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DEVELOPMENT OF LIGHTWEIGHT HYBRID AIRFRAMES BASED ON UNIDIRECTIONAL COMPOSITE STRUCTURE CONCEPTS

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1. Introduction

Composite civil aircraft structures based on conventional semi-monocoque load-bearing elements have a number of fundamental strength problems, which make it impossible to provide real weight decrease for the structure for current level of strength characteristics of composite materials, first of all, resins.

To increase weight efficiency of primary composite structures there is a need to search alternative structure elements and structure layouts based on these elements, which make it possible to realize high specific strength properties of carbon fiber to a greater extent and to minimize the influence of low strength of resin.

The search of such structures, named “pro-composite” was carried out within a number of researches both in Russia and abroad [1][2][3][4]. The researches have shown the lattice layouts make it possible to increase significantly effectiveness of composite airframes, but their effective application can be provided only for some sections of an airframe, due to a number of technological constraints. At the same time, for wing and fuselage sections with large cut-outs and also high-loaded joints application of conventional metallic layouts is more reasonable.

For this reason in the medium-term perspective (5-7 years) it is rational to develop and create hybrid aircraft structures, including the following types of sections/aggregates:

- metallic aggregates with conventional layouts;
- composite aggregates with conventional layouts;
- composite aggregates with lattice pro-composite layout.

In the present work the methodology of weight effectiveness estimation for hybrid structures is described and results of weight effectiveness analysis are shown for:

- cylindrical fuselage of long haul aircraft;
- oval fuselage of middle range aircraft;
- cabin of Flying wing aircraft;
- fuselage of small-dimension supersonic passenger aircraft with limited Mach number.

2. New generation of hybrid structures

The background for researches of hybrid structures for passenger aircrafts was based on the results of adaptation of lattice composite designs, well-proven for civil space modules. Investigations were carries out in frames of international projects FP7 ALaSCA, FP7 PoLaRBEAR, and also some Russian projects on the same topic. It was shown that hybrid structures based on conventional metallic alloys and unidirectional composite lattice structures have a number of advantages as compared to both conventional metallic structures and composite structures of "black metal" type, and also to hybrid structures based on conventional metallic and composite layouts [4].

One of the main results of the investigations is dependencies of allowable strains in primary aircraft structures based on laminated composite packages on values of different structure parameters.

