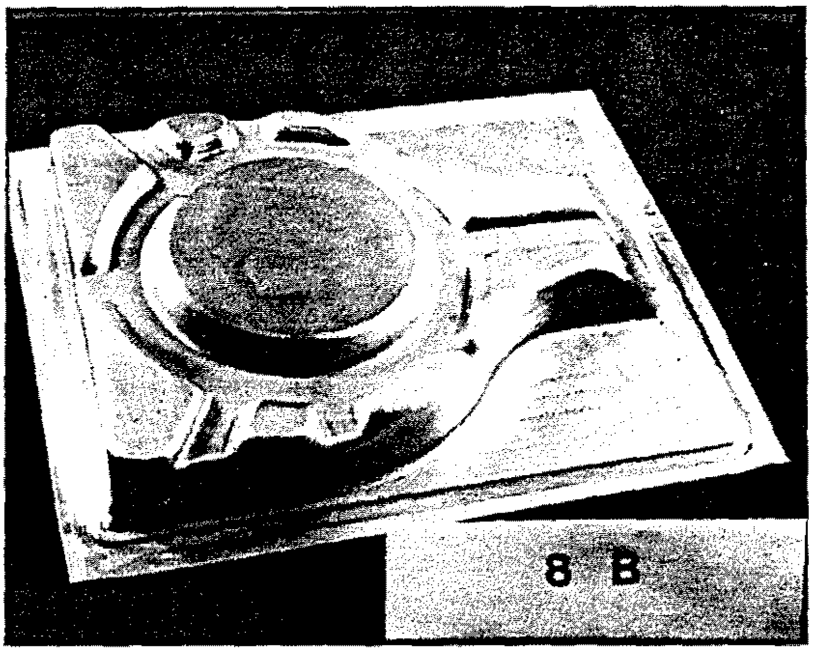

Fig. 8b

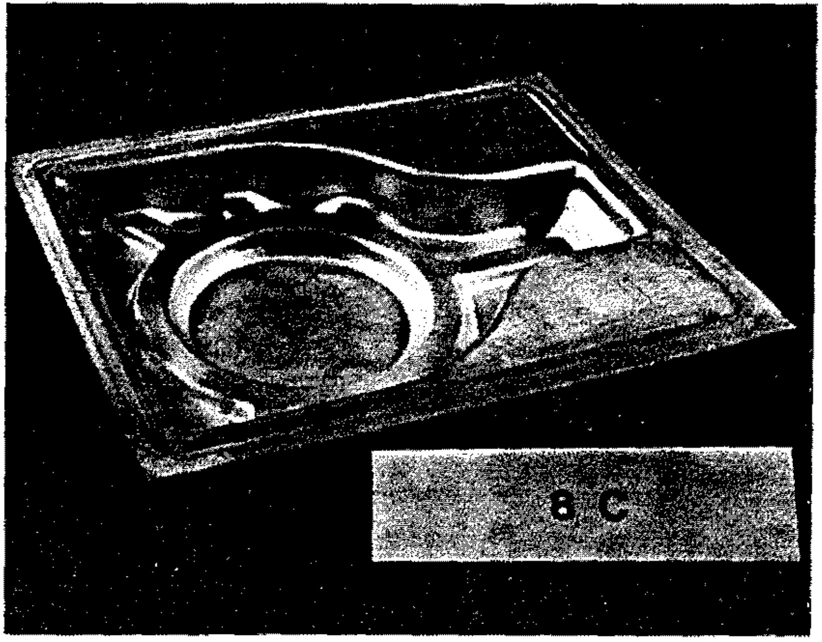

Fig. 8c

6. TECHNOLOGICAL CONSIDERATIONS

- In general, either in respect of formed Aluminum alloy and Titanium alloy components we can say that the most critical areas are those featuring multiple curvatures, such as corners for example.

In these areas, thickness is minimum.

In flat areas and even where fillets and simple curvatures are processed, no consistent local reductions in thickness are experienced.
The trend of the surveyed values is similar both for Titanium alloy and Aluminum alloy components and aside from corner areas, a good uniformity of thickness is experienced.
Fillet radii are rather small and decrease with increasing forming time.

The degree of forming for the various tests has been varied to reflect different drawing levels, starting from normal fillet radii values equal to 5 times the local thickness, up to extreme values equal to 1,5 times.
Thickness does not seem to constitute a too important parameter in respect of the appropriate reproduction of the mold shape, but it appreciably impacts on forming time.

