COMPUTATIONAL STUDIES OF DIFFERENT TAIL ROTORS CHARACTERISTICS UNDER «SPONTANEOUS» ROTATION OF HELICOPTER

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Abstract

In this work, the factors that make the helicopter to enter into the «spontaneous» rotation were computationally analyzed. The characteristics have been calculated of different tail rotors under rotation conditions with the angular velocities $\omega_y = 0\ ^0$/sec, $\omega_y = 30\ ^0$/sec, $\omega_y = 60\ ^0$/sec and $\omega_y = 120\ ^0$/sec to the left side when hovering without the ground effect. The computational studies have been carried out by using the helicopter mathematical model, developed in TsAGI. A relationship between the tail rotor relative thrust coefficient and the angular velocities $C_T/\sigma(\omega y)$ has been obtained.

INTRODUCTION

The helicopter «spontaneous» rotation to the left side (for the clockwise main rotor rotation) is one of the most dangerous mode for helicopters with tail rotors (T/R). Nowadays, this mode is not sufficiently researched.

One of the main causes of entering helicopters into «spontaneous» rotation is the main rotor vortex influence on the tail rotor. The crosswind from the right side will cause the main rotor vortex to be blown into a tail rotor [1]. There are other contributing factors, which may cause the entering of helicopters into «spontaneous» rotation, such as: the maximum gross weight, the high ambient air temperature, the engine power low margin, the main rotor reduced rotational speed, the blustery wind, the landing site blanket created by buildings and constructions that are capable to generate the wind flow vortices or its directivity and velocity variations. As well as the takeoff or the sideslip landing may be considered as contributing factors.

Curves on figure 1 demonstrate the relationships between the trim tail rotor pitch increments $\Delta\varphi_{TR} = \varphi_{TR} - \varphi_{TR(hover)}$ (φ_{TR} – trim tail rotor pitch, $\varphi_{TR(hover)}$ – trim tail rotor pitch under hovering) and a lateral velocity V_z for four rates of longitudinal velocities V_x. These curves have been obtained from the flight tests and show, that the significant increase of trim tail rotor pitch occurs in the interval -5 m/sec < V_x < 12 m/sec and 3 m/sec < V_z < 12 m/sec.

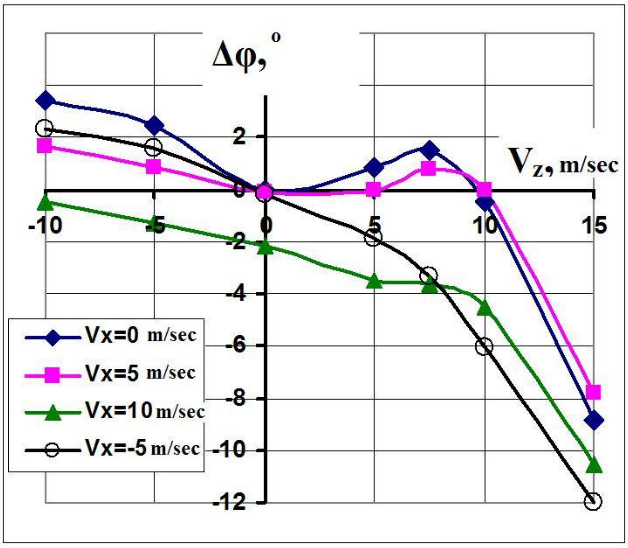


Fig. 1

There tail rotor streamline conditions are changed in the «spontaneous» helicopter rotation mode, but these changes do not facilitate recovering from the dangerous mode. Moreover, the angular velocity progressive increase occurs.

1. ANALYSIS OF T/R MOTION

The following elementary inertial forces act on the blade of T/R by rotation of a helicopter with the angular rate ω_y (fig. 2): the centrifugal force:

(1) $$dF_{CF} = m\omega_{TR}^2 rdr ,$$

the inertial force of flapping:

(2) $$dI = m\frac{d^2\beta}{dt^2}r^2 dr,$$

the Coriolis inertial force:

(3) $$dK_C = -2m\omega_y\omega_{TR} r\sin\psi dr$$

and the aerodynamic force dL [2]. The aerodynamic forces acting on the blade element depend on the approach stream velocity U (fig. 3). Components of the velocity U are equal to:

(4) $$U_x = \omega_{TR} r,$$

(5) $$U_y = -v_i + \omega_y \cdot (l_{TR} + r\cos\psi) + \omega_y r\cos\psi - r\frac{d\beta}{dt}.$$

