CYBERNETICS AND PHYSICS, VOL. 6, NO. 2, 2017 , 71–75

INCREASE IN THE AERODYNAMIC QUALITY OF GROUND EFFECT VEHICLE DUE TO THE BIG WAVES TURNING AROUND

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Abstract

One of the main obstacles to widespread the adoption of ground effect vehicles in the world market is their high sensitivity to sea waves. This prevents the implementation of safe and cost-effective long distance passenger transportation over water. The paper proposes a method for avoiding crests of waves, allowing increasing aerodynamic efficiency of the ground effect vehicle in intensively disturbed sea. The solution of this problem is the next step in the development of automatic control systems of the ground effect vehicles and facilitation of the mass use of ground effect vehicle technologies.

Key words

GEV, automatic control systems, altitude minimization, confused sea, advanced transport, aerodynamic quality.

1 Introduction

The ground effect vehicle (GEV) (Fig.1) is a promising vehicle of the future, it is able to have the carrying capacity of sea vessels and the speed close to aircraft, combining the advantages of both types of transport vehicles [Rozhdestvensky, 2000]. In the case of detection of faults, it is possible to land on the water surface without making special landing maneuvers, thus increasing its safety. The GEV is referred to the airfield transport [Zhukov, 1997; Plisov, 1991; Panchenkov, Drachev and Lyubimov, 2006].

This type of aircraft may be used to solve many transportation problems. Possible countries where they can be developed are determined on the basis of their geographic location and strategic interests. The countries with the high economic and technological level of development that have access to the sea represent the greatest interest in the development of GEV technologies and their promotion to the market. In particular, the greatest attention is paid ground effect vehicles at Russia, South Korea, China, United States, Japan and Australia. For example, in South-Korean company Wingship Technology Corp. is already preparing batch-mode production of large ground effect vehicles WTC-500 and WTC-1500 and has the possibility of entering the Asian and American markets [Nebylov and Nebylov, 2014].

Until the late 1980s Russia paid great attention to the development of GEV, conducted a lot of research and development projects, but later state funding of R&D was suspended for more than 20 years. Some technological lag formed over the years requires quite serious attitude to the manufacturing of ground effect vehicles.

GEV benefit from the use of ground effect, i.e. formation of the area of high pressure between its body and the supporting surface, with the distance of less

Figure 1. Ground effect vehicle.

than 0.2 of the wing chord between them. Increased pressure is formed as a result of reflections of the incoming air flow between the lower plane of the wing and the supporting surface. The principle of air cushion occurrence when flying near the ground effect is illustrated in Figure 2 [Pagowski and Szafran, 2014; Pagowski, Szafran and Konczak, 2014; Yun, Bliault and Doo, 2010].

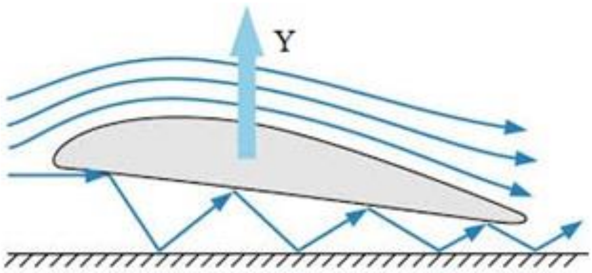

Figure 2. Creation of internal lifting force.

Thus, when flying in ground effect the lift effect of the aircraft is formed not only by the pressure reduction over the top plane of the wing as in conventional aircraft, but also as a result of pressure increase at the bottom.

Most GEV rely on the water surface, but flights over the steppe, desert and any other flat surface are also possible. Flights over the last types of surfaces are limited due to the high and poorly predicted probability of collision with obstacles. Above the water surface, marine vessels that pose the greatest danger to marine low-altitude vehicles can be detected during the flight by the active location method. The negative side of using the water surface as a supporting one is its exposure to disturbance, especially in the ocean. This is one of the main obstacles for the intercontinental flights of ground effect vehicles. Marine disturbance reduces the aerodynamic quality of low-altitude vehicles, scattering the re-reflective oncoming stream. Strong confused sea also increases the probability of collision with the crests of the waves, making it necessary to raise the altitude of flight. The adequate models of wave disturbances are considered in the papers [Nebylov and Wilson, 2001; Nebylov, 2011, Nebylov and Nebylov, 2011].

