INNOVATIVE COMPOSITE STRUCTURES FOR SMALL AIRCRAFT

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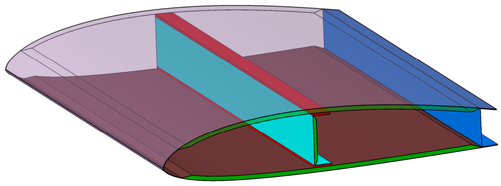
Abstract

This paper presents design, development and experiments with innovative fiber reinforced structures. Two kinds of non-traditional composite structures, geodesic and multi – web structures, are presented and compared to broadly used sandwich structures. These three structures are compared from weight, ultimate strength capacity and manufacturing cost point of view.

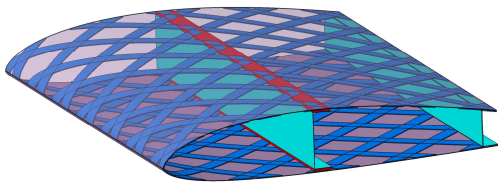
1 Introduction

Fiber reinforced plastic (FRP) structures which are used on smaller aircraft (up to c. 1500 kg of TOW) are more or less based on traditional metal structures. For example wings are designed as one or two spar structures with sandwich skin (Fig. 1a) and less loaded control surfaces are constructed as simple sandwich structures with reinforced leading edge. More detailed research and development of innovative composite structures for these types of aircraft is not so common. Intensive research in this field is carried out only for military and large civil transport aircraft, but technologies developed for these categories are not always suitable for small manufacturers especially due to cost reasons. Therefore the presented work is devoted to new innovative composite structures suitable mainly (but not entirely) for lighter aircraft categories.

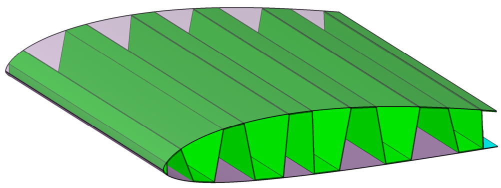
In this stage of research our focus is aimed at compact smaller parts as a wing box or control surfaces. The effort to find some alternatives and innovative structures which can be used instead the standard sandwich structure is presented. Particularly two kinds of non-traditional composite structures are presented and compared with broadly used sandwich structures and they are geodesic and multi – web structures (Fig. 1b, 1c).



a) standard sandwich box



b) geodesic box



c) multi – web box

Fig. 1 Schemas of investigated structures

Some of examined structures were already used in past. Their performances were good but cost of their production, due to different types of used materials, was high (e.g. a geodesic wing of Vickers Wellington). It means that next to superior structures we are also trying to develop cost effective manufacturing technologies.

2 Design and manufacturing of specimens

As demonstrator specimen was chosen a closed box which can represents the control surfaces (such as aileron, elevator, etc.). Set of boxes with same outer geometric parameters (Fig. 2) were made. Each box was closed by two ribs. The standard sandwich box was used as referential specimen.

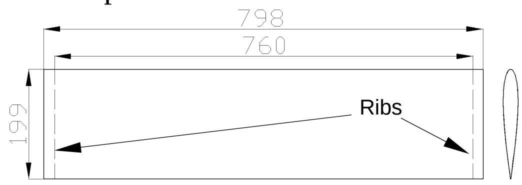
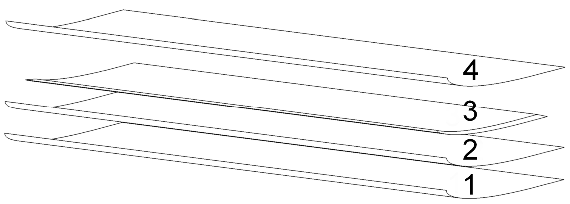


Fig. 2 Geometric characteristics of specimens (mm)

One of the basic intentions was to use as much as possible mold and fixturing designed for manufacturing of standard sandwich box. Manufacturing of special fittings, fixturing and additional molds was reduced to minimum. All three types of specimens were manufactured by hand lay-up with consequence vacuum-bagging in split mold. Layers stacking sequence varied from structure to structure but same matrix system (epoxy resin LF + hardener LF1) was used for all structure types.

