Progress on Extruded Structures

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Abstract
For several years experimental research is being carried out at the "Politecnico di Torino" aiming at the realization of a whole wing structure through the combination of large extruded light alloy profiles.
In particular cases the use of large extruded profiles allows a remarkable reduction of labour costs and the correct reproduction of section contours.
The design criteria and the first realizations achieved are reported. The behaviour of wing box beams, realized by extruded profiles, is presently under investigation by pure bending tests.

Introduction
Many technological innovations have been introduced in the construction of aircraft mainly to simplify the conventional construction methods.

Indeed these innovations have not always introduced a reduction in manufacturing costs in the assembling stage. Several years ago Alberto and Piero Morelli conceived the idea of realizing a whole wing structure by one or more extruded light alloy profiles, longitudinally connected one to the other [1].
The advantages of this type of structure are:

1. Reduction of labour hours required to realize the structure, mainly in the assembling stage.
2. Reduction of manufacturing costs in a series production, owing to the high cost of the extrusion dies.
3. Correct reproduction of section contours, with particular advantage for the aerodynamic behaviour of laminar flow airfoils.

On the other hand extruded structures are subject to the following practical limitations:

1. It is difficult to extrude complex section shapes using high strength light alloy 2024-T or 7075-T. At present these profiles are realized in Italy using medium strength light alloy 6061–T6 or 6063–T6.
2. The maximum linear dimension of the section is limited by the power of the extruding press. By an extruding press of 50,000 N, the biggest machine presently existing in Italy, the maximum dimension achieved is 360 mm. In U. S. A. and U. S. S. R. extruding presses exist with "power" up to 250,000 N; by which linear dimensions can be achieved up to 1,000 mm.
3. The minimum wall thickness imposed by the extrusion process is excessive in relation to the strength and weight/strength ratio required for small-size sections. Consequently an appropriate reduction is necessary for the profile wall thickness. Of particular interest is the chemical milling process by which it is possible to remove uniformly the metal in all directions dipping the part in sodium hydroxide etching solution.

In spite of these limitations, extruded structures seem to be able to find a wide field of industrial applications for gliders. They seem to be suitable for powered aircraft too.

Extruded Structures in the M-300 Sailplane
The M-300, designed by Alberto Morelli, was conceived to incorporate extruded profiles for some of its parts.
The aerodynamic behaviour of the rectangular-trapezoid wing is not sensibly worse than that of an ideal elliptical wing [2]. This allows an extruded structure to be used for the whole rectangular part of the wing. A rectangular planform was given to the horizontal tailplane too.
Two M-300 prototypes were built by the Centro di Volo a Vela del Politecnico di Torino, from 1965 to 1969. The extruded parts were: the wing spar, the ailerons and the horizontal tailplane.
The original idea for the extruded wing was set aside temporarily owing to the high cost of the dies and to the long time required for research and development.
The wing spar (fig. 1) was realized as an H beam extruded from an aluminum alloy AlZn5.8MgCu TA (corresponding to the 7075–T4 Aluminum Association Designation).
A correct extruding process required a 3 mm minimum web thickness, though this was excessive in relation to the shear stresses to be carried. The excess weight was reduced by cutting circular holes in the web. Furthermore the flange width was mechanically tapered along the span.

