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UNSTEADY AERODYNAMICS OF HELICOPTER ROTORS:

MATHEMATICAL MODELS

BY

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Unsteady Aerodynamics of Helicopter Rotors: Mathematical Models.

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UNSTEADY AERODYNAMICS OF HELICOPTER ROTORS: MATHEMATICAL MODELS.

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The interaction of rotor blades and vortex sheets coming from the front blades supposes the calculation of the nonlinearity in the helicopter aerodynamic problems.This influence increases when the rotors work near the ground or when the helicopter descents with positive angles of incidence. The extensive flow-separation zone often realizes on retreating blades.

As a matter of fact, in all these cases the calculation of a real form of a vortex jet, the nonlinearity of the processes can significantly increase the precision of the lefiniution of the rotor aerodynamic characteristics.

For purposes of modeling if some rotor operation regimes a set of nonlinear unsteady mathematical models of helicopter rotors aerodynamics is proposed. A method of descrete vortices is put into a basis of the models as well recommended in airplanes aerodynamic research practicing.

The mathematical formulation of nonlinear problems is considered on the example of rotor operation on the perfect incompressible fluid flow. The form of blades and rotor movement character has no limitations.

The flow is unvortex everywhere outside the rotor blades Si and their wake σ_i, i.e. the Laplace equation is true for disturbant velocities potential Φ (x,y,z,t):

$$\frac{\partial \Phi}{\partial x} + \frac{\partial \Phi}{\partial y} + \frac{\partial \Phi}{\partial z} = 0. \qquad (1)$$

If suppose $\bar{W}^*$ is a velocity of lift airfoil points movement supported either by forward movement or by rotation, as well as flapping movement and deformation, so the boundary condition of no-penetration is executed in these points:

$$(\nabla\Phi - \bar{W}^*)\,\bar{n} = 0; \quad (x,y,z)\in S_i, \qquad (2)$$

$\bar{n}$ is an external normal to the surface Si in the examined point here.

Pressure continuation and velocity normal component conditions are observed at the transition through the vortex wake surface σ_i:

$$P_- = P_+ \ ; \ (\nabla\Phi \cdot \vec{n})_- = (\nabla\Phi \cdot \vec{n})_+ ; \quad (x,y,z) \in \sigma_i, \qquad (3)$$

Here, indexes '-' and '+' are applied to the different sides of the surface σ_i. The Chaplygin-Joukovsky hypothesis of velocity finishing on those blades' edges which the vortex surfaces σi flow from is executed:

$$P_- = P_+ \ ; \ (\nabla\Phi\vec{n})_- = (\nabla\Phi\vec{n})_+ ; \quad (x,y,z) \in L_i, \qquad (4)$$

The disturbances reduce at the endless distance from the rotor and its wake, so

$$\lim_{R \to \infty} \nabla\Phi = 0, \quad R = \sqrt{x^2+y^2+z^2}, \qquad (5)$$

Blades and their wake are changed by the continued vortex layer which, in its turn, is changed by the descrete vortces system modeling the blades and the wake. Continuous process of all parameters' change in time is changed by staged one with a step Δt.

The solution of rotor's aerodynamical characteristics' definition problem is to find the blades' modeling vortices' intensity. The vortices intensities must satisfy no-penetration conditions in control points (fig.2) and loop circulaion constancy condition. These relations for unseparated flow around blades will be follows:

$$\sum_{m=1}^{k_L} \sum_{k=1}^{N} \sum_{\mu=1}^{n} \Gamma_{\sum m\mu k}^{\mu k-1 r} \, a_{m\mu k\nu_i}^{\mu k k-1 \rho\rho-1} + \sum_{m=1}^{k_L} \sum_{k=1}^{N} \delta_{mkk-1}^{(1)r} \, a_{mn+1 k\nu_i}^{n+1 k-1 \rho\rho-1} = H_{\nu_i}^{\rho\rho-1}$$

$$\sum_{\mu=1}^{n} \Gamma_{\sum m\mu k}^{\mu k-1 r} + \delta_{mkk-1}^{(1)r} = -\sum_{S=1}^{r-1} \delta_{mkk-1}^{(1)S}, \qquad (6)$$

$$i = 1, \ldots, k_L; \quad \rho = 1, \ldots, N; \quad \nu = 1, \ldots, n.$$

Here, k_L - rotor blades' number;

N - number of areas located on the blade's radius;

n – number of areas located along the blade's chord;

r – number of calculation step;

a_i – known analitical relations defined by lift system geometry and chosen break of the blade into plots [1].

