EXPERIMENTAL TECHNIQUES FOR WIND TUNNEL TESTS ON MODEL BUILDINGS

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Experimental techniques used in the low-speed wind tunnels at the Building Research Station when studying air flow around buildings and pressure distribution over their surfaces, are described. These include flow visualisation both in the stream and in boundary layers over surfaces, velocity measurements around small-scale models, and methods of building models containing pressure tappings. The names of suppliers and details of some instruments and equipment are given.

An Appendix by J G Davies and G G J Cooper describes how a simply constructed heated-sphere anemometer is made.

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EXPERIMENTAL TECHNIQUES FOR WIND TUNNEL TESTS ON MODEL BUILDINGS

by P F Grigg and D E Sexton

INTRODUCTION

An earlier paper[1] gave some brief details of the instrumentation and experimental techniques used in studying the effects of wind on buildings in low-speed wind tunnels. Enquiries received by the Building Research Station and discussions with other research workers have suggested that the earlier notes should be extended. This paper gives some practical details of methods of flow visualisation and velocity and pressure measurement that have been evolved during the course of several years' work. For more comprehensive discussion of experimental techniques used in industrial aerodynamics a number of excellent treatises are available[2,3,4].

FLOW VISUALISATION

One can learn much about the effects of wind on a building and its surroundings by making visible the flow around a model. A few minutes' observation can be sufficient to give a clear impression of air flow patterns and different cases can be studied as rapidly as the model details can be changed. The low speeds normally used for model studies of buildings impose limitations on the visualisation techniques that can be employed, and for this reason many methods described in aeronautical textbooks are unsuitable. Experience has shown that smoke is the most versatile medium, both for studying details of the bulk flow over a whole model and for investigating conditions in restricted areas, eg in a pedestrian passageway through a building. A paint-film technique, similar to those described by Maltby and Keating[5], has been used to study flow over horizontal surfaces.

Bulk flow

Methods of generating a cold smoke consisting of an aerosol of oil droplets, have been devised. Smokes of this type are non-toxic and present no particular safety hazards, though it is unsafe to inhale them in high concentrations because of the possibility of lung damage. A commercially available generator * which produces smoke from a medium viscosity 'cosmetic oil', similar to medicinal paraffin, has been used in the arrangement shown in Figure 1. Oil is lifted from a reservoir and forced into a vapouriser by a stream of carbon dioxide. The oil vapour is taken from the outlet of the generator, through a copper tube (1.6mm bore and 2m long) which is loosely wound with a heater tape rated at 150W/m, into a water-cooled condensing pot. A small pump supplies air, at a maximum rate of about 1 m^3/h, which mixes with the condensed vapour and delivers the resulting smoke to a distributor. This may be a single small-bore tube, for visualising local flow patterns, or a smokestack of hollow, symmetrical aerofoil section (a stack of 50mm chord and 600mm long has been found to be suitable) from which smoke enters the

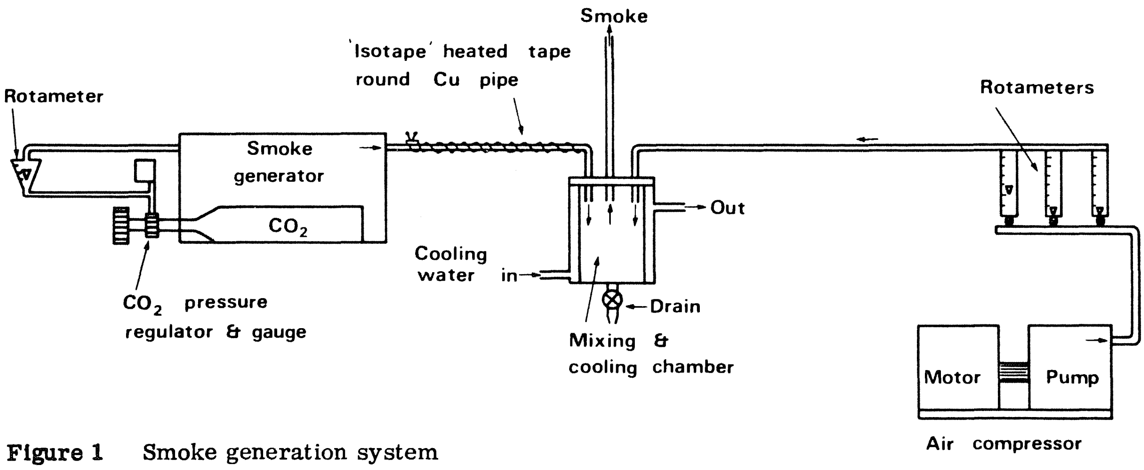

Figure 1 Smoke generation system

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* A list of suppliers of items marked with an asterisk is given after the References.

airstream through slots in the trailing edge. This is used when examining general flow patterns covering a relatively large area. Flowmeters are inserted in the air-lines and CO_2-lines for measuring the volume flowrate of smoke when testing model chimneys.

The highly turbulent airstream causes rapid diffusion of smoke. This presents no problems for direct visual observation but makes effective photography difficult. It is essential to allow sufficient exposure time to record a mean flow pattern, rather than an instantaneous picture, and the lighting must be adjusted to ensure that whilst the smoke is visible the rest of the negative is not entirely 'burnt-out'. Strong top lighting of models finished with dark, matt paints against a matt, black background was used to produce the photograph in Figure 2.

