ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Structural and Technological Solutions Used in the Manufacture and Assembly of Functional Units of an Aerodynamically Stabilized Aerostatic System.

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ABSTRACT

This article presents the design and technological solutions adopted by developers in the implementation of the project on producing an experimental sample of an aerodynamically stabilized aerostatic system (ASAS) designed to measure wind flow energy at altitudes up to 1,000 meters. At earlier stages of development, ASAS demonstrated that an aerostatic balloon of small volume that forms an integral part of ASAS (about 10 m^3) successfully maintained flight altitude due to application of a hybrid circuit using both aerostatic balloons and a wing as the lifting force sources. The article presents the results of the selection and validation of materials and techniques for manufacturing individual functional units of the ASAS experimental sample. The development of ASAS construction was carried out taking into account the stringent requirements for the apparatus weight and engineering simplicity. An original design of tooling for manufacturing fuselage sections, wing and fins of the ASAS experimental sample was provided.

Keywords: tethered balloon, hybrid balloon, carbon fibre, manual moulding, balloon design, tooling.

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INTRODUCTION

The works [1-2] present a project of a small-sized tethered balloon complex developed by TECHNOCOMPLEKT JSC, designed for meteorological measurements at altitudes up to 1,000 m. The balloon is manufactured according to a hybrid scheme, which provides it with a capability of maintaining flight altitude when exposed to wind, unlike conventional balloons of the same volume. A distinctive feature of the balloon is the aerodynamic stabilization of its position with respect to the horizontal plane, which is necessary to measure accurately the horizontal and vertical components of the wind speed. Using the aerodynamic and aerostatic flight principles is reflected in the name of the apparatus – an aerodynamically stabilized aerostatic system (ASAS).

This paper presents the design and technological solutions implemented within ASAS to ensure the minimum weight of the apparatus and ease of manufacture and assembly.

ASAS scheme is shown in Figure 1. Lifting force is generated by aerostatic balloons 1 with total volume of about 12 m^3. Under wind effect, the aerodynamic lifting force is generated on the wing 2. As shown in work [1], when exposed to strong wind, the classically drop-shaped tethered balloons of small volume that do not feature aerodynamic lift lose their flight altitude under the force of resistance. Due to the presence of wing, the balloon under study loses almost no flight altitude, and its allowable wind speed is determined only through the strength of construction and tether. Measuring gauges 4, a control unit 5 and a battery 6 are arranged on the fuselage 3. Changing the battery position along the ASAS fuselage allows the adjustment of pitch moment, which is necessary for a precise balancing of the apparatus. The advanced vertical 7 and horizontal 8 fins support the sustainable position of the apparatus with regard to the wind. Vertical tail fin is uncontrollable. When the wind direction is changed, ASAS turns its head to the wind featuring longitudinal stability. The consoles of horizontal fin are configured turnable for pitch guidance in order to maintain a specified position relative to the horizontal plane. Ailerons 9 are used to perform roll guidance. The balloon is fixed on the tether 10 through the pivot fitting 11. The transmission of control commands is carried out by radio channel. The flight altitude is adjusted through a winch installed on the ground.

