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LASER VELOCIMETRY MEASUREMENT IN A TRANSONIC TUNNEL

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INTRODUCTION

The design of efficient airfoils for transonic vehicles has been a goal of aerodynamicists over the past four decades. Although advances have been made, there are several problems which require careful investigation if additional improvements are to be realized. These problems are related to the management of the boundary layer and associated problems such as shock induced separation and shock-boundary layer interaction.

In the last decade, computational methods have been developed which, when combined with analytical and experimental studies, have added to our understanding of the flow over transonic airfoils. Computational methods, like analytical methods, required physical experiments in order to formulate and verify the modelling assumptions made and the numerical procedure used. The sensitivity of flows near a Mach number of one is well known. Wind tunnel wall interference like blockage and shock wave reflection and flow disturbances caused by physical measurement probes have made transonic experiment difficult, especially since even boundaries far away will influence an airfoil near Mach one. Many advances have been made in recent years to alleviate the wall interference problem by reducing model size, utilizing ventilated wall wind tunnels, and applying theoretical and empirical corrections (ref. 1). In addition, advances in non-intrusive measurement techniques have enabled the obtaining of quantitative flow data without introducing probes which invariably disturb the flow.

Optical methods of investigation which depend on density changes are especially suited to the visual study of transonic flows. The interferometer, the schlieren, and the shadowgraph are commonly used optical methods of this type. These methods provide an overall picture of the density field. The recent development of another optical technique--the laser velocimeter (LV)--provides the opportunity to make detailed and potentially more reliable quantitative velocity measurements. This report will describe a transonic airfoil study currently under way at the University of Notre Dame. The study is supported by the Naval Research Laboratory under contract No. N00014-84-K-2013.

TRANSONIC TUNNEL

The transonic tunnel used for the experiment has slotted walls, 6% open area on the top and bottom walls and solid and easily removable glass side walls with a square cross-section and area 16 sq. in. (104.0 cm^2). The flow in the tunnel is controlled using a second throat downstream of the test section. The second throat is composed of a series of cylindrical rods normal to the flow. Rods of various diameters can be used to provide different throat areas. The plenum pressure can be controlled by two valves connected into the diffuser downstream of the second throat. A schematic of the test section is shown in Figure 1. This is an indraft tunnel which draws air from inside the laboratory and exhausts outside.

As shown in Figure 2, the inlet of this tunnel consists of 11 screens (five aluminum and six nylon) followed by a 150:1 contraction in area to the test section. This inlet produces excellent smoke streakline quality in the test section. Preliminary data indicates the turbulence intensity in the test section is less than 0.5%. Three 3130 cubic ft (17.70 m^3)/minute vacuum pumps, each driven by a 125 hp AC motor, permit continuous operation of this tunnel with schlieren and shadowgraph systems. The maximum Mach number attainable is about 1.4, depending on the ambient pressure and temperature.

The bi-convex airfoil used in the study, shown in Figure 3, is pinned between the circular plexiglass test section windows. These windows can be rotated as one unit to change the angle of attack. The airfoil has a one inch cord and a 10% thickness.

LASER VELOCIMETRY SYSTEM

The relatively high velocity of the flow under study is one of the major considerations for choosing a suitable LV system. The LV system used for the study is a single-component system (manufactured by TSI) with provision for later expansion to two-component. Due to the high flow velocity, a 4-Watt argon ion laser is used to provide sufficient scatter light intensity. With the green (514.5 nm) line the maximum single line power output is about 1.2 Watt. To maximize the signal to noise ratio and to minimize light reflection from solid surfaces into the receiving optics, an off-axis, forward scattering configuration is used. Both the transmitting lens and the receiving lens have a focal length of 241.9 mm, with beam spacing of 50 mm. Windows on the sides of the test section facilitate optical access to flow for LV scanning. The LV system is placed on a 3-dimensional traversing table (modified from a milling table) with position resolution of one thousandth of an inch. The receiving optics are physically connected to the traversing table by an overhanging structure so that the receiving and the transmitting optics can be moved as a single unit. A counter is used for signal processing and data acquisition is carried out using a PDP-11/23 computer.

PARTICLE GENERATION FOR LV MEASUREMENT

Two major factors influence design of the particle generation system for the LV measurement: (1) the open-loop design of the wind tunnel; and (2) the high flow velocity. The open-loop design coupled with the high speed of the flow means that a large quantity of particles would have to be generated continuously. Furthermore, the high speed flow requires particles of very small size in order that velocity slip not be a problem.

