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An Electric Tank for the Determination of Theoretical Velocity Distributions

By
T. J. HARGEST, B.Sc.

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Summary.—An analogy due to Relf has been applied to the design of apparatus for quickly determining the theoretical velocity distributions around an aerofoil in cascade.

The accuracy of the apparatus was tested by determining the velocity distribution around a cylinder. An accuracy of within 1 per cent of the approach velocity was obtained for this case. The apparatus has since been applied to determine the theoretical velocity distribution around various aerofoils in cascades ; an example is given of the pressure distribution around an aerofoil at zero incidence. An application to determine the theoretical velocity distribution around the central aerofoil of a nozzle cascade where the effect of the ducting side walls is included, is also given.

1. *Introduction*.—A knowledge of the velocity distribution along a surface in contact with an air stream is desirable in many fields of aerodynamic research associated with the gas turbine. In the case of an aerofoil in cascade, the particular example considered here, the velocity distribution around an aerofoil is required both for the interpretation of cascade performance and for the calculation of the heat transfer coefficients. The velocity distribution around an aerofoil can be determined in a wind tunnel by static pressure measurements on the blade surface or by interferometric observations; both methods, however, involve manufacturing difficulties. Although in most cases the theoretical velocity distribution can be and has been used, its determination by calculation is laborious. So using an electrical analogy, apparatus has been developed which provides a simple means of determining the theoretical velocity distribution around an aerofoil in a cascade. The apparatus could readily be adapted to determine the theoretical velocity distribution in ducting, in intakes as in the work of Hahnemann[1] and Lewis[2] and allied investigations in other fields as shown by Malavard[3] and Peres[4].

2. *The Analogy*.—Taylor and Sharman[5] have shown that two analogies can be established between an aerodynamic field and a geometrically similar electric field. In both cases the aerodynamic velocity is proportional to the local electric potential gradient at a similar point in an electric field but only in one analogy, the streamline/equipotential line analogy, can circulation be easily stimulated by maintaining electrodes at a suitable potential value. Thus, although the other analogy between aerodynamic streamlines and electric current lines has been used extensively to study the flow in intakes, the study of the flow around an aerofoil in a cascade at several deflections necessitates the use of the streamline/equipotential line analogy if computation from the irrotational case is to be avoided.

* N.G.T.E. Memorandum No. M.48, received 19th July, 1949.

3. *The Method.*—3.1. *The Problem.*—In the study of the flow around aerofoils whether an isolated aerofoil or an aerofoil in a cascade the only region of aerodynamic interest is in the small area surrounding the aerofoil. Within these regions in an electric tank model

(a) the electrolyte must not vary in depth,

(b) the electrolyte immediately outside the electrode representing the aerofoil must be at the same potential as the electrode, that is, the transition layer effects (*see* section 3.2) which can ordinarily be neglected, must be reduced or eliminated,

(c) a probe must be introduced to determine the potential and in so doing must not disturb the local electrical conditions,

and (d) the electrical potential gradient must be measured in order to determine the local velocity on the aerofoil in the aerodynamic case.

With isolated aerofoils the mechanical problems can be reduced by enlarging the size of the aerofoil thus increasing the region of operation. By this means Malavard[3] and Peres[4] were able to use a simple two-probe dipper and measure the potential difference between them which was proportional to the local velocity. With a cascade of aerofoils, however, the increase in size is limited by the number of aerofoils required to reduce the inaccuracy of the assumption of straight inlet and outlet air directions to the outer blades of the cascade and by the allowable overall dimension of the tank, thus accuracy must be obtained by mechanical precision and electrical refinements.

3.2. *The Development.*—The problems of the meniscus effects and the transition layer effects are both due to properties of the liquid surface in contact with air in the first case and with the conductor in the second instance. In the small region of the surface, in both cases about a molecule thick, a vast amount of energy is being interchanged. In the surface exposed to the air transition between the gaseous and liquid states occurs, while in the surface adjacent to the electrode transition between electronic and ionic conduction occurs. In the case of the meniscus effect the discontinuity is revealed by the curve of the liquid near the boundary showing the variation of pressure, while the electrical transition effects are revealed by a discontinuity of the electrical potential at the liquid/electrode interface. This latter discontinuity is best explained in terms of the more familiar properties of liquids. In the liquid/air surface a continuous interchange of liquid molecules occurs but if the air is saturated there is no net gain of vapour in the air space and if the liquid vapour is added to the air, liquid escapes from the air to the surface of the liquid. Similarly in the electrical transition layer there is no net escape of electrons from the surface of the conductor unless a certain minimum electron pressure, *i.e.*, potential, is exceeded. This minimum electron pressure corresponds to the electrical overvoltage whose value depends upon the substance of which the electrode is made.

The electric overvoltage is a complex phenomenon[6] but it can be related to the thermionic work function ϕ of the conductor, thus the rate of escape (i) of electrons from a metal charged to a potential V

$$i = ke^{-(\phi + VF)/RT} \qquad \ldots \qquad (1)$$

where F is one Faraday for univalent ions, R is the gas constant and T is the absolute temperature.

