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Use of cycloidal rotors for airships

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Abstract. A scheme for using cycloidal rotors to ensure high maneuverability of airships has been developed. High maneuverability indicators (turn on the spot, side slip, forward/backward movement, wind load parrying, operational change of flight altitude without the use of ballasting) of the airship with two cycloidal propellers was confirmed experimentally. A design of an airship with cycloidal propellers without a tail unit, providing a lifting capacity of the airship of 3 tons and the possibility of loading and unloading without mooring devices was proposed.

1 Introduction

Airships left the world arena of aviation works in the 50s of the last century, having lost the war for economic efficiency to airplanes and helicopters. The loss was connected with a combination of factors. The most important one is the society's demand for speed. Airplanes have successfully overcome the sound barrier, and commercially profitable flights are carried out at transonic speeds. At the same time, no one seriously thought about energy efficiency until a certain time. With the development of ground transportation technologies, the network of automobiles and railways has increased by an order of magnitude. On highways in Europe and America, cars can move at speeds of 100-150 km/h, which is comparable to the cruising speeds of airships, and trains rush at speeds of 200-300 km/h. Therefore, in territories well developed by people, there are simply no tasks for airships other than entertainment. On the other hand, the airships stopped developing at the designs of the early 20th century or acquired forms that negated all their advantages.

What is the main advantage of airships? And its main advantage is the amazing energy efficiency of cargo delivery in cases where the delivery speed is not critical and there are no roads to the places where the cargo needs to be delivered. For example, for the Mi-8 helicopter, the energy efficiency of cargo delivery (with the equivalent of 1 kg of fuel for 4 kW·h) is about 0.43 kW·h / kg when transporting 100 km, and for an airship this figure will be 0.025 kW·h / kg. That is, these are shipments across Siberia, the Far East and the Far North during the period of absence of "winter roads" or there is no possibility of delivering cargo along rivers. Modern conditions in Russia create the most favorable environment for the operation of airships. The country is very large and covers different climatic and geographical zones, while flights can be carried out without crossing state

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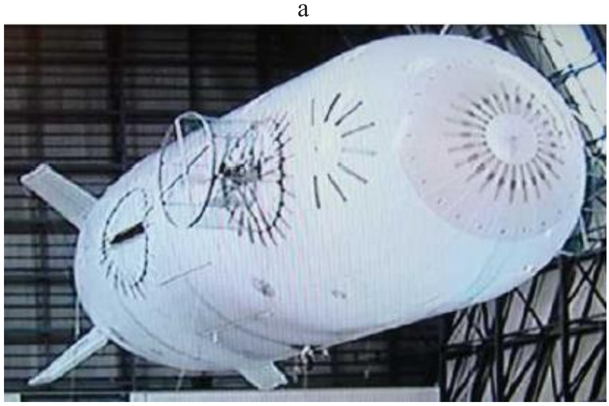
borders. Modern forecasting models of weather and wind flows at different altitudes make it possible to build a network of transportation that, on the one hand, can use tailwinds, and on the other hand, leave areas where weather conditions become dangerous for the operation of airships.

In recent years, interest in airships as alternative aircraft has increased again. The emergence of new materials and automatic flight control systems, and the increased reliability of meteorological forecasts allow us to hope that modern airship systems will be able to find their niche in the development of airspace. Both abroad (USA, Europe, China) and in Russia, airships are being developed to solve transportation problems, monitor the environment, organize communications systems, rescue operations, and elite tourism. The Russian airship AU-30, designed for 10 passengers, has set several world records. In recent years, experimental devices of larger sizes have appeared - Airlander 10, Pathfinder 1 (USA), Zeppelin NT (Germany), AS700 (China).

To truly become an alternative to airplanes and helicopters, airships themselves must change.

One of the main problems in the operation of airships is the strong dependence on wind gusts, which is especially relevant in the ground zone during loading and unloading operations. Attempts to solve this problem using cycloidal rotors as the main propulsion engines was made around the world [1-3] , but these efforts have not led to significant success (Figure 1). The reason is that at that time, the aerodynamic and design features of cycloidal rotors were insufficiently studied, which prevented a correct understanding of their optimal dimensions and obtaining the necessary thrust characteristics.