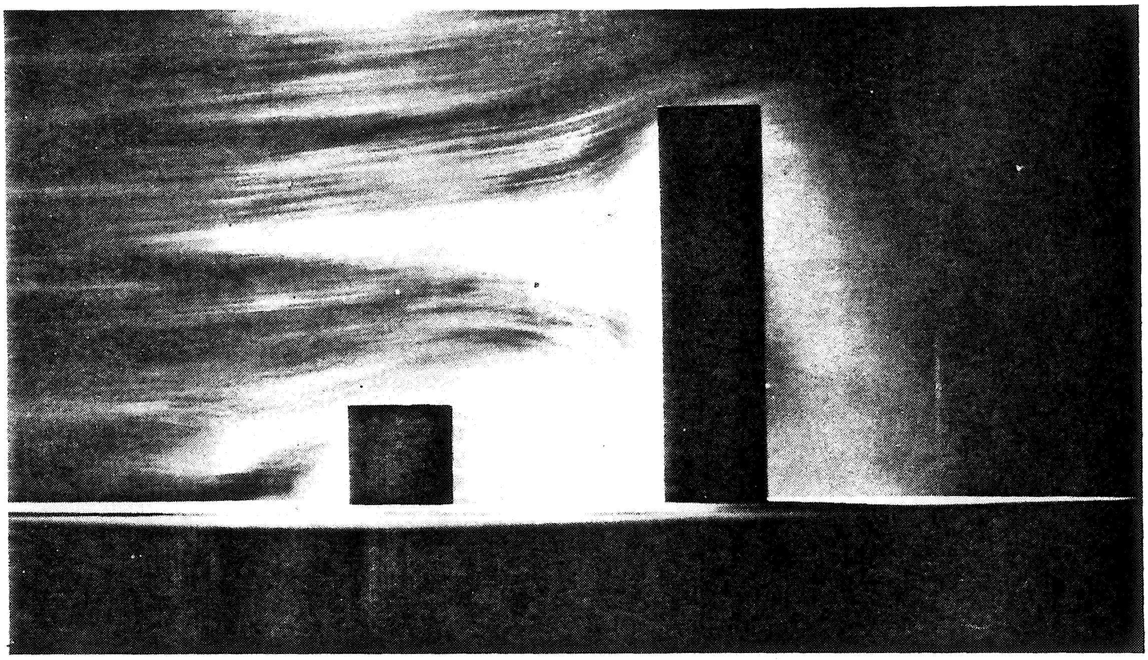

Figure 2 Smoke visualisation of a typical model arrangement

Surface flow

It is sometimes necessary to study the flow close to a surface. Injecting smoke into the air-stream in the usual way is not satisfactory since large-scale movements in the stream confuse the eye and obscure the small movements being studied. If the surface forms the wall of a building, the model may be made hollow and smoke can be emitted from the surface itself through weep holes. The pressure within the model needs to be just sufficient to overcome ambient pressure and allow the smoke to emerge into the boundary layer of the model. Figure 3 shows flow over the windward face of a simple model using this technique.

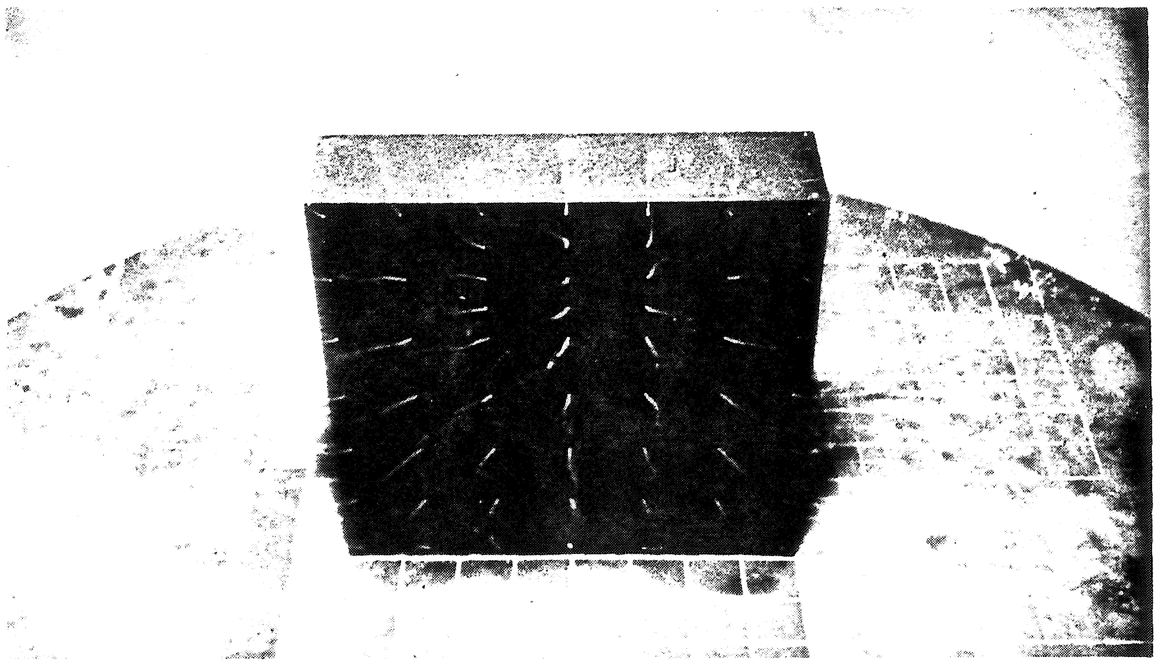

Figure 3 Flow over the surface of a perforated model

Paint-film visualisation is widely used in aeronautical work, but in a low-speed wind tunnel its use is limited to horizontal surfaces. Figure 4 shows flow over the ground in the vicinity of a tall, slab-shaped building with a low building to windward. The positions of the horseshoe vortex to windward of the tall building and the two standing vortices in its wake show clearly. The models were stood on a polished aluminium sheet that had been coated by flooding with paint made up as follows (all parts by volume):

1 part Dayglo Saturn yellow pigment *

3 parts kerosene

7 parts white spirit.

The pattern was developed in about 5 minutes' running, and was photographed before the paint had time to flow back to its original state, in the light of a 125 W ultra-violet lamp on FP4 film at f 22. Exposure time was 3 minutes and the camera and lamp were about 1 m above the pattern. A Wratten 2B filter was used to exclude reflected uv light and to ensure that only visible yellow light was admitted.

