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Economic Feasibility of Using Airships in Various Sectors of the Economy

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Abstract **– The article proposes principles of airships classification. Here we discuss methodological approaches to the economic evaluation with regard to application efficiency of airships. The results of the study are the analytical dependencies of reduced costs and prime cost of flight hours on the airship performance, the main flight technical and cost characteristics.**

Keywords **– aerostatic aircraft, airship, application efficiency, aircraft.**

1. Introduction

We need to study the economic feasibility of using airships comprehensively, considering the conditions in which goods are transported, as well as the specifics of them. A comparative assessment of technical and economic indicators showed the high efficiency of airships in areas where, by technical or economic conditions, the use of helicopters and aircraft is impossible or irrationally.

Currently, aircraft manufacturers, summarizing the significant experience in creating and operating airships based on modern technologies, have reached a qualitatively new level in the design, production and the usage of them.

In our opinion, the creation of airships, regardless of type and size, is achievable only if there is scientific and technical policy, coordination of whole range of work on the airships, and a single center (alliance), which will centralize the financial flows to their development, both in the framework of state programs, and by potential customers of aviation services.

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2. Methodology

The evolution of airships contributed to the emergence of classes and types that had never existed before, and could not exist. Many researchers attempted to classify airships both in Russia and in foreign countries. Thus, the SCDETEG Transconsult Company (France) proposes to divide airships into airships with a carrying capacity of 2.5-5 tons (light airships), 10-25 tons (small airships), 50-100 tons (medium airships) and 150-500 tons (heavy airships).

Classification of airships by R.A. Hoffmann (Kiev Design Bureau) provides such categories of classification as the body shape, size of the bearing volume, power circuit, etc., which cover all the main features of airships and give them technical and economic certification [1]. In order to assess the possible range of use of airships for aircraft operations in economy and to consider the features of the technology for their implementation, we have chosen the method of creating lift as the main feature of the classification.

Aerostatic aircrafts include aerostats and airships (controlled aerostats), which are divided into three types: free aerostats (balloons), and if they move with the air mass, then moored aerostats (the second type) are held off the ground with a cable. In addition to the lift generated by the carrier gas in the shell of the aerostat, a dynamic force occurs when the air flows around it. In order to reduce drag, the shells of moored aerostats are made aerodynamically configured. The stability of the aerostat is achieved by installing stabilizers and a suspension system to the cable. The third type includes energy aerostats, on which small motor devices are installed to adjust the position relative to a given point on the ground. The design of the above aerostats is not complicated, and they are different only in the volume of the shell.

Airships can be classified by the following criteria: carrying capacity, body shape, power circuit of the hull, type of carrier gas and control system. The airship capacity is the value of its dense load. So, airships are divided into ultralight (with a carrying capacity of up to 5 tons), light (with a carrying capacity of up to 5-25 tons), medium (with a carrying capacity of up to 25-100 tons) and heavy (with a carrying capacity of up to more than 100 tons).

The aerostatic aircraft classification is shown in the Figure 1. [2].

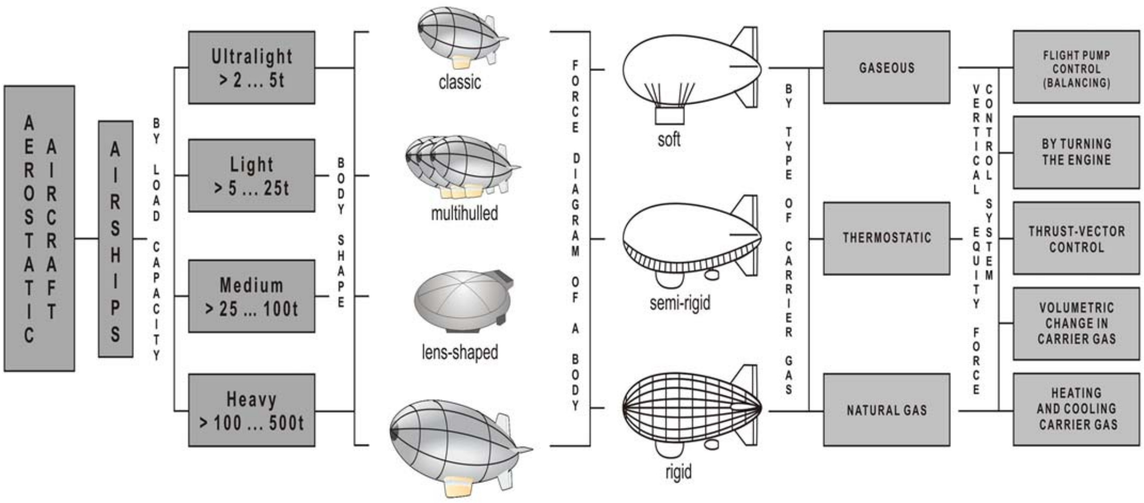

Figure 1. Aerostatic aircraft classification

Useful weight return (as a percentage of the normal flight weight of the airship) increases when the volume rises. In ultralight and light airships, the value of this indicator is slightly worse than in airplanes, while in airships of medium and especially heavy carrying capacity they are significantly higher. This is due to the fact that as a result of the increase in the size of the airship, its lift increases faster than the weight of construction. The light airships have a large surface with respect to their flight weight (increase in friction resistance, leakage of carrier gas through the shell, etc.).

