Evaluation of the possibility of developing and manufacturing integral composite structures for airframe elements

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Abstract. Nowadays, the degree of structural integrity is as important as the specific load bearing capacity. An integral product can be called a product obtained by combining structural elements of different configurations and functional purposes into a single object that does not contain joints. The concept of "integral", obviously, is synonymous with the concept of "monolithic". However, the word "monolithic" is traditionally identified with a massive structure, in which all fragments have the same order of measurement. The very concept of "degree of integration" is very conditional, since now there is no clear methodology for its assessment in quantitative terms. Issues related to the design, manufacture and operation of such products should be addressed in a comprehensive manner based on design solutions, technological capabilities, as well as data obtained as a result of strength calculations. In this paper strength calculations were made for metal and composite panels. Besides, composite panel has integral design. Production specifics of integral composite structures as well as advantages and disadvantages.

1 Introduction

The existing trends in the development of aviation technology show a constant increase in the flight speeds of modern aircraft, both cruising and marginal. This leads to the emergence of new tasks requiring solutions at various stages of the life cycle, taking into account the assessment of their cost and the possibility of cost optimization [1-3]. The most important of them are the tasks of modeling working conditions [4], the development of new structural materials, design optimization [5], the organization of conditions for their production and tests [6], as well as supply and quality management of all processes.

2 Statement of the problem

Consider the possibility of using integral structures in the airframe of an aircraft wing, as well as the design, technological and operational features of the products being developed

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using the panel as an example. Draw conclusions about the pros and cons of using such structures.

3 The concept of integral construction

An integral product can be called a product obtained by combining structural elements of different configurations and functional purposes into a single object that does not contain joints. That is, the fewer joints and seams in the design of the connection, the higher its integrity. This helps to reduce the mass of the structure [7, 8], improves technological and operational properties [9], reduces the thermal conductivity of airframe elements during aerodynamic heating [10].

Fig. 1. Example of an integral design.

Table 1. Advantages and disadvantages of integral structures comparably to non-integral ones.

Advantages	**Disadvantages**
Weight reduction by reducing the number of joints	Reduced maintainability
Structures far more hermetical	More difficult production technology
Increasing the resource of the structure	
Simplified assembly technology	

4 Composites

In the 21st century, the proportion of metal products in aviation technology is decreasing and the volume of structures made of polymer composite materials (PCM) is growing.

Composite materials (CM) are a complex system consisting of at least two components: a filler and a matrix, which, unlike metal alloys, have a clear interface between them, and determines its properties depending on the volume ratio of the components, their structure and manufacturing technology. The reinforcing filler bears the load, provides the strength and elastic properties of the CM. For example, glass, carbon wires. The binder perceives and evenly distributes the load between the fibers of the reinforcing filler, ensures the solidity of the material and the shape of the product. For example, thermosetting and thermoplastic polymers. This comes at the cost of a number of benefits.

Table 2. Advantages and disadvantages of integral structures comparably to non-integral ones.

Advantages	**Disadvantages**
Low density	Low operating temperatures
High specific strength	Tendency to aging.
High specific stiffness	
High absolute strength and elastic properties	

5 Some types of integral structures

5.1 Bar and tubular elements

Reinforcement is made in axial or radial directions. Such designs may include integral flanges and ring reinforcements. They perceive axial loads and torsion. They may be subject to dimensional stability requirements. Reinforcement is preferred in the axial and helical directions, depending on the load taken by the part.

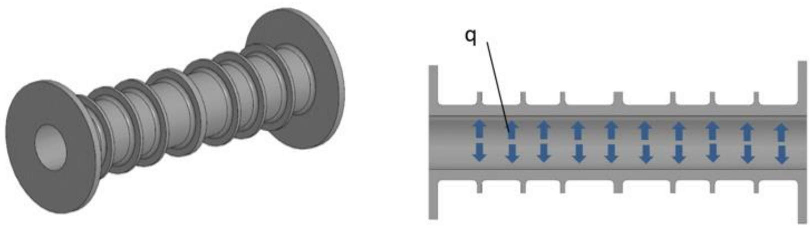

Fig. 2. Tubular element strengthens with radial direction of reinforcement (Distributed load is applied $[\frac{H}{м^2}]$).

5.2 Panels loaded with distributed load on two opposite sides

Usually, such panels consist of skin and stringers arranged in the longitudinal direction. Stringers can have a different cross-sectional shape - open and closed, which will affect the choice of the panel manufacturing process. Reinforcement is usually regular. It can be implemented in textile options - satin, linen, etc. Stringers are reinforced by roving in the axial direction [11].

