troducing the effects of changes in vorticity distribution (compared with the case of infinite uniform wing) by changes in the effective angle of attack is well known and accepted. Such an approach is used, for example, in the classical lifting line models of finite wings.

The Discrete Model

In this section, a discrete model of an infinite swept wing is derived and solved. The discrete model also helps to prove that it is not the lift curve slope that is changed owing to the slope. The wing is modeled as a series of shifted rectangular segments, as shown by the broken lines of Fig. 2. The width of each segment is d, while its length is the chord c. The problem is solved by using the vortex lattice method. Therefore, the whole vortex sheet is represented by the thick "stairway shape" vortex line, as shown by Fig. 2. According to the vortex lattice method, the boundary condition is reduced to the requirement of nonpenetration of the resultant flow through the control point, which is positioned at the three-quarters chord point of the middle chord of the segment. The reason for choosing the three-quarters chord point as the point where the boundry condition should be satisfied is its exactness in the case of a two-dimensional airfoil with lift curve slope 2π. Therefore, in cases where the lift curve slope is different from 2π, this scheme should result in increasing errors in the calculations.

The lift per unit length in the y direction, L, can be expressed as follows:

$$L = L_0/k \qquad L_0 = \pi\rho U^2 c\alpha\cos\Lambda \tag{13}$$

The exact analytic expression for k (in the form of an infinite series) is given in Ref. 4. Figure 3 shows k as function of d/c and Λ. It is shown that as d/c approaches zero, k approaches unity, and the correct value of L_0 is obtained. This means that, although the wing is swept, the lift curve slope remains 2π. On the other hand, as d/c increases, an increase in L by a factor of $1/\cos\Lambda$ is asymptotically approached. In this case, an artificial correction factor of $\cos\Lambda$ in the lift curve slope is required.

Conclusion

As the result of the sweep of an infinite wing, the field of induced velocities over the wing is changed. This change is a result of a relative shift of the cross sections in the freestream direction and the appearance of vorticity components in the same direction. From the point of view of the two-dimensional behavior of the cross sections, it is better to describe the influence of sweep as a change in the effective angle of attack. This approach is equivalent to the classical method of the lifting line, when dealing with finite wings.

The correction in the effective angle of attack is more consistent and has better physical explanation than a correction in the lift curve slope of the profile. This is shown even more clearly in the case of a discrete model of the infinite swept wing.

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Economical Influence Function Calibrations Using the Distributed Loads Code

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Introduction

THE Influence Function Method (IFM)[1] is a new technique for the prediction of store loads within an aircraft interference flowfield. A major step in the IFM procedure involves calculating the "influences" various segments of the store body have on the total forces and moments of the store. This process, known as "store calibration," requires that the total store forces and moments, as well as the local angle-of-attack distributions along the store length, be either calculated or measured at several axial positions as the store is traversed through a known "calibration" flowfield. The difficulty and expense involved in obtaining these force, moment, and local angle-of-attack distributions have been the major limitations of the IFM.

Typically, two approaches have been taken. In the first approach, a wind tunnel test is conducted in which a model of the store to be calibrated is traversed near a body that creates a known flowfield (supersonically, this may be done by traversing the store through a two-dimensional wedge shock wave; subsonically, determination of the known local flow angles is more difficult). This method requires wind tunnel support which is expensive. The second approach to store calibration involves theoretically calculating the total store forces and moments at several axial stations within a theoretically modeled flowfield (typically, calculations are required at 15-20 store axial positions in the flowfield). The PANAIR code[2,3] is the state-of-the-art computational technique usually used to obtain these force and moment predictions. However, PANAIR predictions at 15-20 locations are relatively expensive[4] and, therefore, are generally not very attractive (they would use approximately 75 min of CPU time using the version of the PANAIR Pilot code installed on the AEDC Amdahl 5860 computer).

