A PROBE TO MEASURE STAGNATION PRESSURE, STATIC PRESSURE, YAW AND PITCH ANGLE

by

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SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

May 26, 1958

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Department of Mechanical Engineering, May 1958

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Accepted by Signature redacted
Chairman, Departmental Senior Thesis Committee

ABSTRACT

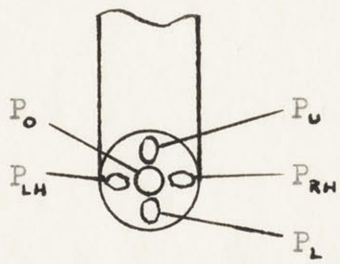
A six-hole probe which can be used to determine the pitch angle, yaw angle, stagnation and static pressures in a stream was designed and tested. Readings obtained for the probe for the static and stagnation pressures were compared with those for a conventional pitot tube in the same flow and the results of the test indicated that the six-hole probe functions properly.

Detail traverses of the flow in the inlet section of the flutter tunnel located in building 33, Massachusetts Institute of Technology, were made using the six-hole probe in order to determine the stagnation and static pressures and the direction of the flow. The results showed maximum variations of the stagnation and static pressures of $\pm 2\%$ and $+12\%$, respectively, based on the dynamic head. The maximum yaw angle variation was from $-.5^{\circ}$ to $+2.5^{\circ}$, and the maximum pitch angle variation $-.5^{\circ}$ to $+1.5^{\circ}$.

TABLE OF CONTENTS

NOMENCLATURE

P_{orc}	reference stagnation pressure in calibration tunnel
P_{rc}	reference static pressure in calibration tunnel
P_{REF}	pressure read by reference probe
P_o	stagnation pressure
P_{or}	reference stagnation pressure
P	static pressure
P_r	reference static pressure
P_{RH}	pressure at right hand hole
P_{LH}	pressure at left hand hole
P_L	pressure at lower hole
P_U	pressure at upper hole
α	pitch angle: determined by P_U, P_L and positive for $P_L > P_U$
β	yaw angle: determined by P_{RH}, P_{LH} and positive for $P_{RH} > P_{LH}$



Looking at tip of probe

I INTRODUCTION

The standard procedure used to establish the static and stagnation pressures and the direction of flow in a stream requires the use of at least two different probes. A five-hole probe is employed to measure the pitch, yaw and stagnation pressure and some other probe to determine the static pressure. Therefore, in order to determine these properties at any point in a stream two separate measurements are required.

It should be possible to design a six-hole probe which would record all the pressures at one reading. If such a probe could be made to function properly the time required to obtain the data necessary would be greatly reduced, especially if many points in the flow field are to be investigated.

The purpose of this report is to design and test a six-hole probe and to use the probe to investigate the flow in the inlet section of the flutter tunnel located in Building 33, Massachusetts Institute of Technology.

II PROBE DESIGN

It was decided to build the six-hole probe combining the usual five hole probe with the pitot probe. The position of the static pressure holes was determined from "Aerodynamic Measurements" by R. C. Dean and is shown in Fig. 1.

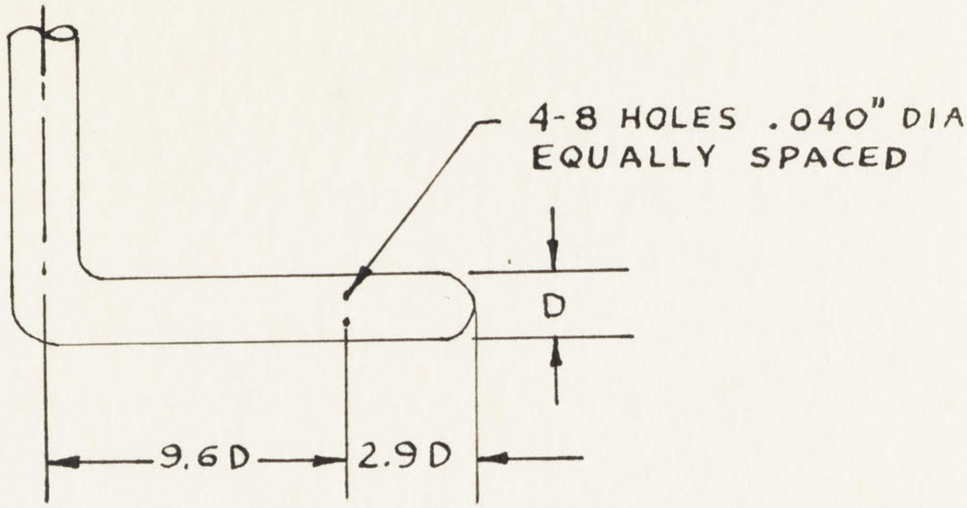


FIG. I-Standard stream pressure probes

A detail drawing of the probe is shown in Fig. 2. Especially noteworthy is the static pressure duct, which from the tip of the probe to section A-A is represented by the probe stem itself, (Fig. 2). At A-A a plug is fixed, sealing the rest of the stem from the front part of the probe (Fig. 2, section A-A and B-B). The five pressure tubes, representing yaw, pitch and total pressure, which up to section A-A ran inside the static pressure duct (or stem) are lead through a sealed hole in the plug. The static pressure is from here on transmitted to the end of the probe by a separate tube which is inserted in another sealed hole in the plug, and is open on both ends.

III PROBE HOLDER

The overall length of the probe is three feet and it was desired to take measurements at points four and one-half feet below the top of the tunnel in the test section. A one-half inch O.D., threeeighths inch I.D. and three and one-half feet long extension tube was used. Slots were milled in the probe, extension tube and center piece (Fig. 3 and 4), assuring no relative motion between them when locked in place by the locking pieces (Fig. 4). The slots milled in the extension tube were spaced six inches apart so that measurements could be taken vertically every six inches in the test section. All slots were milled such that the angular position of the probe was preserved independent of the vertical position. The flat plate holding the extension tube (Fig. 3 and 4) was fastened to the top of the tunnel. The center piece was passed through a hole in the plate and tunnel and held in place by a collar. The center piece was free to rotate about its axis. In order to measure the yaw angle at each point a protractor was fastened to the flat plate and a pointer was fixed to the center piece.

If the probe and extension tube are not exactly vertical there will be quite a large error in the position of the tip of the probe when it is in its fully extended position (four and one-half feet below the top of the tunnel). In order to insure that the probe and extension tube were vertical, points were marked on the tunnel floor using a plumb line hung from the center of the holes on the top of the tunnel and the probe was lined up with these points by adjusting three set screws in the flat plate. It was also necessary to use the same reference direction when measuring the yaw angle at each point. To do this parallel lines were drawn through the points on the tunnel floor and the probe was lined up with these lines at each station.

When the traversing rig was tested in the tunnel it was found that the probe vibrated in the extended positions. In order to reduce this vibration the small part shown in Fig. 5 was designed. This part, in the form of a wing, was fastened on the probe as shown. Piano wire was then hung over this part and held in place by a small groove. The piano wire was passed through two holes in the tunnel floor with a weight of about five pounds attached to it below the tunnel floor. This arrangement proved very satisfactory for reducing the vibration and also helped to line up the probe.