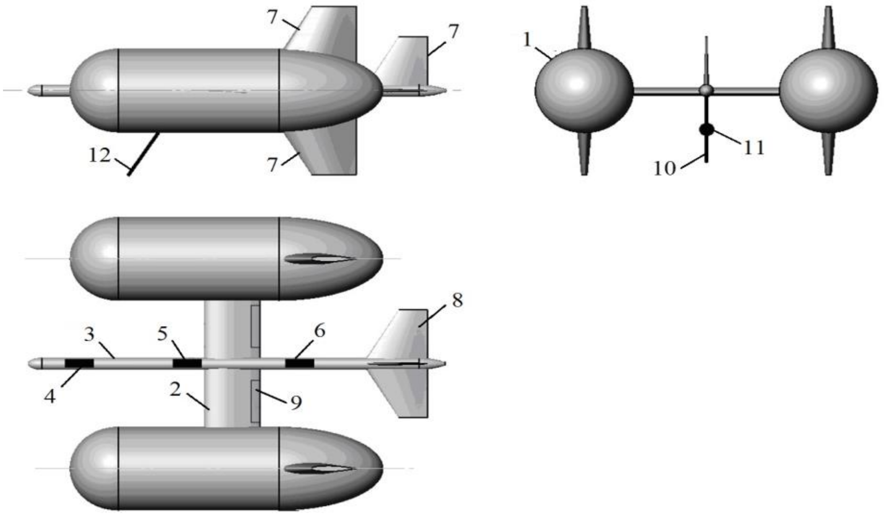

Figure 1. ASAS scheme

METHODS FOR MANUFACTURING AND ASSEMBLY

One of the key requirements to the design of ASAS is a need to minimize the weight of the apparatus. Otherwise, the growth in structural mass increases the size of the balloons, which reduces the ability of the apparatus to maintain altitude under the wind effect. After analysing the properties available in the market of construction materials and modern variants of composite products manufacturing technology [3-5], with regard to their economic and technological accessibility, it was decided to produce hard elements of ASAS (fuselage, wings, fin) from the sandwich panels based on carbon fibre and filler, and the aerostatic balloons – from the metalized Mylar film. The manual contact moulding method was chosen to manufacture carbon fibre parts as the most affordable one and the one that does not require special engineering equipment (autoclave, mould, vacuum unit, etc.). Especially for the manufacture of ASAS aggregates, a set of engineering tooling was developed that includes a mandrel for winding fuselage sections and templates for forming the covering of a wing and fins. Individual elements (fuselage nose section, flanges for joining sections) are supposed to be produced through a 3D printing method.

RESULTS AND THEIR DISCUSSION

Let us consider in detail the construction of ASAS units and the technology of their manufacture.

According to the results of detailed calculations performed during the previous phases of the project with respect to the aerodynamics and simulation of the ASAS experimental sample moving modes, the precise geometric shapes, sizes and material of the individual assemblies of the construction of the ASAS experimental sample were defined. Thus, the fuselage is a tube of a circular cross-section with an inner diameter of 130 mm and a length of about 6 m. For convenience of manufacture, the fuselage is configured assembleable consisting of five sections, each of which is a sandwich structure (Figure 2). The outer and inner covering of the section are made of carbon fabric [6] with a surface density of 86 g/m^2, which is placed in two layers. The epoxy resin [7] is used as a binder. To prevent the loss of the local stability of covering, the space between them is filled with Rohacell 31A filler [8]. This material has good mechanical properties at low density (31 kg/m^3), ensuring its wide spread within aircraft structures [9]. The Rohacell material responds well to machining and has closed pores, which prevents excessive penetration of resin inside the material.

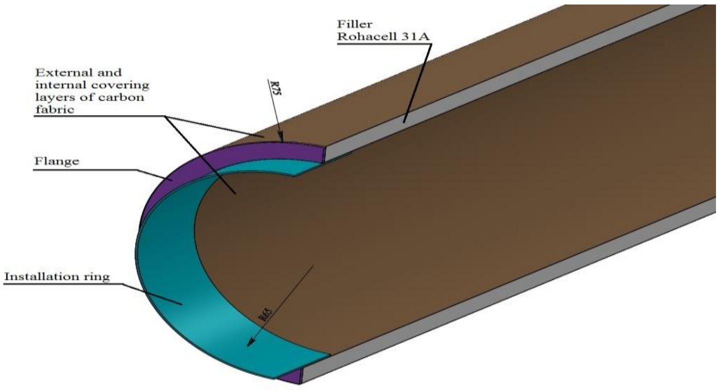

Figure 2. Construction of the fuselage section

The sections are joined using the composite mounting rings glued inside the section and lacing (not shown in Figure 2) with a caprone thread through the loops made of the same thread glued into the outer covering fabric. Such a process would ensure a minimum weight of the joint and evenly distribute the load from the bending and twisting moments.

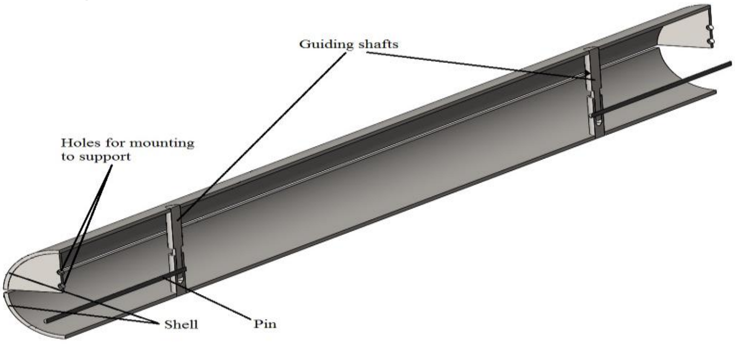

Figure 3. A longitudinal cut of the mandrel used for manufacturing fuselage sections

A mandrel for manufacturing fuselage sections is made from a thick-walled steel pipe cut longitudinally (a shell, see. Figure 3). Shell elements can slide relative to each other along the guide axes. The axes have holes for pins that hold the pipe halves at a distance from each other with a small gap (about 5 mm).

