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EXPERIMENTAL INVESTIGATION INTO THE FEASIBILITY OF AN "EXTRUDED" WING

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SUMMARY

Research work in the Politecnico di Torino and realizations (fabrications) of extruded aluminium alloy structures during the past years is briefly reviewed. The design criteria and the realization of the main structure of a sailplane wing made of a few extruded profiles longitudinally connected one to the other are then illustrated. Structural tests recently carried out are reported upon.

INTRODUCTION

Early research work and the first realizations on the M-300 sailplane prototypes were reported upon in reference 1. Figure 1 illustrates the cross section of the M-300 extruded structures: first and second realization of the ailerons (a,b), tailplane (c), wing spar (d). An aluminium alloy AlMgSi TA16 (A.A. 6063-T6) was employed for the extrusion except for the spar, which was of A.A.7075.

In more recent years the same structural concept was adopted by the firm Caproni Vizzola Costruzioni Aeronautiche, manufacturer of the two-seater sailplane Calif A-21S (ref.2 and 3). Figure 2 illustrates some of the parts of this glider which were realized by extrusion using the same aluminium alloy mentioned above: airbrake (a), flap (b), aileron (c), elevator (d), and leading edge of the wing central part (e). The aileron and elevator extruded profiles incorporate the hinge (A). In the aileron leading edge lodging is provided (B) for the counterweight, uniformly distributed along the span for static and dynamic balance.

In the M-300 and Calif extruded structures the original wall thickness of 1.8 to 2.0 mm was reduced to design values of .5 to .8 mm by chemical milling of the outer surface.

All these structures are basically ribless. They proved light and largely adequate in strength and stiffness.

One of the M-300 prototypes is still active. The Calif two-seater has been series produced with the extruded parts mentioned here since 1975, except the extruded airbrake which was introduced in 1978.

Advantages and limitations of the extruded structures were discussed in references 1, 2, 3. They are briefly summarized here.

Main advantages are:

1. **Reduction of manhours required to realize the structure, mainly during the assembling stage.**
2. **Reduction of cost in a series production when the cost of the expensive extrusion dies can be distributed over a high number of pieces.**
3. Correct reproduction of section contours with consequent aerodynamic benefit.

The practical limitations are principally the following:

1. The extruded profile has necessarily a constant cross section. Through suitable mechanical and chemical operations, however, it is possible to achieve a certain degree of cross section variation along the beam axis.
2. The maximum linear dimension and net area of the profile section are limited by the power of the available extrusion press.
3. The difficulty of extruding increases with high strength aluminium alloy such as 2024 or 7075.
4. A minimum wall thickness is imposed by the extrusion process, which is sometimes excessive in relation to the strength and weight/strength ratio required.

A wide field of possible applications seem to exist notwithstanding these limitations, particularly for gliders and light powered aircraft.

A glider has been conceived, which is similar to the M-300 from which it is derived and is suitable for a wide use of extruded structures, whose locations are indicated by the shadowed areas in figure 3.

The realization of the central part of the wing of this glider is the aim of the research work started a few years ago at the Politecnico di Torino, after the completion of the first stage which led to the realization of the above described M-300 extruded parts.

THE DESIGN OF AN "EXTRUDED" WING

The wing illustrated in figure 3 is 15 m span with rectangular-trapezoid planform, the central rectangular part being extended over 9 m.

It is a three-piece wing: the central part is a flat single piece connected to the fuselage by a 4-point attachment; the outer trapezoid panels are attached to the ends of the central part and give the wing the required dihedral angle.

The central part is conceived as a combination of extruded profiles: a possible typical cross section is illustrated in figure 4 (airfoil FX 67-K-170/17), which is purely indicative of the basic idea. Corresponding to the airfoil maximum thickness a box structure can be seen which carries practically all bending loads and a good portion of the shear/torsion loads. The other two thin walled extruded profiles are riveted to the central box and contribute to the shear/torsion strength and stiffness of the whole structure. The extruded profile at the trailing edge is a flap.

The wing structure is intended as basically ribless, as far as tests will confirm that ribs can be eliminated.

In order to provide the central box with the required bending strength and stiffness under the prescribed loading conditions (according to the OSTIV Airworthiness Requirements, ref.4) a cellular structure was adopted for the dorsal and ventral panels. This multi-cell structure was tentatively designed to prevent general and local elastic instability.

The central box is made of two profiles joined by riveting the two halfwebs along the span (A.A. 6061-T6).

The large bending deformation, typical of a high aspect ratio sailplane wing, combined with the absence of ribs makes the problem of resisting the "crushing " loads a basic one. One of the main objectives of the testing program is to ascertain how far the webs alone are capable of withstanding the crushing loads.

The central box section is reduced along the span by chemically etching the outer surface of each of the two profiles so that the original wall thickness of the skin panels is decreased from 2.3 mm down to .8 mm at a spanwise station about 2.65 m from the wing centerline. This thickness is then kept constant over the rest of the wing.

Figure 5 shows the reduction of skin thickness along the span in two possible ways. A step reduction (above) or a continuous tapering (below) can be realized, the latter requiring, however, additional equipment for chemical milling at variable time of immersion.

Figures 6 and 7 show the central box cross sections at the wing root and at a spanwise station from 2.65 m on.

EXPERIMENTAL PROGRAM AND RESULTS

Several problems are to be faced in the realization of a wing as described in the preceding paragraph.

A preliminary experimental investigation was considered necessary in order to check the following points:

1. The capability of the cellular panels to withstand the high design compression

stresses without incurring local instability phenomena at low load factors.

2. The capability of the box structure to withstand the design bending moments and, in particular, the crushing loads due to bending deformation.

3. The capability to obtain the central box profiles by extrusion of a suitable material at an acceptable degree of accuracy and reasonable cost.

4. The feasibility of satisfactory chemical milling in relation to the particular aluminium alloy adopted for the extrusion.

With reference to points 1 and 2, it was decided to check the general design of the central box structure, and of the cellular panels in particular, by realizing a "simulated" extruded structure and submitting it to pure compression and pure bending tests. The cross section of the simulated structure in figure 8 shows its conventional construction through Z-stringers and metal sheet, both of dural, connected by rivets.

Notwithstanding the difference in material and some geometrical features these tests gave some valuable indications (ref.2) so that the realization of the expensive extrusion dies could be undertaken with reasonable confidence.

