SEA PLANE LANDING CONTROL
BY EMPLOYING MEASURED DATA OF IRREGULAR SEA WAVES

Vladimir Nebylov[1], **Fedor Voronin**[2]

State University of Aerospace Instrumentation,
67, Bolshaya Morskaya, Saint-Petersburg, 190000 Russia
Fax: +7 812 4947018, E-mail: nebylov@aanet.ru

Abstract: WIG-craft Wing-in-Ground Effect vehicle (WIG-craft) or ekranoplane landing direction optimization criteria is suggested which heeds the irregular sea waves features and provides the minimal mechanical strain on the vehicle body at hydrodynamic braking. The problem of automatic choice of the landing trajectory direction regarding the main direction of sea waves propagation has been considered. The peculiarities of marine landing at different characteristics of three-dimensional irregular model of sea waves and flying vehicle characters are investigated.

Keywords: wave disturbances, landing mode, landing direction, optimization criteria, hydrodynamic braking.

1. INTRODUCTION

The take-off and landing modes at rough sea are the most difficult and dangerous stages of sea plane flight. Sea plane landing on the disturbed sea surface provokes the essential mechanical loads applied to vehicle body during the bottom contact of a water surface when hydrodynamic breaking starts. Irregular rough sea does these influences non-uniform and stochastic. With the purpose of decrease of these specified loads designers try for lower landing speed of seaplanes in comparison with planes which perform landing on air-strip, however it can be made only due to impairment of other parameters of flying vehicle efficiency or due to the elaborate mechanization of a wing. On the other hand, the opportunity of mechanical breakage at contact with a wave increases at elaboration of wing mechanization. Therefore optimization of the landing trajectory direction regarding the main direction of sea waves' propagation that allows to lower the mechanical loads in more simple way, has the great importance.

The problem of optimum choice of landing approach direction is not trivial. Landing against wind allows to lower vehicle landing velocity in relation to a surface, but water surface deviation has a greater steepness. At the approach perpendicular to wind direction the average deviation of water surface decreases, but danger of greater lateral disturbances and overturning increases. The optimal landing approach direction depends on characteristics of sea surface, wind speed and features of flying vehicle construction. For optimization of landing mode it is necessary to define automatically the main direction of sea waves' distribution by means of on-board equipment.

2. LANDING MODE OPTIMIZATION CRITERION

The criterion and methods of seaplane landing mode optimization in rough sea conditions, provide the minimal mechanical strain at hydrodynamic braking, are offered in the paper. The key factor is automation of landing approach direction selection in relation to a general direction of sea waves' propagation, leading to extremum the criterion pointed. The rather simple criterion of "softness" landing, which is represented by the r.-m.-s. value of vertical velocity of vehicle bottom immersing into water σ_V , was accepted as the most successful one after consideration several variants of formal criteria. This criterion is formularized:

$$\sigma_V = V\sigma_\alpha ,$$

where V is the vehicle landing horizontal velocity, σ_α is the r.-m.-s. value of waved surface bias along the landing trajectory.

When deducing a resulted expression for criterion σ_V, the rather adequate mathematical model of

---

[1] Postgraduate student of SUAI
[2] Programmer

completely developed windy sea is necessary, as only this general occasion of sea wave disturbances is of great interest and allows to do the widest conclusions. The formulae of Neumann and Pierson-Moskowitz as the basic spectral models of irregular sea waves, the r.-m.-s. values of waved surface bias along a landing trajectory and the expression for the spatial spectrum $E(k, \psi)$ were used [1, 2].

