Numerical simulation of the helicopter ditching on a calm water surface

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The authors of report summarized the results of computational and experimental work carried out within the ANSAT helicopter certification for compliance with the requirements of the AP-29 standard. On the basis of summarization of these results a mathematical model of the forced ditching was developed for helicopter equipped with cylindrical floats.

Keywords: Helicopter, ditching, design modeling, tests.

Experts of all European helicopter companies pay special attention to discussion of problems of helicopter crew and passenger survival during a forced ditching. To provide the required safety level during such landing, a wide range of technical measures should be considered and provided. One of the most important measures is the necessity for adequate piloting the helicopter during its approach to the water surface and entering the helicopter directly into the water. The development of the necessary instructions for pilot for adequate piloting the helicopter in this case must be performed on the basis of detailed preliminary computational investigations of helicopter ditching. The basic requirements for the helicopter ditching are in existing AP-29 (FAR-29) standards, but the actual conditions of such a process should be investigated in detail for each particular helicopter based on its configuration and shape of the main elements of Emergency Flotation System (EFS).

In the process of certification tests of ANSAT helicopter equipped with EFS, the full range of model tests was performed in experimental pool of TsAGI Moscow complex. A series of calculations was also carried out to reproduce the conditions of model tests and full-scale helicopter ditching. The purpose of this report is to summarize the experience made for ANSAT helicopter certification work and demonstrate the ability to apply this experience to confirm the safety of modern helicopters forced to ditching.

The specialists of all leading world-wide helicopter companies pay special attention to solving the problem of helicopter crew and passenger survival during forced ditching. To provide the required safety level during forced ditching, a wide range of technical measures, including computational and experimental investigations, should be considered and provided.

To ensure a safe emergency landing on water ANSAT helicopter is equipped with EFS company AERAZUR (see Figure 1). The use of such a system approved by the relevant certificate type for compliance with the requirements of the AP-29 in conditions of the helicopter ditching.

Figure 1 The appearance of ANSAT helicopter with installed EFS

Demonstration of compliance with the requirements for emergency landing and subsequent navigation of the helicopter can be carried out on the results of model tests (in case of identification of correlation between the results of model tests and full-scale tests) and using the results of model tests and other data for rotorcrafts with similar configuration.

The ditching investigations of ANSAT helicopter equipped with EFS with a dynamically similar model [2] were carried out in 2004 in the experimental pool of TsAGI Moscow complex.

The ditching investigations were conducted on the helicopter dynamically similar model helicopter with 1:7 scale. Figure 2 shows a model photo.

The model was made to be a hollow fiberglass one. The removable floats in working condition are installed on the model. The floats are rigid, i.e. the elasticity of air float are not simulated. The models of skid landing gear, main and tail rotors, similar to full-scale as per overall dimensions are installed on the model. The main rotor thrust in the tests is not reproduced.

Figure 2 Dynamically similar model of ANSAT helicopter

Tests of the model were dropping it into the water with a fixed or moving tow truck of experimental pool. Figure 3 shows a photo of installation with the model attached to it. The installation allows you to set the drop height, as well as the angles of pitch, roll and yaw.

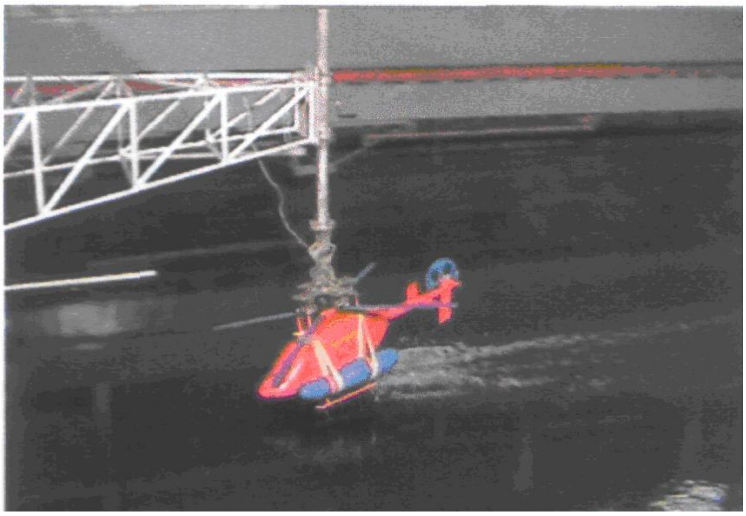
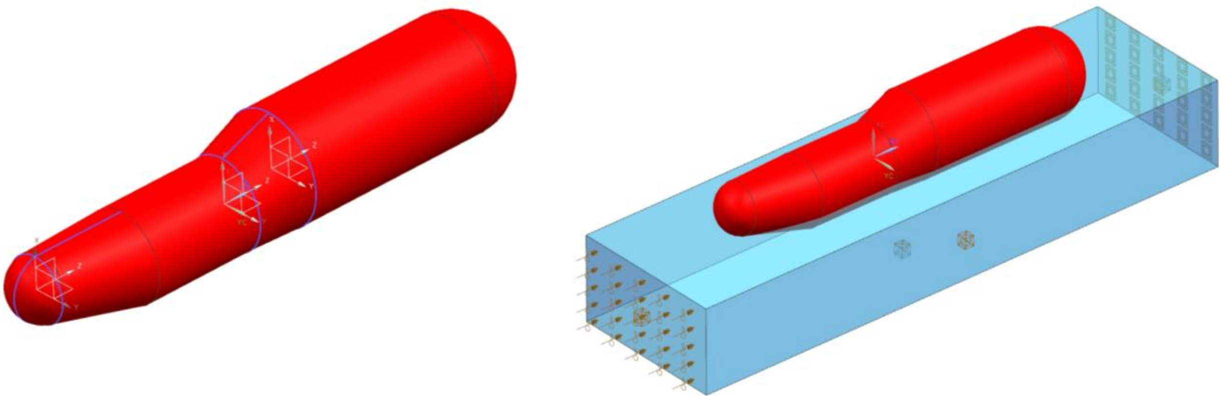