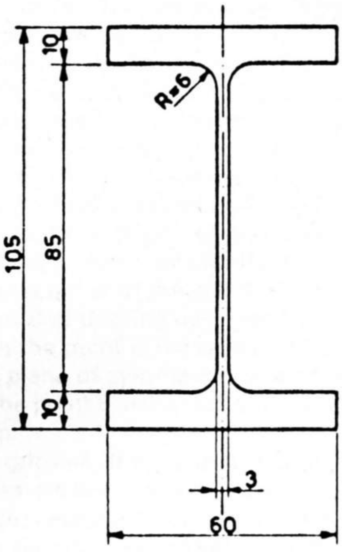
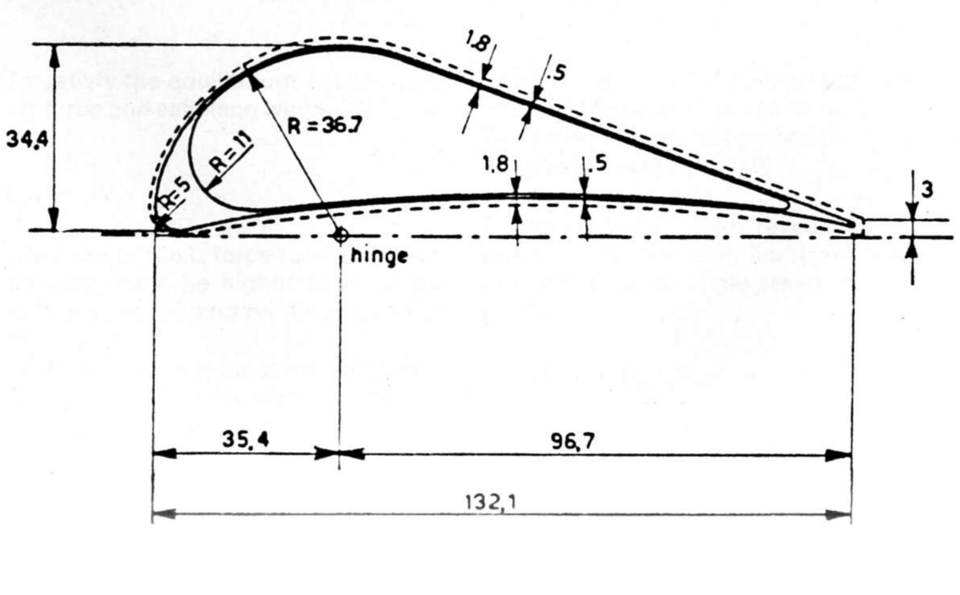


Fig. 1 M-300 Extruded Wing Spar Root Section.

Fig. 2 M-300 Extruded Ailerons Section (1st Version).



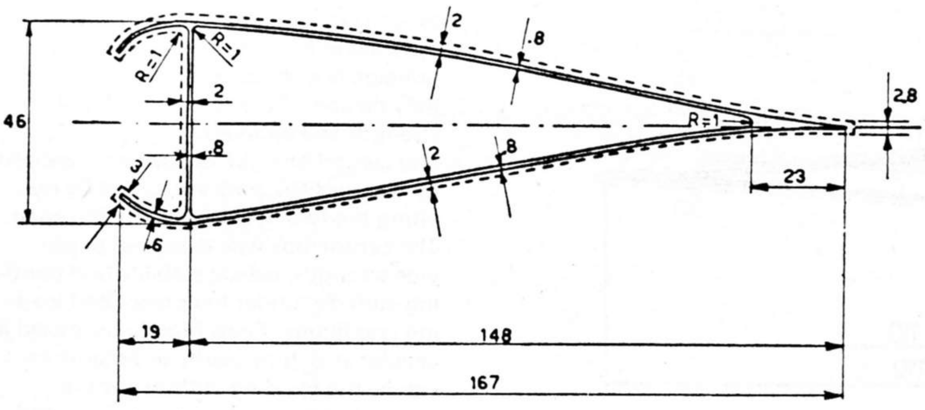


Fig. 3 M-300 Extruded Ailerons Section (2nd Version).

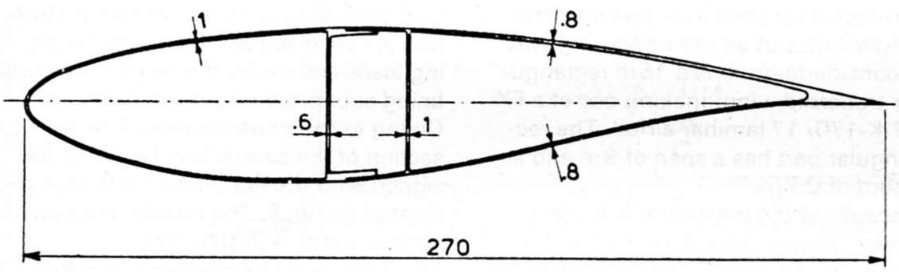


Fig. 4 M-300 Extruded Horizontal Tailplane Section.