IV MEASUREMENTS IN THE TUNNEL

Measurements were taken in the inlet section of the wind tunnel at twelve different stations. At each station measurements were taken every six inches from a point six inches from the bottom of the tunnel to six inches from the top. Thus, nine points were investigated at each station or a total of 108 points throughout the test section.

The yaw angle was determined by rotating the probe until the pressure in the yaw tubes was balanced ($P_{RH}=P_{LH}$) and noting the angle through which the probe was turned from the reference position established by the parallel lines on the tunnel floor.

In order to determine the pitch angle the probe was calibrated in a tunnel where the direction of flow was known and a plot of $\frac{P_L - P_U}{P_o - P}$ versus pitch angle constructed. Therefore, by noting $P_L - P_U$ the pitch angle was determined.

The static and stagnation pressures were measured independently with respect to the reference pressure P_r.

V RESULTS

The six-hole probe was compared with a conventional pitot tube in the same flow. The stagnation pressure ratio $\frac{P_o - P_{orc}}{P_{orc} - P_{rc}}$ was plotted against y/h where y is the distance from the bottom of the calibration tunnel and h is the height of the tunnel (8 inches). The results of this comparison are shown in Fig. 7.

Fig. 8 shows the results of plotting the static pressure ratio $\frac{P - P_{rc}}{P_{orc} - P_{rc}}$ against y/h for both probes.

The calibration of the probe for pitch angle is shown in Fig. 9 where the ratio $\frac{P_L - P_U}{P_o - P}$ is plotted against the pitch angle.

In Fig. 10 contour lines of constant pitch angle in the inlet section of the tunnel are plotted, and in Fig. 11 contour lines of constant yaw angle are plotted. Contour lines of constant stagnation pressure ratio $\frac{P_o - P_{or}}{P_{or} - P_r}$ in the inlet section are plotted in Fig. 12, and in Fig. 13 lines of constant static pressure ratio $\frac{P - P_r}{P_{or} - P_r}$ are plotted.

VI DISCUSSION OF RESULTS

Figures 7 and 8 show that the six-hole probe functions properly and is a perfectly good means of measuring the static and stagnation pressures as well as the pitch and yaw in a flow.

From the contour plots of pitch angle and yaw angle it is evident that the direction of the flow does not vary a great deal in the inlet section of the tunnel. The largest pitch angle found in the test was 1.5° and the largest yaw angle determined was 2.5°.

The stagnation pressure ratio also shows very little variation throughout the test section. The largest difference in the ratio between any two points in the section is .04. The static pressure ratio varies more than the stagnation pressure ratio, the largest value being .12.

The irregular shapes of the contour plots could be accounted for by looking at the schematic diagram of the wind tunnel as shown in Fig. 14. The supports for the motors of the flutter project and the supporting structure for the helicoptor project are in the stream and the wakes from these objects are probably still in evidence in the inlet section of the tunnel in addition to the wakes of the fan motor and turning vanes.

Even though the contour shapes are irregular there is little variation in the stream properties in the inlet section of the tunnel and the flow is essentially two-dimensional.

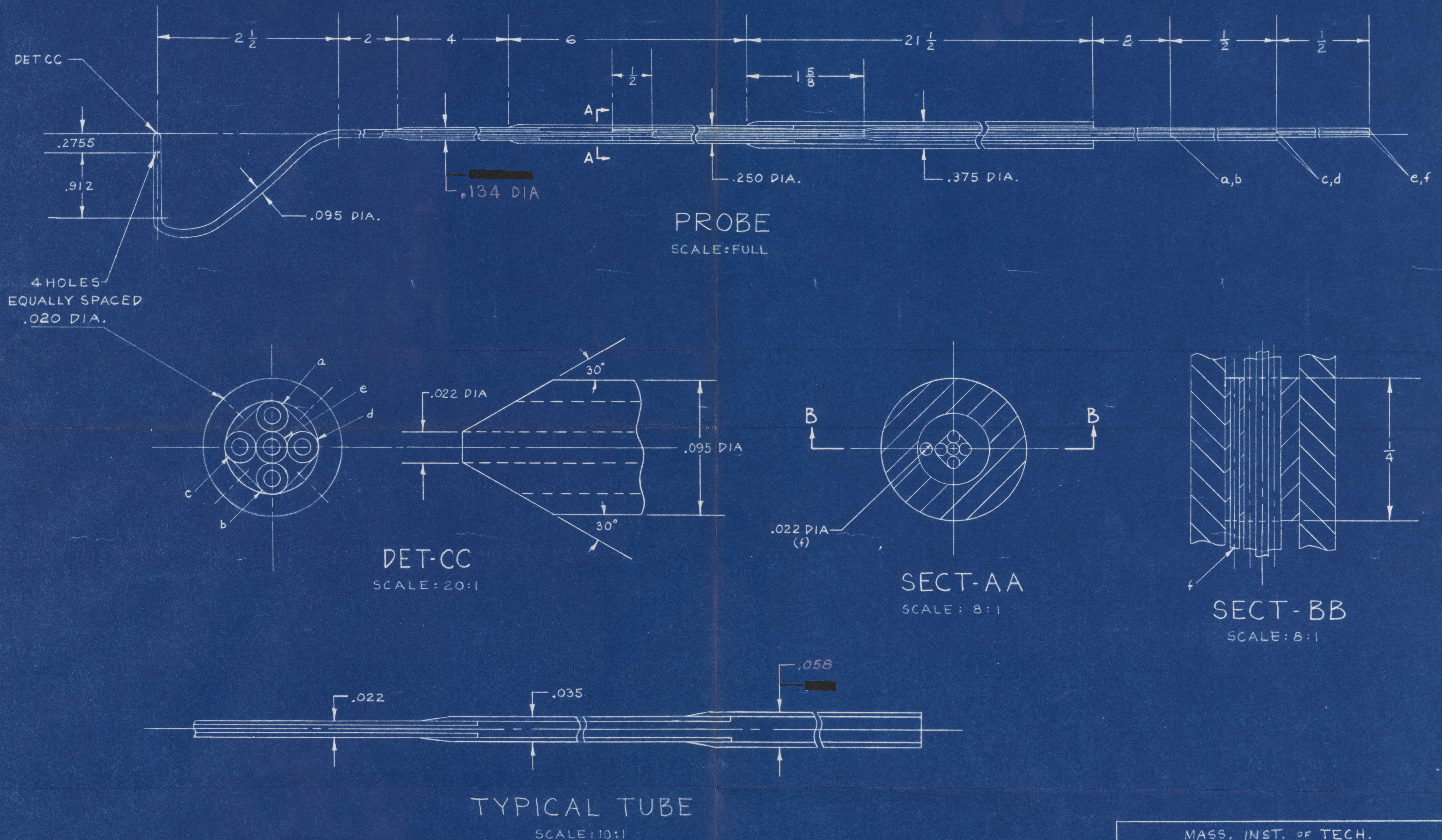


FIG. 2

MASS. INST. OF TECH. GAS TURBINE LABORATORY	
6 HOLE PROBE	
DRAWN BY: D. SAMELA	DATE: FEB. 20, 1958
CHKD. BY: K. SCHNEIDER	SCALE AS SHOWN
PROJ. NO 2005C	DRWG NO.

