Subsonic Flow Visualization Using Steam

C. J. Prentice* and F. X. Hurley†
McDonnell Douglas Corporation, St. Louis, Mo.

THERE exists a variety of streamline tracing techniques for flowfield study in the low subsonic speed regime.[1] At moderately fast subsonic speeds (i.e., over 200 fps), it is rather difficult to produce a sufficiently dense "smoke," although certain oil vapor generators have achieved this capability.[2] The purpose of this Note is to draw attention to a simple method of streamline tracing above 200 fps which does not require any special chemicals or mechanical or heating equipment.

A standard method of supersonic flow visualization is the vapor screen technique[3] wherein the working gas is moistened at some point upstream. Upon isentropic expansion through the supersonic nozzle, the gas experiences a temperature drop, and it surrenders some of its moisture as a fog of water droplets which when properly illuminated reveals the details of the flow. It seems reasonable that the same principle should work in a subsonic tunnel if steam accompanied by a cooling agent from an external source is introduced into the flowfield. Preliminary tests discussed below have shown that a mixture of steam and cold nitrogen gas produces a streamline-tracing fog which is persistently visible.

Saturated steam was tapped from the building supply line at a nominal gage pressure of 25 lb/in^2. The source of nitrogen gas was a standard 110 l liquid nitrogen Dewar at 23 lb/in.^{2} gage. Fifteen-foot lengths of $\frac{1}{2}$-in. hydraulic hose and $\frac{1}{4}$-in. copper tubing carried, respectively, the steam and the nitrogen into the tunnel where they were allowed to mix annularly at a point 1-ft upstream of the model being tested.

Uncalibrated valves at both the steam and nitrogen sources were used to control the mass flows of each component. The "best" valve settings depend in a complex manner on tunnel speed and test setup, but it was not difficult to achieve the preferred balance through trial and error adjustment during the run. Also it is noted that several minutes were required for the steam hose to reach a sufficiently high temperature so that the steam was not condensed before reaching the test section.

Figure 1 illustrates stream tube marking by the steam plus nitrogen mixture in the McDonnell Low Speed Wind Tunnel at a flow velocity of 250 fps. The high aspect ratio airfoil model has a chord of 9 in. The flow visualization effect was improving somewhat with speed at this point for the relative spreading of the fog lessens with speed. The photograph presents the effect as it was seen by observers during the event; normal tunnel lighting was used, and no special film or time exposure was employed.

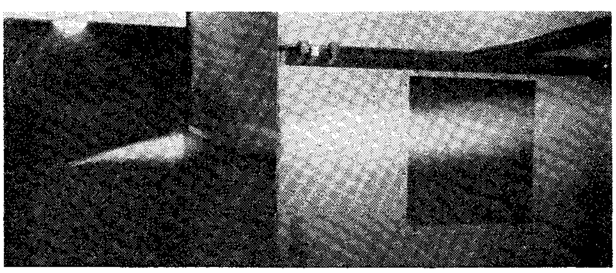

Fig. 1 Fog produced by a mixture of steam and cold nitrogen gas in a 250-fps airflow over a 9-in. chord airfoil model.

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* Senior Engineer, Gas Dynamics Laboratory, McDonnell Aircraft Company.

† Research Scientist, Fluid Mechanics Group, McDonnell Douglas Research Laboratories. Member AIAA.

References

[1] Maltby, R. L. and Keating, R. F. A., "Smoke Techniques for Use in Low Speed Wind Tunnels," AGARDograph 70, Pt. III, April 1962, NATO.

[2] Sellberg, L. D., "Smoke Generator Type Lorinder for Flow Visualization in Low Speed Wind Tunnels," KTH-AERO-TN-55, June 1966, (Swedish) Royal Institute of Technology.

[3] McGregor, I., "Development of the Vapor Screen Method of Flow Visualization in a Three-Foot Supersonic Wind Tunnel," AGARDograph 70, Pt. IV, April 1962, NATO.

Test Section for a V/STOL Wind Tunnel

Ching-Fang Lo*
ARO Inc., Arnold Air Force Station, Tenn.

Introduction

IT has been recognized[1] that a wind tunnel with ventilated walls offers promise as a configuration for V/STOL testing in an acceptable environment. Among some previous investigations, Wright[2] suggests a test section with a solid upper wall, slotted vertical walls, and an open lower boundary for small interference. The drawback of the open lower boundary is that it may introduce oscillations of the test section flow; however, these oscillations could be removed by replacing the open lower boundary with a many slotted boundary as suggested in Ref. 2. A closed-on-bottom-only configuration with a selected height-to-width ratio for each wake angle is suggested by Heyson[3] but poses many related practical problems in designing the wind tunnel.

A test section having solid vertical and slotted horizontal walls with equal porosity has been studied by the author.[4] The value of slot opening which results in zero interference has been found as a function of model wake angle. However, since the proper value of slot opening is a function of wake angle, it seems that one more variable is needed to achieve a configuration yielding zero upwash interference for all wake angles. Hence, a test section with solid vertical walls and different porosities for the top and bottom walls has been chosen for the present study. This did result in a configuration which gives nearly zero interference at the model position for every wake angle. The interference distributions along the streamwise and spanwise directions were determined for this selected configuration.

Analysis

The field equation of an inviscid, irrotational fluid for incompressible flow in terms of the perturbation velocity potential φ in Cartesian coordinates (Fig. 1) is

$$(\partial^2\varphi/\partial x^2) + (\partial^2\varphi/\partial y^2) + (\partial^2\varphi/\partial z^2) = 0 \qquad (1)$$

The boundary conditions for a tunnel consisting of solid vertical walls and slotted horizontal walls with different

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* Research Engineer, Propulsion Wind Tunnel Facility. Member AIAA.