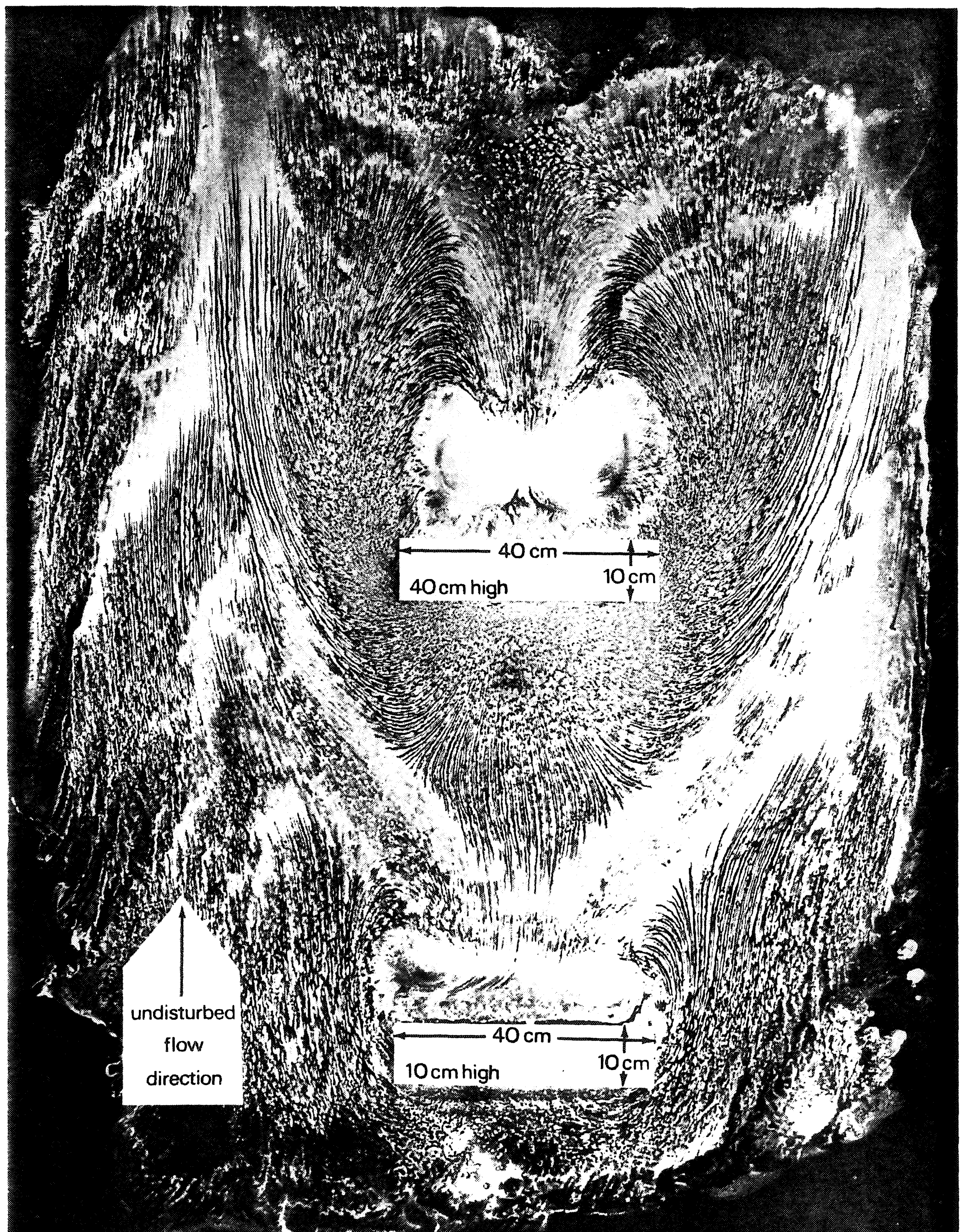

Figure 4 Dayglo surface-flow pattern

VELOCITY MEASUREMENT

The standard instrument for velocity measurement is the Pitot-static tube*, and many different types of pressure tube anemometers are described by Bryer and Pankhurst[4]. With a correctly designed instrument the pressure difference between the tubes is the velocity pressure $p = \frac{1}{2}\rho v^2$, where ρ is the air density and v is the velocity.

In practical terms

$$v = 6.50\left(\frac{T + 273}{B}\right)^{0.5} p^{0.5} \quad ms^{-1}$$

where T is ambient temperature in ^oC

B is barometric pressure in mm of mercury

and p is Pitot pressure in mm water gauge.

At normal temperatures and pressures v is approximately $4.1p^{0.5}\ ms^{-1}$. The output of these instruments becomes very small at low velocities, eg 0.25 mm water gauge at $2.1\ ms^{-1}$, and difficult to measure with even the most sensitive micromanometers. At these low speeds instruments based on the principle of measurement of the rate of cooling of a heated body are used, for instance the Simmons shielded hot-wire anemometer[6]. An anemometer of this type which can be used with small-scale models and is relatively insensitive to incident flow direction is illustrated in Figure 5 and its method of construction is described in the Appendix. The bronze ball is internally heated by the coil, which is fed from a constant-current source. The negligibly small temperature coefficient of resistance of constantan ensures that the power dissipation of the coil is not affected by variations in its temperature. Thus the ball temperature, measured with the thermocouple, is solely a function of heat loss from the ball. With a heater current of 250 mA the ball temperature is about 80^oC above ambient and the instrument may be used over a range from 0.5 to $15\ ms^{-1}$. Figures 6 and 7 show the effect of wind direction on instrument output for three instruments from a batch. With a time constant of the order of several seconds the instrument measures mean speeds and is unaffected by short-term fluctuations.