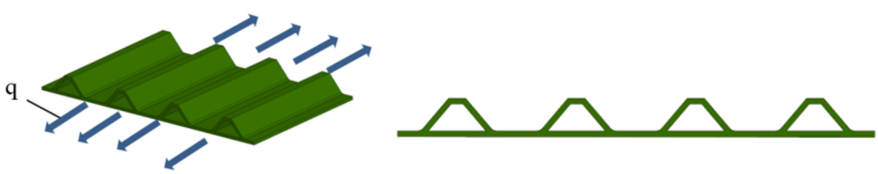

Fig. 3. Panels loaded with distributed load on two opposite sides (The arrows indicate the distributed load $\boldsymbol{q}[\frac{H}{м}]$).

5.3 Structures that take bending moments

This group includes spars, ribs, frames. Such elements for the most part perceive bending moments in their plane. The structures are similar, consisting of walls, belts and racks. Belts should be reinforced with a high content of longitudinally directed fibers, because in the design of the unit, they are responsible for the perception of the bend [12]. In turn, the walls of these aggregates perceive shear loads, so they must be reinforced with fibers, which are located at certain laying angles to each other.

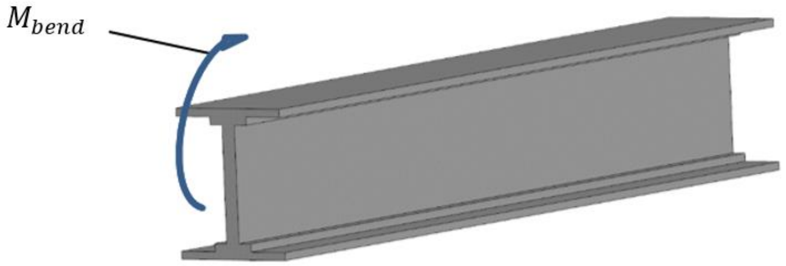

Fig. 4. Longeron, with integral design.

5.4 What areas of the airframe should such structures be used in?

• Units in direct contact with the environment (panels, skins, fairings, branch pipes),
• Units in compartments that require increased tightness (for example, in areas of fuel placement, system pipes),
• Details working on a certain type of load.

5.5 Problem solving technique

To confirm the theses, two panels were calculated. The first, consisting of skin and riveted stringers, is made of D16. The second one is integrated – longitudinal elements and skin form whole body. The design case for both panels A', the dimensions of the panels and the pitch of the longitudinal elements are equal. The panels are loaded with bending and torsional moments, shearing force. The loads were taken from the corresponding diagrams constructed according to the method from [13]. That is, both variants of the panel are in equal conditions. Panel material KMU-3.

The skin thickness was determined from the strength condition for local buckling:

$$\delta_{skin} = b_c \sqrt{\frac{\sigma_{skin}}{k_{1\delta} E_1}},$$

b_l -pitch of longitudinal elements
σ_{skin} -actual stresses of the skin
$k_{1\delta}$ -stability coefficient
E_1 -elastic modulus of the monolayer along the reinforcement fibers
The height of the stiffener was determined from the condition of the total loss of stability of the panel between the ribs:

$$h_c = \frac{L}{\pi} \frac{1 + r}{\sqrt{r}} \sqrt{\frac{\sigma_{-b_1}}{E_1}},$$

$L -$ Distance between ribs;
r -the ratio of the areas of the cladding and stoppers to the area of the wall and shelf of the longitudinal element.
At the same time, the area of the skin reduced to a monolayer.

$$\mathrm{f_{obsh}} = \mathrm{b_c} \delta_{\mathrm{skin}} \frac{\mathrm{E_{x\,skin}}}{\mathrm{E_1}}$$

$E_{x\ skin}$ – modulus of elasticity of the skin package

The thickness of the rib wall was determined by the formula:

$$\delta_h = \sqrt{\frac{\sigma_c}{k_{1\sigma}E_1}}$$

Then the safety margin coefficients were determined.

5.6 The method of calculation of the aluminum panel

The calculation was carried out according to the methodology described in [14]

Determination of the smallest required thickness of the skin

$$\delta_{min} = \frac{q_{\text{sdv}}}{0{,}3\tau_{\text{в}}}$$

Then, the stringer area is selected from the catalog and the actual stresses and strength reserves are determined:

$$\sigma_{a\ com} = \frac{q_{com}t}{F_{str}},$$

t -pitch of longitudinal elements

F_{str} -stringer area with attached skin

$$\tau_{\text{D}} = \frac{q_{shear}}{\delta_{skin}}$$

5.7 Production process

The panel is a unit that includes a skin and reinforcing stiffeners. If necessary, additional elements of docking with neighboring nodes and edging cutouts can be part of the panel. The method of manufacturing the unit and the design of the tooling is primarily influenced by the shape of the cross-section of the reinforcing elements and the dimensions of the panel. Due to the fact that the panels perceive external loads, which means they are power elements, for example, wings, an autoclave is most often used for their molding. Of the transfer methods, infusion is used for large dimensions. Also, with large dimensions of the panel, infusion is used, a method related to transfer [15]. Consider the manufacturing process of manufacturing a panel with a longitudinal power set. Such technology is used, for example, in Aerocomposite JSC. The process is performed according to the algorithm shown in Fig. 5:

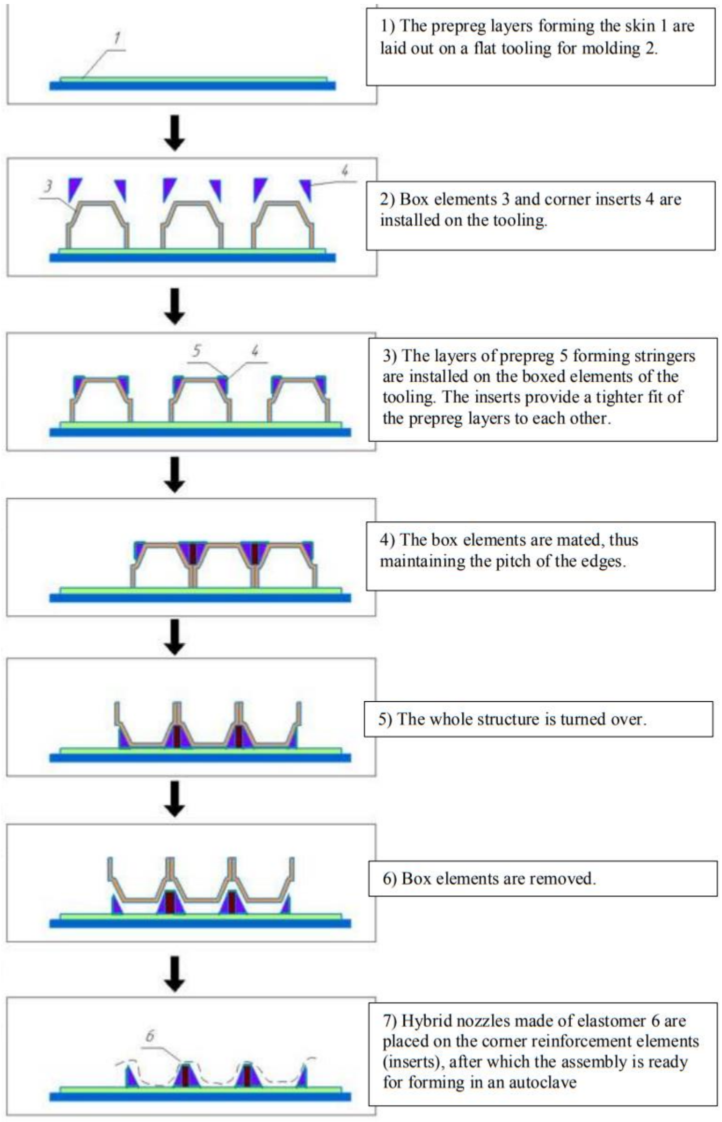

Fig. 5. Algorithm of the production process.

This algorithm shows the complexity of the process, the versatility of requirements for information support, the supply of components during production and operation [16], the organization and control of work performance in accordance with ISO quality standards [17, 18].

5.8 The results of the study

The methods of calculating panels, both made of aluminum and composite material, are considered. Geometric, strength, and mass characteristics of panels made of composite material and aluminum are obtained. The difference in mass is determined. An algorithm for the production of a panel with a longitudinal power set made according to an integrated circuit made of composite material is considered.

Table 3. Results of the calculations.

	D16	CM
Thickness, mm	2	4
Factor of assurance	1.69	1.94
Mass, kg	24.65	17.28

$m_{D16} - m_{CM} = 24.65\ kg - 17.28\ kg =$ 7.37 kg or $\frac{m_{D16}-m_{CM}}{m_{D16}}100\% = \frac{24.65-17.28}{24.65}100\% = 29.89\%$.

6 Conclusions

• By reducing the number of fasteners and joints, the composite panel is lighter and also more airtight.
• The PCM panel is not affected by the external environment, which means there will be no corrosion damage. The number of repairs will decrease. The service life will increase.
• The complexity of the geometry of the structure leads to a decrease in maintainability, for the same reason, the production process is hampered.
• It is necessary to control the degree of integrality of the designed product in order not to reduce the maintainability and manufacturability of the design beyond measure.

