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A Compact Mini Smoke Wind Tunnel*

C. Y. LIU†
School of Mechanical & Production Engineering, Nanyang Technological Institute, Nanyang Avenue, Singapore 2263, Republic of Singapore

A compact mini smoke wind tunnel of overall length 0.6 m was designed and constructed. The total weight of the tunnel was 4 kg. The magnetic model fixture and the convenient oil application mechanism made it a perfect teaching aid for the subject of fluid mechanics. The small size and light weight allows the tunnel to be carried by one hand to classrooms for demonstrations. Reasonable quality photographs were also presented to demonstrate the capability of the tunnel.

INTRODUCTION

SINCE the early days of fluid mechanics research flow visualization by smoke has played an important role in the advancement of our physical understanding of fluid motion. The utmost development of this technique is the smoke tunnel, where smoke is introduced into a uniform stream of air with a low turbulence level in the form of thin smoke filaments. These filaments mark the streamlines around the model being tested. The smoke tunnel is a well known tool for industrial and academic research as well as teaching fluid mechanics [1]. There are many types of smoke tunnel; most have a rectangular test section of narrow width, especially those used for teaching purposes. This type of smoke tunnel can only be used to demonstrate two-dimensional flow. Smoke tunnels designed for teaching are of medium or small size. However, even the small ones are not easily transportable by one person. For this reason, Liu and Ng [2] developed a miniature size and lightweight smoke wind tunnel with automatic smoke wire fuelling mechanism. This tunnel has been used effectively as a teaching aid for 3rd year students for the subject of Thermo-fluids in our school. However, after the first experience, it was realized that it was possible to make the tunnel even smaller, lighter and more compact.

This paper describes the design and construction of the new mini smoke tunnel which can be carried easily by one hand from one place to another to demonstrate the flow patterns around two-dimensional and three-dimensional models. The new design has an overall length of 0.6 m and a cross-section of 0.09 m × 0.09 m. It is driven by a low power a.c. motor with variable speed controller. The speed of flow can be adjusted from approximately 0.4 to 1.7 m/s.

Five smoke wires are mounted upstream of the test section. A manually operated oil application mechanism was also designed and tested. The operation can be done easily by pushing a handle back and forth once. For each operation of this mechanism, five demonstrations can be conducted. The tunnel incorporates an internal light source to illuminate the test section for better observation of the streamlines. It was not easy to arrange external light sources for photographing such a small test section. However, photographs were taken to demonstrate the capability of the tunnel.

THE SMOKE WIND TUNNEL

The layout of the tunnel is shown in Fig. 1. The air flow passage is similar to the tunnel presented by Liu and Ng [2], except that the present tunnel has much smaller dimensions. It consists of three sections, namely the entrance section, the test section and the fan section. All sections have an internal dimension of 0.09 m × 0.09 m. Similar to the tunnel presented by Liu and Ng [2], the entrance section consists of an inlet mouth followed by a honeycomb and three fine meshes of 50 holes/cm. The honeycomb was made of plastic drinking straws with a length to diameter ratio of 10. On top of the entrance section there is a small compartment which houses the automatic control push-button unit and a space to house the guide rail of the oil application mechanism. At 100 mm downstream of the last wire mesh, there are five smoke wires installed in parallel near the inlet of the test section. The middle smoke wire is mounted

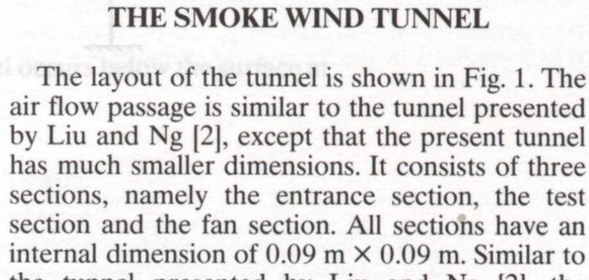

Fig. 1. The portable smoke tunnel.

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† C. Y. Liu is Professor.

exactly in the centre of the test section and the distance between adjacent wires is 5 mm. When the Reynolds number is less than 40, there will be no shedding vortex behind the smoke wires [3]. The disturbance due to the wake of the wires will be small. The maximum Reynolds number, based on the diameter of the wire is far less than 40. Therefore there is no interference. On top of each wire there is a small spring to preload the wire and to prevent distortion during heating. The five springs are mounted on a common fixture above the test section inside the compartment. The oil application method and the detail of the mechanism will be discussed in the next section.