Since neither dedicated calibration testing nor high-order computational aeropredictions are desirable from a cost viewpoint, an engineering methods prediction technique—the AEDC Interference Distributed Loads (IDL) code[5]—has been modified to predict store force and moment coefficients along an axial traverse through a simple calibration flowfield. IDL predictions were made for both the generic planar wing weapon (PWW) and the GBU-15 CWW stores at a total cost of 6 s of Amdahl CPU time. This represents a three-order-of-magnitude cost reduction over PANAIR calibrations. Preliminary comparisons of F-15 right inboard pylon flowfield predictions and grid loads on the PWW and GBU-15 stores in that flowfield indicate that the IDL-produced influence coefficients provide very accurate grid predictions which agree well with predictions derived from influence coefficients determined by calibration testing.

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Description of Influence Function Method

The IFM is basically a three-step process implemented in three separate computer codes. Each of the three steps is governed by the same general equations which take the following forms for the normal force and pitching moment coefficients:

$$C_N - C_{N_0} = \sum_{i=1}^{N} A_i \alpha_i \tag{1}$$

$$C_m - C_{m_\phi} = \sum_{i=1}^{N} B_i \alpha_i \tag{2}$$

where A_i and B_i are the normal force and pitching moment influence coefficients, respectively, distributed along the store length. α_i is the distribution of the local flow angle along the store. The zero-angle-of-attack normal force and pitching moment coefficients, C_{N_0} and C_{m_ϕ}, may be taken as zero for an axisymmetric body. The first step of the IFM procedure is the calibration process; C_N and C_m data are either calculated or measured experimentally at each axial station along a traverse through the calibration flowfield. At each station in the traverse, C_N and C_m, combined with the known local angle-of-attack distribution along the store, provide one pair of equations. The resultant two systems of equations are then solved for the unknown influence coefficients. In the second step of the IFM process, C_N and C_m measurements on that same store along an axial traverse within an unknown aircraft flowfield are combined with the known infuence coefficients of the store to provide two more systems of equations, which can be solved for the unknown local flow angles in that flowfield. In the third step, the local flow angles from the second step, and influence coefficients from any other calibrated store, can be inserted into the equations to predict the loads on that other store in the aircraft flowfield.

Description of Interference Distributed Loads Code

The Interference Distributed Loads (IDL) code is a semiempirical code which uses a component buildup approach to calculate static aerodynamic loads on missile- and bomb-type configurations. Calculation of loads in an interference flowfield is based on a superposition of the store on the flowfield. For this effort, the IDL code was modified to include a simple discontinuous flowfield. One half-space of the flowfield was set at a constant local flow angle of zero, the other half-space was set to a constant 5 deg. Such a flowfield is, of course, not physically realizable; however, that does not hinder the IDL load calculations. The modified code starts with the store totally immersed within the $\alpha = 0$ half-space, and steps it one-fifteenth of a store length forward until it lies totally within the $\alpha = 5$ half-space, calculating the total store loads at each step.

Results and Discussion

Total loads acting on the GBU-15 store at Mach 1.2 were calculated using the IDL code, and are shown in Fig. 1 as a function of store c.g. location. Note from the right-most points that as the store nose enters the discontinuity, a positive pitching moment at near zero lift develops. This can be attributed to trailing vortices shed from the nose exerting a downward influence on the wings. The GBU-15 pitching moment influence coefficients calculated from these predicted loads by the IFM are shown in Fig. 2. Also shown are the results of a $M = 0.6$ IDL calibration (previously, theoretical subsonic calibrations were very difficult to obtain). Agreement between the subsonic and supersonic calibrations is excellent. Similar calculations were made using the IDL code to calibrate a generic planar wing weapon (PWW) store.[1]

The PWW influence coefficients were used with experimental $M = 1.05$ data from an axial traverse of the PWW in the F-15 aircraft flowfield to predict the F-15 flow angularities. These predicted flow angles were then combined with the GBU-15 influence coefficients to predict loads on the GBU-15 in the F-15 flowfield. The predicted C_N and C_m values along the traverse are shown in Fig. 3, along with experimental data and additional IFM predictions from Ref. 6. The predictions of Ref. 6 were made using influence coefficients derived from experimental calibration test data. As can be seen, the IFM predictions using IDL calibration data show good agreement with both experimental data and experimentally calibrated IFM predictions. For this case and for the other cases modeled, the IDL-calibrated IFM predictions provided close agreement to experimental grid data at greatly reduced time, effort, and cost.