Thus it can readily be seen that the electron rate or current is a function of the electrical voltage and its sign and also depends upon the thermionic work function of the material of which the electrode is made.

In the meniscus case, therefore, the energy of the gaseous phase and its rate of interchange with the surface is fixed by the pressure and temperature thus the effect can only be minimised by making the height of the liquid equal to the height of the electrode; with the electrical transition layer effects however one may vary the electrical potential and the rate of interchange of energy in the surface by varying the frequency of the applied potential. By this means it was discovered that with copper electrodes and water the use of an audio frequency current of three kilocycles/second eliminated the transition layer effects. An alternative approach was used by Haller[7] who varied the material of the electrode while keeping the frequency of the applied alternating current constant and found that graphite electrodes were satisfactory at low frequencies. The use of copper, however, enables the ordinary manufacturing facilities to be used and the use of the audio frequency current simplifies the electrical circuit.

Normally in electric tank work a resistance potentiometer network is used to maintain the values of the potential of the electrodes at the correct level, then the potentiometer, however, requires adjustment if the position of any of the electrodes is changed relative to the others, thus altering the input impedance of the circuit. With an audio frequency current, however, we may resort to inductive coupling as in an accurately tapped secondary of a transformer providing the required voltage steps. Such an arrangement (*see* Figs. 1 and 2) acting as a low impedance source of current does not require resetting if the electrodes are moved slightly and in the case of a cascade of aerofoils the correct degree of circulation is automatically introduced when the deflection is altered by moving the side walls.

To measure the potential at a point near the aerofoil a probe is placed in position and its potential is balanced against the potential at the junction point of a resistance capacity bridge (Fig. 2). The off-balance current is preamplified and after filtering off the mainspickup at the probe, is fed to the oscilloscope so that when the reading of the potential is taken no current is withdrawn from the local electric field in the tank. To facilitate the balancing of the bridge circuit a synchronising signal from the master oscillator is fed to the second beam of the oscilloscope so that the out-of-balance component of the bridge is indicated by the phase relationship between the two traces on the cathode-ray tube screen. To measure the potential gradient the potential is measured at several points at intervals of 0·015 in. along the normal to the aerofoil surface using the micrometer traverse gear (Fig. 4) which is brought into position using the main traverse gear (Fig. 3), by means of which the position of the probe can be accurately determined over the whole region of the tank.

3.3. *Calibration.*—To facilitate the development of the apparatus and its associated technique a tank representing flow around a cylinder was built. In this tank the theoretical streamlines passing at a minimum distance of $4r$ from the centre of the cylinder of radius r were shaped in copper and formed the bounding side walls, while the tank, which was $\frac{1}{2}$ in. deep, was closed by two Tufnol end walls which represented the hydrodynamic potential lines. The results obtained are compared with the theoretical curve in Fig. 5. The results were found to be within 1 per cent of the approach velocity.

3.4. *Applications.*—To facilitate the electric tank determination of flow around many cascades of aerofoils at varying incidences and outlet angles a universal electric tank (Fig. 6) was constructed. Upon an iron framework base is clamped a tank, 1 in. deep, in the base of which a Tufnol insert may be placed. Upon this Tufnol insert the aerofoils of a $\frac{1}{2}$ in. span may be mounted with all their electrical connections readily accessible in a waterproof junction box. The stagger of the aerofoils and the angles of the inlet and outlet side walls are set by means of a goniometric bar which is attached to the micrometer traverse gear which can be rotated in a goniometric head (Fig. 4).

To measure the local potential gradient the probe is set against a mark on the central aerofoil, which is scribed at intervals of 5 per cent chord. The micrometer traverse gear is aligned with the measured direction of the normal at the point. The potential is then measured at intervals along the normal direction. From the results the local potential gradient is calculated which is then divided by the observed potential gradient in the outlet section to give the ratio of the local velocity to the outlet velocity from the cascade. Using Bernoulli's equation the pressure distribution may be found and the lift coefficient calculated. The deflection through the cascade is checked by measuring the direction of a stream-line one chord upstream and downstream of the cascade, using the main traverse gear.

This tank has been used successfully to determine the theoretical velocity distribution around several cascades at various inlet and outlet angles. A typical derived pressure distribution is shown in Fig. 7. The accuracy of the pressure distribution is within 4 per cent showing a velocity distribution accurate to within 2 per cent of the outlet velocity of the cascade.

A particular problem which arose in heat transfer work was to determine the theoretical velocity distribution around a central aerofoil of a cascade enclosed in ducting, the side walls of which did not represent the inlet and outlet streamlines of an infinite cascade. A diagram of one of the heat transfer rigs is shown in Fig. 8. To obtain the theoretical velocity distribution a five times full size model was constructed as an electric tank and the apparatus which has been discussed was used to determine the theoretical velocity distributions which included the effect of the ducting side walls. This resulting velocity distribution is shown in Fig. 9.

