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ANALYSIS OF EFFICIENCY OF DECK DIVERCE MASKING FROM DISTRIBUTION-DIVERSION GLAIDERS BY A FORMABLE EMBODY BUFFER ZONE

Проведено аналіз одного з технічних рішень засобів ефективного маскування літаків тактичної палубної авіації корабельного базування. Розглянуто механізм досягнення невидимості літака штучним формуванням в рідині огороджувальної поверхні міжоболочного простору у вигляді зони каустики, конфокальної внутрішньої поверхні зовнішньої оболонки. Сформульовані умови ефективного досягнення необхідного ступеня скритності літака на палубі авіаносця.

Ключові слова: *кут аберації, ультразвукове випромінювання, резонанс хвильового збіги, зони каустики, огороджуюча поверхня.*

1. Introduction

Flight tests of hypersonic weapons give grounds for a real change in the appearance of modern warfare and will make helpless air defense weapons. Once again, military technology ahead of time and raise new questions about the security of billions of people on Earth [1] (Fig. 1).

Fig. 1. Hypersonic aircraft on alert

The US and China are working on hypersonic *glider* projects, which receive the initial acceleration due to the rise to a greater height with the aid of a launch vehicle, and then accelerated during controlled descent from high altitudes. The advantages of such system are determined, at first, long range, up to a global impact on any point of the Earth's surface, secondly, relatively simple glider device (no propulsion engine), third, a large mass of the military unit and, finally, high speed flight, more than *10 Mach*.

Russia focused on the development of missiles with hypersonic direct-flow air-jet engine, which can be launched from the Earth, ships or combat aircraft. There is a Russian-Indian project to develop similar weapons systems, so that by 2023 *India* also be able to enter «*Hypersonic Club*». The advantage of hypersonic missiles is a lower cost and more possible applications, unlike gliders, launched with the help of ICBMs [1].

Hypersonic aircraft enter the *target* by relatively *shallow trajectory*, which are in the air for a short time and can maneuver. In most scenarios, modern air defense systems cannot in a short time to detect and strike a hypersonic *target*.

Hence the main task is outlined – to complicate for reconnaissance identification and delineation of the prominence of the means of defense. This, in turn, will complicate the use of firearms by the enemy. Using the well-known assertion «To surprise is to win», a reliable foundation of victory will be laid. Camouflage – this is the decisive means to mislead the enemy and the main factor of the victorious step.

Aircraft are located on the upper deck (schavot) of the aircraft carrier. Accordingly, can be qualitatively, and in a short time identified and classified by means of detection gliders. Thus, the «snoring eye» of the enemy, barraging in a given waiting area, has an excellent opportunity to react instantly, already from the very beginning of the flight means movement. Perform tasks to defeat tactical deck and strategic bomber aviation without unnecessary loss of precious time. The time factor in combat conditions is decisive. Therefore, the analysis of the technological situation in the air is relevant, as this helps to reduce the level of technological risks in combat conditions.

2. The object of research and its technological audit

The object of research is the process of elastic interaction of an ultrasonic beam with the enclosing cylindrical module in the form of two circular shells of the same length coaxially joined by their ends, the hermetic gap between them is filled with liquid.

Irradiation from the outside with an ultrasonic beam affects the properties of the enclosing cylindrical module, in particular, on the appearance of local features of the outer shell, as well as on the change in the energy state liquid in the gap between the shells.

Calculation model corresponds to the technical solution in the form of a fencing cylindrical module.

This phenomenon is the product of securing decked aviation from aerial reconnaissance in the pre-launch position (vertical launch or runway) under operational conditions.

One of the problematic areas of the study is that the dislocation of deck aviation in the open waist plane enables the means for detecting the suborbital and atmospheric reconnaissance of the enemy to determine undefined not only the initial coordinates but also its coordinate functions for the entire period of subsequent trajectory travel. Finally, the on-board glider equipment, taking this information as the original one, makes it possible, with anticipation, accurately, to fire at the theoretical trajectory of motion, thereby increasing the probability of hitting the target.

