parachutes were ignited and burned well as shown in Fig. 3. Test no. 3 demonstrated that the rocket blast could ignite the parachute, even though the rocket burn time is very short.

Two suitable pyrotechnic formulations, mixtures nos. 8 and 9, described in Table 1 were developed and used successfully to disintegrate the 4.5-ft-diam ribbon parachutes after completion of the deceleration phase. It is believed that pyrotechnic disintegration of lighter weight parachutes, such as solid cloth personnel canopies, would be a more complete disintegration because of the lighter material. Safe methods of treating and handling were devised and used with no inadvertent ignition incidents.

If further work is conducted with pyrotechnic parachutes, the packed parachutes should be evaluated for premature ignition hazard characteristics. Degradation of materials with respect to compatibilities and shelf storage should also be investigated.

Conclusions

A flammable impregnant has been developed which when applied to a nylon parachute will promote disintegration of the parachute after the deceleration phase of a drop has been completed.

Drop tests of a 50-lb total weight low-level delivery sensor delivered by a parachute impregnated with the flammable pyrotechnic have made possible the following conclusions:

1) An impregnating mixture of powdered metal such as magnesium, Viton A, and TNT can be used to produce a disintegratable parachute. A mixture of titanium powder and aluminum powder may be substituted for the magnesium powder. In either case, the use of finely divided powder is required. Precautions should be taken during handling to prevent accidental ignition, which is inherent with the use of finely divided pyrophoric metals.

2) Treating, packing, handling, deployment, and ignition have been shown to be feasible. All were successfully accomplished during the development of this program.

Acknowledgment

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References

[1] Pepper, W. B., Jr. and Buxton, R. J., "Destructible Parachute," United States Patent No. 3,814,355, June 4, 1974.

[2] Pepper, W. B., Jr. and Maydew, R. C., "*Aerodynamic Decelerators – an Engineering Review,*" SC-R-61-3156; also, *Journal of Aircraft*, Vol. 8, Jan. 1971, pp. 3-19.

Vortex Lattice Prediction of Subsonic Aerodynamics of Hypersonic Vehicle Concepts

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Introduction

A JOINT USAF/NASA study is underway to define the vehicle requirements for a hypersonic research aircraft which is currently designated the National Hypersonic Flight Research Facility (formerly the X-24C).[1] The vehicle will be air-launched from a B-52, rocket-boosted to the cruise condition of Mach 6, and will then glide to an unpowered landing. The constraints imposed by the launch aircraft result in low-aspect-ratio vehicles, and the high drag associated with certain experiments such as the research scramjet cause the unpowered approach and landing phase of the flight to be a critical design problem. This problem is associated with the high angles of attack required to develop the needed L/D. At these angles of attack, vortex flows are expected. Several configuration concepts have been developed by USAF and NASA studies, some of which have been tested at subsonic speeds. The majority of them have either marginal or unacceptable subsonic performance. Therefore, a requirement exists for a reliable analytical method which could determine the subsonic aerodynamics of candidate concepts.

The vortex lattice method of J. E. Lamar and B. B. Gloss,[2] with unpublished improvements in the leading-edge suction computation by Lamar, was used to estimate vortex flow aerodynamics. The suitability of this method was investigated by comparing calculated and experimental aerodynamic characteristics of two National Hypersonic Flight Research Facility (NHFRF) concepts at Mach 0.2. The unpublished experimental data were obtained in the Langley Research Center Low Turbulence Pressure Tunnel at a Reynolds number of 10×10^6. The comparisons presented are for a lifting-body concept (12I) and for a distinct wing-body concept (L16) which was developed at NASA-Langley (Fig. 1).

Configuration

Each of the concepts have several features in common. At high speeds, the underbody ahead of the engine inlet acts as a precompression surface for the research propulsion system, whereas the underbody aft of the exit acts as an external exhaust nozzle. The requirement for precompressed inlet air results in negative wing incidence in order to increase the underbody angle of attack at cruise. The blunt base is primarily the result of the rocket boost system.