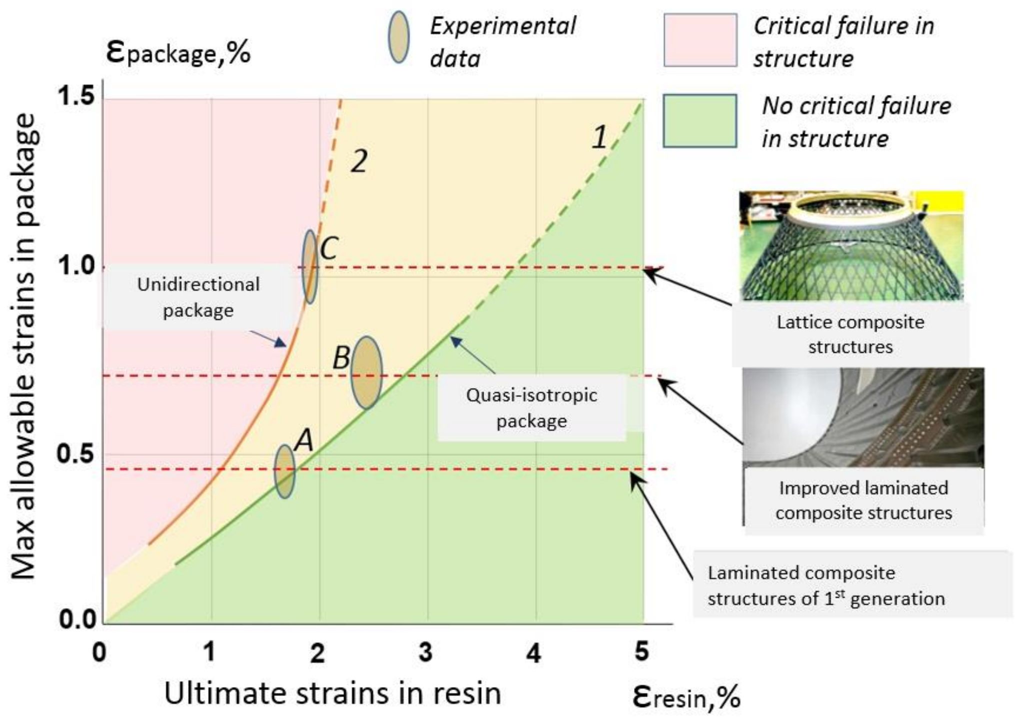

Figure 1 – Correlation between ultimate strains of resins and allowable strains in composite packages

Fig. 1 demonstrates one of such dependencies, illustrating connection between values of allowable strains in composite packages and values of ultimate strains of resins at tension. Two curves presented on the Figure were derived as a result of numerical strength analysis of a composite package, taking into account degradation of properties of the package on microlevel:

- curve 1 corresponds to quasi-isotropic package with layers 0, 90°,±45°,
- curve 2 corresponds to unidirectional package with 95% monolayers directed to 0°.

Experimental data shown of Figure correspond to three groups of specimens: A – quasi-isotropic specimens based on epoxy resin of the first generation; B – specimens with stacking 0^0/65%, $\pm45^0$/25%, 90^0/10% based on current resin close to Hexcel 8552; C – unidirectional specimens based on the same resin. The same correlation was obtained also for compression. From the Figure it becomes obvious that unidirectional composite structures have higher levels of allowable strains.

But the investigations have shown that weight effectiveness of lattice layout considerably decrease for structures with high level of impact loads [5] and also for structures having zones with high load concentrations. For such structures metallic layouts are more rational.

It becomes obvious that search of rational structures in terms of weight should be performed in frames of hybrid schemes with various layouts. For such structures TsAGI has developed concepts of joints, which have been successfully validated. Fig.2 shows a principal scheme of a joint, having high strength and weigth effectiveness.