The two extruded profiles were then obtained, having the cross section shown in figure 6.

Several attempts were necessary, with modification of the die, before an acceptable degree of accuracy of the section contour was achieved.

The aluminium alloy employed on the first extruded profiles was not satisfactory (inadequate values of the yield and rupture stress). A different aluminium alloy was then used of higher strength but, perhaps, rather poor plastic characteristics.

It should be remarked here that, in our Italian situation, the choice of materials for extrusion is extremely limited. In fact, since our factories are not furnishers of the aircraft industry, the supply of a small quantity of extrusions such as required for research can only be made of a material of current use, i.e. having rather low strength characteristics.

Pure bending tests were planned and carried out on several specimen,1000 mm long, of the real extruded structure using the bending test machine of the Istituto di Progetto di Aeromobili - Politecnico di Torino.

Figure 9 shows the testing equipment. Figures 10 and 11 show the deflection curves measured on specimens with wall thickness of 2.3 and .8 mm, i.e. having the cross sections illustrated in figure 6 and 7, respectively.

Figure 12 shows the typical failure in compression due to bending which occurred on one of the t=.8 mm specimen.

The results of these tests were encouraging, although of still limited validity for two main reasons:

1. Since the ends of the specimen are rigidly attached to the test machine, only a rather short central portion of the structure is free from their restraining influence. Therefore, the capability of the structure to withstand the crushing loads cannot be fully evaluated.

2. Shear is not present.

Testing on a full scale structure was therefore planned.

A test structure was prepared corresponding to the central box of the rectangular part of the sailplane wing illustrated in figure 3.

The span of this test specimen was 7.67 m, less than the 9.0 m span of the wing rectangular part, due to limitations of the available equipment for chemical milling.

The skin thickness was reduced spanwise through chemical milling by .3 mm steps from 2.3 down to .8 mm as shown on the upper part of fig. 5. Two extensions were added at both ends of the structure to allow the application of concentrated loads corresponding to the actual distributed load carried by the outer portions of the wing (see figure 13).

The spanwise wing lift and mass distributions were evaluated and then replaced by ten concentrated loads, giving a good approximation of the bending moment and shear distribution (see figure 13).

Figure 14 shows the structure under the load corresponding to load factor n=8.

The incremental load was 2,413 N corresponding to a unity load factor increment. The ultimate load was 24,074 N corresponding to a rather high ultimate load factor of 9.975.

The structural failure occurred at a load factor n=8.72.

As shown by figure 15, the dorsal cellular panel between the fittings, simulating the wing-fuselage attachments, collapsed under the combined effects of compression and crushing loads. In this area both webs were largely cut out to allow the connection of the fittings to the structure.

Figure 16 shows the deflection curves of the whole structure at load factors of 2, 4, 6 and 8. It can be seen that, at high load factors, the deflection of the left wing becomes a little higher if compared with the other wing. This is presumably due to the growing elastic buckling of the dorsal panel caused by the large cut-outs of the wing central part where the failure finally occurred (fig. 15).

The deflections at different stations are plotted versus load factor in figure 17.

Strain gage measurements showed: a) a slight elastic buckling of both webs in their longitudinally compressed part at load factors above $n=4$; b) no buckling whatever of the dorsal panels along the span; and c) a maximum local normal stress of 235 N/mm^2 at $n=8$ on both dorsal and ventral panels.

CONCLUSIONS

The failure under bending having occurred at a very high load factor ($n=8.72$) and in the central part of the structure where the webs can be easily reinforced, the result of this first static test can be considered successful. There is a reasonable confidence that, after reinforcement of the web cut-outs in the central portion of the structure, the residual load factor increment $\Delta n=9.975-8.720=1.255$ will be attained.

Although torsion static strength and fatigue life are to be demonstrated before a structure of this type can be assessed to be adequate for a sailplane wing, the result of the actual shear/bending test should probably be considered of basic importance as it practically demonstrates the feasibility of a ribless structure made of a few extruded profiles longitudinally connected one to the other.

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2. Romeo, G.: Realizzazione per estrusione di strutture aeronautiche - Ricerca su struttura alare estrusa. Prestampa AIDAA n.60, IV Congresso Nazionale dell'Associazione Italiana di Aeronautica e Astronautica, Milano, September 1977.

