THE CALCULATION OF AERODYNAMIC FORCES ON FLEXIBLE WINGS OF AGRICULTURAL AIRCRAFT

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Abstract

Agricultural flights at a low height arise a lot of important problems in aspect of aerodynamics. In this work the effect of possible motion styles on aerodynamic forces near the ground for the flexibility of wings is calculated supposing an ideal fluid.

The calculation is performed for an agricultural aircraft of M 18 type used in Hungary.

The result of calculation: the average aerodynamic force arising at low height unsteady stream - in the case of constant velocity and mean angle of attack - decrease, the decreasing is the highest in the middle of the wing and it is insignificant at the outer part of the wing.

I. Introduction

This study investigates the unsteady lift force on wings of agricultural aircrafts. The flight level of the agricultural aircrafts is low, so the consideration of ground effect is important.

The calculation supposes symmetrical flight. The calculation method used in this study is also capable of calculating the rolling up of the wake behind the wing, but it doesn't take place in this study because of computer capacity problems.

The method of calculating was chosen according to /3/. The advantages of this method comparing with the surface-singularity method was shown also in /3/.

The calculating has been adapted to an "M 18 Dromader" type aircraft /made in Poland/ operated in Hungary.

II. The velocity potential

The full velocity potential is superposed of three parts:

$$\Phi = \Phi_o + \Phi_S + \Phi_D$$

where: Φ_o - the potential of free stream;
Φ_S - the potential of sources;
Φ_D - the potential of dipoles.

The free stream potential:

$$\Phi_o = V.x$$

The potential of sources:

$$\Phi_S = -\frac{1}{4\pi}\iint_{A_{WS}} \frac{\sigma(P)}{r}\, dA \quad ;$$

where: r - distance from the field point to the point on the singularity surface;

$\sigma(P)$ - the source intensity at point P;

A_{WS} - interior singularity surface.

The potential of dipoles:

$$\Phi_D = -\frac{1}{4\pi}\iint_{A_{WS}+A_{WW}} \frac{\mu(P)z'}{r^3}\, dA \quad ;$$

where: $\mu(P)$ - intensity of dipole strength in singularity point P;

z' - local coordiantes /see Fig.2./;

A_{WW} - wake surface.

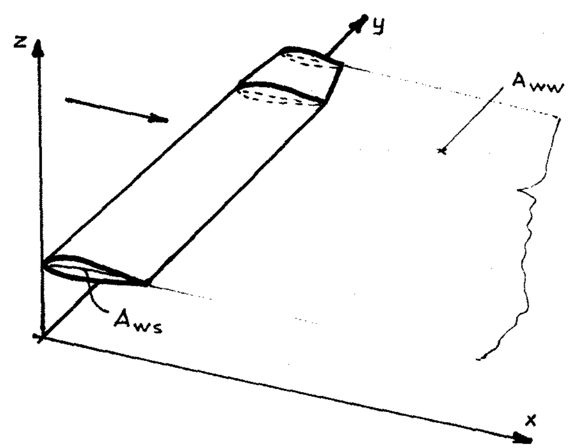

Fig. 1. Coordinate system

III. The initial and boundary conditions

The calculation supposes symmetrical flight. Due to symmetry:

$$\vec{\nabla}\phi_y = 0 \quad \text{at} \quad y = 0.$$

Due to ground effect:

$$\vec{\nabla}\phi_z = 0 \quad \text{at} \quad z = 0.$$

The wing surface is stream surface:

$$/\underline{V}+\underline{w}+\underline{v}/ \;.\; \underline{n} = 0 \quad \text{at} \quad /x,y,z/ \in \{A_w\}$$

where: $\{A_w\}$ - the manifold of the wing surface points;
$\underline{V}$ - free stream velocity;
$\underline{w}$ - induced velocities;
$\underline{v}$ - velocity due to deformation of wing;
$\underline{n}$ - normal vector of surfaces.

The Kutta-Joukowsky condition for unsteady flow according to [3]:

$$\frac{v_l + v_u}{2}\left(\frac{\partial\mu}{\partial x'}\underline{i}' + \frac{\partial\mu}{\partial y'}\underline{j}'\right) = -\frac{\partial\Gamma}{\partial t}$$

where: $\underline{v}_l$ - velocity vector at point Q_l ;
$\underline{v}_u$ - velocity vector at point Q_u.