Figure 2 – Principle scheme of a joint

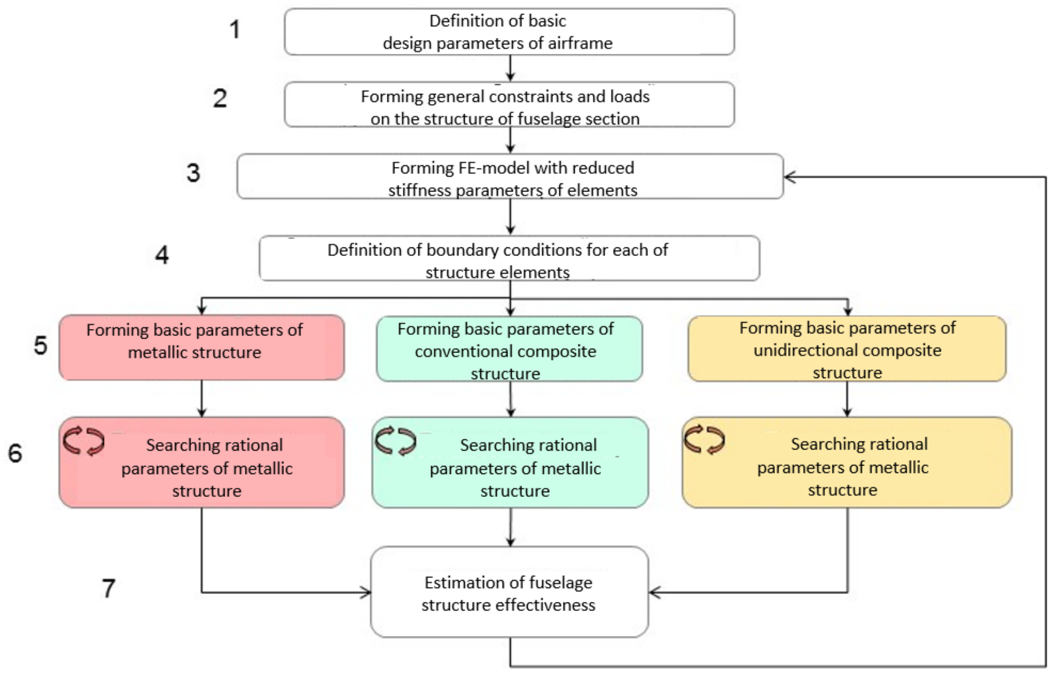

Figure 3 – Block-scheme of design investigations

For strength analysis and design investigations of hybrid structures the multilevel approach to solution of complex multidisciplinary tasks was applied. [6]. Fig 3 illustrated block-scheme of searching rational parameters for the proposed hybrid structure. Within this approach the results of investigations aiming to decrease labor of strength analysis of lattice structures and search for rational modeling method for lattice composite structures, obtained in [7], were used, and also the procedure of harmonization of stiffness parameters of semi-monocoque and lattice structures, proposed in [8].

3. Hybrid structure of cylindrical fuselage of long haul aircraft

For estimation of weight efficiency of hybrid fuselage structure a hypothetic aircraft 1 was considered, having conventional concept with take-off weight about 70 t, fuselage diameter about 4 m, passenger capacity about 150 persons and range about 4000 km. In the considered variant of hybrid fuselage, it consisted of 6 sections with different structure layouts (see Fig 4):

- sections 1,3,6 – conventional metallic layout,
- sections 2,4 – lattice composite layout,
- отсек 5 – composite layout of “black metal” type.

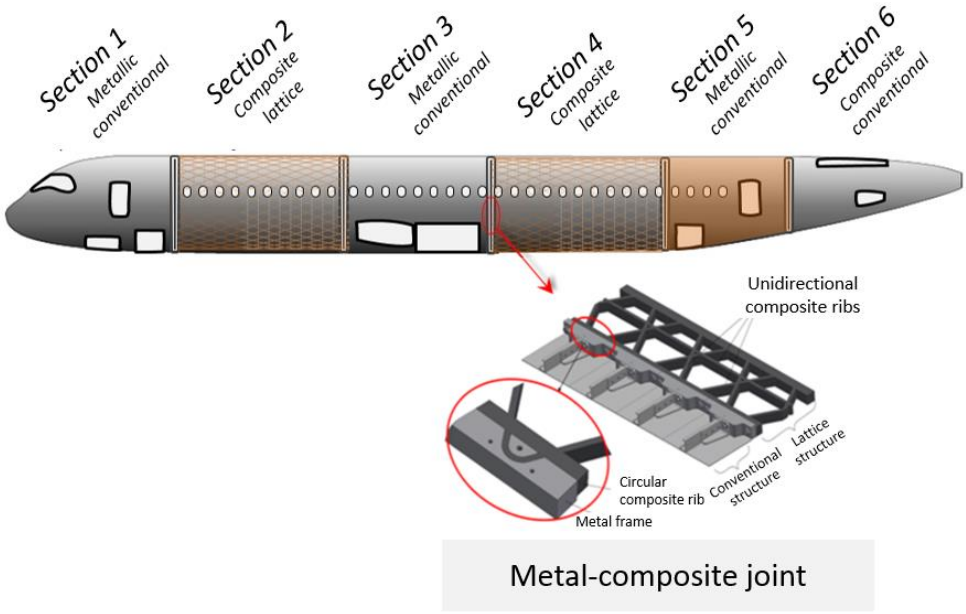

Figure 4 – Fuselage of a hypothetic aircraft 1

Effectiveness of the lattice structure was demonstrated on fuselage section 4.

