Engineering Notes

ENGINEERING NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes cannot exceed 6 manuscript pages and 3 figures; a page of text may be substituted for a figure or vice versa. After informal review by the editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Supersonic Flow about Slab Delta Wings and Wing-Body Configurations

CHONG-WEI CHU*
Northrop Corporation, Hawthorne, Calif.

THE three-dimensional characteristics algorithm presented in Ref. 1 has been applied successfully to calculate supersonic flowfields over a number of bodies under various freestream conditions. Two examples relating to spacecraft are presented here. One is the flow over a 70°-slab delta wing and the other is the flowfield about a space shuttle wing-body configuration resembling the 040A baseline orbiter. These and the many published and unpublished results[1-6] have established the algorithm and computer program as an important numerical tool, which can provide inviscid solutions for boundary-layer analysis, and can determine complete super/hypersonic flowfields as input to design of global gliders, shuttle orbiters or similar vehicles.

Slab Delta Wing

The flow over a 70°-sweep slab delta wing was calculated at Mach 9.6 and 15° angle of attack. A blunt body program and an axisymmetric characteristics method were used to provide the initial value surface. The body and the computed bow shock are shown in Fig. 1. We note that the plan view of the shock wave has a point of inflection near the last calculated station. This means that further downstream the bow shock will be nearly parallel to the leading edge and will eventually bend away from it. This phenomenon can be seen in schlieren photographs of Ref. 7.

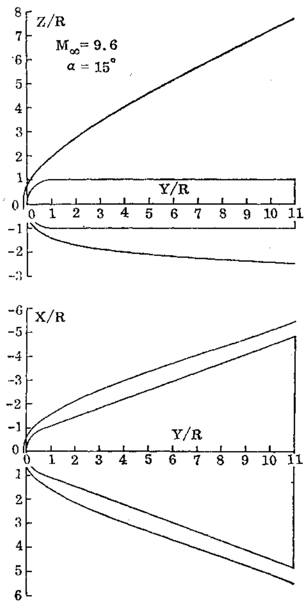

Fig. 1 Bow shock on a spherically-nosed slab delta wing with 70° sweep.

