New Generation of Automatic Control Systems for WIG-craft

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Abstract: An accident-free flight at very low altitude over the disturbed sea surface and also marine landing and take-off requires the application of the special methods and means of motion control which are able to solve the corresponding specific problems. Methods of stability provision and solving some other problems of WIG flight by means of automatic control are analyzed[1]. The requirements for motion control systems are reviewed and the criteria for their improvement are given. The statement of the main problems of equipment and software design for flight control at small altitude above the disturbed surface is performed. The aim of investigation is to define the way for operational performance improvement of the vehicles of advanced design. A promising way is by implementation of modern navigation and motion control systems. The experience and achievements in this field of high technology are described. Probable areas of the most effective application of vehicles with such equipment are indicated.

Keywords: low altitude flight, flight control, marine landing, sea waves, radioaltimeter, sensors integration.

1. INTRODUCTION

Ekranoplane is a flying vehicle with special structural distinctions providing low altitude flight ability by using wing-in-ground (WIG) effect. This phenomenon consists of substantial wing lift force increasing and air drag decreasing when moving close to the supporting surface. In this case the air-cushion action in the space between wing and supporting surface is added to the normal mechanism of lift force formation. The velocity of WIG-flight may be around 200-500 km/h depending on vehicle dimensions. The altitude has to be in the range from 0.5m for small vehicles to 5-10m for big and great ones.

Ekranoplanes (or WIG-effect vehicles, WIG-craft, WISE) occupy the specific place among the winged means of trans-porttation. Flight in close vicinity to the underlying surface gives a lot of specific features to these machines, most of which are valuable for effective transportation. But flight control in WIG mode is more complex and difficult against control of free flight at great altitude due to dependence of all aerodynamic indexes on the flight altitude regarding the ground or water surface. It is usually accepted to consider the relative altitude $h_r = h/b$ as the important index of WIG-flight, where h is an altitude of gravity center of ekranoplane concerning an average level of wave surface, b is the wing chord. If $h_r<0.5$, practically all aerodynamic indexes depend on the h_r value, including the aerodynamic coefficients c_x and c_y. Complex character of these dependences often gives the loss of the vehicle stability at some mismatch of flight parameters values for some vehicle aerodynamic configuration.

The idea of ekranoplane may be considered as the inverse of hydrofoil with shallow submerged foils both of which Russian designer Rostislav Alexeev suggested. Hydrofoil has a submerged wing, ekranoplane has a wing above the water. The tandem scheme of such hydrofoil is very effective and gave a good account of itself during many realized projects.

The first ekranoplane constructed by R. Alexeev at Nizhni Novgorod SM-1 was also of tandem scheme and it had not serious problems with longitudinal stability providing, but met difficulty in steady motion above the stormy sea. After these first experiments. Alexeev suggested the well known presently “plane-like” scheme of ekranoplane with high T-like rear tail taken out from the zone of aerodynamic interference with the main wing. It also provides the vehicle longitudinal stability, but only in rather narrow corridor of flight parameters values. The stability can be lost at some mismatch of altitude, pitch and attack angle.

However, originally R.Alexeev expected to hold the mode of flight inside this permissible corridor by experienced pilots and without application of any automatic control systems. The autopilots Smena-4 and Smena-3 (Diomidov, 1996; Zhukov, 2007) were created later, in seventies and eighties, mainly under the formal requirements of the Navy. It was the analog systems for damping and stabilization of 5 main parameters of flight, but without adaptation and using the facilities of modern control theory. Unfortunately, the principles of digital control and integrated multi-channel systems were not realized in the first prototypes of Smena,

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and crash of Soviet Union in 1992 stopped the development of any ekranoplanes and their equipment under the order of Navy.

Two features could characterize the years passed from that time. The commercial rather small ekranoplanes were developed at several countries, but any serious attempts to construct the automatic control system for ekranoplanes motion control were not done (Nebylov et all., 2000; Nebylov et all., 2007). The main aim consisted in creation of the cheapest vehicles under the request of the market, and automation means did not correspond to this concept.