a



b

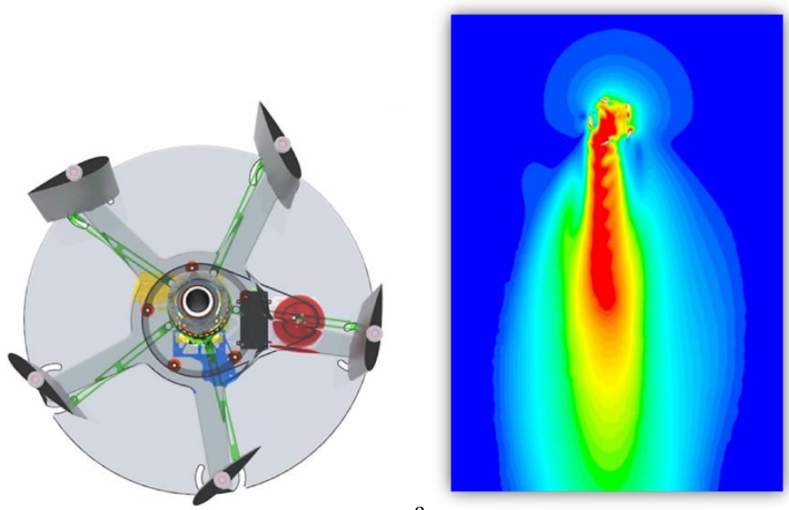
Fig. 1. Airships with cycloidal propulsors (a - [1], b - [3])

2 Cycloidal rotor

A cycloidal rotor (cyclic rotor propulsion device) is a device that generates a gas or liquid flow by moving blades rotating in a circular orbit around the rotor axis and turning around their own axis (Figure 2). The rotor's operating mode is set by changing the blade pitch angle according to a law that results in the blade creating an aerodynamic force during its rotation, such that the vector sum of the aerodynamic force for the entire rotation is not zero. In this case, the direction of the thrust generated by the rotor can change almost instantly in the range of 0 - 360°, and the thrust value is determined by the rotor speed and the blade pitch angle.

The Institute of Thermophysics SB RAS has carried out a series of computational and experimental studies of the traction and energy characteristics of cycloidal rotors in a wide range of their sizes – from 300 to 1600 mm. Based on numerical modeling and tube experiments, the dependences of rotor characteristics on the number and aerodynamic type of blades, on the angles of installation of the blades and their rotation speed, design features of the rotor, etc. were obtained. As a result of the studies, a cycloidal rotor was designed and manufactured (Figure 2), which formed the basis of a four-rotor aircraft – a cyclocopter.

Cycloidal rotor parameters:
- rotor diameter – 700 mm;
- blade length – 750 mm;
- rated rotor speed (in hover mode) – 700-1000 rpm;
- blade – NACA 2416 profile with a chord length of 158 mm;
- rotor weight – 2570 grams;
- number of blades – 5 pcs.;
- the blades are located between two blind disks and are connected by rods to the blade position control mechanism.



a b

Fig. 2. Cycloidal rotor (a – schematic diagram, b – the velocity field generated by the rotor)

Figure 3 shows the traction and energy characteristics of this rotor.

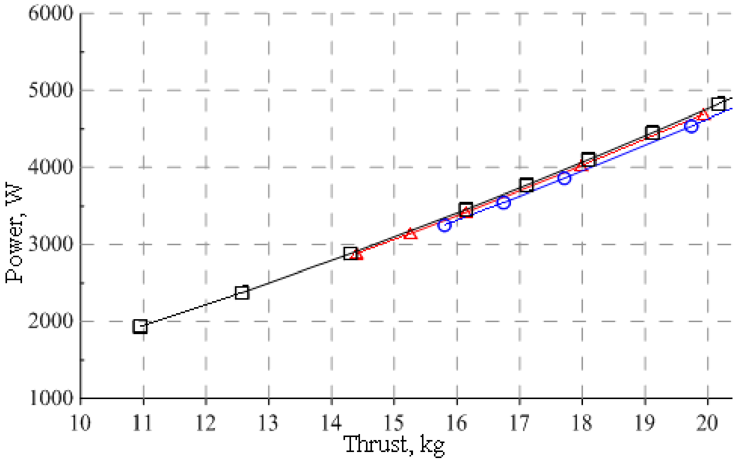


Fig. 3. Traction and energy characteristics of a cycloidal rotor 700*750 mm.
Three variants of blade attack angles setting at different rotor speeds are shown in colour.