The development of large-capacity airships is related with significant financial costs and a high degree of technical risk. However, the need for airships with a carrying capacity of more than 100 tons will be significantly higher than in medium ones. As a result of this, it is more expedient to build medium airships, and to develop a technology for connecting such airships into blocks in order to transport bulky indivisible goods.

The classic airship body design is aerodynamically configured, elongated with a cross section close to the circle. For modern airships created by foreign companies, the lengthening of the body (the ratio of length to maximum diameter) is 3.5-5.3. The projects for multibody airships are formed by docking the body side to side in a horizontal plane. The prerogative of these projects is to simplify production and increase the annual use of airships. Nevertheless, there are significant disadvantages: decrease in the coefficient of weight return and large coefficient of drag.

According to the power scheme of the body, the airships are divided into nonrigid, semi-rigid and rigid ones. The choice of the power circuit depends, first of all, on the volume of the shell despite the fact that rigid airships have a low weight return. In order to achieve the necessary strength characteristics, high-volume airships are preferred to be rigid.

According to the carrier gas used, the airships are divided into the following main types:

- gaseous airship with the light gas (hydrogen or helium);
- thermal airship with air or other gas with an increased temperature to a value at which the heated gas will have a sufficiently low density;
- those with natural gas in its natural state using its own lift (the project of aerostatic fuel transportation system developed by the Kiev Public Design Bureau for Aeronautics in Antonov State Company).

The most perspectives, in our opinion, are gas-powered aircraft, because the possibilities of providing helium with the required amount for the required fleet of airships are more than sufficient, and its consumption through the body does not exceed 0.5% per year (Figure 1.).

The advantage of heat exchange airships is the possibility of ballasting over a wide range by changing the temperature of the carrier gas and using ordinary air instead of expensive helium. However, there are some disadvantages: significant size compared to similar aircraft using helium, increased requirements for heat resistance of structural materials, the need for continuous operation of the engines to compensate for heat loss inside the body and the associated fuel consumption.

To be able to maneuver aloft, take off and land, the airships have to have controlled vertical force. Traditional methods include controlling aerostatic vertical force by dropping ballast or releasing part of the carrier gas, as well as controlling dynamic lift by changing the angle of attack in the airship body. For modern airships, there is a number of new ways to control vertical force:

- thrust vector control;
- change in flight weight (there are systems where the flight weight is changed due to recharging with atmospheric air, trapping water from the atmosphere);
- change in aerostatic force due to heating or cooling of the carrier gas.

The eclectic use of the above control principles can expand the range of applications of airships.

While improving the airships, the concept of the new aircraft was formed. It is the aerostatic combined aircraft, which is based on a combination of aerostatic and aerodynamic principles within creating lift. The idea of the creating is, first of all, that the structures are supported by the aerostatic force of the carrier gas, and the payload weight is balanced by the aerodynamic force created by the rotor, wing, etc. Aerostatic combined aircrafts do not need ballasting, maneuverability increases with significantly greater productivity than aircraft and helicopters.

Further, the following main groups that are divided by the structural feature while implementing lifting force aerostatic combined aircraft are:

- helistat (helicopter and airship),
- plainstat (plain and airship),
- mixed, combining elements of an airship, airplane and helicopter.

Aerostatic combined aircraft is classified according to load capacity, layout scheme and power scheme of the body. According to their carrying capacity, they are divided into ultralight (up to 5 tons), light (up to 25 tons), medium (25-100 tons) and heavy (100-500 tons). In terms of carrying capacity, the larger the aerostatic combined aircraft, the more efficient it is. The size of aerostatic combined aircraft can be increased to some reasonable limits until technological restrictions come into effect. So, the specialists of the American company «Airon» consider it quite realistic to develop a device with a payload of 3 000 tons.

