Potential Flow Calculation for Three-Dimensional Wings and Wing-Body Combination in Oscillatory Motion

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Abstract

A METHOD based on camber surface source-vortex distribution has been developed to calculate steady and unsteady pressure distribution on wings and wing-body combinations undergoing small-amplitude simple-harmonic pitching motion in incompressible potential flow. The method is linearized with respect to amplitude of oscillation, but is numerically exact in representing the sectional profile shape. Problems considered in this paper include wings, control surfaces, and wing-body combinations oscillating in pitching mode. To demonstrate the accuracy of the present method, results are compared with other available theoretical as well as experimental data.

Contents

A method based on the mean camber surface singularity distribution (as shown in Fig. 1) is presented here. One major advantage of this method is that, for the same number of unknowns, it requires only half the number of influence coefficients to be calculated as compared to other contemporary panel methods employing singularities on the wetted surface. This makes the mean camber surface singularity distribution approach to be more economical for comparable numerical accuracy as demonstrated in Ref. 1. When the problem is linearized with respect to amplitude of oscillation, the flow-tangency condition, which is satisfied on the mean position of the wetted surface, can be decomposed into steady and oscillatory components. The Kutta condition for the present method is that the vorticity is continuous at the trailing edge to ensure zero loading there. For the oscillatory part of the problem, the vorticity shed into the wake is related to the unknown vorticity strength at the trailing edge of the corresponding spanwise strip ensuring zero loading in the wake. The shed vorticity in the wake γ_w at a distance s_t from the trailing edge can be expressed in terms of vorticity strength at the trailing edge γ_{OTE} for the kth spanwise strip as

$$\gamma_w(s_t) = \gamma_{OTE}^{(k)} e^{-i\nu s_t} \tag{1}$$

where ν is the nondimensionalized frequency parameter.

For N number of collocation points on the wetted surface, the present numerical model will have $N + N_s$ number of unknown singularity strengths. For the calculation of steady pressure distribution, the steady component of the flow-tangency condition is satisfied at N collocation points along with the Kutta condition of zero vorticity strength at the trailing ege of the N_s spanwise strips. Thus, for steady calculation the number of equations is reduced to N. However, for oscillatory calculations there are $N + N_s$ number of unknown complex singularity stengths which have to be solved for each frequency parameter. A simplified technique has been adopted here which requires the inversion of the large $(N \times N)$ matrix only once and small set of equations are solved for each frequency parameter. A very brief description of the procedure is given below.

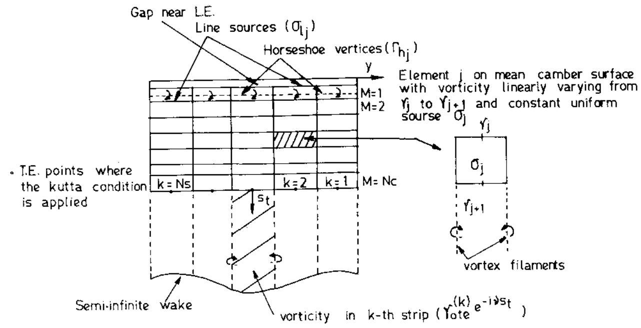

Fig. 1 Distribution of singularities on mean camber surface and semi-inifinite wake.

The set of linear algebraic equations for an oscillatory problem can be written as

$$\sum_{j=1}^{N} G_{ij}\mu_{oi} = F_i^{(k)}, \qquad i = 1,2,\ldots,N \text{ and } k = 1,2,\ldots,N_s,N_s + 1 \tag{2}$$

where G_{ij} are the normal velocity induced at the ith control point by jth singularity strength μ_{oj} (μ_{oj} includes all of the oscillatory singularities). $F_i^{(k)}$ is the normal component of velocity induced due to vorticity distribution in the wake of the N_s values of k when the trailing-edge vorticity strength is unity. $F_i^{(N_s+1)}$ represents the contribution to the normal velocity due to the freestream and steady-perturbation velocity components.

