Supersonic Laser Velocimeter Measurements in Untreated Air

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Introduction

THE use of laser velocimetry (LV) for obtaining velocity data in supersonic flows has been previously reported.[1,2] If care is taken to insure that the seed particles accurately follow the flow, LV has the advantage over more conventional measurement techniques (e.g., hot-wire anemometry) that the data is a function only of the kinematics of the flow. Data analysis is therefore greatly simplified.

The current application of LV to supersonic flows differed from previously reported efforts in that the air used was untreated because of the mass-flow requirements. All previous tests were conducted with predried air. This Note outlines a probable explanation for the failure of previously published particle seeding techniques as well as an alternate technique for overcoming the problem for the current situation.

Discussion

The flow to be investigated is shown in Fig. 1. Testing was done along the tunnel centerline on both sides of the oblique shock. The flow was documented with conventional total and static pressure measurements as well as schlieren photographs. The perforated plate was used to minimize shock reflections.

Standard fringe mode transmitting optics were used. The 5145 Å line from an Argon-ion laser was used for incident radiation. Backscatter off-axis collection was required because of facility limitations. The photomultiplier output was processed utilizing single-realization counter processing. The data were stored digitally and analyzed statistically on a PDP-11 computer. Typically, 500 to 1000 samples were acquired for each data point. For the turbulent levels encountered in the tests, the statistical error associated with those samples sizes was one to three percent.

Initial attempts to make LV measurements utilized seeding techniques similar to those reported in Ref. 1. Diopthal Pthalate (DOP) was used in solution with alcohol, the percentage of DOP ranging from ten to ninety percent. Measurements in the $M = 1.5$ region indicated that the particles were lagging the flow velocity by as much as 100 fps (Fig. 2). The velocity data calculated from pressure data shows the velocity change across the shock to occur over a relatively large distance (about 0.5 in.). This may be attributable to the unsteadiness of the shock pattern. The large discrepencies between DOP velocities and those calculated from pressures upstream of the shock location are indicative of the inability of the DOP particles to follow the flow. Note there is some indication of the shock (a $\Delta u \pm 25$ fps change). A plausible interpretation of the DOP results can be made, referring to Fig. 1. The DOP particles accelerate through the throat but do not adjust completely to the expansion fan. As such, the apparent agreement downstream of the shock is of no significance since the particles (lagging the local gas velocity upstream of the shock) have a much smaller velocity change to adjust to crossing the shock.

Several other seeding materials were also tried: aluminum oxide, titanium dioxide, and geon plastics. Additionally, seeding was injected at several locations: in the plenum, just upstream of the throat, and just downstream of expansion fan (Fig. 1). In all cases, the particles were found to lag the local gas velocity upstream of the shock.

The proposed explanation for the failure of the technique (which had been successfully applied in supposedly similar flows) involves the humidity level in the flow. Previously reported tests (as well as preliminary tests at UTRC) were made in facilities using air predried to a dew point 50°F below ambient temperatures. The current tests were conducted at elevated temperatures (approximately 200°F total temperature) but with untreated air. Seed particles were injected into the flow with sizes (about one micron or so) adequate for tracking the gas velocities. The particles acted as nucleation sites for the moisture with the water condensing out. The resulting larger particle was too large to accurately follow the flow changes. Estimates using simple drag equations suggest that particles about five microns in size could be expected to produce the effects measured. Given the moisture content for the tests, this size is not unreasonable. While particle agglomeration would also produce larger particles, careful attention was given to the particle injection procedure and this

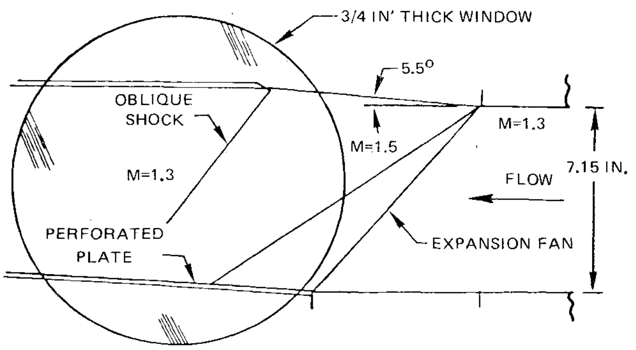

Fig. 1 Schematic of test configuration.