According to the layout, the helistats can be divided into the following ones:

- aerodynamically configured, with the elongated airship-type body, structurally combined with helicopter power plants located in the lower part of the body («Helistat», developed by an American firm «Piasecki Aircraft»);
- multibody (Helicostat, France), with two gas-filled casings and a rotor installed in the central part of the shaped structure connecting the cylinders;
- toroidal (hybrid airship of the company «Akrazur»). In the center of the toroidal cylinder there is a rotor of a serial helicopter Sicorsky-584-34;
- rotational (spherical balloon airship, in the diametrical plane of which carrier blades are mounted perpendicular to each other, they are controlled by helicopter). On the leading edge of each of them there are pulling propellers that rotate the balloon body. Cabs and cargo are suspended from below the spherical shell;
- lenticular (airships of the Seab-Mura, Flipper group) with horizontal tail inflatable feathers. The power plant consists of three engines spaced along the outer contour of the airship through 120º. The horizontal movement is ensured by the corresponding components of the thrust vectors of the rotors spaced far enough apart. With this layout, one can create the required control moments and provide control of the device in hover mode with the same efficiency as for a helicopter.

A distinctive feature of the plainstat is that the lift, which is necessary to balance the payload, is obtained by creating dynamic lift by the wing, or the airship body, or a combination of them. For example, well-known layout schemes are the following: plainstat (project of the American company «Megalifter»), which has a simple aircraft layout with an average wing position, the fuselage across has the shape of an ellipse, most of which is filled with helium. Since the width of the fuselage is much bigger than its height, the lifting force created by it in addition to the wing is significant.

There are projects with the shape of the body type «bearing body». It is called «Deltoid», most of which is filled with helium. Aerostatic lifting force is not enough to take off a loaded vehicle, so it takes off like an airplane, but at a much lower separation speed. The advantages of aerostatic combined lavers of the «carrying body» type compared to the airplane scheme are its smaller dimensions. Aircraft scheme is designed for flight in the vicinity of the earth. The lifting force of the aerostatic combined aircrafts is created aerostatically and aerodynamically due to the supporting body and wing, and as a result of the effect of the proximity of the earth. Analysis of operating costs shows that such an aerostatic combined aircraft is more efficient than conventional airships of the same weight.

According to the type of construction, aerostatic combined aircrafts are divided into nonrigid, semi-rigid and rigid ones. Some of the previously considered types of aerostatic combined aircrafts are currently supposed to be created by a number of foreign companies, whose experts express their opinion about their extreme potential, and the fact is that the future of aviation belongs to these types of aerostatic combined aircrafts.

When tasks are set to improve economic security and energy conservation, it is advisable to continue the development and creation of aerostatic aircraft. The effectiveness of the use of airships in many types of work in the economy sectors in comparison with traditional aircraft has sufficient evidence both in domestic practice and in foreign ones [3].

3. Results and Discussion

Airships can be used in various sectors of the economy [4]. This is due to the wide range of commercial loads compared to airplanes and helicopters, and a number of other advantages compared to dynamic aircraft.

The main advantage of airships is cost-effectiveness, since fuel energy is not expended on creating lift, as for airplanes and helicopters. The power ratio of airships, starting with a volume of 50 000 m^3, remain almost constant and equal to 0.01. The required power of the power plants comprising airships is 15-16 times less [5]. The absence of the need for continuous operation within power plants increases the level of flight safety in case of failure a lot. Airships provide the ability to transport large indivisible super heavy loads over long distances on an external sling. They are easy to manufacture, reliable, provide the possibility of vertical take-off and landing, hovering, flying at low speeds and altitudes. Possibility of anchoring, comfort, lack of vibration in flight, positive environmental impact on the environment, ability to operate without expensive runways are important advantages of airships.

There are disadvantages, which are:

- large airships (over 100 m), and as a result, high aerodynamic drag;
- difficulty of controlling aerostatic lifting force (burning 1 kg of fuel requires compensation for a weight loss of 1.4 kg of ballast);
- sophisticated mooring and storage technology;
- complicated operating conditions (refueling with helium, shell repair, etc.);
- difficulty in ensuring regular flights (increased restrictions on the wind: takeoff 15-20 m / s, crosswind 5-10 m / s, headwind 35 m / s (from statistics));
- relatively high cost of helium;
- gas losses during operation (0.5% per year);
- poor airship handling at low flight speeds;
- high windage complicating mooring and storage;
- need for ballast on board when flying without cargo.

All of the above disadvantages with the current level of technology can be minimized, and some of them are excluded.

To assess the economic efficiency with respect to the use of airships, economic, mathematical and analytical methods based on statistical domestic and foreign data on aerostatic aircraft were used. The methods were the same as for the dynamic aircrafts [6]. However, the following features of airships were considered:

- duration and range of flight (for an airship they are not limited);
- large and overall dimensions and the use of gas in hard shells, which complicates their operation, increases operating costs;
- large aerodynamic drags, which has a significant impact on the speed characteristics;
- reduced operating modes of engines mounted on airships, which affects the resource characteristics of the engines and, in turn, the environment;
- lack of need for the operation of airships of expensive runways and helipads (only additional devices are necessary for their mooring);
- possibility of operating airships at helicopter-based aerodromes.