Gradually it became clear that this concept cannot permit to solve the problem of perfect commercial ekranoplane creation and the modern means of automatic control must be the essential part of the vehicle. Automatic control system must be designed in parallel with the vehicle design and influence on the acceptable class of vehicle's aerodynamic characteristics. It is especially important that vehicles without own good stability can be considered as admissible or even optimal if the lift-to drag ratio is great and fuel consumption is least. Providing of flight stability can be imposed entirely on the automatic control system which reliability must be without a shadow of doubt.

2. MOTION CONTROL PRINCIPLES

WIG-effect is an interesting physical phenomenon with multilateral characters, having positive and negative influence for providing the flight in WIG-mode. In order to make the full use of the WIG-effect and to provide high functional characteristics of ekranoplanes as transport vehicles they usually have the following features that distinguish them from the ordinary airplanes:

- wing with small aspect ratio that is relatively lowly attached to the body, or "flying wing" configuration;
- boundary plates on wing ends that enhance wing aerodynamics when moving close to the supporting surface, often - float plates;
- developed tail assembly;
- special equipment to expedite taking off from the water and water landing.

Notice, that the modern ekranoplanes have in the majority a plane-like aerodynamic configuration with a wing of small outstretch index and highly raised tail stabilizer (Fig.1). However, the promising large ekranoplanes are designed under the scheme "combined wing" having a number of advantages. The appearance of the ekranoplane-catamaran of such a scheme with mass of 1500 tons is shown in Fig.2, this ekranoplane was designed for cargo and passenger transportation by "Central Design Bureau on Hydrofoils" named after R. E. Alexeev.

For the essential action of WIG-effect the altitude of ekranoplane flight has to be under the limitation h_r<0.2. At the certain size of ekranoplane it is possible at the limited height of sea waves. Anyway it is necessary to choose the extremely low flight altitude, permissible as to criterion of flying safety at the definite height of sea waves. Even if the vehicle has the natural properties of self-positioning as to the altitude and attitude, only the facilities of automatic control can ensure the required functionality under the circumstances of rough sea.

Unfortunately, ekranoplane has the essential instability of motion in the longitudinal plane and perfect automatic control system is necessary first of all for providing the flight stability. It has been proofed during the operation of the big Russian ekranoplanes Orlyonok and Lun (Nebylov and Wilson, 2001).

For such heavy machines (in 140 ton and 400 ton respectively) the automatic control systems are required definitely (Nebylov, 1996, 2006). For smaller ekranoplanes many attempts to exclude any automation of motion control are known, but only the grim necessity to lower the cost of commercial vehicles causes such attempts that certainly degrade the safety of motion. When the means of automatic control will be more perfect and cheap, the automation of motion control will become callable for all ekranoplanes.

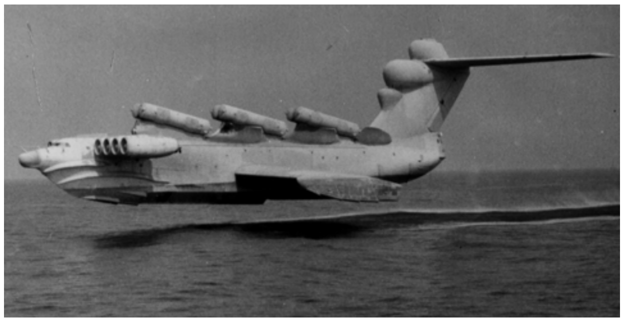

Fig. 1. Ekranoplane Lun

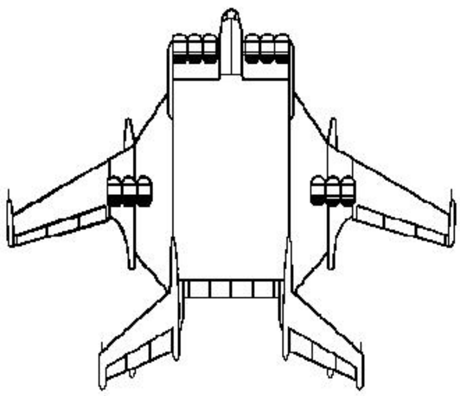

Fig. 2. Ekranoplane with "combined wing" configuration.

Trouble-free motion close to disturbed sea surface may be guaranteed by the application of special methods and means of navigation and control, which must have capability to solve the following specific problems (Nebylov and Wilson, 2002):

- the precise control of the altitude of motion with the error not above 3-10 cm;
- restriction the angles of airframe inclination for the preventing of undesirable tangency of water by the extreme points of body or wing;
- ensuring of the vehicle stability in the circumstances of the action of flake non-linear aerodynamic effects attributed to nearness of surface;

- non-contact measurement, tracking and prediction of ordinates and biases of the field of sea waves for the rising of motion control effectiveness.

