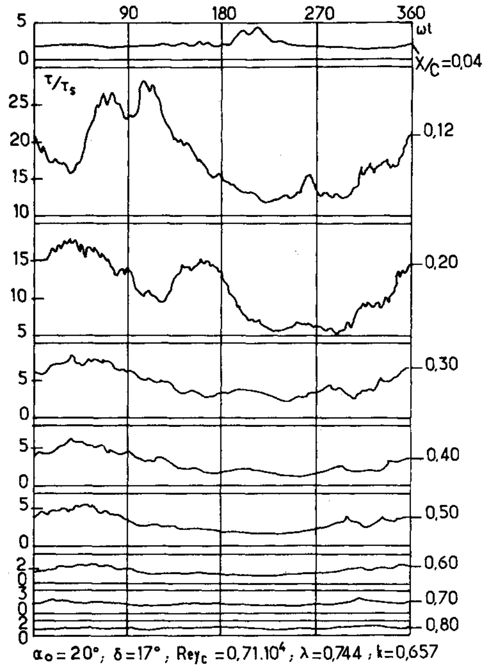

Fig. 4 Waveforms of skin friction on the upper surface.

phase of incidence and velocity. It can be concluded that such kinds of combined two-dimensional flows would bring a new contribution in modeling the basic three-dimensional rotor problem.

Acknowledgment

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Improved Free-Vortex, Subsonic Aerodynamic Window

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I. Introduction

AERODYNAMIC windows have been developed to take the place of more conventional solid windows in laser systems where the high intensity of the laser beam precludes the use of solid windows. They serve to contain the gas in the laser, maintain a desired laser cavity pressure, and optically transmit the laser beam into the outside environment. Various types of aerowindows have been developed since the introduction of the first high-energy laser, the GDL. Most of them are supersonic,[1-3] but some are subsonic, such as the free-vortex window developed for use with atmospheric lasers.

It has been observed that in this type of subsonic aerowindow, significant optical distortions are caused by the large-scale turbulent mixing that takes place in the shear layer at the jet boundary with the ambient. The reason for this observation is as follows. The window jet is optically matched to the laser gas; thus, the index of refraction of the window jet differs, sometimes significantly, from the index of air. As a result, a "marble cake" effect takes place in the shear layer. Ambient air and jet gas mix together in this flow region, giving rise to large-scale index variations that cause the observed optical distortions.

Sutton[4] has shown that the phase aberration produced by turbulent refractive index changes is given by:

$$\frac{\Delta I}{I_0} = \frac{I_0 - I}{I_0} = 2\left(\frac{2\Pi}{\lambda}\right)^2 \overline{\langle \Delta n \rangle^2 \Lambda \delta}$$

where I_0 is the nondegraded laser radiation intensity, I the interface degraded intensity, $\overline{\langle \Delta n \rangle^2}$ the square of rms refractive index variations, and λ the laser wavelength. From this relation we see that the width of the turbulent interface δ and the value of the typical turbulence scale size Λ have a pronounced effect on laser beam degradation. We also know that in turbulent shear layers, Λ is proportional to δ. Thus, by reducing the width of the refractive index shear zone, reduction in the phase aberration can be achieved.

In the present study we demonstrated a novel approach for reducing the optical distortions caused by index fluctuations in the subsonic free-vortex aerowindow flow. The scheme is based on eliminating the index of refraction discontinuity at the intensely sheared free-mixing layer, and taking it at a location where the two gases are made to flow in parallel with similar or identical velocities, thus reducing the width of the index discontinuity and the associated turbulence scale size. As a result, the optical quality of the flow is significantly improved and laser beam intensity losses reduced.

II. Experiments and Results

Experiments were carried out on an improved free-vortex subsonic aerodynamic window depicted in Fig. 1. A compact inlet divided into two chambers by a splitter plate serves to generate the two parallel flowing jets of the aerowindow. These traverse the laser exit and exhaust through a diffuser into the atmosphere. Each jet is supplied with gas from a

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Index categories: Jets, Wakes, and Viscid-Inviscid Flow Interactions; Subsonic Flow; Lasers.

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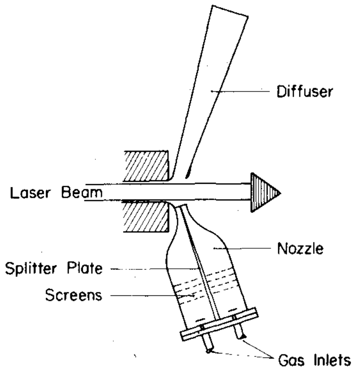

Fig. 1 Schematic diagram of the free-vortex aerowindow.