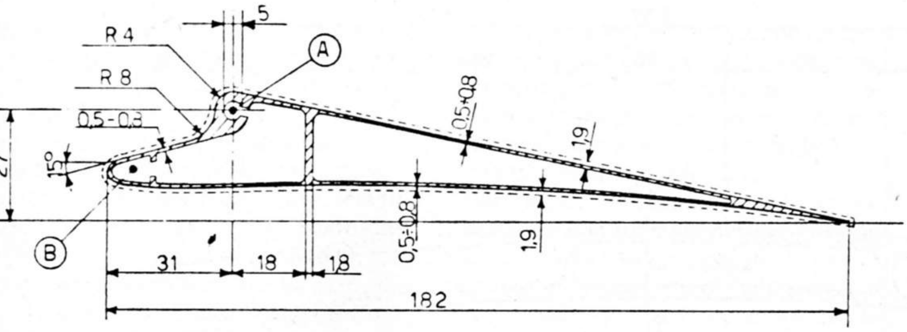


Fig. 5 Calif A-21 S Extruded Aileron Section.

In the first version the ailerons were made with the section shape shown in fig. 2 and extruded from an aluminum alloy AlMgSi TA16 (A. A. 6063–T6). Because of the unsatisfactory aerodynamic behaviour the ailerons were modified: the section shape of the second extruded version is shown in fig. 3.
The thickness, imposed by the extruding process, was uniformly reduced by chemical milling all over the outer surface, from an initial 1.8 mm down to 0.9 mm in the first version and from 2.0 mm to 0.8 mm in the second.
The all-moving horizontal rail was realized by two tubular extruded profiles rivetted one to the other along the span (fig. 4). The same aluminum alloy was employed. The 2 mm thickness was chemically etched to 1 mm in the leading edge and to 0.8 mm in the trading edge.

The tailplane was hinged to the fin by a stell tube T junction connected to the tail web. The tailplane was completed with two vacuum moulded ABS tip fairings.
The bending and torsion static tests proved the strength and stiffness of this structure. The load carried was more than twice the design ultimate load.
In all three cases the labour hours required to realize the structures were sensibly less compared with any other construction method.

Extruded Structures in the "Calif A-21 S" Sailplane

The "Caproni Vizzola" took this fulfilment as a starting point in the realization of extruded structures for the "Calif A-21 S" Sailplane.
The parts actually extruded are: the ailerons, the flaps and the elevator.
The ailerons consist of a twin cell ribless shell structure extruded from an aluminum alloy AlMgSi TA16 (A. A. 6063-T6). The section is shown in fig. 5.
The aileron hinge (opening A) and the counterweight slot for static and dynamic balance (opening B) were directly made out in the extruding process.
The flaps were extruded with the section shape shown in fig. 6 by the same aluminum alloy employed for the ailerons.
The flap hinge line coincides with that of the airbrake. The airbrakes lean on the flaps over 12° of flap deflection and they rotate together up to 74° ± 8°.
The elevator consists of a twin cell ribless shell structure extruded by the same aluminum alloy. It is hinged to the stabilizer in three points by the hinge A of fig. 7, which has been directly made out in the extruding process.
All three structures had originally a wall thickness of 1.9 mm, imposed by the extruding process. Weight was reduced by chemically etching all the outer surfaces down to a thickness of 0.5 or 0.8 mm, depending on the component, as shown on the diagrams.
These structures were very light and perfectly suited to provide the necessary strength and stiffness under the