7. PRODUCTION OF OTHER HELICOPTER COMPONENT

- Because of interest, coming from this first work on superplasticity, two programs are started to produce other components.

The first one is related to the production of a Sikorsky helicopter component "antenna support installation". In this case it is fully utilized the material superplastic feature to obtain a deep-drawing in one step without intermediate treatments (Fig. 9), the application of the new tecnology has given a drastic cost reduction.

The second one is a program related to the prototype construction of an Agusta A 129 component wich has a complex aerodynamic shape and the start of a research work related to superplastic high strength light alloys for future structural applications.

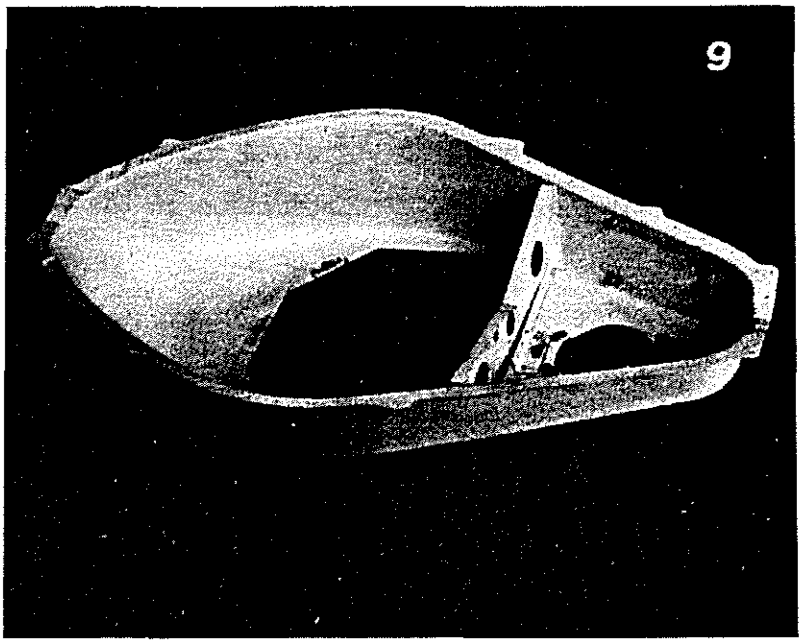

Fig. N. 9

8. CONCLUSIONS

- Experimental test have been conducted covering the development of an aeronautical structural component using the superplastic forming technology.

An experimental facility has been set up for superplastic forming with a capacity to operate up to the highest temperatures required by Titanium alloys.

A comparison made between the technology of Aluminum superplastic alloys and Titanium alloys leads to the following considerations:

a) the higher times and temperatures necessary for the Titanium alloys imply higher costs and increased engineering effort;
b) the trend for the achieved thicknesses is similar for the components of the two different alloys;
c) the highest reduction in thickness is experienced in the fillet areas between dihedrals and are in percentage higher in components with higher thickness features;
d) in the case of Titanium alloys an accurate study of the molds and of the diffusion inhibitors has proved necessary in order to prevent the component from sticking to them;
e) for both alloys, proportionings have been achieved in respect of fillet radii, corners and detail geometries, with a view to assess the possibility, if ever necessary, to exasperate the deformation in areas not excessively stressed, in order to obtain special contours;
f) the surfaces of the component in contact with the mold walls will assume the finishing degree of these latter;
g) the solution chosen for mold pressure scaling, has proved satisfactory.

From the metallographic viewpoint it is observable a fine grain structure, of equally oriented type for both alloys and it does not alter following the deformation process.

Minor variatons in grain size as a result of the process are experienced but these are uniform and the grains do not exhibit strain. This also applies for corner areas where the major deformations are experienced.
Under the manufacturing aspect, several alternate solutions which differ in material and geometry, have emerged for the components under examination.

The adoption of this technique permits to achieve a lighter component, with equal stiffness and strength features, than the component presently in use.
Other components developed by superplastic technology are now under study or in production at Agusta, with consistent saving as regards cost and weight; the effort to match the design technique to the requirements of this new technology are beginning to bear the expected fruits.

This work is also directed towards a program for mechanical and fatigue testing of superplastic formed components.