3. Romeo, G.: Progress on Extruded Structures. 16th OSTIV Congress,Chateauroux, France, July 1978.

4. OSTIV Airworthiness Requirements for Sailplanes, September 1976.

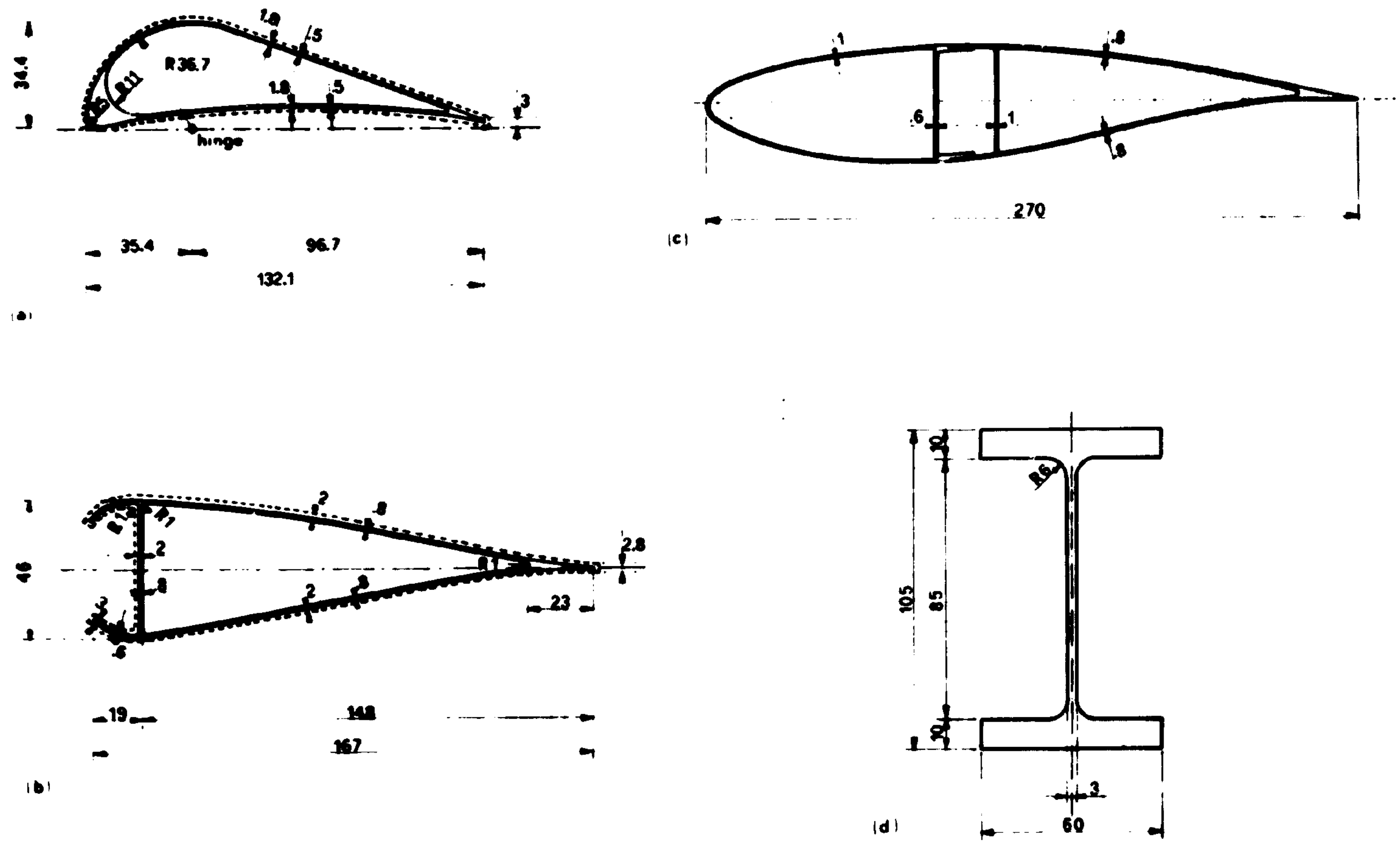

FIG.1 – M-300 EXTRUDED STRUCTURES

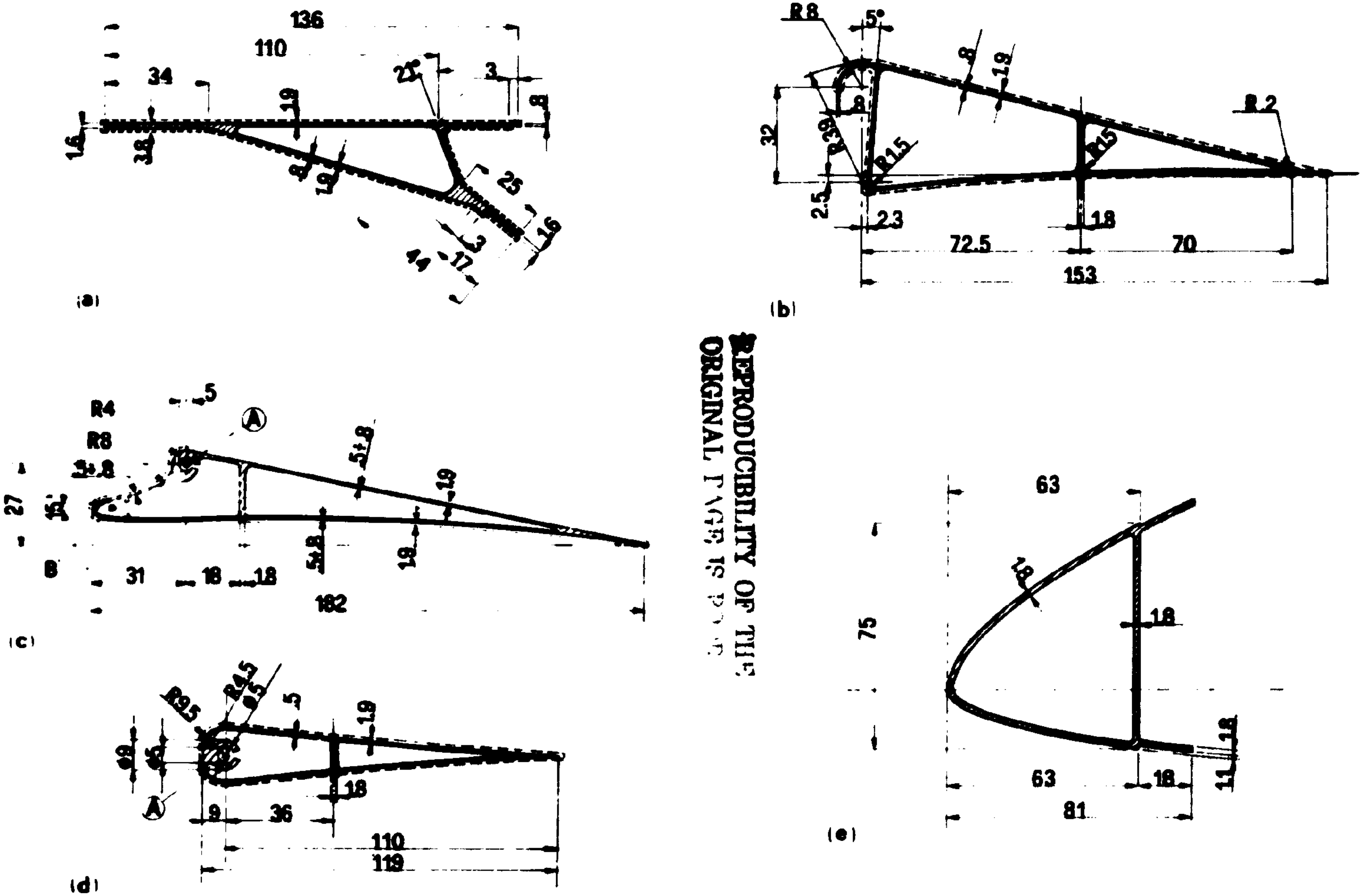

FIG.2 - CALIF A-21S EXTRUDED STRUCTURES

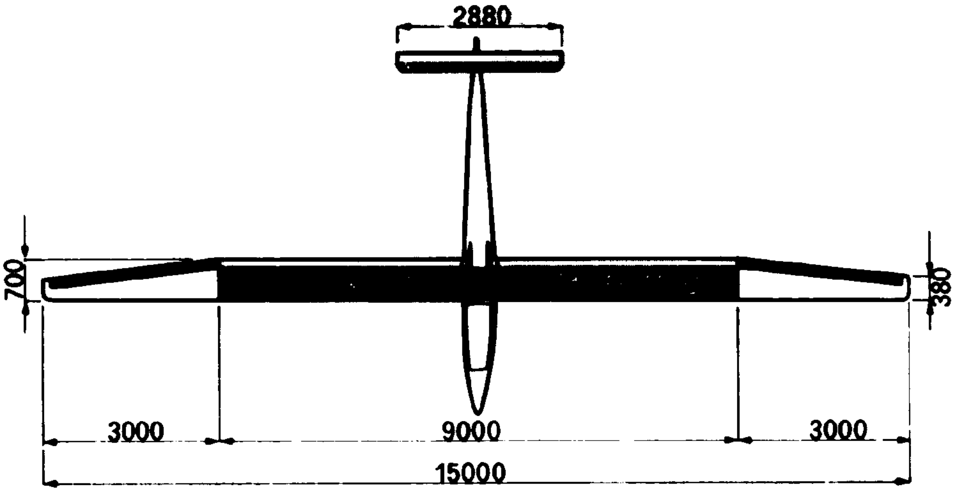

FIG.3 – GLIDER DESIGNED FOR WIDE USE OF EXTRUDED STRUCTURES

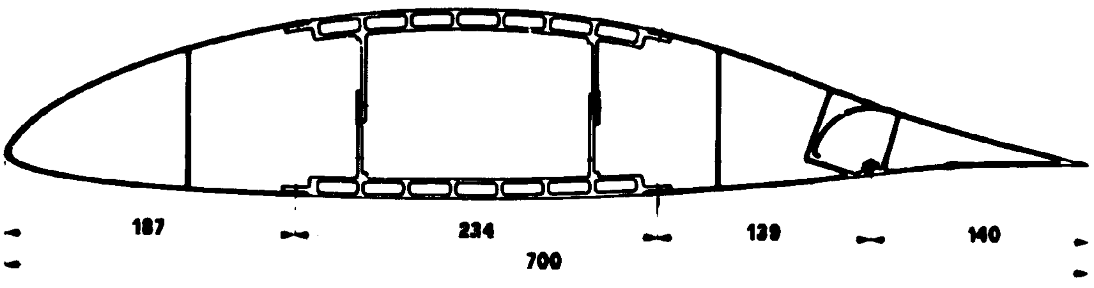

FIG.4 – TYPICAL CROSS SECTION OF AN "EXTRUDED" WING

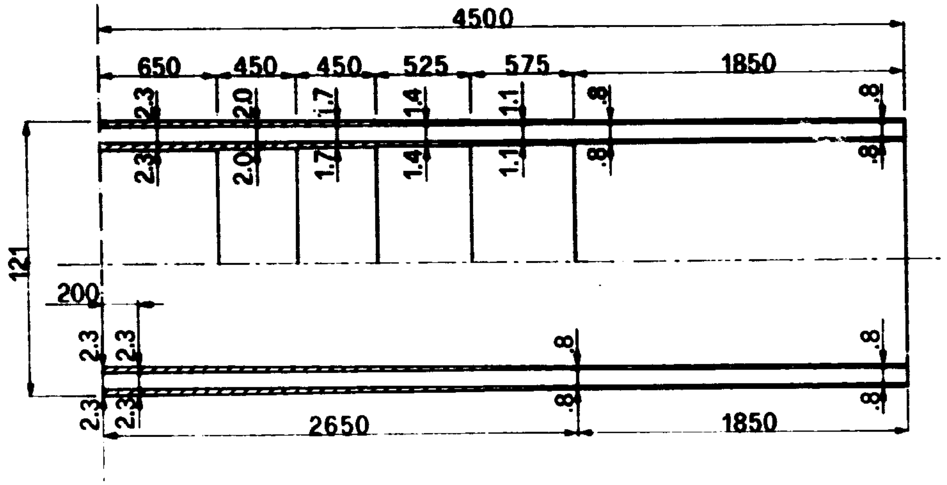

FIG. 5 - SKIN THICKNESS REDUCTION ALONG THE SPAN

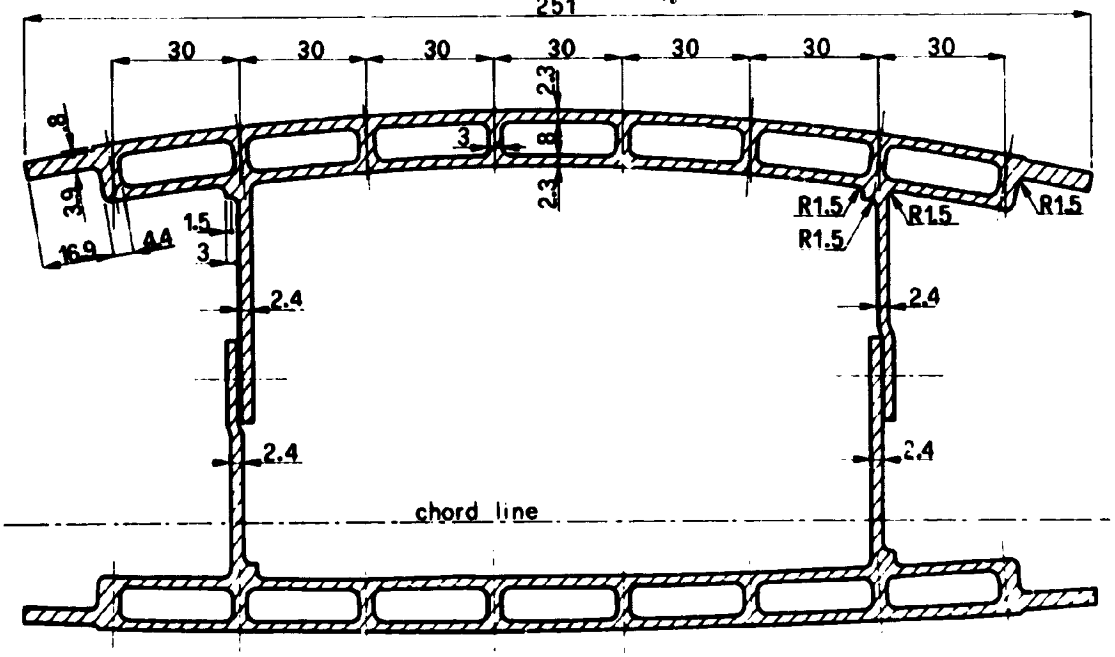

FIG.6 - CENTRAL BOX ROOT SECTION