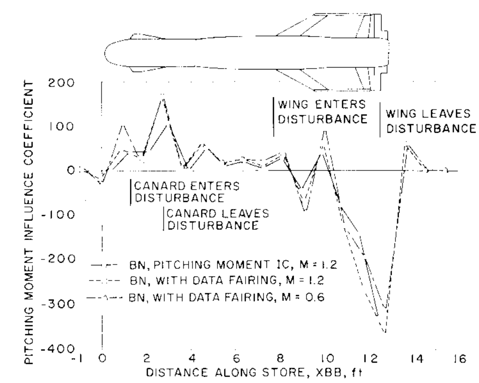

Fig. 2 GBU-15 pitching moment influence coefficients.

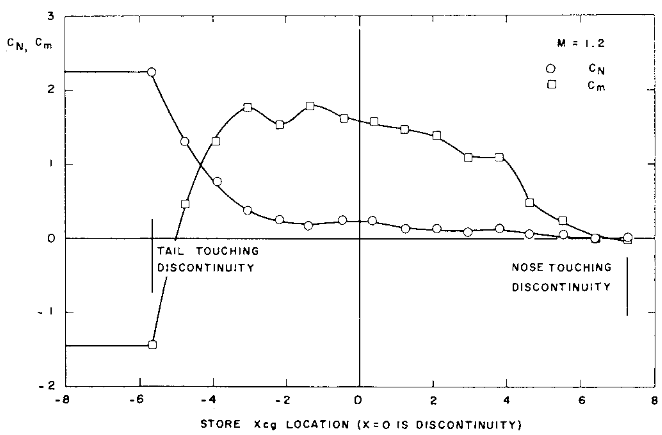

Fig. 1 IDL code forces on GBU-15 traversing discontinuous $\alpha = 0$ to $\alpha = 5$ flowfield.

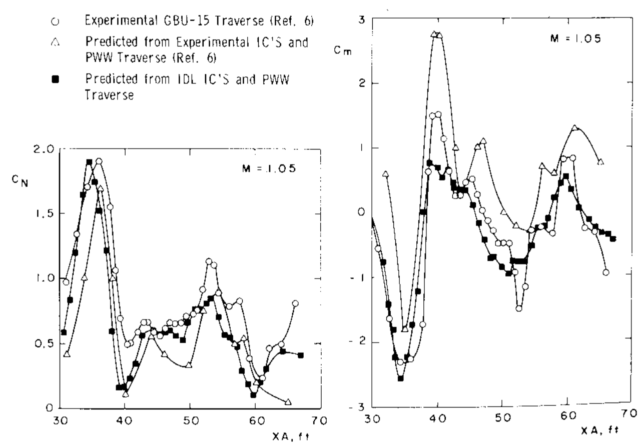

Fig. 3 GBU-15 force prediction.

Conclusions

The Infuence Function Method previously has been demonstrated to be a revolutionary new tool for the prediction of store loads in aircraft flowfields. The major limitation of the method—the difficulty and expense involved in the calibration process—has been addressed for standard missile configurations by coupling the IFM with the Interference Distributed Loads code. Significant cost reductions have been realized with no compromise in the accuracy of the IFM predictions.

