

“KAZAN HELICOPTERS” JSC
CENTRAL AEROHYDRODYNAMIC INSTITUTE
KAZAN STATE TECHNICAL UNIVERSITY
(RUSSIAN FEDERATION)

**Numerical study of a mathematical model of the controlled helicopter
ditching dynamics**

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Introduction

Increase of reliability and safety of operation of helicopters when flying over sea has special relevance nowadays due to development of offshore fields of oil and gas.

For solving such a problem when producing a helicopter it is required to develop the special design measures and guidelines for crew safety in case of a helicopter ditching and maintaining the buoyancy of helicopter during time, which is sufficient for evacuating the people from inside. It is evident that one of the most important safety factors is the proper piloting the helicopter at its ditching, precluding the possibility of its turning and flooding. For proving the safety method of piloting, it is required to perform numerical modeling of ditching process taking into account all the factors that affect it. This mathematical model is being developed by specialists of JSC «Kazan Helicopters» now.

The results of scientific research carried out by teams of Central Aerohydrodynamic Institute named after Zhukovsky N.E. and Kazan State Technical University named after Tupolev A.N. were brought for its creation.



Figure 1 – ANSAT helicopter equipped with Emergency Flotation System

1 Calculation of the hydrodynamic forces and moments at steady gliding of cylinder

At development of mathematical model of ANSAT helicopter ditching, the approximate theory of submersion and cylinder gliding is used to determine the hydrodynamic loads on the EFS elements. This theory is developed by research scientists of Central Aerohydrodynamic Institute. It is assumed that the interaction with water occurs only on the surface of the EFS element (hereinafter - float), the middle part of which is a circular cylinder, and the tail and nose parts approach the spherical shape. At this stage of investigation it is considered that their form is cylindrical.

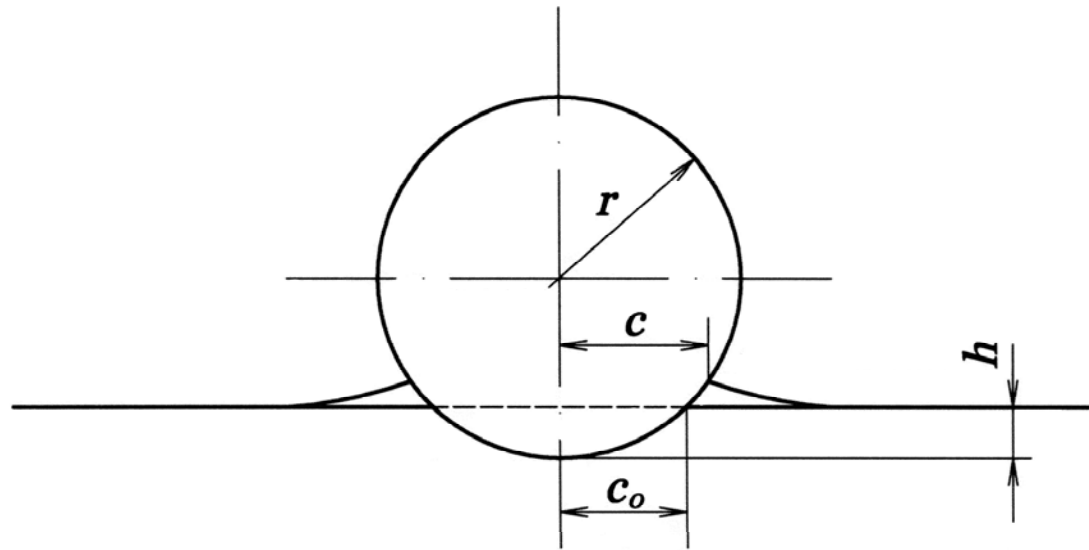


Figure 2

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

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

$$(2) \quad y = r - \sqrt{r^2 - x^2}$$

$$(3) \quad \frac{h}{r} = \frac{1}{4} \left(\frac{c}{r} \right)^2 + \frac{3}{64} \left(\frac{c}{r} \right)^4 + \frac{5}{256} \left(\frac{c}{r} \right)^6 + \dots$$

$$(4) \quad \frac{h}{r} = 1 - \frac{2}{\pi} E \left(\frac{c}{r} \right)$$

$$(5) \quad f = \pi \rho V_n^2 c \frac{dc}{dh} \left[1 - \frac{1}{\pi} \frac{dh}{dc} \left(1 + \ln 4 \frac{dc}{dh} \right) \right]$$