At the high speed and low altitude of motion, proper to ekranoplanes, the problem of collision avoidance with conflict vehicles in the circumstances the time scarcity for maneuvering also originates and has a great peculiarity in compare with planes.

3. STABILITY PROBLEM

Ekranoplane as the controlled plant has an essential specificity in comparison to ordinary plane, connected with a sharp non-linear dependence of all aerodynamic coefficients and character of their correlation on a relative altitude of flight h_r Great specificity exists also in the wave disturbances.

When flying far from the supporting surface, an ekranoplane, like an airplane, can have longitudinal stability if its center of gravity is ahead of aerodynamic center. At correct center of gravity positioning, aerodynamic center in airplane flight depending slightly on angle of attack provides fulfillment of this condition with a certain margin.

In the supporting surface action zone the longitudinal stability can be disturbed because the aerodynamic force depends not only on the attack angle but also on motion altitude. Besides, aerodynamic center position may vary depending upon several factors under supporting surface influence. When the altitude decreases, focus moves backwards due to pressure increase at the wing back edge area under positive angles of attack and moves forward - under zero and negative angles of attack.

As the lift force of a wing increases with h_r decreasing, the achievement of the natural stabilization of a flight altitude is possible. However, the range of inherent stability in the space of flight parameters is usually very narrow. In this connection the automatic control system must not only prevent escaping this range, but also essentially correct the dynamic properties of ekranoplane for increasing a stability margin for all controlled parameters of motion. The activity of the channels of damping and stabilization of altitude and pitch is especially relevant.

Undoubtedly, the effective way of stable motion area extension and even of formation of such an area for structurally unstable craft is the use of special autopilots for ekranoplane.

4. ADVANTAGES OF LARGE COMMERCIAL EKRANOPLANES AGAINST THE SMALL ONES

The evolution of planes, hovercraft, hydrofoils and many other types of transport vehicles went "from small to large". But in the case of WIGs the inverse way could be more successful. Several reasons could prove up this thesis.

1. Wing-in-ground effect is especially effective when the altitude of flight is less then 10-15% of the wing chord value. In this case the lift-to-drag ratio may be almost two times more comparably the case of great altitude of flight. If the wing chord is 30-50m and the vehicle configuration is "flying wing", such ekranoplane practically will not have any limitations for flight at stormy sea.

2. Only rather large WIG-craft can perform take-off and landing at stormy sea, and also float as a ship among the great sea waves.

3. The price of perfect autopilot for WIG-craft could be approximately 70,000-100,000 US Dollars (Ambrosovski and Nebylov, 2000), and it increases slowly with increasing the vehicle mass (mainly at the account of more developed actuators). If the reasonable market price for simple in construction 6-8 seater WIG-craft is 300,000-400,000 US Dollars, it is impossible to involve good autopilot in this frame. So, automatically controlled WIG-craft has to be rather large. But as the digital electronics and mechatronic devices became cheaper, after some years the autopilots developed for large WIG-craft will be possible to apply also at smaller vehicles (Nebylov et al., 2007).

Certainly, it is more difficult to provide full load for the large passenger or cargo ekranoplane. It is necessary to find the adequate lines with permanent rather great density of passenger traffic (Nebylov et al., 2009; Nebylov and Tomita, 2003).

5. CONTROL LAWS SYNTHESIS

It is possible to execute the altitude control under the change of wing lift force at:

a) Trailing-edge flap deflection;

b) Elevator deflection (thus a pitch varies);

c) Change of speed of flight at the expense of engines thrust control.

As at pitch angle variation the drag and, therefore, the flight speed changes, the version *b)* demands the presence of velocity stabilization system. Thus all channels of the control complex substantially participate in maintenance of the ekranoplane demanded motion in the longitudinal plane. The synthesis of control laws can be fulfilled under several criteria, but their general structure appears to be almost similar in the majority of cases. The estimations of the vehicle stabilization errors, linear and angular rates and also wave disturbances, being filtered accurately, have to be used at the formation of control signals (Ambrosovsky and Nebylov, 2000; Nebylov, 2002, 2006, 2008).

