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Extension of a Vortex-Lattice Method to Include the Effects of Leading-Edge Separation

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Introduction

THE accurate determination of the aerodynamic characteristics of thin, highly swept wings having sharp leading edges at low, subsonic Mach numbers is a long-standing problem. The major difficulty stems from the fact that the flow separates from the wing along the leading edge, even for moderate angles of attack. Peckham[1] describes the actual flowfield. Maddox,[2] who reviewed the earlier attempts to model this separated flowfield, found that all of these attempts were analytical, and none resulted in accurate predictions of lift, pitching moment and pressure distribution.

Vortex-lattice methods have been used successfully to obtain the aerodynamic coefficients of lifting surfaces without leading-edge separation. In the present Note, we describe how an existing vortex-lattice method can be modified to include the effects of leading-edge separation and then use the modified version to calculate the aerodynamic loads on a highly swept delta wing. The present results are compared with Peckham's experimental data.

Description of the Method

The leading-edge vortex system is represented by a family of discrete vortex lines. Each line is composed of a series of straight segments joined head to tail. This system of discrete lines is superposed on the existing vortex-lattice system. The arrangement is illustrated in Fig. 1. Points A, B, and C lie on a typical vortex line in the leading-edge system. The semi-infinite segment from A to B is coincident with a leg of one of the horseshoe elements of the vortex lattice. The portion of the line between B and XMAX is composed of a series of short, straight segments; the lengths of these segments increase with the distance from B. The remaining semi-infinite segment from XMAX to C is straight and parallel to the undisturbed freestream velocity. As in the vortex-lattice method, the velocity field generated by the leading-edge system is calculated with the aid of the Biot-Savart law. This flowfield is added to that generated by the lattice and the free stream.

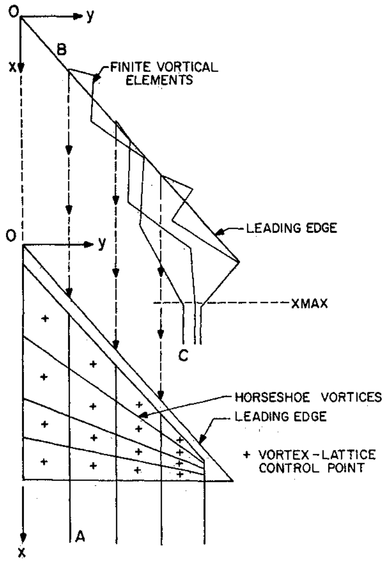

Fig. 1 Arrangement of discrete vortex lines.

Following Belotserkovskiy,[3] who considered wing-tip vortex systems and nonplanar wakes adjacent to the trailing edge, we make each of the segments between B and XMAX parallel to the velocity at its upstream end. This approximately renders each segment force free. A row of control points, one point for each line in the leading-edge vortex system, is added midway between the foremost spanwise elements of the lattice and the leading edge. Consequently, there is now a row of control points between the lattice and the leading as well as the trailing edge, and according to one of the basic notions of the vortex-lattice method, we are now satisfying a leading-edge as well as a trailing-edge Kutta condition.

Method of Solution

When the directions of the short, straight segments are specified, one can solve for the circulation around each vortex in the entire system by simultaneously satisfying

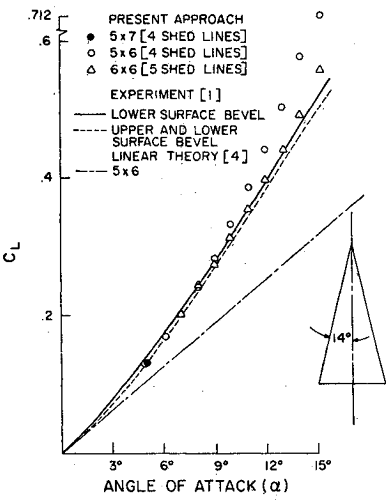

Fig. 2 Lift coefficient vs angle of attack.

Received August 8, 1973. Research sponsored by NASA Langley Research Center under Grant NGR-74-004-090. The authors acknowledge the numerous helpful comments and criticisms of Drs. A. H. Nayfeh, E. C. Yates, and W. P. Rodden.

Index category: Aircraft Aerodynamics.