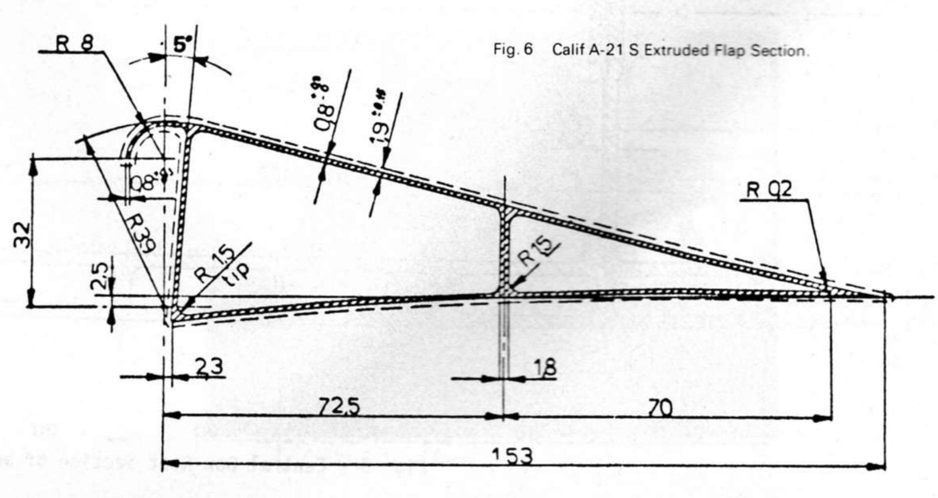


Fig. 6 Calif A-21 S Extruded Flap Section.

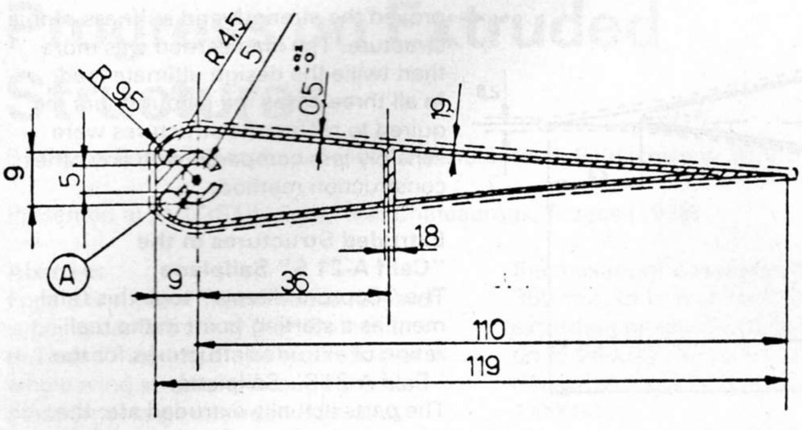


Fig. 7 Calif A-21 S Extruded Elevator Section.

prescribed loads. The low costs achieved, with respect to other methods, were of utmost interest. In fact two years ago the manufacturing cost of the flap, all included, was only ⅙ of the price paid to a supplier for the same flap realized in glass reinforced plastic.

Wing Structure Design

In consideration of the good results achieved on the M-300 with extruded structures for small components, the original idea of an extruded wing was reconsideration. It is a 15 m rectangular-trapezoid wing, making use of a FX 67-K-170/17 laminar airfoil. The rectangular part has a span of 9 m and a chord of 0.7 m.

Because of the maximum extruding press "power" available in Italy, the wing structure had to be constructed in three pieces: the central box beam, which has to carry shear, bending and torsion stresses, the leading edge and the trailing edge; these last two have principally a shape function: however, they do contribute to the structural strength and stiffness.

The central box (fig. 8) has been realized by two profiles; they are joined by riveting the two halfwebs along the span. The central box was designed to provide strength, elastic stability and bending stiffness under the prescribed loading conditions. Piero Morelli proposed a cellular structure, partly in order to increase the bending stiffness of the panels but also to prevent general and local elastic instability phenomena [3]. Of great importance are the crushing load phenomena. In fact the wing structure is conceived as ribless, the crushing loads caused by the beam curvature being supported only by the webs.