Therefore, it is necessary to ensure 100 % masking of deck aviation at open launch positions. This will significantly reduce or completely eliminate and improve the efficiency and life-span of the aircraft as a whole.

3. The aim and objectives of research

The aim of the research is an assessment of the effectiveness of the technical solution in question to achieve full (or partial) camouflage and the limited prominence of deck aviation from aerial reconnaissance.

The objectives of the research are as follows:

1. Construction of a computational analytical model of the chosen technical solution in the form of two coaxial shells separated by a liquid and irradiated externally with an ultrasonic beam.
2. Justification of the need to fulfill the conditions for the large wave size of the outer shell surface.
3. Explanation of the conditions for the necessary aberration degree of sound waves radiated into the liquid by the circumferential wave of the outer shell and the formation of the surface of the caustic.
4. Determination of the angle of incidence of the ultrasonic beam on the surface of the outer shell necessary for the emergence of a resonant environment in a mechanical system – wave coincidence (geometric resonance).

4. Research of existing solutions of the problem

Time inevitably singled out decisive priorities in creating ways to defend and mask flight manned and unmanned products (flying robots). Masking (from the French *masquer*) involves ensuring partial or complete invisibility or secrecy of material and technical means of defense, as well as military personnel. Masking provides surprise operations of troops, shock and firepower of fire equipment, prolongation of their combat readiness and increase of survivability. In terms of the scale of application and the nature of the tasks to be solved, masking is divided into - strategic, operational and tactical. Depending on what technical intelligence-diversionary means camouflage measures are carried out, the optical disguise is distinguished (masking color) [2], thermal, radar [3], radio and radio engineering, sound (acoustic – direct location and echo-location), special hydroacoustics (sub-keel stations, descending and towed containers with variable depth antennas) and others [4].

The main methods of masking are hiding, imitation and demonstrative actions.

Hiding is the elimination or weakening of unmasking features. Hiding is ensured by the observance of camouflage discipline, using masking properties of the terrain, natural conditions and using special engineering techniques and means.

Simulation consists in creating false objects and false environments by using mock-ups of equipment and other means [3].

In 1932 in the Military Invention Administration (USSR) I. I. Varshavskiy suggested making the aircraft invisible in the air for a ground observer, i. e. create a mirror mask, and also carry out work to protect metals from corrosion [5].

It is also proposed to conceal objects using smoke masking (aerosol formations) – smoke curtains are used to hide objects from visually-optical means of the enemy. To eliminate the definition of the exact location of the object, smoke curtains several times the size of the object. But the effectiveness of smoke masking should pay attention to the meteorological conditions (wind speed and direction, precipitation), as well as the nature of the area (relief, vegetation, rivers, lakes, settlements) [6].

The development of approaches to radar invisibility led to the creation of invisible aircraft based on technology such as «Stealth» [7]. However, this technology did not become a solution to the problem, and more in-depth studies and original approaches are needed to achieve the set goal – the stealth of the combat vehicle. Masking an aircraft by creating jammers and reflections is a rather auxiliary method, since it cannot solve the problem of «disappearing» an airplane from enemy radars. Russian researchers proposed their own method for masking the aircraft – an active method. If the American technology «Stealth» to reduce radio visibility used special absorbent coatings, it uses its own technology, which for the same purpose uses an artificial plasma formation obtained by ejecting electron beams into the atmosphere. Near the plane, plasma clouds are created that actively absorb the electromagnetic wave, so that the visibility of the aircraft on the radar screen falls more than 100 times [8].

Thus, taking into account that the tactical deck aviation aircraft are based on open starting positions, the features and specificity of the means for camouflaging aircraft from enemy air reconnaissance. Known ways of solving the problems of camouflage and limited prominence of flight products contours, based on passive methods, which allows us to conclude that the most promising are all the same means, based on resonant phenomena of a different physical nature.

