High Angle-of-Attack Hypersonic Aerodynamics

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Abstract

A PRELIMINARY design aerodynamics force model has been developed for determining the aerodynamic force on complete vehicles from takeoff to orbital speeds. The model is based on modified Newtonian theory and empirical correlations. Lift and drag predictions have been compared to results for 1) a wind-tunnel model at a Mach number of 20, and 2) the full-scale Shuttle Orbiter for Mach numbers from 0.25 to 20 with angles of attack from 0 to 50 deg. Good agreement between the test data and the predictions has been obtained. Lift-to-drag (L/D) predictions are presented for the Shuttle and a Shuttle derivative, a transatmospheric vehicle, at hypersonic speeds and high angles of attack. Changes in L/D with changes in nose angle, sweep angle, and volume$^{2/3}$/planform area are quantified for the Shuttle derivative.

Contents

In the preliminary design of hypersonic cruise and orbital vehicles, researchers evaluate many different configurations. Aerodynamic, propulsion, structural, and material factors impose constraints and compromises that complicate the design process. An aerodynamic analytical model to quickly evaluate aerodynamic forces of different configurations has been developed; it is presented in the full paper.[1] The model is based on modified Newtonian flow theory and empirical correlations. Lift, drag, and friction forces are summed for the vehicle components, which include nose, body, wing, tail, and afterbody. Laminar, turbulent, and transitional boundary-layer skin friction are accounted for. Real-gas effects are not considered.

The model has been used to compute the overall lift and drag for several vehicles. Configurations investigated in the full paper[1] include a Mach 20 wind-tunnel model, a transatmospheric vehicle that is a derivative of the Shuttle Orbiter, and the full-scale Shuttle Orbiter. Additional examples can be found in Harloff and Petrie.[2] The Shuttle Orbiter aerodynamic data are from the Shuttle data book[3] for a clean configuration, i.e., the control surfaces are not deflected. Lift and drag predictions for the Shuttle Orbiter are compared to data for Mach numbers from 0.25 to 20 in the full paper. The predictions are in good agreement with the Shuttle data book values.

Predicted Shuttle Orbiter hypersonic L/D vs Mach number, at constant angle of attack, are shown in Fig 1. The flight path for this prediction, and for the transatmospheric vehicle discussed below, is the re-entry trajectory for the Shuttle. At 5- and 10-deg angle of attack, increasing the Mach number results in decreasing L/D. For example, at 5-deg angle of attack, the predicted L/D is 1.15 at Mach 4.4 and about 0.2 at Mach 26. At 10-deg angle of attack, the L/D decreases from 2.2 to about 1.4 as the Mach number increases from 4.4 to 26. In the hypersonic regime, the predicted L/D ratio is independent of Mach number for angles of attack of 20 deg and higher. The sharp drop in L/D vs Mach number near Mach 26 is due to rarefied gasdynamics effects. This is discussed further in Ref. 1. Boundary-layer transition for the Shuttle occurs near Mach 10 and the L/D slope changes for the 5- and 10-deg angle-of-attack predictions between Mach 5 and 10.

The Shuttle Orbiter has relatively low L/D values, as observed in Fig. 1. Increasing the L/D ratio would increase the vehicle maneuverability and enable orbital transfers, or orbital inclination changes, by aerodynamic means. To obtain a vehicle with an increased L/D, the Shuttle Orbiter math model was modified by decreasing the nose cone half-angle from 22 to 8 deg and by uncanting the nose relative to the vehicle centerline. The length of the nose, for the transatmospheric

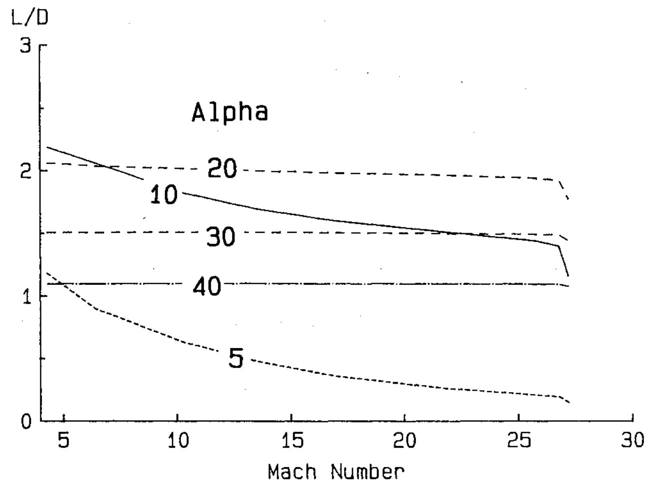

Fig. 1 Shuttle Orbiter L/D.

