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EXTRUDED LIGHT ALLOY AIRCRAFT STRUCTURES

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ABSTRACT

Advantages and limitations of extruded structures in aircraft construction are discussed. Some solutions adopted for the M-300 sailplane are illustrated. Procedures and results of static structural tests performed at the Politecnico di Torino are briefly reported. Considerations are made on the possible development of this structural concept.

INTRODUCTION

Extruded light alloy structural elements are of wide use in aircraft metal structures (spar flanges, stringers, etc.). Consideration is given here, however, to the possibility of realizing full extruded structures as a replacement of conventional metal structures (a combination of assembled stringers, panels and ribs, or frames).

The main practical advantages of this solution are the following:

1. Reduction of man-hours required for the construction, once the extruded element or elements are available.
2. Reduction of costs in the case of series production. The cost of the expensive extrusion dies, in this case, can be distributed on a high number of pieces.
3. Accuracy in the reproduction of particular section shapes. This advantage is particularly appreciable when complex section shapes are required or when the correct profile realization is important in relation, for instance, to the aerodynamic behavior of a wing or tail (laminar flow airfoils, slotted control surfaces, or flaps).

The extruded structures, however, are subject to limitations as far as the possibility of their realization is concerned:

1. The maximum dimension and net area of the profile section are limited by the power of the available extrusion pressing machines. The maximum capacity of the biggest pressing machine actually existing in Italy, for instance, is 5000 tons. By such a machine, the maximum practicable net section area is 5000 sq mm for dural; the maximum workable linear dimension of the section is 350 mm. In other countries (i.e., U.S. and USSR), much bigger machines exist (up to 25,000 tons) with proportionally higher possibilities.

2. The extruded structures are typically at constant geometrical and structural section. Through suitable mechanical and chemical operations, however, it is possible to realize a certain degree of cross section variation along the structure axis. Either the overall linear dimensions of the section or the dimensions of its elements (wall thickness, for instance) can be tapered to a certain extent.

3. A minimum value of the wall thickness is imposed by the technological process of extrusion. As a consequence, in the case of small size sections, such a thickness is excessive in relation to the strength and weight/strength ratio required. A subsequent operation of thickness reduction is necessary in such cases. At this aim, a particularly interesting process is the chemical milling.

Notwithstanding these limitations, a wide field of applications seem to be possible for the extruded structures on motorplanes as well as on gliders. On gliders, in particular, owing to their dimensions and to the high wing and tail aspect ratios, the adoption of extruded structures seems to be particularly interesting.

THE M-300 SAILPLANE

Some extruded structures have been introduced in the design of a high-performance "standard class" glider: the M-300, designed by Alberto Morelli.

Two M-300 prototypes have been built by the "Centro di Volo a Vela del Politecnico di Torino, CVT." The first of them made her maiden flight in April 1969. Both have been flown for several hundred hours and took part in national and international competitions. An early photo of the first M-300 is shown in Fig. 1. Figure 2 shows a three-view drawing. Extruded parts are: (1) the wing spar; (2) the ailerons; and (3) the horizontal tail ("all-moving" type).

Wing Spar

Two-thirds of the wing span is at constant chord. The original intention was an extruded structure for the whole rectangular part of the wing. This idea was abandoned in consideration of the high cost of the dies; the Italian extruding machines being, moreover, inadequate; and a long time needed for experimentation and development.

The wing was thus realized as a composite structure, the skin being made of special preformed thick plywood panels and the ribs milled out of a wooden sandwich. The spar was designed as I-beam obtained from an extruded "ERGAL 55" (approximately corresponding to the 7075 Al-Zn alloy).

The spar section is indicated in Fig. 3. Taper of the flanges was realized by a progressive reduction of their width. The web thickness (3 mm) was excessive in relation to the shear stresses, but necessary for a correct extruding process. Weight was saved, however, by cutting circular holes (60-mm diameter, 105-mm spacing) on the web.

Ailerons

A slotted aileron was envisaged first in correspondence of the tapered outer parts of the wing. Its section is shown in Fig. 4. It is a pure shell structure made out of a tubular extruded profile. The material employed was an Al-Si-Mg aluminum alloy (ANODAL UNI 3569 TA). The wall thickness was originally 1.8 mm in order to have a correct extrusion process. The thickness was then reduced to 0.5/0.6 mm through uniform chemical milling of the exterior surface. The bulky leading edge (Fig. 4) was so designed as to fulfill mass balance requirements.

The structure has no ribs at all except at its ends, where two small ribs, made out of a thin steel plate, are riveted to the skin and carry the two hinges and the control lever (at the aileron inner end).