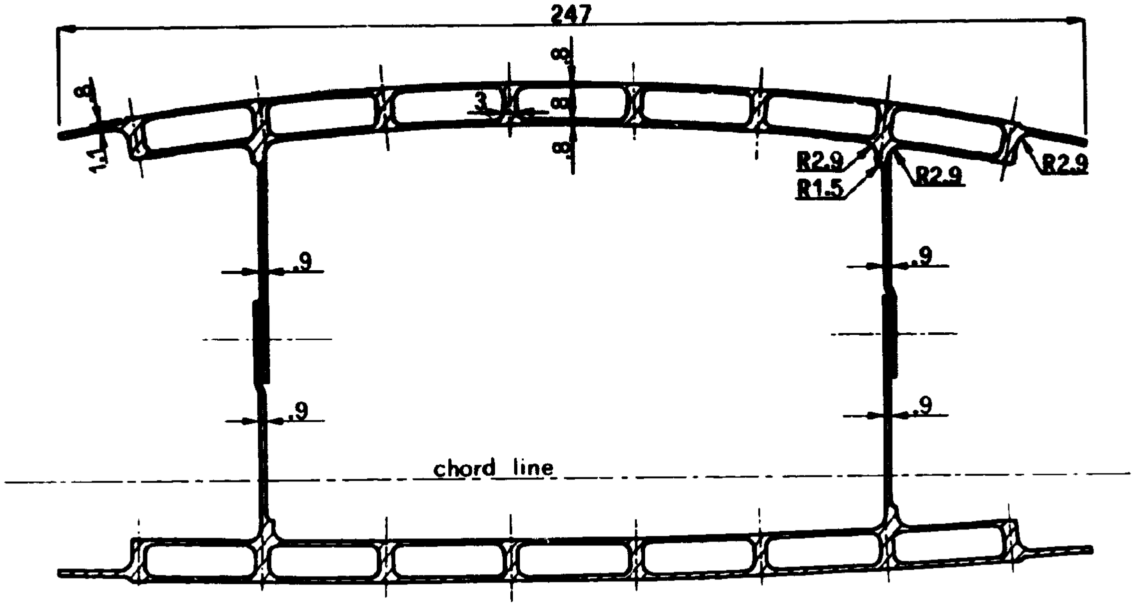

FIG.7 – CENTRAL BOX OUTER SECTION

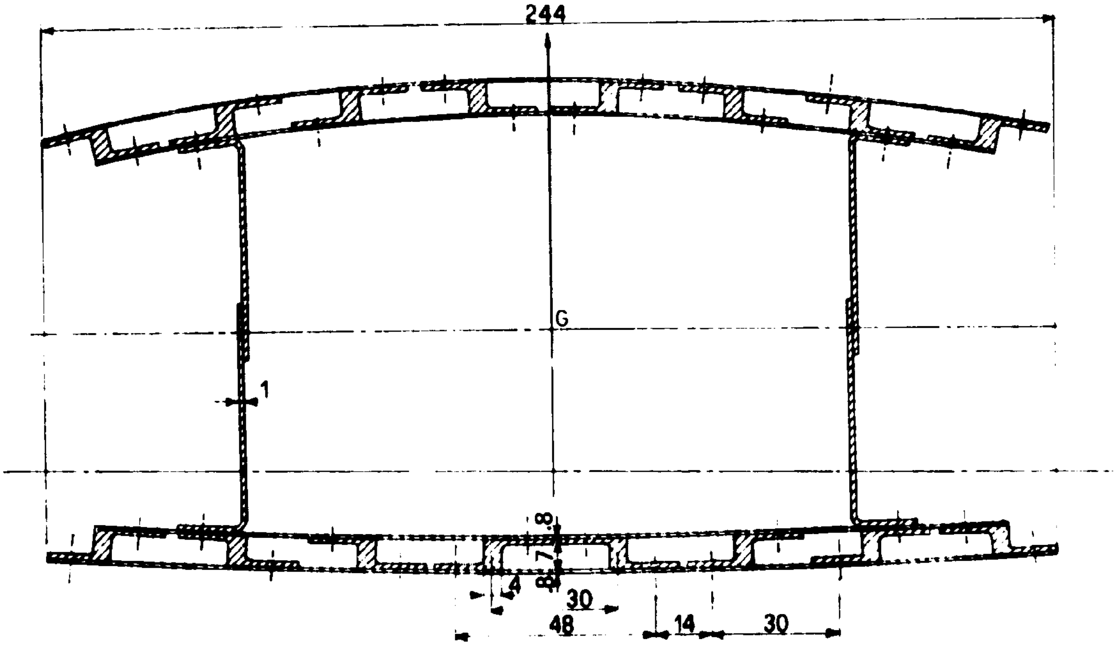

FIG.8 – CROSS SECTION OF "SIMULATED" STUCTURE

FIG.9 - EXTRUDED SPECIMEN TESTED AT BENDING MACHINE

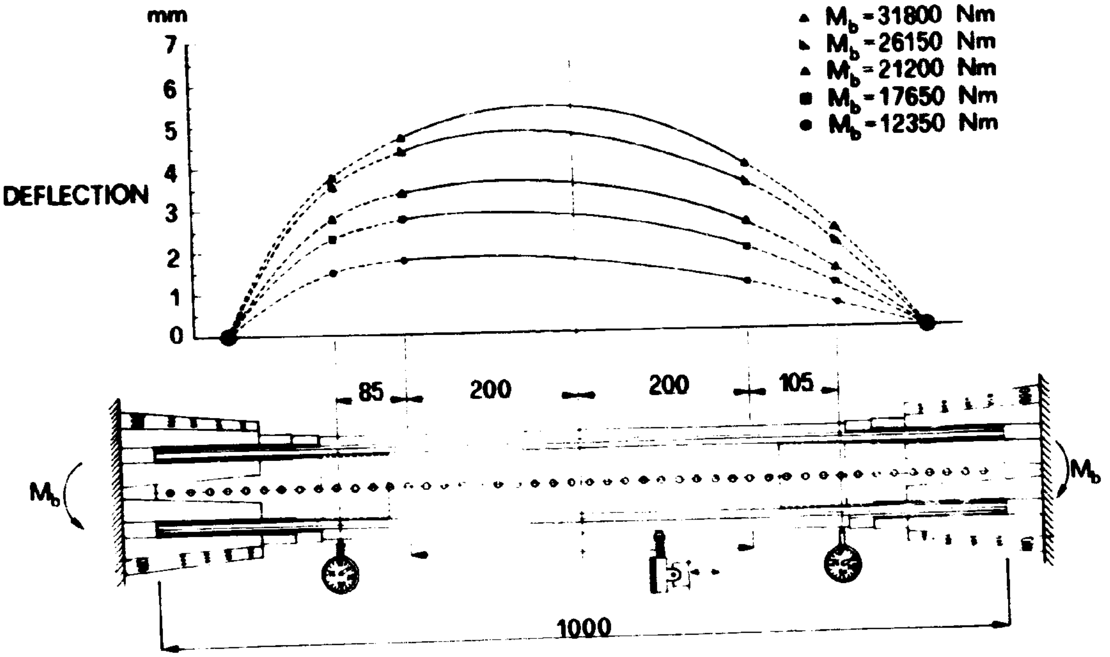

FIG. 10 – DEFLECTION CURVES OF THE EXTRUDED SPECIMEN t=2.3mm UNDER BENDING TEST

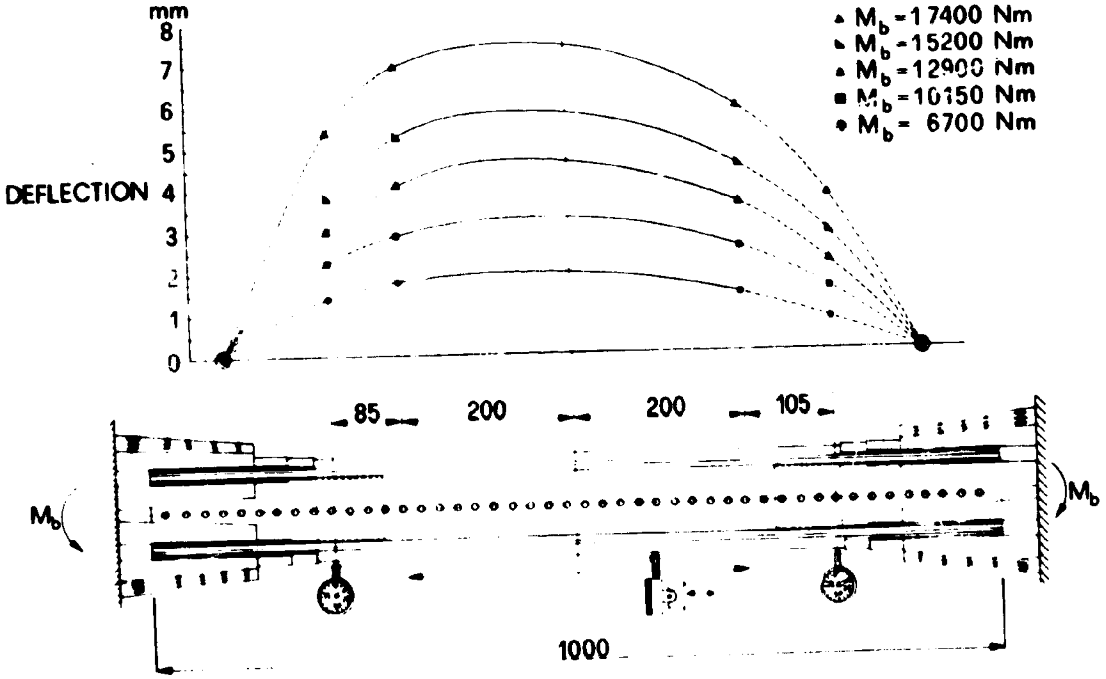

FIG. 11 – DEFLECTION CURVES OF THE EXTRUDED SPECIMEN t=.8mm UNDER BENDING TEST

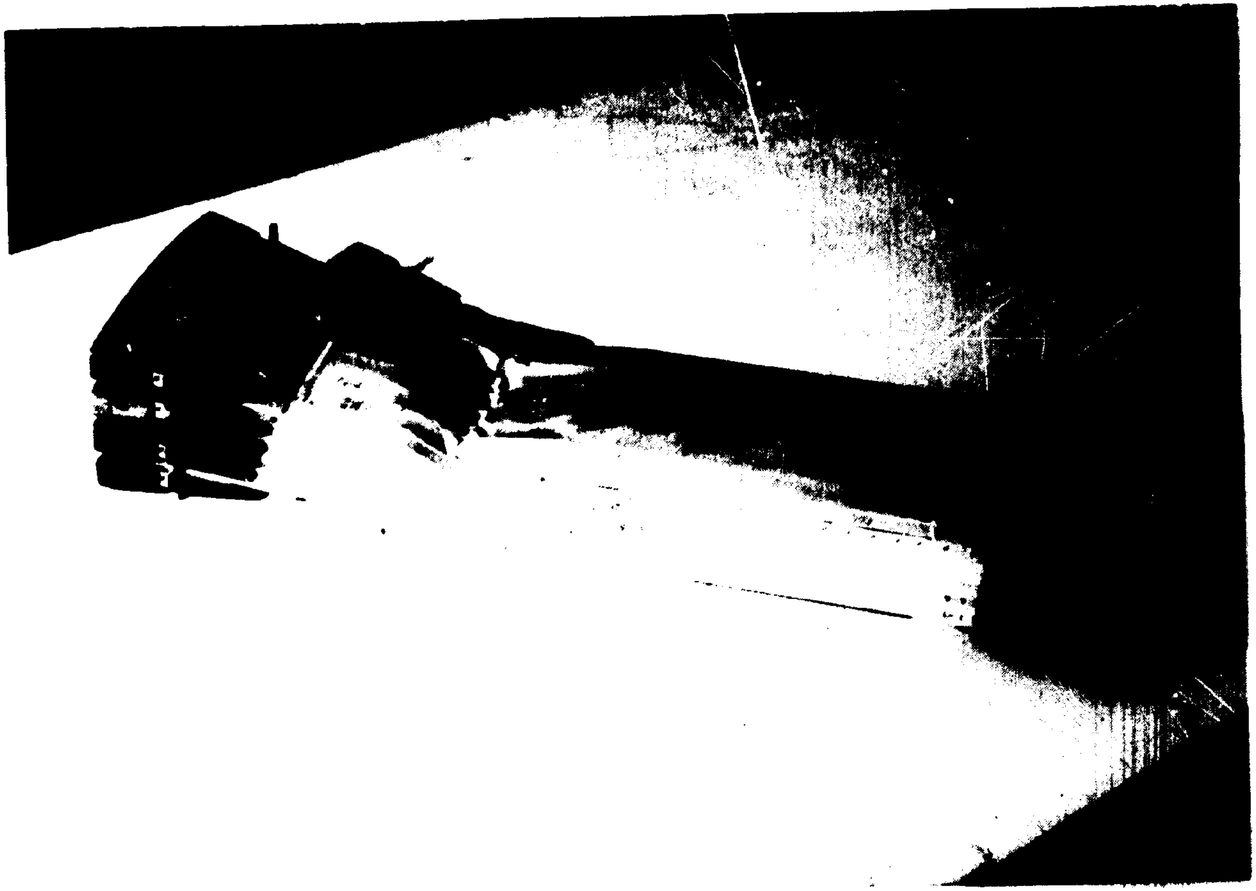

FIG. 12 - BENDING FAILURE OF THE t=.8 EXTRUDED SPECIMEN

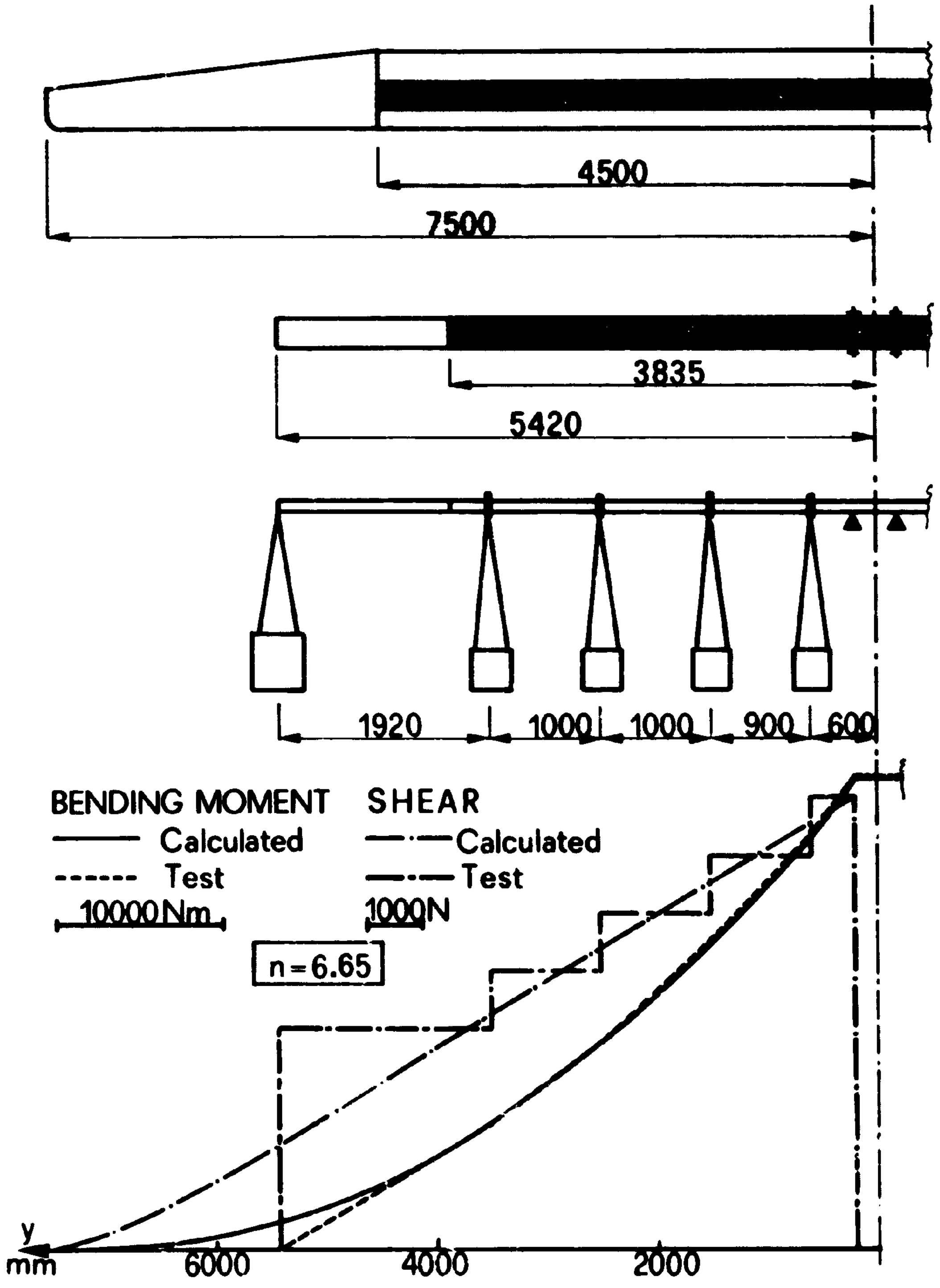

FIG.13 – LOAD DISTRIBUTION ON TEST STRUCTURE

