Research of wing in surface effect ship configuration and development of an experimental model of increased stability

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Abstract. The article provides an analysis of the foundations of wing-in-surface-effect ship (WISE) development and describes the experiments conducted using the constructed three radiocontrolled and one virtual model of the WISE. The main problems identified during the experiments are described, as well as further prospects for the development of the project.

Keywords: wing in surface effect ship (WISE), ground effect, hydroaircenter, duplex tandem, wing ship, virtual modeling, inductive vortex

1. Introduction

Currently, existing modes of transport effectively use the conditions of the elements, but have the potential for development. The key to the development of existing transport is to find solutions to the main problems:

1. Limited movement speed of vessels in the water environment;
2. Large energy costs for overcoming gravity and preparing special areas for take-off, landing and maintenance of aircraft;
3. Limitations of the earth's surface and heterogeneity of cover when using land transport.

Actual experience in application of the laws of aerodynamic and hydrodynamics has the potential for the development of a new type of transport with a synergistic use of air space, water and land surface. An example of this synergy is the movement of wing-in-surface-effect ship (WISE) in the air, but using the proximity of the earth or water surface:

1. The increase in lift capacity [1];
2. Reducing drag and increasing speed [1];
3. The ability to move over any smooth surface regardless of its composition [2, 3];
4. Safe height and possibility of smooth descent in case of emergency situations [2, 3].

At the moment, there are 4 theories of possible use of WISE:

1. Transportation of people and goods [5];
2. Rescue service [6];
3. Scientific and military surveillance [6];
4. Shock military systems [6].

In view of the existing potential for creating and implementing a new type of transport, 2 goals were set in the study. Firstly, the long-term goal is to create and implement WISE as a new type of transport that more effectively uses the potentials of water and air elements. Secondly, the goal of this stage of work is to study the existing layouts of WISE and create an experimental model of increased stability.
2. Methods for increasing the stability of various schemes of WISE configuration

To achieve the goals of the current stage of the research, the following methods were applied:

1. Collecting and summarizing information about existing WISE projects based on books, articles.
2. Development of prototypes of a new vehicle in the form of radio-controlled and 3D models.
3. Testing of prototypes for stability in the cruise mode during launches of radio-controlled models over a flat earth surface and virtual blowing of models in a virtual environment simulating the movement of the device above the surface 10 cm height.

In the long term, with the accumulation of sufficient information and experience, it is planned to create, test, refine and implement the effective WISE.

During the collection of information, it was found out that at the moment there are 3 lines of WISE development: "airplane", "back-deltoid", "tandem", each of which is developed in connection with the work of the corresponding designers: R. E. Alexeev, A.M. Lippish and G. V. Yorg. Prominent representatives of these lines are the machines: KM [2], [3], X-113 [7] and TAB 8 [8]. At the same time, the development of WISE is currently carried out mainly according to the first two types of layouts. For example, the aircraft scheme is developed in the domestic company RDC-Aqualines [9], and the second type of WISE is actively developed by the South Korean firm WingShipTechnology [10] and the Singapore firm WigetWorks [11].

Common features of the described devices are:
1. Movement at a height of 1 wing chord
2. Converting the incoming flow into a dynamic air cushion
3. Use of combinations of air and underwater means of stabilization and control.

For a visual introduction to the ground-effect, an experimental radio-controlled model of the hydroair-center HAC-1 was assembled, the design of which includes:
- the main fuselage, which is a flat-convex profile with a chord of 0.48 m and a span of 0.52 m, with a relative thickness of 10% and a maximum thickness at a distance of 25% from the leading edge.
- U-shaped tail stabilizer for yaw and pitch stabilization, as well as for the ability to mount the engines above the plane of the main fuselage.
- elevators and rudders,
- 2 brushless electric motors,
- additional wings with a positive V-shape to stabilize the machine on the roll and to install the ailerons at a distance from the center plane to create a sufficient moment of roll control.
- a rotary flap that allows you to transform the wing profile by changing the angle of deflection of the flow coming off the wing.
- catamaran floats-washers for limiting the minimum flight height of the carrier plane, reducing the area of contact between the hull and the underlying surface, and for creating an obstacle to the formation of inductive vortices on the carrier fuselage-wing.

Figure 1. HAC-1 model
During the HAC-1 tests, the calculated cruise mode was achieved, while low stability in pitch and roll was detected, which was manifested in leaving the calculated mode when the slightest disturbances in the form of wind gusts or changes in terrain occurred (Figure 1).

Additionally, the difficulty of maneuvering was revealed due to the deterioration of the ground-effect when trying to perform turns.

Taking into account the test experience, the experimental device HAC-2 was developed, which was based on the previous device, but the wing chord was doubled and a more forward alignment was installed (Figure 2).

![Figure 2. HAC-2 model](image)

HAC-2 after adjusting the S-shape by deflecting the flow flap to the 1-2 degrees top, the device showed greater stability in pitch, but it remained on the ground-effect only in case of active control. During uncontrolled flight, the device either descended to the ground, or went to a height of more than 1 chord. However, compared to the previous model, this device showed smoother fluctuations in pitch and roll, allowing the pilot to control the flight more accurately on the ground-effect.

The turns were performed only in the mode of increased engine power and in conditions of air flight in isolation from the ground-effect. However, compared to the previous model, this device failed to a lesser extent at the time of the roll and more easily moved to horizontal flight after performing the maneuver.