2.1 Standard sandwich box

Design of this box is based on real control surface of light sport aircraft. Layer stacking sequence of sandwich structure is displayed in figure 3. The sequence was symmetrical for top and bottom shell.



Layer	Type: SB
1	Glass: Interglas 90070, 81g/m2, plain, 45°
2	Glass: Interglas 92110, 163g/m2, twill, 45°
3	Foam core: Herex C70.55, 750x180x3 mm
4	Glass: Interglas 90070, 81g/m2, plain, 45°

Fig. 3 Sandwich box layers stacking sequence top (bottom) shell

Critical regions of sandwich structure are the secondary adhesive bonding joints at leading and trailing edge (see Fig. 4). Top and bottom shell is joined together (after curing) by two additional layers of glass fabric Interglas 92110 (163g/m^2, 45°) at leading edge and by epoxy resin with short cotton fibers at trailing edge.

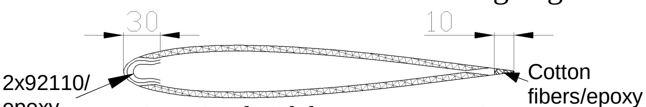
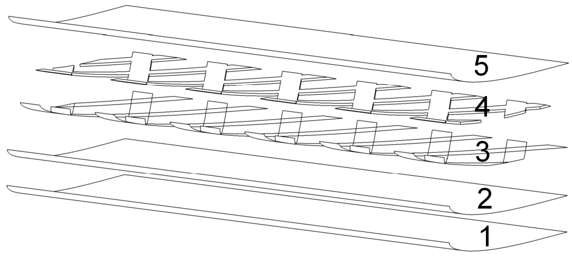


Fig. 4 Sandwich box cross – section

2.2 Geodesic composite box

This type of structure was inspired by Vickers Wellington aircraft. Main goal was to decrease weight of final geodesic structure. Two types of geodesic structures were made (GEO1, GEO2). Layers stacking sequence of both geodesic specimens was based on standard sandwich box and it was also symmetrical for top and bottom shell. Figure 5 describes layers stacking sequence of geodesic structure GEO1.



Layer	Type 1: GEO1
1	Glass: Interglas 90070, 81g/m2, plain, 45°
2	Glass: Interglas 92110, 163g/m2, twill, 45°
3	Carbon tape: KDU – 1002, 25 mm
4	"Geodesic" foam core: Herex C70.55, 3 mm
5	Glass: Interglas 90070, 81g/m2, plain, 45°

Fig. 5 GEO1 layers stacking sequence top (bottom) shell

Main differences between GEO1 box and standard sandwich box are:

a) Skin of the geodesic box is strengthened by carbon tapes.

b) Sandwich core creates (same as carbon tapes) geodesic structure (Fig. 6) and stabilizes skin with carbon tapes.

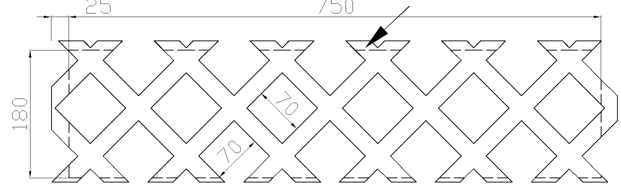
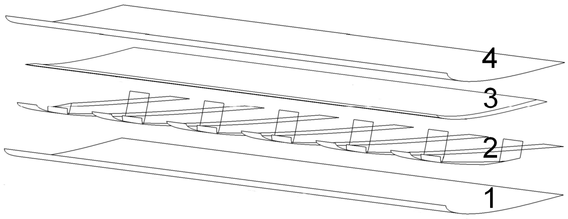


Fig. 6 Parameters of geodesic reinforcement

Leading and trailing edge were made same as with sandwich structure (Fig. 4). Contrary to sandwich box manufacturing time was slightly increased because of lay-up of carbon beams and preparation of geodesic sandwich core.

Whole sandwich core was used and one layer was removed in the second type of geodesic box GEO2 (Fig. 7). Parameters of carbon beam geodesic reinforcement remained same as with box GEO1.