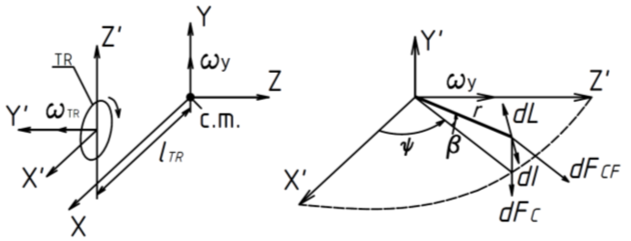


Fig. 2

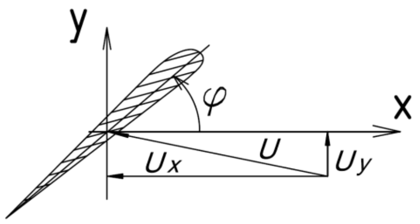


Fig. 3

At the expense of Coriolis forces dK_C there occurs the longitudinal T/R tilting β_{1c} at azimuths ψ =0 ° and ψ =180 ° (fig. 4). Around the azimuth ψ =90 ° the blade makes a flapping with the maximum angular rate therefore the component of velocity $r\frac{d\beta}{dt}$ will be maximum; the angles of attack increase ($\alpha_2 > \alpha_1$) and by reaching some rotation rate ω_y, the angles of attack α_2 go beyond stall. Lift coefficient C_l ceases to increase. Around the azimuth ψ =270 ° the blade flapping is directed to the opposite direction therefore the component of velocity $r\frac{d\beta}{dt}$ will be minimum. Angles of attack are decreasing ($\alpha_2 < \alpha_1$) and the lift coefficient C_l starts to reduce sharply (fig. 5).

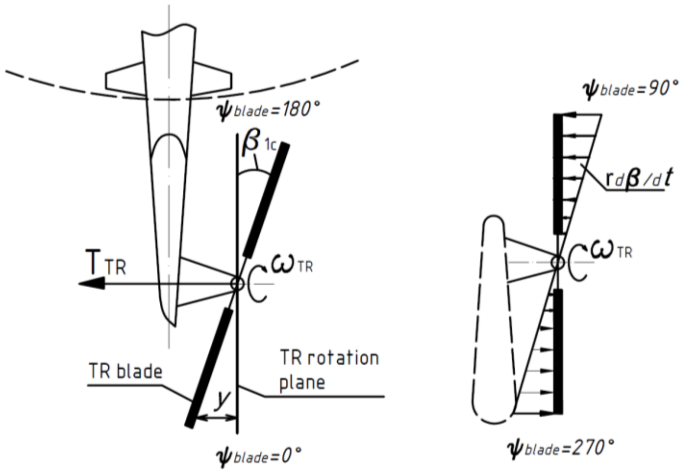


Fig. 4

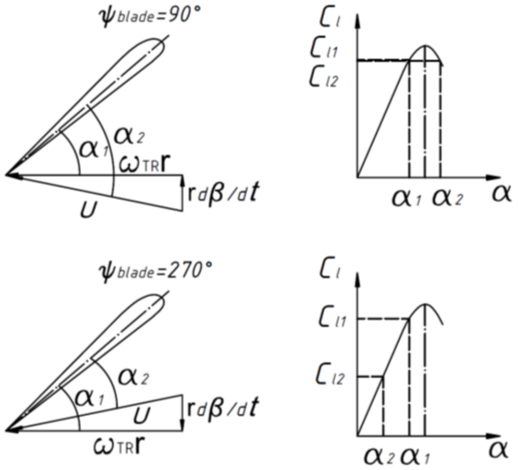


Fig. 5

At small velocities of helicopter angular rotation ω_y velocity of blade flapping weakly influences the T/R thrust. There occurs compensation of the blade lift decrease at ψ =270 ° by its increase at the azimuth ψ =90 °. But beginning with some value ω_y the blade gets into stall at ψ =90 ° falls and ceases to compensate lift decrease at the opposite azimuth what results in thrust decrease of the T/R.

Components of velocity $\omega_y \cdot (l_{TR} + r\cos\psi)$ and $\omega_y r\,cos\psi$ also change flapping motion of the blade. At the azimuth ψ =0 ° there occurs summation of velocities $\omega_y \cdot (l_{TR} + r\cos\psi) + \omega_y r\cos\psi$ and at ψ =180 ° - their subtraction $\omega_y \cdot (l_{TR} + r\cos\psi) - \omega_y r\cos\psi$ (fig. 6) what results in redistribution of the lift and in transversal rotor tilting β_{1s} at the azimuths ψ =90 ° and ψ =270 ° (fig. 7). The pitch-flap coupling strongly influences the transversal rotor tilting of the T/R. For example for a helicopter for which the angle δ_3 =45 ° tilting occurs in the opposite direction (fig. 8).