SYMBOL	MEASUREMENT
○, ●	PNEUMATIC DOCUMENTATION
□	LDV (TEFLON SEEDING)
△	LDV (DOP SEEDING)
◇	LDV (DOP/ALCOHOL SEEDING)

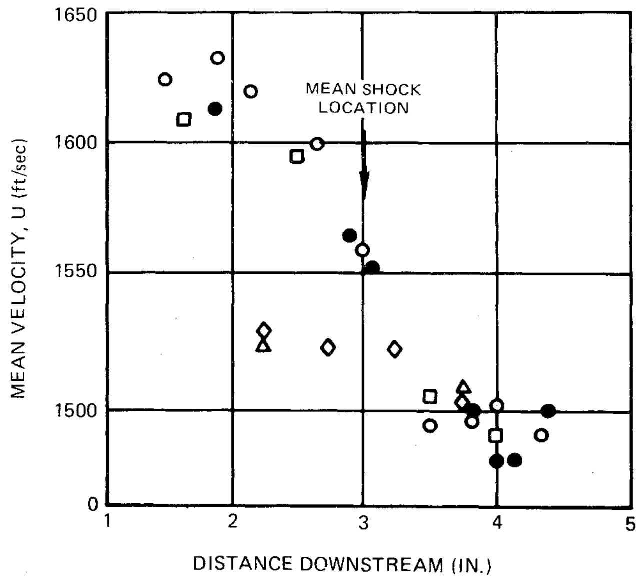

Fig. 2 Laser velocimeter measurements across an oblique shock.

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effect is not believed to contribute significantly to the problem.

To overcome the nucleation problem, a teflon powder was substituted for the DOP. Teflon was chosen because of its nonwetting property. The particles were found to be approximately one-half micron in diameter, a size sufficiently small to ensure accurate flow tracking. Particle sizes were estimated by looking at samples with an electron microscope. Particles this size were generated by grinding the much larger (20-100 μm) particles as supplied by the manufacturer. Teflon particles are typically 0.5 μm but agglomerate during packaging and shipping. The particles were injected into the plenum. The results obtained agreed with pneumatic data on both sides of the oblique shock to within two percent (Fig. 2). This agreement was well within the combined accuracies of the two measuring systems. Teflon powder therefore appears to be a suitable LV seeding material in applications where predried air cannot be provided.

References

[1]Yanta, W.J., "Measurements of Turbulence Transport Properties with a Laser Doppler Velocimeter," AIAA Paper 73-169, Washington, D.C., 1973.

[2]Johnson, D.A. and Rose, W.C., "Turbulence Measurements in a Transonic Boundary Layer and Free-Shear Layer Using Laser Velocimetry and Hot-Wire Anemometry Techniques," AIAA Paper 76-399, San Diego, Calif., 1976.

Supersonic Wave Drag for Nonplanar Singularity Distributions

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Introduction

THE wave drag for a general distribution of sources and doublets on an arbitrarily curved surface is considered. The linear differential equation of supersonic flow is assumed, with no linearized restrictions placed on the boundary conditions. An expression is derived that extends Hayes'[1] wave drag results to arbitrary curved surface doublet/source representations as are produced by recently developed panel-type computational methods.