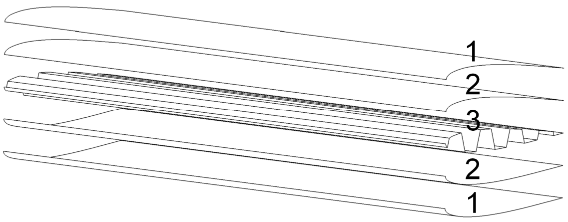


Layer	Type 2: GEO2
1	Glass: Interglas 90070, 81g/m2, plain, 45°
2	Carbon tape: KDU – 1002, 25 mm
3	Foam core: Herex C70.55, 750x180x3 mm
4	Glass: Interglas 90070, 81g/m2, plain, 45°

Fig. 7 GEO2 layers stacking sequence top (bottom) shell

2.3 Multi – Web composite box

The multi – web design is different especially because no foam sandwich core is used compared to previous two structure types. The multi – web box consists of outer skin and a compact multi – web core (Fig. 8). Two different multi – web boxes were made for this type of structure but difference was only in number of carbon layers in multi – web core.



Layer	Type 1: MW1
1	Glass: Interglas 90070, 81g/m2, plain, 45°
2	Glass: Interglas 92110, 163 g/m2, twill, 45°
3	Carbon: 80 g/m2, plain, 45°

Layer	Type 2: MW2
1	Glass: Interglas 90070, 81g/m2, plain, 45°
2	Glass: Interglas 92110, 163 g/m2, twill, 45°
3	2 x Carbon: 80 g/m2, plain, 45°

Fig. 8 Schema of multi – web box

One of the main advantages is that multi – web core connects upper and lower skin and so whole structure creates compact sandwich. Web core substitutes function of additional layers at leading edge and it is joined together with top and bottom shell by epoxy resin with short cotton fibers (Fig. 9).

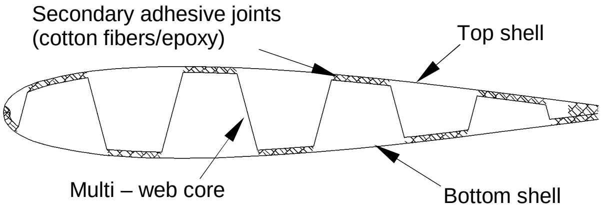


Fig. 9 Multi – web box cross – section

Web core was manufactured in special mold by hand lay-up with consequence vacuum-bagging. Manufacturing, assembling time and material cost of multi – web box itself was comparable to referential sandwich box. Special mold for multi – web core was manufactured by unique low cost approach from basic mold.

3 Experiments

Two main areas were examined: manufacturing technology and mechanical properties of investigated specimens. Manufacturing technology of particular structure type was monitored in order to identify and compare manufacturing cost. Cost of input material and production time of specimen were under consideration. Mechanical properties of specimens were tested by combined bending and torsion loads during three point static test (Fig. 10). Force F (N) and displacement d (mm) were measured during test.

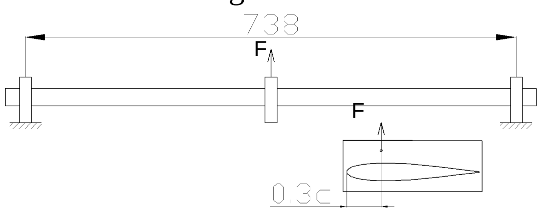


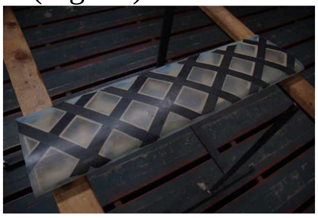
Fig. 10 Specimen static test

The loading of specimens more or less corresponded to real applied loads on control surfaces. Therefore resultant force which acted during specimen tests was placed into 30% of airfoil chord.

4 Results and Evaluations

Five testing boxes were manufactured: SB, GEO1, GEO2, MW1, MW2 (Fig. 11).

a) SB



b) GEO1

c) GEO2

d) MW1

e) MW2

Fig. 11 Testing boxes
a) sandwich box SB
b) geodesic box GEO1
c) geodesic box GEO2
d) multi – web box MW1
e) multi – web box MW2

Consequently all specimens were weighted and tested by three point static test. Force/displacement dependence $F = f(d)$ was measured for all of them (Fig. 12).