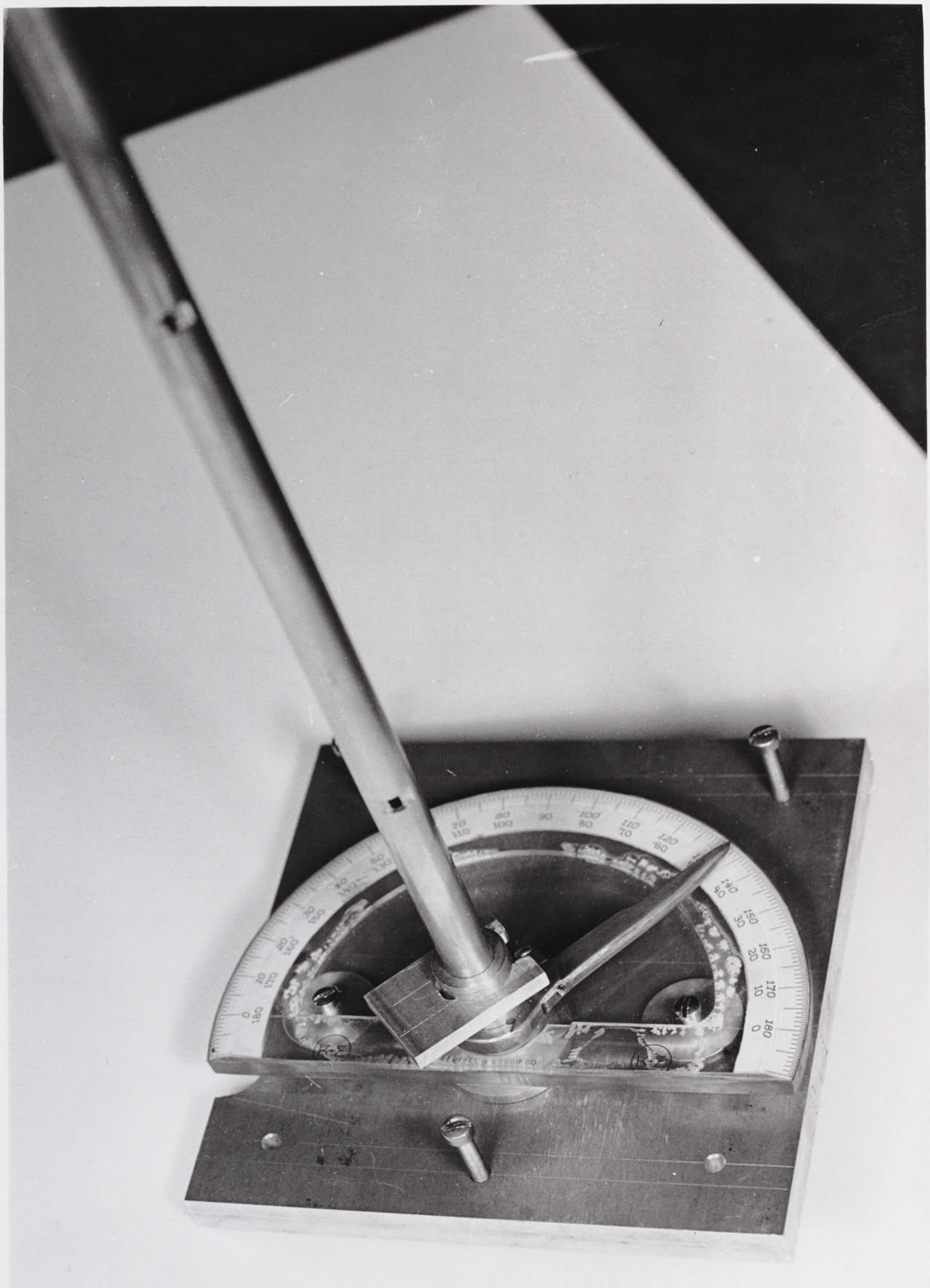


FIG. 3 - TRAVERSING RIG

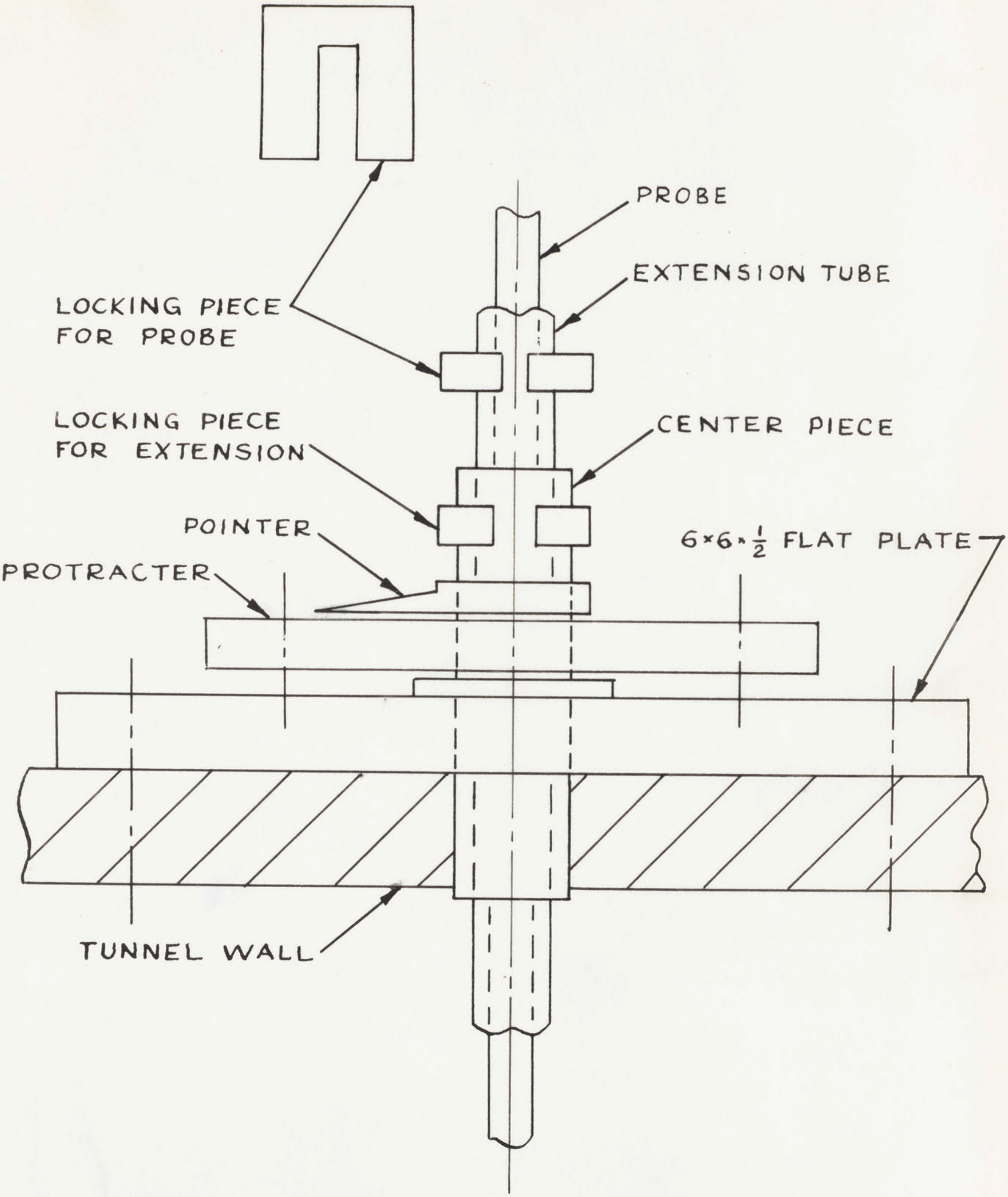


FIG. 4 - SCHEMATIC OF TRAVERSING RIG