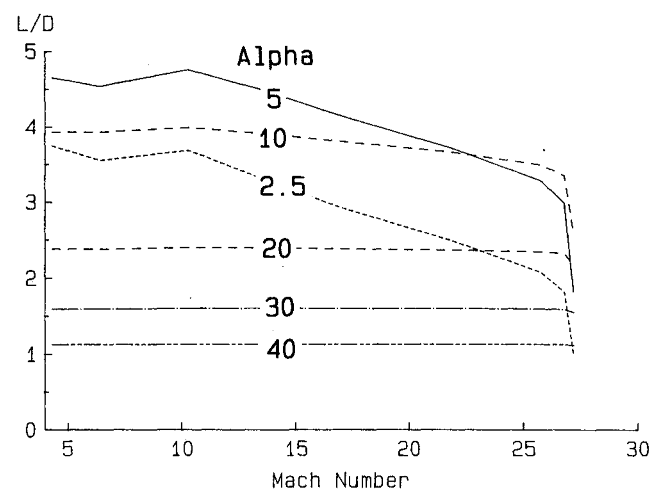

Fig. 2 Transatmospheric vehicle L/D.

Received June 9, 1987; presented as Paper 87-2545 at the AIAA Applied Aerodynamics Conference, Monterey, CA, Aug. 17-19, 1987; synoptic received March 28, 1988. Full paper available from AIAA Library, 555 W. 57th Street, New York, NY 10019. Price: microfiche, $4.00; hard copy, $9.00. **Remittance must accompany order.** Copyright © 1988 by Gary J. Harloff. Published by the American Institute of Aeronautics and Astronautics, Inc., with permission.

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vehicle, increased from 18.5 to 71 ft. The wing sweep angle was increased from 58 to 70 deg. The resulting L/D values are presented in Fig. 2 for Mach numbers from 4.4 to 27. The predicted L/D values at 5-deg angle of attack are 4.6 at Mach 4.4 and about 3.0 at Mach 26. These L/D values compare to 1.15 and 0.2, respectively, for the original Shuttle Orbiter at the same conditions. Boundary-layer transition for this vehicle is predicted to occur between Mach 5 and 10, as indicated by the change in L/D slope; see Fig. 2.

A parametric study was conducted with the preceding transatmospheric vehicle to determine the sensitivity of L/D to changes in nose angle, wing sweep angle, and volume$^{2/3}$ planform area. The effects of increasing the nose half-angle from 6 to 10 deg are shown in the full paper[1] at Mach 10 and 26. This increase in nose half-angle decreases the predicted L/D at Mach 10 from 5.1 to 4.9 at 5-deg angle of attack. At Mach 26, the maximum L/D occurs at 10-deg angle of attack and L/D decreases from 3.7 to about 3.2 with an increase in nose half-angle from 6 to 10 deg.

The effects on L/D of changing wing sweep angle from 65 to 75 deg are shown in the full paper[1] for Mach 10 and 26 for angles of attack to 40 deg. The maximum L/D increases from 4.4 to 5.2, at Mach 10 and 5-deg angle of attack, when the wing sweep angle increases from 65 to 75 deg. At Mach 26 and 10-deg angle of attack, the L/D increases from 3.4 to 3.6 as the wing sweep angle increases from 65 to 75 deg.

The effects of increasing the body volume$^{2/3}$/planform area on L/D are shown in the full paper.[1] The volume$^{2/3}$/planform area was increased from 0.25 to 0.30 for Mach 10 and 26 and for angles of attack to 40 deg. The maximum L/D increases from 4.5 to 5.0 when the volume$^{2/3}$/planform area decreases from 0.30 to 0.25 at Mach 10 and 5-deg angle of attack. The increase in L/D is from 3.4 to 3.5 at Mach 26 and 10-deg angle of attack for the same decrease in volume$^{2/3}$/planform area.

In conclusion, an algebraic aerodynamics model has been developed to predict lift and drag forces for complete hypersonic vehicles from takeoff to orbital speeds with reasonable accuracy for preliminary design. The model can be used over a broad range of Mach number, Reynolds number, and angle of attack. Predicted L/D for transatmospheric vehicle indicates that L/D ratio of about 5.2 at Mach 10 and about 3.6 at Mach 26 should be obtainable. The L/D increases with decreases in nose half-angle and volume$^{2/3}$/planform area, and with increases in wing sweep angle. The L/D ratio is independent of these variables for angles of attack in excess of 20 deg at Mach 10 and 26.

Acknowledgment

Prepared for the NASA Lewis Research Center under Contract NAS 3-24105.

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