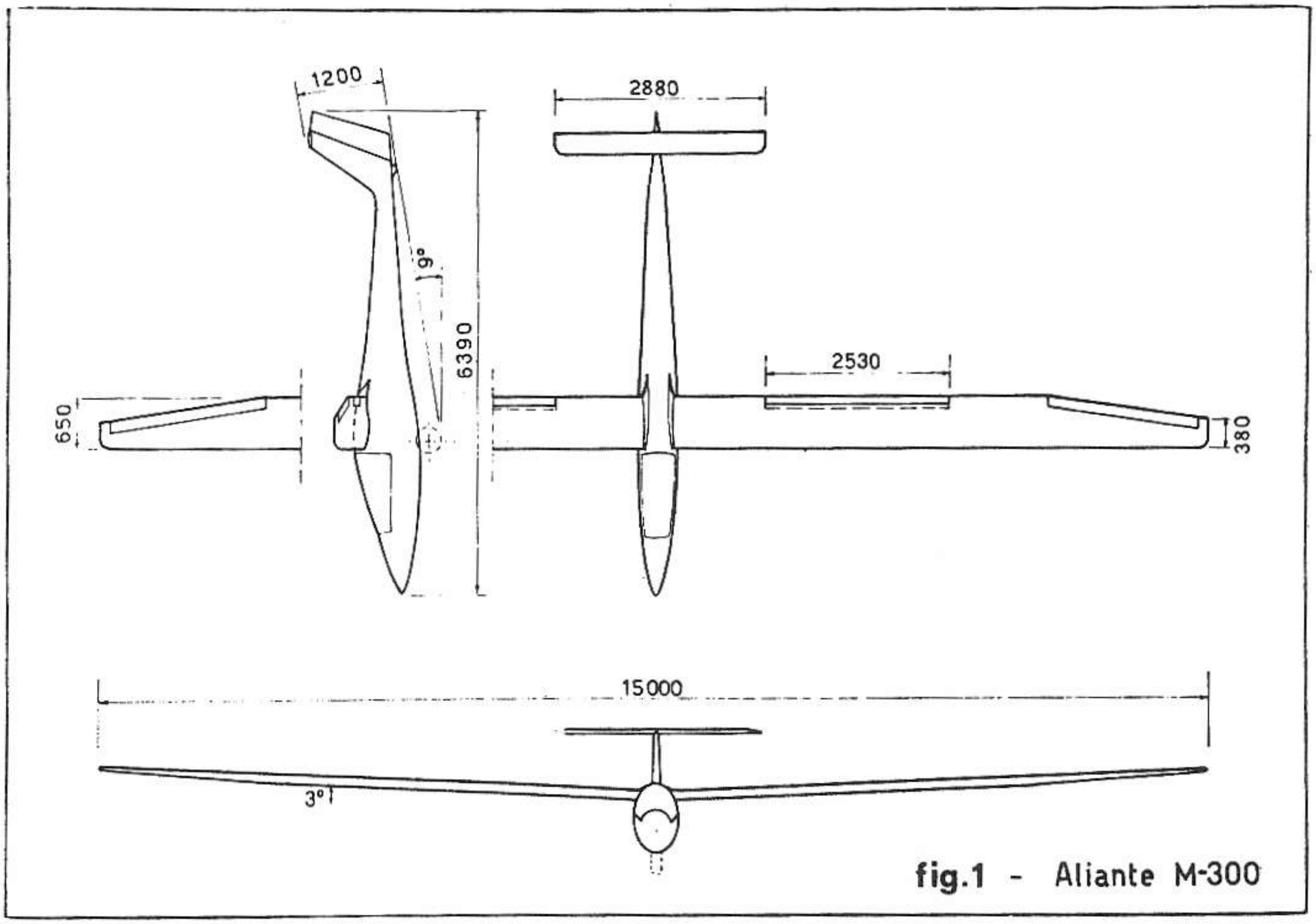

FIGURE 1

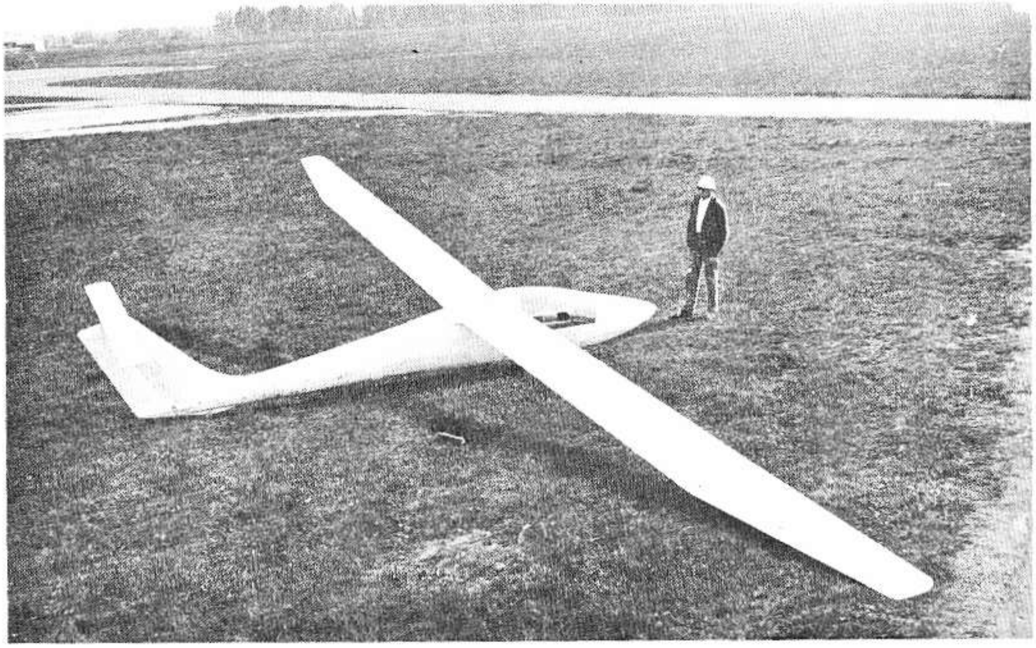

FIGURE 2

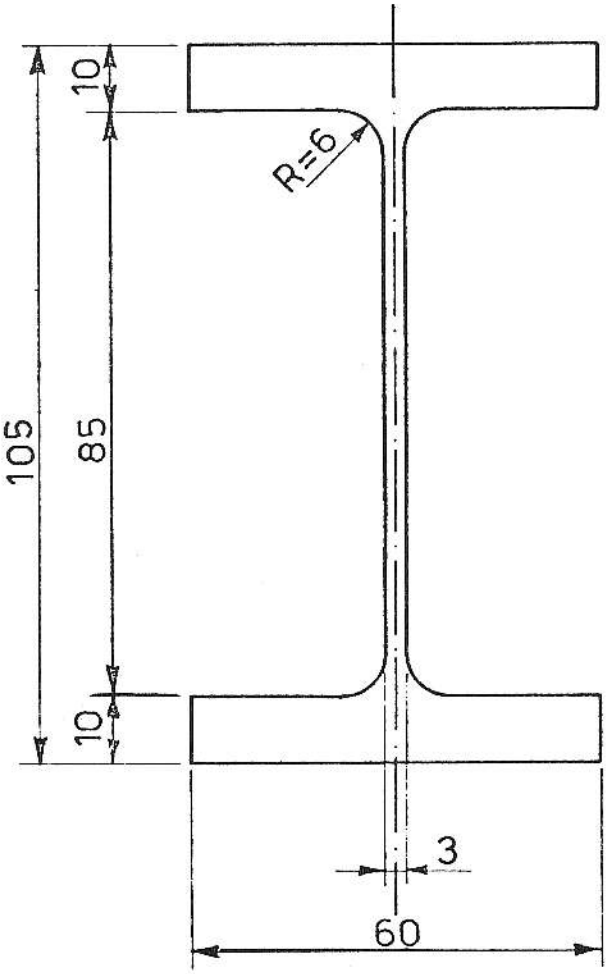

FIGURE 3

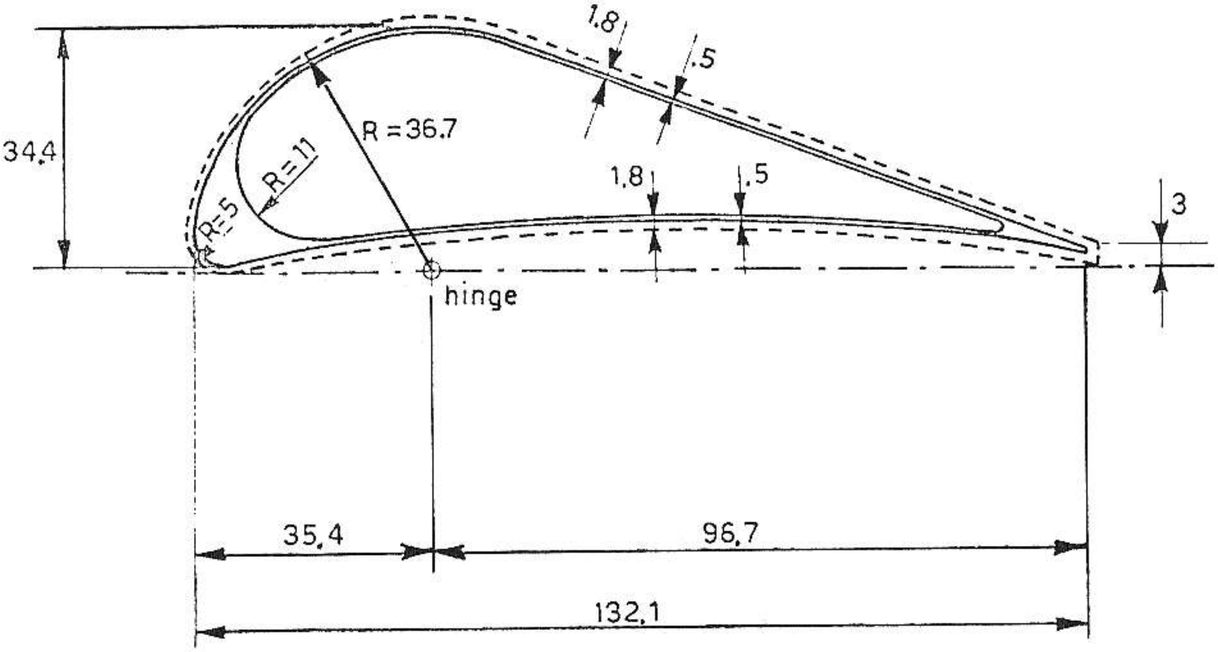

FIGURE 4

This type of structure resulted in being very light (2.3 kg/aileron) and more than adequate as far as strength and stiffness under the prescribed loading conditions were concerned. The most interesting gain was, however, on the man-hours required for the construction: a very remarkable difference with respect to any other conventional construction method from wood, glass/epoxy, or metal.

During test flights, however, these ailerons proved inadequate from the aerodynamic point of view. They were then replaced by "plain" ailerons of increased chord and span (section shown in Fig. 5).

The construction method was similar to the previous type, the structure being again realized out of a tubular extruded profile. In this case, an intermediate hinge was added. At the same span station, the control lever was located as required by the increased aerodynamic hinge moments due to the total absence of aerodynamic balance.

Though a little more complicated than the previous solution, the advantages of the construction method were largely maintained. The weight of the new aileron was 2.35 kg.

Although the ailerons are applied to the tapered outer portions of the wing, their cross section is constant along the span. This required a slight modification of the wing profiles in the tapered outer part. How much this modification affects the aerodynamic airfoil behavior, we are not able to say.

