Features and prospects of using ekranoplanes in the Arctic

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Abstract. The article is devoted to the problem of year-round transport service of the Arctic territories and settlements, necessary for their sustainable economic and social development, for the functioning of the units of the Ministry of defense. It is shown that the solution of this problem can contribute to the revival of construction in Russia of large Wing-in-Ground craft (WIG-craft) of the new generation, the first of which «Orlan», as stated by the heads of the relevant Russian agencies, is planned to be built before 2027. Its application can be multifunctional. The features of the organization of takeoff, cruising flight mode and landing on ice, snow or water are discussed. The advantages of using ekranoplane in the Arctic in comparison with other vehicles are estimated. The problem of ensuring safe and effective flight near the surface with ice hummocks, the problem of rough alignment of such a surface in a narrow corridor allocated for takeoff and landing of ekranoplanes is discussed. In contrast to the airfields for planes, this "strip" may be acceptable for a large airplane bumps up to half a meter tall. A special technique may be required for rough smoothing of hummocks with minimal energy consumption. Previously Arctic conditions of flight of WIG-craft were not considered. The main idea of the article: in the Arctic, in some cases, it is better to use an ekranoplane to fly over the ice, than to break the ice with an icebreaker for the wiring of ships or to build a highway for the movement of cars.

1. The territory of the Arctic
The territory of the Arctic is the North polar region of the Earth. The Arctic includes the Northern margins of the continents of Eurasia and North America, almost the entire Arctic Ocean with Islands, except for the coastal Islands of Norway, as well as adjacent parts of the Atlantic and Pacific oceans. With the Arctic "border" Russia, Canada, the United States, Norway, and Denmark, but for Russia the border with the Arctic is particularly long and is in the Arctic Ocean 19.7 thousand km.

A comprehensive international Treaty defining the legal status of the Arctic currently does not exist. The legal status of the Arctic is governed by international law, national legislation of the Arctic States and bilateral agreements.

Russia has repeatedly applied for the expansion of its Arctic shelf, to justify which appropriate studies have been conducted. Other Arctic countries are also stepping up activity in Arctic territorial disputes. The real development of the Arctic territories, supported by the gradual deployment of forces and means of their defense, is of no small importance in such disputes. This requires not only year-round planned transport services for new Arctic settlements but also the possibility of urgent delivery of people and equipment to any desired point in the Arctic, regardless of its location on the mainland, Islands or in the ocean, even at the North Pole.
The Arctic occupies a special place in the Russian economy. It is in these territories, where less than 2% of Russians now live, that more than 11% of the country’s gross domestic product is created and a quarter of its exports is provided. Huge supplies of clean drinking water are also important.

The Economics of polar projects is unusual. Construction and maintenance of one kilometer of railway cost about five times more expensive than in the southern latitudes. But the cost of production of liquefied natural gas is a third lower than in Qatar. This affects both the pace and industry specifics of Arctic projects. Russia has no other way but to develop a full-fledged industrial development of raw materials of its Arctic zone.

2. The Northern sea route

The Northern sea route (NSR) is a shipping route in the Russian Arctic. In official Russian document, it is defined as «historically developed national transport communication of the Russian Federation». It runs along the Northern shores of Russia on the seas of the Arctic Ocean (Barents, Kara, Laptev, East Siberian, Chukchi, and Bering), connects the European and far Eastern ports of the Russian Federation, as well as the mouths of navigable Siberian rivers into a single transport system. The length of the NSR from the Kara Gate Strait to the Bay of Providence is 5.6 thousand km. The route through the NSR is almost twice as short as other sea routes from Europe to the far East. The way from St. Petersburg to Vladivostok through the Suez Canal is 23200 km and along the NSR - 14280 km. The duration of navigation is two to four months, the use of icebreakers allows you to extend this period, but it requires huge financial costs.

3. Icebreaking fleet.

It is constantly updated, which is not cheap. In the western section of the NSR, this means free-swimming almost all year round. Nuclear icebreakers provide year-round traffic in the Eastern section.