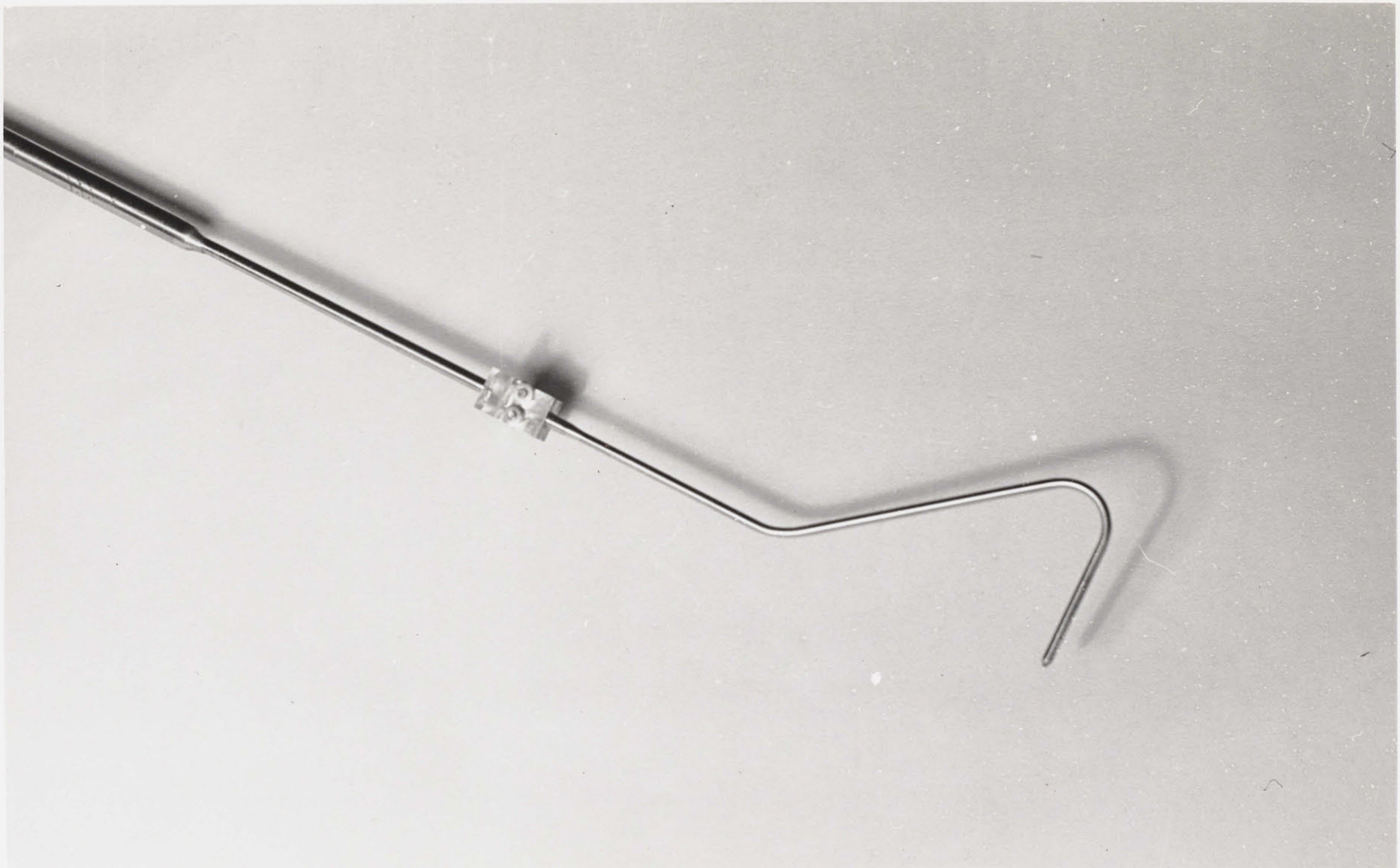


FIG. 5 PART USED TO REDUCE VIBRATION

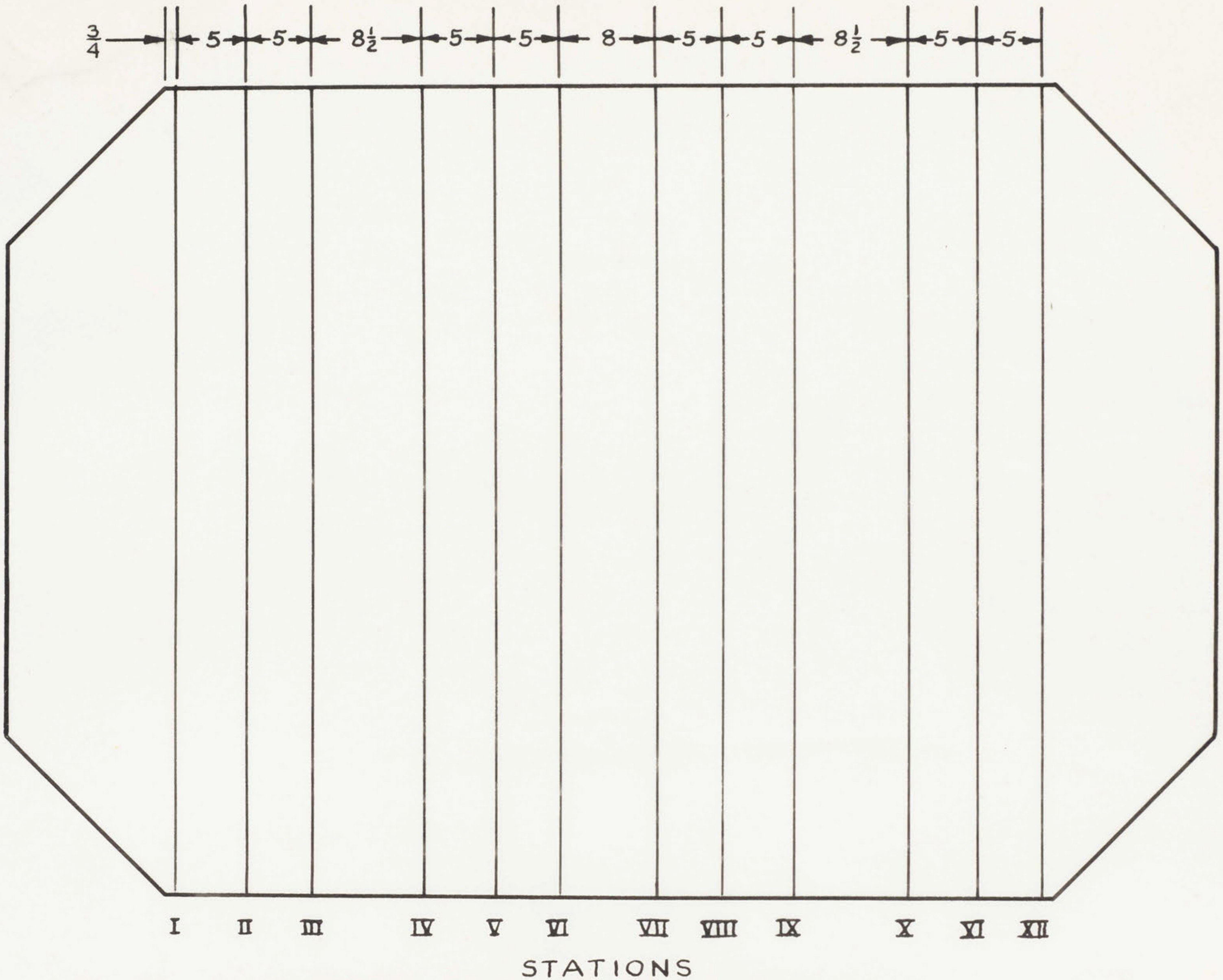


FIG. 6 - LOCATION OF STATIONS IN TEST SECTION