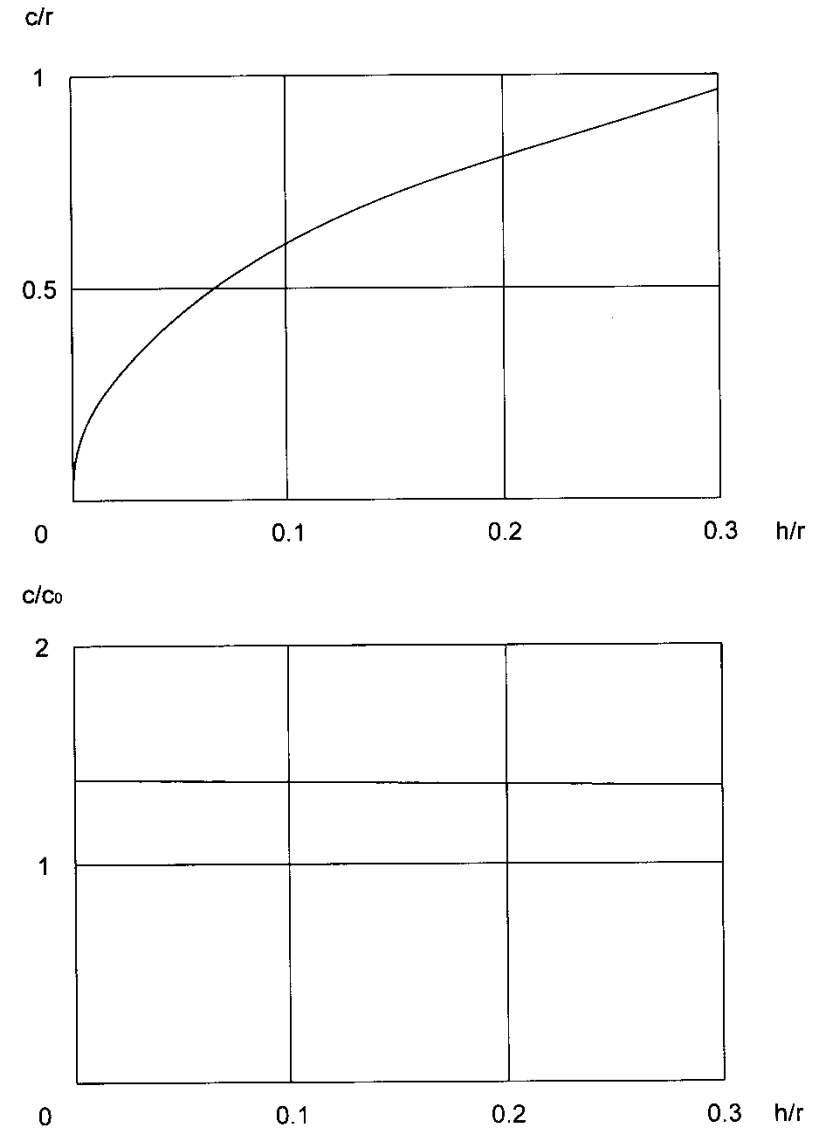


Figure 3

At calculation it is required to take into account the added mass, hydrodynamic force, buoyancy force and cavitation drag, which are calculated by the following formulas:

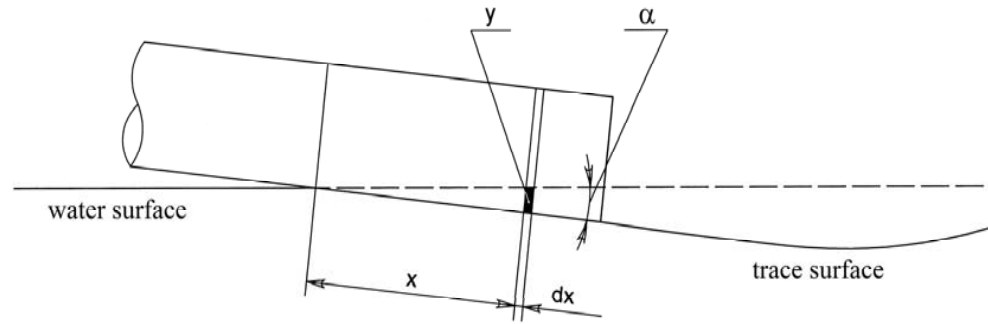


Figure 4

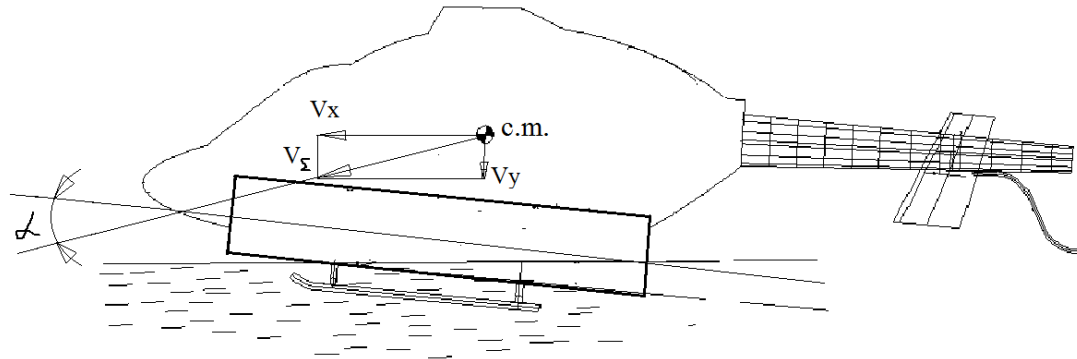


Figure 5

$$dF_G = 2\pi\rho V_n^2 r \varphi \left(\frac{h}{r} \right) dx, \quad V_n = V\alpha$$

$$dF_K = C_k \rho V^2 r \alpha^2 dx \quad (7)$$

$$dF_A = S \rho g dx$$

$$m^* = \frac{1}{2} \rho \pi c^2, \quad \frac{y}{r} \leq 0,33 \quad (8)$$

$$m^* = \frac{1}{2} \rho \pi r^2, \quad \frac{y}{r} > 0,33 (c = r)$$

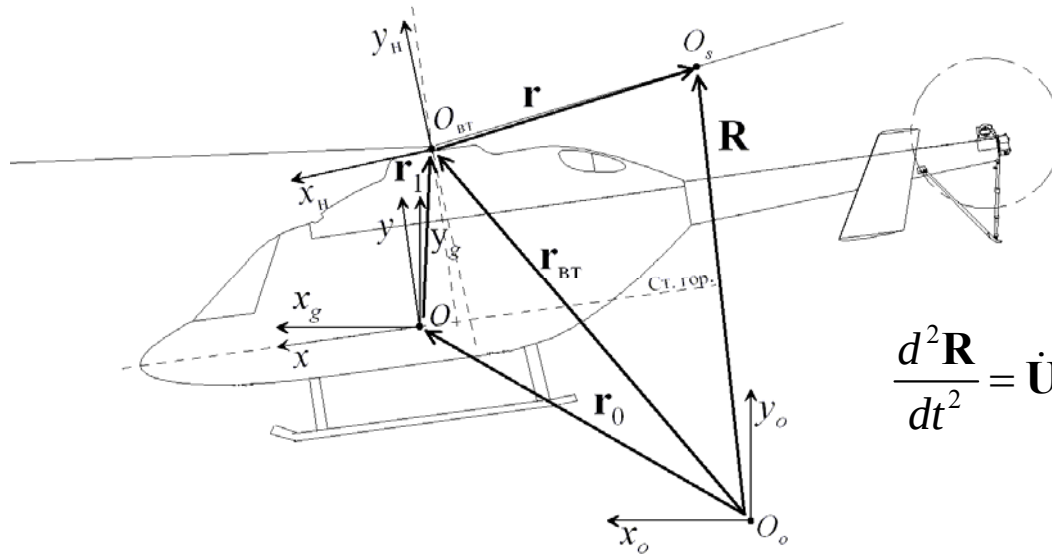
$$F_f = C_f \frac{\rho V^2}{2} S \quad (9)$$

$$C_f = 0,445 (\lg Re)^{-2,58}$$

2 Method of taking into account the forces and moments, generated by main rotor

This method is developed by research scientists of Kazan State Technical University named after Tupolev A.N.