Figure 3 Test set with dynamically similar model of ANSAT helicopter

To investigate the hydrodynamic characteristics of EFS floats, a series of calculations was performed using the licensed «NX-Flow» compitational finite-element complex. At that the float geometry (without elasticity) is given and its flow is modeled by fluid flow at different values of submersion depth and different flow velocities. The computational float model and flow model are shown in Figures 4a and 4b. The computational model takes into account the conditions of turbulent flow and the fluid flow inhibition factor.



a *b*

Figure 4

Figure 5 shows the results of calculating the float resistance when longitudinal fluid flow for various flow velocities and angles of attack. Based on the analysis of the conducted calculations (and by analogy with the requirements of § 29.521 AP -29 standard), it is assumed that the float drag coefficient is 0.25.

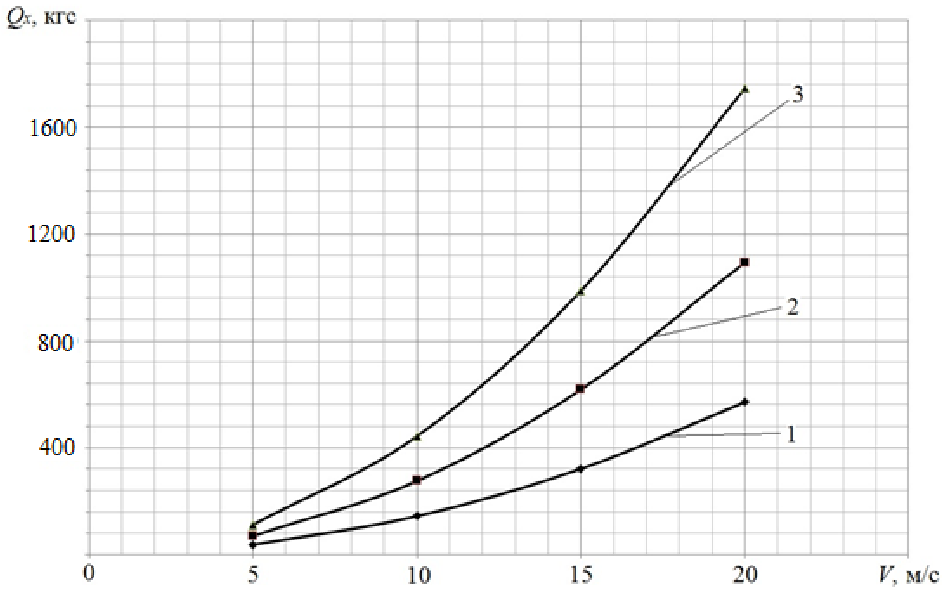


Figure 5 Resistance
1 - 200 mm depth, 2 - depth 300 mm, 3 - 400 mm depth

Figure 6 shows an example graph of distribution of excess hydrodynamic pressure on the wetted float surface. The graph is based on the chosen path of finite elements, which coincides with the direction of the longitudinal axis of float. This pressure distribution is obtained for the zero angle of float attack. Analysis of the flow pattern shows the presence of vacuum pressure in the rear of float, because of the development zone of separated flow. This fact leads to the practical absence of the lift in this part of the float surface. At that the absence of significant sudden changes in pressure on the rest of the float regular surface allows its approximate consideration as a cylinder, flowed by fluid. The application of the theory of gliding cylinder developed by the Central Aerohydrodynamic Institute named after Zhukovsky N.E. was based on this statement to calculate the total hydrodynamic force acting on the EFS float when it enters the water.