In the working position, the shell elements are fixed with removable pins so that there is a gap between their side edges. Thereafter, the mandrel is attached to the outer support and the section manufacturing process begins. To prevent adhesion of the binder (epoxy resin) to the mandrel, it is wrapped with several layers of thin polyethylene film, and then the binder-impregnated carbon fabric (the internal section covering) is wound onto the mandrel. The section moulding is carried out manually; the excess resin is removed using a plastic spatula. The experience in manufacturing sections has shown that the resin [7] features a sufficiently low viscosity and impregnates fabric well. A layer of Rohacell is glued on the layer of carbon fabric, above which 2 layers of resin-impregnated carbon cloth are wound that is a component of the outer section covering. The caprone thread loops are inserted under the top layer of covering to perform connection with the neighbouring sections.

After 24 hours of binder polymerization at room temperature, the mandrel is removed from the supports, and the pins are removed from the mandrel. The shell elements are moved close to each other to eliminate the gap, and then the section can be easily removed from the mandrel. The produced pipe is connected with its cut disc. The carbon fibre discs (flanges) are glued to the ends to uniformly transmit loads at the section junction.

Figure 4 shows the structure of the fuselage at the place of its connection with the wing. The main wing load bearing elements are the front and the rear centerplanes cut from the carbon fibre plates of 3 mm thick each. Cutting a sheet carbon fibre is carried out using a water-jet cutting. The connection of centerplanes with a cylindrical part of the fuselage is reinforced with foam plates (it is not shown in Figure 4).

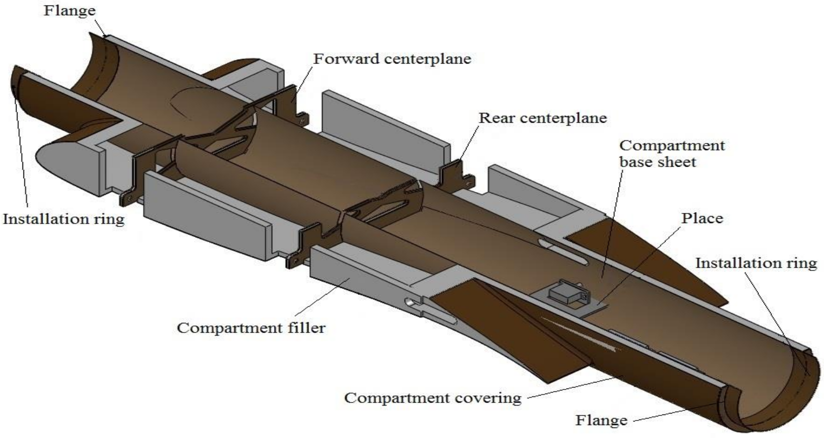

Figure 4. The construction of a wing fuselage section

The fuselage nose section contains the target ASAS load: sensors for measuring airflow parameters (thermoanemometers, barometer, pitot tubes) and related electronic units for processing sensor data (Figure 5). The sensors are combined in two groups for measuring horizontal and vertical components of wind velocity vector.

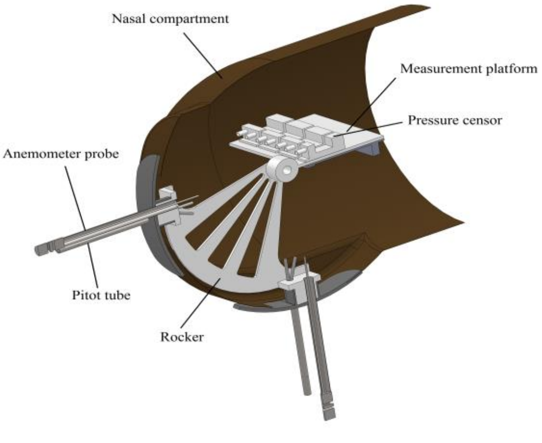

Figure 5. The ASAS nose section with the equipment placed therein

To stabilize the sensor position with respect to the horizontal plane, they are installed on a shaker, which is driven by a servo according to the commands sent from an ASAS airborne guidance system. The nose section housing is manufactured from ULTEM 9085 plastic using 3D printing [10].

The ASAS wing has two spars and a working covering (Figure 6) made of the same material as the fuselage.

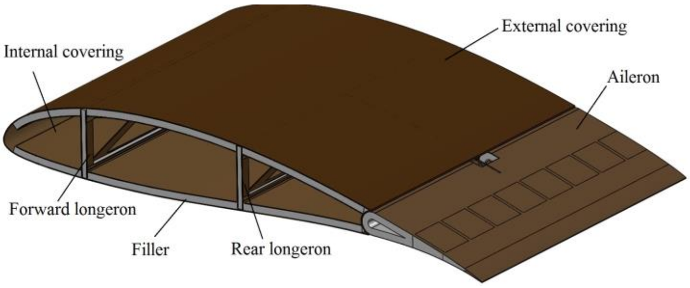

Figure 6. Wing design

The wing assembly is carried on a matrix (Figure 7) made of Obomodulan plastic through milling [11].