The aerodynamic load on the blades of aeroelastic main rotor is determined by the element-impulse theory. The elastic deformations of the blade are taken into account on the basis of geometrically nonlinear theory of spatially deformed rods of wing profile. At that in order to take into account the actual flow velocities at blade elements with rapid change of transient ditching regime the following calculation scheme is adopted



$$\frac{d\mathbf{R}}{dt} = \mathbf{U}_0 + \boldsymbol{\Omega}_0 \times \mathbf{r}_1 + \dot{\mathbf{r}} + \boldsymbol{\Omega} \times \mathbf{r},$$

$$\begin{aligned} \frac{d^2\mathbf{R}}{dt^2} = & \dot{\mathbf{U}}_0 + \boldsymbol{\Omega}_0 \times \mathbf{U}_0 + \dot{\boldsymbol{\Omega}}_0 \times \mathbf{r}_1 + \boldsymbol{\Omega}_0 \times (\boldsymbol{\Omega}_0 \times \mathbf{r}_1) + \\ & + \ddot{\mathbf{r}} + \dot{\boldsymbol{\Omega}} \times \mathbf{r} + 2\boldsymbol{\Omega} \times \dot{\mathbf{r}} + \boldsymbol{\Omega} \times (\boldsymbol{\Omega} \times \mathbf{r}), \end{aligned} \quad (10)$$

Figure 6

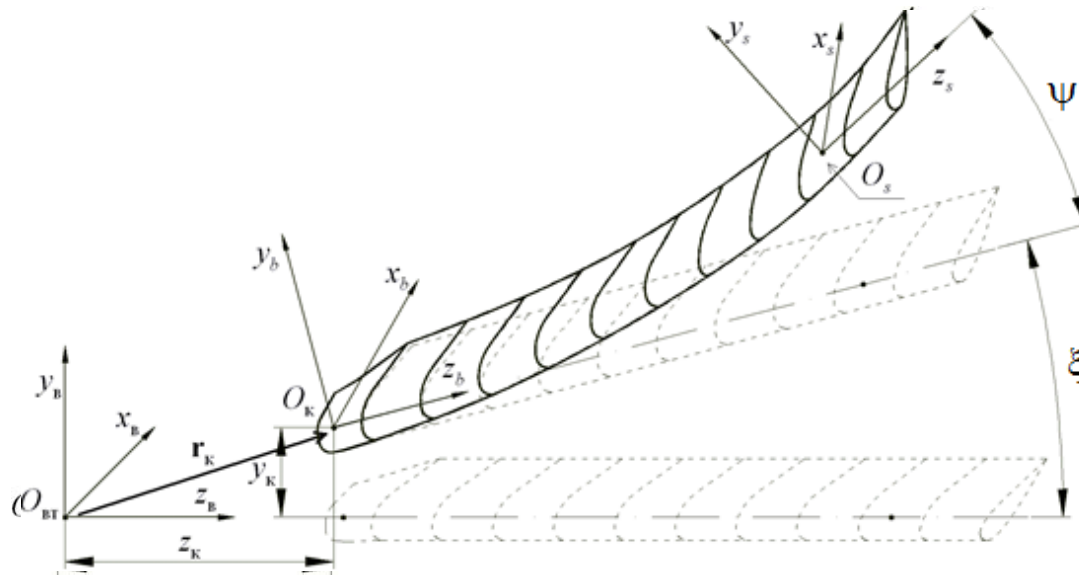


Figure 7

$$\xi = \alpha_0^\xi + \sum_{k=1}^{\infty} (\alpha_k^\xi \cdot \cos k\psi_H + b_k^\xi \cdot \sin k\psi_H);$$

$$(11) \quad \eta = \alpha_0^\eta + \sum_{k=1}^{\infty} (\alpha_k^\eta \cdot \cos k\psi_H + b_k^\eta \cdot \sin k\psi_H);$$

$$\zeta = \alpha_0^\zeta + \sum_{k=1}^{\infty} (\alpha_k^\zeta \cdot \cos k\psi_H + b_k^\zeta \cdot \sin k\psi_H);$$