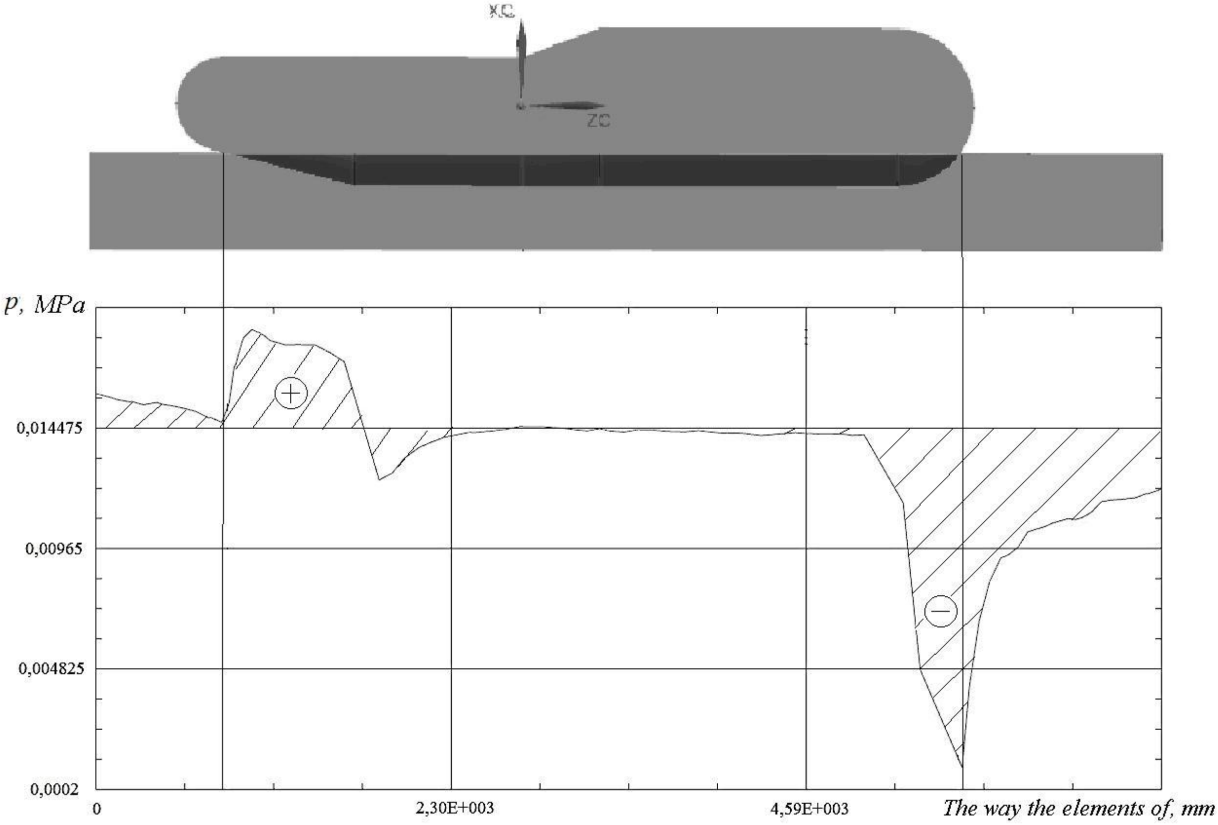


Figure 6

Fundamentals of the approximate analytical theory of immersion into the liquid and the cylinder gliding are presented in works [2] and [3]. The method of plane sections normal to float axis and fixed in an absolute coordinate system is used when calculating the hydrodynamic forces. It is considered that the fluid flow occurs only in the plane of the layers, and the overflowing of the longitudinal is absent. Then, in each of the flat layers at float passing through it, there will be flow, similar to cylinder immersion into liquid with a free surface. The total hydrodynamic load will be determined by integrating over all the elementary cross sections at each fixed point of time, and the elementary hydrodynamic force acting in the plane sections, will be determined only by the instantaneous value of the kinematic parameters of cylinder movement - its vertical and horizontal components of movement velocity. The case of cylinder gliding over the liquid surface with an attack angle α and transom immersion into some depth with respect to the undisturbed level of free water surface is shown in Figure 7.

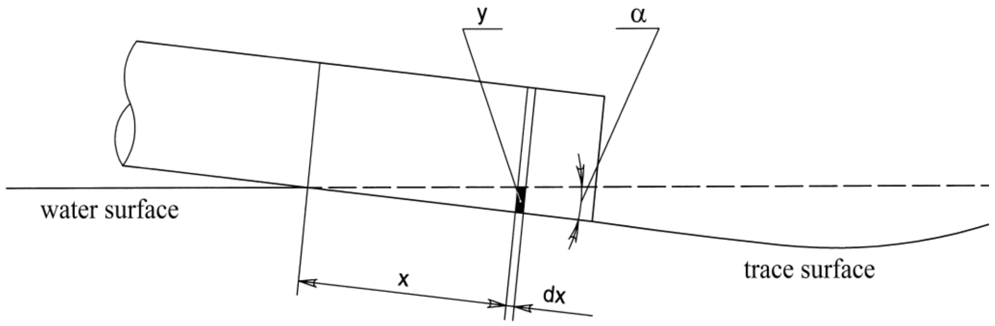


Figure 7

The basis of the approximate theory of this process is a method for determining the kinematics of movement of the free surface towards the body and the value of body wetted 2c width, corresponding to each value h in relation to free surface (the method of Wagner). It uses cross-flow velocity potential of expanded plate with a variable width 2c. As a result of counter rise of water, the width 2c is greater than the geometrical width $2c_0$ of segment, cut off by the undisturbed free surface (see Figure 8).