The minimum altitude limit can be raised by increasing the size of the aircraft, which is not always advantageous because it increases the cost of development and operation, which cannot always be justified. The article proposes a method for lowering the true altitude of flight and increasing the aerodynamic quality of the aircraft due to turning around the large waves by the GEV. Such control mode will reduce the probability of collision of the aircraft with the supporting surface.

2 The Study of the Minimal Gradient Control Method

The aerodynamic quality of the aircraft wing is the lift-to-drag ratio. Proceeding from the fact that the lift and drag forces are determined by the formulas

$$Y = c_y S \frac{pv^2}{2}, \qquad (1)$$

where c_y is lift coefficient, depending on the elongation, the shape of the wing profile and the angle of attack and the blow model of the wing;

$$Q = c_x S \frac{pv^2}{2} \qquad (2)$$

where c_x is wing drag coefficient, characterized by its blow model. The aerodynamic quality can be determined by the ratio of their coefficients

$$K = \frac{Y}{Q} = \frac{c_y}{c_x}. \qquad (3)$$

When flying in ground effect, the aerodynamic quality increases significantly with the altitude decreasing. Therefore, minimization of the average true altitude of the flight is one of the main problems to be solved in the construction of automatic control systems of ground effect vehicles.

Laying path through the chutes of large waves reduces the probability of collision of the ground effect vehicle with waves by reducing the average altitude of the true flight, increasing the aerodynamic quality of the vehicle. Chutes of waves have the smallest heights in comparison with other areas of the sea surface. It means that the movement on it simultaneously can be regarded as a movement in the direction of the minimum gradient of sea surface heights ε, calculated with respect to a certain point of the surface under the hull of the ground effect vehicle

$$\gamma(t) = min\nabla\varepsilon(x, y)\ with\ \gamma_{min}(t) < \gamma(t) < \gamma_{max(t)}. \quad (4)$$

The sector of allowed directions of motion $[\gamma_{min}, \gamma_{max}]$ is determined depending on the speed, distance to the final destination, shortest movement direction and wave height, and has a center point directed to the sequent point. If the desired trajectory of the vehicle is very different from the direction perpendicular to the direction of wave propagation, for example perpendicular to it, then the recommended trajectory of motion will slightly minimize the altitude determined by the minimum gradient method. In this case, depending on the task being solved, it is possible not to use this method of controlling the vehicles or to move at a certain acute angle constant modulo, to the desired course of motion, changing its sign at a distance from the desired trajectory of motion by more than a certain predetermined value.

Moving in the direction of the minimum gradient of the underlying surface decreases the frequency of changes in the true altitude of the aircraft, thus reducing the reference altitude with the same probability of touching the sea surface by the body of the GEV. The cause of the fluctuations of the true altitude of the GEV is sea disturbance, representing the sum of an infinite number of spatial harmonics with different frequencies, amplitudes and phases. Sea waves are described in detail in [Borodai and Netsvetaev, 1986; Galenin, Duginov et al, 1986; Davidan, Lopatukhin and Rozhkov, 1985; Bahar and Zhang, 1995; Wang, Teo, Khoo and Goh, 2013].

The ground effect vehicle has the property of self-stabilization by the true altitude, because when it is modified the lift force which depends on the distance to the supporting surface restores its original value. Therefore, when passing through a wave chute the GEV gradually reduces the absolute altitude while increasing it during the flight over a crest. Since the length of the ocean waves often exceed 300 m and sometimes 500 m, we can talk about the possibility of reducing fluctuations of the true altitude of the ground effect vehicle, despite the low frequency roughness of the sea surface.