Owing to this consideration the root section of the central box has been designed with the nominal dimensions indicated on fig. 8. The design ultimate normal stress is 240 N/mm².

The beam shall be tapered along the span by chemically etching the outer surface down to a 0.8 mm wall thick-

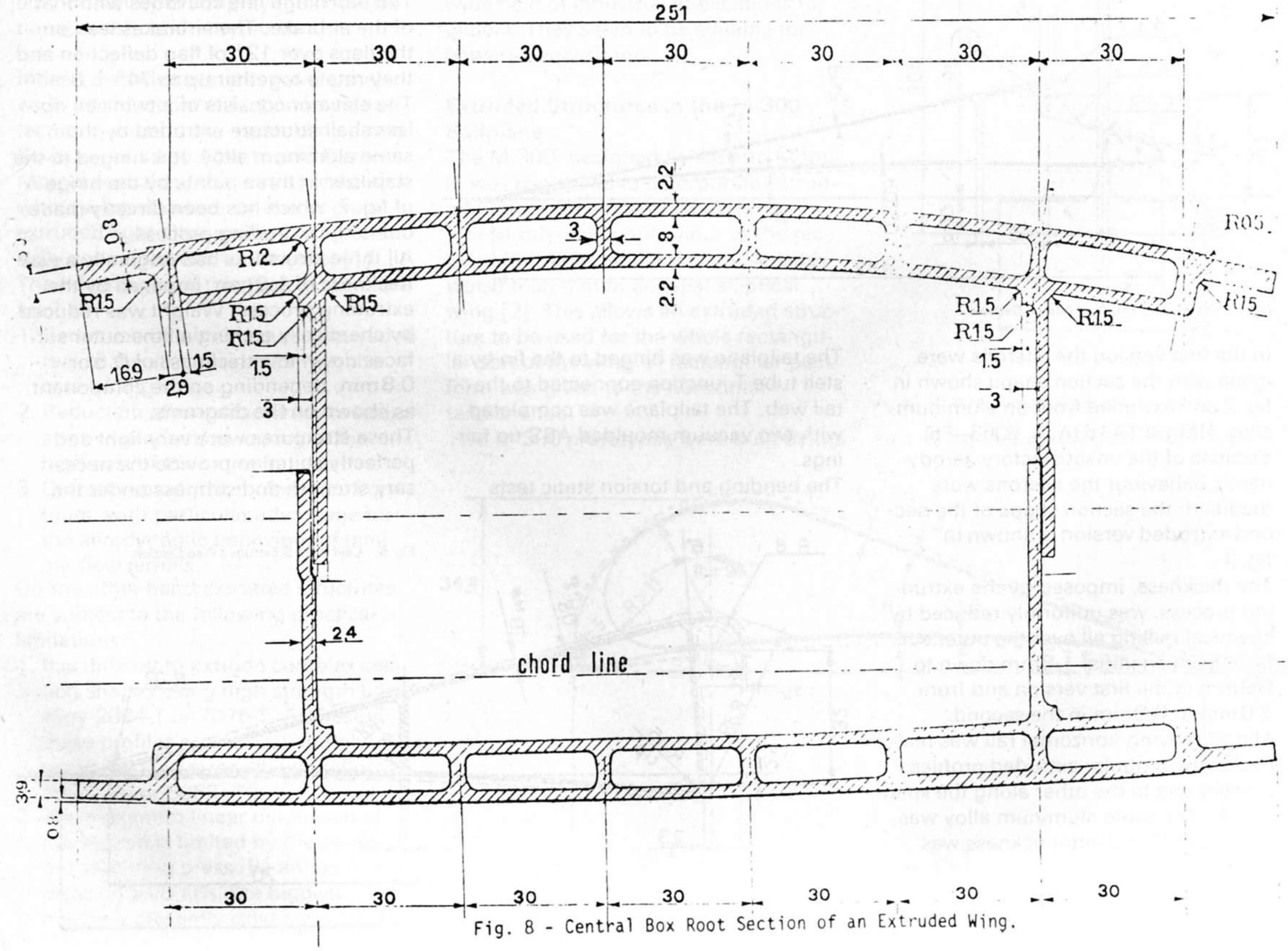


Fig. 8 - Central Box Root Section of an Extruded Wing.