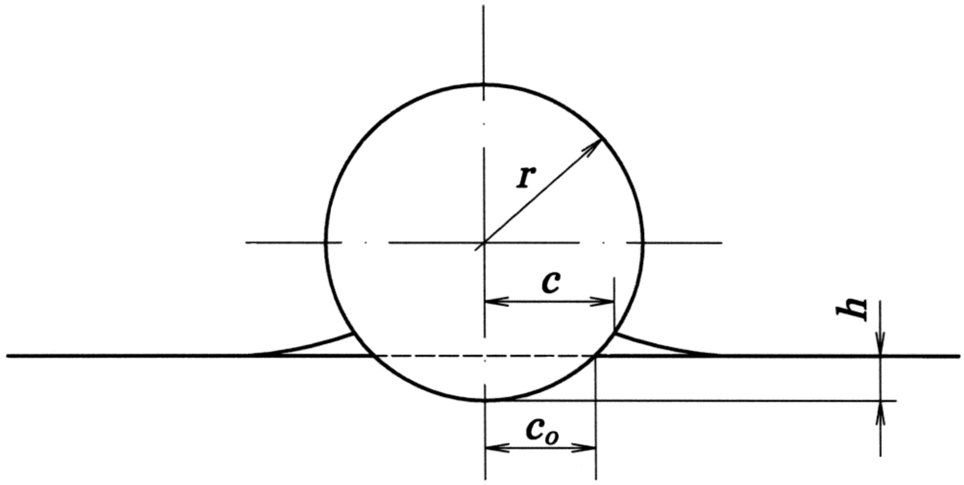


Figure 8

The dependence 2c versus h is determined by the well-known equation of Wagner, whose solution is the following expression:

$$h = \frac{2}{\pi} \int_0^c \frac{y(x)}{\sqrt{c^2 - x^2}} dx, \quad (1)$$

where $y = y(x)$ is a wetted surface profile equation in the coordinate system connected with body immersion (y - perpendicular to the direction of the free surface). For a circular cylinder of radius r, this equation is as follows $y = r - \sqrt{r^2 - x^2}$. Based on the equation of Wagner, Russian scientist G. Logvinovich [4] derived an equation for the hydrodynamic lift gliding cylinder at the rate of its dive V_n:

$$F_y = \pi\rho V_n^2 c \frac{dc}{dh}\left[1 - \frac{1}{\pi}\frac{dh}{dc}\left(1 + \ln 4\frac{dc}{dh}\right)\right] \qquad (2)$$

The basic relations for calculating the hydrodynamic lift forces are given in [3] more detailed.

As a result of an elementary section of the cylinder dx (Figure 7) the following elementary forces should be taken into account.

1) The hydrodynamic force is determined on the basis of relation (2), which goes into effect the cavitation resistance at a depth of immersion of the cylinder section $h > 0{,}33\ r$:

$$dF_K = C_k \rho V_n^2 r dx, \qquad (3)$$

where C_k - coefficient of cavitation resistance of the cylinder equal to 0.5.

2) the Archimedean buoyancy force is equal to

$$dF_A = S\rho g dx, \qquad (4)$$

where S - area of submerged cylinder section relatively undisturbed liquid level of cylinder section, g - gravity acceleration.

3) The inertia force proportional to acceleration $\dot{V}_n$, acting in this section. It is assumed that the elementary force is the product of the acceleration and the added mass value corresponding to this section. The added mass is assumed to be equal to half of the added mass of the cylinder located in an unbounded fluid and having a diameter equal to the width of the wetted section $2c$. The added masses are determined by the known expressions [5].

The total lift force equal to the integral over the wetted length of the float from the above differential expressions for the hydrodynamic force is directed along the normal to the longitudinal axis of the cylinder. It should be noted that this theory is limited by the positive values of the cylinder attack angle.

Verification of the above methods of calculating the values of the hydrodynamic loads on the gliding cylinder is made on the basis of analysis of the cylinder model test results in the experimental pool of TsAGI named after Zhukovsky N.E. Figures 9 and 10 shows the results of calculating the parameters of stationary cylinder gliding with a constant attack angle of 2^o and constant longitudinal velocity Vx = 12 m/s. In this case the vertical velocity at the moment of touching the water was Vy = 0.5 m/s.

Comparison of calculated and experimental results for the congestion n_y in the process of cylinder immersion (Figure 9) and the relative depth of immersion of the cylinder transom h_0/r (Figure 10) shows, that the developed theory describes the process of hydrodynamic loading of gliding cylinder quite well.