Solution of Eq. (2) gives N values of μ_{oj} for each onset flow $F_i^{(k)}$, and the combined set of singularity strengths can be written as

$$\mu_{oj} = \mu_{oj}^{N_s+1} + \sum_{k=1}^{N_s} \mu_{oj}^{(k)} \gamma_{OTE}^{(k)} \tag{3}$$

where $\gamma_{OTE}^{(k)}$ are the unknown oscillatory vorticity strengths at the trailing edge. By invoking the Kutta condition and using Eq. (3), a set of linear equations in $\gamma_{OTE}^{(k)}$ can be obtained as

$$\sum_{k=1}^{N_s} P_{ik}\, \gamma_{OTE}^{(k)} = Q_i, \qquad i = 1,2,\ldots N_s \tag{4}$$

where P_{ik} and Q_i are complex constants. Substituting $\gamma_{OTE}^{(k)}$ in Eq. (3), the unknown oscillatory singularity strengths can be obtained. Once the singularity strengths are known, the pressure distribution and overall forces can easily be calculated.

Results of the present method have been compared with the existing theoretical results[2] and measured experimental val-

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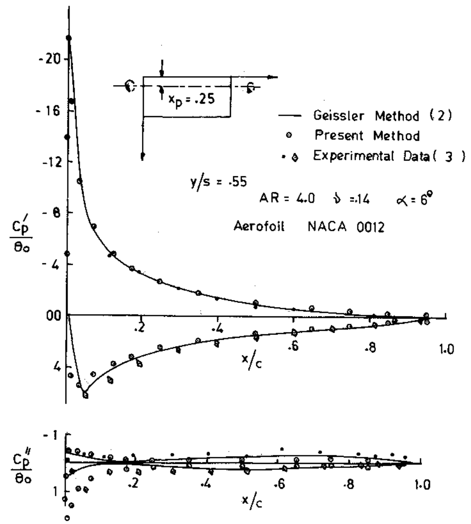

Fig. 2 Comparison of unsteady pressure distribution C_p $(= C_p' + iC_p'')$ for a rectangular wing oscillating with amplitude θ_o about mean angle of incidence $\alpha = 6$ deg at 55% semispan.

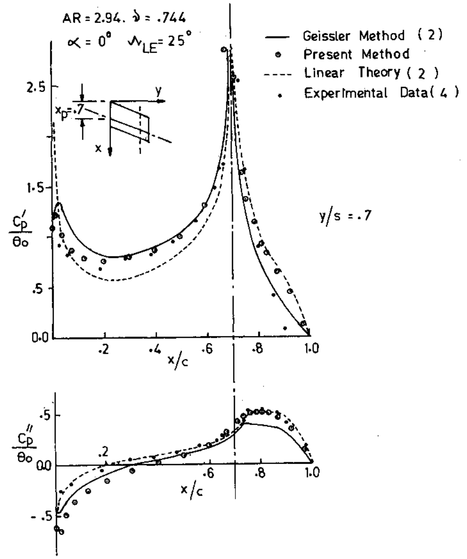

Fig. 3 Comparison of unsteady pressure distribution C $(= C_p' + iC_p'')$ for a swept wing with oscillating control surface having amplitude of deflection θ_o.

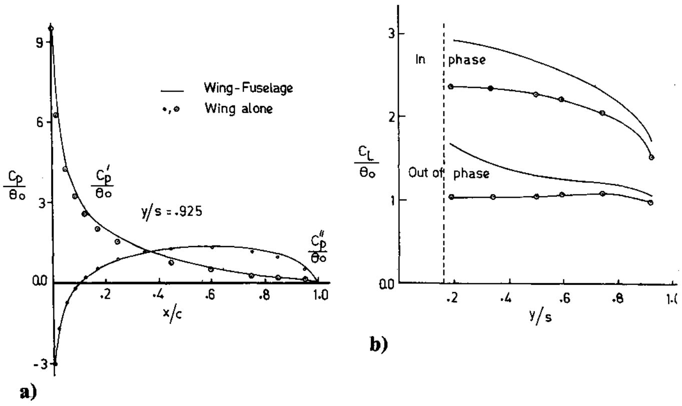

Fig. 4 Unsteady pressure $(C = C_p' + iC_p'')$ and lift distribution on a rectangular wing with and without fuselage oscillating with amplitude θ_o about mean angle of incidence $\alpha = 0$ deg. a) Chordwise pressure distribution at 92.4% semispan; and b) Spanwise distribution of unsteady sectional lift coefficient.

ues[3,4] in Figs. 2 and 3. The comparison shows good agreement. A simple case of wing-body combination, a rectangular wing mounted on a circular fuselage, has been considered. In order to show the effect of the body, the pressure distribution on the wing with and without the body has been plotted in Fig. 4.

Acknowledgment

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