There is no contraction section before the test section in the present design. It was proved by Liu and Ng [2] that the honeycomb and three fine wire meshes could produce a reasonable flow quality for low speed visualization. The length of the test section is about 0.3 m. At 30 mm downstream of the smoke wires, there is a magnetic model fixture mechanism. It is a circular magnet 15 mm diameter and 3 mm thick. Since the inside of the test section must be smooth, the mounting of the magnet was made flush to the inner surface of the test section by cutting a hole 3 mm deep on the back surface of the tunnel. At the centre of this hole a small hole of 5 mm was drilled across the remaining part of the surface to provide a passage for a rod connected to the magnet to pass through. A handle was used to fix the rod outside the test section to ensure a good contact between the magnet and the bottom surface of the hole in order to prevent leaking. The handle was used to change the angle of attack of the model being tested. This arrangement provided a convenient and fast method for changing the models during demonstration. The angle of attack of the model could be altered from outside the tunnel by turning the handle connected to the magnet. At one end of the two-dimensional models, there is a metal piece used to connect the model and the magnet. The model can be fixed easily. In front of the test section, a door is mounted for convenient model changing and refilling the reservoir of the oil application mechanism. At the edge of the door, opposite the hinge side, a thin magnetic strip prevents leakage through the door.

In the fan and motor section, a honeycomb was also installed to reduce the swirl motion transmitted from the fan to the test section. The axial flow fan is a standard square-shaped cooling fan driven by an a.c. motor. The maximum speed of the fan is 2700 rpm and the power consumption 9 W. A variable speed controller varies the flow velocity in the test section. The air velocity can be varied from approximately 0.4 m/s to 1.7 m/s. The air velocity is measured by a bi-directional probe in conjunction with a twin-wire resistance probe water manometer [4].

On top of the fan and motor section, there is also a small compartment to house the speed controller, d.c. power supply, the power cable and plug, and to provide a surface for mounting the on-off switch. In between the left hand and right hand compartments, a shorter compartment houses a fluorescent lamp for illuminating the test section. Illumination is necessary for visualization of the smoke lines. The two sides and the upper surfaces of the light cover are opaque. Light can only illuminate the test section downward and cannot penetrate through the front surface to glare the observers. A hollow tube is mounted above the light housing to bridge the left and right compartments. It serves two purposes; to carry the wire from the power supply to the smoke wire control knob and to be used as a handle, so that the operator can carry the tunnel by one hand, just like a brief case.

THE SMOKE GENERATION MECHANISM

The smoke generation mechanism consists of a d.c. power supply, five smoke wires, oil application mechanism, and a remote control push-button unit. The 24 V d.c. power supply has a dimension of 120 mm × 80 mm × 30 mm. It can provide a maximum current of 0.5 amp which is sufficient to heat the smoke wires one by one and to produce clear smoke lines. Stainless steel wire of 0.1 mm diameter is used for the smoke wires. An oil application mechanism was designed and constructed to simplify the troublesome and tedious steps in conducting flow visualization by smoke wire technique. The usual method means repeatedly opening and closing the door of the tunnel to apply oil to the surface of the wire for each observation [3]. The present system consists of a small oil reservoir and a horizontal guide rail, as shown in Fig. 2. The outside dimension of the reservoir is 25 mm × 15 mm × 5 mm. It is made of plastic sheet 1.5 mm thick. All the five smoke wires pass through the reservoir through the five holes on the bottom. A small cotton piece inside the reservoir contacts the smoke wires. The cotton piece can absorb a few drops of oil. However, it was realized

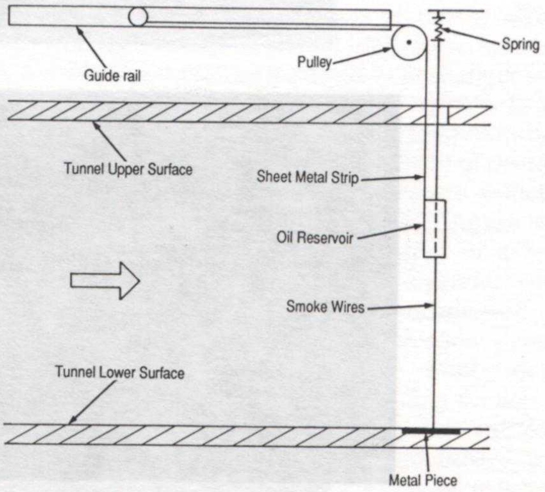


Fig. 2. The oil application mechanism.

that a few drops of oil could last for 20 operations. Since there are five smoke wires, moving the reservoir up and down once is sufficient for five demonstrations. Thus one hundred observations can be conducted before the reservoir needs to be refilled. This number is sufficient for each demonstration in a classroom. Kerosene is used as the liquid to generate smoke. After the oil coats the surface of the wires, fine droplets are formed and roughly uniformly distributed on the surface of the wires. The number of droplets per unit of length depends upon the diameter of the wire, the viscosity, surface tension and the vapour pressure and saturation temperature of the oil.