State subsidies for the construction of new generation nuclear icebreakers in 2020 may amount to 24.7 billion rubles, according to the draft Federal budget prepared by the Ministry of Finance for 2020 and for the planning period of 2021 and 2022. The Baltic plant commissioned by Rosatom previously built the head universal nuclear icebreaker «Arctic» project 22220, is building two serial nuclear-powered ships «Siberia» and «Ural». Contracts have been signed for the creation of two more such vessels. Designed as the world's most powerful nuclear icebreakers (120 MW), the 10510 Leader will be built by the Zvezda shipbuilding complex, created by a consortium led by Rosneft on the basis of the far Eastern plant of the same name. It is planned to build three icebreakers «Leader».

Russia is an absolute leader in icebreaking shipbuilding and is able to provide year-round transport services to the ports of the NSR with a maximum thickness of ice up to about 4 m. Note that icebreakers do not have amphibious and can only pave the way on the seas and oceans.

4. Hummocks

Hummocks — a pile of fragments of ice, sometimes up to 10-20 meters in height, which are formed as a result of compression of the ice cover. There are two types of formation of hummocks (or hummocks): breaking and fragmentation of the ice cover.

Breaking - a kind of ridging, when cracks are formed in the ice cover and there is a pile of large fragments of ice, taking different positions, up to and including the vertical (Fig. 1);

Fragmentation - the destruction of the ice cover into smaller parts; it is accompanied by the formation of hummocks of small pieces of ice (Fig. 2);

Smoothest can be the surface of the crushed ice without hummocks (Fig. 3); It requires minimal energy from icebreakers (Fig. 4).
5. Ekranoplanes.
Ekranoplanes are designed for a fast and energy-saving flight over a fairly flat support surface while creating a dynamic air cushion between the wing and the support surface. This type of high-speed transport is amphibious and can move over water, ice or land. For effective operation of the screen effect, the flight height should be no more than 0.2 of the wing chord, then the aerodynamic quality of this aircraft can increase by tens of percent compared to the aircraft.

The flight speed for the vehicle with a take-off weight of 400-600 tons can be 350-500 km/h with fuel efficiency, significantly exceeding the helicopter and aircraft. Recently, as one of the advantages of the ekranoplane, its low radar visibility is also considered.

Russian experience of WIG-craft design. Our country has accumulated a unique experience in the design and construction of large ekranoplanes, conducted their tests in various flight conditions, including in stormy seas. First, we are talking about was built by order of the Navy [1-4] experimental ekranoplane «KM» with a maximum take-off weight 544t and cruising speed of 430 km/hour, freight-landing winged «Eagle» with a maximum take-off weight of 140 t and a cruising speed of 350 km/hour and shock rocket ekranoplan «LUN» maximum take-off weight 380t and a cruising speed of 500 km/h (Fig.5). All these devices are designed in the «JSC DESIGN BUREAU» which now bears the name of General Designer of R. E. Alekseev. With the collapse of the Soviet Union, state funding ekranoplanes subject is almost stopped, since the big WIGs was not cared by MOD or MOE. Attempts to design small WIG with rare exception were unused because of their poor seaworthiness.

The situation changed last year, when Deputy Prime Minister Yuri Borisov told the press that Russia plans to create a prototype ekranoplane «Orlan», armed with missiles. This will happen within the framework of the state arms program until 2027: «in the state arms program 2018-2027, there is a development work «Orlan», which provides for the construction of an ekranoplane. The prototype will be created within the framework of this weapons program, it will carry missile weapons». The take-off weight of this ekranoplane is also declared-up to 600 tons [5,6]. Yu. Borisov noted that «ekranoplane will be used to protect the Northern sea route, where the infrastructure is poorly developed». It is clear that not only the NSR should be protected, but also all the Arctic territories of Russia. Of course, the decision was influenced by the need to activate the Russian Navy in the Mediterranean Sea, where there was a Russian airbase «Hmeimim» in Syria.

Other details of the project «Orlan» are not reported, but it is clear that the main prototype for the «Eagle» may be the last of the «Alekseevsky» ekranoplanes «Lun», slightly increased to improve seaworthiness to 6 points (the height of the sea waves of three percent security 6 m). Of course,
adjustments to the aerodynamic scheme are possible, but basically, the «airplane» scheme of R. E. Alekseev with a highly raised tail stabilizer should remain as well-worked in Russia.