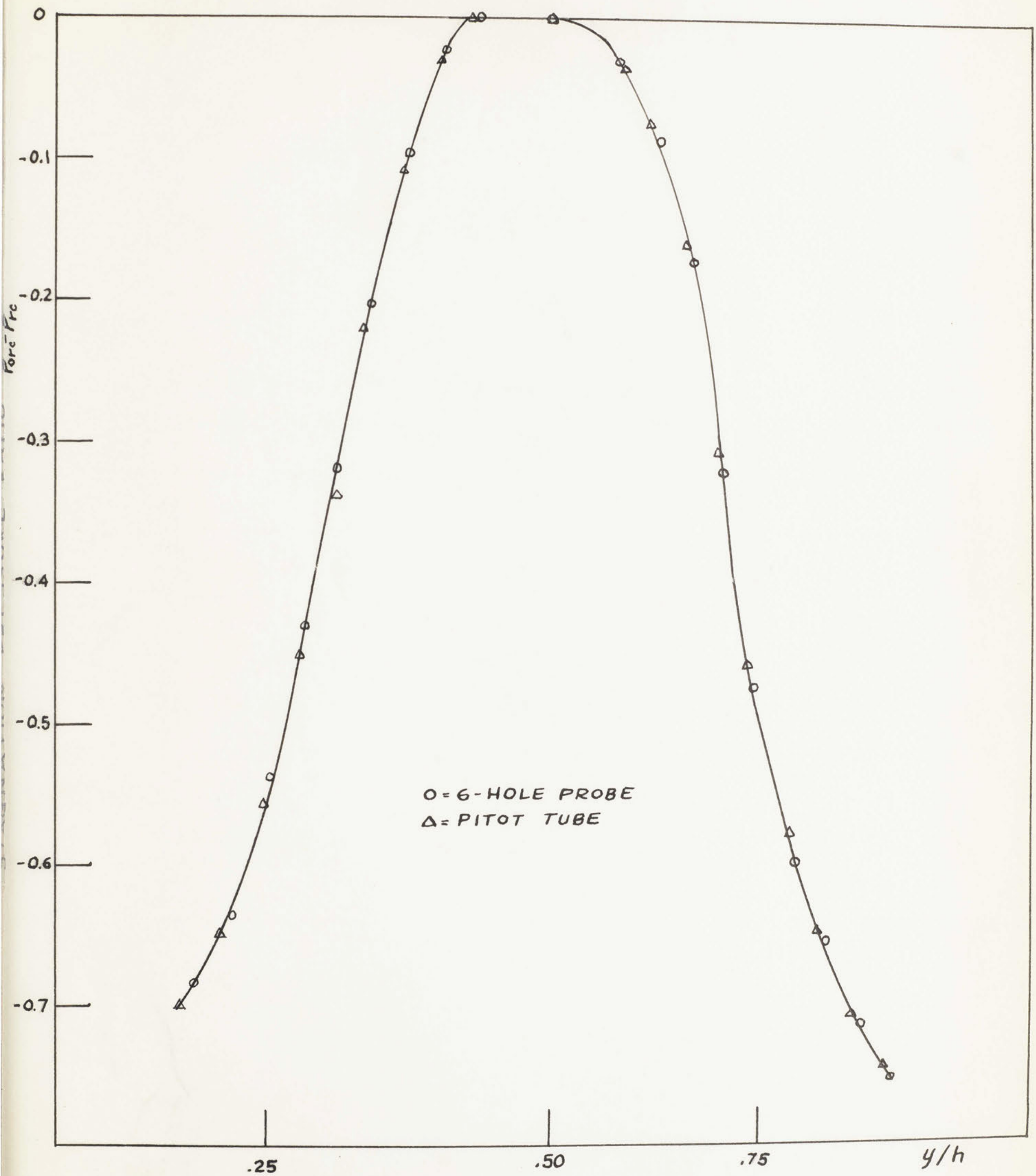


FIG. 7 - COMPARISON OF 6-HOLE PROBE WITH CONVENTIONAL PITOT TUBE

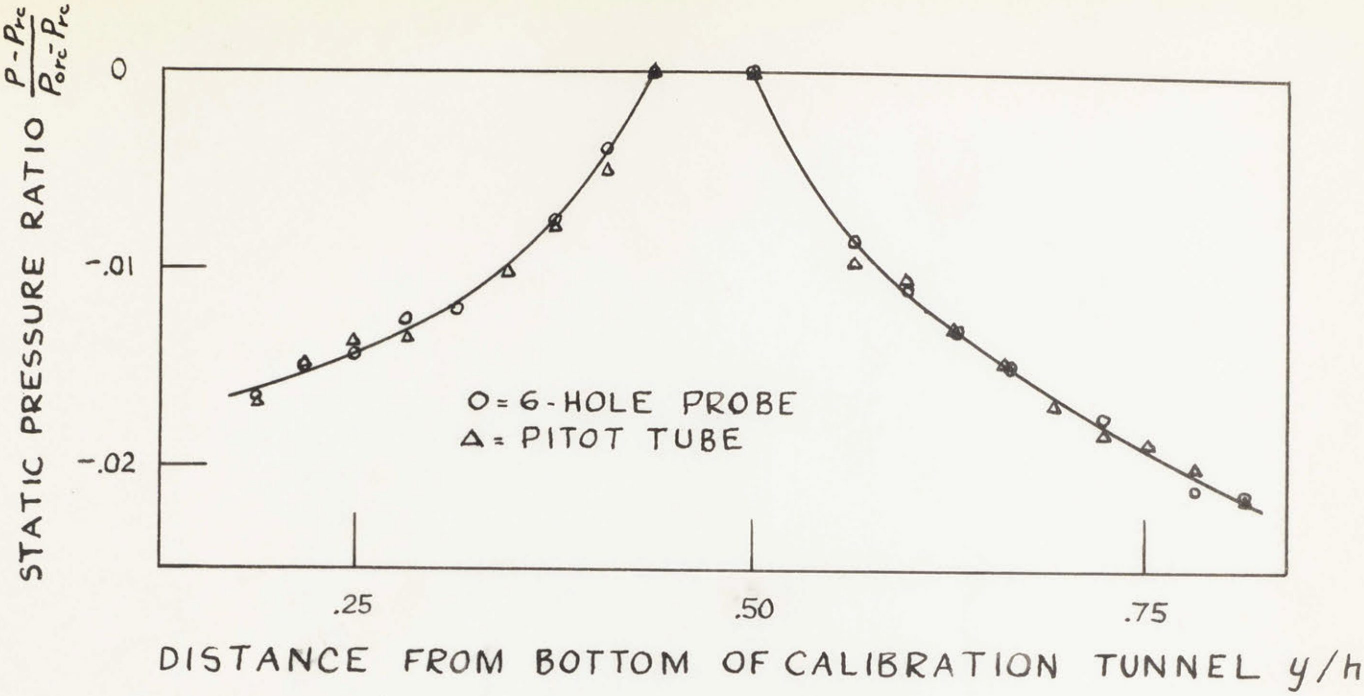


