WIG-Craft Flight Control Systems Development

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Abstract: Wing-in-Ground Effect vehicle (WIG-craft) or Ekranoplane as it is called in Russia could take the significant part of the projected air traffic growth. The numerous changes appeared presently in the concepts of WIG-craft design and application during the last years. The modern means of motion control automation has become applicable. The aim of such technologies development is to improve the operational performance of the vehicles of advanced design. The primary sensors and measuring systems for operation at low altitudes were designed to increase the accuracy of control and to provide the fault-tolerance properties. Methods of stability provision and solving other problems of WIG flight by means of automatic control are analyzed[1]. The experience and achievements in this field of high technology are described.

1. Introduction

The border layer between water and atmosphere is gaining in importance as the zone of operation of flying and other type transport vehicles. WIG-effect consists in substantial wing lift force increase and air drag decrease when moving close to the supporting surface. The main control problems arise at such mode of flight at the extremely low altitude are correspond to the ensuring of vehicle motion stability in the circumstances of the action of flake non-linear aerodynamic effects attributed to nearness of water surface.

Trouble-free motion at the altitude of 1-10 m close to disturbed sea surface may be guaranteed by the application of special methods and means of navigation and control capable to solve a set of specific problems [1-9]:

2. General information on ekranoplanes

The important advantages of ekranoplanes are:

potentially higher safety of flight due to possibility of urgent ditching;

reduced requirements to engines operation reliability and, therefore, possibility of their service life fuller use;

absence of necessity for runway and possibility to perform special transport operations using amphibian property.

Along with these advantages there is a negative exhibition of WIG-effect consisting in redistribution of pressure on lifting and control aerodynamic surfaces that complicates vehicle longitudinal static stability provision.

3. The criteria of WIG-craft control quality

It is advisable to consider the following criteria: of control quality of motion above disturbed sea surface:

- guaranteed stability of the vehicle motion at any permissible mode;
- rise of seagoing ability of a vehicle, i.e. its capability to move in required direction at the largest height of sea waves;
- reduction of fuel consumption;
- depression of vehicle rocking for creating the favorable conditions for crew and passengers or for functioning of on-board equipment.

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Naturally, it is impossible to reach the extremum of all these criteria simultaneously and each case of design requires appointing the only main criterion of control effectiveness, transforming other ones to the rank of limitations. It is necessary also to provide economical expenditure of control elements resource. The possible effectiveness of development and application of ekranoplanes with automatic control facilities is stated [2,3]. The aim of investigation is to define the way for operational performance improvement of the vehicles of advanced design by application of modern control systems. The experience and achievements in this field of high technology are described. It is shown that automatic systems are unexpendable for comparatively big ekranoplanes. Unfortunately, all attempts to construct the automatic control system for small commercial ekranoplanes were unsuccessful because the market requested the cheapest vehicles and automation means were not corresponding to this concept.

Step by step it became clear that this concept cannot permit to solve the problem of perfect ekranoplane creation and the modern means of automatic control must be the essential part of the vehicle. Automatic control system has to 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 good own stability can be considered as admissible or even optimal if the lift-to drag ratio is good and fuel consumption is least. The control algorithms and some hardware of automatic control systems of ekranoplanes differ essentially from airborne ones and require the special research and design. Some new results in this field are described.

4. The stability problem

In the supporting surface action zone the longitudinal stability can be disturbed because of aerodynamic force dependence 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.

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

The adoption of WIG has been slow due to the complicated technology issues surrounding the vessel; it is a hybrid vehicle that combines marine and aviation theory, wing theory and air cushion theory, aerodynamic and hydrodynamic theory.

5. The influence of wave disturbances.

The effect of wave disturbances on the vehicle moving at small altitude is complex and can have the following consequences:

- appearance of periodical forces and moments exciting trajectory of motion (rocking, the reduction of speed, the deterioration of the indexes of fuel saving);
- likelihood of the appearance of abnormal situation or catastrophe due to the impulsive exposures of too large value (the hazard of destruction or overturning of a vehicle);
- creation of significant interference for sensors (radar, sonar and others) of the parameters of low altitude motion of vehicle due to tracking by them of the profile of large sea waves.