The particle used in this experiment is kerosene smoke generated by an oil smoke generator. This four-tube oil smoke generator is shown schematically in Figure 4. A flat electric heater strip is located inside a 51 mm square thin wall conduit tube. The entire unit is set at a convenient angle (about 60°) and the sight-feed-oiler is mounted on the unit at the upper end of each tube so the oil drips on the upper end of the heater strip. The drip rate can be adjusted to give the desirable amount of smoke. A squirrel cage blower mounted at the low end of the unit is used to force the smoke through the system. The squirrel cage blower is more or less mandatory--in the event of backfiring the sudden increase in pressure is easily transmitted through the rotor.

After leaving the generator, the smoke is allowed to pass through a heat exchanger made of 42 millimeter diameter pipe, as shown in Figure 5. In passing through the heat exchanger the smoke is cooled down to near room temperature, and the larger size droplets will coalesce and settle at the bottom of the heat exchanger tube. The entire system has drain corks conveniently located; one at the bottom of each tube of the generator itself to remove excess oil not converted to smoke, and others at the bottom of the heat exchanger to remove whatever oil might have condensed. After passing through the heat exchanger condenser system, the smoke flows into a 117 millimeter manifold and is passed through an absorbent cloth filter.

This filter is made of thick cloth and removes most of the remaining lighter tars, allowing only very fine and even sized smoke particles to pass through. After the filtering, the smoke is passed into a circular tube of about 30 mm in diameter with several fine mesh screens inside to produce a uniform stream of smoke at the tube outlet. The entire smoke generating assembly can be traversed up and down, as desired, by using the attached remotely controlled motor.

A high quantity of very fine smoke particle suitable for LV application can be generated continuously using the smoke generator. The smoke has to be distributed into the test section. If the smoke is to be evenly distributed over the entire flow field, a very effective mixing system will be required at the inlet of the tunnel. The designing of such a system can be very difficult. Furthermore, the high air flow rate will require an enormous amount of smoke to be generated. Thus a more practical way, though less convenient, is to direct the smoke stream at the exit of the smoke generating system to the position of the LV probe in the flow. Since the smoke stream does not cover the entire flow field, measurements at different locations will require the repositioning of the smoke stream. This method of smoke distribution is being used in this study and is found to be satisfactory.

PRELIMINARY TESTING

Some preliminary velocity measurements had been carried out inside the transonic tunnel using the LV system in association with the smoke generator. Pressure measurments were also performed using a pressure tap located on the side wall of the test section slighly upstream of the windows. Though the pressure measurements and the LV measurements were not taken at exactly the same location, extrapolation of the pressure data into the location of the LV measurements indicated a very close agreement between the velocity values obtained using the two different methods. Thus it is believed that the smoke particle is following the air flow with little or no velocity slip. Velocity measurements with airfoil at various angles of attack are now being carried out in conjuction with schlieren flow visualization. In the near future pressure distribution around and on the airfoil will be obtained by putting pressure taps on the side windows and using a pressure tap model (currently under construction) of the airfoil.

REFERENCE

1. Blackwell, J.A. Jr., "Experimental Testing at Transonic Speeds," Progress in Astronautics and Aerodynamics, Vol. 81, pp. 189-238, 1981.

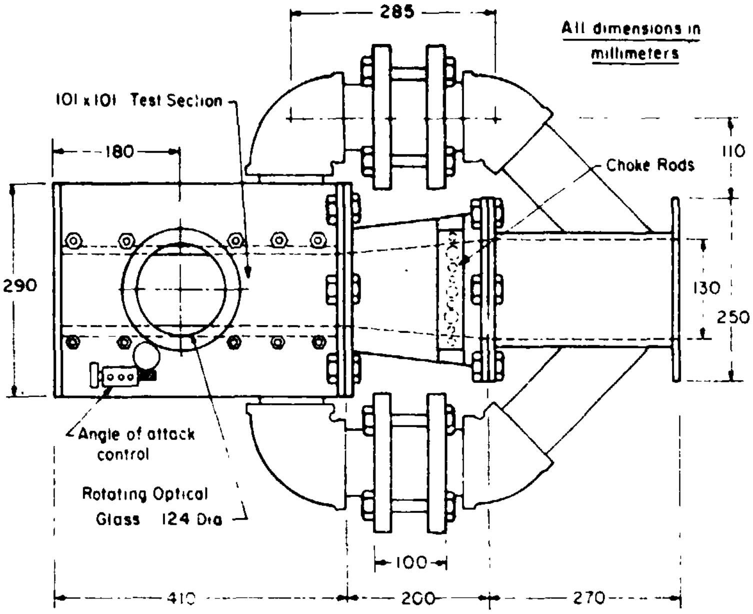

Figure 1. Schematic of the transonic tunnel test section.