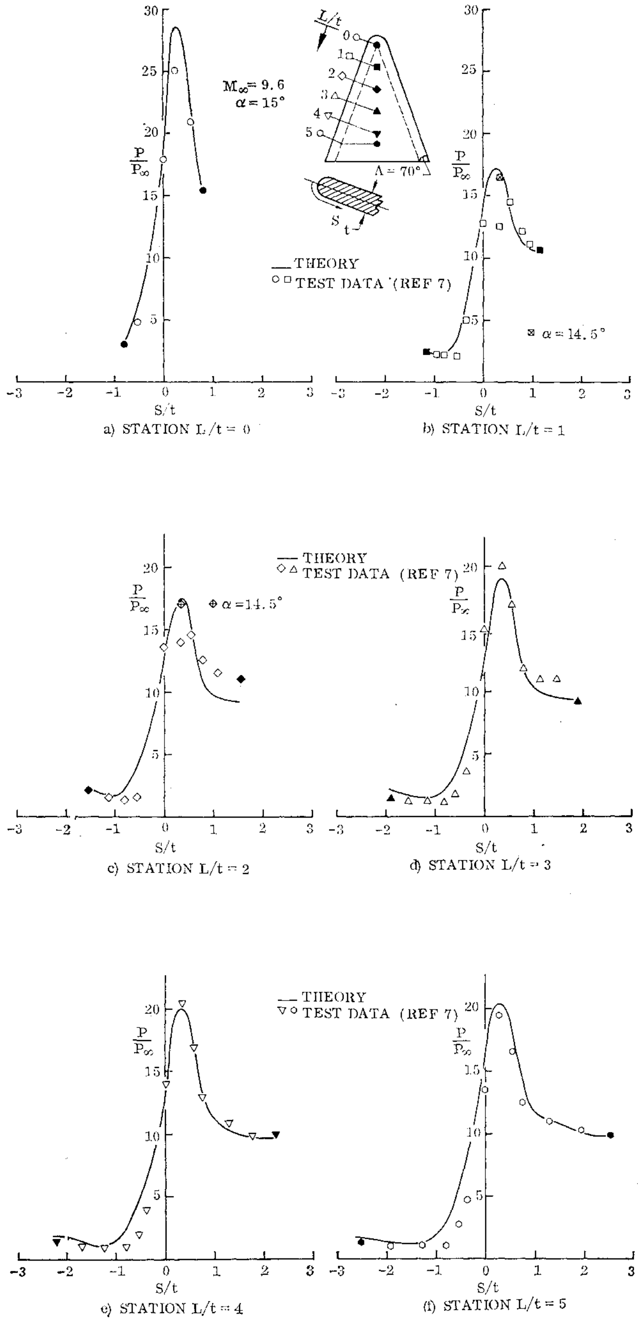

Fig. 2 Pressure distribution on a 70° sweep slab delta wing.

Received April 5, 1973; revision received July 2, 1973.
Index categories: Supersonic and Hypersonic Flow; LV/M Aerodynamics.

* Senior Scientist, Aerodynamics Research, Aircraft Division.

Figure 2 compares the computed surface pressure distributions with experimental data[7] in planes normal to the wing's leading edge. The abscissa is the ratio of the distance along the surface to the wing thickness. The positive values of S/t refer to the windward side; the negative values, the leeside. Very good agreement between theory and experiment is seen on the compression surface. A few isolated experimental data points fall below the theoretical curves; however, the counterpart data points at 14.5° angle of attack are located very close to the curves. Surprisingly good pressure agreement is obtained on the leeside of the wing (negative S/t) even though the present method does not account for vortices which exist in the real flow.

Space Shuttle Orbiter

In Ref. 2 the flowfield about a wing-body configuration resembling the 040A baseline orbiter at Mach 5 and 20° angle of attack was given. To appreciate the effects of the angle of attack and of the wing-body junction geometry, we now present the calculated flowfield about a modified configuration at 5° angle of attack. The modified configuration is very similar to the original configuration in Ref. 2 except that the latter has a more distinct wind-body juncture.

The top, front, and cross-sectional views of the modified orbiter are shown in Fig. 3 together with the computed bow shock geometry. The orbiter has a spherical nose and at Sec. C-C the wing begins to emerge from the body. The wing sweep gradually decreases until it attains a minimum of 58° at Sec. E-E, beyond which the sweep gradually increases to 90° at the tail. Unlike the kinked shock cross section† shown in Ref. 2 the present shock shape is fairly regular; its cross section remains essentially circular, as might be expected under these freestream conditions, i.e., low angle of attack and moderate Mach number for shuttle orbiters.

The pressure distribution on the surface of the orbiter is shown in Fig. 4, where the local to total freestream pressure ratio is plotted vs the spanwise distance on the plan view of the body at five different stations. On the left is the windward

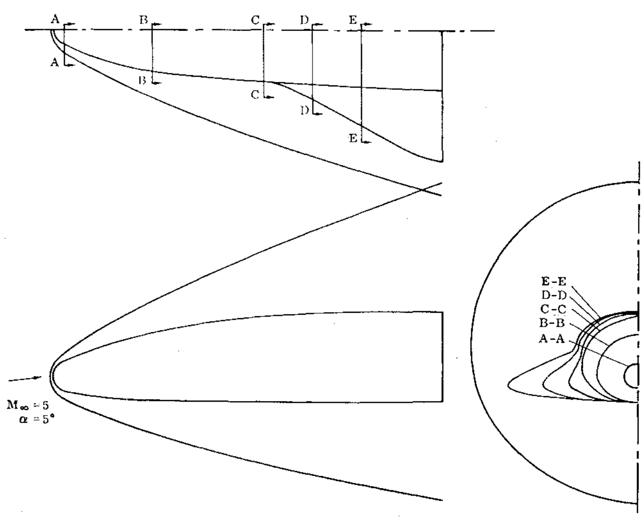

Fig. 3 Bow shock on a space shuttle orbiter.