The resulted formula is:

$$\sigma_V = (V_l - \upsilon\cos\psi)\times$$

$$\times\sqrt{\int_0^{\infty}\left(\begin{array}{l}\int_0^{\pi/2}(\cos^2\psi\cos^4\chi P(\chi,k)d\chi + \\ +\sin^2\psi\cos^2\chi\sin^2\chi P(\chi,k))d\chi\end{array}\right)dk}\,,$$

were for Neumann's spectrum and for Pierson-Moskowitz spectrum correspondently

$$P(\chi,k)=\frac{1.03\cdot 10^{-2}}{k}\exp\left[-\frac{0.112\cos^2\chi}{\left(k\left(3.95_{m*c^{-5/2}}\right)(\upsilon/g)^{5/2}\right)^2}\right]$$

and

$$P(\chi,k)=\frac{1.03\cdot 10^{-2}}{k}\exp\left[-\frac{0.112\cos^2\chi}{\left(k(0.391)(\upsilon^2/g)\right)^2}\right];$$

χ is the angle in relation to a wind direction, k is a spatial frequency, υ is a wind velocity, ψ is the angle in relation to a wind direction, V_l is the air velocity.

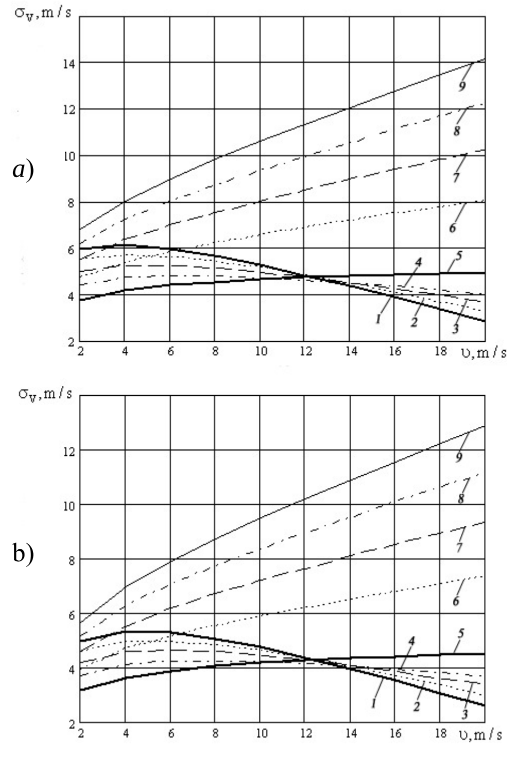

Fig. 1. Criterion σ_V for Neumann's spectrum (*a*) and for Pierson-Moskowitz spectrum (*b*) at landing velocity 40 m/s and at different landing directions: 1 - ψ =0, 2 - ψ = 30°, 3 - ψ =45°, 4 - ψ =60°, 5 - ψ =90°, 6 - ψ =120°, 7 - ψ =135°, 8 - ψ =150°, 9 - ψ =180°.

The obtained expression permits to investigate the “softness” value dependence on many factors, firstly, on the landing direction in relation to a wind direction coinciding with the general sea waves’ propagation. As a result the 2D and 3D-plots have been constructed. The required parameter σ_V was calculated at an angle between a landing approach direction and a wind direction values from 0 up to π; landing velocity of 30 m/s and the wind velocity from 1 m/s up to 20 m/s.

3. OPTIMIZATION RESULTS ANALYSIS

The analysis of the constructed plots allows drawing a conclusion that the optimal landing approach direction depends on wind velocity which for completely developed windy sea waves’ defines all its characteristics. At wind absence (in the case of υ=0) the landing mode is equally favorable ball-park for all directions. At wind appearance the load of wave disturbance on the vehicle during the contact with water is higher at use of Neumann model for sea disturbance spectrum. It is connected with exceeding of Neumann spectrum values against Pierson-Moskowitz spectrum values at high frequencies that gives "rugged" waved surface. It is possible to note also that at small wind velocity and, accordingly, small power of sea waves disturbance the complexity of landing practically does not depend on a direction at Pierson-Moskowitz model also as at Neumann's model. The most important is optimal landing conditions dependence on a direction at various sea roughness numbers. At the small disturbance at wind velocity of 2-10 m/s the most favorable landing approach direction is ψ =90°. At the moderate disturbance corresponding to the wind velocity of 10-14 m/s all directions in the interval 0-90° are acceptable for landing approach and provide rather similar conditions in the sense of mechanical loads on the body. In rough sea, corresponding to the wind velocity of 14 m/s and above, the situation sharply varies, and the most favorable direction of landing approach will be against the wind (ψ =0). The difference in loads at favorable and adverse landing approach directions can exceed an order. The disturbance load at landing decreases approximately twice in the cases of a direction choice ψ equal to 0° or 30°, in comparison with the case of ψ =90°. At any wind velocity the most adverse for landing approach is the direction 180°. Any direction between 90° and 180° could not be favorable at any significant disturbances. It is interesting that the approach direction ψ =60° is rather favorable at any wind velocity.