Computer Model

The fuselage-wing combination is represented by two coplanar lifting surfaces where the dividing line between the lifting surfaces is taken at the body-wing leading-edge juncture and drawn normal to the centerline. The "no flow" constraint is applied simultaneously to each elemental panel at its control point.[3] This constraint is equivalent to requiring that the flow be tangent to the real mean-camber surface. This surface, which can be highly irregular for this class of vehicles, is represented as the local slope of the mean-camber surface at each control point. The process of determining the local slopes of the mean-camber surface is straightforward and could easily be converted to an automated process utilizing any suitable three-dimensional numerical model.

Results and Discussion

Hypersonic configurations are atypical in that the flow around the total vehicle is greatly influenced by interference effects from the massive fuselage. This represents a situation for which the vortex lattice method was not designed.[4] Also, due to the high sweep angle of the fuselage forebody, it was not known whether vortex flow, if generated from the forebody, would be effective in generating forces and moments due to the inclination of the body sides. Comparisons of the data and theory showed that the resulting aerodynamic forces and moments could be modeled by only accounting for vortex flow on the wing leading edge and tip. This procedure was applied to several other NHFRF concepts with good results. Past studies[4,5] have shown that the application of the augmented vortex lift improved the lift and

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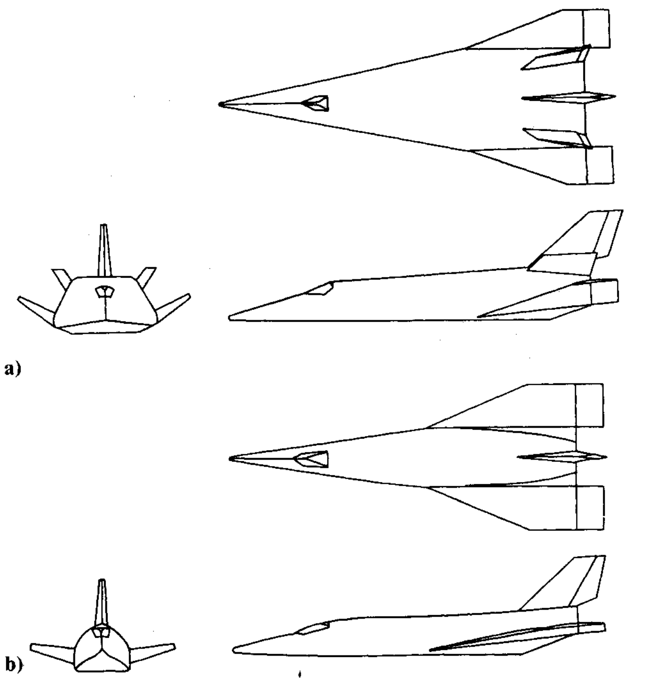

Fig. 1 Three-view drawings of the a) lifting-body configuration and b) distinct wing-body configuration.

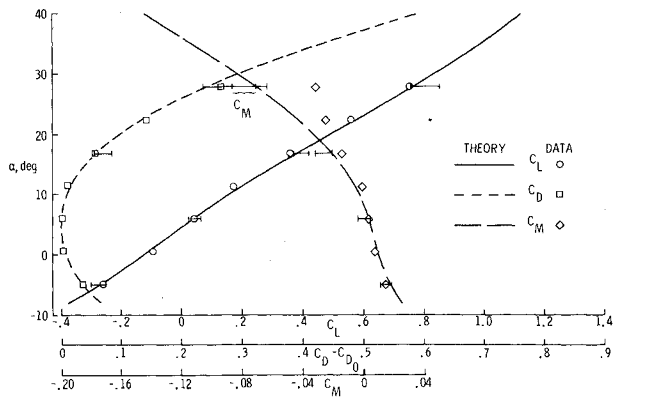

Fig. 2 Comparison of theory and experiment for the lifting-body configuration.

pitching moment estimate for a number of isolated wings. These studies included arrow and diamond planforms as well as the cropped delta. The most complete flow model would include the augmented vortex lift but the predictions did not agree as well with the data probably due to fuselage effects.