Recently, using computer modeling, the intensity is used to predict the distribution of sound in confined spaces to represent sound emitted from various sound sources. This makes it possible to reduce the amount of calculated information and makes the modeling system simple enough for presentation on a desktop computer. With the advent of new computer technologies, it has now become practical to simulate sound distribution using pressure, including phase information, in empty confined spaces [9]. Modeling possibilities are also considered, using methods of optics transformation for bending wave layers within elongated rod designs [10]. The transmission of sound through the double walls of a cylindrical shell with a lining of a vapor-elastic material in the active zone is used, which excites pressure oscillations due to the external turbulent boundary layer [11]. It is proposed to use the acoustics of conformal transformation to create camouflage devices with layered homogeneous structures that can acoustically generate illusions of objects [12]. Based on the optical transformation, it is proposed to use a camouflage cover that can mask an arbitrary object, simulating the electromagnetic scattering of an empty V-shaped cavity beneath a metal surface. This camouflage device will be misleading and confuse detectors and people, and therefore any object hidden under this camouflage cover will not be perceived [13]. As illusion of the radar network, the method of the coherent phantom track is considered by controlling several electronic combat vehicles [14]. The effect of the dispersion of electromagnetic parameters and thickness on the characteristics of the absorbing material is analyzed in the work [15].

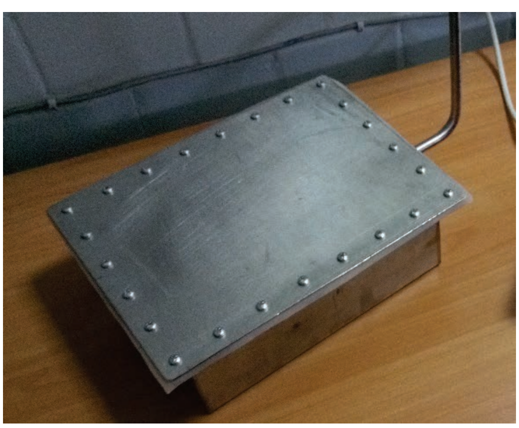
5. Methods of research

The basis of the test stand is a submerged block of ultrasonic radiators of the brand UZ P-6-1 (Ukraine), which forms an ultrasonic beam with a frequency of 42 kHz with a flat front, 300 W power and intensity of ultrasonic oscillations 1.65 W/cm^3.

Inside the water-filled test-bench frame, there is a cylindrical module in the form of two circular shells, separated by liquid.

The experimental setup consists of an ultrasonic generator and an ultrasonic transducer (Fig. 2). The ultrasonic transducer is an immersion unit, which is installed in a container with a working fluid.

a



b

Fig. 2. Experimental device:
a – ultrasonic generator; *b* – ultrasonic transducer

Ultrasonic transducer is made of stainless steel and consists of 6 ultrasonic radiators, which convert electrical energy into ultrasonic vibrations. The immersion unit is connected to an ultrasonic generator and installed in a container, and completely covered with working fluid.

6. Research results

In the absence of irradiation with ultrasound beam of the outer shell of the enclosing cylindrical module in the form of two circular shells on the sensor screen of the glider of the direction finder there are clear images of the aircraft of tactical deck aviation (Fig. 3, *a*). To obtain the desired masking effect under the protection of the surface of the caustic zone, two conditions must be fulfilled – significant wave size of the outer shell of the enclosing cylindrical module in the form of two circular shells and the choice of the coincidence angle of the ultrasonic generator beam [16, 17].

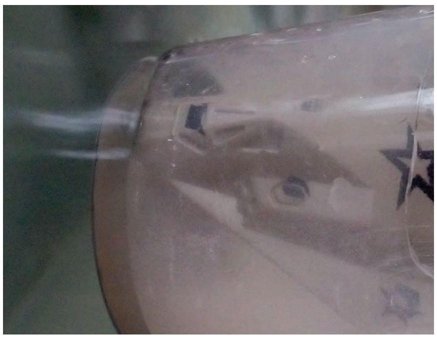
The first condition allows for a significant wave size, those larger than several units, to consider an element of the outer shell of the enclosing cylindrical module in the form of two circular shells as a plate that radiates into the inter-shell liquid a sound wave. The phenomenon of aberration can be regulated by appropriate selection of the material of the outer shell and liquid, In such a way that the ratio of the sound propagation velocities in them makes it possible to construct caustic zones in the form of a confocal shell surface of the enclosing cylindrical module in the form of two circular shells of a given radius. Obviously, for an insignificant wave size, the mechanism for constructing an insulating surface will not work. In Fig. 3, *b*, the initial change in the prominence of contours of a tactical deck aviation aircraft. These changes, as can be seen, are not yet of a fundamental nature, but they also take place.

