rectional derivative $C_{n(p)}$ in particular, but the controversy served to clarify the various applications. What the prospects are for calculating induced drag on wing-body combinations remains to be seen, and further investigations are in order. Certainly, Hua has more to do to improve his drag calculation than simply account for leading edge suction.

The analysis of sideslip is our last area of criticism. The use of dual coordinate systems in linearized theory, i.e., a body-axis system for the elements and control points, and a wind-axis system for the element trailing vortices, not only introduces needless complications in the longitudinal case but also substantial errors in the directional case.** The most complete study of the validity of the Lattice Method is James' investigation[15] of the two-dimensional steady flow case which demonstrated the proper chordwise locations of the bound vortex and the downwash collocation point on each lifting element but obviously had nothing to say about the spanwise location of the collocation point in three-dimensional applications. From numerical experimentation, it has become apparent that the optimum spanwise location of the collocation point is at the centerline of the lifting element which, in the longitudinal case, is halfway between the trailing vortices. In Hua's coordinate systems, the collocation points are not centered between the trailing vortices, and if more vortices had been used, it is likely that at least one trailing vortex would have crossed a collocation point at some sideslip angle (for zero angle of attack) and an infinite downwash influence function would have resulted. This explains the large discrepancy in underestimating the dihedral effect $C_{l(\beta)}$ shown in Hua's Fig. 7. We can also ask how many problems are created by a sideslipping wing as its trailing vortex system intersects the fuselage, but that question may also be asked of our own development.[11] However, there are still some items for further investigation in estimating $C_{l(\beta)}$ for a wing alone. The prediction of dihedral effect for geometric or flexibly induced dihedral can be made by considering sideslip simply as a source of downwash as in Ref. 16 and the Vortex Lattice Method without modification can be used to provide the aerodynamic influence coefficients required in Ref. 16. However, the planform contribution to $C_{l(\beta)}$ from a swept wing requires some modification in procedure but none in principle. This consists of aligning the elements in the lattice system and, thus, also the control points, with the direction of sideslip. For positive sideslip β and sweepback Λ, the right wing will then have less sweep, i.e., $\Lambda - \beta$, and the left wing will have more sweep, i.e., $\Lambda + \beta$, and the wing tip regions will appear triangular. Numerical evaluation of this approach to the planform contribution to $C_{l(\beta)}$ is a topic for further study but the wind axes of Ref. 1 cannot lead to accurate estimates.

To conclude, we will certainly not agree, at least at subsonic speeds, that "the existing methods for predicting aerodynamic coefficients are not very satisfactory," but we hope that this Comment will assist the interested reader in distinguishing between the real and the imagined problems that remain.

References

[1]Hua, H. M., "A Finite-Element Method for Calculating Aerodynamic Coefficients of a Subsonic Airplane," *Journal of Aircraft,* Vol. 10, No. 7, July 1973, pp. 422–426.

[2]Woodward, F. A., "Analysis and Design of Wing-Body Combinations at Subsonic and Supersonic Speeds," *Journal of Aircraft,* Vol. 5, No. 6, Nov.-Dec. 1968, pp. 528–534.

[3]Belotserkovskii, S. M., *The Theory of Thin Wings in Subsonic Flow,* Plenum Press, New York, 1967.

[4]Hedman, S. G., "Vortex Lattice Method for Calculation of Quasi-Steady State Loadings on Thin Elastic Wings," Rept. FFA 105, Oct. 1965, Aeronautical Research Institute of Sweden, Stockholm, Sweden.

[5]Kálmán, T. P., Rodden, W. P. and Giesing, J. P., "Application of the Doublet-Lattice Method to Nonplanar Configurations in Subsonic Flow," *Journal of Aircraft,* Vol. 8, No. 6, June 1971, pp. 406–413.