Relations $H_{\nu_i}^{PP-1r}$ include following four groups of values:

- geometrical parameters of lift system elements;
- cinematical parameters of movement;
- free vortex sheet form;
- prehistory of movement.

The unknown vortices intensities are defined from solution of the system(6). After their definition the velocity fields are calculated in points of free vortices ends $W_x(y,z)_i$ and the coordinates for the next calculation step are defined:

$$(x,y,z)_{r+1} = (x,y,z)_r + W(x,y,z)\,\Delta\tau . \qquad (7)$$

Next, the calculation repeats until the explores values become steady values or the transitive process ends. Using intensities of summary vortices from the solution of the system (6) the aerodynamical loads modeling rotor blades [2] are defined with use of Cauchy-Lagrange integral.

A problem of calculation of aerodynamical characteristics at a movement on the air above the free oriented boundary surface is interesting for helicopter rotors. The rotor and boundary surface mutual orientation is characterized by two parameters: distance from extreme rotor point to the reflecting surface H; slope angle of the rotor surface to the reflecting surface plane γ (fig.3). At the execution of the problem, the separation surface presence results in two extra conditions:

1.The cinematical condition of co-operative flows. It performs the equality of velocity normal components from different sides of the separation surface:

$$\vec{W}_1 \cdot \vec{n} = \vec{W}_2 \cdot n = V_n .$$

2.The dynamical condition of equality of pressures from different sides of the separation surface:

$$P_1 = P_2 .$$

In addition to the rotor vortex system, a vortex cuts system with the same intensities reflected relatively the surface $O_b\ X_b\ Z_b$ is examined.

For substantiation of received results reliability, their comparison with the results of wind tunnel and natural experiment was implemented[3]. Fig.4 performs comparison of calculation and experimental results for normal force sections coefficient $c_y^{н}$, for the four - blade main rotor acting at the wash flow regime

$(u = \frac{V}{\omega R} = 0,25)$.

The comparison of calcilation and test results along the rotor inductive velocities flow is performed on fig.5. In this case, the results are gotten for sections locating below the rotor at distances of 0.33R and 0.66R. On fig.6, the comparison of the helicopter Mi-8 rotor thrust coefficients values received from calculation and flight test[4] accounting the influence of the ground is shown. To note, the mathematical non-linear unsteady model of the rotor provides with reliable results for a set of the aerodynamical characteristics.

Due to the examined model, the wide range of rotor aerodynamics preblems was explored.The rotor summary and distributed aerodynamic load were received, as well as vortex structures after the rotor, velocity fields around the rotor which allow to analize the particularities of its flow.For example, fig. 7 performs the configuration of two vortex spins coming from blade ends of the 5-blade rotor and fig.8 shows the velocity field on the plane after the rotor in a distance of 5 radiuses. Fig.9 shows the dependence of section normal force coefficients c_y' from the azimuth position angle ψ for some blade sections of 4-blade rotor.

The model of a single main rotor was developed for the case of combination of rotors (coaxial, tandem, main and tail),as well as of combination of rotors and lift surfaces.

Particularly, the model of aerodynamics of a converted aircraft with pivotable rotors was examined. Fig.10 shows the rotor in alliance with the lift surface-wing which can be flown with flow separation or without it in dependence on the combination action regime.

The rotor is oriented relatively the lift surface free and its position is characterized by the angle α_p . A point the rotor turns around is selected free, too.

The vortex wake after the pivotable rotor significantly influences on the converted aircraft's aerodynamic characteristics. Fig.11 shows the vortex structure after the aircraft at the airplane regime recieved by calculation, and fig.12 performs the results of modeling showing influence of the rotor angle α_p and a place of the horisintal tail location on its aerodynamical characteristics. For the examined lift system from the point of view of the liest change of the normal force $c_{y\,20}$ and the pitch moment $m_{z\,20}$ coefficients, the location of the horizontal tail above the wing is more improved.