It is necessary to allow for all these factors at the optimization of motion control laws and the ensuring of the potential characteristics of the seagoing ability of each vehicle. Indeed, it is necessary not only optimization of laws of control in classic mean, but also the composition of controlled parameters of motion and parameters of wave disturbances, the composition and the placing of the transducers of these parameters, the algorithms of their integration, the structures of the control channels, the laws of control, the tactics of the application of all accessible piloting-navigational information and the criteria of the choice of phase trajectory of motion.

The models of sea wave disturbances have a principal significance at the examination of the similar algorithms of estimation and control. The methods of calculation of spectral and correlation characteristics of wave disturbances on the base of the three-dimensional irregular model of sea waves are presented in the paper by the typical results for the various modes of vehicle motion. It is shown that the most lowest frequency spectral component of wave surface in moving coordinate system have a maximum at the definite speed of motion reckoned as the function of the course of vehicle and the parameters of the intensity of disturbances.

6. Development of precision instrument for measurement of extra small altitudes.

The non-contact measurement of the characteristics of sea wave disturbance may be produced on the base of processing of indications of several sensors of sea waves profile each of which includes high-precise positioning altimeter and inertial means [1,2]. 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 the principal parameters of flight. The problem of development of high-precise, light, reliable and cheap sensors of altitude in the range up to 10m is very actual.

In the paper the advantages of application of especially designed phase radioaltimeters [1,2,5] in compare with ordinary ultrasonic, radioisotopic or even laser altimeters are substantiated. The sensors on the base of modern TOF-cameras application are described also.

7. Algorithms of navigation sensors integration.

The methods and results of algorithms synthesis for processing of the of indications of several radioaltimeters, several accelerometers, gyro vertical and GPS receiver in the interests of the estimation of the current meanings of the main parameters of low altitude flight above sea as well as of the characteristics of wave disturbances will be given in the paper. Author develops approach to synthesis teaming up Kalman filtration and robust filtration [6], 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 aircraft motion.

8. The algorithms of combined control on errors and wave disturbances

Obtained current data on the field of 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 to arise the quality of motion control as to each criterion, mentioned in the item 3. However, main difficulty in the building of the channel of control on 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 decided enough successfully, but in general case of three-dimensional waves it is necessary to use approximations. But positive effect may be guaranteed in any event.

9. The project of ekranoplane use for aerospace plane assist at take off and landing.

An increasing interest of mankind to space vehicles launches onto Earth orbit and transoceanic hypersonic flights stimulates searching the new reusable aerospace transport means which have lower cost in all expenditure components, are safer and do not disturb ecology. For the today's stage it is rational to search in a wide range of possible approaches using all available kinds of engines for winged and wingless vehicles, and variable variants of landing.

The inexorable demand of insertion means being reusable and other restrictions impel to initiate the horizontal launch and landing systems (HLHLS) development.

In the most of known HLS projects it is expected to use subsonic accelerating airplane as the first stage of reusable transport aerospace system. But as it shown in [4,7] it would be better to use large-scale Ekranoplane for this aim. It could be a good carrier and accelerator for ASP of

500 ton or more take-off mass that practically would solve the problem of passenger ASP horizontal launch. Moreover, heavy ekranoplane may be effectively used not only for take-off but for ASP landing that would allow to refuse from obligatory restriction of landing on special runway and to use natural water aquatories for landing. It would allow to realize fundamentally new variant of space transport system multistageness principle not only by dismating used stages, but also by "mating" last stage when finishing flight.

Apparently, significant outlooks may be connected with the new possible area of the application of heavy ekranoplanes in executing the search & rescue operations in oceans, as well as at horizontal launch and landing of aerospace plane. For the realization of these projects it is demanded the application of the entire possible conceptual resources of the facilities of navigation and automation of motion control.

10. Conclusions

The demanded characteristics of large ekranoplanes can be achieved only at use of the new capabilities of perfecting the systems of navigation and motion control on the basis of modern control theory and powerful onboard computers. The control algorithms and some hardware of automatic control systems for such vehicles differ essentially from airborne ones and require the special research and design. The new results in this field will been described in this paper. The essential difference exists also in principles of design of small and large ekranoplanes. The development of autopilots for WIG-craft has been slow due to the complicated technology issues surrounding the vehicle and its mathematical models. Ekranoplane is a hybrid vehicle that combines marine and aviation theory, wing theory and air cushion theory, aerodynamic and hydrodynamic theory, modern control theory and methods of adaptive control laws optimization.

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