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Feasibility study of reusable space plane landing with WIG-craft assist

Alexander Nebylov and Vladimir Nebylov***

**Doctor of technical Sciences, Professor*

Saint Petersburg State University of Aerospace Instrumentation, 67, Bolshaya Morskaya str., Saint Petersburg.
e-mail: nebylov@aanet.ru

***PhD*

Saint Petersburg State University of Aerospace Instrumentation, 67, Bolshaya Morskaya str., Saint Petersburg.
e-mail: vladnebylov@gmail.com

Abstract

Numerous attempts to reduce the cost of launching a payload into low-altitude orbit were taken in many countries and characterize the current trend to make space projects economically viable and less costly for the budget. Unfortunately, this process has not led to a sharp decrease in the specific launch cost, which for various media appearances on many publications lies in the range of 12000-20000 US $ / kg. Of course, the real value of the cost of launching to a specific orbit in specific circumstances is a corporate secret and is dependent on the cost of insurance. In this paper the use of horizontal take-off and landing (HTHL) is considered in the attempt to make space flights cheaper and more reliable.

1. Introduction

A few examples of innovations of innovations in space launch could be analyzed.

As it was stated, Roskosmos starts the work for creation of Russian extra-heavy rocket. In fact, it would be "a truck for delivery to deep space missions" with a lower unit cost of startup [1]. Details of upgrading a heavy cargo rocket were not disclosed. However, it is clear that this way of "scaling" of the prior art can not reduce the cost of launch at times, and only at tens percent.

The most decisive step in the direction of reducing the specific cost of launch was made by the US private enterprise “Falcome Space Exploration Technologies Corporation (SpaceX)”. Its development of the launch of vehicle Falcon 9, from the very beginning was designed to make it reusable and spaceship Dragon (to be launched by the Falcon 9), should also be reusable. To date, the apparent success of this project is just a soft landing of the spent first-stage of Falcon 9 rocket, but this again cannot reduce the cost of launch several times, but only by tens of percent. Perhaps a greater positive effect will be achieved in the future at the test flight of rocket Falcon Heavy, which is scheduled to 2017. The idea of SpaceX to reduce the cost of launch by making reusable the first stage of the rocket is natural, since the construction of the first stage is the most expensive element of the carrier. However, the promise to reduce the specific cost to $1,100 per kilogram looks impossible to implement at the way selected by SpaceX. It is also important that, in contrast to the commercial launches, government and military launches in the US require special certification procedures, significantly, by tens million dollars, increases the nominal cost of running [2].

Another promising direction to make the launch cheaper is the transition from the vertical to the horizontal launch, which uses an air breathing jet engine, which consumes oxygen directly from the atmosphere (at least on the heights with the required air density), and not from the tank. It is known a simple method of expansion the velocity range being developed by the vehicle use of boosters, able to give to Aerospace Plane (ASP) the aviation speed at which the main air breathing jet engine begins to operate effectively.

Researches in the field of payload horizontal injection into space (HTHL) by the use of scramjet at the final stage of launch were carried out in different countries. For example, in the United States in the frame of the program «Hyper-X» the small drones Boeing X-43 is developing for the ramjet engine test (https://ru.wikipedia.org/wiki/NASA_X-43).

An exceedingly important invention of aviation and space is air launch. Air launch is a method of launching rockets or aircraft from another aircraft (Fig. 1). The main advantages of air launch include the possibility of saving fuel by eliminating low-altitude and low-speed portion of the flight.

Most often, the aircraft is the carrying aircraft, but a balloon or airship can as well be used. The first attempts to carry out air launch of a rocket from the fighter NOTS-EV-1 Pilot were made in the late 1950s in USA, but ended in failure. At the same time, the first aircraft launched from carrier aircraft was created. In USSR, there also existed a project

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“Spiral” aerospace system. The project was planned to launch a booster rocket from a hypersonic spreader, but this idea was never implemented. Since 1990, Stargazer (formerly called Boeing B-52 Balls 8) has operated in the United States based on L-1011 spreader plane and Pegas carrier rocket.

Figure 1: Air launch of a space vehicle from a booster plane

The project of ASP launch from the heavy airplane, that was developed under the leadership G.E. Losino-Loziskiy, s the main famous. It has the name MAKS –Multipurpose Aerospace System. Unfortunately, the project was stopped after the collapse of the SU, as too expensive.