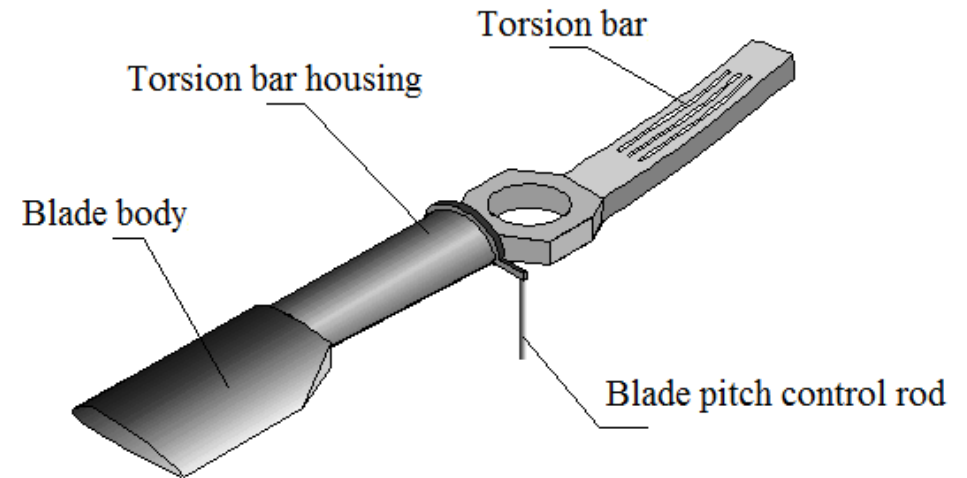
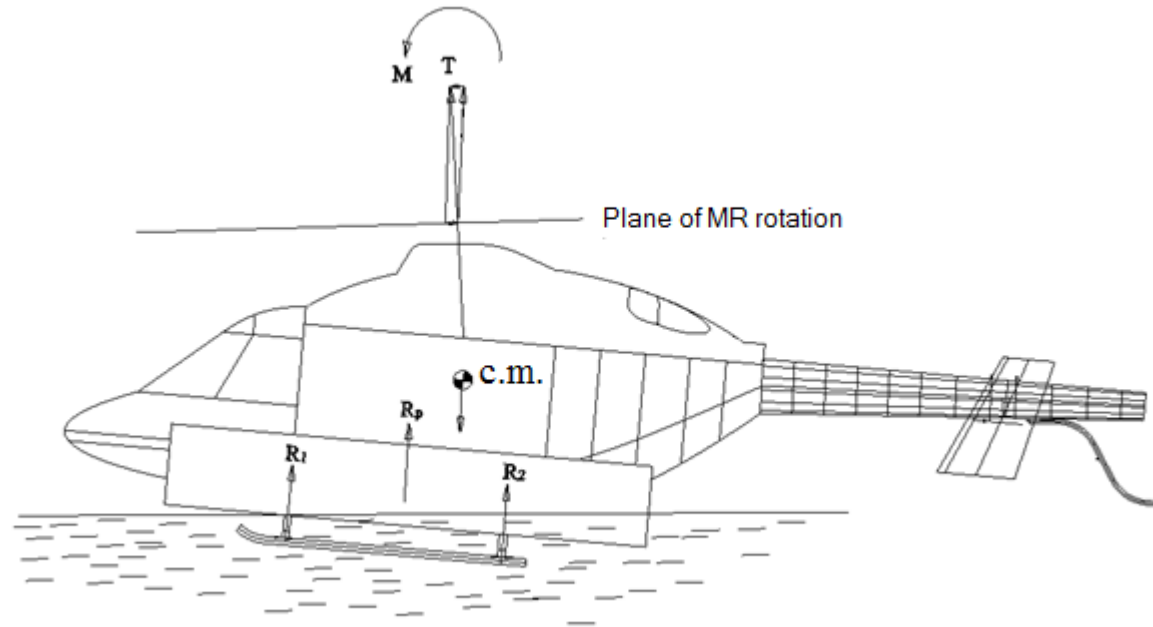


Figure 8

3 Mathematical model of helicopter movement during entry of EFS elements into water



This method is developed by specialists of “Kazan Helicopters” JSC

Figure 9

Equations of helicopter spatial movement at ditching:

$$\begin{aligned}
 & m(a_{xg} \cos \vartheta \cos \psi + (a_{yg} + g) \sin \vartheta - a_{zg} \cos \vartheta \sin \psi) = P_x; \\
 (12) \quad & m \left(a_{xg} (\sin \psi \sin \gamma - \sin \vartheta \cos \psi \cos \gamma) + (a_{yg} + g) \cos \vartheta \cos \gamma + \right. \\
 & \quad \left. + a_{zg} (\cos \psi \sin \gamma + \sin \vartheta \sin \psi \cos \gamma) \right) = P_y; \\
 & m \left(a_{xg} (\sin \vartheta \cos \psi \sin \gamma + \sin \psi \cos \gamma) - (a_{yg} + g) \cos \vartheta \sin \gamma + \right. \\
 & \quad \left. + a_{zg} (\cos \psi \cos \gamma - \sin \vartheta \sin \psi \sin \gamma) \right) = P_z,
 \end{aligned}$$