For this purpose, by simulation based on a predetermined probability of collision with the sea surface, the permissible supporting true altitude of the controlled GEV is determined. Next, the trajectory of controllable and incontrollable flight is calculated and the formulas (1)–(3) determine the average aerodynamic quality of ground effect vehicle during controllable and incontrollable flights.

The overall efficiency of the control algorithm is determined by the ratio

$$(\hat{K}_c/\hat{K}_r - 1) * 100 \quad (5)$$

where $\hat{K}_r$ is the average value of the aerodynamic quality for a straight flight, the average value of aerodynamic quality for a controlled flight. Dependence of the ratio of aerodynamic quality of the GEV under the influence of the ground effect on the aerodynamic quality of the aircraft flying outside the ground effect can be expressed by the formula [Knyazhskiy, Nebylov and Nebylov, 2017]

$$K/K_\infty = 1 + b/25h\ at\ h/b \geq 0.03\ . \quad (6)$$

Figure 3 shows dependence of aerodynamic qualities of the GEV on its distance from the ground surface.

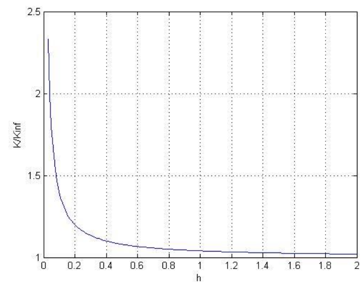

Figure 3. Dependence of aerodynamic qualities of GEV on its distance.

In the simplest case, the direction of motion with the minimum gradient of the underlying surface is determined by comparing the measurements of the point-based location altimeters placed on the body of the aircraft at some distance from each other. The course of the aircraft is deflected to a predetermined angle based on its characteristics, in the direction of the altimeter showing the highest altitude, which makes it possible to gradually approximate the direction of movement of the WIG-craft to the most advantageous direction of motion.

The results of the research were received by simulating a series of low-altitude flights on an agitated sea surface, whose wave heights were determined by the wave model of V. Pearson [Nebylov and Wilson, 2001; Bahar and Zhang, 1995; Knyazhskiy, Nebylov, Nebylov, 2017]. The speed module of the aircraft did not exceed 42 m/s, the width of the sectors of allowed motion accepted values from 10 to 75 degrees. These values were constant for each realization of the flight trajectory.
Figure 4 shows the change of the true altitude of the GEV in time during controllable and incontrollable flights at a speed of 36 meters per second, with an allowed motion sector 50 .

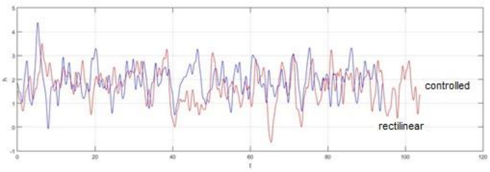

Figure 4. Change of the true altitude of GEV in time.

Figure 5 shows dependence of aerodynamic coefficient on the time for the respective paths.

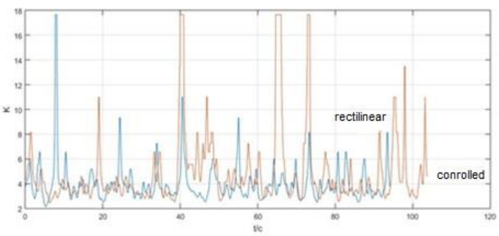

Figure 5. Dependence of aerodynamic coefficient on the time.

Under these conditions, on average, at a controlled flight the aerodynamic quality of the GEV is increased by 21% and the path length grows by 10%.

On average, the aerodynamic quality of the aircraft moving in the direction of the minimum gradient of the underlying surface increases by 10%, but because of the essential differences in the characteristics of the aircraft generalized estimates of the effectiveness of the application of this method must be given for a particular type of vehicles under certain flight conditions.

3 Conclusion

The simulation results show a significant increase in the aerodynamic quality of the GEV using the minimal gradient control method in its autopilot and confirm the expediency of avoiding the crests of waves rough sea waves. It can be concluded that there is a need for the adaptive system of control of lateral movement of the GEV over the disturbed sea surface, adjusting the parameters of movement of the low-altitude vehicles under current weather conditions for improving the aerodynamic quality of the aircraft and flight safety.