Let us consider the project of space launch system with Ekranoplane as a booster for ASP and a mobile landing strip.

The project of ekranoplane (or Wing-in-Ground effect vehicle or WIG-craft) usage for horizontal launch and landing of ASP was offered by N.Tomita, Y.Ohkami and A.Nebylov in 1995 [1,3,6] and since that time it has been developed in a view of detailed reasoning and various feasibility studies [4-11]. The goal of investigation is the creation of space transportation system with reduced commercial cost of payload injection into LEO or MEO and extended functional capacity.

Integrated launch systems that include aerospace plane (ASP) and ekranoplane as a booster are analyzed. It has been proven [15-17, 21] that ekranoplane with mass of 1600-2000 ton is capable to launch ASP with initial mass of 530-700 ton and landing mass of 60-70 ton. Ekranoplane can give to ASP the primary speed of Mach 0.5-0.65 in needed direction which allows to lower the requirements of ASP wing area and its engines. Some other advantages of the offered transport system are connected with possible using of ekranoplane for ASP landing. Heavy ekranoplane is the single vehicle for realizing this innovative idea of docking of the descending ASP in the specific stage allowing to expand opportunities of its landing. The technology of ASP horizontal landing without undercarriage by docking with ekranoplane at the last stage of decent and the requirements of control systems are discussed below.

2. Concept of «ASP-Ekranoplane» Launch System

Four key reasons may be duly noted for substantiated using ekranoplane as an additional component in space transportation system that assists ASP Launch and Landing [18-20]:

The launch point and the landing point can be chosen in any area of ocean that gives wide possibilities for ASP landing trajectory selection.

Ekranoplane can carry heavier ASP than plane, and give to it the necessary initial speed.

The cosmodrome with specially prepared runway is absolutely not required.

ASP can be supplied with simplified and lightened landing gear or no gear at all when landing on ekranoplane, moving with the velocity equal to that of ASP. 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, ekranoplane‘s use can increase the payload of ASP by 30% and accordingly decrease the specific cost of launch by the same 30%. An important reason that makes usage of horisontal launch reasonable is the greater freedom in choosing the time and place of launch. If it is necessary to launch a satellite or spacecraft from a stationary platform to a strictly predetermined orbit, it can primarily be done in a certain period of time ("launch window").

The problem of ekranoplane’s type selection for «ASP-Ekranoplane» system is very relevant.

The variant of ASP landing to the deck of moving ekranoplane by the use of docking and mechanical mating is the most critical one and produces the most harsh demands for motion control systems‘ accuracy and reliability.

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3. Comparison of airplanes and ekranoplanes as boosters/launchers

There are four main problems of air start, which are common to both types of busters/launchers:
1. Delivery of cargo above 30 km by aircraft using a wing to create lift force is practically impossible due to low air density. To bring cargo to a greater height, it is necessary to use the rocket technology.
2. The launch mass of the carrier rocket (CR) is tens, and often hundreds of times higher than its payload. Therefore, in order to put a vehicle weighing about 2 tons into orbit, it is necessary to ensure acceleration and launch of a rocket weighing about 200 tons.
3. Satellites are often adapted to withstand only axial overloads, and horizontal overloads for them may be unacceptable.
4. The efficiency of the buster is determined by its final speed and carrying capacity. The most effective are hypersonic busters. Creating a hypersonic aircraft with a large carrying capacity is a daunting task.

The advantage of aircraft over ekranoplanes: great speed and altitude. The largest An-225 aircraft (Fig. 2) has a payload of up to 250 tons, a cruising speed of 850 km / h, practical ceiling of 12,000 m and a range of about 4,000 km, with a length of 88.4 m, an altitude of 18.2 m, a wingspan of 88.4 m and a mass of 250 tons.

Figure 2: An-225 super-heavy jet aircraft

The advantages of ekranoplanes over airplanes: significantly greater payload and the opportunity of landing and taking off from the disturbed sea. The latter advantage can be used for air launch from any point in the ocean. In this case, the space plane and the rest payload are installed on the ekranoplane. Also, if necessary, it is possible to carry out the refueling. Due to this, it is possible, instead of saving fuel, to take additional payload.

The largest in the world [1,2,21] ekranoplane "KM" had a loading capacity of 304 tons and operating speed of 500 km / h. Its length was 91 m, height of 21.8 m and a wingspan 37.6 m. At the same time, the maximum speed of the ground-effect vehicle "KM" reached 650 km / h, and for some sources it reached 740 km / h.