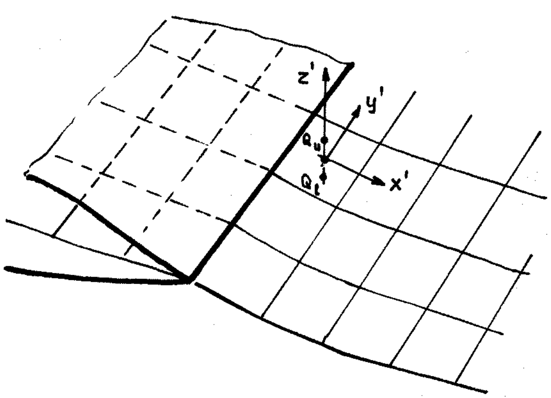

Fig. 2. *Local coordinate system*

During the calculation the Giesing-Maskell condition was considered at the beginning of the wake sheet [6].

IV. The distribution of sources and dipoles

In the calculation continous kernel functions was applied - this method has several adventages over kernel functions with discret points.

For the approximation of the source distribution the Fourier row is applied /at a given time/:

$$\sigma(P) = \sum_{i=1}^{n_i}\sum_{j=1}^{n_j} f_i(x)\, g_j(y) \quad ;$$

where: $g_j/y/ = g_j/-y/$, even functions was only taken in consideration.

The choosen function automaticaly fills the continuity condition.

The dipole strength distribution is approximated /also at a given time/ by bicubical splines:

$$\mu(P) = f_{ij}(x,y) = \sum_{k=0}^{3}\sum_{l=0}^{3} a_{ijkl}\,(x-x_i)^k(y-y_j)^l$$

where: $/x,\ y/ \in R_{i,j}$, $i = 1,2,\ \ldots\ m_i$
$j = 1,2,\ \ldots\ m_j$.

The spline boundary condition at the leading edge and at the side edge is determinated by extrapolation, at the trailing edge-from the unsteady Kutta-Joukowsky condition.

The distribution of dipole strengths behind the wing was approximated by jump-like change of functions because of unsteadiness. This function was integrated along coordinate x according to [1].

V. Motions of the wing

In the calculation bending and torsional motions was approximately considered:

$$z(x,y,t) = \sum_{i=1}^{p_i}\sum_{j=1}^{p_j} \varphi_i(y)\,\xi_i(t)\,\vartheta_j(y)\,r_x\,\zeta_j(t) \quad ;$$

where: $z/x,y,t/$ - point of wing surface;
$\varphi_i(y)$ - i-th bending mode;
$\xi_i(t)$ - supposed time function;
$\vartheta_j(y)$ - j-th torsional mode;
$\zeta_j(t)$ - supposed time function;
r_x - distance from the elastic axis to the point of wing surface.

Functions ξ_i and ζ_j was choosen, because for their calculation the dynamical analysis of the elastic aircraft would be needed.

VI. The results of computation

In this study the time and space variation of the full potential was computed. The pressure yields the unsteady Bernoulli equation.

Thus, the lift distribution according to choosen time functions can be stated. Since the time functions were choosen, the calculated distribution hasn't special phisical reason.

However we can come to a general conclusion. The mean value of lift /at constant velocity and mean angle of attack/ decreases. The decreasing is significant at the middle part of the wing. At the outer parts of the wing the mean value of lift is practicaly constant.

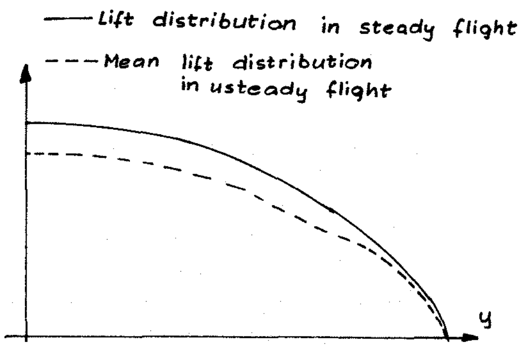

Fig. 3.

This result can sufficiently explain the fact, that during low flights the sensitivity of the ailerons increases.

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