3 Airship with cycloidal rotor

The authors proposed testing these rotors on a small airship, as a result of which, specialists from the SB RAS IT together with colleagues from Bauman Moscow State Technical University implemented a program to conduct test trials of an airship with two cycloidal rotors located along the axis of the airship (Fig. 4). The tests confirmed the high maneuverability of the device: turn on the spot, side slip, forward/backward movement, wind load parrying, operational change of flight altitude without the use of ballasting. At the same time, the propulsors during the flight also created vertical thrust, compensating for about 6 kg of excess weight of the device structure.

Fig. 4. Fly test of airship with cycloidal propulsors. Kirzhach city, April of 2024.

The authors of the article proposed and patented a design for an airship with cycloydal propulsors located not transversely, as in foreign studies, but along the axis of the airship, which allows for the effective creation of transverse thrust and increases the maneuverability of the airship.

The airship is a cigar-shaped body with an aspect ratio of about 4.5 and a fullness of about 0.57. (Figure 5) Experiments show that with such parameters, by selecting the shape of the shell, with longitudinal flow, it is possible to achieve drag coefficients of about Cx = 0.012. To make it clear what this means in practice, we will give an example: an airship with a diameter of 16 meters and a length of 72 meters, with an aspect ratio of $\lambda = 4.5$ and a fullness coefficient of $\theta = 0.57$ with a total air displacement at the ground of 9.8 tons can transport a load of 3 tons at a speed of 100 km / h with a required thrust of about 100 kg (940 N), the required engine power will be about 50 kW. The airship does not have a tail unit, and its stabilization is carried out only by activating the thrust generation posts.

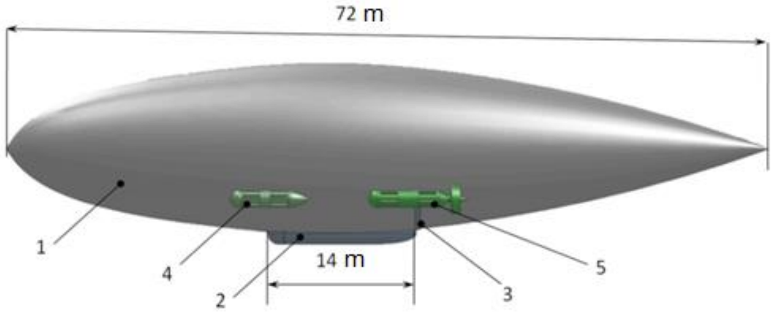


Fig. 5. Airship with cycloidal rotors

1 – soft shell with pressure sensors on the surface;
2 – cargo cabin;
3 – beams for attaching the skin and power plants;
4 – four-vector propulsion system consisting of two cycloidal rotors;
5 – six-vector propulsion system consisting of two cycloidal rotors and a propeller.

The power plant consists of 4 posts (Figure 6), located just below the longitudinal axis of the airship. The specific position must be optimized based on the ratio of dynamic and aerodynamic forces, when performing stabilization maneuvers, taking into account the full and partial loading of the airship.

At the rear posts, six-vector propulsion units are installed (Figure 6), which consist of two cyclic thrusters 2 located one behind the other and allowing independent change of the thrust vector, and a propeller 4. At the front posts, four-vector propulsion units are installed, the tasks of which include only transverse maneuvers of the airship.

4 posts can also create vertical thrust, which makes it possible not to load with ballast during short-term loading and unloading.

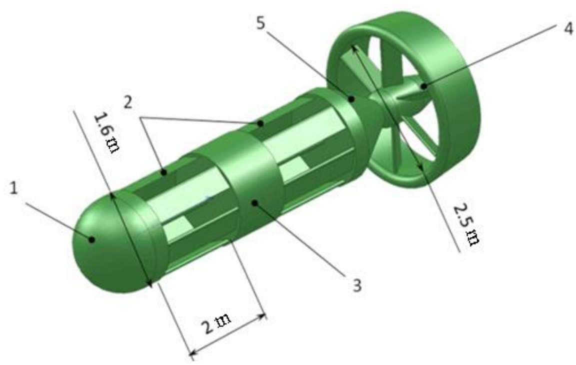


Fig. 6. Six-vector propulsion power system: 1 – nose cone; 2 – cycloidal propulsion unit; 3 – hybrid power plant unit; 4 – reversible propeller; 5 – tail cone.

Thus, this layout of propulsion posts not only increases the efficiency and safety of the airship, but also changes the principles of interaction with the ground infrastructure. The airship does not require a mooring mast, since its stabilization is carried out actively. Placing in a slipway for this type of airship is necessary only for longer maintenance and repair work.

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