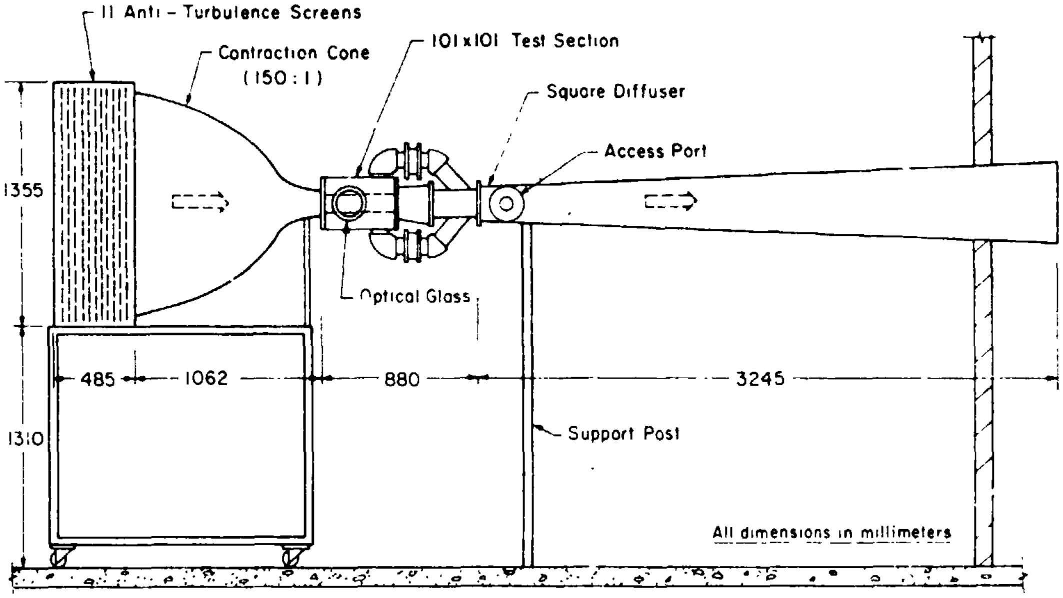

Figure 2. Schematic of the transonic tunnel.