FIG. 8 - COMPARISON OF 6-HOLE PROBE WITH CONVENTIONAL PITOT TUBE

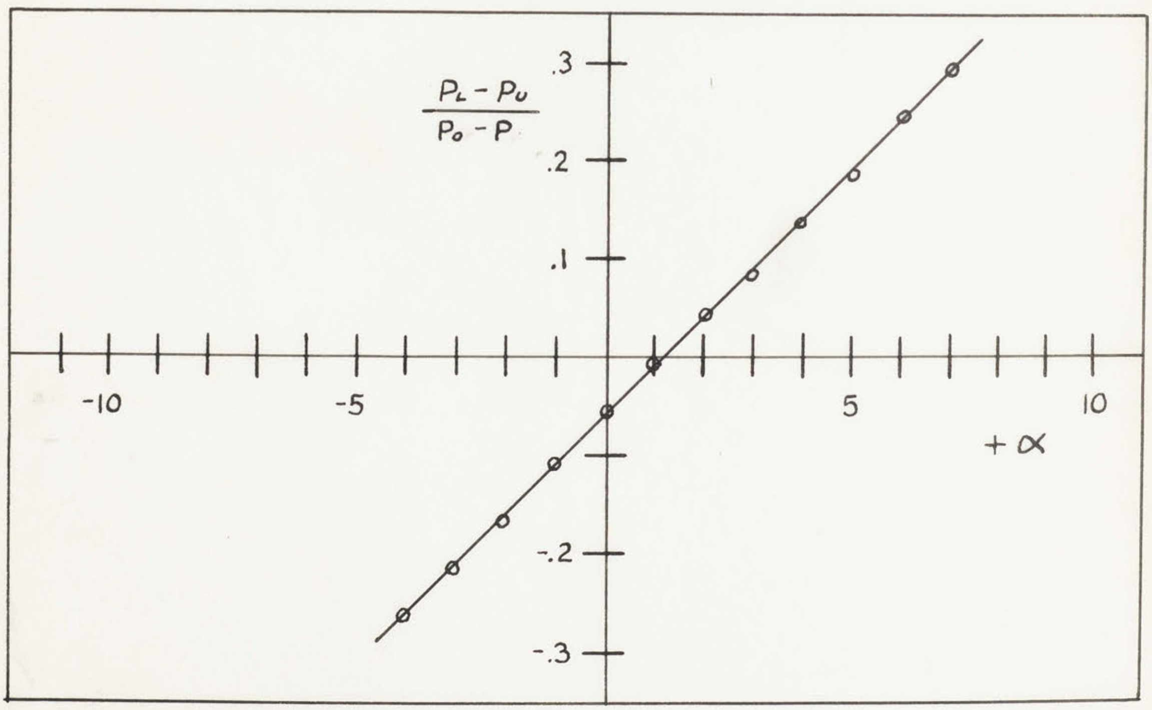


FIG. 9 - CALIBRATION OF PROBE FOR PITCH

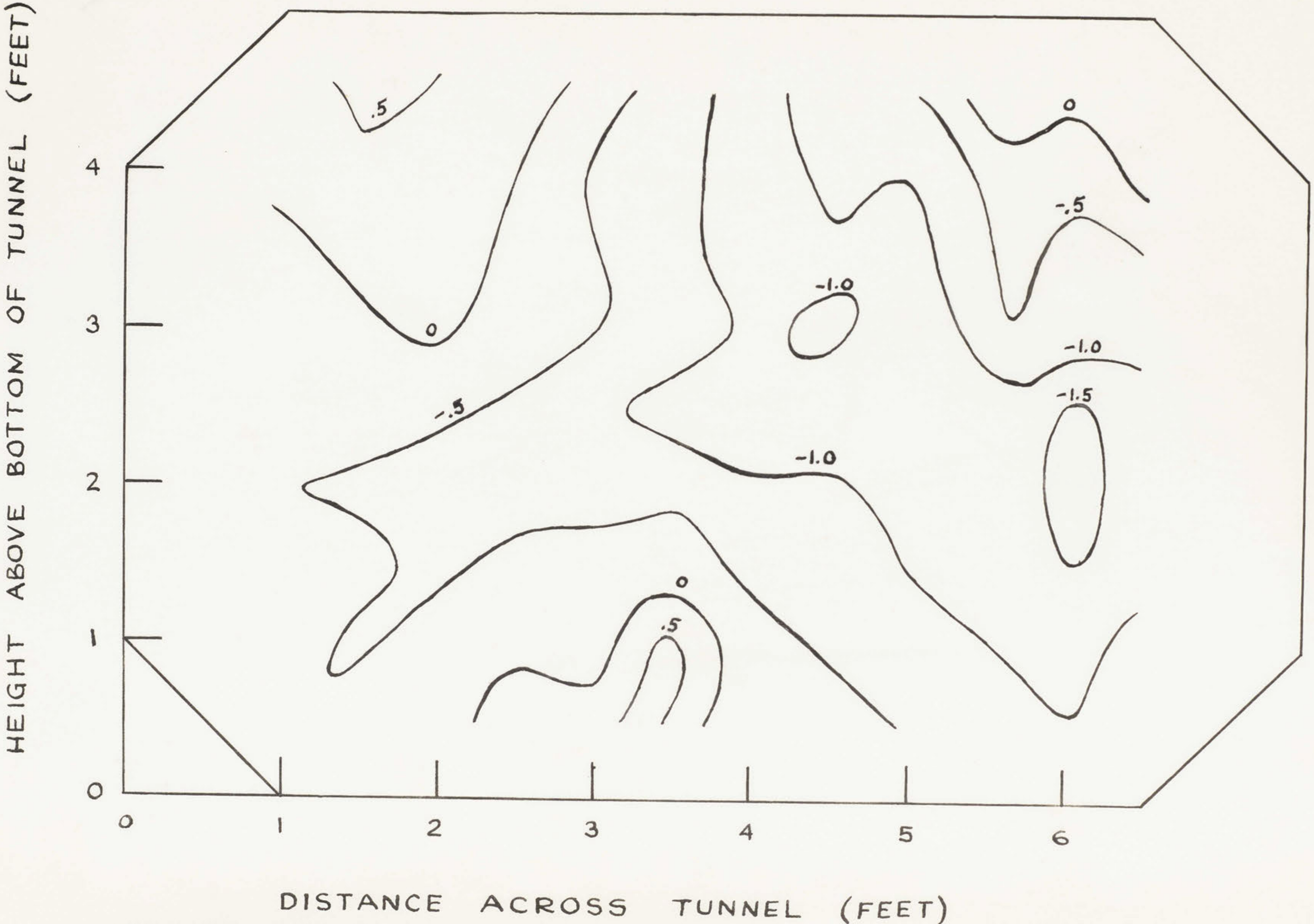