4. *Conclusion.*—Using the electrical analogy between aerodynamic streamlines and electric equipotential lines in geometrically similar systems, apparatus has been developed which can be used to determine the theoretical velocity distribution around any aerofoil in a cascade quickly and accurately. The accuracy of the technique is demonstrated in the determination of the velocity around a cylinder to 1 per cent of the approach velocity. The apparatus could readily be used to determine the velocity over any surface exposed to an air stream if a geometrically similar electric tank model is constructed.

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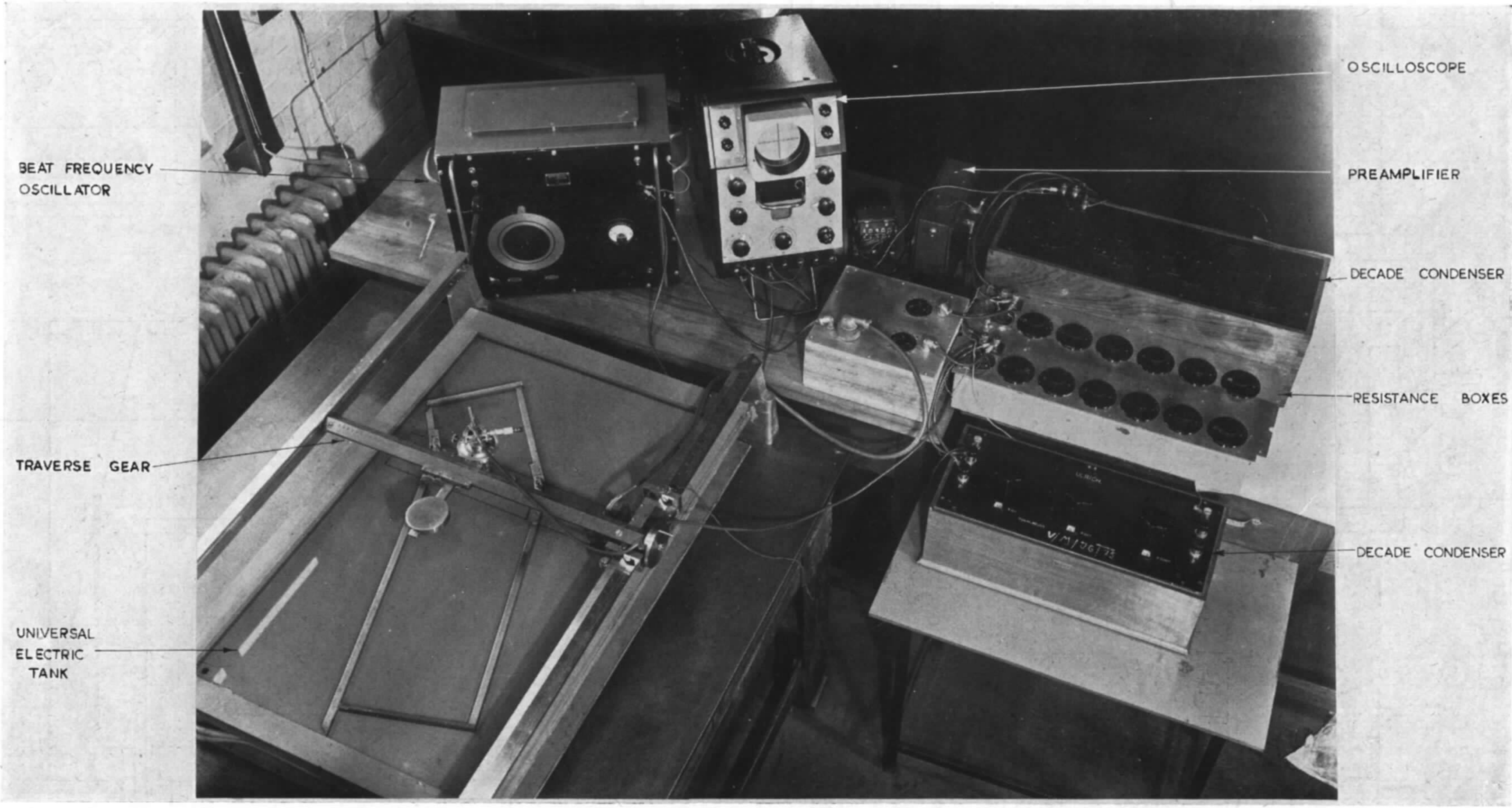

FIG. 1. Electric tank apparatus.

