Abstract. The paper presents the research of the stress-strain state of a multilayer composite shell. The optimal construction of a multilayer shell made of composite materials (CM) in the ANSYS system is determined. The optimal construction of a multilayer composite shell provides maximum strength and rigidity at specified loads. An automated procedure developed for choose the angle of fiber laying in the layer. According to the calculations and constructed models, an experimental model of a multilayer shell made of laminated fiberglass manufactured. For the experimental manufacture of a multilayer shell by cold forming, the working drawings of the press-form made. We manually put the layers of shell made of fiberglass T-25 (BM) TU 6-11-380-76. We made layer-by-layer laying of layers in strict accordance with the calculation model, while observing the sizes of elements and reinforcement angles along the base in each layer. The surface of each layer is an ED-20 epoxy resin with a hardener. This approach can be widely used in the engineering and manufacture of structural elements and products from composite materials.

1. Introduction
In aerospace, the desire for a fuller use of the carrying capacity of equipment while observing safety requirements is one of the priority factors. A significant increase in the number of spacecraft in orbit leads to a strong increase in the clogging of outer space. This represents a potential threat to the long-term safety of space activities and a direct threat to the safe life of people in near-Earth space [1].

Today, composite materials are high-tech materials used in the aerospace field. A key factor in the use of composites is strength. Composite material is a matrix with a reinforcing material inside it. The use of multilayer composites leads to the need for stress analysis and large deformations. Layered composites themselves represent a structure consisting of layers. The composite layers are specially fixed to each other. Due to the various laying angles, we must combine useful properties and obtain a material that provides high specific stiffness and strength of the power elements. However, to obtain structural elements from multilayer composite materials with high mechanical properties, we must take into account many factors of modern technologies. These factors are the sequence of laying the layers, the arrangement of the layers and their thickness depending on the current loads [2].

This article presents the development of optimal modeling of thin-walled elements in the form of a shell made of composite materials.
2. Modelling of composite shell

In this work, we investigated the stress-strain state of a multilayer shell and solved the following problems:

1. An automated procedure developed for choosing the angle of fiber laying in the layer in the ANSYS system [3];
2. The optimal construction of the multilayer shell in the ANSYS system determined, providing maximum strength and rigidity at given loads.

Shell geometry developed in the SolidWorks system consisting of a multilayer composite shell and a cube, which serves to transfer the model to the Fluid Flow (flient) calculation module. Shell geometry is transferred to the Ansys system. We set the orthotropic properties of the composite material (Figure 1). In the Engineering data module, we set the laying angles of the layers, thickness and properties of the composite material. Data is transmitted to the ACP (Pre) module.

![Figure 1. Material Properties.](image1.png)

In parallel, in the Fluid Flow (flient) subroutine, the imported geometry is divided into finite elements (Figures 2 and 3).

![Figure 2. Finite element model constructed by the tetrad mesh method: a – general view; b – front view, fuselage contour.](image2.png)
Figure 3. Placement of the first layer of composite material in ANSYS Composite PrepPost, thickness 1.5 mm.

Then we set the load: air velocity (50 m/s) (Figure 4).

Figure 4. The load assignment: a – air flow velocity vector; b – pressure distribution from the air flow to the fuselage; c – static pressure field; d – pressure gradient; e – components of axial velocities.
The obtained load values from Fluid Flow (flcient) and the data obtained by ACP (Pre) are combined in the System Coupling module. We performed the strength calculation using the Static Structural module. Next we set the limits. Figure 5 shows the stiff limit from the hollow sides of the shell. We set the variables for the optimization process - the maximum strain value and the maximum equivalent stresses of each layer.

![Figure 5. The limit of shell: a – computational grid and boundary conditions; b – total deformation.](image)

We determined the optimal construction of a multilayer shell made of composite materials in the ANSYS system, which provides maximum strength and rigidity at specified loads [4]. Figure 6 presents the optimal calculation of the multilayer shell. The shell consists of four complete layers. We developed an automated procedure for choosing the angle of fiber laying in each layer. The calculation begins with the first layer of the shell. Table 1 shows 22 different fiber angles depending on the stiffness of the sheath. From the obtained options, we chose three options for optimal reinforcement.
Figure 6. The optimal process for calculating a multilayer shell, depending on the rigidity and strength of the structure.

Table 1. The optimization of first layer

| №  | The angle of laying of material layers | Maximal load, MPa | Maximal displacement, mm |
|----|--------------------------------------|-------------------|--------------------------|
| 1  | 90                                   | 21,10183          | 1,095093801              |
| 2  | 162                                  | 9,661041          | 0,931453943              |
| 3  | 18                                   | 9,653471          | 0,934260152              |
| 4  | 126                                  | 14,90961          | 0,838294026              |
| 5  | 54                                   | 14,89833          | 0,840930263              |
| 6  | 126,4851                             | 14,83455          | 0,839032358              |
| 7  | 63,55716                             | 16,21259          | 0,898816012              |
| 8  | 0                                    | 9,233469          | 0,98680513               |
| 9  | 144,4851                             | 12,7972           | 0,858866131              |
| 10 | 49,75054                             | 14,22289          | 0,846322747              |
| 11 | 102,5839                             | 21,22485          | 1,030649697              |
| 12 | 140,4485                             | 13,28761          | 0,851333735              |
| 13 | 35,30204                             | 12,76257          | 0,862188449              |
| 14 | 124,2555                             | 15,17309          | 0,840140706              |
| 15 | 111,404                              | 19,37293          | 0,957054006              |
| 16 | 134,1003                             | 13,83165          | 0,846248119              |
| 17 | 125,5222                             | 14,98282          | 0,837507553              |
| 18 | 113,8144                             | 18,32689          | 0,915484652              |
| 19 | 119,9556                             | 16,4864           | 0,880575914              |
| 20 | 129,1943                             | 14,40154          | 0,842196203              |
| 21 | 137,708                              | 13,54989          | 0,841213248              |
| 22 | 116,5059                             | 17,74648          | 0,911944311              |

The optimal options for the angle of laying of the fibers of the first layer of the shell model:
1. The angle of laying 125⁰, maximal displacement 0.84 mm;
2. The angle of laying 140⁰, maximal displacement 0.85 mm;
3. The angle of laying 54°, maximal displacement 0.84 mm.

For increase the rigidity of the multilayer shell, we added an additional three layers over the entire surface of the shell. When calculating the shell, we looked at 11 options for laying fibers in 2 layers, at 47 options for laying fibers in 3 layers, at 41 options for laying fibers in 4 layers. As a result of calculating the optimal multilayer shell, taking into account the minimum deflection, we obtained:

1. The first layer - 150°, the second layer - 35°, the third layer - 147°, the fourth layer - 71° (displacement is 0.11 mm);
2. The first layer - 26°, the second layer - 48°, the third layer - 131°, the fourth layer - 62° (displacement is 0.12 mm);
3. The first layer - 89°, the second layer - 53°, the third layer - 136°, the fourth layer - 59° (displacement is 0.12 mm).

Figure 7 shows the stress state of the shell, consisting of one layer, of two layers, of three layers and four layers.

![Figure 7](image)

**Figure 7.** The stress state of the shell: a – one layer; b – two layers; c – three layers; d – four layers.

3. **Conclusion**

The use of multilayer composites leads to the need for stress analysis and large deformations. As a result, we presented the optimal construction of a composites multilayer shell in the ANSYS system, which provides maximum strength and rigidity at specified loads, and developed an automated procedure for choosing the angle of fiber laying in each layer.

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