$$\begin{aligned}
(13) \quad & J_x \dot{\Omega}_x - J_{zx} \cdot \Omega_x \Omega_y + J_{yx} \cdot \Omega_x \Omega_z + (J_z - J_y) \cdot \Omega_z \Omega_y - J_{zy} \cdot \Omega_y^2 + J_{yz} \cdot \Omega_z^2 = M_x, \\
& J_y \dot{\Omega}_y - J_{xy} \cdot \Omega_y \Omega_z + J_{zy} \cdot \Omega_y \Omega_x + (J_x - J_z) \cdot \Omega_x \Omega_z - J_{xz} \cdot \Omega_z^2 + J_{zx} \cdot \Omega_x^2 = M_y, \\
& J_z \dot{\Omega}_z - J_{yz} \cdot \Omega_z \Omega_x + J_{xz} \cdot \Omega_z \Omega_y + (J_y - J_x) \cdot \Omega_x \Omega_y - J_{yx} \cdot \Omega_x^2 + J_{xy} \cdot \Omega_y^2 = M_z,
\end{aligned}$$

Method of numerical integration of spatial movement equations

$$\begin{aligned}
(14) \quad & \Omega_x = \dot{\gamma} + \dot{\psi} \sin \vartheta, & V_{xg(j+1)} &= V_{xg(j)} + \frac{1}{2}(a_{xg(j+1)} + a_{xg(j)})\Delta t_j; \\
& \Omega_y = \dot{\psi} \cos \vartheta \cos \gamma + \dot{\vartheta} \sin \gamma, & (15) \quad V_{yg(j+1)} &= V_{yg(j)} + \frac{1}{2}(a_{yg(j+1)} + a_{yg(j)})\Delta t_j; \\
& \Omega_z = \dot{\vartheta} \cos \gamma - \dot{\psi} \cos \vartheta \sin \gamma. & V_{zg(j+1)} &= V_{zg(j)} + \frac{1}{2}(a_{zg(j+1)} + a_{zg(j)})\Delta t_j; \\
(16) \quad & \dot{\gamma}_{j+1} = \dot{\gamma}_j + \frac{1}{2}(\ddot{\gamma}_{j+1} + \ddot{\gamma}_j)\Delta t_j; & \gamma_{j+1} &= \gamma_j + \dot{\gamma}_j \cdot \Delta t_j + \frac{1}{6}(2 \cdot \ddot{\gamma}_j + \ddot{\gamma}_{j+1}) \cdot \Delta t_j^2; \\
& \dot{\psi}_{j+1} = \dot{\psi}_j + \frac{1}{2}(\ddot{\psi}_{j+1} + \ddot{\psi}_j)\Delta t_j; & (17) \quad \psi_{j+1} &= \psi_j + \dot{\psi}_j \cdot \Delta t_j + \frac{1}{6}(2 \cdot \ddot{\psi}_j + \ddot{\psi}_{j+1}) \cdot \Delta t_j^2; \\
& \dot{\vartheta}_{j+1} = \dot{\vartheta}_j + \frac{1}{2}(\ddot{\vartheta}_{j+1} + \ddot{\vartheta}_j)\Delta t_j; & \vartheta_{j+1} &= \vartheta_j + \dot{\vartheta}_j \cdot \Delta t_j + \frac{1}{6}(2 \cdot \ddot{\vartheta}_j + \ddot{\vartheta}_{j+1}) \cdot \Delta t_j^2,
\end{aligned}$$