† It is now believed that the kinked cross section was due to the interaction between the bow shock and a series of compression waves generated by the wing since at 20° angle of attack the bow shock was very close to the wing leading edge to make such interaction appreciable.

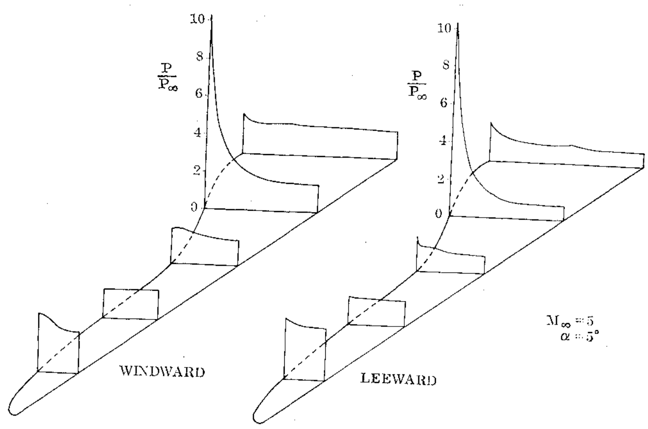

Fig. 4 Pressure distribution on a space shuttle orbiter.

pressure distribution. The widening of the body downstream of the spherical nose accounts for the pressure rise on the side at the first station shown. The pressure on the side increases as the wing emerges from the body and attains a maximum along the wing leading edge at the fourth station (Sec. E-E of Fig. 3) where the wing has a minimum sweep. Further downstream the pressure drops because of the sweep back. At each station downstream of the Sec. C-C, the maximum pressure occurs at or very close to the wing leading edge since the angle of attack is low. At higher angles of attack the maximum pressure point gradually moves to the windward side.[2] On the right of Fig. 4 is the pressure distribution on the leeward surface. Because of the low angle of attack, the pressure distribution on the leeward surface is roughly similar to that on the windward surface. However, we notice a slight pressure ridge near the wind-body juncture, as seen at the last two stations. This pressure ridge is produced when the flow, after turning around the wind leading edge, goes inboard along the wing surface and creates a series of compression waves as it hits the wing-body junction. The pressure ridge is barely noticeable since the inwash is small owing to the low angle of attack and since the fuselage merges gradually with the wing in such a way that the juncture is barely recognizable. In the case of a higher angle of attack and a more distinct wing-body juncture, a stronger embedded shock would be generated.[2]

References

[1] Chu, C.-W., "A New Algorithm for Three-Dimensional Method of Characteristics," *AIAA Journal*, Vol. 10, No. 11, Nov. 1972, pp. 1548–1550.

[2] Chu, C.-W. and Powers, S. A., "Determination of Space Shuttle Flow Field by the Three-Dimensional Method of Characteristics," TM X-2506, Feb. 1972, NASA, pp. 47–63.

[3] Chu, C.-W., "Calculation of Steady Three-Dimensional Supersonic Flow about Fuselages," NOR 70-150, March 1972, Northrop Corp., Hawthorne, Calif.

[4] Chu, C.-W. and Powers, A. A., "The Calculation of Three-Dimensional Supersonic Flows around Spherically-Capped Smooth Bodies and Wings," AFFDL-TR-72-91, Sept. 1972, Air Force Flight Dynamics Lab., Wright-Patterson Air Force Base, Ohio.

[5] Chu, C.-W., "Calculation of Three-Dimensional Supersonic Flow Fields about Aircraft Fuselages and Wings at General Angle of Attack," NOR 72-182, March, 1973, Northrop Corp., Hawthorne Calif.

[6] Chu, C.-W., "Calculation of Supersonic Flow Fields about Slab Delta Wings and Space Shuttle Wing-Body Configurations," NOR 73-007, April 1973, Northrop Corp., Hawthorne, Calif.

[7] Bertram, M. H. and Everhart, P. E., "An Experimental Study of the Pressure and Heat Transfer Distribution on a 70° Sweep Slab Delta Wing in Hypersonic Flow," TR-153, Dec. 1963, NASA.