In parallel with the construction and testing of models it was revealed that the first models of designers who were engaged in WISE faced similar problems of stability in pitch.

For example, one of Alekseyev's experimental devices was named "the frog" [3] due to the appearance of oscillatory pitch changes that looked like jumps on a water surface. The same problems were encountered by the designer Troeng on the "Aerobot" machine [1].

It is known that the problem with pitch stabilization in WISE occurs due to the movement of the pressure center along the wing. The research given in the book "Airfoil boat" by Belavin clearly expressed the inverse relationship of the pressure center distance of the wing leading edge from the height of flight [1]. Thus, the higher the wing flies, the greater the moment of force that tends to increase the angle of attack and lift the device. This tendency manifests itself in a clear instability of the device in pitch and requires additional balancing forces.

In the WISE history a lot of techniques of pitch stabilization was applied, which represent:

1. Developed horizontal fins, raised high above the boat and maximally moved away from the plane of the wing forward or backward
2. S-shaped wing profile
3. Duplex tandem wing configuration
4. Reverse delta wing configuration
5. Means of contact with the surface (sledges, skis, hydrofoils, wheels, etc.)
To study of the proven methods of WISE stabilization by pitch, a radio-controlled model of the HAC-3 was built according to the scheme of the Lippisch WIG series with a reverse delta wing and a developed tail fins. At the same time, to speed up the work, the project was greatly simplified, which showed:
• Model span 0.5 m;
• Flat bent wing profile made of single-layer polystyrene foam plate;
• Placing controls and electronics directly on the upper plane of the devise.
At the same time, the main conceptual features of Lippisch models were preserved.

During the tests, the HAC-3 model showed greater pitch stability than the previous two models, which was manifested in an easier hold on the cruise mode (Figure 3). However, when interference occurred, the model also left the ground-effect and required intervention in the control to return to the cruise mode.

3. Development of virtual HAC model
As a result of testing 3 models we made a conclusion that in order to simplify pitch stabilization methods, you need a second pivot point on the ground-effect. This method was used by R. E. Alekseev when building his first SM1 and SM 2, as well as by Gunter V. Jorg, who built a whole series of devices with such component. We decided to design the fourth model according to the duplex tandem scheme, presented on the Figure 4.

During the calculations of the layout of the 4th model, it was decided to conduct initial design and testing in the virtual environment of the Solid Works program. It is assumed that in the virtual environment, even before the construction stage, it will be possible to design and test in more detail a layout that will hold the device on the ground-effect without interference with the control.

The layout of the HAC-4 apparatus was developed based on the ideas of Gunter V. Jorg about duplex-tandem with a convex-concave profile of the front wing and an asymmetric biconvex profile of the rear wing, as well as the ideas of R. E. Alekseev about a longitudinal cargo fuselage and enhanced engine blowing under the wing in the launch mode.

Initially, attention was focused on the study of the wings interaction in duplex-tandem, in this regard, many parts of the body were not installed on the layout. Taking into account the possibilities of virtual modeling, a full-scale size was chosen (span 7.87 m, length 16m, height 2m).
The model was blown by a stream of air at a speed of 120 m/s without attack angle at 0.1 m height above the surface.

A large inductive vortex has been identified that occurs at the ends of both wingtip and especially is demonstrated on the hind wing (Figure 5). The vortex disrupted the flow, shifting the air flow to the side and created a difference in lift between the front and rear wings. As a result of this flow, the model in real conditions would lower the rear wing and raise the front one, which would lead to destabilization of the model in pitch.

To minimize inductive vortices, an endplate was designed that connects both wings, descends to the surface level and rises above the wing by an average of 0.25 m.

After installing the endplate, the end vortices decreased and the flow pattern of the wings became more longitudinal, providing sufficient and smooth flow around both the front and rear wings, as shown in Figures 6-7.
The phenomenon of inductive vortices is compensated by the installation of endplates of different shapes and length, as well as an increase in wing elongation. However, in this work the effect of end vortices clearly showed us the reality of virtual blowing methods, as they clearly demonstrated a phenomenon previously known to us only in theory.

The flow nature of the front and rear wings demonstrated the possibility of normal operation of two wings running behind each other at the same height, which again clearly proved the reality of using a tandem layout for the development of the future device. Project work HAC-4 gave us our first experience of developing and testing the model in a virtual environment, but the main part of the work on the model is still ahead.

4. Conclusion

All the phenomena and theoretical justifications discussed in this paper have already been described in the literature related to aircraft and ekranoplan development. However, it was important for us to get acquainted with the described phenomena in real experiment.

In this regard, we have made 4 important steps of our work:
1. reviewed the basics of WISE development;
2. experimentally tested the ground effect on three real and one virtual models;
3. in practice, we have identified problems of pitch stabilization;
4. initiated the research and use of methods for virtual design and testing of ekranoplan models.

Future research is planned to obtain:
- virtual tests with the identification of specific numerical values of the model's dive and nose up at different speed, height and angles of attack;
- adjusting the layout and working out the additional parts of the model;
- creation and research of a reduced radio-controlled prototype based on a machine developed in a virtual environment;
- testing of radio-controlled models with the revealing of specific digital data on the ground effect depending on the layout, speed, altitude, angle of attack, alignment and other factors.

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