Tailplane

The "all-moving" tailplane was given a rectangular planform for the purpose of employing extruded profiles for its structure.

The high aspect ratio (A=11) was adopted for aerodynamic reasons, the required stability and elevator power being thus achieved with a smaller surface.

Figure 6 shows the tailplane cross section. The airfoil was designed for: (1) an optimum negative angle of attack; (2) laminar flow within a given range of incidence; and (3) a prefixed value of the pitching moment coefficient in relation to the desired "stick force vs. airspeed" characteristics.

The structure consists of two aluminum alloy tubular extruded profiles, joined together by rivets along the span.

As in the case of ailerons, the original skin thickness was higher than required (2 mm). This value was reduced to 0.8/1.0 mm by chemical milling.

The only additions necessary to complete the tailplane were: (1) a T steel tube fitting for the tailplane/fin attachement. This was connected through hinges to the web of the front extruded profile. A cutout (60 x 300 mm) was therefore necessary on the lower skin of the front profile; (2) a faired tip at each tailplane end. These were made of vacuum molded ABS and directly riveted to the skin; (3) a simple fitting for the control rod connection at the trailing edge of the root section.

The same advantages as claimed for the ailerons were obtained. The reduction of man-hours was even more striking, if compared with conventional construction methods. Less skilled labor, moreover is required as the handwork is practically limited to assembling of already shaped parts.

The load carrying capability and stiffness, as determined through static tests, resulted by far in excess of specified limits.

The weight of the tailplane structure, not including the tailplane/fin connection fitting and the tips, resulted 4.4 kg corresponding to 6.3 kg per sq.mi.