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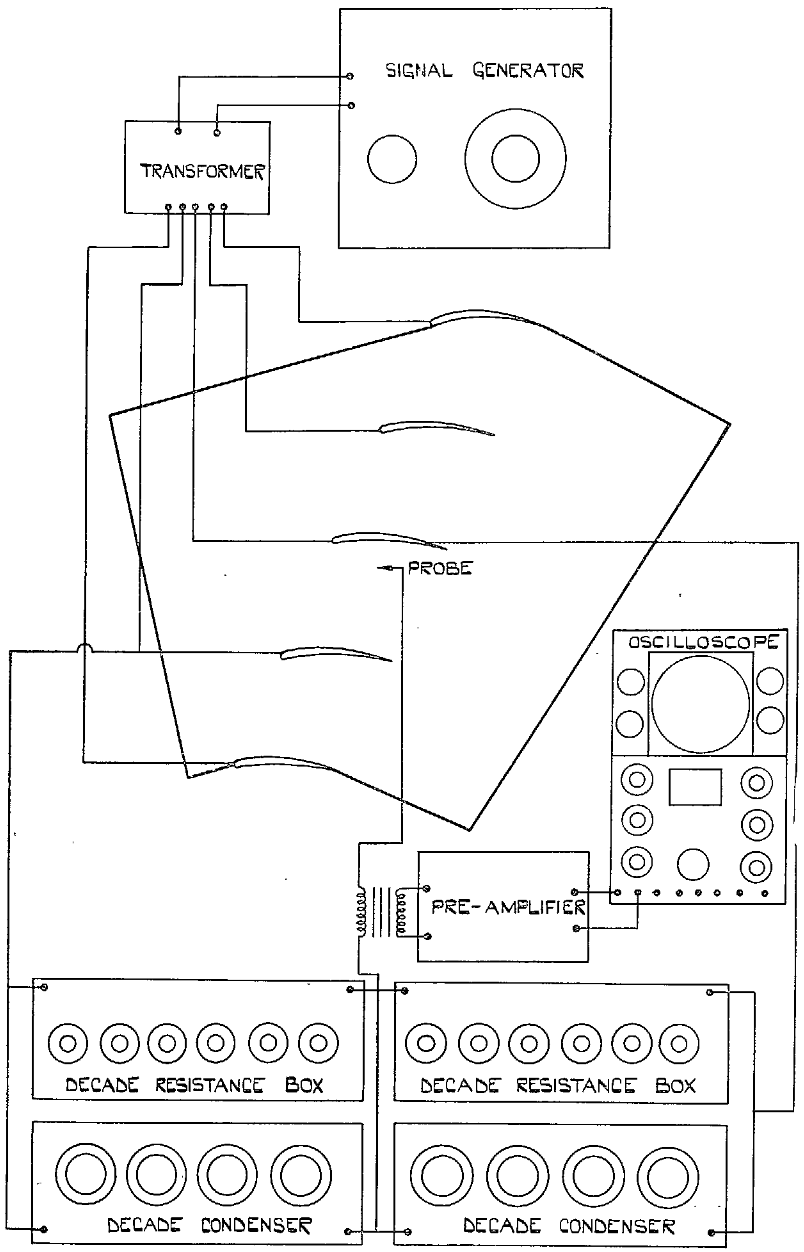

FIG. 2. Electrical circuit layout.