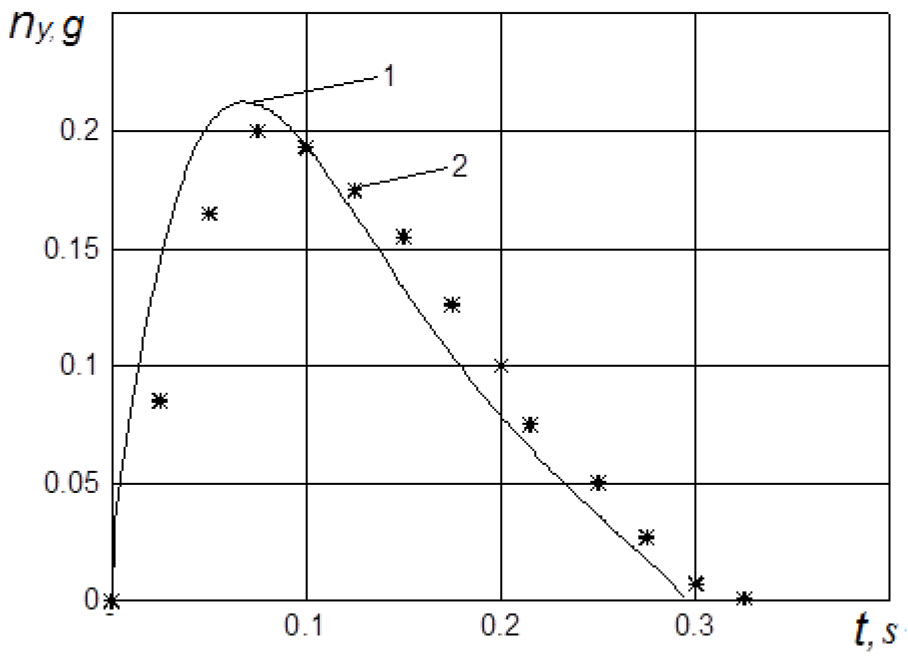


Figure 9

1 - calculation, 2 – experiment

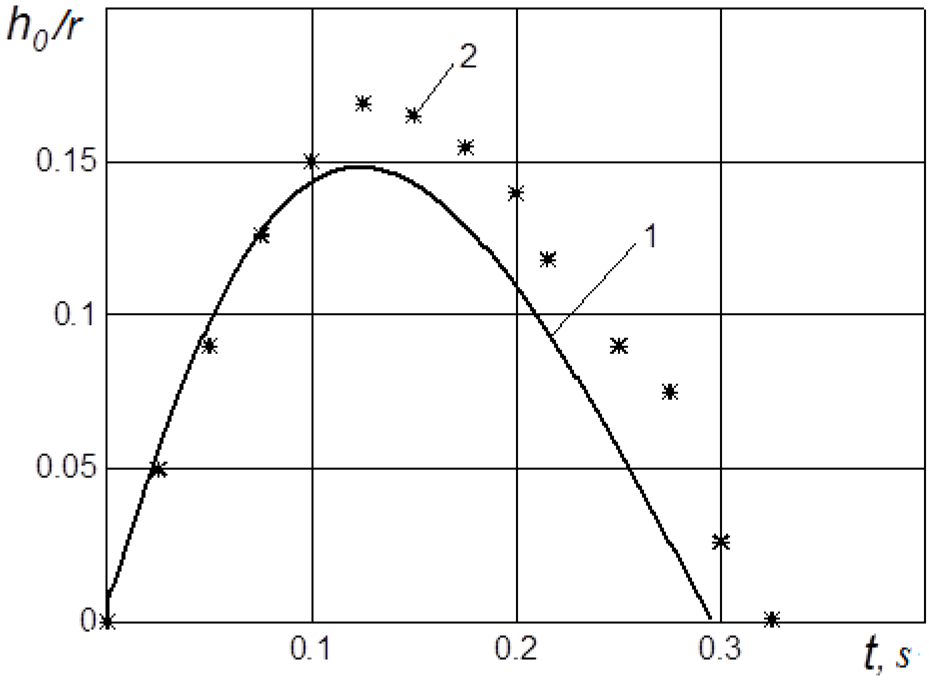


Figure 10

1 - calculation, 2 – experiment

The above theory is applied to the gliding cylinder modeling the hydrodynamic EFS float loading conditions during ANSAT helicopter ditching. The main coordinate systems, which in this case used in the helicopter simulation ditching are common system: connected $OXYZ$, earth $O_0X_0Y_0Z_0$ and normal earth $OX_gY_gZ_g$ [6] (see Figure 11).