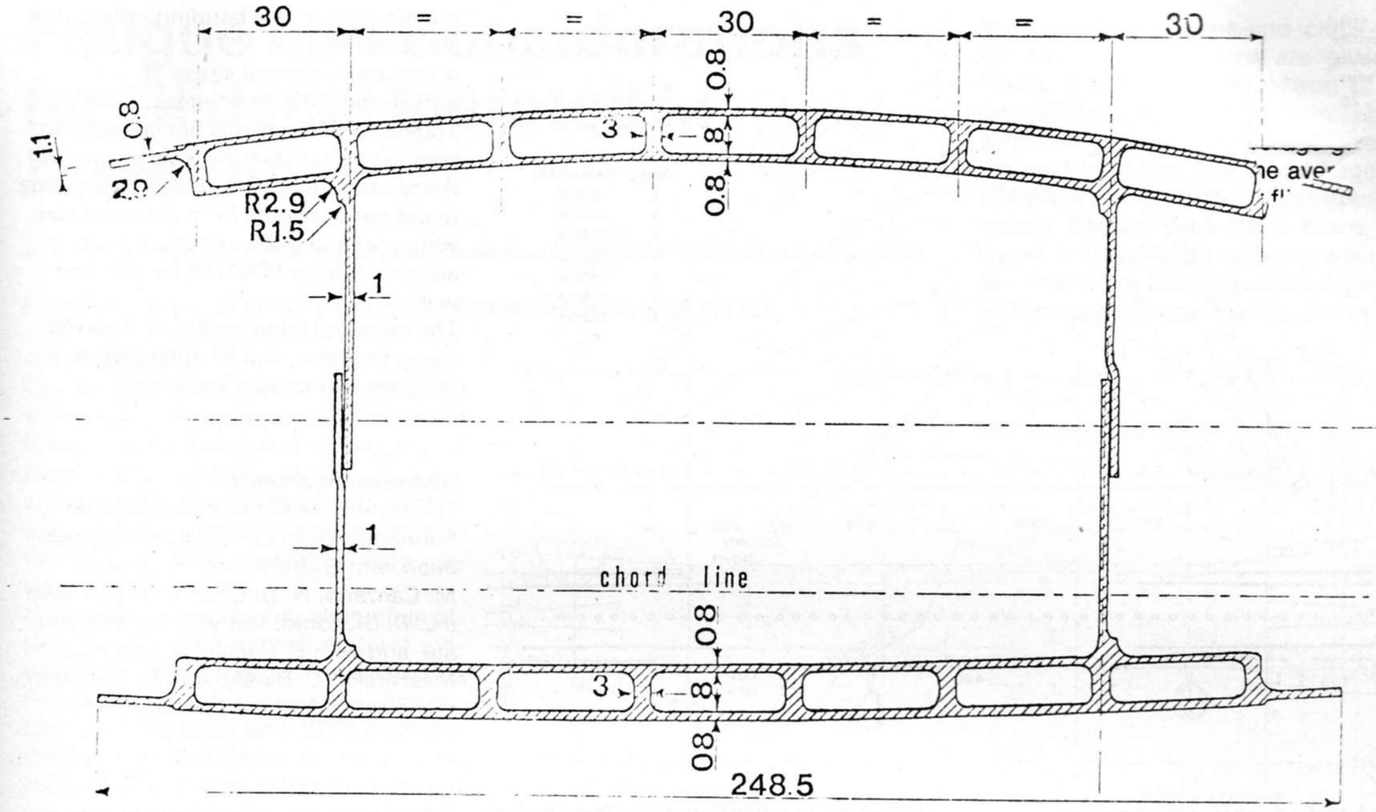


Fig. 9 Central Box Tapered Section of an Extruded Wing.

ness at a spanwise station distant about 2.3 m from the root section (fig. 9); this thickness is then kept constant all over the rest of the wing.