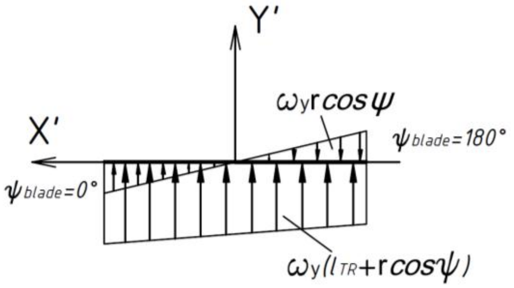
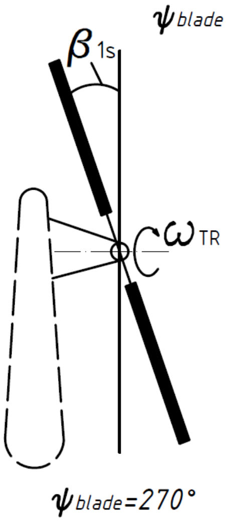


Fig. 6



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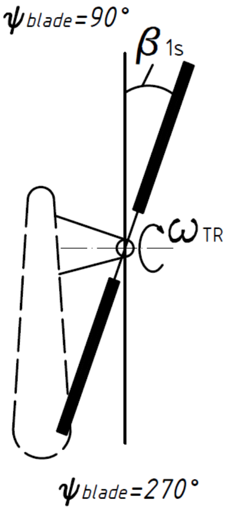


Fig. 8

2. DESCRIPTION OF MATHEMATICAL MODEL

Calculations were carried out with the help of the mathematical model of helicopter motions FDH_tr, developed in the department NIO-5 of the Central Aero-hydrodynamic Institute (TsAGI). This mathematical model allows to perform calculations of trimming, maneuvers, stability and controllability of a helicopter.

The mathematical model FDH_tr allows to carry out calculations of flexible blades motions of tail rotors and main rotors. Detailed description of equations of flexible blades motion and their solution is presented in the paper [3]. Aerodynamic loads acting on a blade are determined on the basis of the hypothesis of plane sections taking into account variation of the angle of attack α and Mach number in the ranges $0 \leq \alpha \leq 360\ ^0$ and $0 \leq M \leq 1$. Coefficients of aerodynamic characteristics of profiles are determined through processing nonlinear experimental relationships gained by tests of profiles in wind tunnels. Besides, instability of the flow around blade sections according to the method indicated in [4] is taken into account. For calculation of velocities induced by the rotor in the proper plain of rotation the quasi-linear disk vortex theory of the rotor in oblique flow of E. S. Vozhdaev [5] , [6] is used, and circulation of the lifting line is adopted to be stationary through the blade azimuthal angle at the given radius.

3. ORIGINAL DATA FOR CALCULATIONS

For the T/R of a helicopter of medium weight class three solidities σ =0,12, σ =0,16 and σ =0,2 were chosen for calculations.

For each solidity the calculation of variation of $C_T/\sigma(\omega_y)$ by the values of T/R pitch: φ_{TR} =8,2 ^{0} … 25 ^{0} was carried out. This range is the most typical for modes of entry into "spontaneous" rotation and operation of the T/R in this mode. Velocity of angular rotation was equal to the following values ω_y =0 ^{0}/sec, 30 ^{0}/sec, 60 ^{0}/sec, 120 ^{0}/sec. For the T/R with solidity σ =0,12, σ =0,16 calculations were carried out for the altitude of 50 m and for the T/R with the solidity of σ =0,2 calculations were executed for the altitudes of 50 m and 4000 m.

For the T/R with the solidity σ =0,12 calculations of variation of parameters $y(\psi_{blade})$, $\alpha(\psi_{blade})$, $C_l\,(\psi_{blade})$ at the reference radius of the blade r =0,75R were carried out by velocities of an angular rotation of a helicopter ω_y=0 ^{0}/sec, 30 ^{0}/sec, 60 ^{0}/sec for φ_{TR} =8,2 ^{0} and φ_{TR}=25 ^{0}.

4. RESULTS OF COMPUTATIONAL RESEARCHES

In figures 9-14 relationships $y(\psi_{blade})$, $\alpha(\psi_{blade})$, $C_l\,(\psi_{blade})$ for the T/R with the solidity σ =0,12 are presented.

Blade flapping motion is increasing with growth of φ_{TR} and ω_y (fig. 9, 10). Around azimuth angles ψ =0 ^{0} and ψ =180 ^{0} there occurs maximum deflection of the blade from the plane of rotation and around ψ =90 ^{0} and ψ =270 ^{0} the velocity of blade flapping is maximum $r\dfrac{d\beta}{dt}$.