Wave drag comprises a significant portion of the total drag in supersonic flow, and for this reason, accurate prediction methods are desirable. Hayes'[1,2] results are well known and have been accepted in general use. He examines far-field momentum considerations and, for example, arrives at a wave drag formula for a general distribution of sources without restrictions on thickness. His results showed how, for arbitrary nonlifting bodies, von Karman's[3] formula for lineal source distributions applied locally at any azimuthal station. However, in treating the effects due to lift, certain implied near-planar assumptions were made. They arose in considering the far-field momentum flux due to a distribution of horseshoe vortices, which are restricted to lie along surfaces whose generators are aligned with the streamwise axis of the governing differential equation. Recent advances in panel method computational technology (e.g., Ehlers et al.[4]) have provided methodology for completely nonplanar representation of a configuration surface by surface source and doublet distributions. These later developments also embody composite source/doublet distributions which no longer bear the classical but limiting relationships relating local source strength to local frontal area change and local vorticity strength to local lift (as an example, a fuselage can be represented entirely by a surface distribution of doublets alone, with no sources). Thus, there is a need to extend Hayes' work to handle the types of configuration representation that are made possible with the newer panel methods.

Hayes' exact result for the source problem is easily summarized. Essentially, consider sources of density $\tilde{f}(Q)$ where Q is the source coordinate. Define an equivalent density f such that

$$f(x_i;\theta)\,\mathrm{d}x_i = \iiint_{V(x_i;\,\theta)} \tilde{f}(Q)\,\mathrm{d}V \qquad (1)$$

where θ is an angle measured in a plane normal to the freestream; $V(x_i;\theta)$ is the region contained between two Mach planes $x_i = x - \beta y\cos\theta_0 - \beta z\sin\theta_0$ perpendicular to a given meridian plane $\theta = \theta_0$, and intersecting the x-axis at $x = x_i$ and $x = x_i + \mathrm{d}x_i$. Note x is aligned with the undisturbed flow at infinity, and $\beta = (M_\infty^2 - 1)^{1/2}$ where M_∞ is the freestream Mach number. Invariance arguments suggest local application of von Karman's drag formula, i.e.,

$$\mathrm{d}D_w/\mathrm{d}\theta = -\frac{\rho_\infty U_\infty^2}{8\pi^2}\int_0^\ell\int_0^\ell f'(x_1;\theta)f'(x_2;\theta)\,\log_e|x_1 - x_2|\,\mathrm{d}x_1\mathrm{d}x_2 \qquad (2)$$

where ρ_∞ is the undisturbed density, U_∞ is the speed at infinity, and ℓ is the body length. The net wave drag D_w is obtained by integration, giving

$$D_w = \int_0^{2\pi} (\mathrm{d}D_w/\mathrm{d}\theta)\,\mathrm{d}\theta \qquad (3)$$

The results mentioned previously were amended by Hayes to include the influence of elementary horseshoe vortices such as were used in the classical theory to represent lateral force components (lift and side-force). A function $\tilde{h}$ is defined, such that

$$\tilde{h} = \tilde{f} - \beta(\tilde{\ell}\sin\theta + \tilde{S}\cos\theta) \qquad (4)$$

where $\rho_\infty U_\infty^2\tilde{\ell}$ and $\rho_\infty U_\infty^2\tilde{S}$ are lift and side forces per unit volume. As before, define

$$h(x_i;\theta) = \iiint_{V(x_i;\,\theta)} \tilde{h}(Q)\,\mathrm{d}V \qquad (5)$$

Then, Eqs. (2) and (3) hold with f replaced by h. This constitutes the wave drag theory as it presently stands. It is limited to the use of elementary horseshoe vortices for lift and side-force representation, which is overly restrictive in terms of the surface modeling used with the newer panel-type computational methods.

Analysis

We consider an arbitrarily curved surface S localized in space upon which are distributed sources and doublets. The flowfield at an observation point (x,y,z) in space depends only on the singularities upstream of the intersection defined by S and the upstream Mach cone. Let the projection of this curve on the horizontal plane be C. If $z_1 = z_1(x_1,y_1)$ describes S, C is defined by the solution $x_1 = C(y_1)$ to the equation

$$(x - x_1)^2 - \beta^2(y - y_1)^2 - \beta^2[z - z_1(x_1,y_1)]^2 = 0$$

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