Table 1 presents weight parameters of load-bearing structure of the fuselage section, obtained as a result of rational parameters' definition for three variants of the section layout: conventional layout for metallic and composite (black metal) variants, and also for the lattice composite structure.

Table 1 Relative weight of fuselage section structure (section 4)

Variants of the structure	%
Metallic	100.0
Composite "black metal"	95.8
Composite lattice	88.7

Comparison of weight parameters of hybrid fuselage structure with the weight of an alternative variant of structure, made entirely metallic, have shown weight saving 4.7 % for rational hybrid fuselage structure. Also, it was shown that fuselage structure made using design of "black metal" type has no advantages in weight efficiency as compared to metallic.

4. Hybrid fuselage structure for aircrafts with integral concepts

In this chapter the results of investigation of effectiveness are presented for hybrid fuselage structures of aircraft with integral concepts:

- pressurized fuselage of "oval fuselage" aircraft concept (low structure integrity);
- pressurized cabin of "Flying wing" aircraft concept (high structure integrity).

Both concepts have differences from conventional airframe, having a fuselage with circular cross-section. For such structures an additional critical factor occurs – local bending in fuselage (or cabin) cross-section, leading to appearance of significant stress concentrators in the structure. In frames of "metallic" layouts it is difficult to find suitable solutions in terms of weight for such concepts of large dimension aircrafts. But in frames of hybrid layouts of the new generation such solutions exist.

For estimations of weight efficiency of hybrid structure of an oval fuselage the comparative weight analysis of alternative fuselage structures was performed on a hypothetic aircraft 2 (see Fig. 5) with take-off weight 90 t, passenger capacity 240 persons and range 6000-7000 km.

Main characteristics of the hypothetic aircraft 2 are listed in Table 2.

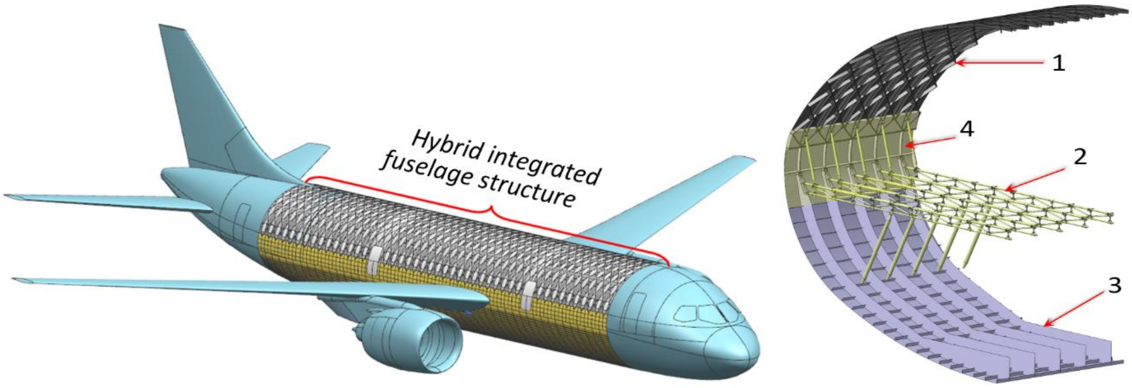

Figure 5 – Structure layout of a fuselage with oval cross-section

Table 2 – Main characteristics of a hypothetic aircraft with oval fuselage

Parameter	Value
Range with max load, km	6000 - 7000
Maximal take-off weight (MTOW), kg	90000
Maximal number of passengers, per	240

Fig 6 shows cross-sections of a hybrid, partly integrated fuselage structure and alternative conventional metallic structure. In this work the parts of the fuselage, limited by first and last row of passenger seats were considered. Cabin length for hybrid fuselage was 23 m for seating 240 passengers in 30 row, 8 persons each row, and the length of cabin for metallic fuselage – 30 m for seating 240 passengers in 40 row, 6 persons each row. Seat pitch was taken 0.71 м and ≈1.5 was added to fuselage length for placement of toilets.