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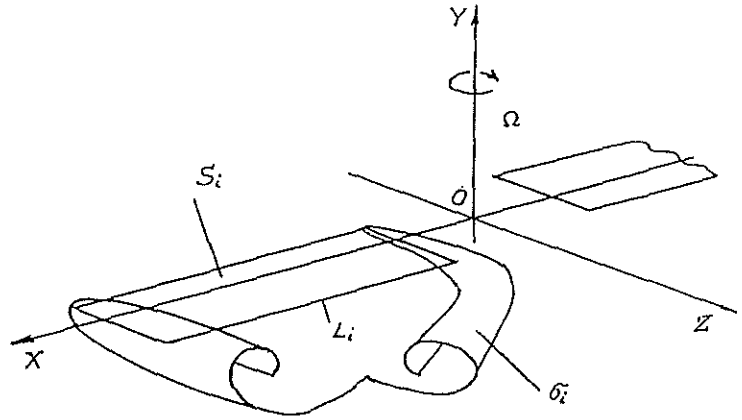

Fig. 1

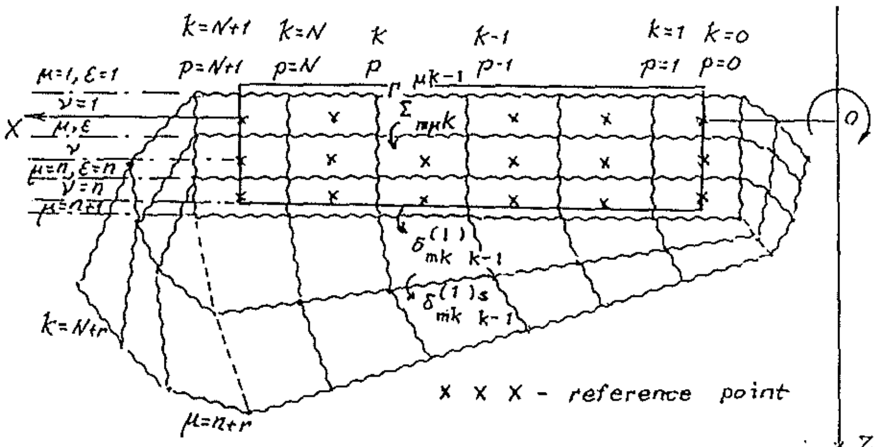

Fig. 2

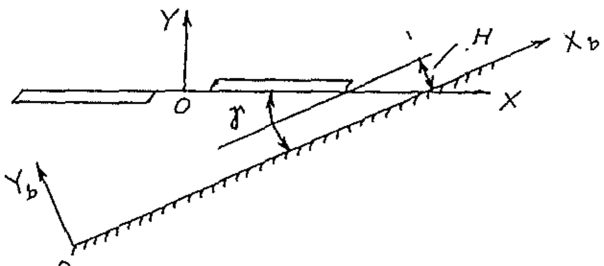

Fig. 3