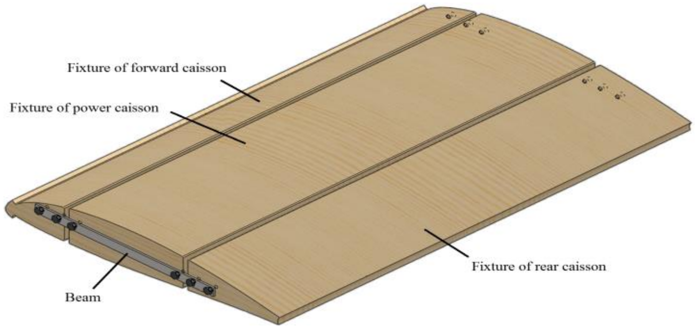

Figure 7. The matrix design for manufacturing a wing

When being prepared for work, the front, middle and back mandrels are wrapped with a polythene film. Then a layer of carbon fabric constituting the inner covering is applied thereto [6]. After polymerizing the binder, mandrels are fixed with beams, spars are mounted, a reinforcing layer of Rohacell 31A filler with a thickness of 10 mm is laid, and then the outer carbon fabric covering layer [12] with a density of 200 g/m^2 is provided. The wing spars are also made of sandwich panels consisting of 1.5 mm thick carbon fibre plates, between which there is a 5 mm thick layer of Rohacell 31A filler. After curing, the binder of the wing's outer covering is removed from the matrix, and the nodes of aileron hinges are glued therein. The aileron axis is made of a carbon fibre tube with 12 mm in diameter [13]. The centerplane and spar connection assembly is made according to the lug joint with the fixation by the axis of 6 mm in diameter and locking with a locking pin.

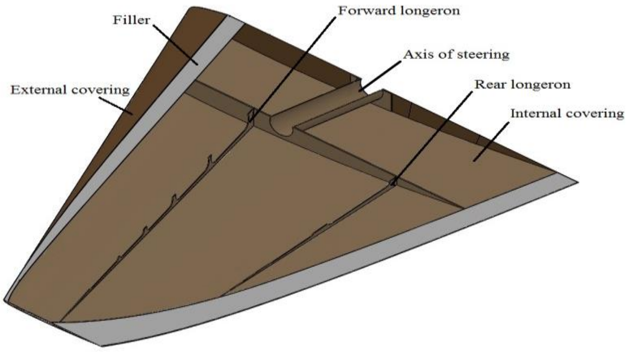

Figure 8. The design of a fin plane (horizontal cut with an offset)

The fin design and manufacturing techniques are similar to the wing structure (Figure 8). The carbon fibre tube with a diameter of 40 mm is used as the fin panel rotary [14]. The position of the rotary axis was chosen based on the condition of minimizing hinge moment that occurs on the wheel because of both the gravity force and the aerodynamic load.

The ASAS aerostatic balloons (see. Figure 1) are made of a metallized Mylar film [15] laminated on one side with polyethylene to ensure weldability. The mylar layer thickness is 8 microns, of the polyethylene layer – also 8 microns. The surface density is 18.7 g/m^2. The selection of Mylar film is determined by its high specific strength and low gas permeability. Helium is used to fill balloons. To prevent a catastrophic loss of altitude at shell breakage, each balloon is divided into independent sections. The rigidity of the ASAS structure is generally provided due to the connection of balloons between each other and with the fuselage through thin braces made of a nylon fishing line.

CONCLUSION

As part of a project on the production of an aerodynamically stabilized aerostatic system, a design of a small-sized hybrid aerostatic balloon was developed. Design was carried out taking into account the stringent requirements to the structure weight and its engineering simplicity. The main part of the balloon design is made of sandwich structures with the outer and inner covering made of carbon fibre and filled with aviation Rohacell filler. To manufacture an aerostatic balloon, an original tooling including mandrels for winding cylindrical fuselage sections and a matrix for the formation of wing and tail fins were developed.

ACKNOWLEDGEMENTS

This article was prepared within the framework of the implementation of the applied scientific researches and developments (ASRED) on the Grant Agreement No. 14.579.21.0082 under financial support of the Ministry of Education and Science of the Russian Federation. The unique identifier of the applied scientific researches and developments (of the project) – RFMEFI57914X0082.

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