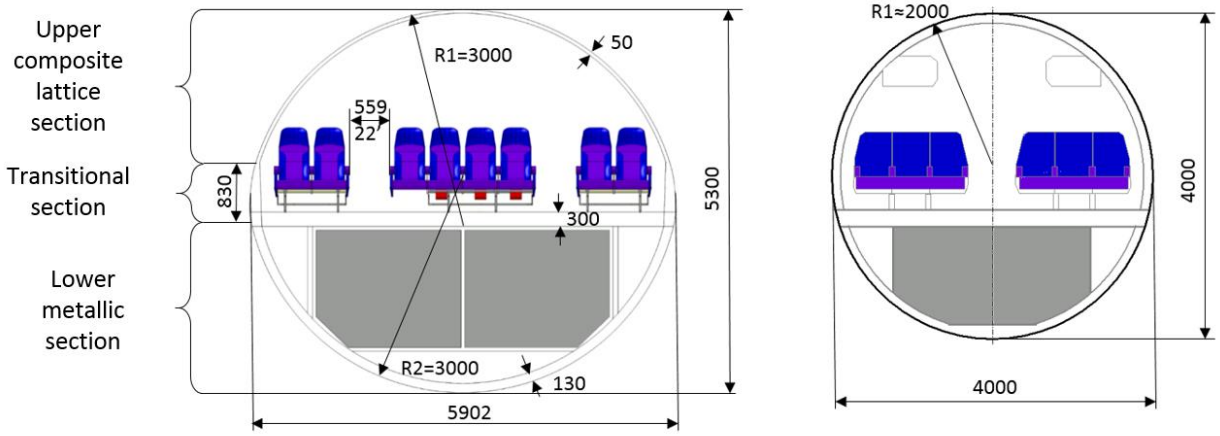

Figure 6 – Parameters of alternative fuselage structures

Fig 6 presents parameters of the fuselage structure in two alternative variants. It is worth to note, that non-cylindrical fuselage length is significantly lower than the one for cylindrical fuselage having equivalent passenger capacity, that leads to decrease of vertical bending moment.