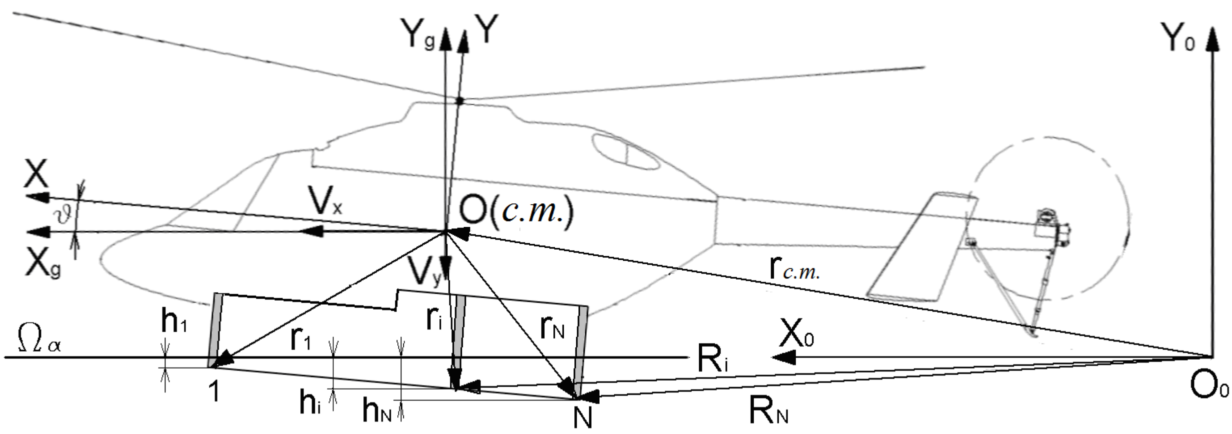


Figure 11

The EFS float in Figure 11 is schematically represented by two-piece cylinder and divided into N elementary parts. Each volume element is regarded as a rigid body. The radius-vector $\mathbf{r}_i$ (i = 1, ..., N), linking the helicopter center of gravity with this point, is drawn to the bottom point of each elementary volume. At that the value h_i (i = 1, ..., N) characterizes the depth of immersion of the point relative to the water surface Ω_α.

The used method of calculating the dynamics of helicopter landing is described in detail in [7].

The calculation of dynamic parameters of the helicopter movement is performed after determining the values of loads on the EFS floats. At the same time the well-known equations of movement are used (see, eg, [6]).

The solution of the equations of helicopter spatial motion is performed by the well-known numerical methods.

It should be noted that the approximate consideration of helicopter bottom influence on its hydrodynamic loading is carried out at this stage of investigation. In this case, the helicopter bottom with a complicated contour is approximately replaced by the equivalent cylinder during calculation. When determining the parameters of the equivalent cylinder it is taken into account that first of all the EFS floats perceive the basic hydrodynamic loads during helicopter entry into water. The very bottom is immersed into a relatively shallow depth, thus substituting equivalent cylinder shall be immersed into about the same depth and should have area of contact with water, approximately equal to the wetted surface area of the bottom. Figure 12 schematically shows a cross section of the bottom of the ANSAT helicopter and equivalent cylinder.

To check the correctness of developed method of calculating the dynamic parameters of helicopter ditching, the simulation of test conditions of ANSAT helicopter dynamically similar model is performed under the following conditions:

- the model pitch angle in the moment of contact with water is 4^{o};
- the longitudinal velocity at the time of contact with water is equal to 15.3 m/s (for helicopter);

- the vertical velocity at the moment of contact with water is equal to 2.6 m/s (for helicopter).

The results of calculation and experiment for the model CG acceleration (as a fraction *g*) are shown in Figure 13.