FIG. 14 - STRUCTURE AT LOAD FACTOR n=8

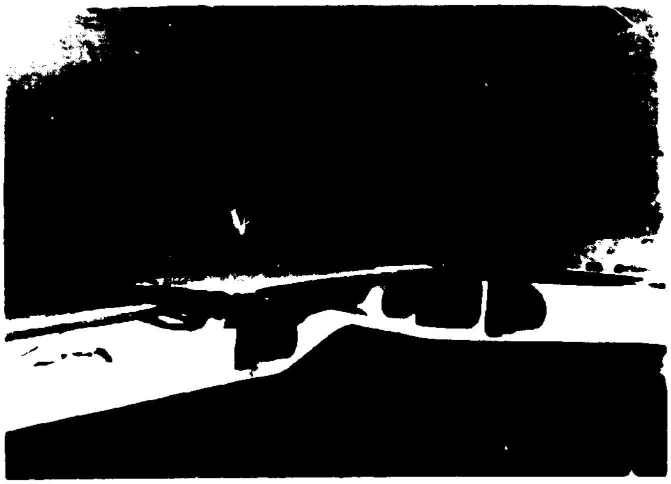

FIG. 15 - STRUCTURE FAILURE

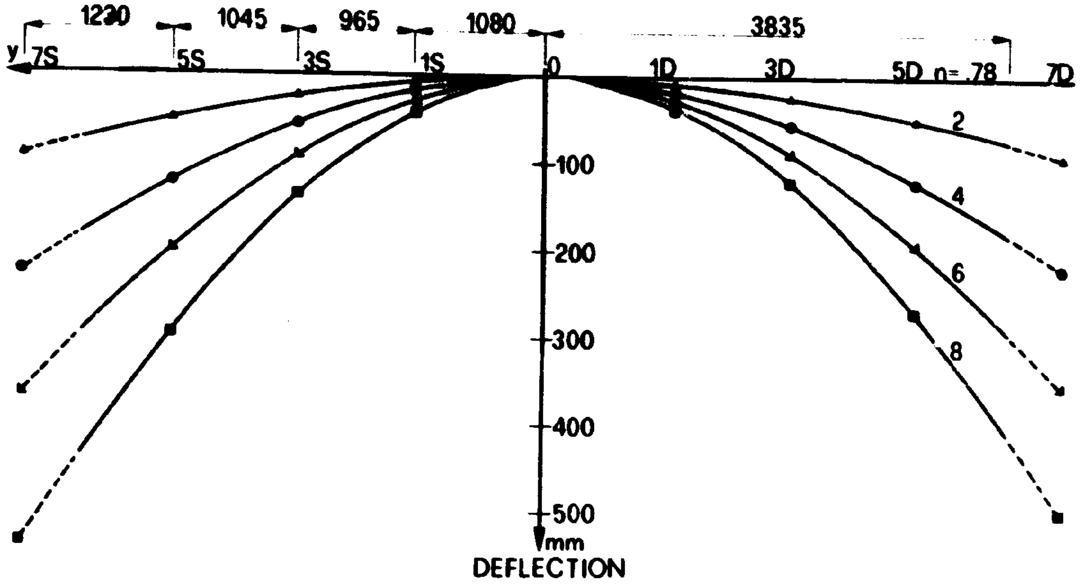

FIG.16 – DEFLECTION CURVES

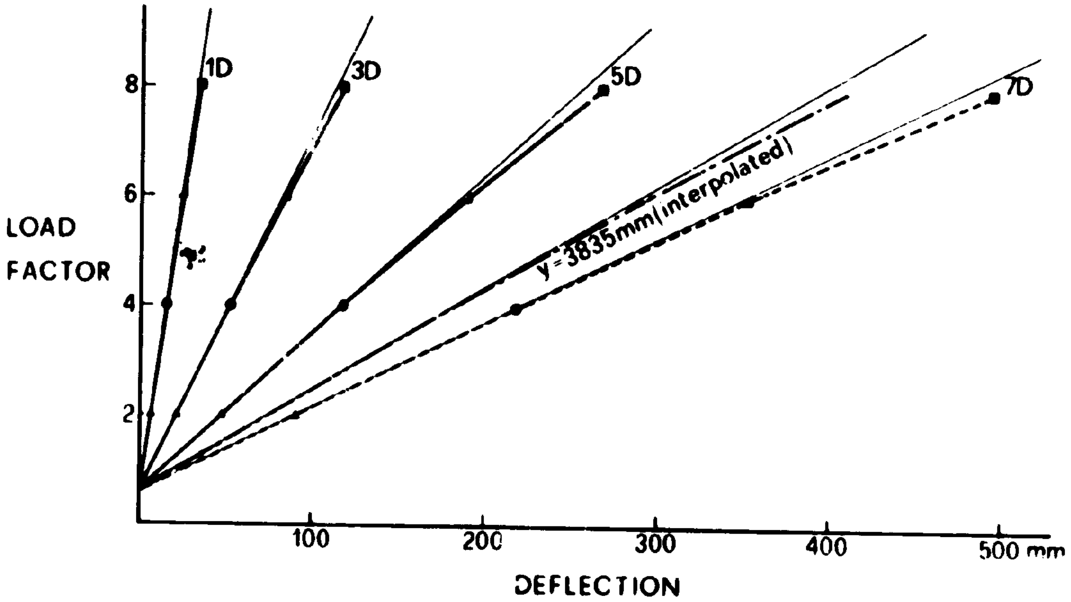

FIG. 17 – DEFLECTION VS. LOAD FACTOR

D8

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TREATMENT OF THE CONTROL MECHANISMS OF LIGHT AIRPLANES IN THE FLUTTER CLEARANCE PROCESS

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SUMMARY

Recently, it has become more and more evident that many difficulties encountered in the course of aircraft flutter analyses can be traced to strong localized nonlinearities in the control mechanisms. To cope with these problems, more