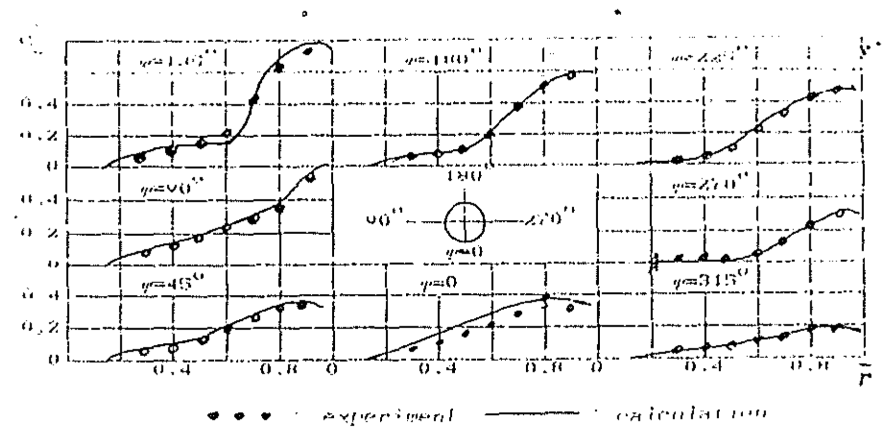

Fig. 4

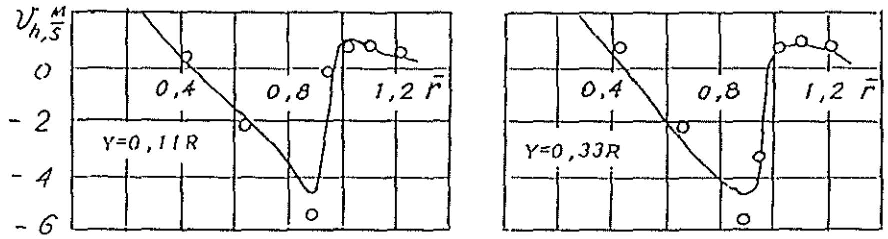

Fig. 5

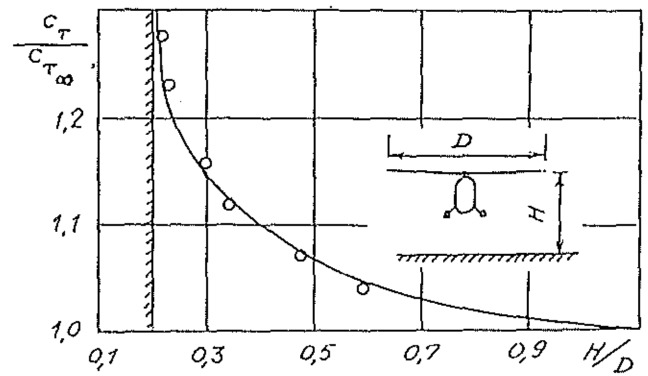

Fig. 6

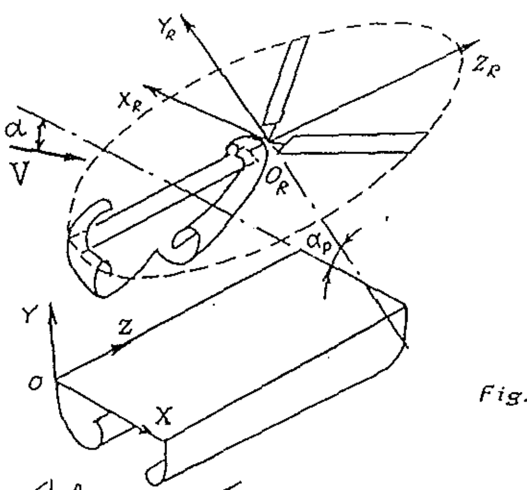

Fig. 10

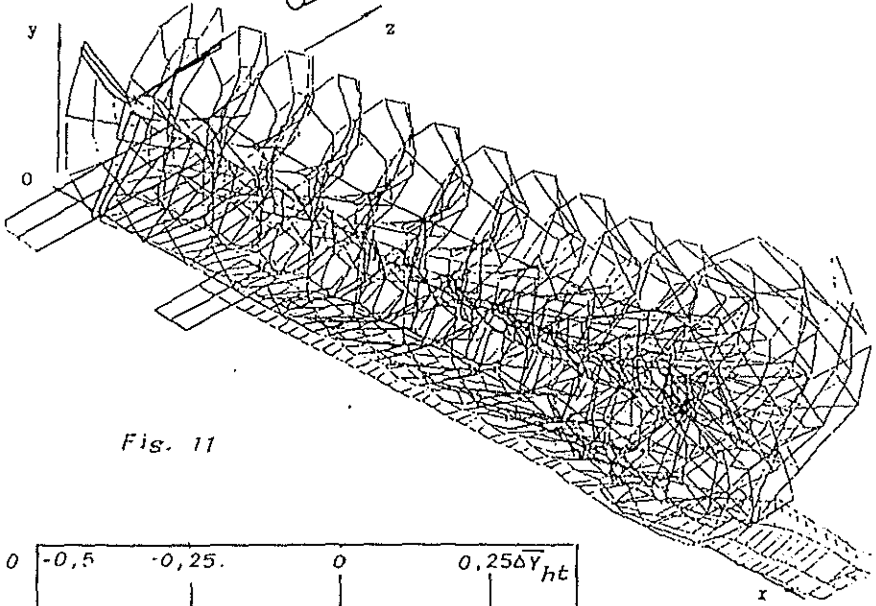

