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Technical Comments

Comment on "Measurements in the Laminar Near-Wake of Magnetically Suspended Cones at $M_\infty = 6.3$"

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THE gap at low hypersonic Mach numbers in the data on interference-free, laminar near-wakes has been well filled by the extensive survey of Blankson and Finston.[1] However, in discussing earlier work, they have not referred to preliminary measurements made using the Royal Aircraft Establishment magnetic suspension system[2,3] in 1967-8. These were mentioned by Crane in Ref. 4 and the full details form part of a thesis.[5] Subsequently, the correspondent's namesake[6] investigated more fully the extent of interference to the flow pattern resulting from probe stems, a point which Blankson and Finston did not discuss.

These measurements were made behind sharp, 10° half-angle cones at $M_\infty = 8.5$ in a blow-down tunnel, the jet having a uniform core around twice the diameter of the cone base. In addition to a flat-base cone, a model with a partially rounded base was tested, the corner being rounded to a radius of half the original base radius. The short period of time between model launch and recapture (around ½ minute) was one factor limiting the amount of data which could be obtained, also preventing data reduction to give the primary flowfield variables. Freestream stagnation pressure and temperature were 2.86 MPa and about 660K, giving a freestream Reynolds number of 312,000 based on the 50.8 mm cone base diameter. The model wall temperature (determined by thermocouples in separate tests) varied during and between tunnel runs, and also varied over the surface in a different manner for each model; values of $T/T_{0\infty}$ for the conical surface ranged from 0.57 to 0.65, while values for the base were estimated to be typically 0.09 lower than these.

Pitot tubes sufficiently large to give an acceptable response time (outer diameter $0.03D$ or larger) were mounted on a transverse wedge-plus-afterbody stem such that the probe head moved in an arc of radius $2D$ passing through the wake centerline. On the basis of the data of Zakkay and Cresci (Ref. 2 of Blankson and Finston), it was assumed that these tubes were not subject, in the region of use, to large errors from viscous effects which can occur at probe Reynolds numbers below about 150. Equilibrium hot-film temperatures were measured using conical probes; the data were adjusted to a model surface temperature of 0.60 times the freestream stagnation temperature by an approximate procedure involving repetition of a series of tunnel runs with a reversed sequence of probe positions, but the lack of an adequate range of flow conditions for calibration limited the value of these results.

Blankson and Finston's observations on the merging of the lip and wake shock waves at hypersonic M_∞, and on the location of the wake shock origin near $X/D = 0.8$, confirm the evidence of schlieren photographs in Ref. 5, from which Fig. 1 was sketched. A lip shock was not detected by the schlieren or the coarsely-spaced probe measurements, but the orientation of the shock behind the rounded base suggests a continuous lip and wake shock structure.

Some pitot pressure profiles from Ref. 5 are reproduced in Fig. 2. The estimated error in the quantity $10^3 p_p/p_{0\infty}$ is ± 0.02 for r/D less than about 0.25 and ± 0.1 elsewhere. Perpendicular traverses to check the symmetry of the flowfield were not possible, and reliance was placed on mechanical prealignment of the model with the nozzle to give a zero angle of attack. At $X/D = 1.5$, a small amount of probe stem interference was noted, causing a 2 to 3% reduction in drag (measured by electromagnet current) as the probe covered its "radial" traverse; measurements at $X/D = 1.0$ were possible with a longer probe head. Axial movement of the probe over the measuring range, with the head on the wake axis, did not cause any detectable change in drag. Schlieren photographs indicated that at $X/D = 1.5$, the probe radial position also affected the local wake shock diameter, but the axial position did not affect the shock diameter measured at $X/D = 2$. Later observations,[6] with the tip of a probe stem positioned on the axis, indicated a reduction in the diameter and a downstream movement of the wake shock source on the photographs as the stem approached the rounded-base model. Location of the shock source is somewhat subjective and the measurements showed con-

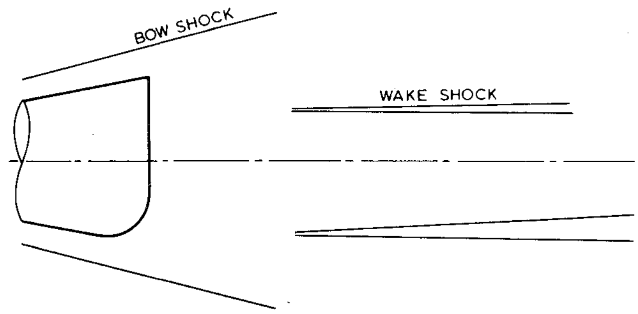

Fig. 1 Composite schematic of near-wake geometry (based on schlieren photographs).