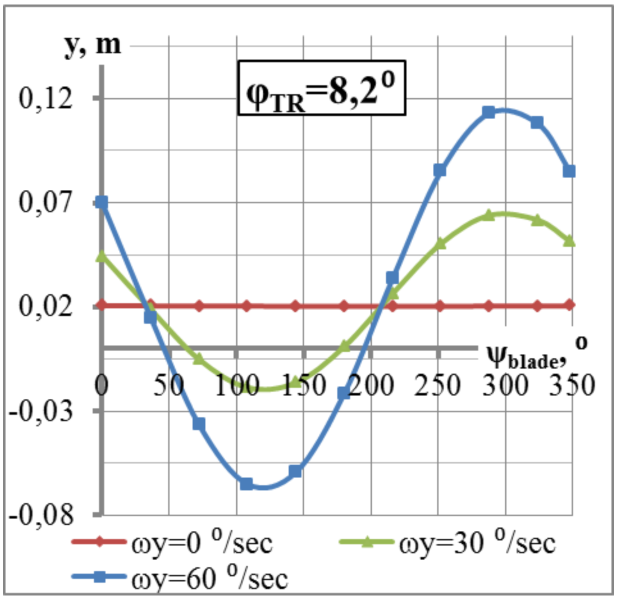
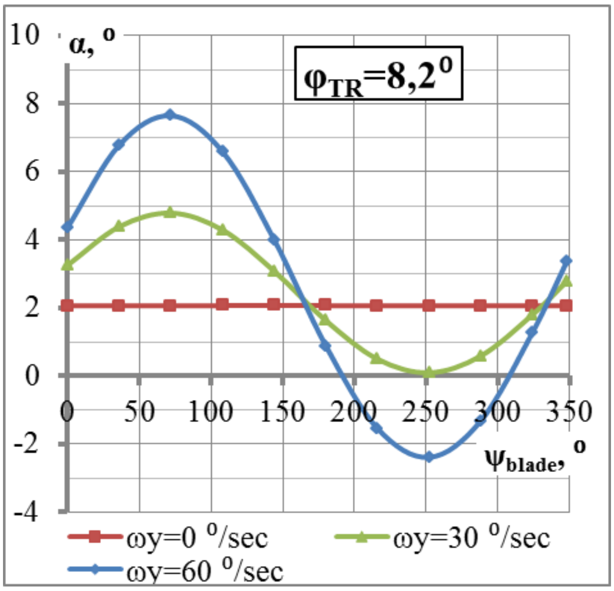


Fig. 9



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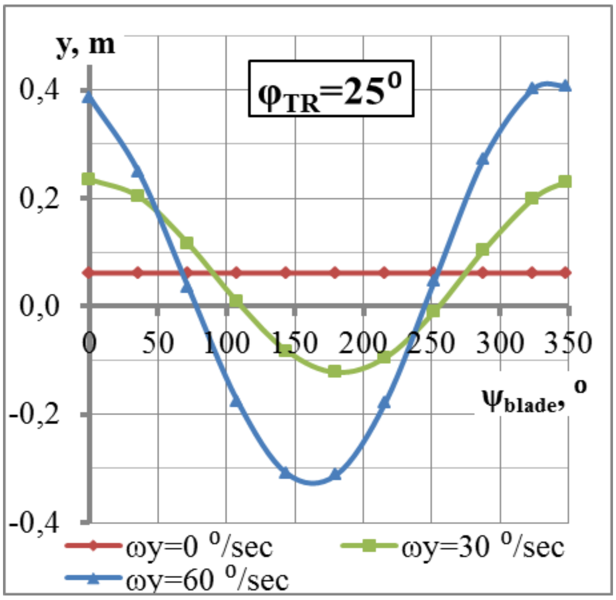

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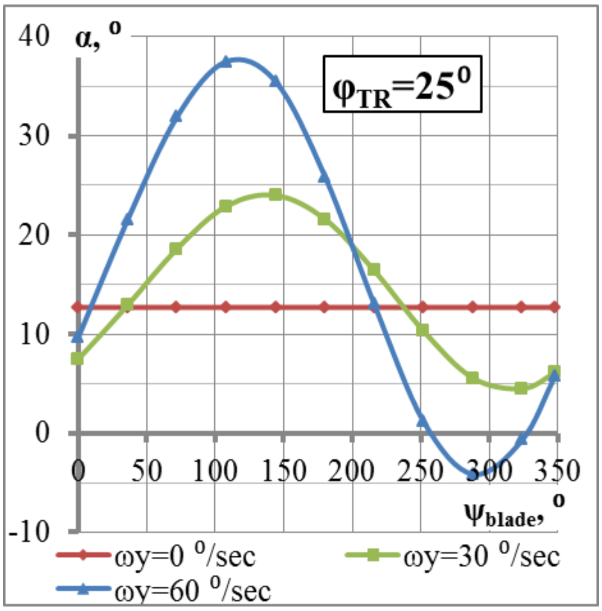


Fig. 12

Angles of attack of the blade section are increasing around the azimuth ψ =90 ° and decreasing around ψ =270 ° (fig. 11, 12). At the collective pitch angle φ_{TR} =25 ° the angle of attack of blade section reaches 38 ° what is significantly beyond stall.