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Roll Up of Strake Leading/Trailing-Edge Vortex Sheets for Double-Delta Wings

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Introduction

IN recent years there has been interest in the interaction of leading/trailing-edge vortex sheets. Hummel[1] and Brennenstuhl and Hummel[2] have published a series of experimental data on the formation of leading/trailing-edge vortices for delta or double-delta wings. Kandil[3] first carried out a theoretical calculation by means of a three-dimensional nonlinear discrete vortex method. Hoeijmakers et al.[4] reported their experimental and theoretical results for delta-like wings and developed a new second-order panel method to compute double-branched spiraling vortices.

Around the same time the author attempted to simulate rolling up of leading/trailing-edge vortex sheets using a two-dimensional point vortex method in combination with a leading-edge suction analogy. The calculated results for a delta wing will be published in China. The preliminary results for a double-delta wing will be presented in this Note. In view of the inevitable instabilities in the movement of point vortices and the complex nature of vortex sheets of double-delta wings (according to Hummel's experiments, three concentrated vortices are probably formed), the author will not employ any artificial smoothing scheme. The main purpose of this Note is to examine the capability of a simple, two-dimensional point vortex method to simulate roll up of complicated strake leading/trailing-edge vortex sheets rather than to investigate smoothing schemes. Further, the effect of the interaction of those vortex sheets on the downwash field will be considered.

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Theoretical Model

This model is similar to the one used by Sacks et al.[5] According to the slender wing assumption, the original three-dimensional steady flow around a wing can be analyzed approximately by a two-dimensional time-dependent flow analogy. The separated free shear layer emanating from the leading edge of the wing is replaced by a finite number of two-dimensional point vortices. Each point vortex represents the vorticity shed from the leading edge during a time interval. Sacks' model does not rely on the assumption of conical flow.

It is convenient to use complex variables. In terms of conformal mapping, the wing section in the physical plane, $X=y+iz$, is mapped onto a circle in the transformed plane, $\zeta=\xi+i\eta$, and the resulting problem is reduced to the flow around the circle with a finite number of point vortices outside the circle. For flat-plate wing the transformation is the Joukowski transformation, $X=[\zeta+(a^2/\zeta)]$, where a is the radius of the circle. Therefore, the complex velocity potential,

$$W(\zeta)=-iV_\infty \sin\left(\zeta-\frac{a^2}{\zeta}\right) - \sum_{j=1}^{N}\frac{i\Gamma_j}{2\pi}\ell n\frac{(\zeta-\zeta_j)[\zeta+(a^2/\zeta_j)]}{(\zeta+\bar{\zeta}_j)[\zeta-(a^2/\bar{\zeta}_j)]} \tag{1}$$

$$(v-iw)_k=\frac{dW}{dX}\bigg|_{X_k}+\frac{d}{dX}\left[\frac{i\Gamma_j}{2\pi}\ell n(X-X_k)\right]\bigg|_{X_k} \tag{2}$$

Note that the number of point vortices, N, is variable. A new vortex shed from the leading edge is introduced into the

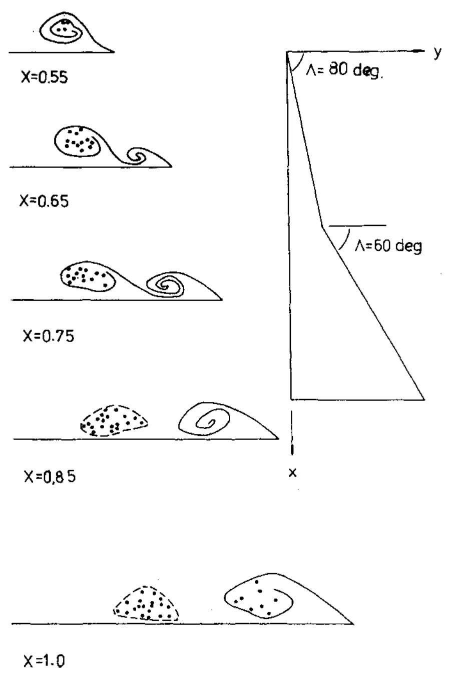

Fig. 1 Evolution of the strake leading-edge vortex sheet at $\alpha=12$ deg for Hummel's No. VI model.