[6]Isogai, K. and Ichikawa, T., "Lifting-Surface Theory for a Wing Oscillating in Yaw and Sideslip with an Angle of Attack," *AIAA Journal,* Vol. 11, No. 5, May 1973, pp. 599–606.

[7]Hancock, G. J., "Comment on 'Spanwise Distribution of Induced Drag in Subsonic Flow by the Vortex Lattice Method'," *Journal of Aircraft,* Vol. 8, No. 8, Aug. 1971, p. 681; Kálmán, T. P., Giesing, J. P., and Rodden, W. P., "Reply by Authors to G. J. Hancock," *Journal of Aircraft,* Vol. 8, No. 8, Aug. 1971, pp. 681–682.

[8]Hancock, G. J., "Some Aspects of Subsonic Linearized Wing Theory, with Reference to Second Order Forces and Moments," Rept. Q.M.C.E.P.-1006, March 1973, Queen Mary College, University of London, London, England.

[9]Rodden, W. P. and Giesing, J. P., "Application of Oscillatory Aerodynamic Theory for Estimation of Dynamic Stability Derivatives," *Journal of Aircraft,* Vol. 7, No. 3, May–June 1970, pp. 272–275.

[10]Albano, E. and Rodden, W. P., "A Doublet-Lattice Method for Calculating Lift Distributions on Oscillating Surfaces in Subsonic Flows," *AIAA Journal,* Vol. 7, No. 11, Feb. 1969, pp. 279–285, and Errata, Nov. 1969, p. 2192.

[11]Giesing, J. P., Kálmán, T. P., and Rodden, W. P., "Subsonic Steady and Oscillatory Aerodynamics for Multiple Interfering Wings and Bodies," *Journal of Aircraft,* Vol. 9, No. 10, Oct. 1972, pp. 693–702.

[12]Giesing, J. P., "Lifting Surface Theory for Wing-Fuselage Combinations," Rept. DAC-67212, Aug. 1968, McDonnell Douglas Corp., Long Beach, Calif.

[13]Multhopp, H., "Zur Aerodynamik des Flugzeugrumpfes (On the Aerodynamics of the Fuselage)," *Luftfahrtforschung,* Vol. 18, 1941, pp. 52–66; see also: Donovan, A. F. and Lawrence, H. R., eds., *Aerodynamic Components of Aircraft at High Speeds,* Vol. VII of *High Speed Aerodynamics and Jet Propulsion,* University Press, Princeton, N.J., 1957, pp. 316–363.

[14]Kálmán, T. P., Giesing, J. P., and Rodden, W. P., "Spanwise Distribution of Induced Drag in Subsonic Flow by the Vortex Lattice Method," *Journal of Aircraft,* Vol. 7, No. 6, Nov.–Dec. 1970, pp. 574–576.

[15]James, R. M., "On the Remarkable Accuracy of the Vortex-Lattice Discretization in Thin Wing Theory," Rept. DAC-67211, Feb. 1969, McDonnell Douglas Corp., Long Beach, Calif., also "On the Remarkable Accuracy of the Vortex Lattice Method," *Computer Methods in Applied Mechanics and Engineering,* Vol. 1, No. 1, June 1972, pp. 59–79.

[16]Rodden, W. P., "Dihedral Effect of a Flexible Wing," *Journal of Aircraft,* Vol. 2, No. 5, Sept.-Oct. 1965, pp. 368–373.

**Figure 1 of Ref. 1 appears to have the lifting element drawn incorrectly; i.e., the side edges are not parallel to the x-axis.

Reply by Author to W. P. Rodden, J. P. Giesing, T. P. Kalman and J. C. Rowan

Hsichun M. Hua*

Aeronautical Research Lab., AIDC, Taichung, Taiwan, Republic of China

THE preceding Comment by W. P. Rodden et al. shows that several points in my original paper should be further elaborated. In the early stage of preliminary design, air-

Received March 22, 1974. The author is grateful to W. P. Rodden and his colleagues for providing the opportunity to clarify several points in his paper which may have caused confusion.