The reservoir is connected to the horizontal guide mounted on the compartment on top of the inlet section by a flexible metal strip. The strip is a piece of measuring tape of 15 mm width. By moving the handle in the guide rail, the reservoir can be moved up and down. Thus oil is applied to the surface of the smoke wires. There is an opening on the supper surface of the tunnel above the smoke wires. After the oil is applied the reservoir rests inside this opening to seal the gap by moving the handle to the utmost left end.

A push-button is connected in series with each smoke wire. Heating the smoke wires is controlled by a hand held push-button set. A variable resistor is also connected in series with the push-button and the smoke wire. The duration and the intensity of the smoke lines can be adjusted by adjusting the variable resistor.

APPLICATIONS

The advantages of the constant square shaped section throughout the length of the tunnel are two fold; firstly, there is no contraction section upstream of the test section. This reduces the length and cost of the tunnel. Secondly, both two-dimensional and three-dimensional models can be mounted in the test section. Its small size and light weight allow the teaching staff to carry it by one hand and the demonstrations can be conducted at the laboratory, in the classroom and even in the office of the staff.

Two-dimensional flow models, such as flow around cylinders and aerofoil sections can be mounted on the magnetic model fixture. Flow patterns around cylinders of any shape and Karman vortex Street can be seen clearly. Aerofoil sections can also be used to demonstrate the separation phenomenon when the angle of attack is large. Photographic results can be produced similar to those presented by Liu and Ng [2].

The advantage of the square-shaped test section is that it can be used to test three-dimensional models such as the wing-body combination model, tip vortex near a finite wing model, body of revolution model and delta wing model. Figure 3 shows the curved streamlines near the nose of a projectile model at angle of attack of approximately 30°. Figure 4 shows the streamline patterns around a delta wing at different distances from the centre of the wing. Figures 4(a) and 4(b) are the streamlines located 10 mm and 5 mm from the centre on the right hand side of the wing. Counter clockwise vortex sheets can be observed. Figure 4(c) is the streamline pattern near the centre of the wing; there are two vortex cores on the upper surface. Similar to Fig. 4(b) and 4(a), Fig. 4(d) and 4(e) are the streamline patterns on the left hand side of the delta wing. Clockwise vortex sheets can be seen clearly. Other models such as land vehicles and wing-body combinations can also be tested.

CONCLUSIONS

A small, lightweight and compact smoke wind tunnel with a convenient oil application mechanism was demonstrated to be an effective teaching aid for the subject of fluid mechanics. Both two-dimensional and three-dimensional models can be tested in this tunnel. The small size and light weight make it possible to be carried by one hand to a classroom for demonstration.

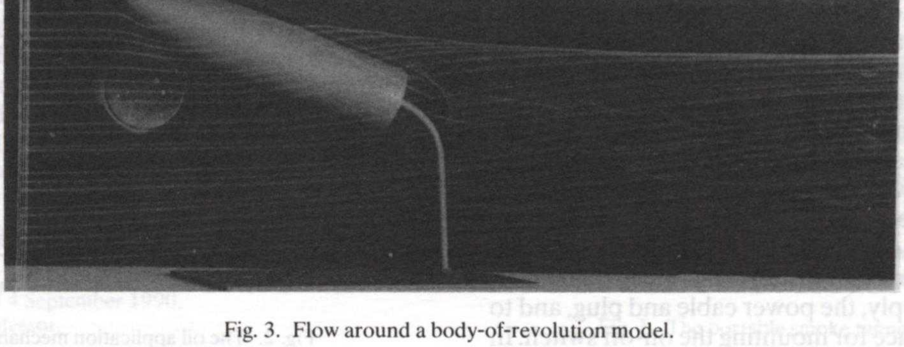
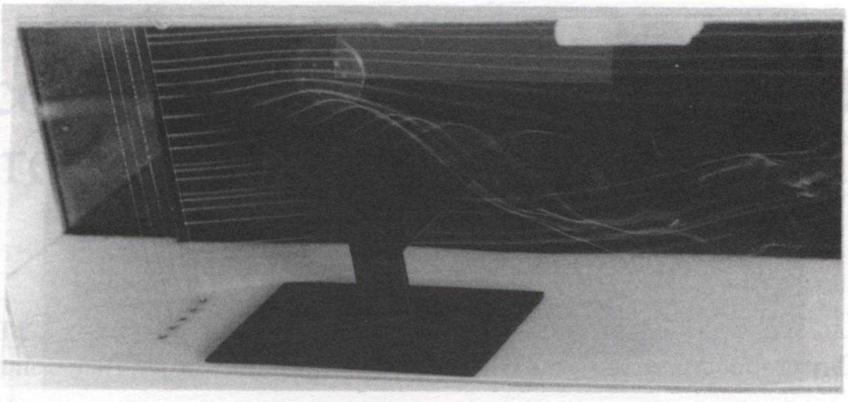
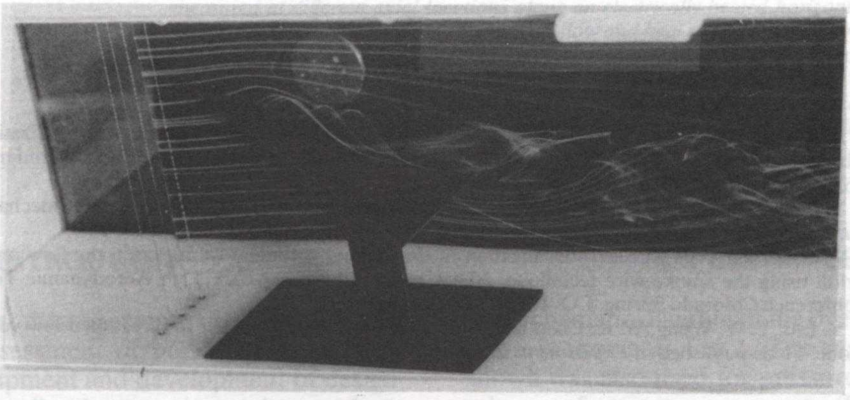