4 Parametric analysis of calculation results of helicopter ditching

Figure 10

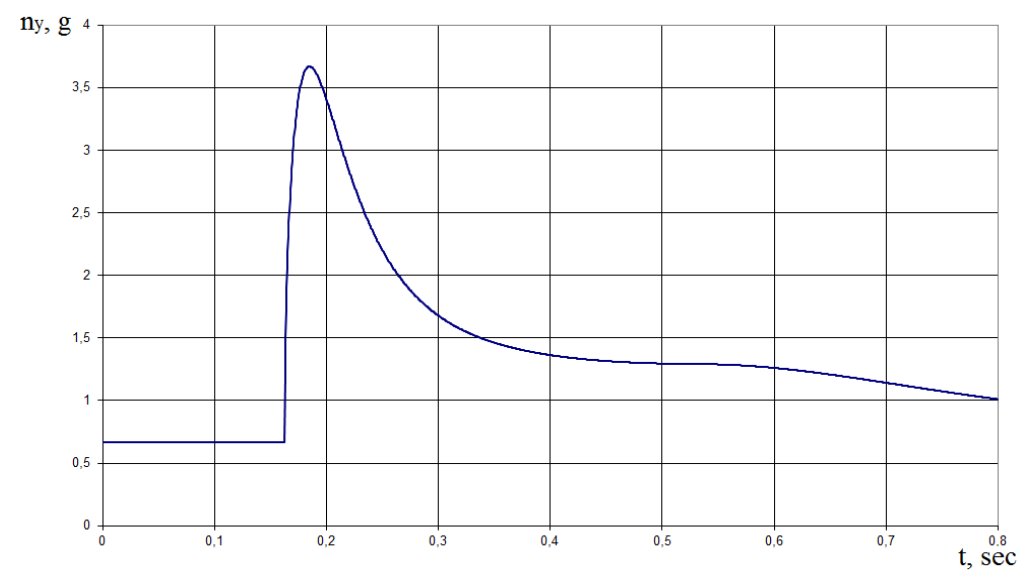
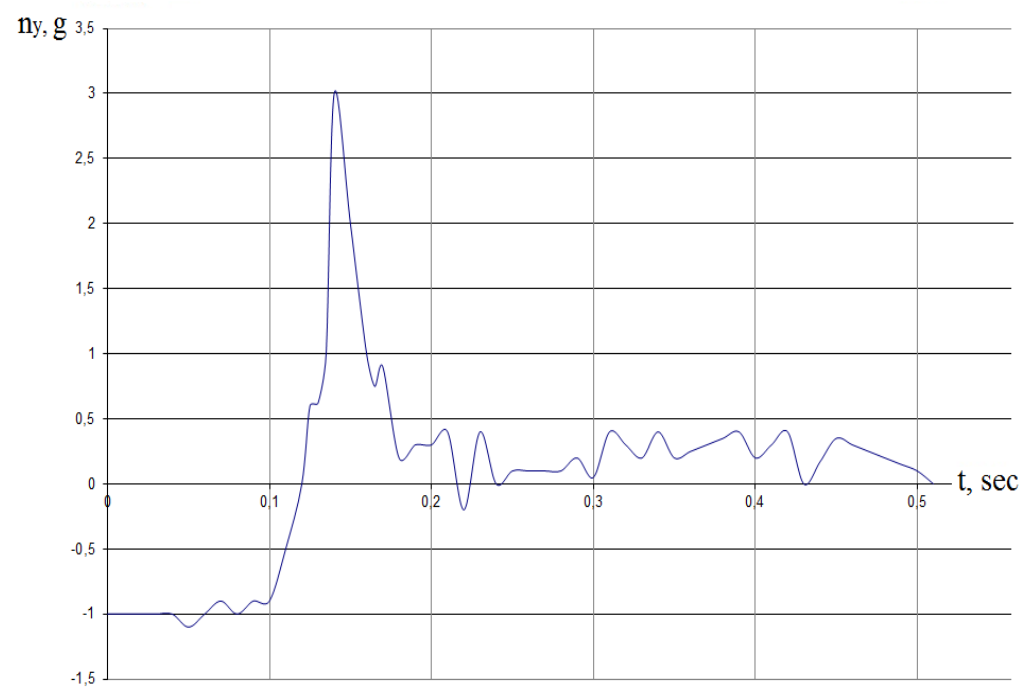


Figure 11



Calculation of helicopter movement parameters : 1 – as per FAR-29 requirements;
 2 – when applying the constant point moment to MR hub; 3 – when changing the value of MR thrust during ditching