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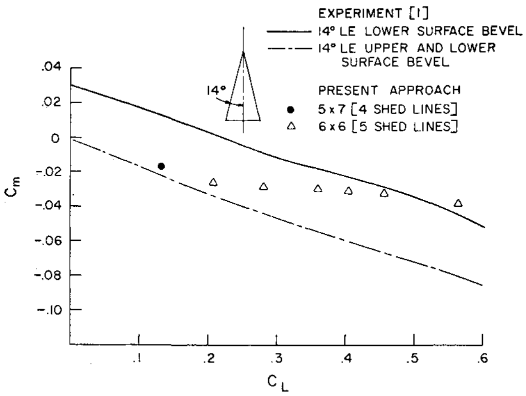

Fig. 3 Moment coefficient vs lift coefficient.

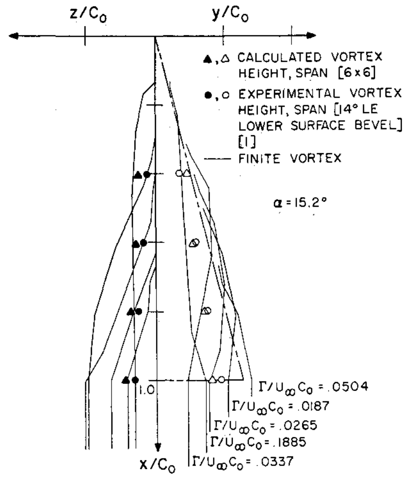

Fig. 4 Circulation centroid and vortex core positions.

the zero-downwash condition at each control point. This problem is linear. Consequently, we use the following iterative procedure: first, the directions are specified (parallel to the freestream initially) and then the circulations are determined. Then, with the circulations fixed, the directions are changed to make each segment between B and XMAX be parallel to the velocity at its upstream end. Because the velocity field changes when the directions (and positions) of these segments change, this step also required iteration. With the directions now fixed, the circulations are re-determined, etc. This procedure is repeated until the maximum change in the direction of any segment is less than a specified limit.

Application

As a numerical example, we chose a flat, delta wing having a semiapex angle of fourteen degrees because Peckham experimentally obtained the lift, moment, and position of the vortex core. Peckham used two models (thickness to cord ratio = 0.01): one with its leading edge beveled along the lower side only, and one with the upper and lower sides beveled symmetrically. The former exhibited camber effects, and as a result Peckham used a "zero shift" in order to make the lift curve pass through the origin. Wherever possible, the data from both models are used. The steady-flow portion of the Air Force version of the program by Giesing, Kalman and Rodden[4] was modified according to the discussion above and used to make the present calculations.

The iterative scheme did not converge for angles of attack below five degrees. This is attributed to the fact that the leading-edge vortex lines are very near the vortex lattice representing the lifting surface and, consequently, are in a grossly distorted velocity field. Increasing the number of chordwise elements beyond five had practically no effect on the predicted values of lift and moment but increased the rate of convergence for angles of attack near five degrees. Increasing the number of spanwise strips (and thereby the number of lines in the leading-edge system) increased the accuracy significantly at large angles of attack. The calculations were made on an IBM 360/70 in single precision (to minimize storage requirements) and, consequently, we encountered round-off errors when we attempted to put more than five lines in the leading-edge system. Nevertheless, it is clear from the results at lower angles of attack that the numerical results will converge to values which are independent of the number of spanwise elements when the number of spanwise elements increases.

The results for lift and moment are shown in Figs. 2 and 3. It should be noted that with the present modifications there is a force on those portions of the "legs" of the horsehoe that are on the lifing surface due to the crossflow generated by the leading-edge system. In Fig. 4, the position of the centroid of the circulation around the discrete vortex lines of the leading-edge system in various transverse planes is compared with the position of the vortex core determined experimentally by Peckham. The circulation was nondimensionalized by dividing the freestream velocity and the chord. Maddox also compares the results for a flat, delta wing having a semiapex angle of 22° with Peckham's data. Comparisons of pressure distributions are also given; Peckham's data, however, are for wings having a diamond-shaped cross section.

The generally good agreement between the present results and the experimental data indicate that the discrete-vortex-line methods are promising and ought to be investigated in depth.

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