ANISOGRID COMPOSITE LATTICE STRUCTURES
FOR SPACECRAFT AND AIRCRAFT APPLICATIONS

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INTRODUCTION

Modern carbon-epoxy composites whose high specific strength and stiffness are utilized in spacecraft and rocket structures to a sufficiently high extent are now on the way to be widely used in primary airframe structures of commercial airplanes. Existing experience shows that direct substitution of carbon-epoxy composites for traditional ring-stringer stiffened aluminum airframe structures results usually in 15-20% weight reduction accompanied by approximately the same level of cost increase. Taking into account that modern unidirectional carbon composites, being loaded along the fibers, are characterized with specific strength and stiffness which are at least by the factor of 3 higher than the corresponding characteristics of aluminum alloys, one can conclude that the available weight saving is much lower than can be expected. The reason for this situation is associated with specific structural and manufacturing features of traditional airframe stiffened structures which, being made of carbon composites, are sometimes referred to as Black Aluminum (BA) structures. First, the structure of the skin and the stiffeners of BA structures is not unidirectional – the skin and the ribs usually consist of unidirectional or fabric layers with different orientation angles and have efficient mechanical characteristics which are close to those of aluminum alloys. Second, the weight saving that can be expected for such structures due to lower density of composite material in comparison with aluminum is usually not reached because of relatively low level of allowable strain which is reduced in design of composite structures because of low toughness of unidirectional composites experiencing tension across the fibers and interlaminar shear. And third, even though BA structures require usually much less assembling operations than aluminum prototypes, they cannot be made as completely integral structures, and cost savings gained in assembling do not compensate high cost of carbon-epoxy prepregs which are about 25 times more expensive than aluminum alloys. Thus, it can be concluded that BA airframe structures of commercial airplanes provide rather limited possibility for weight saving, whereas their cost efficiency has yet to be demonstrated. The only real advantage of BA structures is associated with their feasibility – they can be designed and built by methods close to those developed for aluminum airplanes. Further reduction of weight accompanied by cost saving can be reached in composite structures satisfying the following conditions:
- principal load-bearing structural elements should have the unidirectional microstructure of composite materials,
- fabrication procedure should involve completely automated processes and provide completely integral structures.

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Aircraft structures whose load-bearing capacity is controlled mainly by the ribs are known for about 80 years and are referred to as Geodesic structures. In this structures, bending moments
as well as torques and transverse forces are taken by a system of helical ribs, whereas the skin transfers the aerodynamic and internal pressure to the ribs and provides the proper external

surface of the structure. In application to composite structures, Geodesic lattice structures developed about 25 years ago [1] and consisting of a system of unidirectional carbon-epoxy ribs supporting an external skin demonstrate high weight efficiency and are widely used as spacecraft and rocket structures. In conjunction with continuous filament winding, which is the less expensive of the existing processes used to fabricate thin-walled composite structures, Anisogrid lattice structures discussed in the paper satisfy both foregoing requirements. In contrast to known Isogrid structures, Anisogrids provide more possibilities for weight savings because the helical rib angle (which is fixed in Isogrids) and the ratio of helical and circumferential rib thicknesses (which is unity for Isogrids) is determined in the process of design which is performed analytically by minimization of safety factors corresponding to possible failure modes – fracture of ribs, local buckling of ribs and general buckling of the structure.

The paper presents design, manufacturing, testing, as well as weight and cost analysis, of existing composite lattice structures used as spacecraft launcher interstages, payload attach fittings and elements of space truss structures. For cylindrical shells loaded with axial compression, weight efficiency of Anisogrid lattice structures is compared with that of aluminum and composite Isogrid structures, aluminum and composite stringer structures, composite sandwich structures. Special attention is given to possible application of anisogrid lattice structures as primary elements of airframe structures, particularly, in application to fuselage sections (Fig. 1) and wing shear webs.

Fig. 1: Anisogrid lattice fuselage panel

REFERENCES