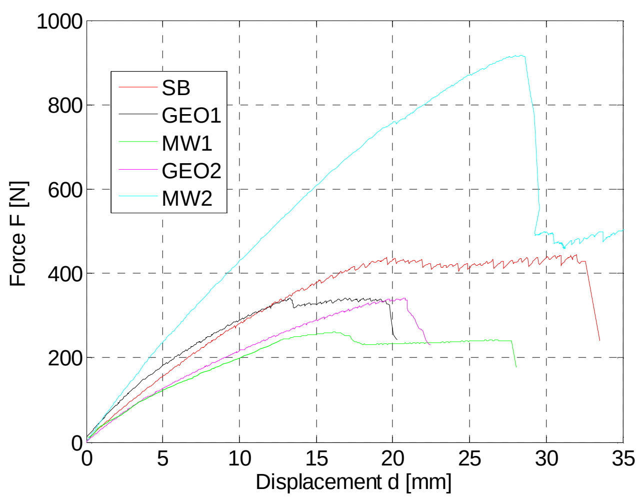


Fig. 12 Force/deformation dependence $F = f(d)$

Examined structures are compared from weight (W, gram), ultimate strength capacity (USC, N), manufacturing time (MT, minutes) and material cost (MC, euro) point of view (Fig. 13). Ultimate strength capacity is maximal force reached during specimen test. Manufacturing time includes only preparation of fabric and sandwich cores, lay – up and impregnation of particular layers and final assembling of box top and bottom shell. Curing process was same for all specimens and it is not counted in manufacturing time. And only material used on particular specimen (incl. fabric, sandwich core, matrix) is considered in material cost.

Structure Type	W (g)	USC (N)	MT (min)	MC (€)
SB	381	437	180	18,6
GEO1	385	342	250	43,4
GEO2	362	341	200	40
MW1	359	261	190	36,3
MW2	379	916	195	56,8

Fig. 13 Structure comparison

Relative results are presented in column diagram (Fig. 14). All investigated parameters of examined structures are compared with relative values of referential sandwich box. Specific ultimate strength (compared in Fig. 14) is a ratio of ultimate strength capacity and weight of specimen.

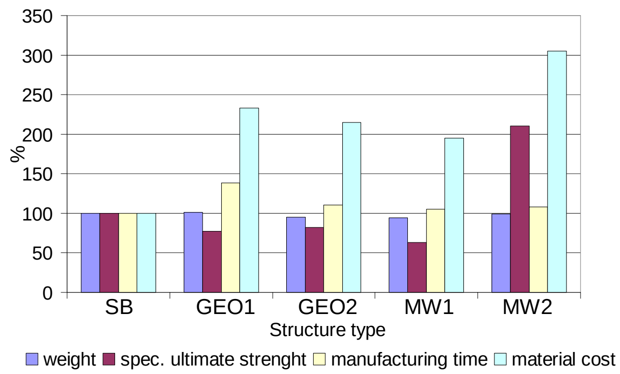


Fig. 14 Structure comparison

Weight of all specimens was more or less same but there are some reserves especially for geodesic structure GEO1 and both multi – web structures MW1 and MW2. Weight growth of these structures was caused by usage of greater amount of cotton/epoxy adhesive during specimen assembling due to manufacturing inaccuracies.

Premature deformation of leading edge was main cause of small strength capacity of both geodesic specimens. The deformation was caused as consequence of small leading edge stiffness. Cut outs around the geodesic sandwich core in geodesic box GEO1 decreased the stiffness of leading edge and these cut outs also caused increasing of weight in area of trailing edge (it had to be used a bit greater amount of cotton/epoxy adhesive in trailing edge). The geodesic box GEO2 suffered by small stiffness of leading edge because of insufficient number of layers in this area. One carbon layer in multi – web core of box MW1 was not sufficient for stabilizing skin and leading edge which was also premature deformed during static test. Details of specimen damages are shown in figure 15.