Figure 5. Rocket ekranoplane "Lun"

On the «Lun» were eight turbojet engines NK-87 with thrust $8 \times 13$ tf. Therefore, this apparatus is jokingly called «digitalis», but more powerful domestic engines did not exist. Modern the most powerful in world aviation engines capable give traction more 57 tons every, that well be appropriate for «Orlan» even under quick only 6 engines. However, it is not the Russian engines and not adapted for the wig, as NK-87. That's the problem. Perhaps, until 2027, more powerful Russian engines will be created.

Another problem of designing «Orlan» is the need to create a special flight and navigation complex with intellectual properties based on the experience of designing an analog damping and stabilization system «Smena-3» installed on the «Lun». It is required by modern means of control automation to guarantee the stability of the vehicle in different flight modes, stabilization of the selected altitude with an accuracy of about 10 cm, 3D-optimization of the trajectory of the ekranoplane over an uneven surface, timely detection and overflight of obstacles, automation of takeoff and landing modes.

Since the Orlan is claimed to be a universal amphibious transport platform, the installation of missiles on the board is not the only payload. Unlike the «Lun», on which 6 missiles «Mosquito» were installed on the upper deck, worsening the aerodynamics of the ekranoplane, the «Eagle» can be more advanced and less dimensional modern missiles, located inside the hull and leaving room for equipment needed for rescue operations, or for the transportation of other goods.

6. The modes of the WIG-craft.

All three main modes of motion of the ekranoplane in the Arctic have their own characteristics: takeoff, cruising flight and landing.

Cruising flight should occur at an altitude that virtually eliminates the touch of the ekranoplane even the highest points of the surface profile (covered with snow or even more ice). Considering the heights of these points distributed according to Rayleigh’s law or close to it, it is possible to calculate the average time between two adjacent touches of the surface $R_K$ for each characteristic case. Then, at flight speed $V$, the average time interval between the moments of contact of the surface will be $T_K = R_K / V$. In the characteristic case, it is possible to provide, for example, the values $V = 150 \text{ m/s}$, $R_K = 105 \text{ m}$, $T_K = 670 \text{ sec}$.

As a rule, for the implementation of such a small probability of easy contact with the surface of the hull flight ekranoplane with the mass of the Eagle should take place at an altitude of about 5-6 m in relation to the average «undisturbed» level of the underlying surface, if the error of automatic stabilization of such an altitude does not exceed 20 cm. Attempts to complicate the flight path by manoeuvring in the vertical and lateral planes to minimize the average geometric altitude in the Arctic zone, it is better not to force and debug this technology when flying over an agitated sea, in the absence of ice with hummocks.

The body of the ekranoplane for mechanically strengthened to eliminate the danger of mechanical damage from such rare touches. The body of increased strength is necessary in takeoff and landing.
modes, so the body of the ekranoplan is always heavier than that of the aircraft. More heavy will always be a set of engines, because the aircraft does not need to overcome the «hump» of hydrodynamic resistance, and the ekranoplan – is. Only if it is possible to take off from a flat surface (airfield or absolutely flat ice surface, covered with snow), it is possible to take off with minimal energy consumption.

The takeoff mode is certainly the most difficult and energy-consuming for the ekranoplan, and in the presence of high hummocks it is not directly realized. However, even the easy leveling of the ice surface by breaking the hummocks with special non-heavy Arctic bulldozers (see below) makes the takeoff regime feasible. The equipment of each even small Arctic settlement with such equipment is quite possible and not expensive. But there is a serious question: what chassis to use? A variant of the wheeled chassis, in principle, also suitable for aircraft landing strips for smooth ice. But more attractive for the Arctic are skis.

Mode off airplane «Eagle» and other amphibious wigs, is the most complex and energy-consuming. It is the take-off from the water that determines the total power of the ekranoplan engines since the maximum thrust is required to quickly overcome the «peak of hydrodynamic resistance». Nevertheless, the rejection of the possibility of taking off from the water would not allow the «Orlan» to be considered a universal vehicle for the Arctic, almost completely covered with ice only in winter.

Takeoff from the surface of the ice is also very popular in the Arctic, but it is clear that this is possible only in the absence of large hummocks from «hacking». Accordingly, it is necessary to assume that soon after the decision to land is possible to find a fairly flat place on the surface of the ice, which after landing, unloading or acceptance of the transported cargo is also suitable for takeoff ekranoplan.