Recently, static tests on wing box beams have been carried out, simulating an extruded wing structure. The fitness of the final design of the extruded structure has thus been verified [4, 5, 6].

The profiles are planned to be extruded from an aluminum alloy AlMg I SiCu TA16 (A. A. 6061-T6). The chemical composition and the mechanical properties of a 6061-T6 aluminum alloy are listed here:

Mg = 1%; Si = 0.6%; Cu = 0.25%; Cr = 0.25%.

$F_{ty} = 240 \div 310$ N/mm²; $F_{tu} = 270 \div 330$ N/mm²; $E = 70{,}000$ N/mm²; $\varepsilon_{max} = 8 \div 15\%$.

The aluminum alloy has been selected in relation to the extruding process. Nevertheless, its medium strength doesn't make the structure too heavy. In fact, the wing flexural deformation must be restrained anyhow to limit the crushing load. The theoretical weight of the extruded central box wing is 480 N.

In a first attempt the profiles have been extruded from an aluminum alloy AlMgSi TA16 (A. A. 6063-T6). The mechanical properties of this alloy are sensibly worse than a 6061-T6 aluminum alloy ($F_{ty} = 235$ N/mm²; $F_{tu} = 265$ N/mm²).

The low cost of the profiles and the correct reproduction of the section contour were very satisfactory. Supposing a series production of 100 extruded wings, the cost of the extruded profiles for a 9 m span central part of a wing box structure is about 250 US$.

With respect to the theoretical section contour maximum deviations of about 0.4 mm have been measured; in the opinion of the technical staff of the extrusion factory, these deviations can be appreciably reduced.

Results of Bending Tests on Wing Box Beams

Before the whole wing is subjected to static and dynamic tests, 7 specimens are planned to be tested in pure bending. Two specimens have the wall thickness of the root section (fig. 8), three have the minimum wall thickness (fig. 9) and two have an intermediate wall thickness. Each is 1,000 mm long.

At the end of the specimens suitable fittings are bolted in order to fix them to the bending machine. The upper and lower side of each panel is reinforced by sheets 3 mm thick for a length of 185 mm from each end (fig. 11).

The specimens are bolted to the bending machine (fig. 10) by two clamps (A) hinged to the frame (B) by four rods (C). On the other side of each clamp an hydraulic jack (D) is hinged, so that