Variation of coefficients C_l (fig. 13, 14) confirms the reasonings made during the analysis above. At small pitch of the T/R thrust does not decrease due to redistribution of the lift on different parts of the rotor disk, but at the large pitch it does not take place and the T/R thrust starts to diminish.

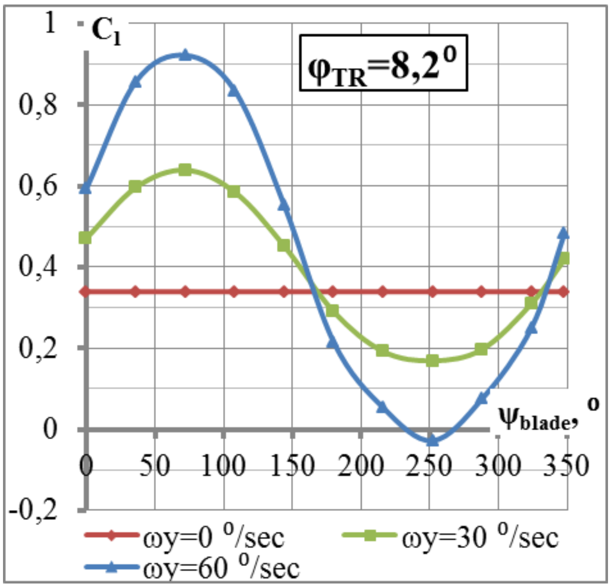
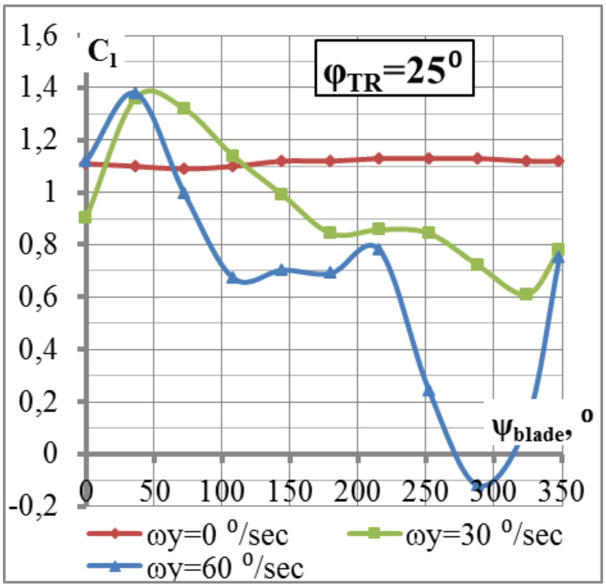


Fig.13



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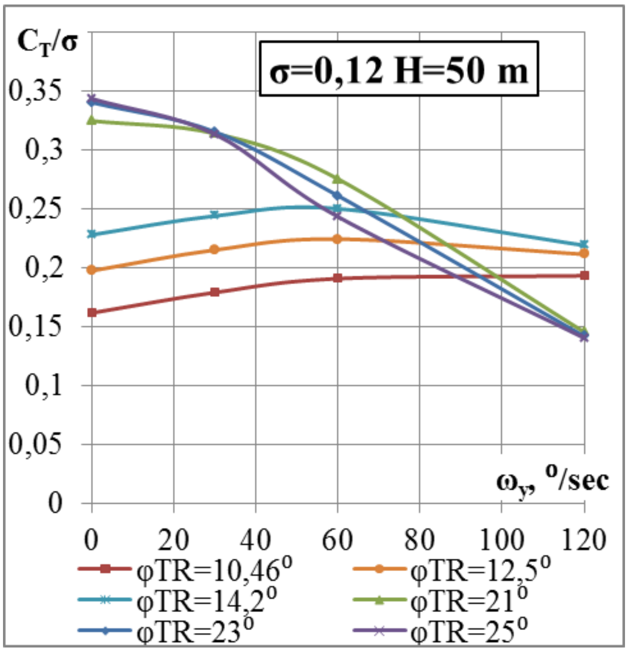