Selection of the angle of incidence of the ultrasonic beam on the surface of the outer shell of the enclosing cylindrical module in the form of two circular shells to the values of the angle of coincidence, those before the onset of geometric resonance in the form of wave coincidence that allows further develop the distortion of the hull of the tactical deck aviation aircraft on the screen finder of the glider (Fig. 3, *c*). This is achieved due to the fact that the turbulence and energy activity of the inter-shell liquid under resonance conditions grows to such a level where the visibility of the contours is practically disappearing and a satisfactory camouflage of the tactical deck aviation aircraft from the direction finding devices of the glider. The mechanism of this phenomenon is caused by a sharp increase in the power of the ultrasonic beam of the sound waves transmitted inside and generated by it, owing to the onset of the so-called acoustic transparency of the outer shell of the enclosing cylindrical module in the form of two circular shells [18–20].

At the time of the launch of tactical deck aircraft, the fencing module is moved away making room for a vertical launch of the aircraft. Upon the return of the aircraft to the base and landing on the deck of the aircraft carrier, the enclosing cylindrical module returns to its original position, while completely closing the aircraft, and, while doing so its main focus – airplane camouflage.

The original side of the obtained results of laboratory studies is the confirmation of the theoretical prerequisites for the technical realization of the artificial formation of the enclosing surfaces in the form of caustic zones (Fig. 4) for concealment and masking of an aircraft of tactical deck aviation.

a



b

c

Fig. 3. Image of a test aircraft:
a – initial position, irradiation with an ultrasonic beam of the enclosing cylindrical module in the form of two circular shells is absent;
b – image of the aircraft with external artificial acoustic radiation of the enclosing cylindrical module in the form of two circular shells (outside the resonance zone); *c* – image of an airplane on the screen of finding devices of the glider when a resonant situation occurs in the space between the shells – wave coincidence

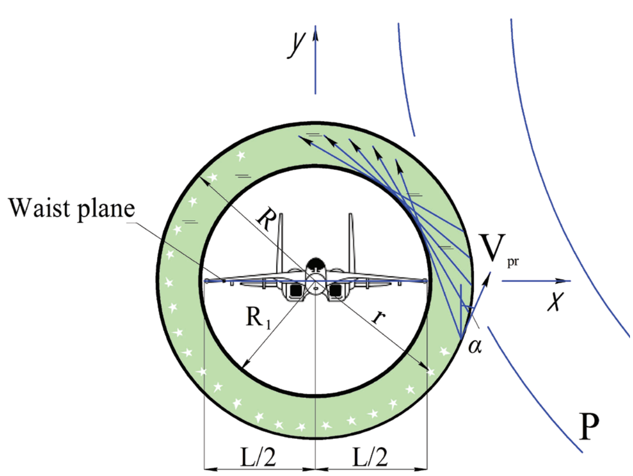


Fig. 4. Artificial formation in the intershell space of a buffer surface in the form of a caustic zone

For concreteness, let's take:
– the wingspan of the aircraft is $L=15$ m;
– radius of the inner shell $R_1=7.5+0.05=7.55$ m;
– radius of the outer shell $R=R_1+0.1=7.55+0.1=7.65$ m.

The shells are assumed to be made of duralumin ($V_{pr}=$ $=6300–5230$ m/s, $V_{pp}=3080$ m/s), as fresh liquids we take fresh water ($c_0=331$ m/s at $t=20$ °C), consider the wave size of the outer shell surface much exceeding one, i. e.:

$$kR \gg 1,$$

where $k=\omega/c$, k – the wave number; ω – circular frequency of ultrasonic radiation in kHz; c – speed of sound in the air.

