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Simple Method of Supersonic Flow Visualization Using Smoke

L. S. Miller* and E. Irani†
Wichita State University, Wichita, Kansas 67208

Introduction

DIRECT smoke injection is a common and popular means for studying aerodynamic phenomena in wind tunnels. A number of smoke flow-visualization techniques currently exist and are used depending on the desired test information, available facilities, available smoke-generation apparatus, and test flow speeds.

Smoke visualization may be conducted in virtually any type wind tunnel. However, a good visualization tunnel will typically utilize a large contraction ratio inlet and inlet face screens and honeycomb to improve flow stability, reduce turbulence scales and flow angularity. These features reduce the likelihood that the injected smoke will dissipate before important model aerodynamic features can be observed.

A number of different smoke-generation techniques are available, each varying in capability and complexity. An overview of methods is provided by Mueller.[1] A common approach involves heating a glycol solution to produce a smoke-like vapor cloud, which is pumped to a rake assembly positioned at the wind-tunnel inlet. About 1-20 smoke filaments can be introduced into a flow in this fashion. This visualization method works well over a range of test speeds and has been demonstrated at supersonic speeds.[2] Although popular and successful, this technique has some disadvantages. The generator and rake assemblies are relatively complicated to build and must be carefully maintained to insure proper operation. In addition, a greater number of smoke filaments may be desirable to improve flow-feature visibility.

The smoke wire method overcomes some smoke-rake problems and has provided spectacular images at low flow speeds. The technique relies on a small 0.025–0.125 mm diam wire for smoke filament generation.[3] The wire, positioned in the wind-tunnel test section upstream of the model, is coated by an oil film and heated for a short period of time electrically. Heating causes the oil to vaporize, generating a large number of smoke filaments (typically 5–10 per cm). It is the method's simplicity and the large number of fine filaments generated which are particularly attractive. Unfortunately, at wire Reynolds numbers above 40, an unsteady wake develops which dissipates the smoke filaments and reduces visualization quality.[3] This Reynolds-number constraint limits tunnel test section speeds typically to less than 10 m/s. In addition, since the wire diameter is small, the amount of smoke produced and the generation duration are limited. This problem can place special demands on the experimentalist for photography.

Alternative Method

A modified smoke wire visualization method for application in high-speed and supersonic flows has been developed which produces a large number of fine smoke filaments that do not dissipate. The principal difference between the new technique and the low-Reynolds-number method discussed earlier is related to the diameter and placement of the smoke-generation wire. The wire diameter has been notably increased and it is now positioned at the wind-tunnel inlet face, instead of inside the test section. Higher test section flow speeds, with excellent visualization, are achieved since the inlet-wire Reynolds number is smaller than the corresponding test section value. Also, interestingly, a greater Reynolds number can be tolerated since the inlet contraction, screens, and honeycomb damp out or reduce unsteady smoke flow from the wire and preserve smoke-filament quality during transit to the test section. In addition, the large-diameter wire is capable of holding more oil and can thus produce smoke for a longer period of time.

Facility, Apparatus, and Procedure

A 0.1 × 0.1-m vacuum induction-type wind tunnel, operating at Mach 2 flow speed, was used for method development and demonstration. Ten layers of common window screen and a single layer of 5-mm cell honeycomb are installed on the tunnel inlet, which has an area contraction ratio of 100:1. A 1.5-mm-diam stainless-steel tube installed vertically, approximately 15 mm upstream from the tunnel inlet, was used to generate smoke (see Fig. 1). By using a tube, as opposed to a solid wire, less current is required for a necessary amount of heating. The wire was kept in tension during runs by a spring to assure that bending due to thermal expansion would not occur.

Glycol or model-train smoke oil, applied with an eye dropper, was used as a fuel for smoke generation. "Life-Like Train Smoke" oil and about 10 amperes of current was found to generate the best quality and longest duration smoke filaments. Around 5–10 smoke filaments per centimeter are produced for 2–4 s.

A conventional 35-mm camera and black-and-white film were utilized to record the visualization results. A motor drive and remote shutter release were fitted to the camera to allow ease of operation and rapid photography as desired. A range of film speeds was examined for use, but 400 ASA film was primarily employed.

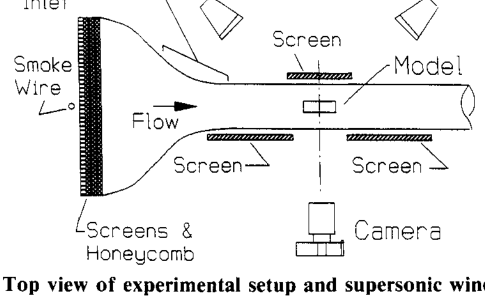

Fig. 1 Top view of experimental setup and supersonic wind tunnel.

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*Assistant Professor, Department of Aerospace Engineering. Member AIAA.

†Research Assistant, Department of Aerospace Engineering. Member AIAA.