FIG.10-CONTOURS OF CONSTANT PITCH ANGLE

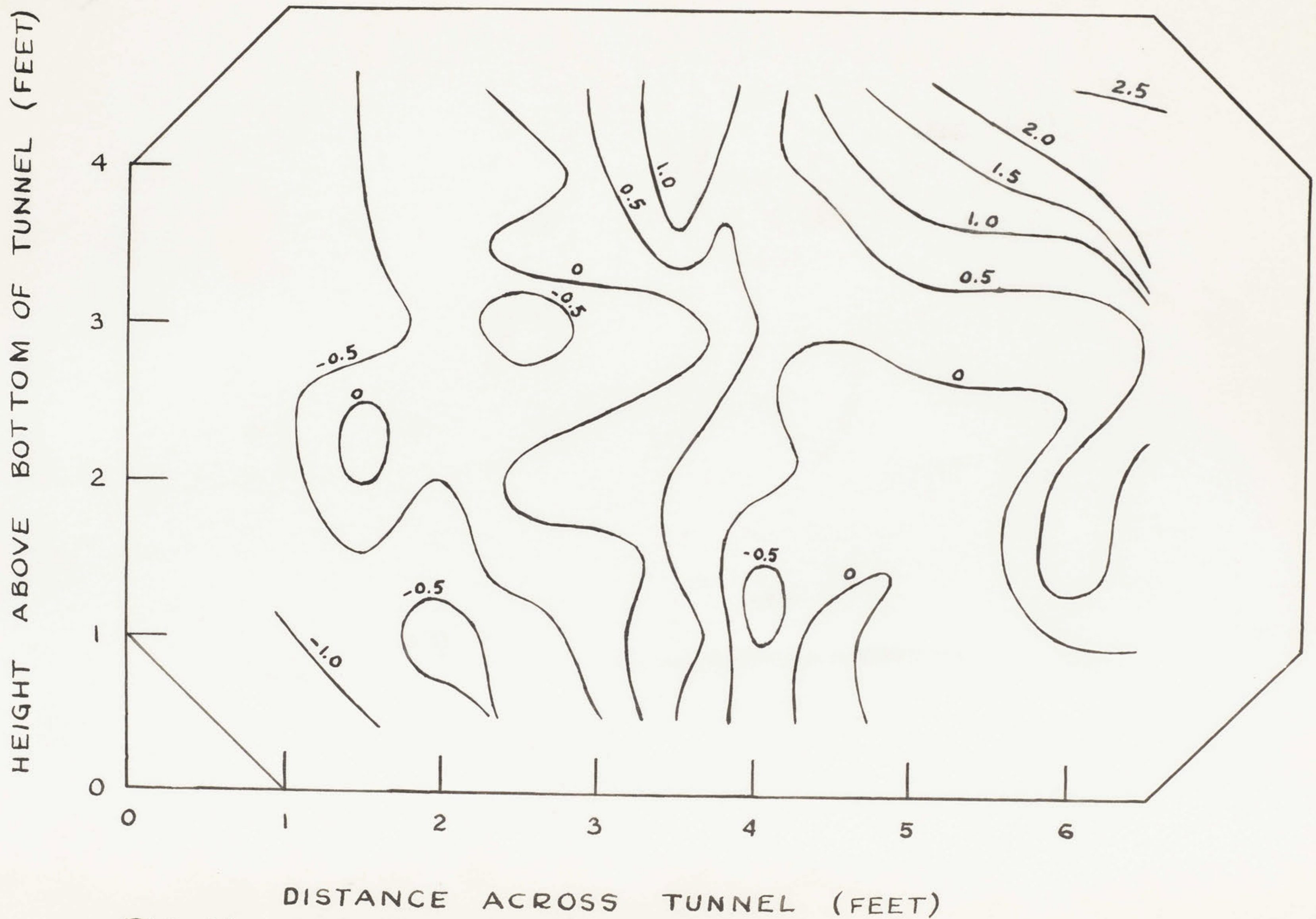


FIG. 11 - CONTOURS OF CONSTANT YAW ANGLE

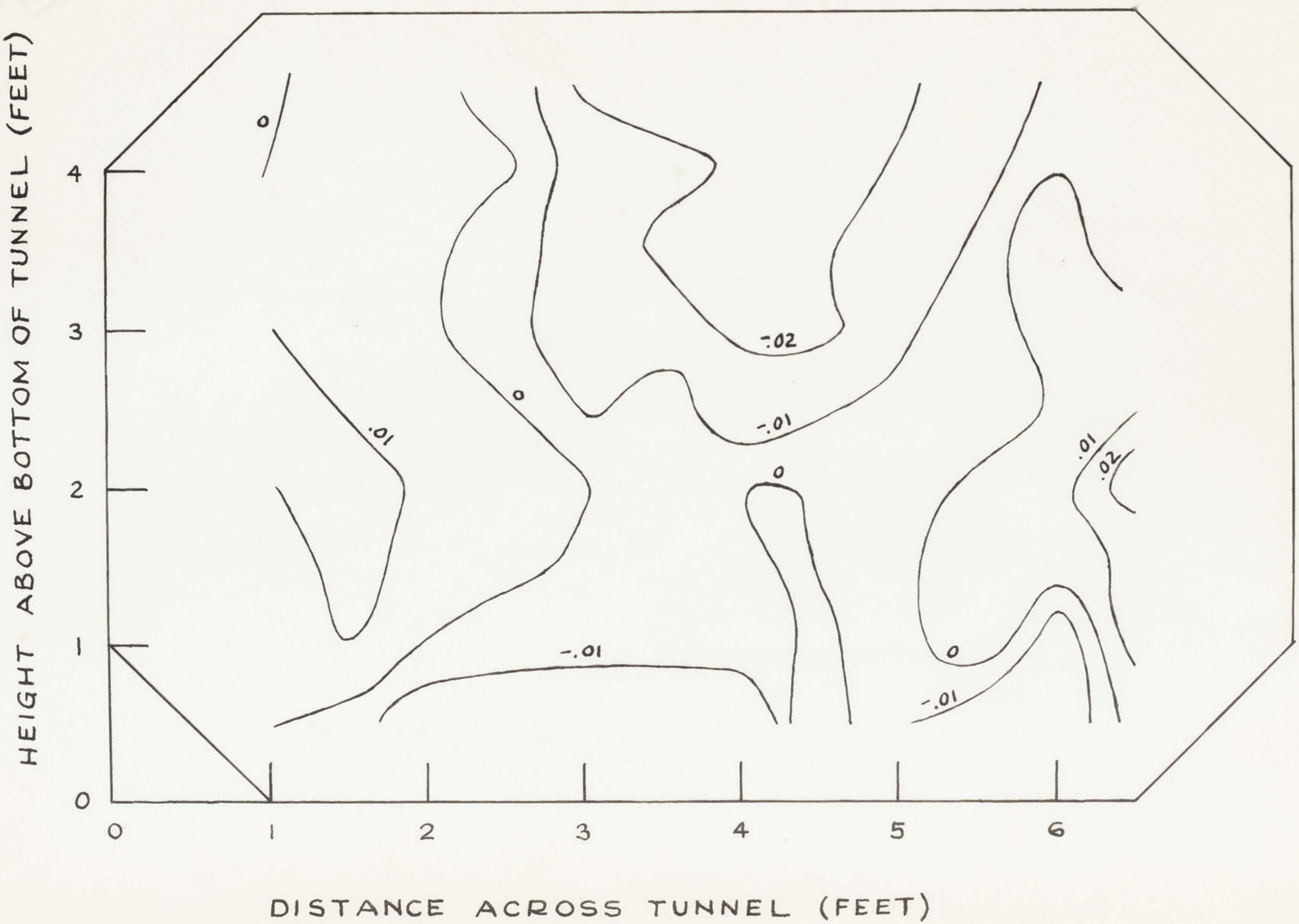