This assumption allows to consider the surface element of the outer shell as flat, in which the circumferential wave in the outer shell generates a flat sound wave into the liquid. Since the speed of sound in the shell and liquid is different, the aberration effect of radiated sound waves from the circumferential wave to the angle α, i. e. $\sin\alpha = c_{liq}/V_{pr} \approx 0.06$ rad [17], will be observed. Hence, $\alpha = 3°41'$.

It follows from Fig. 3, the sound waves emitted by the outer shell form a cylindrical surface of the caustic zone of radius $R=7.65\cos\alpha = 7.63$ m.

This zone will be an energetically active liquid substance, in which, instead of the initial static state, there is a powerful turbulence with cavitation manifestations. The degree of turbulence will increase with the approach of the direction of the wave vector $\vec{k}$ to the value of the coincidence angle, when the trace of the incident ultrasonic wave and the circumferential wave in the envelope coincide. In this case, the so-called phenomenon of the acoustic proxy of the outer shell is observed and the external ultrasonic beam passes inside the shell without dissipation of energy. In the vicinity of the wave coincidence zone, turbulence will occur, but much less intense. Thus, an artificially formed caustic zone of radius r will create a buffer surface for the passage of the beams of the locating means. The zone of wave coincidence is approached, the contours of the image of the aircraft on the screens of the location facilities will gradually blur. As a result, they will turn into a blurred spot, like a blob (Fig. 3, *c*).

7. SWOT analysis of research results

Strengths. Conducted semi-detailed tests on the layout of the aircraft of the deck aviation allow:
– to assess the prospects of the proposed method of camouflaging flight vehicles at open launch positions;
– to deeply analyze the technology of artificial formation of the caustic zone under the assumption of variable values of the speed of sound propagation in the outer shell of the cylindrical module and in the separating shell of the liquid.

The evaluation of the radius of the cylindrical caustic zone in the function of the aberration radiated by the outer shell into the liquid at frequencies below the boundary sound waves confirms the theoretical premises for artificial regulation of the radius of the caustic zone-closer to the surface of the outer shell or further.

The caustic zone is a surface of increased energy activity of the inter-shell fluid – from low kinetic energy of the liquid to high. It includes significant turbulence and cavitation bubbles, as well as the presence of a temperature jump in the liquid. The influence of the wave coincidence of the circumferential waves of the outer shell and the incident sound wave of artificial ultrasonic irradiation is analyzed. It is shown that when approaching the resonance region, the local features of the liquid state rapidly increase. With the onset of the equality of the trace of the circumferential and falling ultrasonic waves, the physical state of the outer shell is formed as an acoustically transparent surface, and the liquid from the initially static state is transformed into a highly turbulent structure with the presence of cavitation bubbles and a heat gradient. The last thesis is most significant in the proposed scheme. Here, the acoustically transparent outer shell does not affect the image quality on the location screen. Further, the highly turbulent liquid will reproduce on the screen a vague cloudy blot, like a blob, which makes it impossible even to outline the contours and, even more so, to classify the object to be determined.

The carried out researches allow to recognize the offered technical decision as an undoubted means of increase of efficiency of use of tactical deck aviation and strategic bomber aviation during military operations on the sea, including, in the case of asymmetric military operations, to protect the territorial boundaries of the state.

Weaknesses. Obviously, the need to ensure the functional requirements of the proposed scheme associated with the movement of the module along the wafer's plane and its further transportation to the below-deck room complicates the work, increases the energy and material consumption of the aircraft carrier mechanism as a whole. Especially in the operating conditions of increased sea surface roughness, as well as a hurricane wind that generates technological risks, due to considerable sailing.

Opportunities. Increasing the level of camouflage of deck aviation will increase the efficiency and rational use of all types of military equipment, which, in general, will increase the safety of aviation equipment on the one hand, as well as combat support for the firepower of weapons.

Threats. Foreign specialists and ideologists of combat and fire equipment, to one degree or another, also began to use the phenomenon of wave coincidence and related local manifestations of the state of systems at a resonant level. For example, for land fire equipment - tanks, armored personnel carriers, armored personnel carriers, self-propelled guns, anti-aircraft and rocket-mortar systems. This was used by the US military in Afghanistan with the help of the shelter of combat vehicles by the «forest» of nanotubes.