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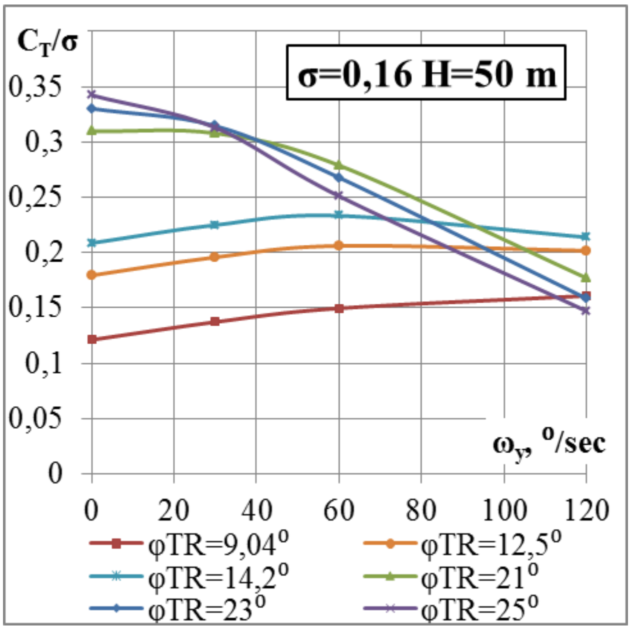


Fig.16

Results describing dependences of the relative coefficient of the T/R thrust force C_T/σ on the angular rate of rotation of a helicopter ω_y are presented in the figures 15, 16, 17, 18.

For all considered tail rotors such variation of the curves $C_T/\sigma(\omega_y)$ is observed. At small φ_{TR}, there occurs minor increase of C_T/σ and blades operate in before stall modes. With increase of φ_{TR} up to 21 ^{0} and more there occurs sharp decrease of C_T/σ, the T/R thrust does not increase with growth of φ_{TR} any more but on the contrary is sharply decreasing.

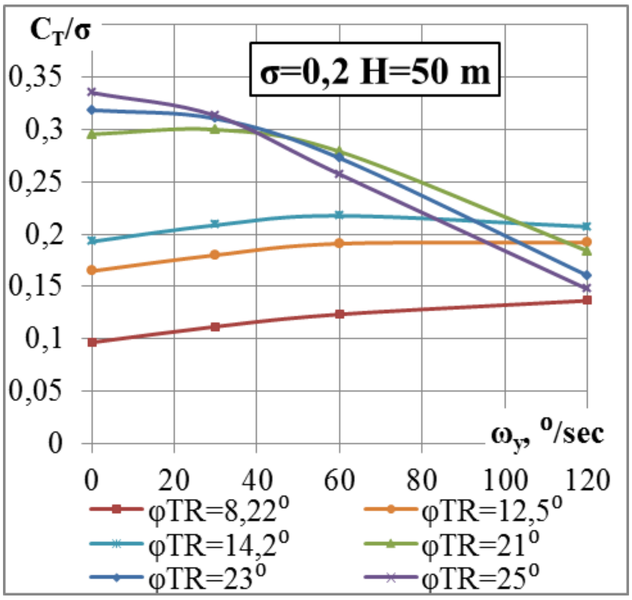


Fig.17

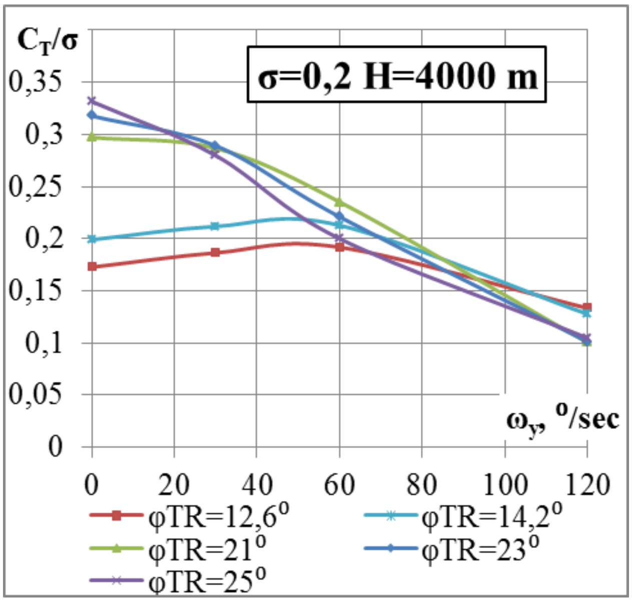
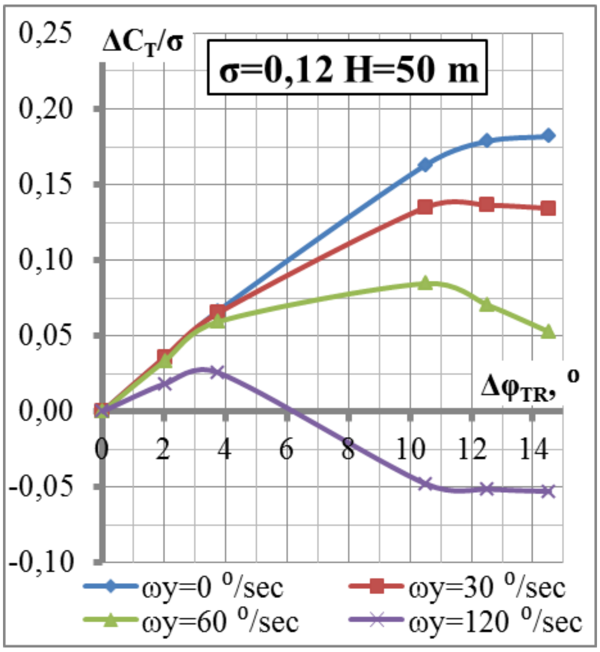