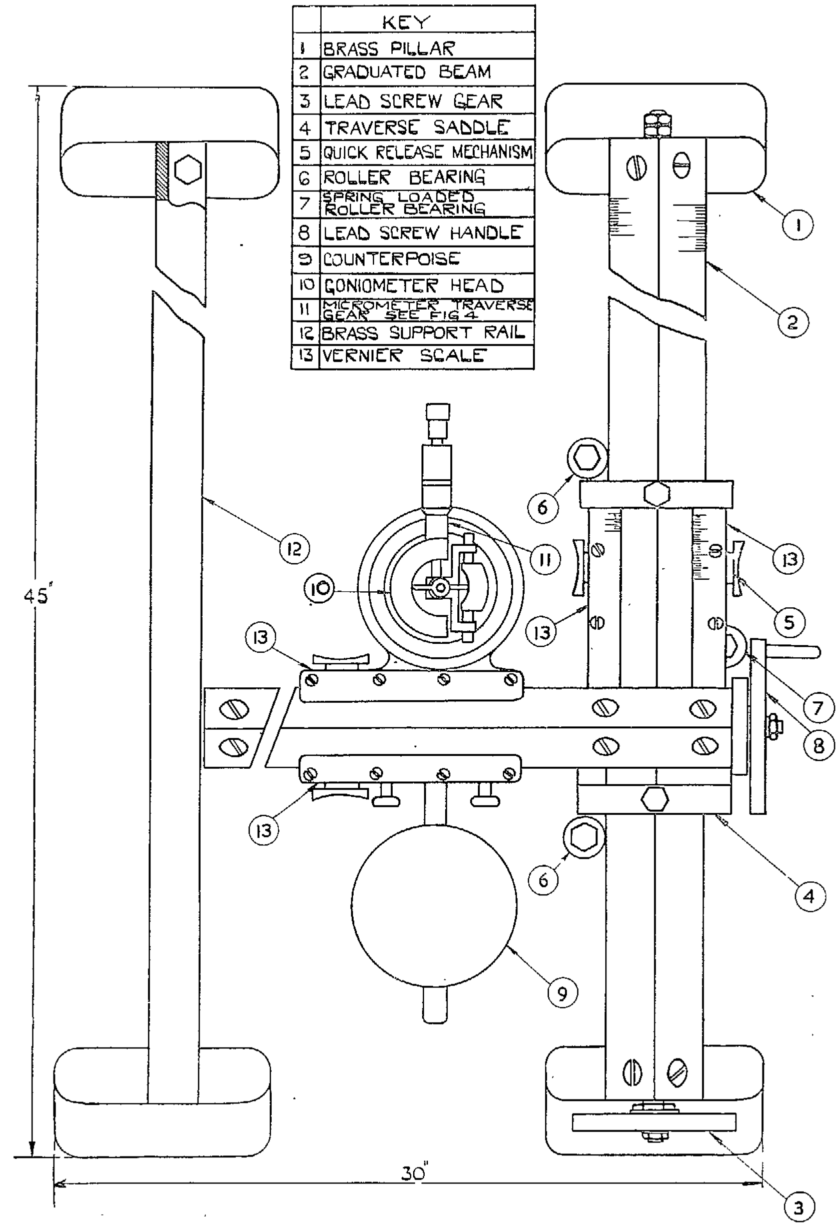

FIG. 3. Electric tank traverse gear.

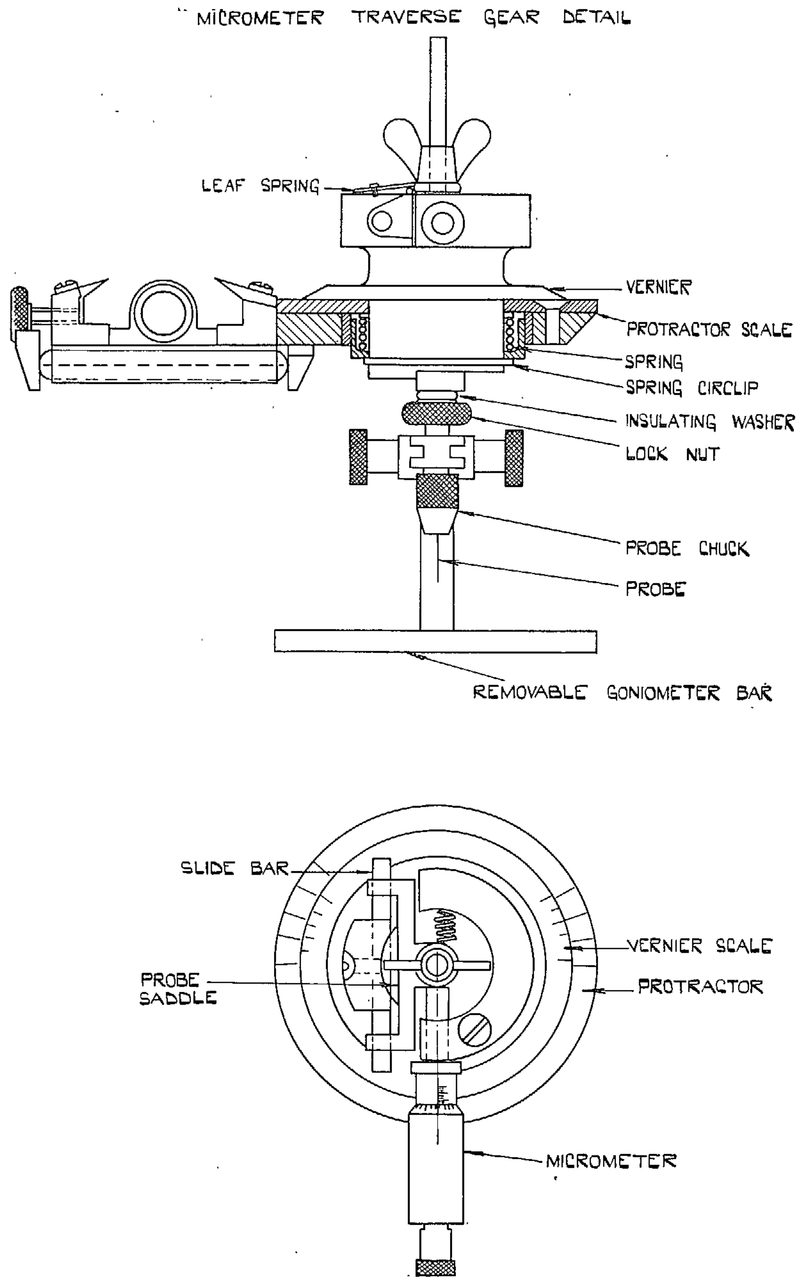

FIG. 4. Electric tank traverse gear.

