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MULTIDISCIPLINARY OPTIMIZATION OF PRO-COMPOSITE STRUCTURAL LAYOUTS OF HIGH LOADED AIRCRAFT CONSTRUCTIONS

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Abstract

The concept of structure layout based on hybrid lattice-rods panels is presented. The algorithm for calculation of rational parameters is developed.

The optimization procedure of hybrid lattice-rods panels, based on the developed algorithm, considering strength, buckling and heat-insulation requirements have been developed. The results of flying wing fuselage panel weight estimation are presented.

1 General Introduction

Composite materials has been using for lightly loaded parts of aircraft structure, such as slats, wing flaps and fairings for a long time. The main feature of these structures is low active strains level (less than 0.3%).

At present time they try to use composite materials for high-loaded parts of aircraft structures. The basic load-bearing element of current high-loaded composite structures is laminated skin. According to a number of investigations, this type of load-bearing elements, due to heterogeneity and large difference of components' mechanical properties, has some essential disadvantages:

- low ultimate deformation of package,
- high sensitivity to the impact,
- low reparability [1].

2 Lattice and truss structures

A method to solve the problems mentioned above is seen in designing the structure based on layouts considering features of composite materials and allowing to use potential of high-strength carbon fibers. Such layouts are called “pro-composite”. The main idea of pro-composite layouts is maximum alignment of main force flow and carbon fiber directions [1].

The example of structure based on pro-composite layout is lattice structure. The main load-bearing element of this type of structure is composite UD-rib, in which carbon fibers are directed coaxial with rib. Such layout allows to reduce level of internal stress concentrations and, due to this fact, increase ultimate deformations.

However, reduction of strength of UD-rib after impact is larger than for laminated skin. It should be noticed that the problem of protection for UD-ribs can be effectively solved, unlike for laminated skin. A question about repairing of lattice structure is stay opened [2][3].

Truss structure based on load-bearing composite rods, whose fiber direction is very close to axis of rod, is another example of pro-composite layout. Rods, as lattice ribs, have a bigger than laminated skin ultimate strains. Protection of rods from impact is very simple. A large quantity of subunits allows repairing the truss structure by replacement a broken part by a new one without weight increase [4].

3 Strength problems of pressurized cabin fuselage of flying wing

New layouts based on new load-bearing elements needs new concept of aircraft, such as plane with long regular fuselage and swept-forward wing, plane with oval fuselage cross-section, flying wing. Object of current work is a concept of flying wing.

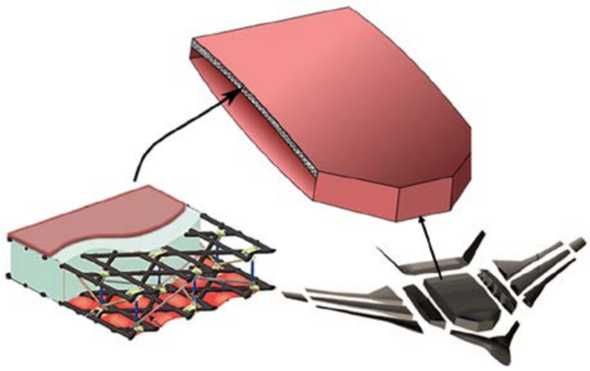

Figure 1. Hybrid fuselage panel of flying wing

The pressurized fuselage cabin of flying wing is unconventional structure with the following features:

- flat form of top and bottom surfaces,
- stiff ribs along the pressurized cabin,
- large panels [5].

Due to features mentioned above new problems of primary design such as nonlinear analysis of deformation of fuselage panels (Figure 1). The fact that panels of fuselage must have high stiffness is the result of primary numerical investigation.

Usage of usual frames in coupe the limits of vertical size (high is limited by 200 mm) become to significant weight increase [6].

Solution of this problem was found in hybrid lattice-rods structure. This type of structures allows increasing the stiffness of panel without great weight penalty.

4 Hybrid lattice-rods panel concept

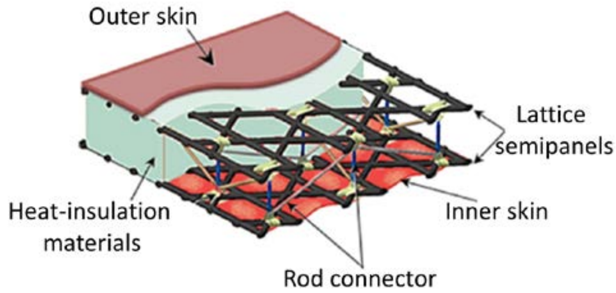

Figure 2. Structure of hybrid panel

Pro-composite panel, designed in TsAGI, is analyzed in this work (Figure 2). The panel consists of two lattice semipanels, connected by rods. Space between semipanels is filled by light heat-insulation material. Load from inner pressure is transferred to the panel by thin inner skin. Aerodynamic outline is beard by stiff outer skin. Described structure of the panel allow to avoid large local deformations of skin, which have strict effect on aerodynamic resistance coefficient.

4.1 Algorithm for calculation of rational parameters and weight analysis of hybrid panel

Two-level algorithm for calculation of rational parameters had been developed for designing lattice-rods panels (Figure 3).