Since both of the considered aircraft are of similar size and weight, it is possible to make a comparison of them as an ASP accelerator/launcher. The speed of the An-225 is 200 km / h higher than the “KM” speed. The load capacity of the KM is higher than that of the An-225 by 54 tons. The most appropriate criterion for evaluating the efficiency of the use of the vehicle is the maximum permissible mass of the payload (for example, ASP), which is being put into orbit using these busters. Since the principle of impulse conservation is the basis of jet propulsion, it is possible to increase the maximum permissible mass of the payload either by increasing the launch speed of the launch vehicle or by increasing the mass of the launch vehicle fuel. Let us estimate the decrease in the minimum mass of the launch vehicle, required for launching a payload into orbit, due to increase in the launch speed of the launch vehicle using the vehicle- buster.

Starting (initial) weight of ASP can be divided into two components

$$m_0 = m_e + m_f , \tag{1}$$

where me is the mass of ASP with the amount of fuel necessary for the flight and landing, after entering into orbit, mf is the mass of fuel necessary for bringing the ASP into orbit.

Since the most important task of an air launch is to minimize the mass of the ASP, it is necessary to calculate the minimum amount of fuel sufficient to place the ASP into orbit. The amount of fuel is proportional to the mass of the ASP, which is a predetermined value.

To minimize the starting mass of the ASP, it is necessary to impose a restriction on not exceeding the required characteristic speed V_x^{req} over the available one V_x^{ava} . In this case

$$m_0 \to \min \left| \begin{array}{l} V_x^{ava} \ge V_x^{req} \\ m_e = const \end{array} \right. . \tag{2}$$

The required speed is calculated by the formula $V_x^{req} = V_{x\,id}^{req} + \Delta V_n$, where $V_{x\,id}^{req}$, is the ideal required characteristic speed, ΔV_n is the loss of the characteristic speed from the action of gravitational, aerodynamic and air pressure forces at the engine nozzle section, usually in the range of 1350-1650 m / s.

The ideal required characteristic speed of the ASP output into the orbit of radius ro is determined by the formula [5]

$$V_{x\,id}^{req} = \sqrt{\frac{\mu_E}{r_o}\left(\frac{2r_o}{R_E}\right)}, \tag{3}$$

where μE = 3.986 · 105 km3 / s2 is the gravitational constant of the Earth, RE = 6371.4 km is the average radius of the Earth. The available characteristic speed can be calculated by the formula Tsiolkovsky

$$V_x^{ava} = w \ln\left(\frac{m_0}{m_к}\right), \tag{4}$$

where w is the effective gas flow rate from the engine nozzle (specific impulse), me is the final mass of the ASP

$$m_0 = m_e e^{\frac{V_x^{ava}}{w}} \tag{5}$$

Given the constraint (2), the minimum m0 will be reached at $V_x^{ava} = V_x^{req}$.

Let us determine the dependences of reducing the minimum starting mass of the ASP from increasing the initial height and speed due to the air start. The higher the launch height of the ASP, the higher the fuel economy due to the change in the potential energy of the ASP and the reduction of losses from the reduction of the influence of gravitational and aerodynamic forces, and the counteraction forces at the engine nozzle section.

The ideal required characteristic speed due to an air start from a height of hst is calculated by the famous formula

$$V_{x\,id}^{req\,as} = \sqrt{\frac{\mu_E}{r_o}\left(\frac{2r_o}{R_E + h_{st}}\right)}, \tag{6}$$

Using (5) and (6), one can obtain the formula for calculating the minimum mass of the ASP

$$m_0 = m_e e^{\frac{\sqrt{\frac{\mu_E}{r_o}\left(\frac{2r_o}{R_E + h_{st}}\right)} + \Delta V_n}{w}} \tag{7}$$

The minimum height of the low near-Earth orbit is 193 km, so we take r0 = 193 km. In this case, when starting from the earth's surface or near it, $V_{x\,id}^{req\,as} = 11.186$ km / s, when starting from a height of 15 km $V_{x\,id}^{req\,as} = 11.173$ km / s. It follows that, without ΔV_n taking into account the change in the height of the air start negligible effect on reducing the required speed and, accordingly, on the starting mass of the ASP. According to [5], when starting from a height of 10-12 km, the required speed decreases by 500-600 m / s due to a decrease ΔV_n.