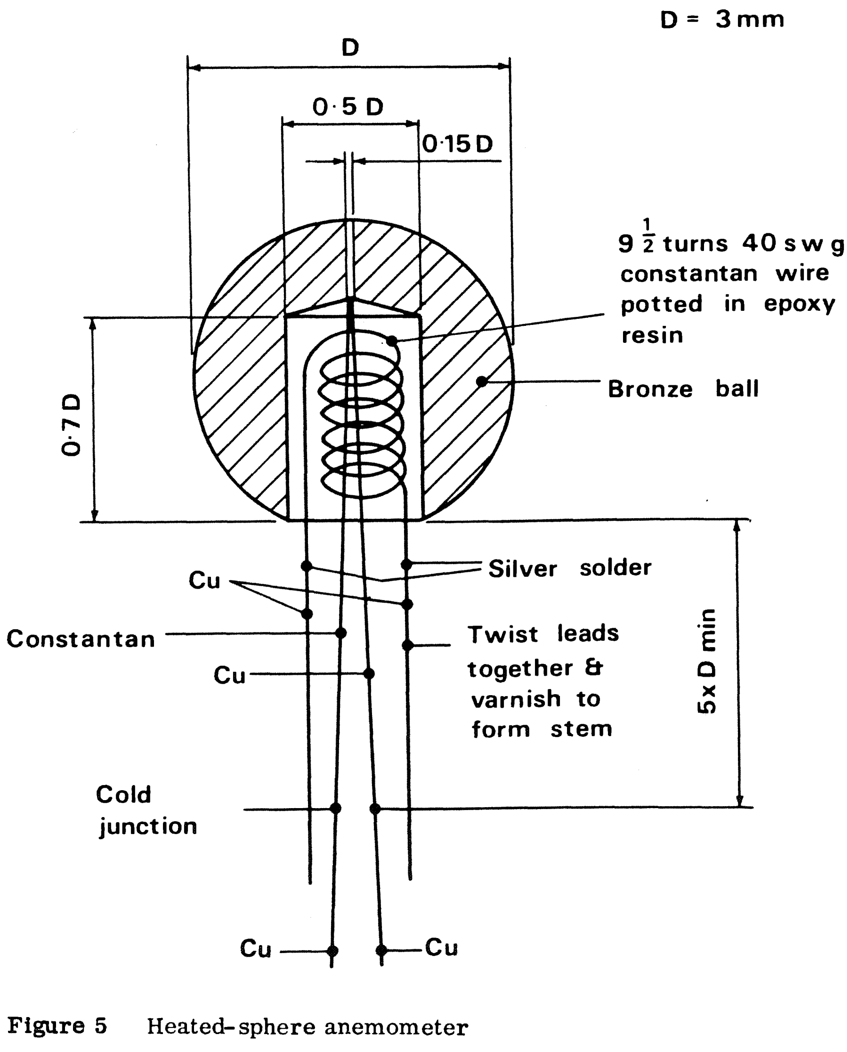

Figure 5 Heated-sphere anemometer

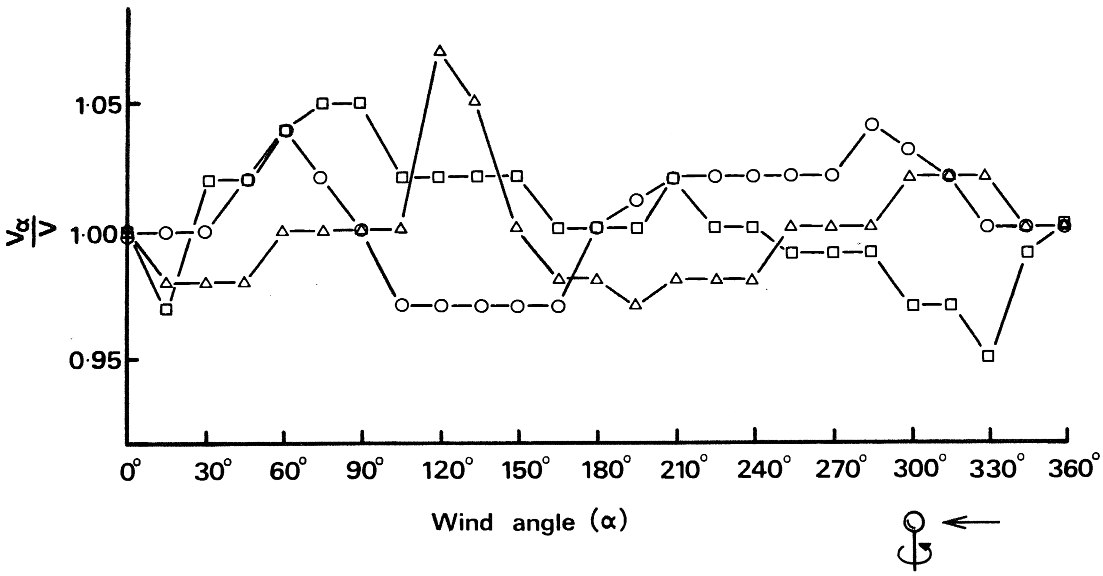

Figure 6 Effect of rotation about support axis (incidence $\alpha°$), measured with three instruments