reliable mathematical models paying special attention to control system nonlinearities may be established by means of modified ground vibration test procedures in combination with suitably adapted modal synthesis approaches. Three different concepts are presented in detail.

INTRODUCTION

At first glance the flutter clearance of soaring and light airplanes does not seem to raise any serious problems which cannot be solved by means of today's aeroelastic tools. This is true even for the determination of the unsteady aerodynamic loads as long as cases with large aspect ratios at comparably low speeds are considered. The elastodynamical characteristics can be determined by using common experimental or analytical methods if structural linearity can be assumed to be a proper approximation. However, as experience has shown, the control mechanisms of light airplanes[1] are generally nonlinear to such a large extent that setting up a dependable mathematical model requires special attention, including modifications to standard linearized procedures.

In the first part of this paper some of the most frequently occurring types of control-system nonlinearities are described. To get an idea of the influence of some typical nonlinearities on the aeroelastic stability the results of wind tunnel flutter tests on a nonlinear wing aileron model are presented. After that, it is shown in detail how the aeroelastic equations of light airplanes with localized nonlinearities may be formulated by using various suitably modified ground vibration test (GVT) procedures all based on the well-known modal synthesis approach. The shortcomings as well as the usefulness of the different concepts are discussed.

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[1] Light airplanes as sued in this paper include both powered and unpowered vehicles where the power to the flight control system is supplied by the pilot without electrical or hydraulic boost through a system of cables, pulleys, pushrods, bellcranks, or other mechanical linkages.