There is only one technical solution for the possibility of taking off and landing on water and on fairly flat ice - it is specially designed skis with effective shock absorbers. Mode "hydrolyze" very well experience "Lun" and "eagle". The mode of «snow» or «ice» skiing is less studied and should take into account the nature of the hummocks, assuming the need to adapt the ski system to a specific situation of takeoff or landing at different disturbances. The strength of skis and their elastic properties are the subject of special research and optimization, especially for takeoff and landing modes. This course should provide the possibility of rotation of the vector thrust engines. To simplify takeoff, the engines must «blow under the wing», strengthening the air cushion. In cruising flight mode, the dynamic airbag is sufficient and there is no need to strengthen it. This requirement is obvious and even more binds the layout of the «Eagle» to the «airplane» layout ekranoplanes developed by R. Alekseev and his followers.

When the hot exhaust of the jet engines under the wing, i.e. on the surface of the ice, we should consider the possibility of melting the ice, and prolonged static boost-mode – up to ice-water. Arising at the same time specific irregularities in the form of a «well» should be aligned with the design of the skis and their size.

7. Skis for ekranoplan.

Two variants of skis were considered: hydro-skiing and conventional snow-skiing. The first is for open water during landing and possibly during takeoff, the second for ice fields without large hummocks. In a rough design, one can consider the same skis for both water and ice, which would simplify their operation without frequent replacement. However, the experience of «JSC ALEKSEEV`s DESIGN BUREAU» makes it advisable to take a more thorough approach to the design of skis.

The design of the hydro lift for the ekranoplan was carefully worked out by «JSC DESIGN BUREAU» under the leadership of R. E. Alekseev and is one of the most valuable inventions. However, it is not a fact that such a design should be exactly reproduced after 40 years. Most likely, the task of developing and optimizing the shape and design of the hydro lift for the Arctic «Eagle» should be solved anew, taking into account modern possibilities, both in the field of heavy-duty
composite materials and software modeling of hydrodynamic objects of complex shape. The following requirements should be presented to the modern design of the hydro lift:

- winning hydrodynamic form, which creates a minimum hydrodynamic resistance;
- elasticity to soften shocks (impulse loads) without structural failure or disruption of the material;
- a sufficient area for the best and simultaneous smoothing of the peaks of several hummocks.

These requirements are somewhat contradictory and can be generalized using efficient optimization methods. From the point of view of mathematical modeling, it is worth noting that in the case of smoothing the ice hummocks, a greater number of surface points will be applied to the ski touches of an impact than in the case of motion over a disturbed sea surface, due to the fact that the profile spectrum of ice hummocks will generally be the higher in contrast to the profile of wave crests.

Note that ekranoplane with ski is not a «hydrofoil», the shape and profile of which, as well as the depth of immersion, are well worked out. In hydrolyzing only the lower surface works, during takeoff creating additional lift to the main wing due to planning when touching the crests of the waves. When landing, the main role of hydrolysis-shock absorption of impulse loads that occur at the first touch. The shape and profile of which, as well as the depth of immersion, are well optimized for hydrofoils.

The principle of the planning plate of small elongation is also used in boats on hydrofoils. The purpose of the skis is the same-to raise the body above the water to reduce its resistance and the degree of impact of the waves. The difference is that the skis are not underwater, and slide on its surface. At landing and at movement with small speed skis are pressed to the bottom and do not influence the force of resistance of the case. At the approach to landing the case "is wrung out" from skis and is not moistened with water. An example of the location the shock-absorbing ski on the ekranoplane "Eaglet" is shown in Fig.6.

The wing of the «Eaglet» and other large ekranoplanes has an aerodynamic layout optimized for movement near the screen. At the ends of the wing floats are installed, playing the role of aerodynamic and planing washers. Along the trailing edge are sectional flaps-ailerons. Along the leading edge on the lower surface of the wing (closer to the ends) are special starting shields.

![Figure 6. Wing "Eaglet" with released hydro-ski](image)

The axis of rotation of the shields passes along their leading edges. Deflection angles: flaps-ailerons - from -10° to + 42°, starting shields -70°. Mechanization of the wing is used at launch to create a gas cushion that lifts the ekranoplane when taking off from any surface of water or land. Afloat, the trailing edge of the wing is in the water. For takeoff, the nose starting engines are turned on, the jet streams from which are directed under the wing. Flaps and flaps at takeoff are lowered, not allowing gases to break through under the back and front edges.