References

1. S. Serebryansky, M. Shkurin, J. of Eng. Sci. and Tech. Rev. **15 (6),** 149 – 154 (2022). doi:10.25103/jestr.156.18
2. A.V. Barabanov, S.A. Serebryansky, Aerospace Systems **4(2),** 171-177 (2021). DOI 10.1007/s42401-020-00079-2
3. M. Kiselev, S. Levitsky, M. Shkurin, AS **5**, 123–130 (2022). https://doi.org/10.1007/s42401-021-00124-8
4. A. Barabanov, S. Serebryansky, *Modeling of Product Life Cycle Stages Optimization Taking into Consideration Uncertainty of the Main Parametrical Variables,* Proc. of 13th Int. Conf. Management of Large-Scale System Development, MLSD 2020: 13, Moscow, 28–30 September, p. 9247777 (2020) DOI 10.1109/MLSD49919.2020.9247777
5. R. Bekirov, D. Strelets, M. Shkurin, *Approach to the Formation of Requirements for the Design of the Aircraft with Increased Load Capacity and Flight Range*, 2022 15th Int. Conf. Management of large-scale system development (MLSD), Moscow, Russian Federation, pp. 1-5 (2022) doi: 10.1109/MLSD55143.2022.9934185
6. E.V. Niselovskaya, M.V. Shkurin, J. Phys.: Conf. Ser. **1889,** 042008 (2021)
7. G. Resulkulyeva, S. Serebryansky, *Aircraft Fuselage, Wing, and Empennage Design Weight Model Based on Regression Analysis*, 15th Int. Conf. Management of large-scale system development (MLSD), Moscow, Russian Federation, pp. 1-5 (2022) doi: 10.1109/MLSD55143.2022.9934439
8. S. Kantimirov, S. Serebryansky, *On the Issue of Weight Design of Aircraft on a Digital Platform in a Single Information Space of the Product Life Cycle,* Proc. of 2021 14th Int. Conf. Management of Large-Scale System Development, MLSD 2021: 14, Moscow, 27–29 September (2021) DOI 10.1109/MLSD52249.2021.9600237

9. Yu.I. Popov, S.A. Serebryansky, M.V. Maysak, *On the issue of ensuring the operational survivability of the airframe structure,* Handbook. *E*ng. J. **12(273)**, 32-39 (2019)
10. A. Shiryaev, S. Serebryansky, *Methods for Reducing Temperature Heating in Supersonic Aircraft Structures*, 15th Int. Conf. Management of large-scale system development (MLSD), Moscow, Russian Federation, pp. 1-5 (2022). doi: 10.1109/MLSD55143.2022.9934688
11. V.I. Khaliulin, V.V. Batrakov, Technology of production of composite products: technology of integral structures: textbook (Kazan: KNITU-KAI Publishing House, 2018)
12. V.S. Pashkov, Yu.I. Popov, O.V. Rusanova, *Application of integral composite structures in the airframe*, *Aviation and Cosmonautics*: abstracts of the 21st Int. Conf., Moscow, November 21-25, 2022, Moscow Aviation Institute (National Research University). Moscow: Publishing House "Pero", pp. 60-61, (2022) EDN TYSQBD
13. A.A.Zotov, S.I. Zhavoronok, A.V. Tkachenko, A.S. Frolov, Calculation of the strength of aircraft wing type structures: Methodological guidelines for the implementation of the course project / Author-comp., Moscow, Publishing House of MAI (2002)
14. A.I. Endogur, Aircraft design. Designing parts and assemblies: Textbook. Moscow; Publishing House of MAI (2013)
15. V.V. Batrakov, V.I. Khaliulin, D.Yu. Konstantinov, Technology of production of composite products: transfer molding methods: textbook [Electronic resource], Kazan: Publishing House of KNITU-KAI (2018)
16. V. V. Korolenko, N. M. Laznikov, S. A. Serebryansky, *Search of effective solutions in the process of creation and implementation of scientific developments in Russian aviation and rocket-space industry*, International scientific-practical conference, 05-08 August 2014. Kazan: Kazan State Technical University Press, pp. 605-608 (2014)
17. S. Serebryansky, B. Safoklov, I. Pocebneva, V. Lepeshkin, *Improving the Efficiency of Production Processes of Enterprises of the Aviation Industry,* Conf. INTERAGROMASH 2021. Precision Agriculture and Agricultural Machinery Industry, **2**, Conf. proc., Rostov-on-Don, 24–26 February 2021. Rostov-on-Don: Springer, pp. 1005-1019 (2022) DOI 10.1007/978-3-030-80946-1
18. S. Serebryansky, B. Safoklov, I. V. Potsebneva, A. I. Kolosov, *Model of Information Support of the Quality Management System,* Conf. INTERAGROMASH 2021, Precision Agriculture and Agricultural Machinery Industry, **2**, Conf. proc., Rostov-on-Don, 24–26 February 2021. Rostov-on-Don: Springer, pp. 993-1003 (2022) DOI 10.1007/978-3-030-80946-1