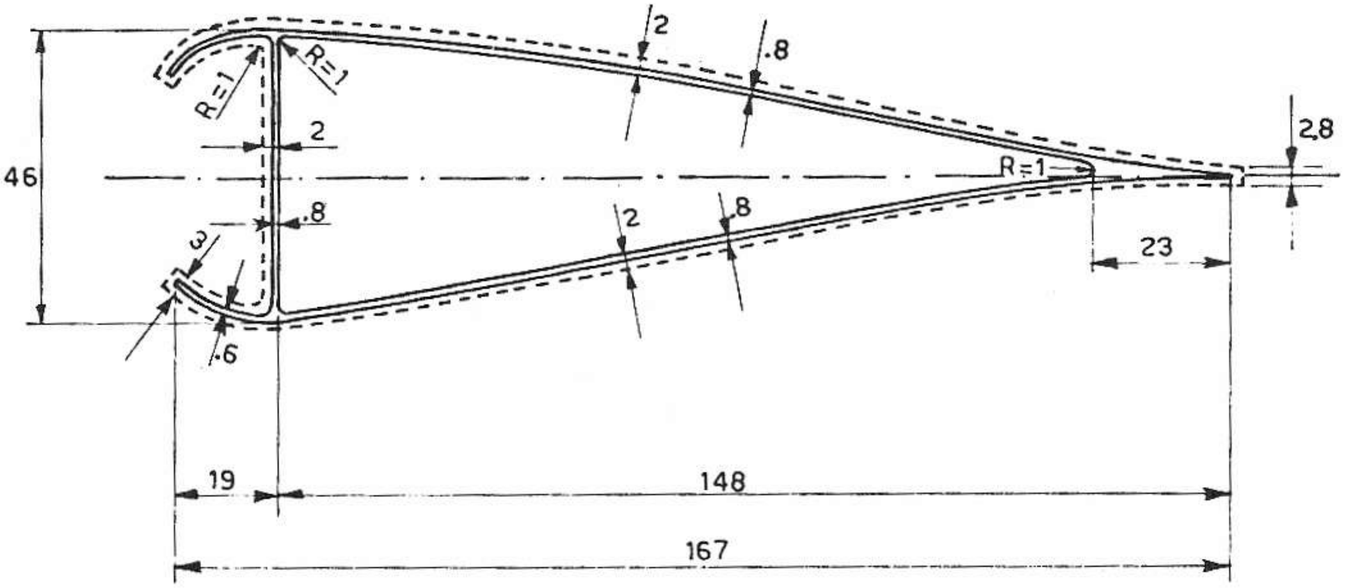

FIGURE 5

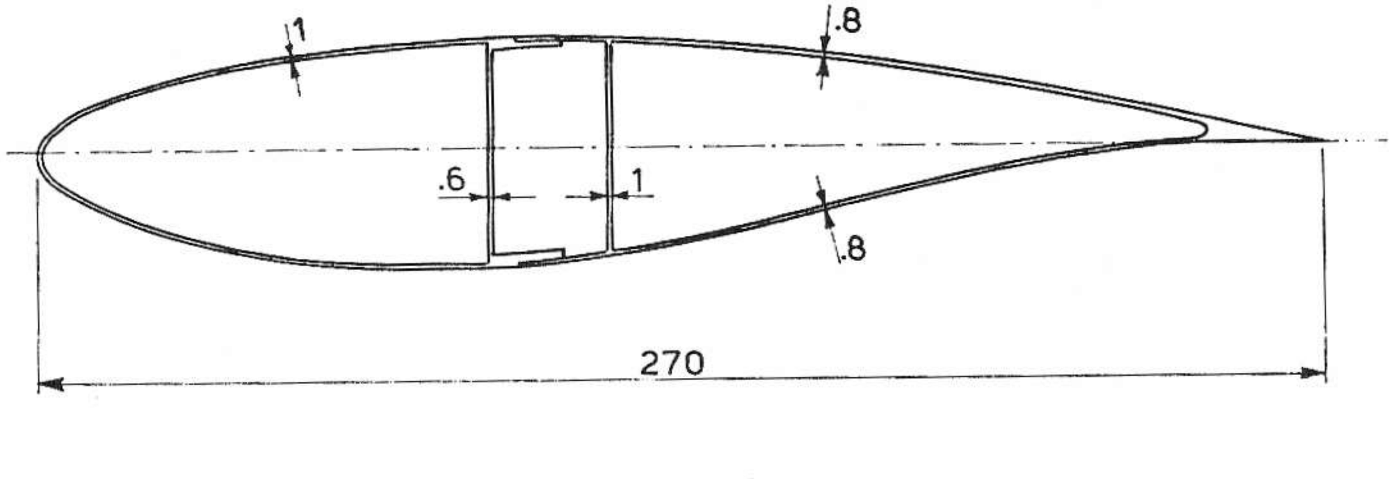

FIGURE 6

STATIC STRUCTURAL TESTS

All above described extruded structures were subjected to an extensive static test program. Bending and torsion, which, of course, occur together in the real loading cases of a tailplane, have been studied separately.

In order to give an idea of test procedures and results obtained, some peculiarities of the tailplane bending test are illustrated here.

The structure was loaded by a simulated span lift distribution, through a single mechanical jack and a system of chain links. The load was distributed along the elastic axis which resulted very close to the tailplane aerodynamic center (and hinge) axis.

At increasing load levels, measurements were taken of: (1) Vertical displacements at nine spanwise stations, (through nineteen mechanical dial extensometers: two on eight stations, three on the center section station) (Fig. 8). Figure 9 shows the deflection curves at loads of 100, 200, 240, 300, 350, 400 kg (240 kg is the design ultimate load of the tailplane). The dotted lines relate to residual permanent deformations after removal of the 300 and 400 kg loads.

In Fig. 10, each curve shows the vertical displacement at a given station as a function of the load. It can be seen that each curve shows a decreasing slope at low load level followed by a wide quasi-linear portion and then again a decreasing slope at high loads.

The first variation is due to progressive buckling of the various skin panels. The linear portion is in the domain of elastic buckling, whereas the last portion corresponds to the appearance of permanent deformations due mainly to local instability.

The rupture load of the structure was considered to be 400 kg. The corresponding permanent residual displacement, evaluated at the outer end of the structure was approximately 5 percent. It is important to note, however, that the permanent deformation was mainly due to local instability effects at the edge of the central cutout (Fig. 11).

Figure 7 shows the structure under the 400 kg load.

The local deformation could be eliminated by an appropriate stiffening of the edge. This was not done, however, as the design ultimate load of the tailplane was largely exceeded.

Strain-gauge measurements of local strains in 27 points located on the outer surface of the skin and on the two webs.

The purpose of these measurements was the determination of buckling stresses of various critical panels, the location of buckles, their behavior at increasing load and the amount of permanent residual deformations.

It would be lengthy to report in detail here the experimental results.

A typical diagram is shown in Fig. 12. It relates to the critical panel at the lower rear surface of the tailplane. This panel is evidently overloaded in compression because of the cutout existing in the corresponding front lower panel.

The strain ($\mu\epsilon$) distribution is reported at different loads (100, 200, 300, and 400 kg) and after removal of the corresponding load.

The buckling wavelength is well in evidence. The residual plastic deformation becomes important at the higher load of 400 kg.

In Fig. 13, the buckling of the lower rear panel and of the rear web is clearly visible (load: 200 kg).