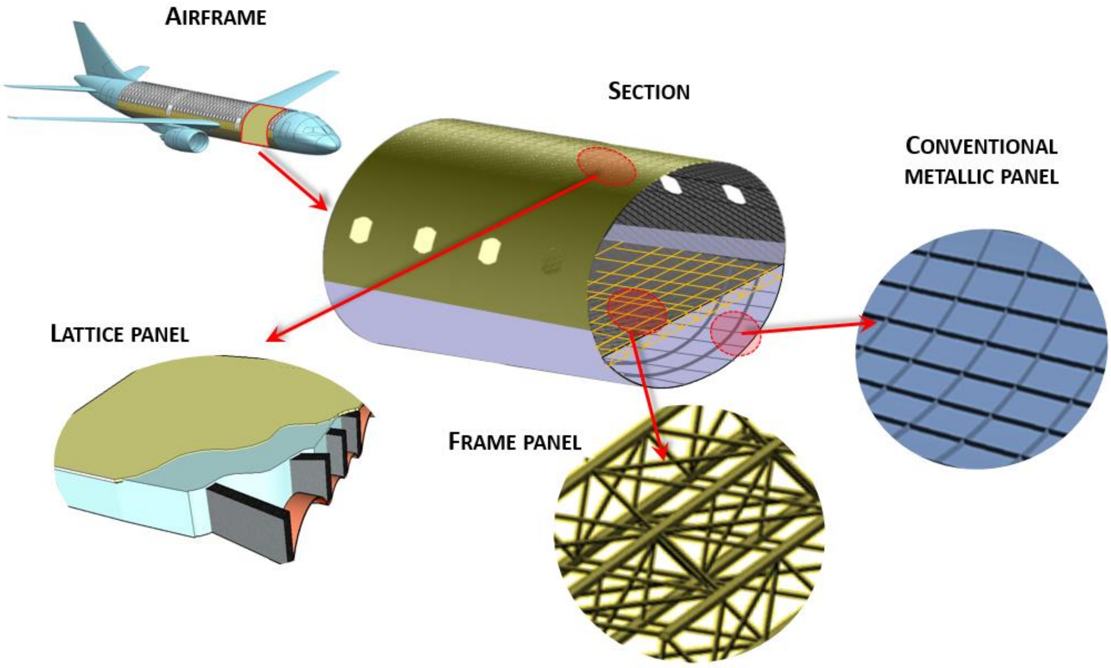

Figure 7 – Main elements of hybrid structure

One important feature of the hybrid fuselage structure is that upper fuselage panels are excluded from high-loaded elements of the structure (Figure 7). The role of the upper panel as a primary structure element is bearing loads from internal pressure, local aerodynamic loads and party the loads from torsion moment. Rational structure concept for the upper panel is lattice layout with regular lattice, consisting of stiff grid and a set of elastic skins for forming aerodynamic surface and providing cabin pressurizing. Low load level in combination with multipath topology of lattice structure makes it possible to provide high reliability and low weight for such structure.

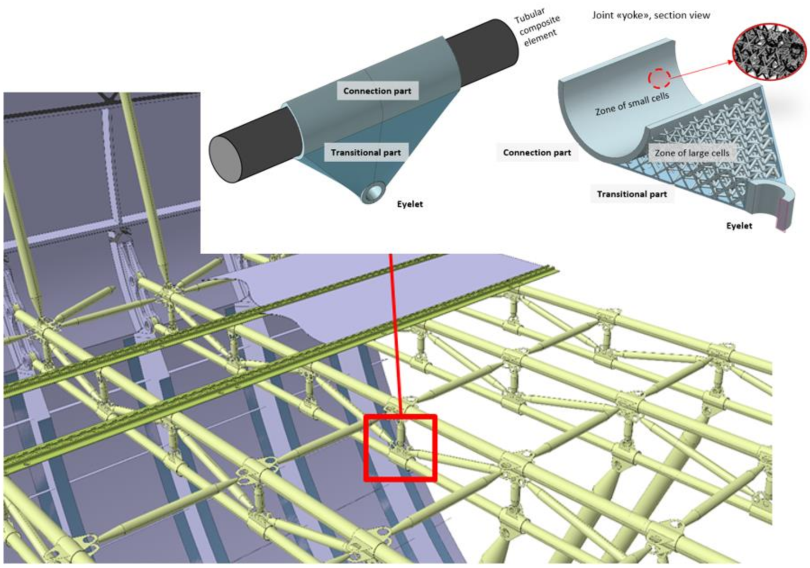

Figure 8 – Transitional section with side metallic panel and frame floor

The most complex and innovative part of the hybrid fuselage is the transitional section, consisting of frame floor structure, integrated with the structure of joining side panels (Fig.8) [11]. The side metallic panel consists of stiffened curved list with variable curvature, having eyelets for joining struts and main elements of the frame.

As for the frame (see Figure 8), it plays the role of the main load-bearing element, which, together with the panels of the lower section, is involved in bearing bending and torsion. At the same time, the frame is the load-bearing element of the passenger floor.

A conventional metallic reinforced panel of an existing wide-body aircraft, including structural elements of the cargo floor, can serve as a rational layout of the lower section. The bottom panel is joined to the side panel using riveted joints and additional joints along the skin and frames, as well as to the load-bearing floor using a system of rod elements. In general, this layout represents a conventional layout, similar to the layout of the panels of the lower nose and aft compartments of wide-body aircraft.