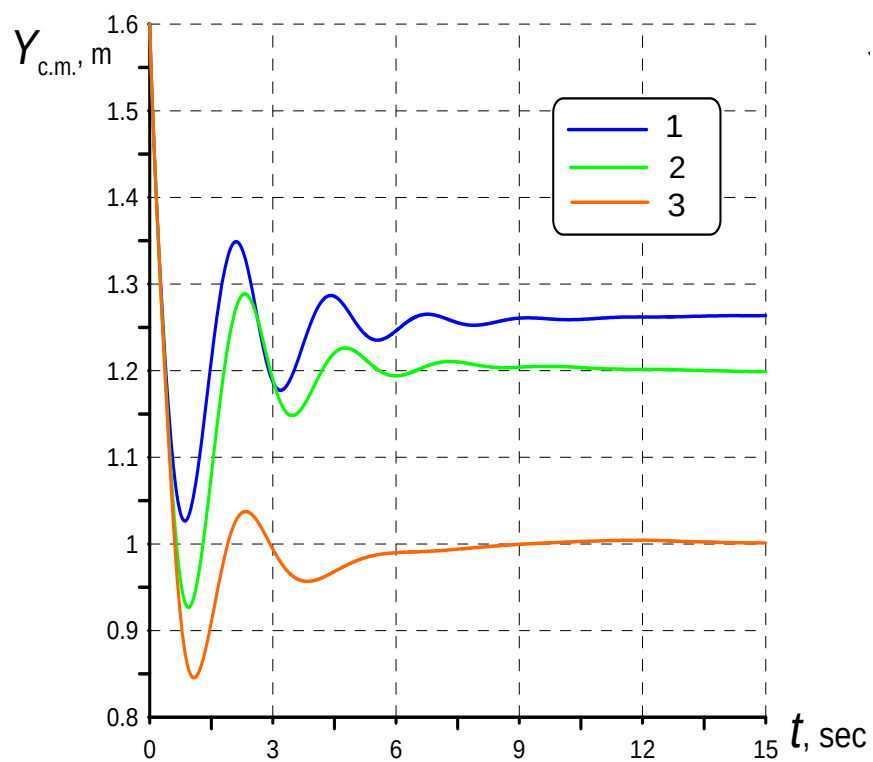


Figure 12

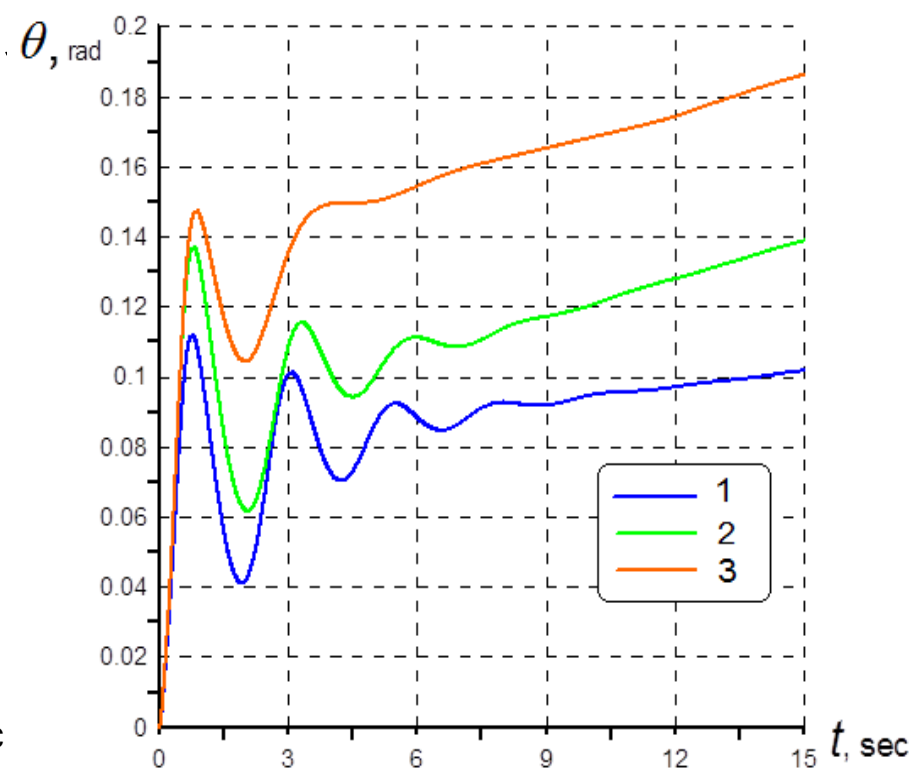


Figure 13

CONCLUSION

The results of investigation show the possibility of solving the task of modeling the dynamics of controlled helicopter ditching taking into account the loads, created by rigid main rotor and hydrodynamic loads on the EFS elements. This provides the possibility for subsequent solving the following tasks:

- the best possible method of implementation of controlled landing on water surface in standard and critical conditions;
- assessing the required level of stability and buoyancy performance of helicopter equipped with Emergency Flotation;
- well-grounded determination of actual loads, effecting on the EFS elements and on the elements of their attachment to helicopter structure;
- assessing the possibility of dangerous proximity of revolving MR blades with water surface.

Further research for creation of mathematical model of controlled helicopter ditching will continue, including revision of calculation model for determining the loads on the EFS float with negative angles of attack during its contact with water surface, as well as calculation taking into account MR influence directly.

Thank you for your attention!