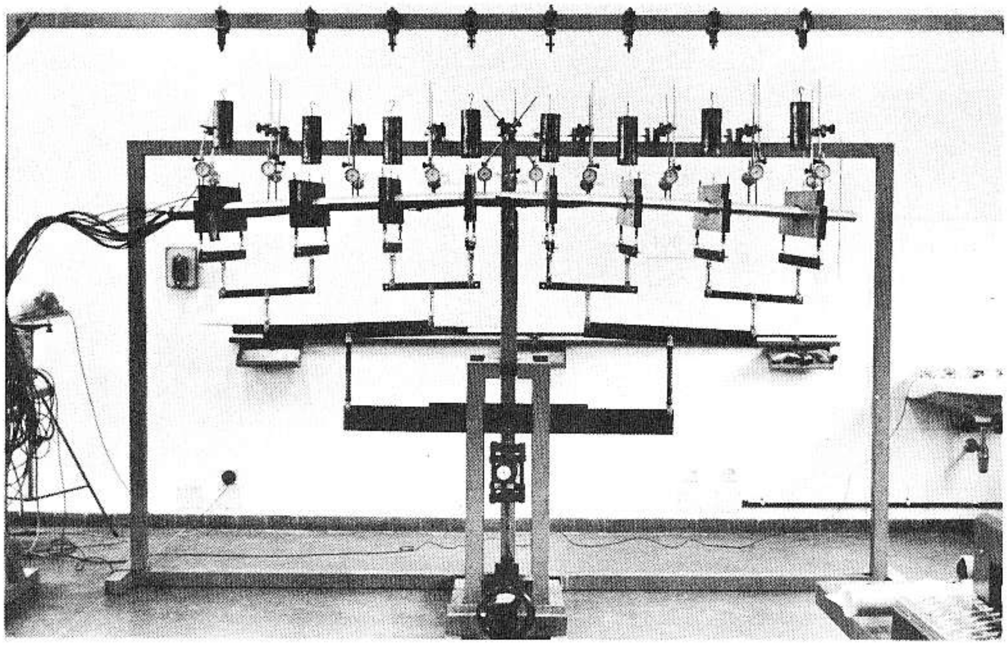

FIGURE 7

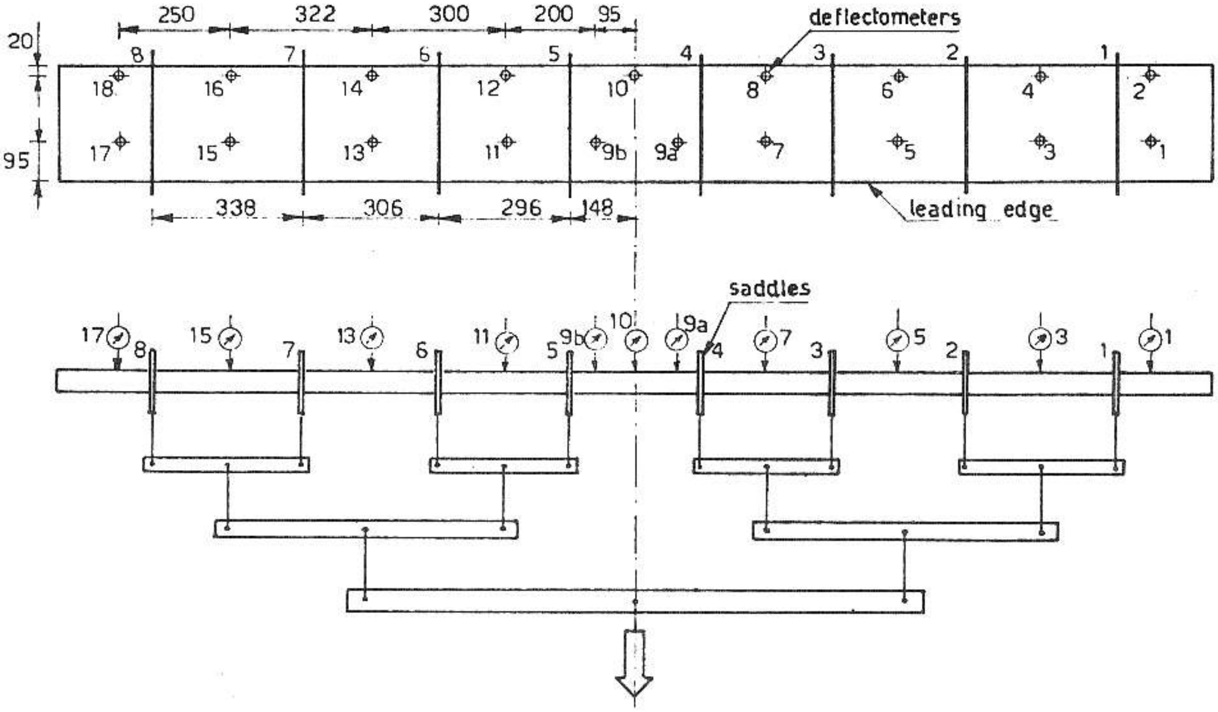

FIGURE 8

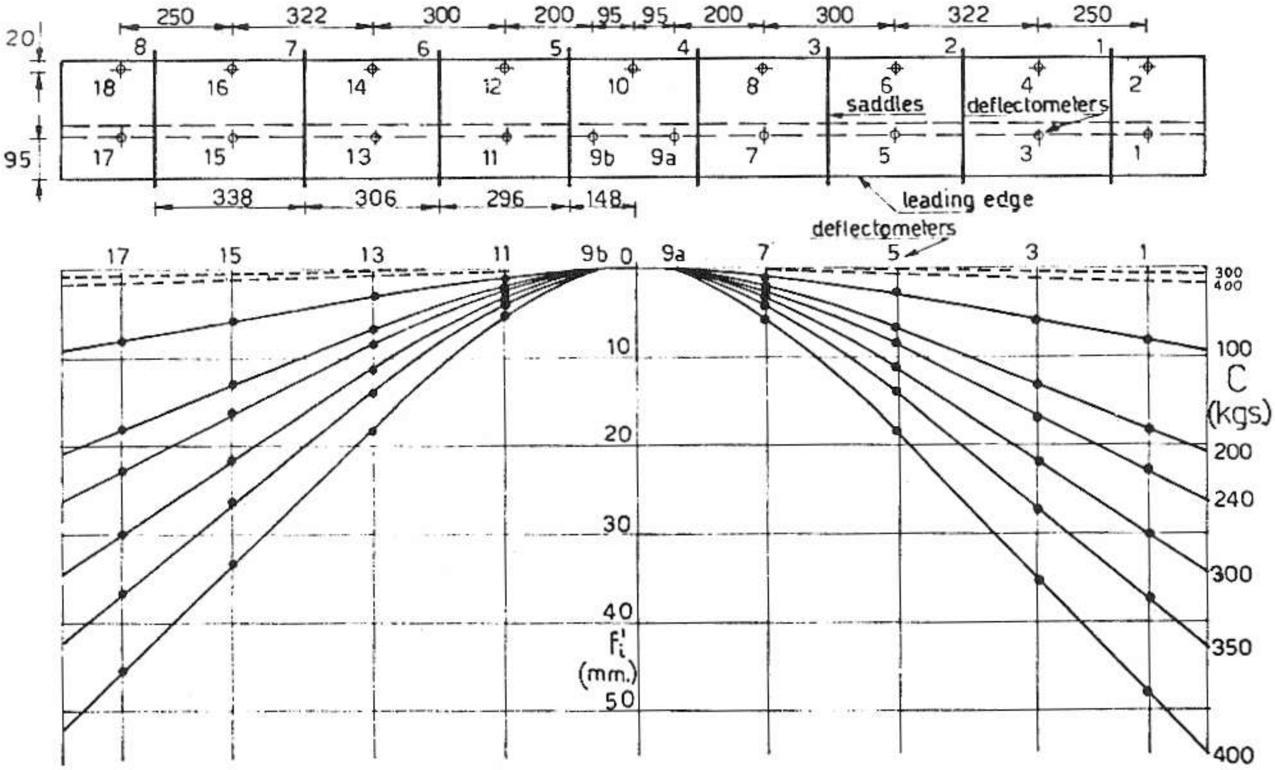

FIGURE 9

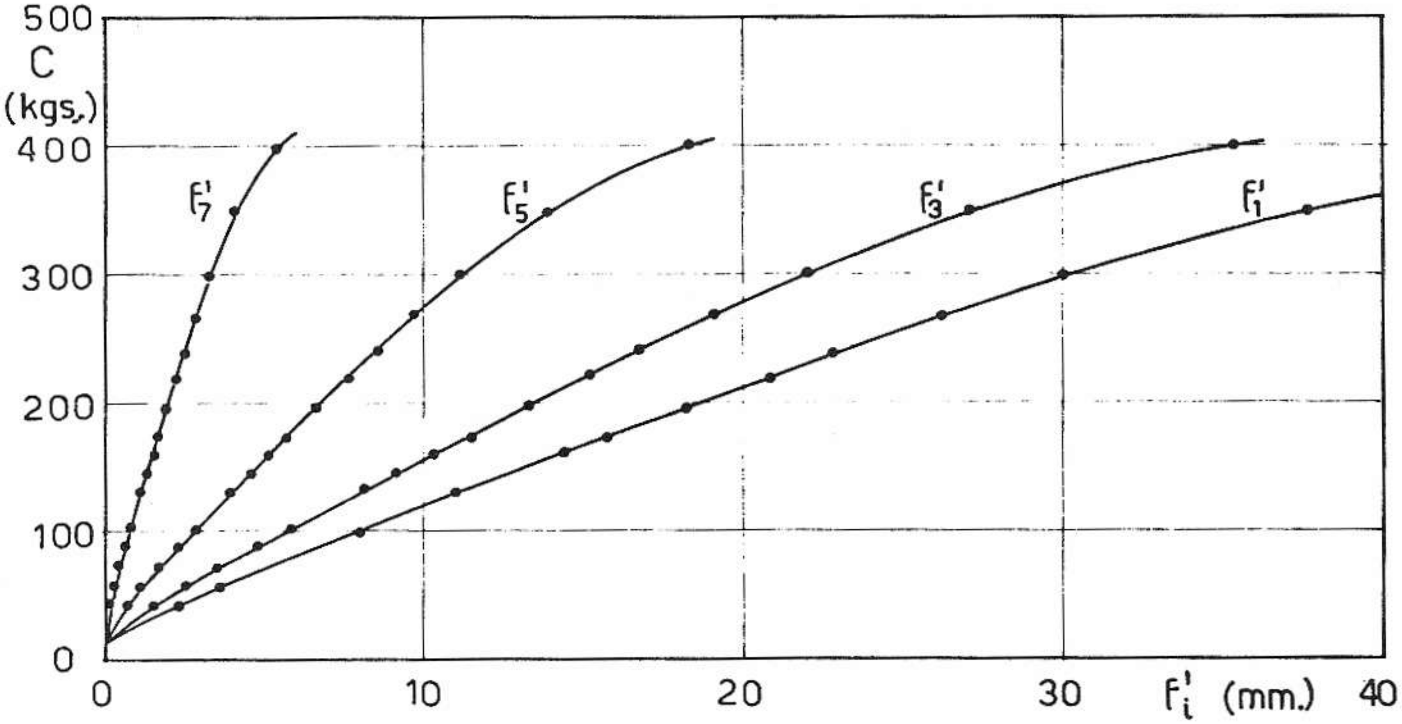

FIGURE 10

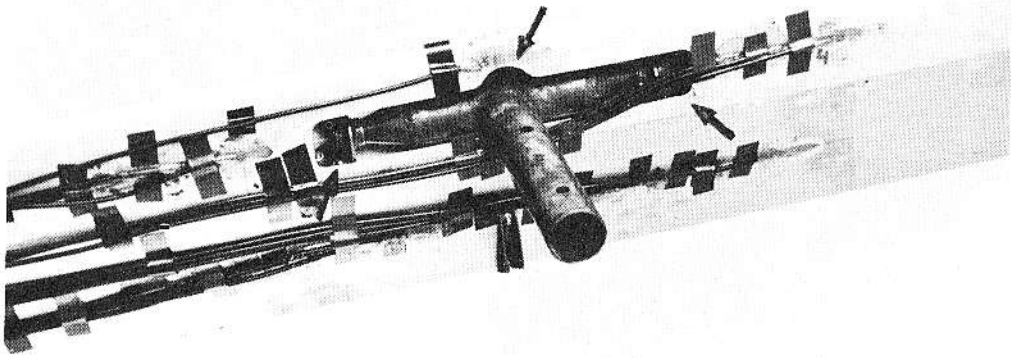

FIGURE 11

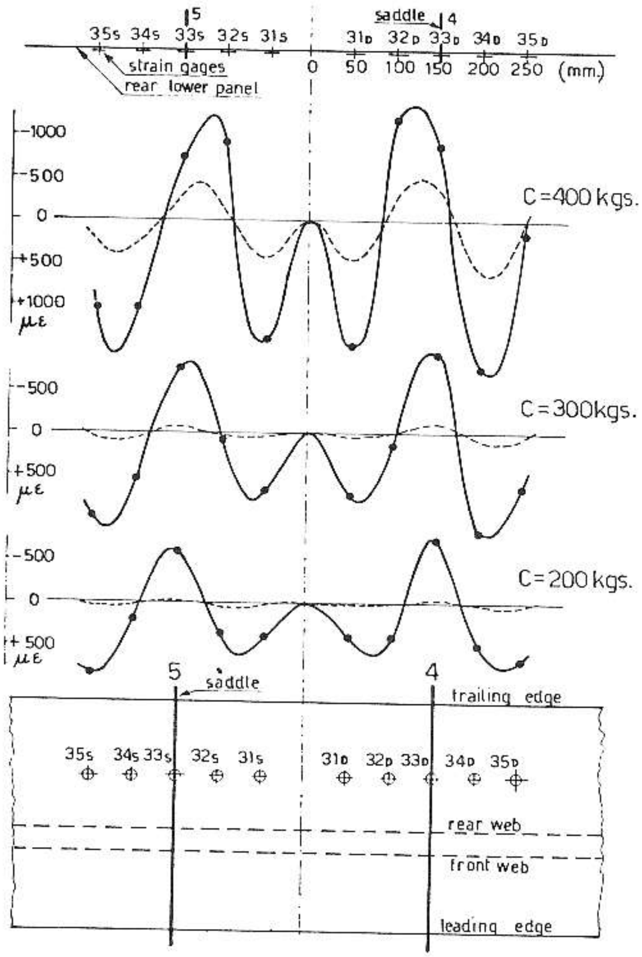

FIGURE 12

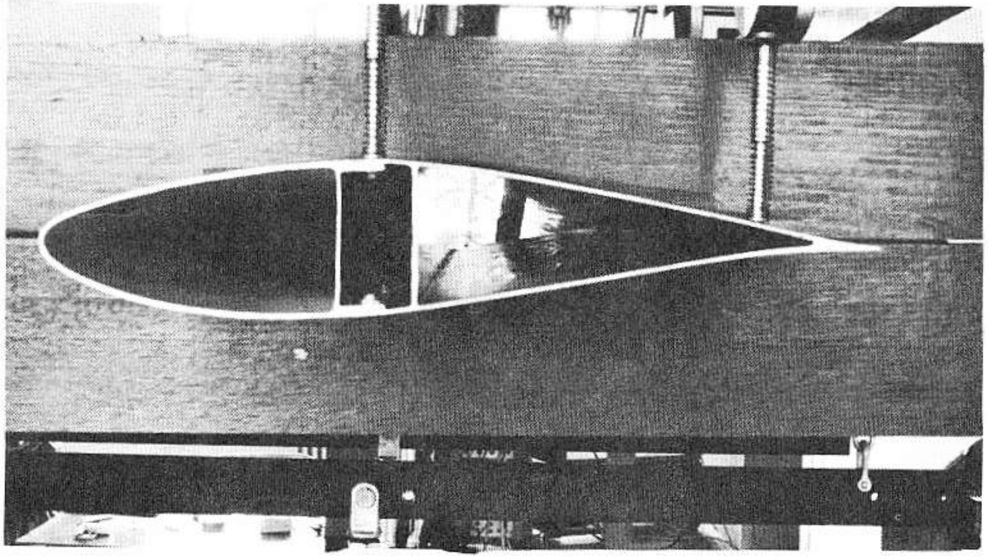

FIGURE 13

CONCLUSION

The application of the structural concept of extruded structures to some parts of the M-300 glider demonstrates the feasibility of this type of construction.

A wider field of application could be attempted. For instance, the construction of a whole wing (or large part of it) through the combination of extruded profiles, longitudinally connected one to the other.

The most attractive advantages of this solution, as already outlined in the introduction, are the reduction of labor costs and the easily obtainable correct reproduction of section profiles.

The structural taper of bending, shear and torsion resisting material could be achieved through the addition of tapered structural elements inside the extruded structures and connected to it, and/or by varying spanwise the wall thickness of the extruded profiles through chemical milling at variable time of immersion.

Of course, buckling problems of panels under compression and shear loads, in such a shell structure without ribs, are delicate. They should be faced with a careful location of webs and stiffening flanges. Expansion of resins, as stabilizing material, inside the structure cells might also be worth investigation.

The cost of extrusion dies makes the process interesting from the economical point of view, only in the case of a series production program.

It can be interesting to note, moreover, that this type of construction may be regarded as a possible way of sorting out, to some extent, of the artisan's work which is typical of actual construction methods, using either wood or metal or reinforced plastics as basic materials.

ACKNOWLEDGEMENTS

The fundamental idea of realizing the extruded structures illustrated in this paper is due to Alberto Morelli, designer of the M-300 sailplane.

The research and test work at the Politecnico di Torino was carried out by Paolo Piantella, Giuseppe Di Grandi and Antonello Cogotti, in close cooperation with the author.