4. IMPLEMENTATION OF MOTION CONTROL METHODS AT LANDING

For realization of the elaborated recommendations concerning a landing direction of flying vehicle it is desirable to have aboard a complex of instruments for estimation of intensity of sea disturbance (r.-m.-s. heights of sea waves’) and the main direction of sea waves’ propagation. There are few types of sensors, capable to solve such problems. The most well-known of them is the around-looking radar with an opportunity of estimation of width of spectrum for the signal reflected from the sea surface [3]. In width of spectrum and other parameters of the reflected radar signal the intensity of sea disturbance is estimated, and the main direction of sea waves’ propagation is defined as a direction with the maximal distinction of the reflected signal. However, the around-looking radar is a rather complex and expensive instrument, and estimation of the main direction of waves' propagation in this way demands significant time to finish it completely during one cycle of angular scanning.

Another well-known way of the main direction of sea waves' propagation estimation problem solution is using of three radioaltimeters with magnitude and Doppler channels for the general direction estimation [4]. Joint processing of such altimeters and inertial sensors signals allows estimation in real time of the main direction of waves' propagation, intensity of wave disturbance, and also the altitude of vehicle flight in relation to an average level of the disturbed sea surface and roll and pitch angles.

Lately, due to quick perfection of digital cameras it is possible to use the simplest method of sea surface characteristics definition, which consists in processing the sea surface photos. Algorithms of remote definition of sea waves' general direction by sequence of current sea surface photos are offered and analyzed [5].

Principles of coordinated control during landing should be developed for all steering structures of vehicle in view of an opportunity of obtaining the current information about sea waves' properties from the on-board instruments. It implies first of all to flaps and an elevator. As for slats and brake dashboards, they provide the maximal aerodynamic factor C_y and accordingly the minimal possible horizontal velocity during the moment of flattening (zeroing of vehicle vertical velocity before the moment of contact with water), not paying attention to the increasing value of factor C_x that would be inadmissible in cruising flight.

5. CONCLUSION

As a result of fulfilled investigation the technology of landing mode optimization for sea plane has been developed with the aim to guarantee the fail-safe landing at heavy sea. The outcomes of investigations show depending of the optimal landing direction on the number of sea roughness, wind velocity and vehicle landing velocity. The developed technology application allows improving the all-weather characteristics of sea planes exploitation.

REFERENCES

Nebylov A.V., Wilson P. Ekranoplane - Controlled Flight close to Surface. WIT-Press, Southampton, UK, 2002.

Ambrosovsky V.M., Nebylov A.V. Flight Parameters Monitoring System for Small WIG-Craft In: III International Conference on Ground-Effect Machines / The RSME, Russian Branch. Saint-Petersburg, pp. 15-25, 2000.

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

Nebylov A.V., et al. Sea wave parameters, small altitudes and distances measurers design for motion control systems. In: AGARD-NATO CP-556, Dual Usage of Military and Commercial Technology on Guidance and Control, Neuilly-sur-Seine, France, pp.201-212, 1995.

Nebylov A.V., Nebylov V.A., Panferov A.I., Shepeta A.P. WIG-craft Marine landing control at rough sea, 17th IFAC Symposium on Automatic Control in Aerospace, Toulouse, 2007.