The automation of ekranoplane take-off and landing is a separate complex problem. It is connected with the coordinated control in several channels, including one of swivel nozzles of engines.

It is important to maximize the seaworthiness of the vehicle. Though it is accepted to consider that in the mode of cruise motion of ekranoplane the sea conditions may not be taken into account, the seaworthiness of such vehicles must be appreciated as a complex index allowing for possibility of planned or crash landing in arbitrary point of a route. It is evident that the seagoing ability is defined by the size and mass of a vehicle and by the peculiarities of its construction.

However, even insignificant rise of seaworthiness and the safety of motion accounted for the optimization of motion control under the concrete characteristics of wave disturbances is very advisable, since it can noticeably heighten the effectiveness of vehicle application by the comparatively simple means. These facilities let, in particular, to ensure the acceptable seagoing ability of the marine fast vehicles of comparatively small size that is very important for the widening of their application at the transport lines with limited freight traffic at high frequency of sailing. At the same time it is absolutely clear that the increase of seaworthiness by means of motion control automation is possible only at a rather high level of intellectuality of the control complex.

The effect of wave disturbances on the vehicle motion at a small altitude above water surface can have the following consequences:

- appearance of the periodical forces and moments exciting the trajectory of motion (rocking, reduction of speed, increasing of fuel consumption);
- likelihood of dangerous situation due to too strong impulsive action;
- creation of significant interference for radar sensors of the parameters of low altitude motion due to tracking by them the profile of large sea waves.

It is necessary to allow for all these factors at the optimization of motion control laws and ensuring the potential characteristics of vehicle seagoing ability. Indeed, it is essential not only the optimization of control laws in the common mean, but also the reasoned choice of controlled parameters of motion and the parameters of wave disturbances, optimization of a set and placing of the diverse transducers, synthesis of algorithms of their integration and the structures of control channels, determination of the tactics of all accessible piloting-navigational information use and the criteria of choice of phase trajectory of motion. The methods of analysis characteristics of wave disturbances are described in details in (Nebylov and Wilson, 2001; Nebylov, 1994; Nebylov et al., 2008, 2009).

Obtained current data on the wave disturbances can be used: (1) for the adaptation of the main motion control loops and (2) for the realization of the principle of combined control. This lets increasing the quality of motion control as to each criterion, mentioned in the item 6. However, main difficulty in the building of the channel of control by wave disturbances is the complexity of the calculation of disturbing forces and moments, attached to the vehicle, based on measured ordinates and the biases of wave field. At two-dimensional sea waves this task is solved enough successfully, but in general case of three-dimensional waves it is necessary to use approximations. However, positive effect may be guaranteed in any case.

The exact calculation of wave disturbances has the special significance at optimization of modes of take-off and landing of ekranoplane. At landing on a strongly disturbed sea surface the course angle with reference to the general direction of the distribution of sea waves should be optimized. At the choice of this angle it is necessary to allow for peculiarities of aerodynamics and hydrodynamics simultaneously.

6. THE CRITERIA OF CONTROL QUALITY OF MOTION ABOVE DISTURBED SEA SURFACE

It is advisable to consider the following criteria:

- rise of seagoing ability of a vehicle, i.e. its capability to move in required direction and to solve other functional tasks at the largest number of sea conditions;

- reduction of fuel consumption;

- depression of vehicle rocking for creating the favorable conditions for crew and passengers or for functioning of on-board equipment.

Naturally, it is impossible to reach the extremum of all these criteria simultaneously and each concrete case requires appointing the only main criterion of control effectiveness, transforming other ones to the rank of limitations. Among a number of limitations it is necessary to consider also the necessity of economical expenditure of control elements resource.

7. DESIGN OF HIGH PRECISION INSTRUMENT FOR MEASUREMENT OF SMALL ALTITUDES

Especially constructed for low altitude measuring, the isotope altimeters have a principle of γ-beam radiation measuring, reflected from the underlying surface. Advantage of isotope altimeters is in its construction simplicity.

However, intensity of measured γ-radiation will depend not only on object altitude, but also on slope structure steepness, situated under the object. Therefore at operation above a structure with large roughness there will be additional errors. The specified lacks of isotope altimeter are essentially irremovable, while in case of radio-altimeter when the information parameter of a radio signal is not energy, theoretically there is an opportunity to improve the measurement accuracy by decreasing a directional pattern of stabilized antenna.