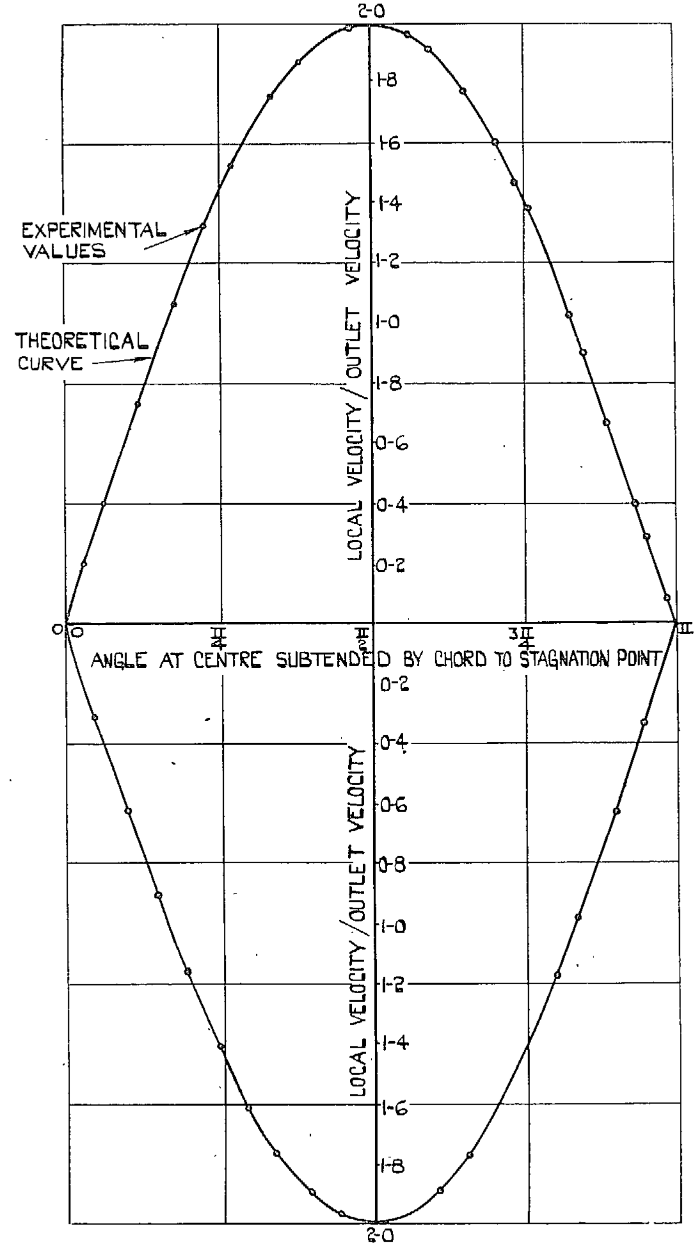

FIG. 5. Velocity distribution around cylinder.

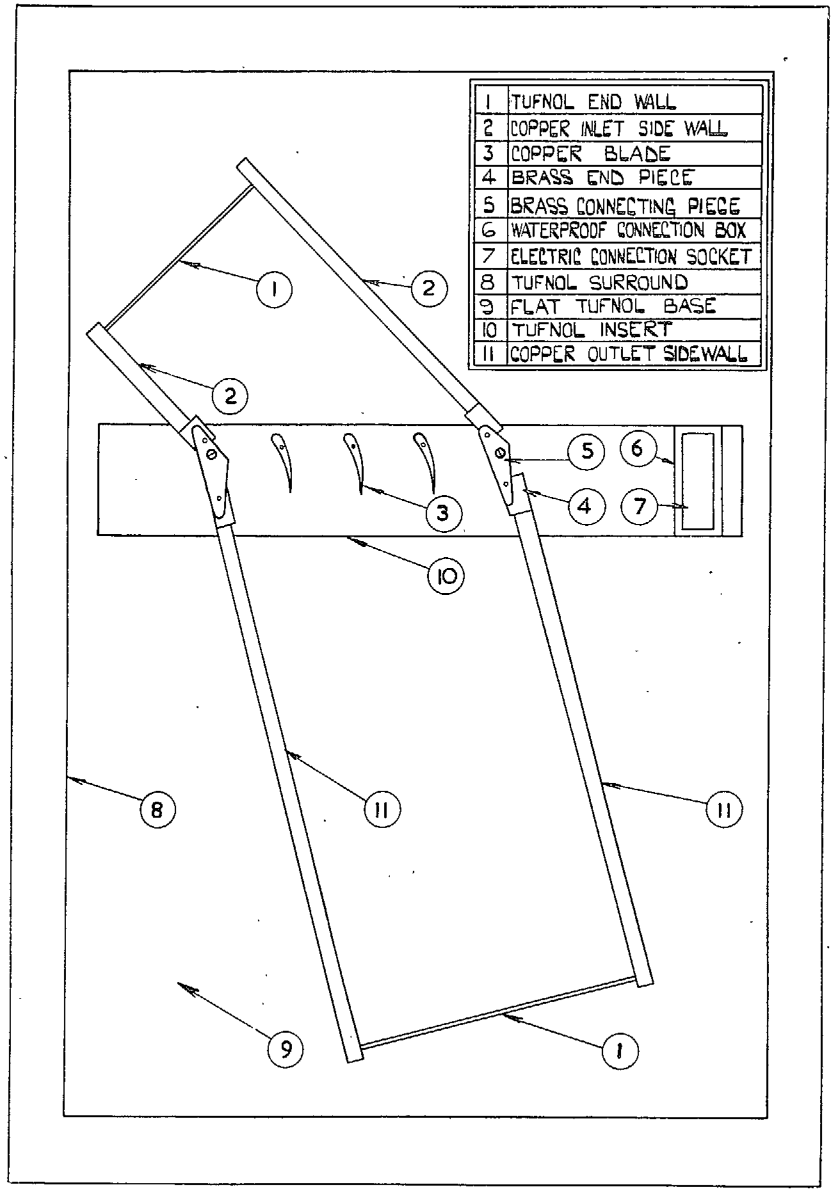

FIG. 6. Universal electric tank.