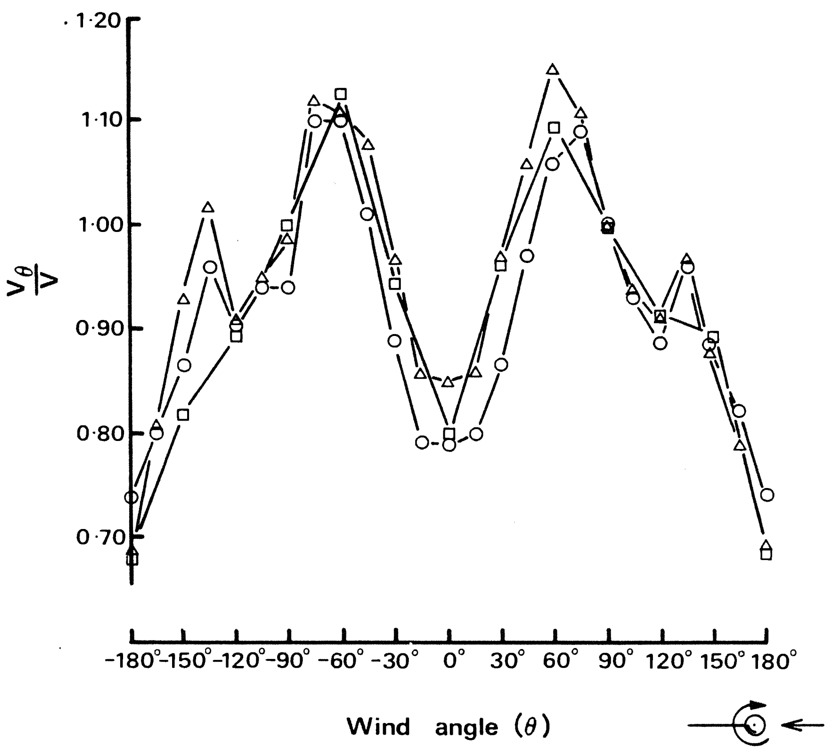

Figure 7 Effect of rotation about a horizontal normal axis, measured with three instruments

PRESSURE MEASUREMENT

The techniques of pressure measurement used at BRS are those that have been fully dealt with in the standard textbooks but the following notes will give sufficient information for most purposes. It is often necessary to know the pressure distribution over the surfaces of a building, for example, to assess the structural load due to the wind or when deciding upon the best positions for intakes and exhausts of a ventilation system. Pressures are measured at tappings in the surface of a model, arranged either in a regular grid-iron pattern or at points of special interest. On a typical model this entails fitting lengths of metal tubing, of about 1.0 to 1.5 mm bore, in the walls, with the outer ends of the tubes finished perfectly square, free from burrs and flush with the surface. A few centimetres of tube left projecting on the inside of the model is connected with flexible tubing to the pressure measuring instrument. An alternative method, especially useful when large numbers of tappings are needed, is to insert lengths of tubing in grooves in the surface of the model and pack the spaces around the tubes with a suitable filler. One end of each tube is sealed whilst the other is taken to the inside to carry the manometer connection. Holes are then drilled along the tubes to form tappings at any selected interval.

In use all the holes except one are blocked with cellulose tape and the pressure at the open hole is then measured. All the holes are of course unblocked in turn. This method was used when pressures were measured at 120 points on half a model roof about 600 mm square. The number of tubes may be anything up to 50. These are conveniently connected to a single-point manometer via a multi-way valve.

During testing, a Pitot-static tube is positioned upstream at the height of the roof of the model under test. The static pressure tube is connected to one side of the manometer and the Pitot tube is taken via one of the inlets to the multi-way valve. Thus the static pressure is the reference pressure to which both the velocity pressure at the Pitot tube, p_v, ie at roof height, and the local pressure acting on the building, p_l, may be compared.

The ratio $p_l : p_v$ is known as the pressure coefficient, C_p, and is, of course, non-dimensional. Whilst the positive pressure on the surface does not exceed the velocity head of the airstream, negative pressures up to at least three times the velocity head are encountered, which determines the minimum range of the manometers.

Bradshaw[7] discusses in detail the types of manometer that are available and the methods of using them. Most work at BRS has used either the Betz projection micromanometer *, with a range of 250 mm water gauge ($2.45\ kN/m^2$), or an electronic instrument * in which an applied pressure difference changes the capacitance of a tuned circuit, giving an out-of-balance reading on a built-in meter. Since the volume displacement for full-scale deflection is only 1.5×10^{-3} ml, the instrument has an extremely high speed of response. Output sockets are also provided to which a recorder or data-logger may be connected. The range of this manometer may be varied by the use of separate 'plug-in' pressure-sensitive capsules.

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3 **Ower, E and Pankhurst, R C.** The measurement of air-flow. London, Pergamon Press, 1966.

4 **Bryer, D W and Pankhurst, R C.** Pressure probe methods for determining wind speed and flow direction. London, HMSO, 1971.

5 **Maltby, R L and Keating, R F A.** Flow visualisation in low-speed wind-tunnels. Current British Practice. RAE Technical Note, No Aero 2715, 1960.

6 **Simmons, L F G.** A shielded hot-wire anemometer for low speeds. Journal of Scientific Instruments, Vol 26, December 1949, p 407.

7 **Bradshaw, P.** Experimental fluid mechanics. (2nd edition.) London, Pergamon Press, 1970.

SUPPLIERS OF ITEMS

Dayglo pigment:	H Haeffner & Co Ltd, Commerce Trading Estate, Kingston Road, Leatherhead, Surrey.
Betz projection micromanometer:	R E Swann Ltd, 109 Fenchurch Street, London EC3.
IRD electric micromanometer (Type MDC):	Furness Controls Ltd, Beeching Road South, Bexhill-on-Sea, Sussex.
Smoke generator and oil:	C F Taylor (Unity Designs) Ltd, Blackwater Station Estate, Camberley, Surrey.
Pitot-static tubes:	Airflow Developments Ltd, Lancaster Road, High Wycombe, Bucks.

Inclusion in this list does not necessarily imply approval of the quality or performance of the items specified.

APPENDIX

MAKING A HEATED-SPHERE ANEMOMETER

by J G Davies and G G J Cooper

INTRODUCTION

The main paper describes an instrument employing a heated sphere as the sensing element for measuring wind speeds around scale model buildings. The instrument was made as a probe with the spherical sensing head 'sting mounted' at one end of a length of hypodermic tube (Figure A1). Figure A2 shows one nearly completed instrument together with an exploded view of another. Figure A3 shows details of the components during manufacture.