High accuracy of altitude measurement is reached at laser altimeter use, which is caused by an opportunity of extremely narrow beam. However, its lack is unreliable operation at hard meteorological conditions, for example at a fog. Besides, the pulse modulation mode as a rule is used currently in laser altimeters, and the effective separation of direct and back beams in the receiver is connected with technical difficulties if the time interval between them is too short. It limits the minimal possible altitude measured by a laser altimeter.

The non-contact measurement of the characteristics of sea wave disturbance may be produced on the base of processing of indications of several (really – three or four) sensors of sea waves profile each of which includes high-precise positioning altimeter and accelerometer. Presence aboard several sensors, actually measuring the geometrical altitude of flight with reference to disturbed sea surface, ensures also (and first of all) the measurement of such the principal parameters of flight as altitude, and roll and pitch angles (as to the difference of altitudes). The problem of development of high-precise, light, reliable and cheap sensors of altitude in the range up to 10m has been solved (Nebylov, 2001, 2002). The created phase radio-altimeter has the following technical characteristics:

- altitude (or distance) measured - 0-10m;
- measurement error - not greater than 5 cm,
- measured parameter frequency range of - 0-20 Hz;
- the operating RF - from X-range (9000 MHz);
- power consumable - 2 W;
- mass - 1.5 kg;
- dimensions of hybrid strip-line antenna – 110x160 mm.

The device has appreciable advantages against ordinary radio, ultrasonic, radioisotopic and laser altimeters in applications for ekranoplanes.

8. ALGORITHMS OF SENSORS INTEGRATION

The methods and results of algorithms synthesis for processing of indications of several radioaltimeters, several accelerometers, gyrovertical or strapdown INS and several GPS receivers with the aim of estimation of the current meanings of the main parameters of low altitude flight above sea as well as of the characteristics of wave disturbances, are given in (Ambrosovski and Nebylov, 2000). The opportunity of MEMS sensors application is considered (Nebylov et al., 2007; Nebylov, 2008;).

Author develop the special approach to synthesis by teaming up the Kalman filtration and the robust filtration (Nebylov, 2004), that ensures the eligible quality of estimation in the circumstances of incomplete a priori information on the errors of primary sensors with allowance for all diversity of the modes of vehicle motion. The dependence of the estimation accuracy on flight parameters and sea conditions are broadly presented in (Nebylov and Wilson, 2001).

With the use of three or four described radioaltimeters, the integrated system for measurement of parameters of motion close to a sea surface was built, the compact INS was also included in the system. This INS involves three angular-rate sensors, three linear accelerometers, calculator and temperature transmitter for compensation of temperature drift of angular-rate sensors and accelerometers. The measuring system allows tracking the profiles of sea waves $\xi_{n,}$ ξ_l, ξ_r in three points, corresponding to the points of three radioaltimeters installation at a nose and both sides of the vehicle, with the accuracy 10 cm at seaway number 4.

The problem of automatic estimation of the general direction of sea waves distribution may be highlighted separately, that is important for optimization of a mode of landing approach and splashdown. Two ways seams to be the most hopeful for such estimation performing. The first one consists in use of three radioaltimeters with range and Doppler channels whose outputs carry the necessary information (Nebylov, 1996). The second one is connected with processing of digital pictures of disturbed sea surface (Nebylov et al., 2007).

9. COLLISION AVOIDANCE PROBLEM

At the high speed of motion, proper to ekranoplanes (similar to planes), the problem of collision avoidance with interfering vehicles in the circumstance of the time scarcity for maneuvering also originates, which is not characteristic to displacement ships. Low altitude of ekranoplane flight gives point to this problem, as the obstacle could be recognized only at rather small distance. From the other side, the task of going round an obstacle became easy as it becomes the single-agent one against the multi-agent approach, which is demandable for relative motion control of ships.