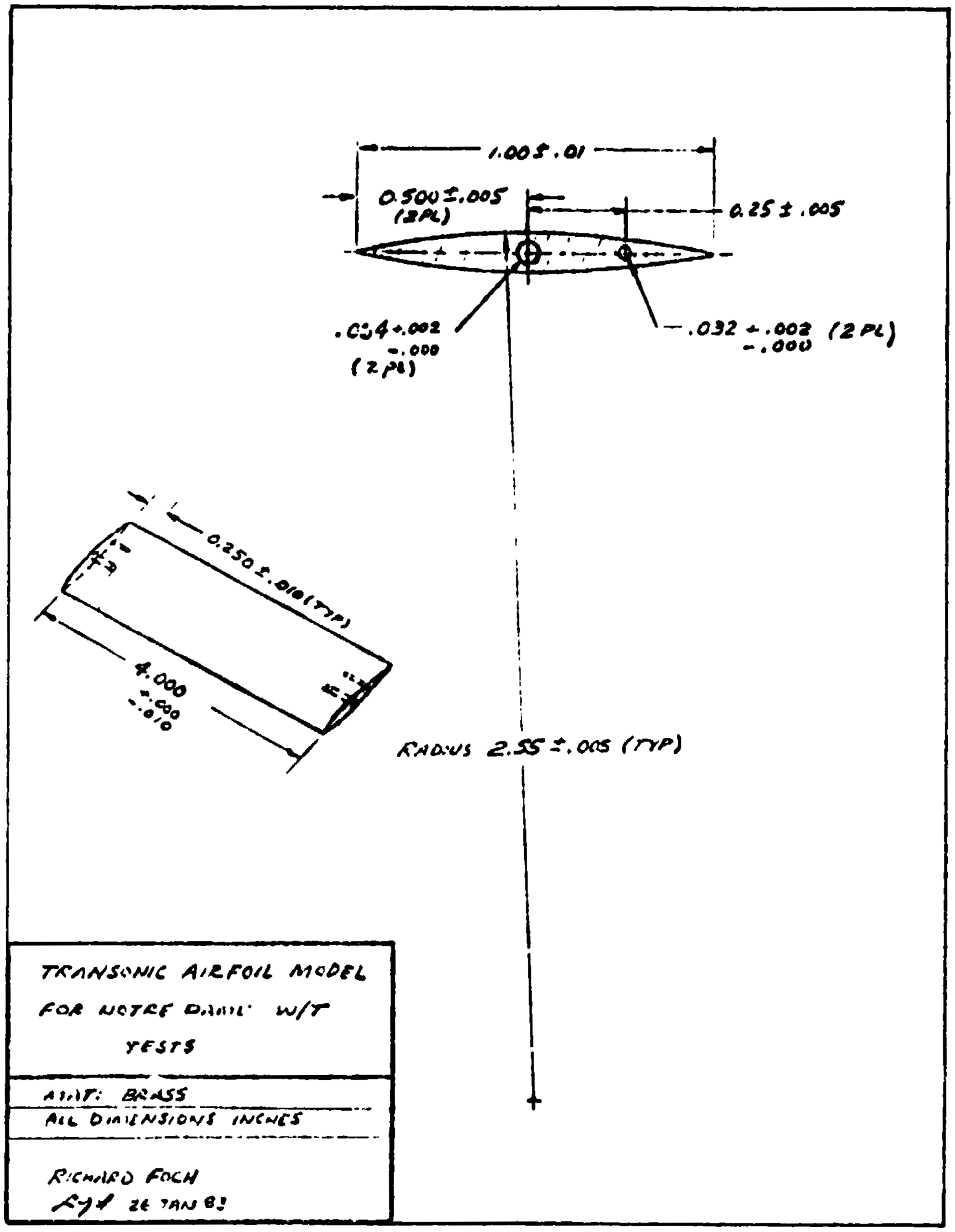

Figure 3. Drawing of a bi-convex airfoil made by the Naval Research Laboratory.

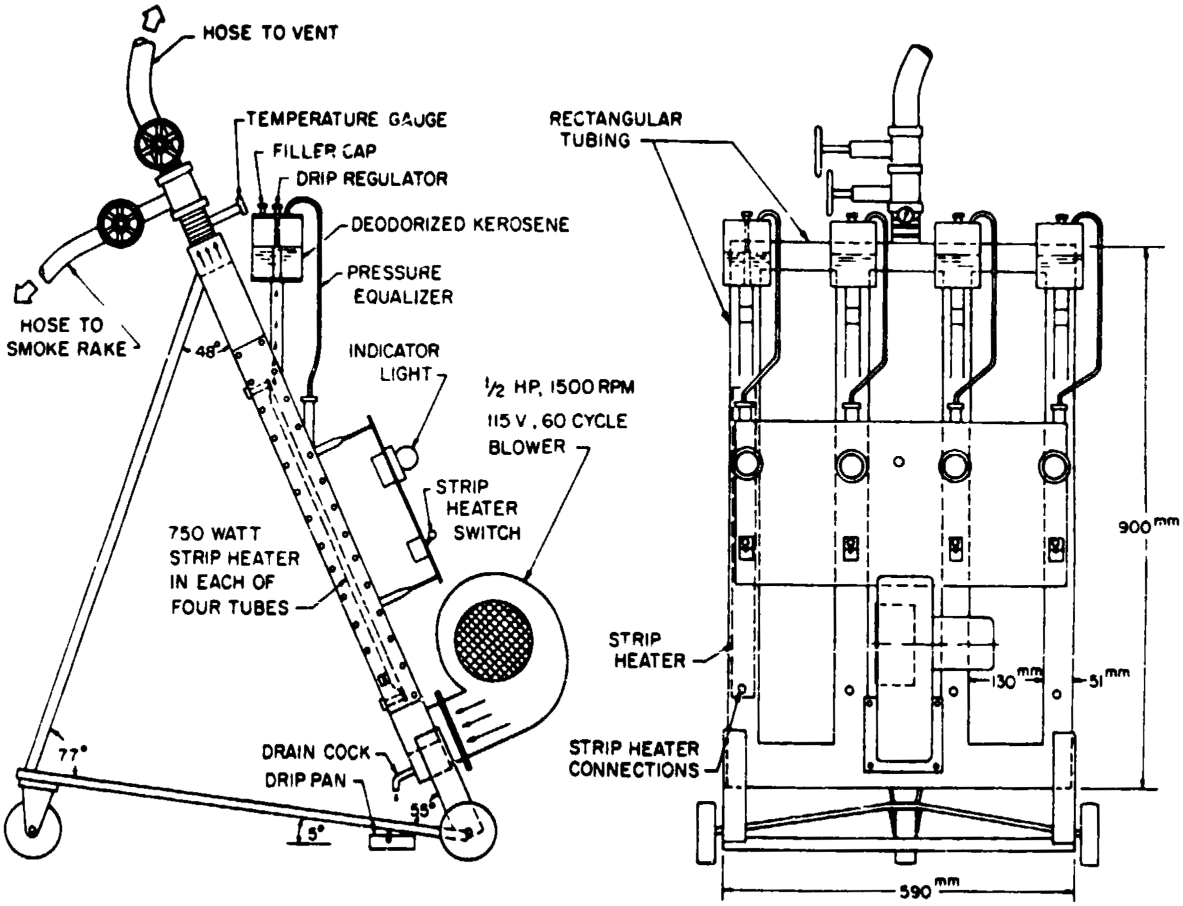

Figure 4. Kerosene smoke generator.