THE SPHERICAL SENSING HEAD

A 3 mm bronze ball was drilled to house the electrical components. It was held in a jig (Figure A4) to prevent surface damage and to ensure concentricity within 0.025 mm limits. Drilling was done in a high-speed lathe, first of all by a No 1 centre drill to a controlled depth of 2.6mm, followed by a 1.8mm drill to the same controlled depth. Finally a 0.35mm drill was taken through the remaining 0.4mm thickness. Slip and feeler gauges between the face of the drilling jig and the drill chuck were used to achieve the controlled depth. Burrs were removed by a Swiss file.

THE HEATER

This was a coil of 0.125mm (40 swg) constantan wire with copper tails of the same size butt-jointed to the ends. A length of constantan wire was de-greased and then oxidised, to provide a primary layer of insulation, by mounting the wire in a special jig (Figure A5) comprising a pair of brass clamps (acting as heat sinks) placed 44 mm apart on an insulated block, and passing a current of about 2 amps at 4.5 volts through it for a few seconds. The constantan was then cut to 46mm length to give 1mm of bare wire at the ends. Two tails were made from one length (200mm) of 0.125mm (40swg) lacquered copper wire. The insulation at the middle of this length was removed for a distance of about 5 mm by preheating a piece of flat brass bar 4 mm wide and laying the section of wire to be stripped across it. A pair of tails was made by cutting at the stripped region and trimming back to leave 1 mm of bare copper.

The joints were made in a second jig (Figure A6) with the mating ends of the copper and constantan wires butting. The wires were positioned in the jig so that the copper wire was gripped close to the bared end to keep it cool. The joint was then moistened and dipped in 'Easy-flow' silver solder powder and heat applied to the constantan wire alone by a low Bunsen pilot flame until the joint was made. This was a difficult operation and great care was needed to produce a good butt joint. With the joints completed at each end of the constantan wire, the heater coil was wound on a hollow mandrel (Figure A7) by threading the wire through the bore until one copper tail and the entire length of constantan wire was projecting, with the joint to the second tail lying at the notch in the end of the mandrel. The constantan wire was wound back along the mandrel until its whole length formed a close coil of about $9\frac{1}{2}$ turns. With the mandrel removed, the first copper tail was dressed back to run alongside the second.

THE THERMOCOUPLE

Constantan and copper wires of 0.125 mm (40swg) were prepared as for the heater. The constantan was oxidised for a length of 30mm. Only one length of copper was needed and this was cleaned at both ends, leaving about 30mm of insulation between. The ends of both wires forming the hot junction were cut back to leave 0.8mm bare of insulation and tinned. This pair of wires was passed through the bronze ball of the sensing head until about 0.4 mm projected above the surface, then carefully soldered to the ball and trimmed back to leave a clear smooth surface. The cold junction was made on final assembly.

ASSEMBLING THE SENSING HEAD

Potting Araldite was mixed and evacuated in a Buchner flask. The heater coil was dipped in the Araldite and then cured, taking care to keep the Araldite from bridging the bore of the coil. Araldite was then run into the bore of the bronze ball until two-thirds full, and the heater coil was inserted next with the thermocouple leads passing through its bore (Figures A1 and A2). The bronze ball was then completely filled with Araldite, evacuated and cured, topping up where necessary. Finally the electrical circuits were checked and the tails identified for connections to be made later.

THE PROBE BODY

The spherical sensing head was cantilever mounted at one end of a 230 mm length of 3 mm stainless steel hypodermic tube (Figures A2 and A3). Four longitudinal slots 0.8 mm wide were cut in the tube at the end which carried the sensing head. Two pairs of deaf-aid wires were drawn through the tube, separated into the slots, bared and tinned, and identified for matching to the tails of the sensing head. A Keramot spacer plug of cruciform section was prepared to fit the slotted end of the tube and a length of 0.25 mm (33 swg) piano wire was inserted in the free end. Over this was fitted a Keramot conical fairing with a bore of 0.55 mm. When loosely assembled, the piano wire projected 15 mm beyond the fairing to provide a cantilever support for the sensing head.

ASSEMBLING THE PROBE

The spherical sensing head was attached to the cruciform plug by passing the four tails (three copper and one constantan) through the conical fairing and twisting them around the piano wire extension leaving a clear distance of 3 mm between the sphere and the end of the piano wire (Figures A1 and A2). The tails were parted at the cruciform plug to match the leads projecting from the slots in th assembly was bonded together with Tensol No 7 adhesive.

When set, this sub- he probe tube, again using Tensol No 7. The tails
were cut back, clea -soldered to the deaf-aid wires. The constantan
connection here for he thermocouple. All connections were insulated
from the probe and :ations of Tensol No 7 until a good streamline
coating was achieve › 7 enabled the probe to be dismantled and repairs
to be made by disso oform.)