The main criterion for the economic efficiency of the airship was the amount of reduced costs per unit during transport work. The additional criteria are the following: cost of 1 tkm, productivity, social and environmental indicators [7], [8].

As a result of the conducted research (comparison of airships with helicopters and airplanes), the analytical dependencies of the reduced costs, the cost of flight hours on the airship performance and the main flight technical and cost characteristics were obtained:

$$Z = \frac{1}{PR}\left(247{,}15 + 0{,}23 \cdot W_T \cdot n + 0{,}87 \cdot 10^{-1} \cdot P_O + 0{,}62 \cdot 10^3 \cdot P_{dv} \cdot n + 6{,}18 \cdot W_{ng} + \frac{0{,}1 \cdot P_{dr}}{R}\right).$$

Also, the dependences of productivity, cost of flight hours, cost of 1 tkm and reduced costs of airship capacity were obtained (Table 1.).

Table 1. Dependence of productivity, cost of flight hours, cost of 1 tkm, reduced costs of airship loading capacity

Indicators	In raw numbers	In per-unit numbers
Prime cost of flight hour (Z_{lc}), rub	Z_{lc}=382,6+18,9$\cdot W_{ng}$	$\overline{Z_{lc}}$=0,61$\cdot e^{-0{,}01W_{ng}}$
Performance, tkm	PR=101,02$\cdot W_{ng}^{1{,}044}$	$\overline{PR}$ =0,52-0,17$\cdot 10^{-3} \cdot W_{ng}$
Cost of 1 tkm, rub / tkm	$Z_{1tkm} = 0{,}17354 \cdot \frac{2{,}975}{W_{ng}}$	$\overline{Z_{1tkm}} = 1{,}086e^{-0{,}01W_{ng}}$
Reduced costs, rub / tkm	Z=0,231+$\frac{2{,}936}{W_{ng}}$	$\overline{Z}$=0,857$e^{-0{,}009W_{ng}}$

These calculations demonstrate that the prime cost of flight hours of airships is about three times lower than the prime cost of flight hours of helicopters with the same carrying capacity, and that the use of airships of higher carrying capacity with a flight range exceeding the practical flight range of helicopters is much more profitable, although the absolute values of the cost of flight hours with increasing range of airships increase.

The performance of airships at hourly flight duration is 2 times lower than the performance of helicopters. With the increase in flight range, that is, when using airships for transporting goods at distances exceeding the practical flight range of helicopters, their productivity increases compared to helicopters. At a cost of 1 tkm and at a reduced cost, low-flying airships (up to 5 tons) are inferior to helicopters for hourly flight duration, and surpass them with a higher carrying capacity and flight range [9].

4. Conclusions

The studies have shown that airships are the most reliable and economical type of transport. With a short flight range (up to 100 km) at a cost of 1 tkm, small airships are like helicopters with the same payload and are inferior to the aircraft in economic terms. At an average flight range (up to 1 000 km), an average airship of a soft design is inferior in economy to an average aircraft with a piston engine. Larger semi-rigid structures are approximately equivalent to the average payload of an aircraft with a turboprop engine, which are 3.5 times more economical than a heavy helicopter. With a longer flight range (up to 5000 km), the medium airship of a rigid structure is inferior to a heavy aircraft with a turboprop engine, and the airship of a large carrying capacity of a rigid structure has advantages over an aircraft with a large payload and a long flight range. Helicopters with such a flight range do not exist at all.

The cost of transportation by airship is approximately the same as the cost of transportation by the sea, and it is much lower than by plane and helicopter, by 1.2.

At a cost of 1 tkm, small airships are not economical for mass freight transport, but they are beneficial when we need specific features of the airships as a vehicle (long flight ranges, special conditions for the delivery of goods, complexity of the route, etc.). Large airships and medium ones are competitive for transport purposes; they can be used for small but constant cargo flows for special applications, where the decisive factor is the advantageous fast transport tasks in comparison with other modes of transport.

Airships are more effective than other aircrafts for working with heavy loads at speeds up to 200 km per hour, for transporting goods of low and medium density (which is less than 0.2 t/m3). Airships are highly economical in a transport performance, and they are relatively lower than airplanes and helicopters.

The calculation results show that the use of airships for performing many types of transport operations is more profitable in comparison with helicopters and airplanes, this is especially noticeable with a long flight range and high carrying capacity, when transporting indivisible bulky heavy load is concerned.

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