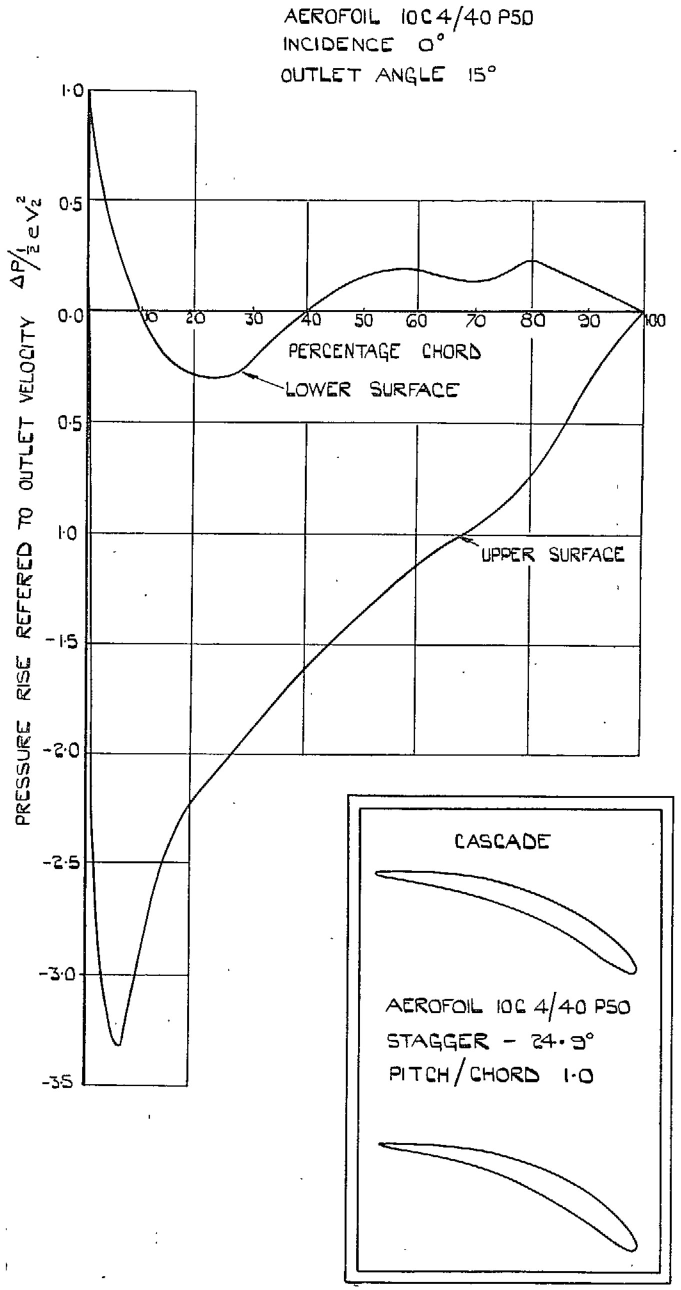

FIG. 7. Pressure distribution.