Figure 2 presents experimental data and vortex lattice predictions for the fuselage-wing combination of the lifting-body configuration. The theory shown utilized 138 elemental panels. The drag data are presented as $C_D - C_{D,0}$ where $C_{D,0}$ is the drag at $C_L = 0$. The theory predicts C_L vs α, $C_{m,0}$, and $C_D - C_{D,0}$ vs α quite accurately. However, the theory fails to predict C_m at high angle of attack. Figure 3 presents the comparison for the fuselage-wing combination of the wing-body. In this instance, the theory shown utilized 125 elemental panels. The agreement between the theory and the data is very accurate for this configuration again with the exception of the C_m prediction at high angle of attack. The slightly improved C_m prediction for this concept is believed to be due to the smaller fuselage of the wing body, which results in reduced body interference on the wing.

A study was made of the effect of vortex density on the predictions for the lifting body. The number of chordwise rows of vortices was varied as well as the number of vortices per chordwise row. The minimum number of chordwise rows was six and the maximum was 15 for the aft lifting surface.

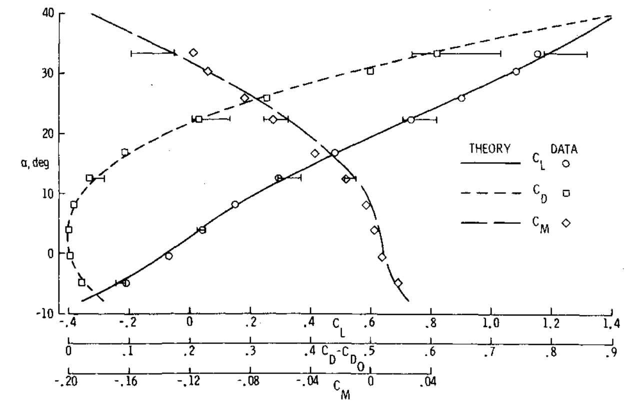

Fig. 3 Comparison of theory and experiment for the distinct wing-body configuration.

The number of chordwise rows on the forward lifting surface was roughly one half the number on the aft lifting surface. Three vortices per chordwise row was the minimum for each lifting surface and the maximum was ten. The total number of vortices used to represent the lifting body ranged from 30 to 184. A minimum and maximum vortex density was applied to the wing-body to obtain the limits of agreement for this configuration.

The variation in predictions caused by differing vortex densities is indicated by the bars on Figs. 2 and 3. The variance increases rapidly with increasing angle of attack, but overall the agreement is good. Increasing the number of chordwise rows is more effective in improving the agreement between theory and data than is increasing the number of vortices per row. The lift coefficient is best predicted by the maximum vortex density case, but the induced drag polar is matched most closely by cases utilizing roughly 120-150 elemented panels. Although the pitching moment prediction is not adequate over the entire angle of attack range, accurate predictions of pitching moments are obtainable with moderate to maximum vortex density for the flight angles of attack of interest which corresponds to lift coefficients of 0.2-0.5.

Concluding Remarks

The vortex lattice method of Lamar and Gloss has been shown to be an adequate method for predicting the low-speed characteristics of hypersonic body-wing combinations. This represents an extension of the usefulness of the vortex lattice method. Variations of the elemental panel density on the lifting-body configuration showed that roughly 120 to the maximum number of panels gives good agreement for the lift and induced drag coefficients, as well as the pitching moment at angles of attack below 10-15 deg. Because this method is simple to apply and lends itself to an automated process for calculating the local slopes of the mean-camber surface, it is ideally suited as an aerodynamic tool for preliminary design.

References

[1] Hearth, D. P. and Preyss, A. E., "Hypersonic Technology–Approach to an Expanded Program," *Astronautics and Aeronautics*, Vol. 14, Dec. 1976, pp. 20-37.

[2] Lamar, J. E. and Gloss, B. B., "Subsonic Aerodynamic Characteristics of Interacting Lifting Surfaces with Separated Flow Around Sharp Edges Predicted by a Vortex-Lattice Method," NASA TN D-7921, 1975.

[3] Margason, R. J. and Lamar, J. E., "Vortex-Lattice Fortran Program for Estimating Subsonic Aerodynamic Characteristics of Complex Planforms," NASA TN D-6142, 1971.

[4] Lamar, J. E., "Summary of Some Recent Studies of Subsonic Vortex Lift and Parameters Affecting the Leading-Edge Vortex Stability," AIAA Paper 76-414, San Diego, Calif., July 1976.

[5] Lamar, J. E., "Some Recent Applications of the Suction Analogy to Vortex-Lift Estimates," NASA TM X-72785, 1976.