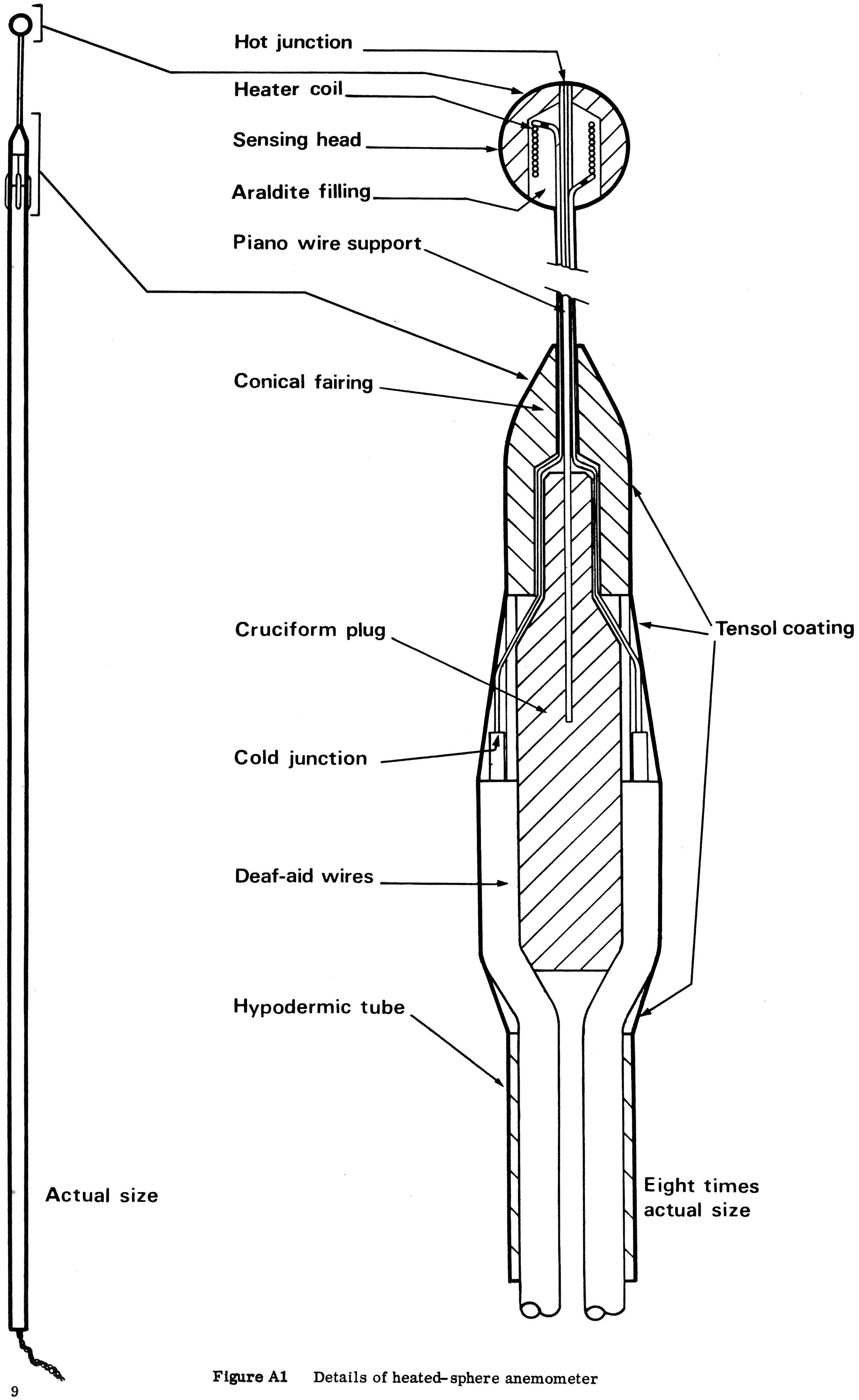


Figure A1 Details of heated-sphere anemometer

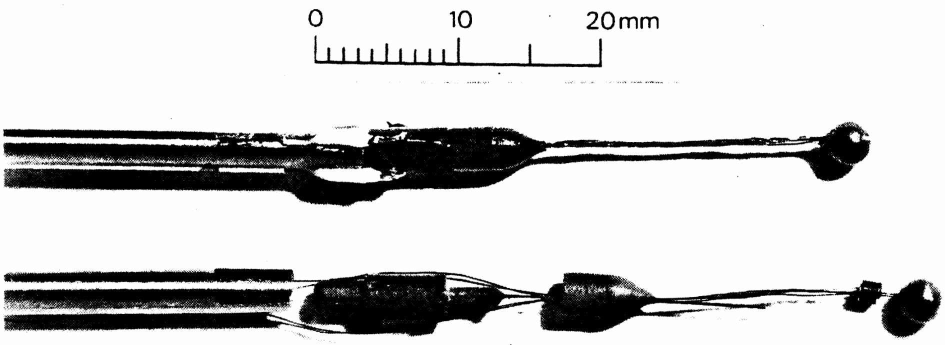


Figure A2 Assembling the instrument

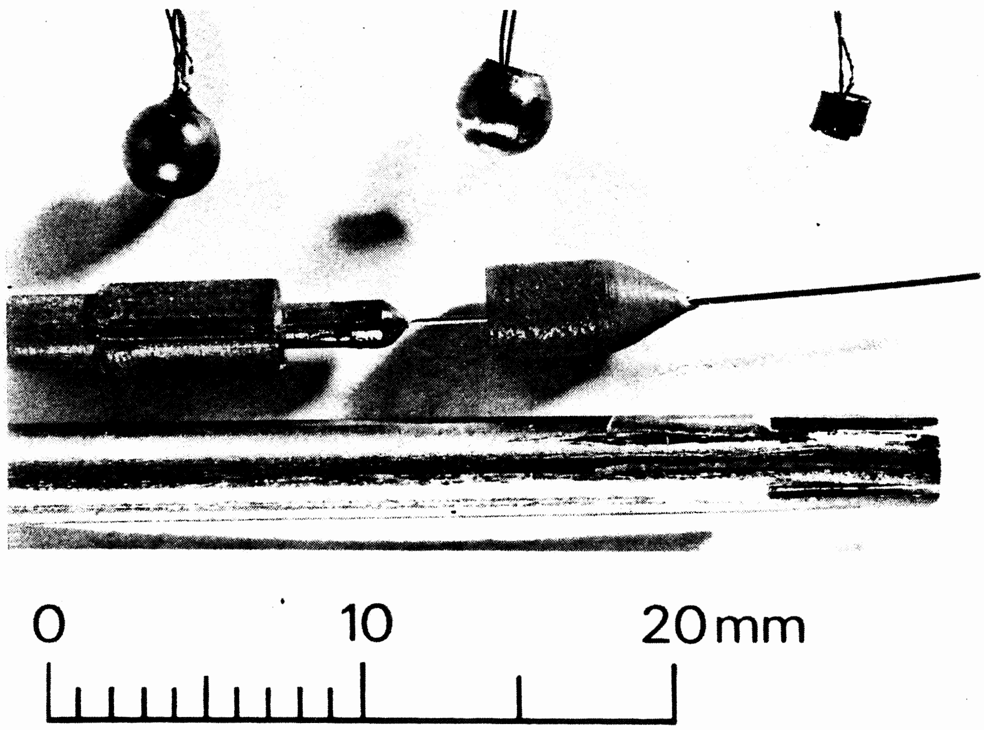


Figure A3 Component details

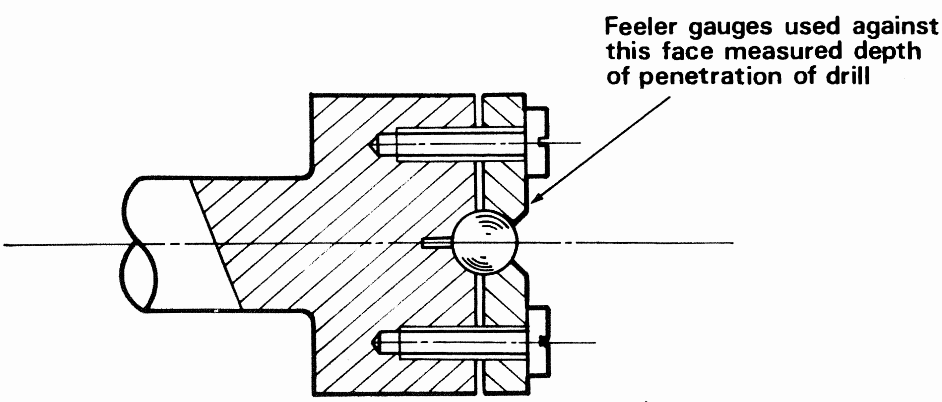
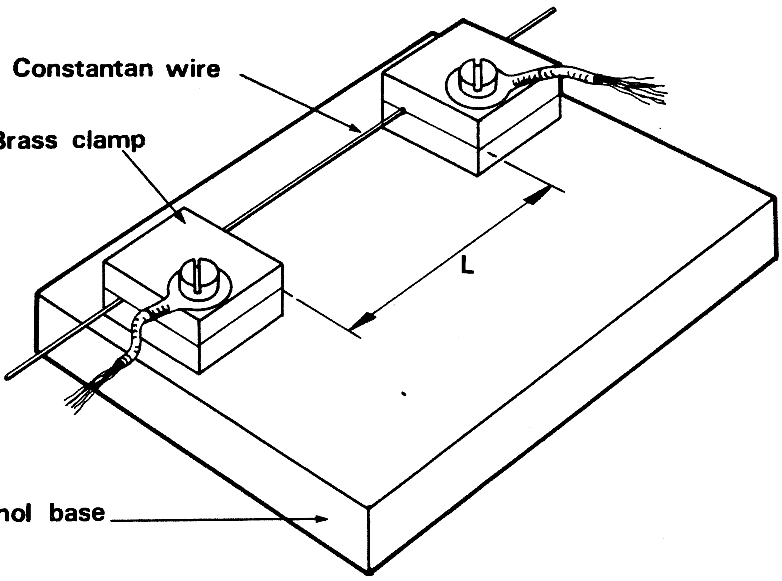


Figure A4 Jig for boring bronze ball