Fig. 11

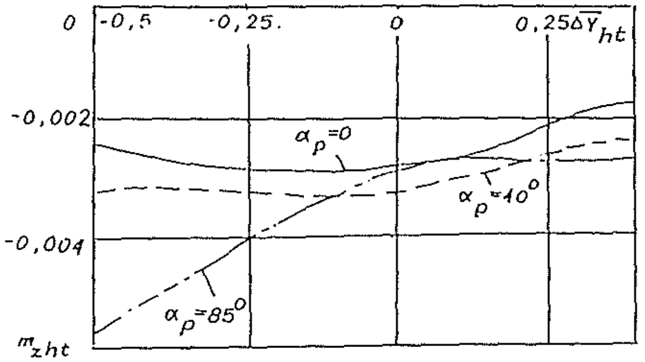

Fig. 12

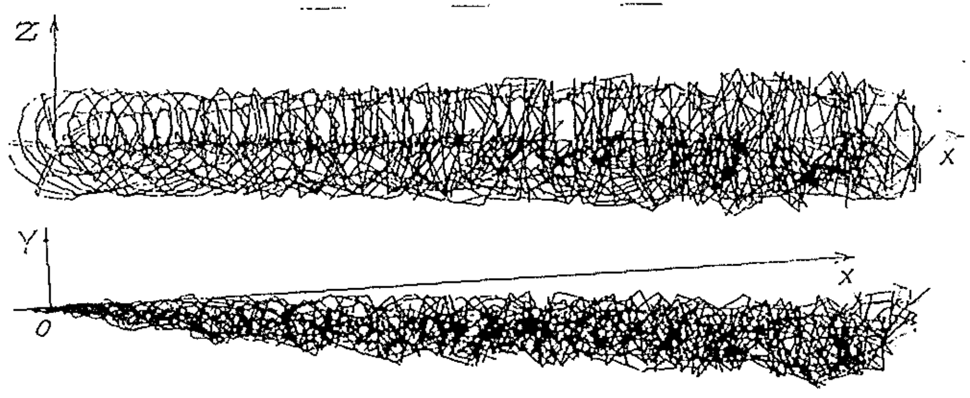

Fig. 7

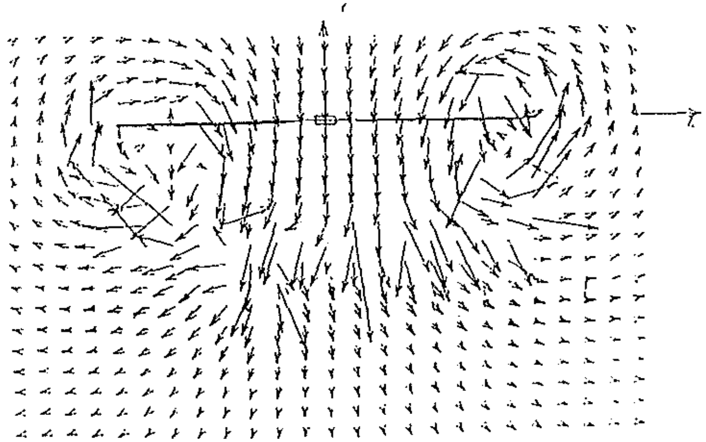

Fig. ò

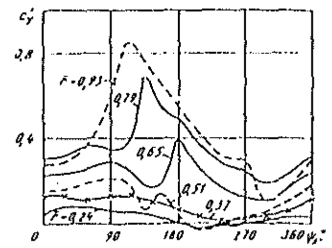

Fig. 9