Since large waves create large shock loads on the hull, the Eaglet had a reinforced bottom. It is formed by a system of transverse and longitudinal redans. To reduce loads, a ski-damping device (hydrolyzing) is installed. In the front part of the hull, there is bow hydrolysis, in the area of the center of mass there is a main hydrolysis. The chassis together with the ski-shock-absorbing device and the blower provide passability on almost any ground, including ice with low hummocks.
In mode cruising flight of the winged fundamental difference in flight over ice and over water no. At a flight altitude of 4-6 m, the screen effect for a large device is still valid and at a height of hummocks 2-3M, there will be no collision with them. Note that the area of tundra surrounding the Arctic Ocean, it is also suitable for flying WIG-craft «Orlan».

Finally, how to ensure successful takeoff and landing in the Arctic regions with high hummocks (such as «fragmentation», Fig.1)? It is necessary to level the site with a width of 120 m and a length of 2 km using construction equipment. Russia has developed a special armored personnel carrier for Arctic military settlements (Fig.7), which can serve as a bulldozer. Clearing the runway for the «Eaglet» will take no more than 8 hours. It is important that one do not need an absolutely flat strip of highway type – small irregularities in height of 0.5 m can remain and their presence during takeoff will be no more harmful than sea waves in height of 1 m. Probably, the task of such a rough alignment of the surface is formulated for the first time, it is relevant only for the ekranoplante and requires special research and appropriate construction equipment. It is desirable to ensure the buoyancy of such an carrier-bulldozer to avoid the possibility of its loss in fragile ice.

Figure 7. All-terrain vehicle for the Arctic

The possibility of using a wheeled chassis on the ekranoplane deserves discussion. This would greatly facilitate the take-off mode and possibly reduce the number of engines, as the thrust requirements would be lower. However, the need for a runway would significantly limit the tactical capabilities of the «Eagle». In contrast to the American project heavy ekranoplane «Pelican-ultra», where it was planned multi-wheeled landing gear and an elongated runway, which may be available in large cities, «Orlan» is focused on the transport service of small Arctic settlements and the solution of special tasks with an uncertain landing point in advance.

The combination of an efficient ski system and a wheeled chassis on one machine seems impossible. Seasonal replacement of skis on the chassis is in principle possible, but with the equipment in the Arctic at least one airfield with a long runway, which at negative air temperature can be artificially covered with a layer of ice. However, any tie - in to pre-prepared infrastructure would reduce the ability to choose complex flight paths.

8. Transport problem.
Possible transport tasks for the ekranoplane «Orlan» are divided into three groups.

The first group of tasks is connected with the military application for the defense of the Arctic territories of Russia and counteraction to violators of rules of their use from foreign warships. Most likely, for this purpose, the multifunctional «Orlan» will be equipped with effective anti-ship missiles of the new generation with the possibility of their rapid replacement with civilian cargo.

The second group of tasks will be formed as a system of transport services in the Arctic zone and adjacent regions of Russia. It is possible to change specialists working in shifts in small Arctic settlements and engaged in the development of their infrastructure and construction of other facilities, periodic delivery of necessary goods, food, ordered medicines, building materials. All this will reduce the expensive routes of ships with ice-breaking support, helicopters.
The third group involves the possibility of flying «Eagle» directly on the NSR, with the task to speed up the transportation of goods. With a range of about 20 thousand km for the «Eagle» will require probably 4 refueling, which is inconvenient. But the period of transportation will be significantly reduced and will be about two days. Obviously, the use of ekranoplan during transportation on the NSR should be cheaper than air transportation, but not by much. The movement of the ekranoplan in areas with intensive navigation can be complicated by the unsettled IMO rules in relation to ekranoplanes.

Since «Orlan» - experimental ekranoplan, it is desirable to check the effectiveness of its use in all these tasks.

9. Conclusion.
The expediency and possibility of using heavy ekranoplan for intensification of the development of Arctic zones of Russia and the organization of their protection are proved. The variants of the ekranoplane take-off from water and ice using the ski system, as well as the features of landing on any fairly flat surface, including ice with slightly smoothed by a special bulldozer hummock, are analyzed. The advantages and disadvantages of the use of wheeled chassis on the Orlan ekranoplane are indicated. It is concluded that in the Arctic the known balance of advantages and disadvantages of ekranoplanes can be positive for the effective use of large ekranoplanes.

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