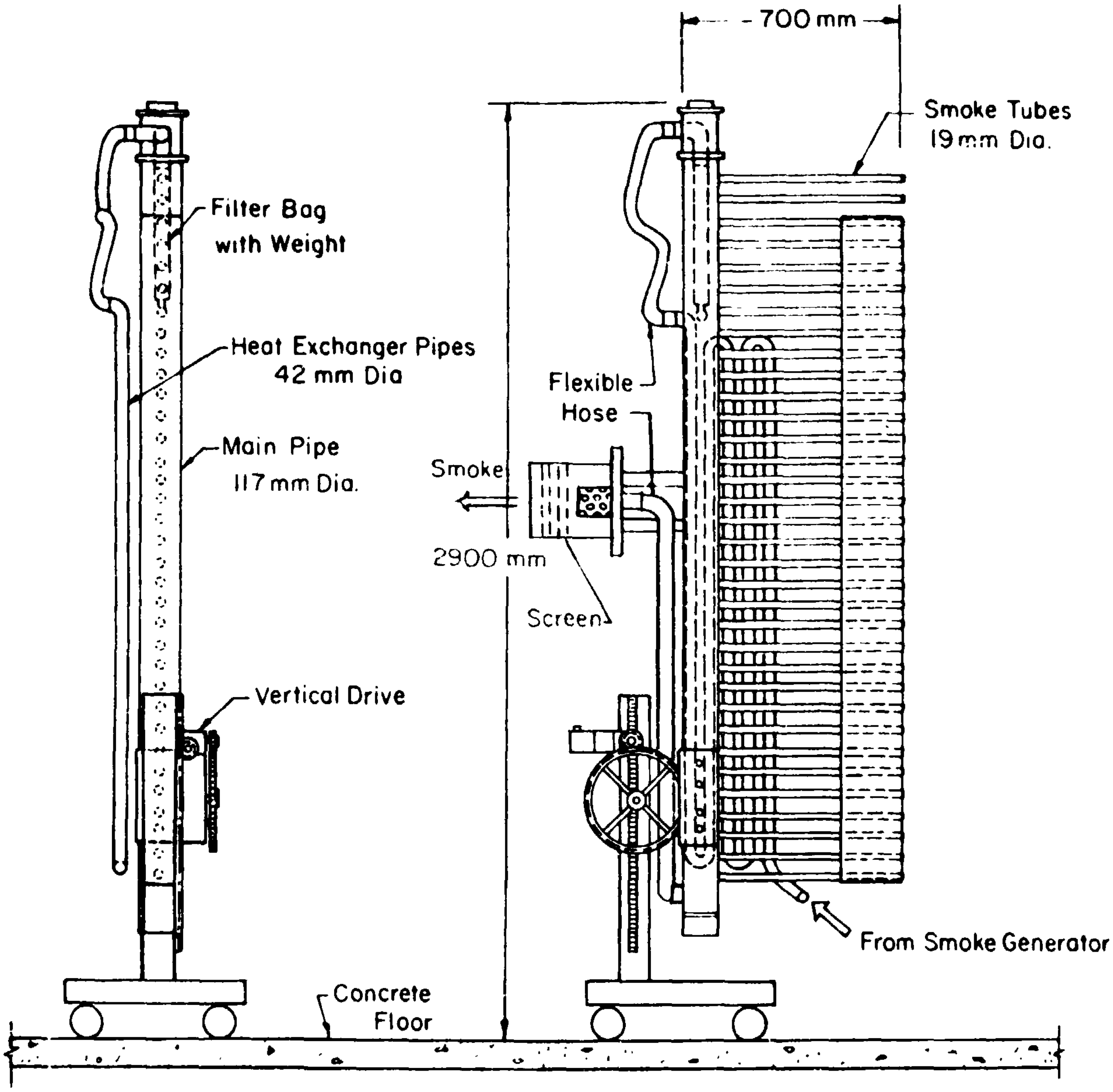

Figure 5. Smoke filter/condenser system.