Acknowledgements

The work was supported by the Russian Scientific Fond under the project 16-19-10381 and by the Russian Foundation for Basic Research under the project 15-08-00423-.

References

Rozhdestvensky, K.V. (2000). *Aerodynamics of a Lifting System in Extreme Ground Effect*. Springer Science & Business Media.

Zhukov, V.I. (1997). *Features of aerodynamics, stability and controllability of the ekranoplan*. TsAGI Publishing Department.

Plisov, N.B. et al(1991). *Aerohydrodynamics of ships with dynamic principles of maintenance*. Shipbuilding, 248 p.

Panchenkov, A.N., Drachev, P.T., and Lyubimov V.I. (2006). *Examination of ekranoplans. N.Novgorod*. Typography Volga Region, 656 p.

Nebylov, A.V. and Nebylov, V.A. (2014). *Problems, theory and systems of the automatic movement control of the ground effect vehicle.* The 12th All-Russia Control Issues Conference VSPU-2014.

Pagowski, Z.T. and Szafran, K. (2014). *“Ground effect” Inter-Modal Fast Sea Transport.* TransNav the International Journal on Marine Navigation and Safety of Sea Transportation, Warsaw, Poland, **8**, No 2, pp. 317–320.

Pagowski, Z.T., Szafran, K., and Konczak, J. (2014). *”Ground effect” Transport on the Baltic Sea, Maritime Transport & Shiping.* Marine Navigation and Safety of Sea Transportation, Warsaw, Poland, **8**, No 2, pp. 221–234.

Yun, L. , Bliault, A., and Doo, J. (2010). *WIG Craft and Ekranoplan: Ground Effect Craft Technology.* Springer.

Nebylov, A.V and Wilson, Ph. (2001). *Ekranoplane “Controlled Flight close to Se”*. nograph. Southampton, UK: WIT-Press. Computational Mechanics Publications. 300 p.

Nebylov, A.V. (2011). *Prospects for Cooperation in New-Generation Alternate High Speed Water-Borne AirTransportation System Development* AeroIndia International Seminar. Bangalore. pp. 1–6.

Nebylov, A.V. and Nebylov, V.A. (2011). *Seaplane Landing Smart Control at Wave Disturbances*. 18th IFAC World Congress. Milano, 2011.

Borodai, I.K. and Netsvetaev, Iu.A. (1982). *Seaworthiness of ships. Shipbuilding*. 287 p. (in Russian)

Galenin, B.G., Duginov, B.A. et al (1986). *Wind, waves and seaports. Gidrometeoizdat*. 264 p. (in Russian)

Davidan, I.N., Lopatukhin, L.I., and Rozhkov, V.A. (1985). *Wind turbulence in the world ocean. L.: Gidrometeoizdat* 256 p. (in Russian)

Bahar, E. and Zhang, Y. (1995). *Scatter cross sections for sea surfaces characterized by Pearson-Moskowitz spectral density function a new unified full wave approach*. Antennas and Propagation Society International Symposium. AP-S. Digest. Newport Beach, USA.

Wang, H., Teo, C.J, Khoo, B.C., and Goh, C.J. (2013)*Computational Aerodynamics and Flight Stability of Wing-InGround (WIG) Craft*, 7th Asian-Pacific Conference on Aerospace Technology and Science , Elsevier, pp. 15–24.

Knyazhskiy, A.Y., Nebylov, A.V., and Nebylov, V.A. (2017) *Optimization of WIG-craft 3D-trajectory near the rough sea surface*, EUCASS (European Conference for AeroSpace Sciences), 3-6 July 2017, Milan, Italy.

Knyazhskiy, A.Y., Nebylov, A.V, and Nebylov, V.A. (2017) *Methods for Signal Processing and Motion Control of Ground Effect Vehicle*. 4th IEEE International Workshop on Metrology for Aerospace. Padua, Italy, June 21-23, 2017.