Let us calculate the effect of the initial velocity and altitude on the ground of the ASP during an air launch from an WIG and airplane. The specific impulse of the liquid rocket engine of the ASP is assumed to be w = 4600 m / s. The speed of the WIG will be assumed to be 650 km / h. Obviously, the height of the movement can be neglected and considered its zero. The speed of the aircraft will be considered equal to 900 km / h. In this case, when starting from a ground effect vehicle, the weight of the ASP with fuel should be 15.7 times higher than its mass without fuel, when starting from an airplane, 13.5 times, respectively.

Thus, with an air launch from an ekranoplane, higher fuel consumption is required to enter orbit than with an air launch from an airplane. But, as mentioned earlier, an ekranoplane has a large carrying capacity, which in many cases can make it possible to compensate for this shortcoming. At the same time, the possibility of taking off and landing from the disturbed sea surface gives WIG clear advantages over airplanes, eliminating the need for a runway near the air launch point and additional fuel consumption for the flight to it.

4. Requirements to Ekranoplane

The demanded carrying capacity in 530-700 ton with a mass ratio of about 35% determines ekranoplane take-off mass in 1600-2000 ton. By accepting specific loading on wing being 5-6 kN/m2, one can estimate the required area of ekranoplane wing S in (3-4)103 m2. With conditional lengthening of the wing λ=3-4 the wing length should make $L = \sqrt{S\lambda}$ = 100-120 m.

With the normal thrust-to-weight ratio of ekranoplane being 25%, the total trust of engines should be of the order (4-5)103 kN, which can be ensured by 6 engines with a single trust of 600-800 kN. As it is important to raise the speed

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of starting ASP to maximum, it is expedient to involve in this mode all engines, as well as during ekranoplane take off. The criterion of fuel saving is not paramount for ekranoplane-launcher. However, the stock of fuel should ensure an opportunity of ferry flight for a distance no lesser than 3000 km.

Seaworthiness of the ekranoplane with linear dimensions of about 100m and mass of 2000 ton can be defined from the experience of Russian ekranoplanes "Lun" and "KM" operation, which with the mass approximately 400 ton have confirmed seaworthiness in 5 numbers appropriate to allowable height of a wave with three-percentage providing in 3.5 m. The factor of recalculation can be determined under the Frude's formula as a cubic root of the relation of weights, that is (2000 / 400)1/3 = 1.71. It gives allowable height of wave 3.5m *1.71 = 6.0 m that corresponds to seaworthiness in number 6 for the modes of take off and landing.

Similarly it is possible to estimate the achievable maximal speed of large ekranoplane-launcher in 600-650 km/hour, though basically the value of 550 km/hour can appear quite sufficient, and the optimal landing speed lies inside the interval 400-550 km/hour. At last, ekranoplane as the control plant should have a good margin of stability and react poorly to any variations of loading and other disturbing forces and torques arising basically at ASP start. The stiffness and correct centering of floating ekranoplane should be also supplied.

The discribed requirements cannot be executed in the framework of the well-explored «plane» configuration of ekranoplane "carrying wing + tail assembly" even with essential increase of the dimensions in comparison with ekranoplane "Lun". It is also clear, that ekranoplane-launcher should be catamaran. The possible design of “combined wing type” ekranoplane with ASP is shown in Fig. 3.

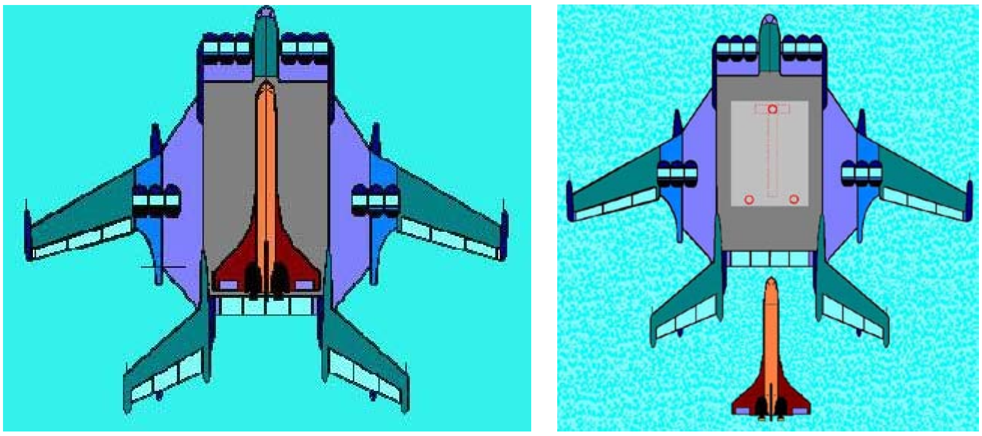
a) b)

Figure 3: Ekranoplane of “Combined Wing” configuration: a) with docked ASP; b) during docking with ASP.