It should be noted that it is proposed to use special metal-composite joints as additional joints of the frame and side panels, in which the metallic part is formed from a porous structure (metal-based metamaterial), which makes it possible to harmonize the stiffness characteristics in the contact zone for joining metallic and composite parts (Fig. 8).

Numerical studies have shown that the hybrid design of an oval fuselage has the potential to reduce weight by up to 15% compared to the weight of a cylindrical fuselage of a traditional layout with an equal passenger capacity (Table 3).

Table 3 - Weight characteristics of the hybrid fuselage structure

Section	**Relative weight,%**
Upper Section - Lattice Composite Structure	18-20%*
Lower Section - Conventional metallic Structure	52-54%*
Transition Section - Frame structure	15-17%*
Total:	85-91%*

*100 % - weight of fuselage with conventional layout

As for the aircraft in the "Flying wing" scheme, for it the analysis of the efficiency of the hybrid layout was carried out for the most loaded part of the structure - the structure of the pressurized cabin of the central part of the airframe (Fig. 9 a)

For the upper and lower panels of the pressurized cabin, hybrid structures were proposed, formed on the basis of a two-layer panel, which includes a load-bearing frame made of unidirectional rod axisymmetric elements (similar to the transition compartment of an oval fuselage) and a system of flexible skins that play the role of protecting the frame from impact and climatic influences, as well as providing stiffness, heat and sound insulation (see fig. 9 b).

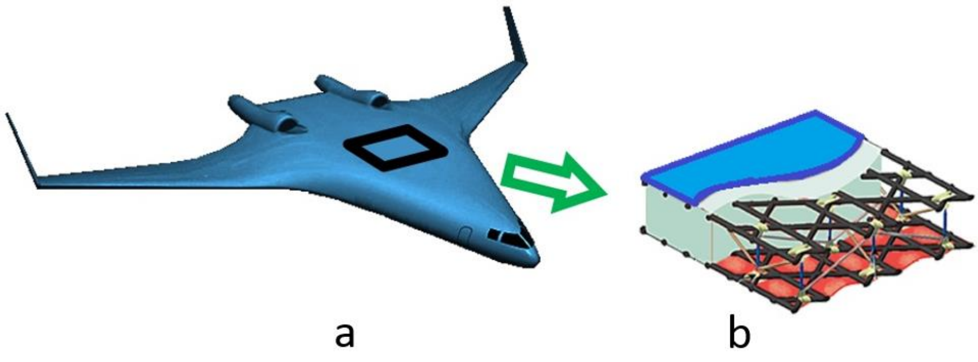

Figure 9 – Two-layer panel of the pressurized cabin of the aircraft in the Flying Wing scheme

Comparison of the results of the weight analysis of alternative designs showed that for the variant of the hypothetical aircraft 2, which has a layout scheme of the Flying wing type, it is possible to obtain a weight gain for the pressurized cabin of up to 12.5% compared to the metallic variant with a conventional layout.

5. Hybrid designs of the nose of a perspective supersonic passenger aircraft of small dimension

The above-considered hybrid airframe designs can also be effective for the designs of the nose of the fuselage of a new generation of supersonic passenger aircraft of small dimension, having small Mach numbers (1.6-1.8) and a take-off weight of 25-30 tons. Such designs have a large elongation of the nose to reduce the sonic boom level. An increase in elongation leads to a decrease in the stiffness characteristics of the nose and, as a consequence, to problems in providing strength.