Received Oct. 4, 1976.
Index category: Jets, Wakes, and Viscid – Inviscid Flow Interactions.

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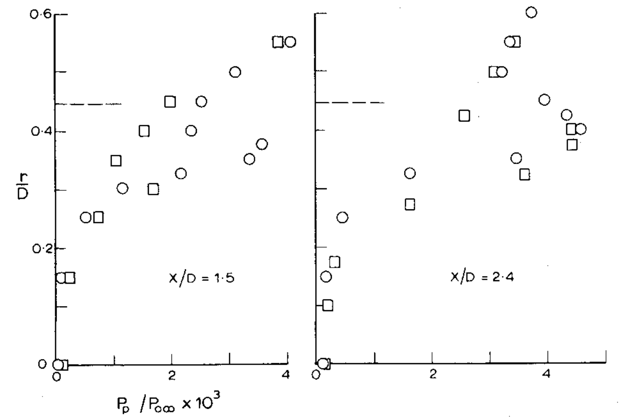

Fig. 2 Pitot pressure profiles (*D* refers to flat-base cone and – – – shows maximum radius of rounded-base cone); □ – flat base; ○ – rounded base.

siderable scatter, but they suggest that some of the advantage of magnetic suspension may be lost unless development of probe support systems includes comprehensive interference tests involving visualization and force measurements. It would be of interest to know whether any similar probe interference problems were experienced with the M.I.T. system.

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Reply by Authors to R.I. Crane

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THE authors express their appreciation to R.I. Crane for bringing our attention to his work (Refs. 1, 2) on measurements in the hypersonic cone near wake. The technical comment by Crane calls attention to the interference to the near-wake flow pattern caused by probe stems inserted into the flowfield. In particular, reference is made to our paper[3] in which measurements of pitot pressure, and the recovery temperature of a cylindrical hot film probe were made in the laminar near-wake of sharp, 7° half-angle, adiabatic wall cones, at $M_\infty = 6.32$ and at freestream Reynolds numbers (based on cone base diameter) of 62,000 to 86,000. These experiments were conducted in a continuous flow hypersonic wind tunnel. This problem of probe-flowfield interference, especially in the wake-neck region, is well-known and has been mentioned by Zakkay and Cresti,[4] and Demetriades and Bauer.[5] Discussion of probe interference was not made in Ref. 3 since this point had been discussed in previous papers.[6-7] The pitot pressure probes used in these investigations, and also in Ref. 3, were glass tubes between 0.007 and 0.013 in outer diameter supported on thin, double-wedge brass stems. The cone base diameter was 0.737 in. The rather small sizes of these probes were carefully chosen to obtain good resolution of the pressure profile at the expense of their associated slow response time. The continuous flow nature of the wind-tunnel enabled the authors to make wake traverses at correspondingly slower speeds.

The pitot pressure profiles presented in Refs. 3, 6, and 7 were obtained in two ways. Firstly, with the double-wedge stem probe support oriented in the vertical plane, the probe was passed through the wake in one direction and then back in the opposite direction. Secondly, the traverses were repeated with the probe stem oriented in the horizontal plane. This procedure was used to obtain wake traverses at axial locations from one-half to about five base diameters. Axial pitot pressure profiles were also recorded with the probe tip on the wake axis. These measurements were also repeated with different probe sizes. In these measurements, it was shown that, with the cone at zero angle of incidence, the results were almost identical (within the limits of experimental error; the uncertainty in the $p_p (p_{o\infty}$ measurement is 0.5%) leading to the conclusion that the probe stem orientation had no effect on the results. A comparison of vertical and horizontal traverses as presented in Ref. 3 is used as a test for both zero incidence and also any probe-flowfield interaction.

Finally, the current through the drag electromagnet of the magnetic suspension was used indirectly to aid the selection of the probe stem dimensions. Estimates showed that the drag force did not change by more than 1% as the probe was moved axially along the wake axis. This also serves to confirm the result that no significant proble-flowfield interference or interaction was present.

Received March 14, 1977.
Index category: Jets, Wakes, and Viscid-Inviscid Flow Interactions.
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