Fig.18

In figures 19, 20, 21, 22 dependences of increments $\Delta C_T/\sigma$ on the T/R pitch (relative to the T/R pitch by hovering) $\Delta\varphi_{TR} = \varphi_{TR} - \varphi_{TR(hover)}$ at various rotation rates ω_y are given. T/R getting into stall mode is well seen in the figures. For T/R with small solidity the stall begins much earlier. Control margins are very small especially at high angular rates ω_y. In the figure 22 the T/R with σ =0,2 at the altitude of 4000 m is presented its performances have considerably deteriorated, control margins at small angular rates became much less and are totally absent at high angular rates.



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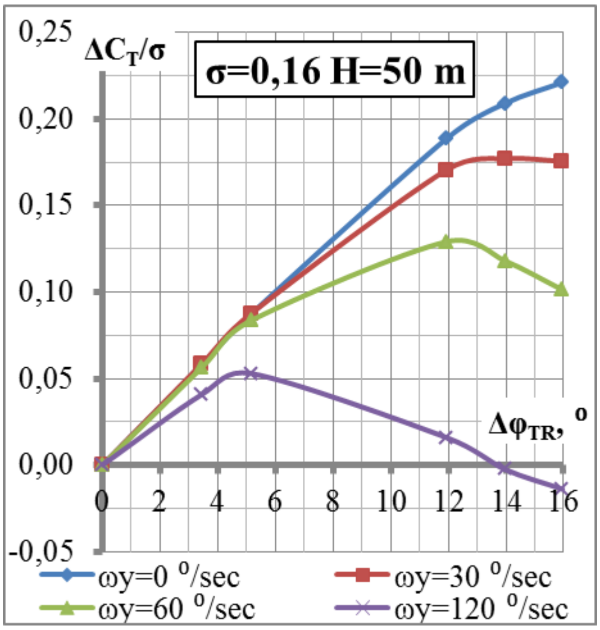