For ASP launch, ekranoplane has to solve the following tasks

(1) carries it to the chosen point of start which may be several thousand kilometers apart,

(2) refuels ASP with the components of liquid propellant directly before start having onboard powerful cryogenic equipment and tanks for liquidized gas,

(3) gives to ASP the initial velocity M=0.5-0.65 at the altitude of 10-20 m. In this case ASP in compare with MAKS project obtains less mechanical energy, but in recalculation to the attainable final velocity this loss does not exceed a few percents [2,3], as it will be shown below. A buster main goal is connected with jumping over the zone of small velocities which is unacceptable for hypersonic wing and engines, and ekranoplane masters this role well.

5. Specific problems of large ekranoplanes automatic control

As during pitch angle variation the drag and, therefore, the flight speed changes, the heavy ekranoplane demands the presence of speed stabilization system. Thus all channels of the control complex substantially participate in maintenance of the ekranoplane's demanded motion in the longitudinal plane. The synthesis of control laws can be fulfilled under several criteria, but the main ones are certainly the admissible values of control errors in different modes and adequate margins of stability in amplitude and phase. The estimations of the vehicle control errors, linear and angular rates and also wave and wind disturbances, being filtered accurately, have to be used in the formation of control signals [7-9,11,12].

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 the swivel nozzles of engines.

Obtained current data of the field of wave disturbances can be used for:

(1) the adaptation of the main motion control loops and

(2) the realization of the principle of combined control.

This lets increasing of the quality of motion control. However, main difficulty in construction of the channel of control for 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. For two-dimensional sea waves this task is solved successfully enough, but in general case of three-dimensional waves it is necessary to use approximations. But positive effect may be guaranteed in any case.

The developed measuring system allows to track the profiles of sea waves in three points, corresponding to the points of radioaltimeters installation on the nose and both sides of the wing, with the accuracy 10 cm at seaway number 5 [6-8]. The problem of automatic estimation of the general direction of sea waves propagation with the use of three radioaltimeters outputs is also solved, which is important for optimization of mode of landing approach and splashdown.

Instead of phase radioaltimeter the laser device drawing a figure on water surface, and cameras, taking the pictures of these figures, may be used. Specially developed algorithms for such images' processing permit to estimate accurately the altitude of flight and sea state [10,17]. This equipment can be cheaper against radioaltimeters, but the reliability in the full spectrum of possible conditions of operation is still under investigation.

6. Arrangement of Mechanical Docking Elements

The initial position of fueled ASP on the ekranoplane deck has to be practically horizontal and close to the deck to reduce the aerodynamical drag during ekranoplane take-off and cruising flight to the area of ASP launch. At the moment of ASP engine switching on the ASP must receive around 15° attack angle [1, 3, 9] and some space between the engine muzzle and the ekranoplane deck. That means that ASP center of gravity is elevated for approximately 10m and, probably, the whole ASP is shifted a bit back to locate the engine muzzle in the free space.

Such initial elevation of ASP could be provided by rather powerful mechanism, which applies lifting force at the area of ASP center of gravity. It may be the extensible hydraulic column that could produce the force in 5000 kN and to be rather stable against longitudinal aerodynamical force applied to ASP connected with ekranoplane motion. Practically this column has to carry the ASP weight minus aerodynamic lifting force of ASP wing.

Another important requirement of the undocking mechanism consists in minimal disturbed forces and moments applied to ASP at its disconnection with ekranoplane. The ASP weight must be balanced by its wing lifting force. Any turning moments in the longitudinal plane must be canceled out by the right deflection angles of the elevator and flaps. That is reason for the ASP attitude stabilization system to be switched on before the launch. ASP engine thrust has to approximately balance a drag force. So, ASP engine has to be switched on also before ASP disconnection with ekranoplane.

Taking into account the above listed requirements, the arrangement of mechanical mating elements for connection and disconnection of ASP with ekranoplane can be drawn out as it shown in Fig.4.

