Engineering Notes

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Inlet Boundary-Layer Shapes on Four Aircraft Forebodies at Mach 6

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HYPERSONIC vehicles at present are primarily spacecraft and rocket-powered missiles, but as the trend toward higher-speed aircraft advances into the high supersonic and hypersonic regime, a new class of aircraft will emerge between the space vehicle and the supersonic airplane. Relative to present hypersonic vehicles, the new class of aircraft, described typcially in Ref. 1, will have good aerodynamic efficiency, steady-state cruise, and airbreathing engines. The fuselage boundary layer will typically be turbulent, high-energy, and may be ingested by the airbreathing engine. Thus, knowledge of the boundary-layer characteristics and its controlling parameters assumes new importance.

For efficient hypersonic aircraft, the forebody flowfield is used as precompressed flow for the scramjet engine, leading to a large improvement in aircraft performance. The design of the forebody geometry for uniform low-loss inviscid flow is discussed in Ref. 2. At this time, there is no design algorithm for the viscous flow into the engine, and the problem is presently in the experimental definition stage, as was reported earlier for one configuration in Ref. 3. The purpose of the present Note is to present the results of boundary-layer shape measurements at the engine inlet (tests made with no engine on forebody) on four different forebody designs, including the one presented in Ref. 3. This information should provide a qualitative assessment of future forebody designs which are to be used as engine-inlet-precompression surfaces.

The tests were conducted in the Langley 20-in. Hypersonic Tunnel at Mach 6 and a nominal freestream Reynolds number of 30.5×10^6 m^{-1} (9.3×10^6 ft^{-1}). Boundary-layer surveys were conducted using a traversing mechanism with a pitot probe as described in Ref. 3. The four configurations tested are shown in Fig. 1. The first configuration is described in Ref. 4 and has a semiconical forebody compression surface. The second configuration has a flat compression surface similar to a slab delta wing and was previously reported in Refs. 3 and 5. The third configuration has a conical nose blended into a flat surface consistent with the inviscid design philosophy of Ref. 2. The fourth configuration has a conical, complex forebody shape[6] resulting from the blending of requirements for pilot visibility, longitudinal stability, volume requirements, and propulsion integration. Figure 2 presents a comparison of the boundary-layer height as a function of forebody compression angle for the four configurations of Fig. 1. Boundary-layer height δ, normalized by engine height h, is presented for the inlet station on the forebody centerline. Forebody compression angle, $\alpha+\epsilon$, is the sum of the angle of attack and the forebody angle at zero angle of attack. The inset on Fig. 2 links α and ϵ with estimated values of α for good altitude and engine performance match. Engine inlet stations, from the nose, for configuration numbers I, II, III, and IV are 35.59, 29.53, 40.64, and 50.98 cm, respectively. The data of Fig. 2 indicate large differences in boundary-layer height at small values of $\alpha+\epsilon$ and show a marked decrease in δ/h with an increase in $\alpha+\epsilon$ for two of the configurations.

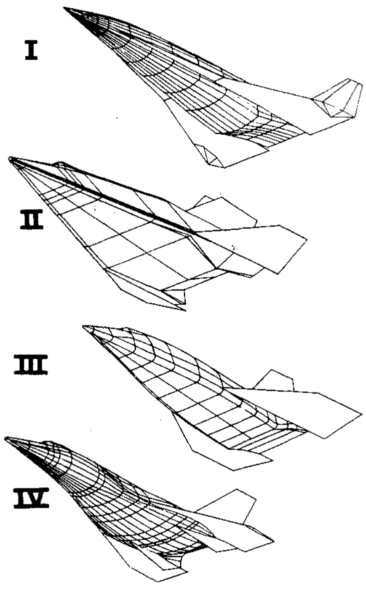

Fig. 1 Configurations used for forebody boundary-layer surveys at the engine inlet.