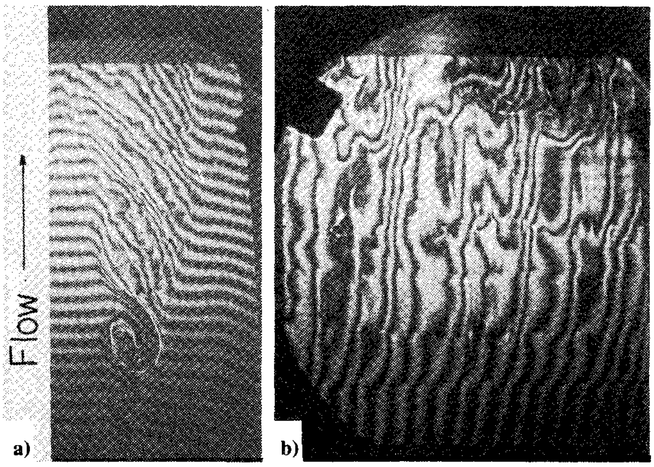

Fig. 2 Interferograms of the conventional free-vortex subsonic aerowindow flow: a) view of the turbulent interface; b) view through the turbulent interface.

high-pressure gas storage reservoir, the inner jet with a gas mixture of Ar:He:N_2 in the ratio 5:4:1 ($\beta = 2\times10^{-4}$) matched to the index of the CO_2 laser, and the outer jet with nitrogen ($\beta = 3\times10^{-4}$). The gas is introduced into each chamber through sonic orifices located at the bottom of the outlet. Splash plates disperse the orifice flow, and a series of four screens located downstream serve to smooth out the flow in the inlet before the jets emerge from the nozzle.

Diagnostics in this study consisted of a hot-wire anemometer utilized for flowfield surveys, and a Mach-Zender interferometer used to study the optical medium homogeneity of the aerowindow flow.

Interferograms of the free-vortex aerowindow operating in a conventional mode with both jets discharging the aerowindow gas mixture (5:4:1), where the index of refraction discontinuity occurs at the turbulent free-shear layer, are shown in Fig. 2. Figure 2a reveals the characteristics of the mixing zone by "looking" with the interferometer parallel to the turbulent interface, and Fig. 2b shows an interferogram "looking" through the turbulent interface. In the former, we notice the vortical structure close to the jet exit which disintegrates further downstream along the mixing zone. Figure 2b shows the large optical distortions introduced into the flow by the large index fluctuations at the free-shear layer. The fringe structure in this picture also reveals the vortical structure of the shear layer and the node points.

The significant reduction in the optical distortions achieved in the flow of the improved aerowindow is reflected in the interferogram shown in Fig. 3. Here the aerowindow gas mixture flows from the inner jet, and nitrogen flows from the outer jet. The index of refraction discontinuity is taken at a region where the two gases flow in parallel with identical velocity. Comparison with the no-flow reference in-

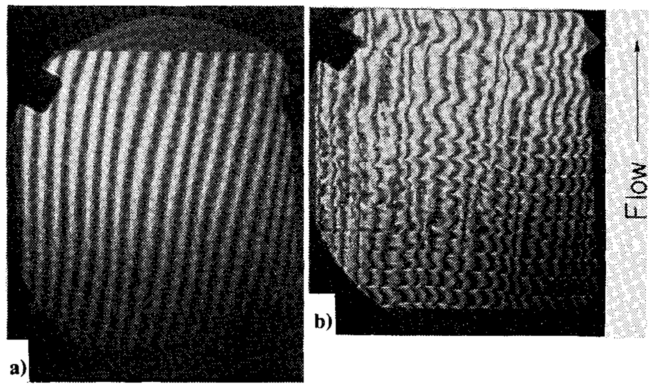

Fig. 3 Interferogram of the improved aerowindow flow: a) no flow; b) with flow.

terferogram shows that the fringes in Fig. 3 maintain the same structure with minimal large-scale distortions, indicating the high optical quality of the flow. The small-scale wake turbulence is reflected in the small wriggles superimposed on the fringes.

Beam-direction interferograms, such as Figs. 2b and 3, were analyzed following the procedure outlined in Ref. 5. The results of this data analysis show the significant reduction in laser beam intensity losses in the improved aerowindow, with

$$\Delta I/I_o = 0.03$$

compared with 0.10 for the conventional-type aerowindow.

Acknowledgment

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Effect of Suction on a Shock-Separated Boundary Layer—A Numerical Study

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I. Introduction

THE performance of many aerodynamic components at transonic and supersonic flight conditions is adversely affected by the interaction of external shocks with the boundary layer. If the shock wave is sufficiently strong, the

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