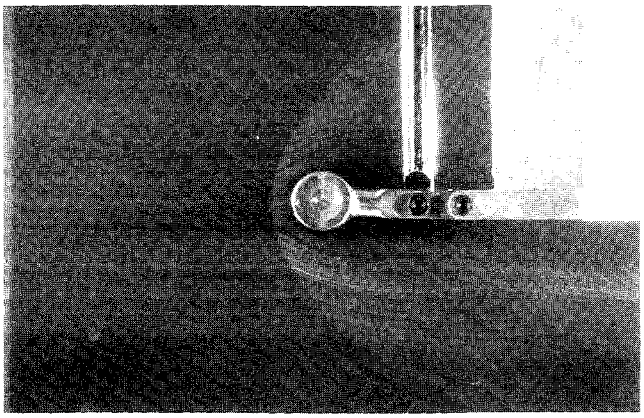

Fig. 2 Double-wedge airfoil at Mach 2.

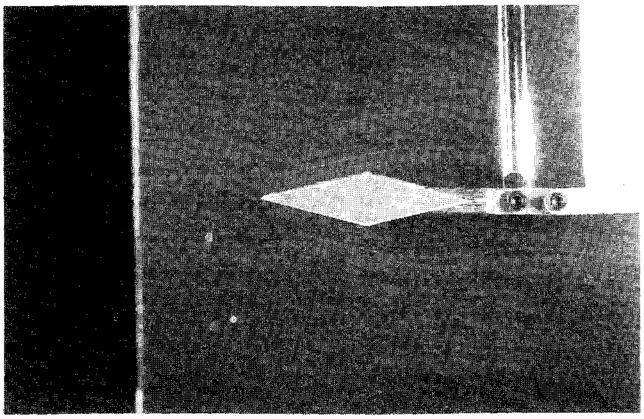

Fig. 3 Circular cylinder at Mach 2.

Two flash units were used to illuminate the smoke flow during tests. Each unit was positioned on the opposite side of the test section from the camera, approximately 60 deg off axis from the viewing direction. This orientation takes advantage of the good light-scattering character of smoke particles in the forward direction. The wind-tunnel window immediately opposite the model was painted black to provide a high-contrast image background. The tunnel windows, on the camera side, upstream and downstream of the model were also painted black to prevent direct viewing of the flash units by the camera. To minimize flash duration and to assure that the smoke motion was "frozen" during photography, each unit's power output was set at the lowest level. This power setting also results in a shorter recharge time allowing rapid photography at rates up to 3 frames/s.

Conducting flow-visualization experiments using this new method is relatively simple. Oil is dripped along the smoke-generation wire, current is applied, and then the tunnel is turned on. Once smoke filaments are produced the camera is activated taking typically 3–5 photographs. A minimal amount of synchronization between each step is necessary since the smoke-generation time is quite reasonable.

Results

The flowfield about a number of models was examined using the new smoke-visualization technique. For reasons of brevity, only the results for two models will be discussed. Each model was installed on a sting mount that was supported by a fairing and a strut allowing angle-of-attack adjustments.

Figures 2 and 3 show the smoke flow about a double-wedge airfoil and a circular cylinder, respectively. The flow is moving from left to right about the models, which have a maximum thickness of 1.12 cm and a span of 5.08 cm. As can be seen, there are a large number of approaching smoke filaments and the spacing is nearly uniform. The oblique shock extending from the airfoil leading edge and the detached shock in front of the cylinder are clearly indicated by abrupt bending of the smoke filaments. Expansion regions, around the models, are indicated by slowly bending or curving filaments. A shock wave produced by the angle-of-attack strut is observed in the area above and behind each model. It is important to emphasize that these images were obtained using only smoke; no schlieren or shadowgraph techniques were employed. The presence of shock waves and expansion regions is indicated strictly by changes in smoke-particle paths.

Smoke filament behavior in expansion regions, next to the models, was difficult to identify under some circumstances. One potential reason for this is that the smoke density is simply reduced as a result of the expansion, making filament visibility difficult. Another possible explanation could be related to the smoke particles' ability to "follow the flow" as affected by aerodynamic and inertial forces. No attempt was made, in this investigation, to assess possible particle inertial effects. The exact particle size and mass distributions are not known and were not measured. Despite this question, the visual quality and usefulness of the results seem worthy of value.

Conclusions

A number of conclusions are offered relative to the new smoke-visualization method developed.

1) The new visualization technique is very simple to implement on open-inlet induction type supersonic wind tunnels and has been demonstrated to be extremely effective. The smoke-generation and photography equipment employed is simple, inexpensive, and commonly available.

2) A large number of uniformly distributed and stable smoke filaments are produced. Shock waves and expansion regions are clearly identified by the smoke filament behavior.

3) The visualization accuracy may be affected by particle inertia effects. No attempt to address this possibility was undertaken.

4) Potential applications of this new smoke-generation technique to induction type wind tunnels operating at lower speeds exist.

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Importance of Fresh Air in Manometer Tubing

John M. Cimbala,* Richard S. Meyer,† and Todd B. Harman‡

Pennsylvania State University, University Park, Pennsylvania 16802

Introduction

IT has been found that poor quality air inside manometer tubing can lead to significant errors when measuring very

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*Associate Professor, Department of Mechanical Engineering. Member AIAA.

†Research Assistant, Applied Research Laboratory, Department of Mechanical Engineering.

‡Graduate Assistant, Department of Mechanical Engineering. Member AIAA.