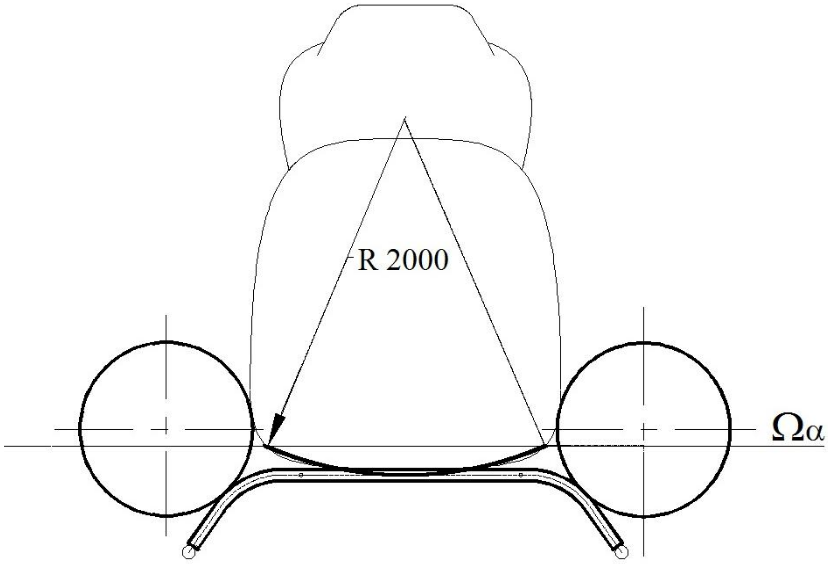


Figure 12 Calculated bottom scheme

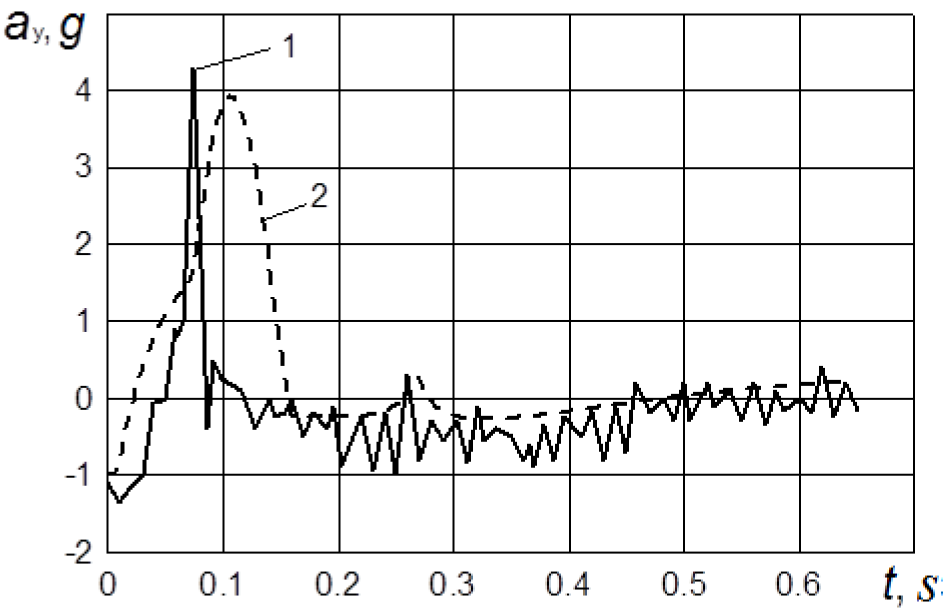


Figure 13
1 - experiment, 2 – calculation

As you can see from the comparison results of calculation and experiment data, the developed calculation method allows sufficient accurate simulation of process of hydrodynamic loading the helicopter when it enters the water. At that the acceleration peak coincides sufficiently close as per time and value, which is available in experiment. Some displacement of calculated and experiment overload peaks is explained by the approximate adopted calculation scheme, including an approximate simulation of the influence of the helicopter bottom.

As mentioned above, in calculation the EFS float was modeled as a two-piece cylinder. The rear part of cylinder has a radius of 0.5 m, the front part - 0.4 m (see Figure 1). To investigate the necessary to consider the influence of two-piece float the ditching conditions are calculated with a solid cylinder of constant radius of 0.5 The Figure 14 shows a comparison of the result with the experiment. Comparison of Figures 13 and 14 shows that two ways of float modeling give sufficiently close results. That is why it is possible to make a conclusion on the admissibility of an approximate modeling the float of solid cylinder at the stage of the design calculations.

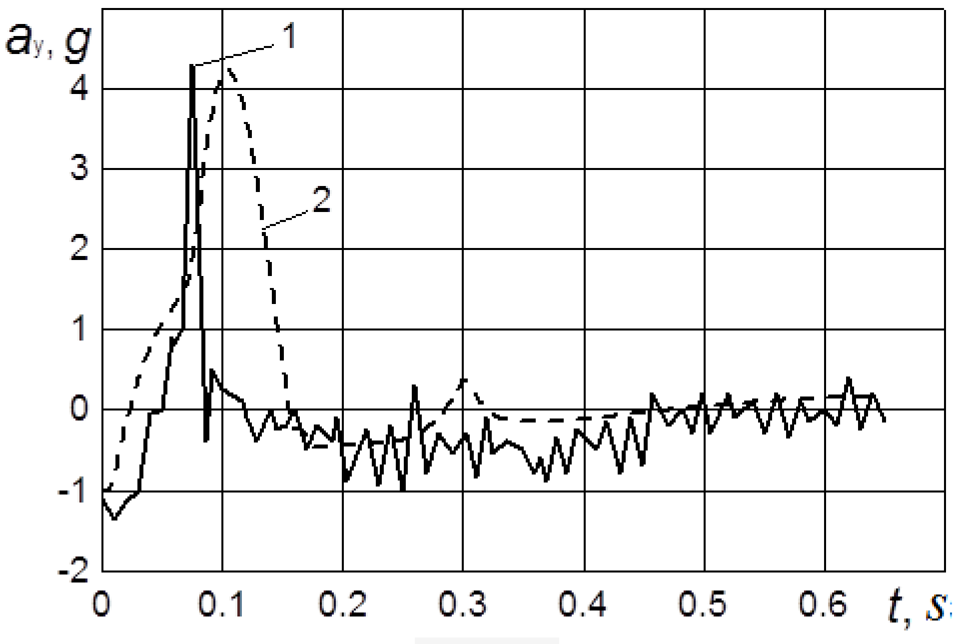


Figure 14

1 - experiment, 2 – calculation

To investigate the effect of vertical velocity at the moment of helicopter touching the water surface on the level of its loading, the design simulation of drop is performed under the following conditions:

- the model pitch angle at the moment of contact with water is 4^{o};

- the longitudinal velocity at the moment of contact with water is equal to 15.3 m/s (for helicopter);

- the vertical velocity at the moment of contact with water is equal to 1.56 m / s (for helicopter), which is stated in § 29.563 AP-29 standard.