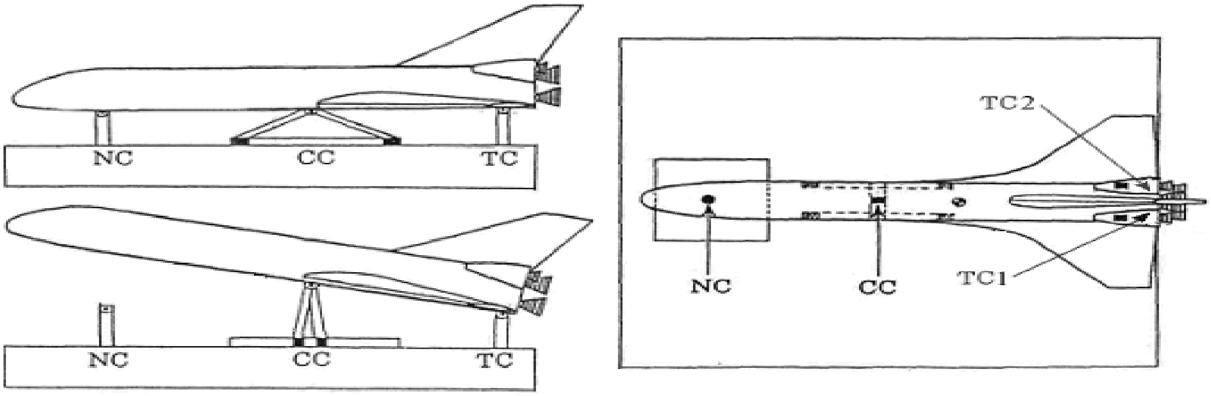

Figure 4: Arrangement of Mating Elements

The central extensible column CC is the main facility for ASP launching procedure. It is burried deeply into ekranoplane body during ASP transportation to the launch area, but arises at maximal height of around 10m before ASP undocking. It is not necessary for CC column to manage the ASP pitch. Directly before undocking this function will belong to ASP flight control system. But for preset ASP the initial angular position and for partly helping CC column in load carrying two or three other connecting elements will be used. For example, it could be a nose column NC and two tail columns TC1 and TC2. NC is located on the central line in a forward part of the Ekranoplane deck.

7. Motion Control during Docking

A generalized scheme of automatic control multi-dimension digital system for mutual motion control during docking is shown in Fig.3. As it follows from the diagram, the docking process of ASP and ekranoplane must be operated under motion control complex which involves closed control loops for ASP and ekranoplane absolute motion with controlled values matrices λASP and λEKR consequently, relative motion closed control loop with the controlled value matrices λASP - λEKR and an additional open loop channel for local shifting the docking element along and thwart landing deck with output coordinates matrix λM.

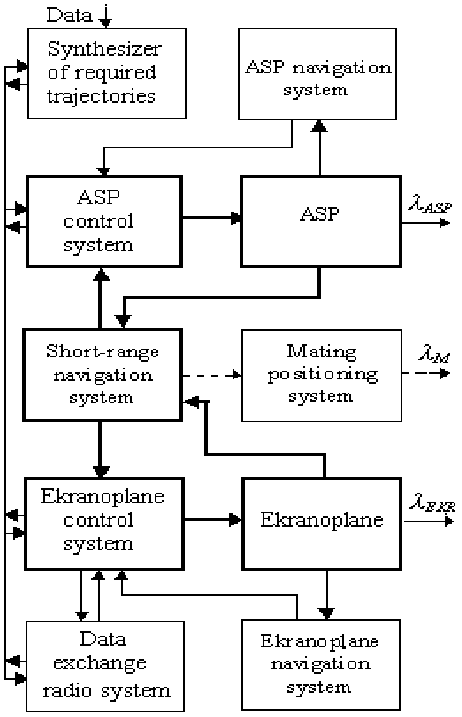

Figure 5: Generalised block-diagram of mutual motion control complex during docking

The required landing trajectory of ASP is determined by synthesizer priory and described by given functional matrix λ(t). The navigation system of ASP generates an estimation of an actual motion trajectory λASP(t). The residual λ(t)-λASP(t) is used in control law. Optimization allows to reduce the norm of the matrix λ(t)-λASP (t) and to provide high accuracy in holding the required landing trajectory. During the final stage of approach, the errors of relative positioning may be within 2-3m, and the local positioning of mating elements (especially, nose element) could reduce the errors to 30 cm.