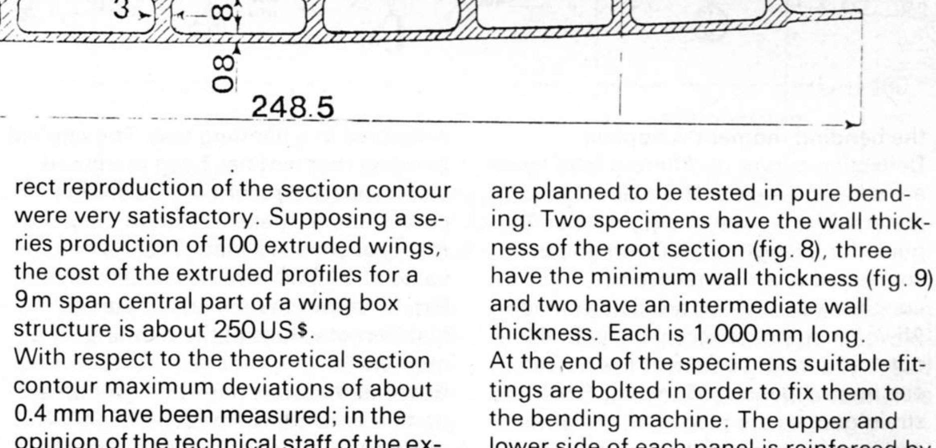
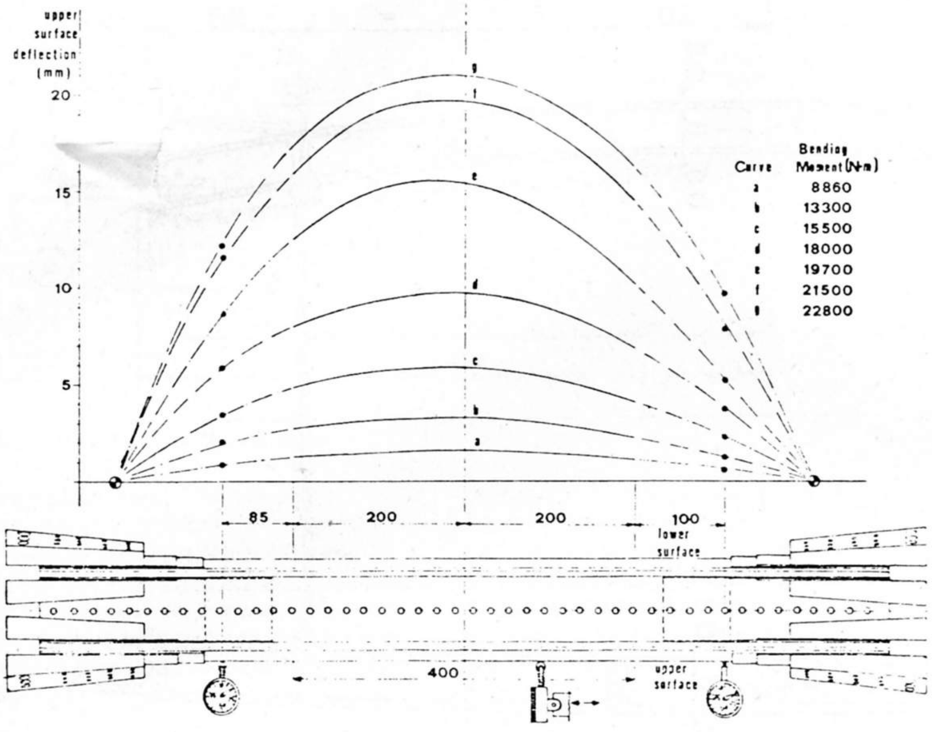


Fig. 10 - Bending Test Machine



the bending moment is applied.
Deflection curves at different load levels are taken by means of 3 dial deflectometers. The central one (E) runs on a guide for a length of 400mm and is connected to an x-y recorder.
Longitudinal stresses are determined by 16 linear strain-gauges placed on the outer and inner surface of the dorsal and ventral panels. Moreover 8 delta strain-gauges are placed on the outer and inner surface of the four halfwebs at a distance of 25mm from the rivet axis. They are used to determine also the transversal crushing stresses.
The first specimen, having the wall thickness of the root section, has been subjected to a bending test. The applied bending moment has been increased step by step to record the deflection curves and to make the strain measurements at constant load. The maximum value of 24,500 N-m has been reached. Fig. 11 shows the deflection curves at different values of the bending moment.
Small deflections have been recorded up to a bending moment of 15,500 N-m. At this value the stresses are still in the elastic range of the stress-strain curve.
At larger loads the curvature of the box beam increases appreciably up to a 20mm vertical displacement of the middle section at a bending moment of 22,800 N-m.
A maximum normal stress of 235 N/mm^2 has been measured.
The result of the test is not considered completely satisfactory, this because of the aluminum alloy employed. We hope to get better results from the box beam wing planned to be extruded by an aluminum alloy 6061-T6 for the next weeks.
The extruded wing structure, tapered along the span, will be subjected to a bending and torsion static test.

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