Fig.20

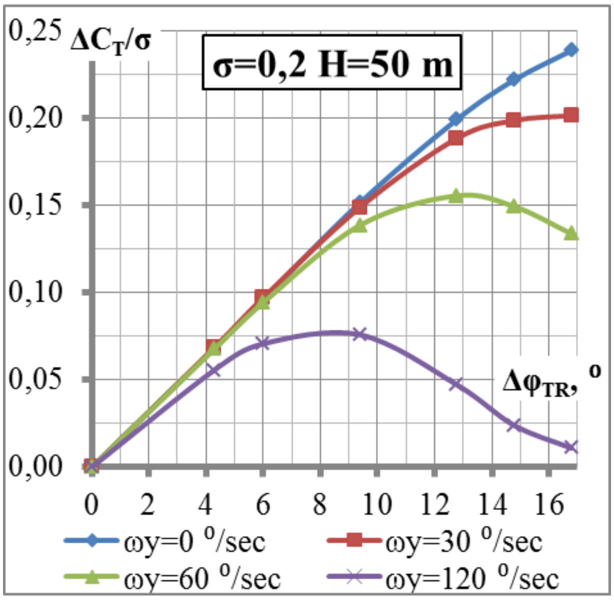

Fig.21

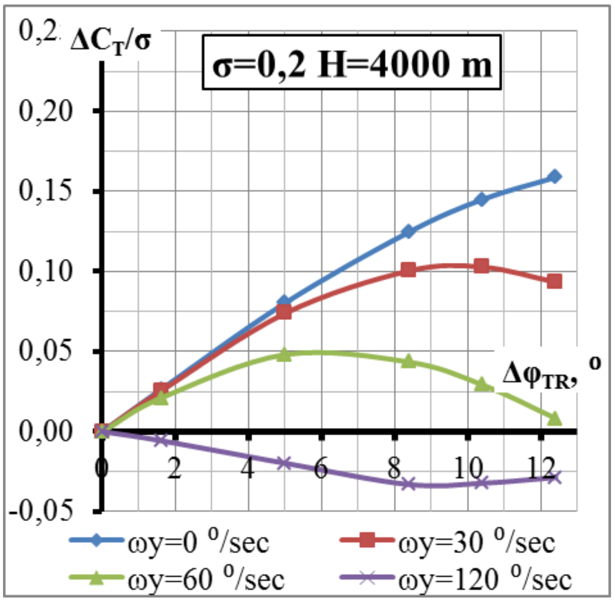

Fig.22

In the figures 23, 24 for the tail rotors with σ =0,2 at the altitude of 50 m and 4000 m the dependences of the helicopter angular acceleration ε [1/sec^2] on the increment of the T/R pitch $\Delta\varphi_{TR} = \varphi_{TR} - \varphi_{TR(hover)}$ in the range of 10 % from the full pedals stroke are presented. In our opinion it is necessary to supplement existing requirements to helicopter designing by the value of minimum admissible angular acceleration by the "stroke forward" of the left/right pedal (depending on the sense of rotation of the main rotor) in the helicopter mode of rotation round vertical axis. In figures 23 and 24 this limit is shown by the black line. It is well seen that the T/R with the solidity of σ =0,2 meets requirements of angular acceleration at the altitude 50 m up to the value of angular rate ω_y =60 ^{0}, but at the altitude of a static ceiling (fig. 24) the value of angular acceleration is less than minimum admissible value in the whole range of angular rates ω_y.

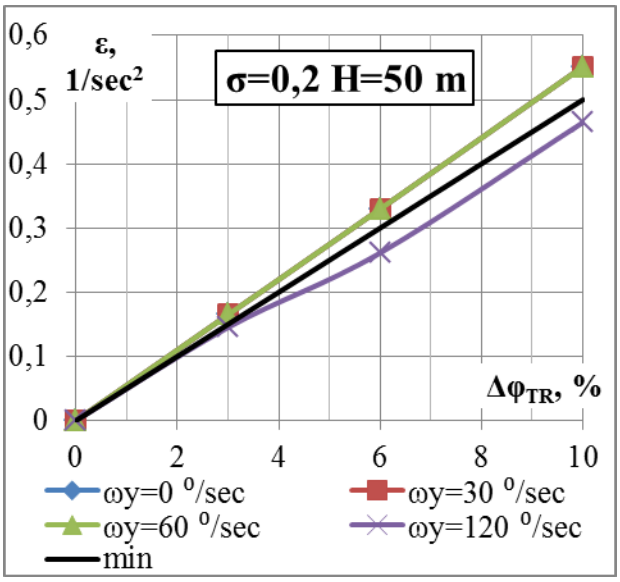

Fig.23

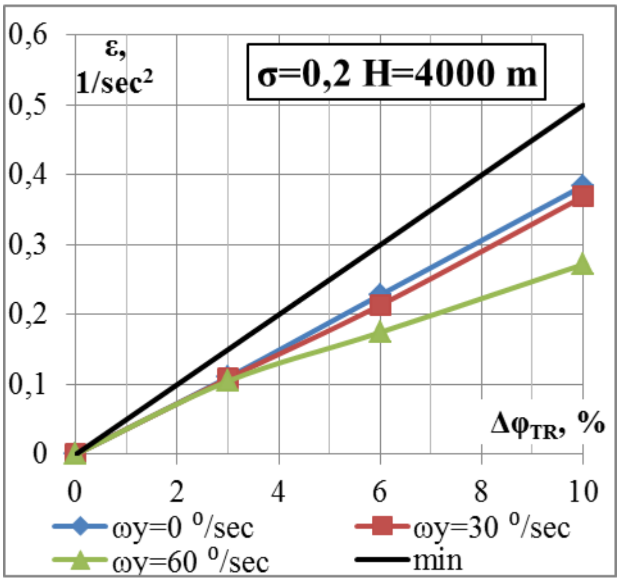

Fig.24

CONCLUSION

Multiple cases of single-rotor helicopters getting into "spontaneous" rotation testify necessity to complete existing requirements to T/R designing with such requirements that would allow to recover a helicopter without fail from the mode of rotation, with a rotary acceleration not less than a specified value. For verification of T/R performances in the mode of "spontaneous" rotation it is necessary to carry out a complex of experimental researches on the rotary installation, which simulates the mode of "spontaneous" rotation. Ensemble of theoretical and experimental results will allow to determine the layouts of tail rotor permitting to recover a helicopter from "spontaneous" rotation with an angular acceleration not less than the preset value.

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