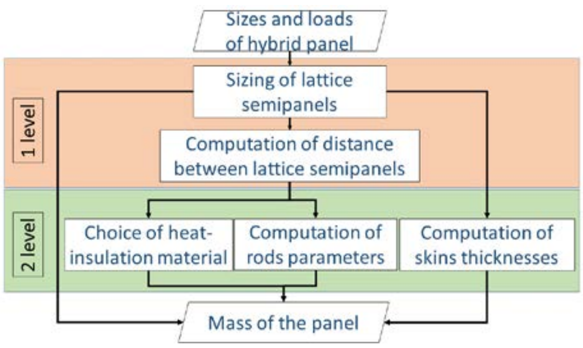

Figure 3. Algorithm of computation of rational parameters and weight efficiency of hybrid panels

Input data for designing the hybrid panel are sizes of the panel and external loads.

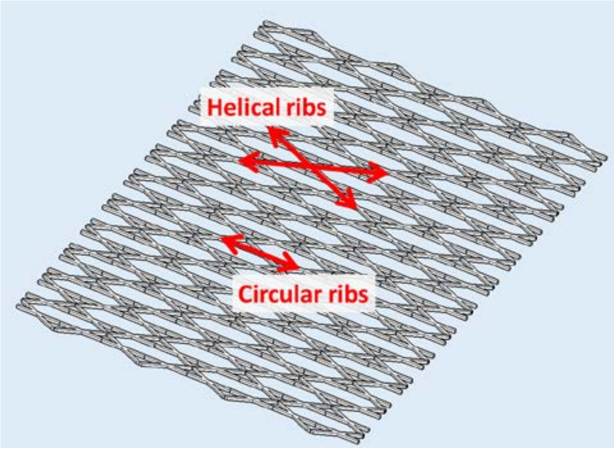

Figure 4. Ribs types of semipanels

According to static strength limitations, parameters lattice parts of panel are computed on the first level. Model of this level is analytic model of regular lattice panel, consist of helical and circular ribs (Figure 4).

As well, distance between semipanels is defined in frame of first level to satisfy stiffness limitation for panel.

Next lattice structure data received on first level have been transferred to the second level, where connective elements parameters are computed with strength and buckling limitations.

Choice of heat-insulation material, computations of thickness of inner and outer skins are made on the second level either.

4.2 Hybrid panel optimization procedure

Quantity of hybrid panel parameters is large therefore quantity of rational parameters sets is large, too. As well large quantity and complexity of different parameters cross-dependences are reason to necessity of optimization of all panel elements at the same time.

Described here algorithm of weight analysis and computation of rational parameters hybrid lattice-rods panel is the basis of panel optimization procedure.

Optimization of hybrid lattice-rods panel was made by the method of Surrogate-Based Optimization in frame of this work. During the optimization work following parameters were variable:

- step of lattice ribs
- angel between helical ribs
- step of rod-lattice fittings.

To simplify, parameters of helical ribs are same for all ribs. In similar way, circular ribs are same.

The parameters of longitudinal and transverse rods are also constant into his groups. At the same time placement of rods were regular.

The objective function in the optimization was the weight of the structure. The requirements on strength, stiffness and buckling of the structure elements were used as constraint functions.

5 Comparison of different structure layouts

The concept of hypothetical flying wings for long-range plane with 150-165 passengers was chosen for analysis of weight efficiency of pro-composite layout. Traditional and lattice-rods layouts was considered as alternative layouts. Weight analysis of traditional layout had been produced into two variants of structure: metal and composite. Possibility of composite structure weight efficiency increasing by lattice-rods layout application was studied.

Supported panels with loaded skin, frames and stringers were used as variant with traditional layout. Composite panels differenced from the metal panel by stringers with closed outline. It increases a local buckling characteristics.

For composite structure variant based on lattice-rods panels were studied.

All aircraft structure was modeled to calculate loads on the studied panel. Aerodynamic loads were computed by discrete vortices method. Inertia loads were defined by iteration process with parallel approximate determination of rational design parameters on beam models. In the analysis of stress-strain state by Finite Elements Method loads produced by pressurizing in the fuselage cabin were added.

Loads on fuselage panels were calculated on the basis of the stress-strains state of strength FEM model.

As a result of design investigations weight characteristics of flying wing fuselage panels for two variants of traditional layouts and lattice-rods layout were obtained.

Preliminary comparative results of weight analysis are presented in Table 1.

Table 1. Relative weight of panels with different layouts

Traditional metal	Black metal composite	Hybrid composite
100%	99.1%	75.4%

According to the results of design investigations, the weight of lattice-rods composite fuselage panels are lower than metal ones by 24.6%.

6 Conclusion

As a result of the preliminary design investigations the efficiency of pro-composite hybrid lattice-rods panels for flying wing fuselage have shown. Preliminary weight saving is estimated as 22-25%.

As further investigations, by improving the design module, it is planned to enlarge the number of variable parameters. As well, studding of irregular rods structure is planned. These investigations could provide further improvement of hybrid panels' weight parameters.

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