Another peculiarity of collusion avoidance problem for ekranoplanes consists in ability of maneuver not only by course and velocity, but also by altitude of flight. In critical case of numerical obstacles at sea surface when the avoidance maneuver in horizontal plane is impossible, ekranoplane with perfect motion control system could jump over the obstacle. This maneuver is not desirable due to additional fuel consumption and complexity, but it could increase the flight safety in general case. The decision for any maneuver has to be automatically produced at analyzing the radar and other kinds of navigational information. Some special regulations are necessary to be adopted by IMO and ICAO for juridical providing of traffic control for WIG-craft and other high-speed undisplacement marine vehicles in the areas of maritime traffic, and this work was already initiated (Vasilevsky, Denisov, Nebylov, 2004).

10. PROJECT OF EKRANOPLANE USE AT AEROSPACE PLANE TAKE-OFF AND LANDING

The concept of heavy ekranoplane use for ASP horizontal take off and landing was suggested by A.Nebylov, N.Tomita and Y.Ohkami in 1995 (Nebylov et al., 1997; Tomita et al., 1999). It was shown that ekranoplane with its own mass of 1500 ton is able to launch ASP with starting mass more than 500 ton and landing mass of 60-70 ton. It can solve the problems of ASP transportation from the base to the launch point which is far from human settlements and advantageous for forming the required orbit parameters, ASP fuel loading directly before launch and providing it with the primary speed of Mach 0.5-0.65 in required direction that allows to lower the requirements to the ASP wing area and its engines. The using of such a heavy ekranoplane for ASP assist at launch and landing permits to create an integrated transport system with a lot of advantageous. Another option consists in using ekranoplane for ASP landing only, supposing its launch by means of any other facilities. In such a case the mass of ekranoplane may be decreased several times and resulted from its required seaworthiness.

Three main reasons of ekranoplane use as an additional component in space transportation system may be pointed:

1. ASP can be supplied with simplified and lighted landing gear or has not gear at all. when landing on ekranoplane moving with the velocity equal to ASP one. Extremely large saving of mass will be provided if all equipment for docking is an accessory of ekranoplane. The mass of gear for landing on runway may be approximately 3% of empty mass or 25–30% of payload. So, the using of ekranoplane can permit to increase the payload of ASP on 30% and to decrease correspondingly the specific cost of launch.

2. The specially prepared runway is not required that also decreases the cost of launch.

3. The landing point can be chosen at any area of ocean that gives wide possibilities for ASP landing trajectory selection.

Studying of feasibility and main principles of motion control at ASP landing on the deck of moving ekranoplane was performed. Reality of creation of the indicating start system and the corresponding financial expenditure are estimated.

11. CONCLUSION

The possible effectiveness of the development and application of ekranoplanes with automatic control facilities was stated. Some new results in this field have been already achieved.

The demanded characteristics of ekranoplanes can be available only at use of the new capabilities of perfecting the systems of navigation and motion control created by modern means of supply with flight information and by resources of on-board computer. The control algorithms and some hardware of automatic control systems of ekranoplanes differ essentially from airborne ones and require the special research and design.

REFENCES

Aframeev, E.A., Nebylov, A.V., Savichenko, N.P., Tomita, N., Yoshida, Y. (2000). Study of a Sea Launch Concept of Aerospace Shuttle with Heavy Class Ekranoplane as Takeoff and Landing Assist. In *Proc. of 6th Intern. Symposium on Marine Engineering,* 744-750. The Marine Engineering Society of Japan, Tokyo.

Ambrosovski, V.M. and Nebylov, A.V. (2000). Flight Parameters Monitoring System for Small WIG-Craft In: *Proc. of III Inter. Conference on Ground-Effect Machines,* 15-25. The RSME, Russian Branch. Saint-Petersburg.

Diomidov, V.B. (1996). *Automatic Control of Ekranoplanes Motion.* CSRI "Electropribor", Saint Petersburg. In Russian.

Zhukov, V.I. (1997). Peculiarities of Aerodynamics, Stability and Handling of Ekranoplanes. In *Proc. of RINA International Conference on WIGs*, 67-72. London, UK.

Nebylov, A.V. and Wilson, P. (2002). *Ekranoplane - Controlled Flight close to Surface.* WIT-Press, UK.

Nebylov, A.V.(1994). *Measurement of parameters of flight close to the sea surface*. GAAP, Saint-Petersburg. In Russian.

Nebylov, A.V.(1996). Structural Optimization of Motion Control System Close to the Rough Sea. In *Proc. of 13th IFAC World Congress*, Q, 375-380. San Francisco.