The calculation results for the acceleration in model CG (as a fraction g) are shown in figure 15.

The calculated modeling of helicopter ditching conditions with vertical velocity prescribed by § 29.563 AP-29, gives an idea of the level of loading the helicopter structure under expected operating conditions.

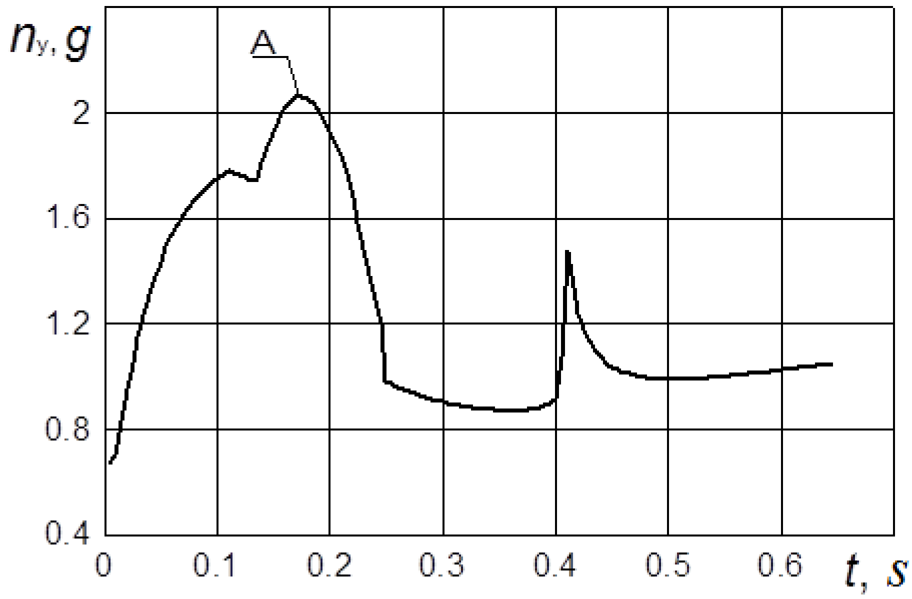


Figure 15

Figure 16 shows the calculation results of process of changing the vertical hydrodynamic forces on the EFS float and helicopter bottom. The maximum of the total overload in the helicopter center of mass, indicated in Figure 15 by point A, is caused by the addition of loads on the EFS floats and helicopter bottom during the time. Next to him during the time is an overload peak (in the vicinity of t = 0.4 s). It corresponds to the re-strike the bottom by the water surface, and before this repeated strike the bottom comes from the water, and floats remain submerged in water. Bottom coming out of the water and re-immersion into water are explained by the presence of a permanently acting MR thrust during ditching (it is equal to two thirds of helicopter weight), which is prescribed requirements by § 29.563 AP-29 [1].

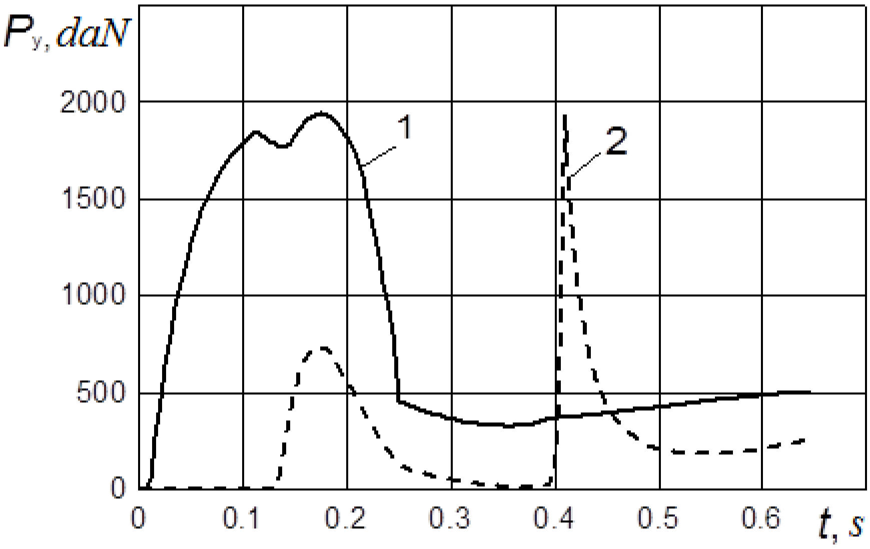


Figure 16

1 - vertical load on EFS float, 2 - vertical load on helicopter bottom

Thus the used dynamic calculation models have been verified according to results of earlier performed experimental investigations. The complex of results of calculation and experiment investigations, performed for ANSAT helicopter, demonstrates the amount of works to be performed to ensure the modern helicopter ditching.

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