8. Conclusions

1. A computational model of the proposed technical solution for masking deck aviation is developed, which allows to deeply analyze the features of the studied phenomenon and ensure a 100 per cent distortion of the image of the aircraft on the radar screens.

2. It is shown that providing a large wave size of the outer shell surface serves as the basis for the transformation of the element of the inner surface of the shell into a flat fragment radiating a sound wave into the fluid of the inter-shell space. The selection of the shell and liquid material can appropriately adjust the magnitude and coaxial arrangement in the buffer zone module.

3. In case of exceeding the allowable value of the wave size which is a consequence of the need to present elements of the outer shell of the enclosing cylindrical module in the form of a set of planar elements, which is achieved either by increasing the radius of the outer shell or by changing the corresponding sound velocities in the shell and separating the liquid shells, either and both factors simultaneously. In this case, the radiation is now provided by the flat elements of the shell of the enclosing cylindrical module inside the fluid and sound waves with a defined degree of aberration.

Achieving a large wave size of the outer shell of the enclosing cylindrical module which confirms eligibility by granting an elementary segment of its surface in the form of a plate, which allows to use the well-known relations of the onset of the resonance environment for the interaction of an acoustic wave and a plate in the form of wave coincidence and the formation of the acoustic transparency condition of the obstacle, when the energy of the ultrasonic beam will pass practically without loss (without dissipation) into the inter-shell acoustic medium.

4. It is shown that the change in the composition of the physical properties of the separating liquid and the material of the outer shell of the enclosing cylindrical module determine the angle of deflection of sound waves emitted into the liquid in the form of a relation $\sin\alpha = c/V$ [10].

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АНАЛИЗ СТЕПЕНИ ЭФФЕКТИВНОСТИ МАСКИРОВКИ ПАЛУБНОЙ АВИАЦИИ ОТ РАЗВЕД-ДИВЕРСИОННЫХ ГЛАЙДЕРОВ ПУТЕМ ИСКУССТВЕННО ФОРМИРУЕМОЙ БУФЕРНОЙ ЗОНЫ

Проведен анализ одного из технических решений средств эффективной маскировки самолетов тактической палубной авиации корабельного базирования. Рассмотрен механизм достижения невидимости самолета искусственным формированием в жидкости ограждающей поверхности межоболочечного пространства в виде зоны каустики, конфокальной внутренней поверхности внешней оболочки. Сформулированы условия эффективного достижения требуемой степени скрытности самолета на палубе авианосца.

Ключевые слова: угол аберрации, ультразвуковое излучение, резонанс волнового совпадения, зоны каустики, ограждающая поверхность.

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INVESTIGATION OF THE INFLUENCE OF GRAVITATIONAL FORCES ON THE PROCESS OF DISPLACEMENT OF VISCOPLASTIC FLUIDS

Досліджено чисельне моделювання процесу двовимірної двохфазної фільтрації в'язкопластичної нафти та води з урахуванням гравітаційних сил, деяких властивостей рідин, а також відносних фазових проникностей і капілярних сил на основі різностно-ітераційного методу в рухомих сітках. Для дослідження впливу цих факторів на процес фільтрації розроблено обчислювальний алгоритм, що володіє властивістю адаптованості до особливостей завдань і відрізняється високою точністю.

Ключові слова: *гравітаційні сили, метод змінних напрямків, локально-одномірні схеми, адаптивна сітка, в'язкопластична рідина.*

1. Introduction

Mathematical modeling of oil production processes, as a rule, reduces to solving boundary value problems for systems of nonlinear partial differential equations. Their research can be carried out by analytical or approximate methods. Analytical solutions can be obtained by substantially simplifying the models of real processes, when most of the main parameters are not taken into account, for example, the inhomogeneity of the seams, the non-stationarity of the operating modes, the compressibility of phases, the complexity of the geometry of the filtration region, etc. Such solutions are undoubtedly theoretical and methodical, but their practical significance is significantly limited. Accounting for factors that determine the specific conditions of oil production, significantly complicates mathematical modeling and generates the need for numerical modeling. For numerical modeling of filtration processes