L= length between clamps
44mm for heater
30mm for thermocouple

Figure A5 Jig for oxidising constantan wire

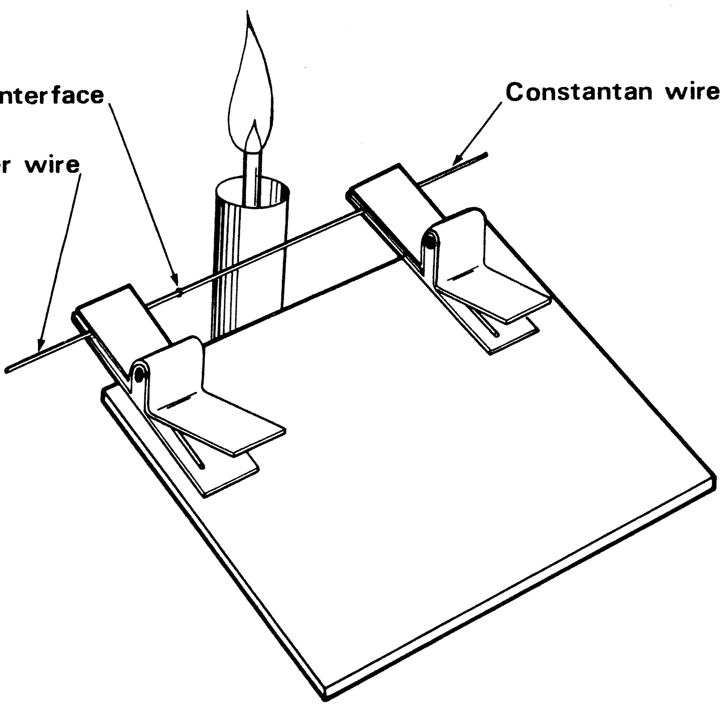


Figure A6 Jig for connecting copper tails to constantan wire

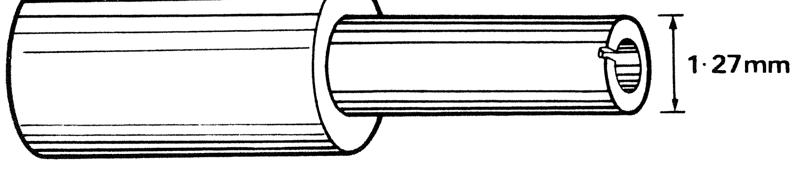


Figure A7 Mandrel for forming heater element

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