Fig. 3. Flow around a body-of-revolution model.



(a)



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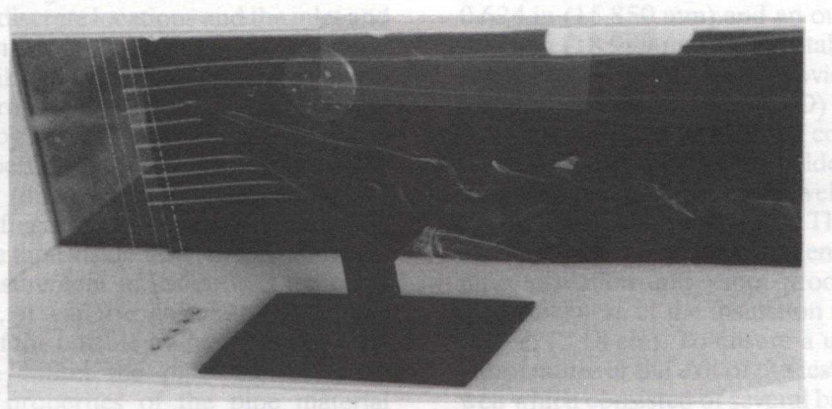

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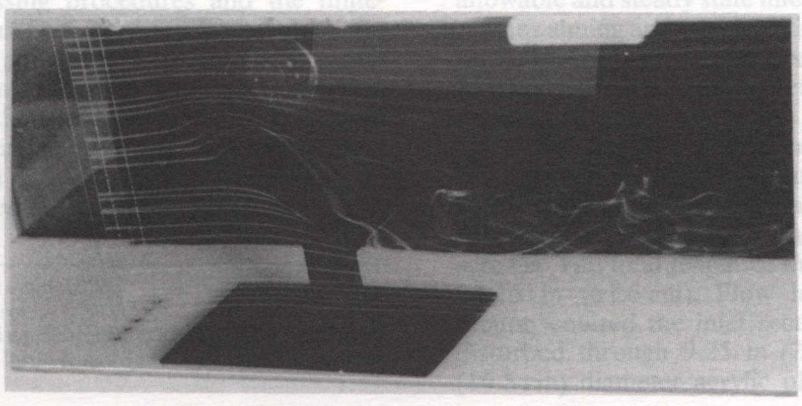

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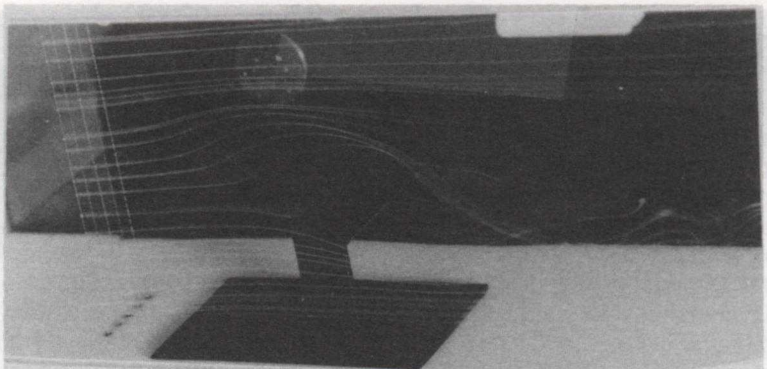

(e)

Fig. 4. Flow pattern near a delta wing.

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