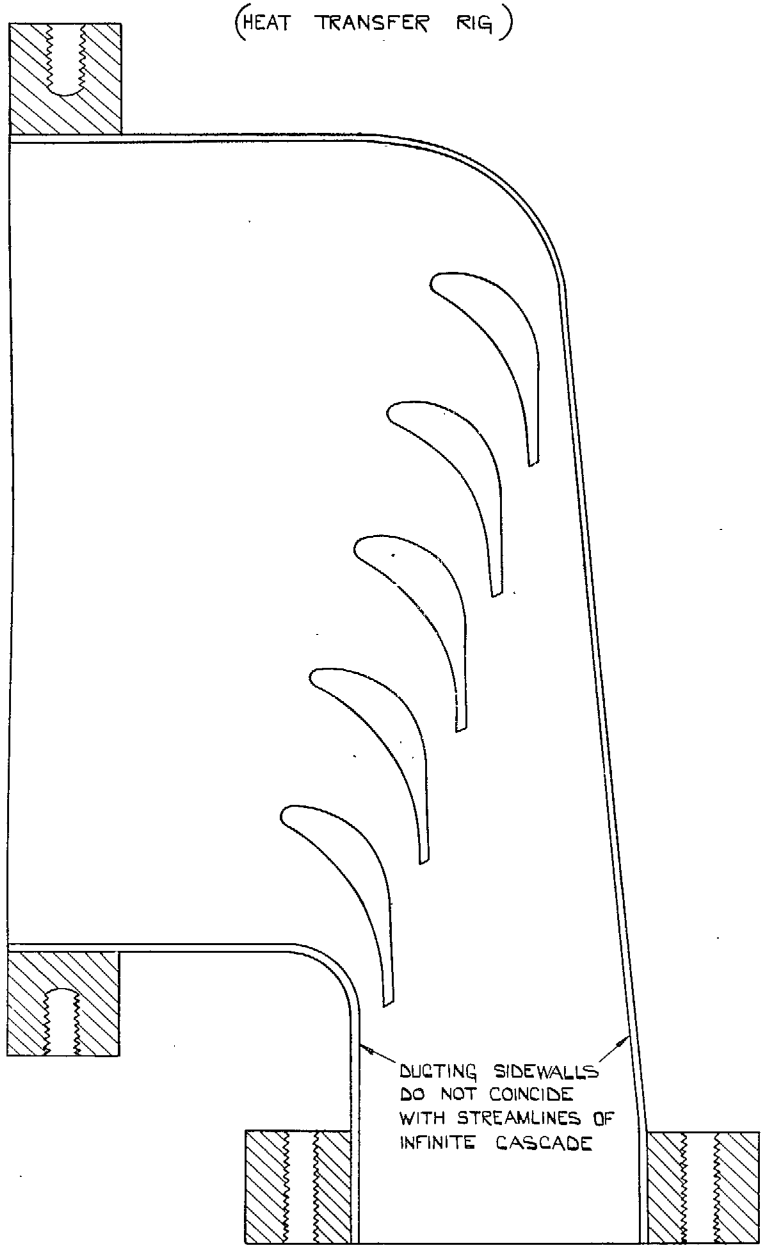

FIG. 8. Nozzle cascade.

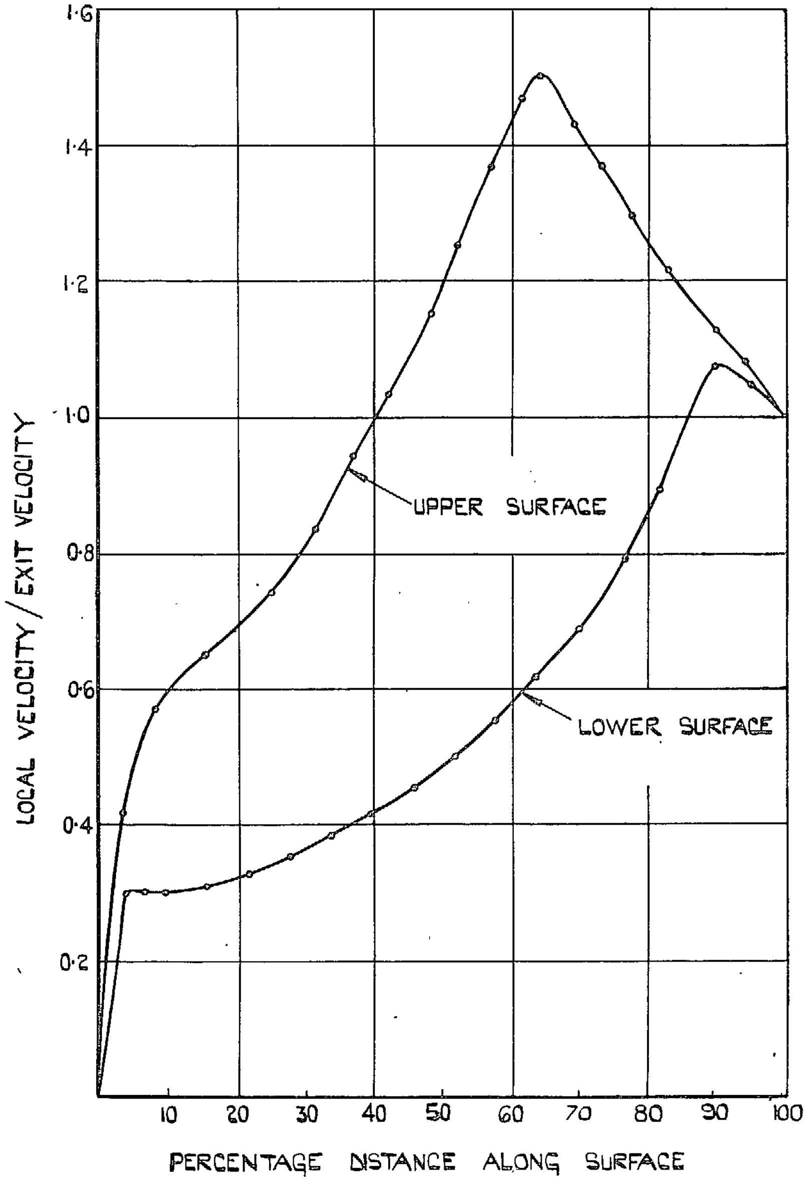

FIG. 9. Velocity distribution of central blade in heat transfer nozzle rig model shown in Fig. 8.

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