Nebylov, A.V. (2001). WIG-Flight Automatic Control Principles, Systems and Application Advantages. In *Proc. of 15th IFAC Symposium on Automatic Control in Aerospace*, 542-547, Bologna.

Nebylov, A.V.(2002). Controlled flight close to rough sea: Strategies and means. In *Proc. of 15th IFAC World Congress.* 8a, on CD. Barcelona.

Nebylov, A.V. (2004). *Ensuring control accuracy. Lecture Notes in Control and Information Sciences*, 305, Springer-Verlag. Heidelberg.

Nebylov, A.V. (2006). Actual Problems of Motion Control Close to the Sea Surface. *Aerospace Instrumentation,* (2), 41-47. In Russian.

Nebylov, A.V. (2008). Wing-In-Ground Effect Flight Control: New Role of Automatic Systems. In *Proc. of the 17th IFAC World Congress,* 1082-1087. Seoul, Korea.

Nebylov, A.V., Davila D., Sharan S., Nebylov V.A. (2008). Flight automatic control system for the wing in ground effect craft BUCHON-1. *Automatic control in aerospace* http://www.aerospace.unibo.it/index.php?e=6 , 1-7.

Nebylov, A.V, Denisov, V.I., Trofimov, U.V. (2000), Commercial Approach to the Problem of Russian Ekranoplanes Development. In *Proc. of the III Int. Conference on Ground-Effect Machines,* 99-111. The RSME, Russian Branch, Saint-Petersburg.

Nebylov, A.V., Nebylov, V.A., Shepeta, A.P. (2008). Sea Plane Landing Control by Employing Measured Data of Wave Disturbances. In *Proc. of 15th Saint Petersburg International Conference on Integrated Navigation Systems,* 196-198. CSRI "Electropibor", Saint-Petersburg.

Nebylov, A.V., Nebylov,V.A. (2008). WIG-Craft Marine Landing Control at Rough Sea. In *Proc. of the 17th IFAC World Congress,* 1070-1075. Seoul, Korea.

Nebylov, A.V., Nebylov, V.A., Shepeta, A.P. (2009). Wing-in-Ground effect Vehicles: Modern Concepts of Design and New role of automatic control. In *Proc. of 3rd European Conference for Aerospace Sciences (EUCASS)*, paper FD-NEF-2. Versailles, France (in printing).

Nebylov, A.V., Ovodenko, A.A., Sharan, S. (2009).Wing-in-Ground vehicles Perspective & Trends for Development, Modern concepts of design, automatic control & application. In *Proc. of Int. Seminar "Aero India-2009"*, paper TC-4B4, on CD, Bangalore, India.

Nebylov, A.V., Rumyantseva, E.A., Sharan, S. (2007). 17th IFAC Symposium on Automatic Control in Aerospace, In *Book of Abstracts*, p.46, and Proceeding on CD. ONERA, Toulouse, France.

Nebylov, A.V., Sharan, S. Davila, D., Nebylov, V.A. (2007). Flight Automatic Control Systems for The Wing-In-Ground Effect Craft Buchon-1. In *Proc. of 3-rd International IEEE Conference on Physics and Control,* http://lib.physcon.ru/?item=1300 , 1-6.

Nebylov, A.V., Tomita, N. (2003). Effective wig-craft - large ekranoplane with facilities of automatic control. In *Proc. of 10th IFAC Symposium on Control in Transportation Systems*, 109 - 114. Tokyo, Japan.

Nebylov, A.V., Tomita, N., Sokolov, V.V., Ohkami, Y. (1997). The Concept of Heavy Ekranoplane Use for Aerospace Plane Horizontal Take Off and Landing. In *WIGs International Conference*, 81-92. The Royal Institution of Naval Architects, London, UK.

Tomita, N., Nebylov, A.V., et al. (1999). Performance and Technological Feasibility of Rocket Powered HTHL-SSTO with Take-off Assist. *Acta Astronautica*, 45(10), 629-637.

Vasilevsky, I.M., Denisov, V.I. and Nebylov, A.V. (2004). Automatically Controlled Ekranoplanes: Experience and Problems. In *Proceedings of 16th IFAC Symposium on Automatic Control in Aerospace*, 519-524. Elsevier Science, Oxford.