The ekranoplane absolute motion control system has to ensure the required trajectory of its flight to the point of ASP landing, approach to this point from given direction at required time, and capture of ASP by the shot-range optic navigation system.

Let us define a mathematical model of perturbations that deviate the vehicle relative to the docking point. The trajectory of the vehicle can be represented by a Gaussian random process with the covariance function

$$K(x(t), x(t-\tau)) = e^{-\frac{|x(t)-x(t-\tau)|}{l}} \qquad \textbf{(8)}$$

Consider the horizontal coordinate system X0Y with an axis 0X oriented along the line of a given path. Denote by x (t), y(t) and v(t), respectively, the coordinates of the longitudinal and lateral motion of the aircraft, and its velocity at time t

$$dy(t) = -\alpha_y y(t)dt + \sigma_y dW_y(t), \qquad \textbf{(9)}$$

where αy and σy are known positive coefficients, {Wy (t)} is the standard Wiener process.

$$dx(t) = (v_0 + u(t))dt, x(0) = 0, \qquad \textbf{(10)}$$

where v0 is the set flight speed, Δu is the deviation from the set flight speed described by a random process

$$du_x(t) = -\alpha_x u_x(t)dt + \sigma_x dW_x(t), \qquad \textbf{(11)}$$

where αx and σx are known positive coefficients, {Wx (t)} is a standard Wiener process independent of the process {Wy (t)}.

Let us write the state vector of each aircraft, characterizing the process of its movement

$$z(t) = \left[x(t)\ \ y(t)\ \ u_x(t)\right]^T$$

$$dz(t) = \left[v_0\mathbf{e} + \mathbf{\Lambda}\begin{bmatrix} y(t) \\ u_x(t) \end{bmatrix}\right]dt + \mathbf{S}d\mathbf{W}(t) \tag{12}$$

, where

e=[1 0 0]T, $\Lambda = \begin{bmatrix} 0 & 1 \\ -\alpha_y & 0 \\ 0 & -\alpha_x \end{bmatrix}$, $W(t) = \begin{bmatrix} W_x(t) \\ W_y(t) \end{bmatrix}$, $S = \begin{bmatrix} 0 & 0 \\ 0 & \sigma_y \\ \sigma_x & 0 \end{bmatrix}$

Let e1j and e2j be unit basis vectors in the corresponding local system in a common coordinate system, rj0 be the vector corresponding to the point 0j of the initial position of the jth aircraft, and r(0) = r0 = r20-r10 be the vector corresponding to the initial relative position of the aircraft. Then the vector of the relative position of the aircraft is

r(t)=(r20-r10)+x2(t)e12+y2(t)e22-x1(t)e11-y1(t)e21. **(13)**

This equation determines the relative position of the ekranoplane and the ASP landing on the ekranoplane. The coefficients αx, σx, αy and σy are selected based on the specific types and characteristics of the ASP and ground effect vehicle.

The ekranoplane absolute motion control system has to ensure the required trajectory of its flight to the point of ASP landing, approach to this point from given direction at required time, and capture of ASP with application of the shot-range optic relative navigation system.

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9. Conclusion

The use of «ASP + Ekranoplane» concept can be considered as one of the effective ways to solve the problem of launch system perfecting. Unfortunately, there are not created the multi-mode air-breathing jet engine for a wide range of speeds, nor the large Ekranoplane with takeoff weight of about 2000 tons. But great practical demand for these innovations should rapidly lead to the creation of the required technology.

The analysis of the financial profitability of the project is not simple. In order to achieve the specific cost of such launch in 5000 $ / kg, for launching the payload in 5t, it is necessary to reduce the total cost of launch up to $ 25 million. At about $1 billion cost of development and construction of heavy ekranoplane, this amount for new vehicle most likely will not be paid off even at multiple application of heavy Ekranoplane. Therefore it is necessary to provide the heavy WIG-craft use not only to assist ASP at launch and landings, but also as an intercontinental container carrier, as a mobile airfield for military and civil aviation (high-speed aircraft carrier [12,13,16,17] and for other applications. All these issues require the further study. ASP with ekranoplane‘s assistance for horizontal take-off could be competitive with vertical space launch system from aggregate functional, technological and life cycle cost point of view. The accurate and reliable control of relative motion at undocking and docking is the key problem of «ASP-Ekranoplane» integrated space system feasibility.

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