Index categories: Aircraft Configuration Design; Aircraft Handling, Stability, and Control; Aircraft Aerodynamics (Including Component Aerodynamics).

*Deputy Director. Member AIAA.

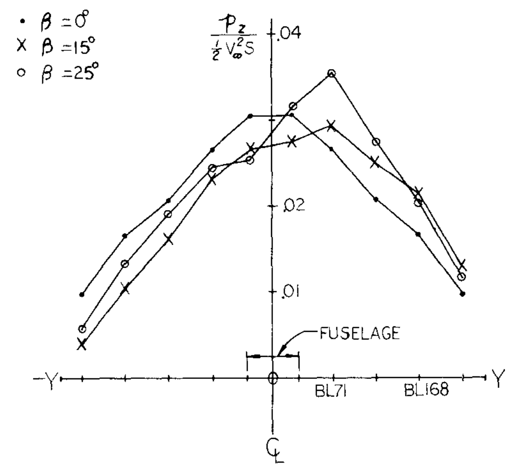

Fig. 1 Normal load distribution of aircraft in yaw, $\alpha = 2°$.

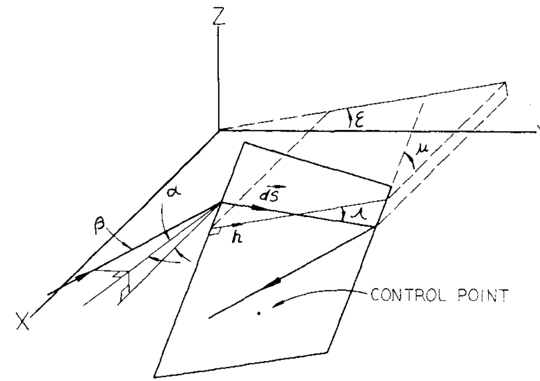

Fig. 2 Lifting panel with horseshoe vortex and control point.

craft designers predict the performance and control effectiveness (an item of flying qualities[1]) based mostly on the steady-state data measured in a wind tunnel. The work done in the paper was intended only to analytically estimate these data to alleviate the wind-tunnel test load.

While constructing a mathematical model to estimate the aerodynamic coefficients of an aircraft in sideslip, it was found that the trailing vortices fixed with the body axes of a sweepback wing produce a force contradictory to observations. The model was then refined by orienting the trailing vortices to the wind. This is why the author does not understand how the lateral coefficients can be calculated merely by integrating the load distribution calculated with a system fixed by the body axes.

While the dual system does introduce complications, it is still possible, using a computer of 8K memory,[2] to calculate all the results in the paper. The author was aware of the problem caused by the trailing vortices moving close to the control points. (This condition may happen in vortex system fixed with body axes, e g., a trailing vortex from the wing may cross a control point on horizontal tail.) He tried to manipulate the computer program by neglecting the parts of trailing vortices close to the control points. This scheme was later disregarded as it showed little improvement in the results. Fortunately, the trailing vortices almost always come from neighboring bound vortices in pairs with opposite directions, and this problem can be avoided by making proper arrangement of the lifting panels or by taking data only at small sideslop angles.

The preceding Comment has brought the author's attention to an important point which was not reported in his paper. To compute using this subject method, coordinates of elements on both wings and both horizontal tails should be included in the input data, not the half airplane, as with most methods. In this way the image system may not be needed, as can be seen in Fig. 1. The author also realizes the error in Fig. 1 of his paper in angles α and β. The correct figure is Fig. 2.

References

[1]"Flying Qualities of Piloted Airplanes," MIL-F-08785A, Oct. 1968, U.S. Air Force, Washington, D.C.

[2]Hua, H. M., "A Finite-Element Method for Calculating Aerodynamic Coefficients of a Subsonic Airplane," AIDC-6205, 1973, Aeronautical Research Lab., AIDC, Taichung, Taiwan.