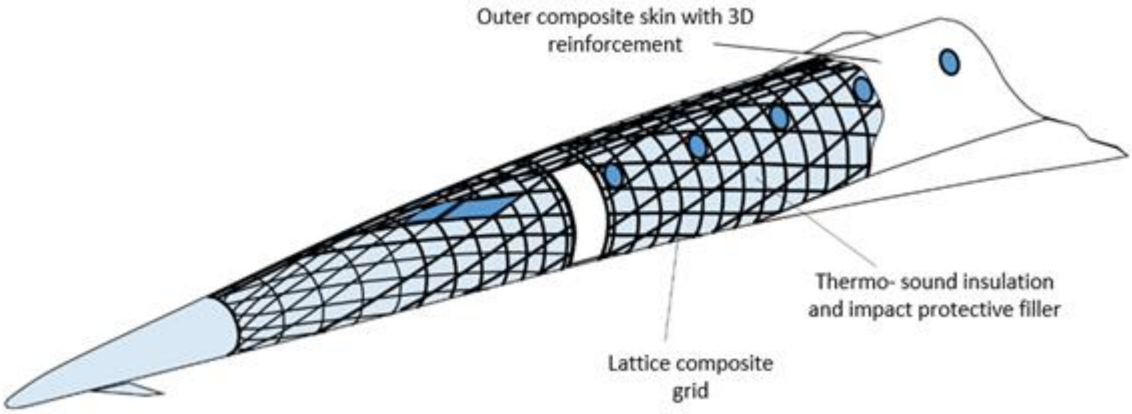

Рисунок 10 – Concept of the bionic layout of the forward section of the fuselage structure

Numerical studies have shown that the use of unidirectional composite ribs (the main part of the hybrid structure) allows increasing the stability of the nose of the structure up to 30-40% without additional weight costs (Figure 10). However, the lattice structure (without protection) has low impact resistance, which leads to ineffectiveness of its application.

Studies of the effectiveness of impact protection of ribs, carried out in , showed that within the frame of a new generation hybrid layout, it is possible to provide reliable multi-level protection of ribs without significant weight costs. Figure 11 shows the ultimate strength of the ribs after receiving an impact with an energy of 30 J. At the same time, the use of such a protection system can not only fully protect, but also increase the buckling characteristics of the ribs.

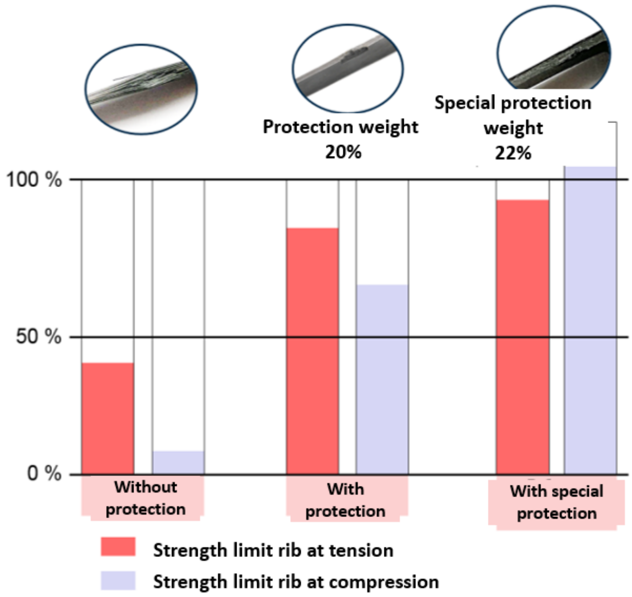

Figure 11 – Reduction of the strength characteristics of a rib with and without protection after a certified impact with an energy of 30 J

Considering that the protection system includes aerodynamic skin and pressurized skin, these results should be considered successful in realizing the high weight efficiency of the design of a supersonic passenger aircraft with an elongated fuselage.

6. Conclusion

On the basis of numerical and experimental studies carried out at TsAGI, the effectiveness of hybrid (metal-composite) structures of a new generation in relation to unconventional concepts and structure layouts of perspective passenger aircrafts has been shown. The presented preliminary estimations of the weight reduction of the structure show that the use of a new generation of hybrid structures makes it possible to increase the weight efficiency of airframe structures on 5-15% for various types of aircraft structures of passenger aircraft. The results obtained are planned to be used for the development of bionic aircraft designs for a perspective passenger aircraft

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8. Copyright Statement

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