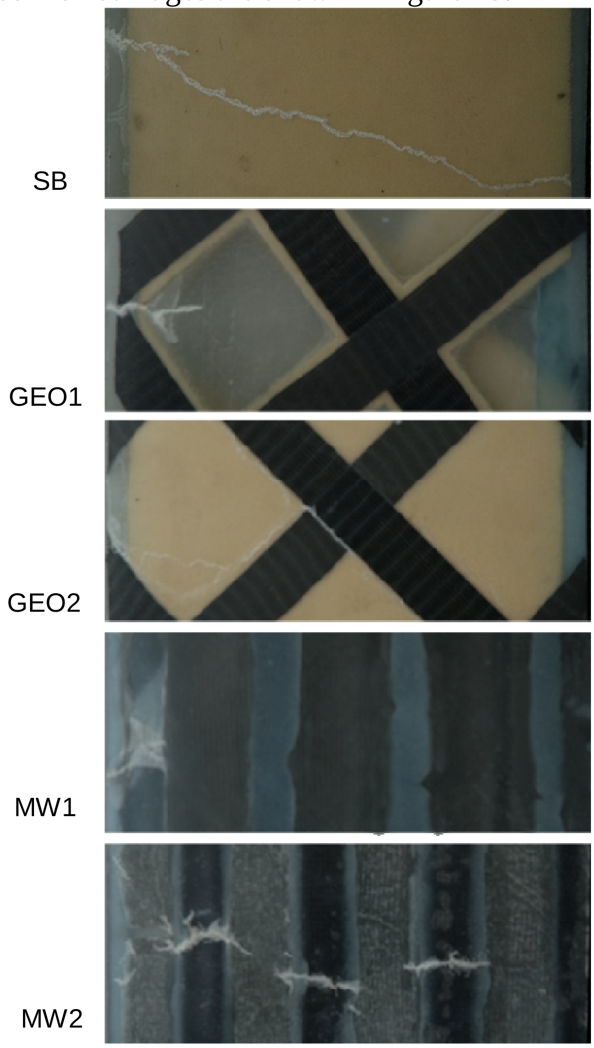


Fig. 15 Details of specimen damages

The finite elements method analyses in MSC. Patran/Natsran and MSC. Patran/Dytran software packages of examined structures are in progress. Series of simulations, with different available modeling approaches, will be carried out. Adhesive bonding and fabric overlap joints influence will be considered. Model and the first results using quad elements with linear elastic orthotropic material properties are presented in figures 16 and 17. Rigid elements are used as the anchors.

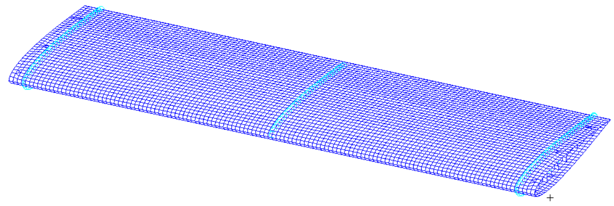


Fig. 16 MW2 model

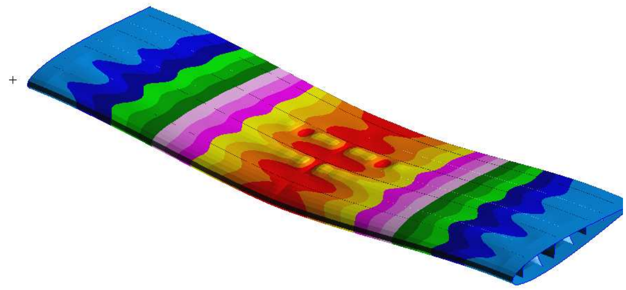


Fig. 17 The skin buckling of the MW2 box

5 Conclusions

The sandwich box SB and multi – web box MW2 were the best designs from complex point of view. Sandwich structure was the best from manufacturing time and material cost point of view. Multi – web box MW2 has significantly higher specific ultimate strength than other specimens, manufacturing time was same as with sandwich box SB but in the other hand MW2 material cost was three time higher than SB material cost.

Both examined innovative designs had some reserves in manufacturing. In the case these shortcomings will be eliminated, geodesic and multi – web structures have potential to replace sandwich structure especially in the area of higher stiffness and small weight requirements.

Partial results of research in the area of innovative composite designs and structures are presented in the paper. In next few steps, after technology improvement, the investigated innovative designs will be examined from statistical point of view and possibility of preliminary design by finite elements methods of particular aircraft part subjected to particular loads will be verified.

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