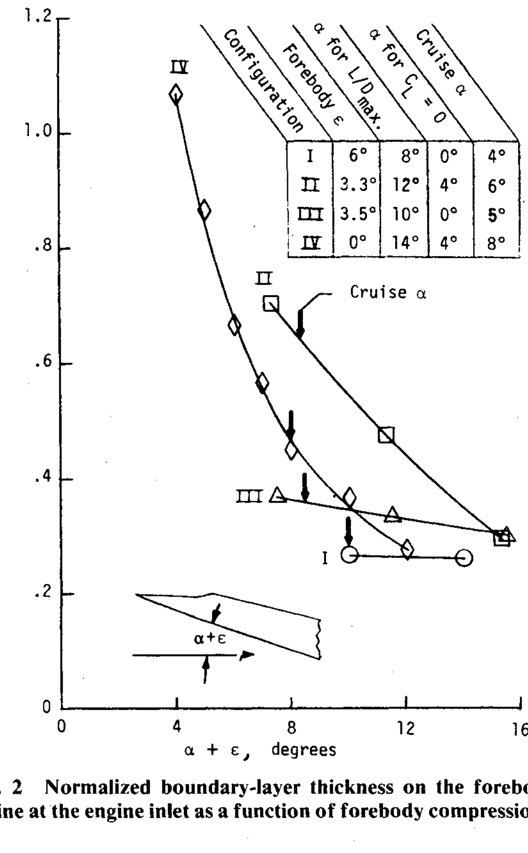

Fig. 2 Normalized boundary-layer thickness on the forebody centerline at the engine inlet as a function of forebody compression angle.

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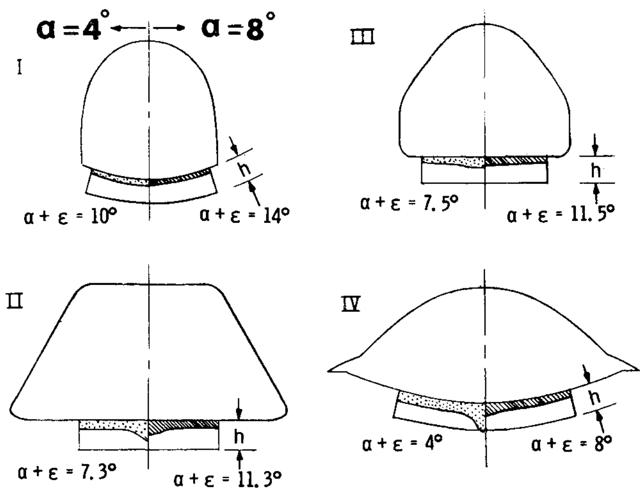

Fig. 3 Boundary-layer shapes for two angles of attack compared to scramjet engine outline of height *h*; fuselage cross sections shown are at the engine inlet station.

Figure 3 presents boundary-layer height superimposed on a vehicle cross section and engine height sketch to show the distribution of boundary-layer height with engine width as well as the portion of engine area filled by boundary layer. The data of Fig. 3 are for angles of attack of 4 deg and 8 deg, for which surveys were taken across the engine face as well as at the centerline.

From Figs. 2 and 3, the boundary layer on the forebody of configuration I is shown to be relatively thin and to change relatively little with angle of attack, based on the limited data available. Note from Fig. 1 that this forebody compression surface is both convex and isolated from the upper side of the forebody by the long strakes ahead of the delta wing. Configuration II shows somewhat thicker boundary layer with a "bump" at the center. The thickening at the center might have been expected from previous delta wing literature, but the abruptness of the bump would probably not have been anticipated. This forebody is flat and is isolated from the rest of the forebody by the blunt leading edge. That is, for this angle-of-attack range the static pressure gradient induces flow away from the leading-edge stagnation line, thus tending to prevent crossflow from the forebody sides from reaching the compression surface. The third configuration shows an intermediate boundary-layer thickness with gradual thickening at the center. Although flat at the measuring station, much of this compression surface is convex, and not isolated from the rest of the forebody. The fourth configuration exhibits a thick boundary layer and a sharp bump at the center. As seen in Fig. 1, there is isolation of the compression surface at this station, but it extends only a small way up the forebody and the compression flowfield is influenced by the crossflow from the forebody sides. At the lower angle of attack, the transverse static pressure gradient can induce crossflow from the nose-canopy region to the bottom centerline. As indicated in Fig. 2, the boundary layer rapidly thins with increasing angle of attack as the transverse pressure gradient weakens and the influx of crossflow from the forebody lee side declines.

In summary, the experimental results have been presented showing boundary-layer thickness at the engine for four forebody designs, and the boundary layers are quite different in both height and shape and fill a significant fraction of the engine inlet area. Although there is no analysis of the differences, they may be generally discussed in terms of forebody transverse curvature, overall transverse static pressure gradients, and isolation of the forebody compression flowfield from the influence of crossflow.

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