FIG. 12 - CONTOURS OF CONSTANT STAGNATION PRESSURE RATIOS

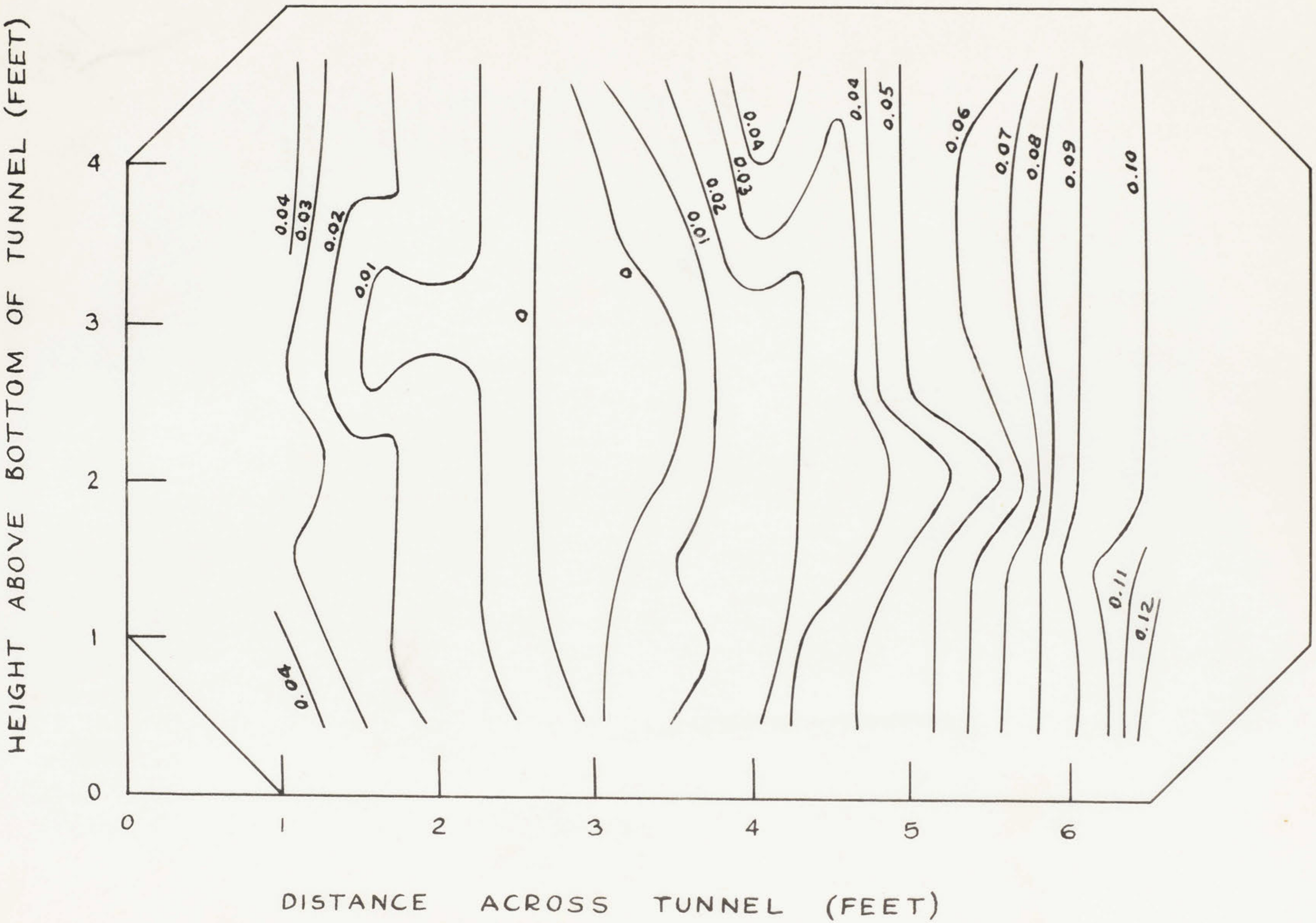


FIG. 13 - CONTOURS OF CONSTANT STATIC PRESSURE RATIOS

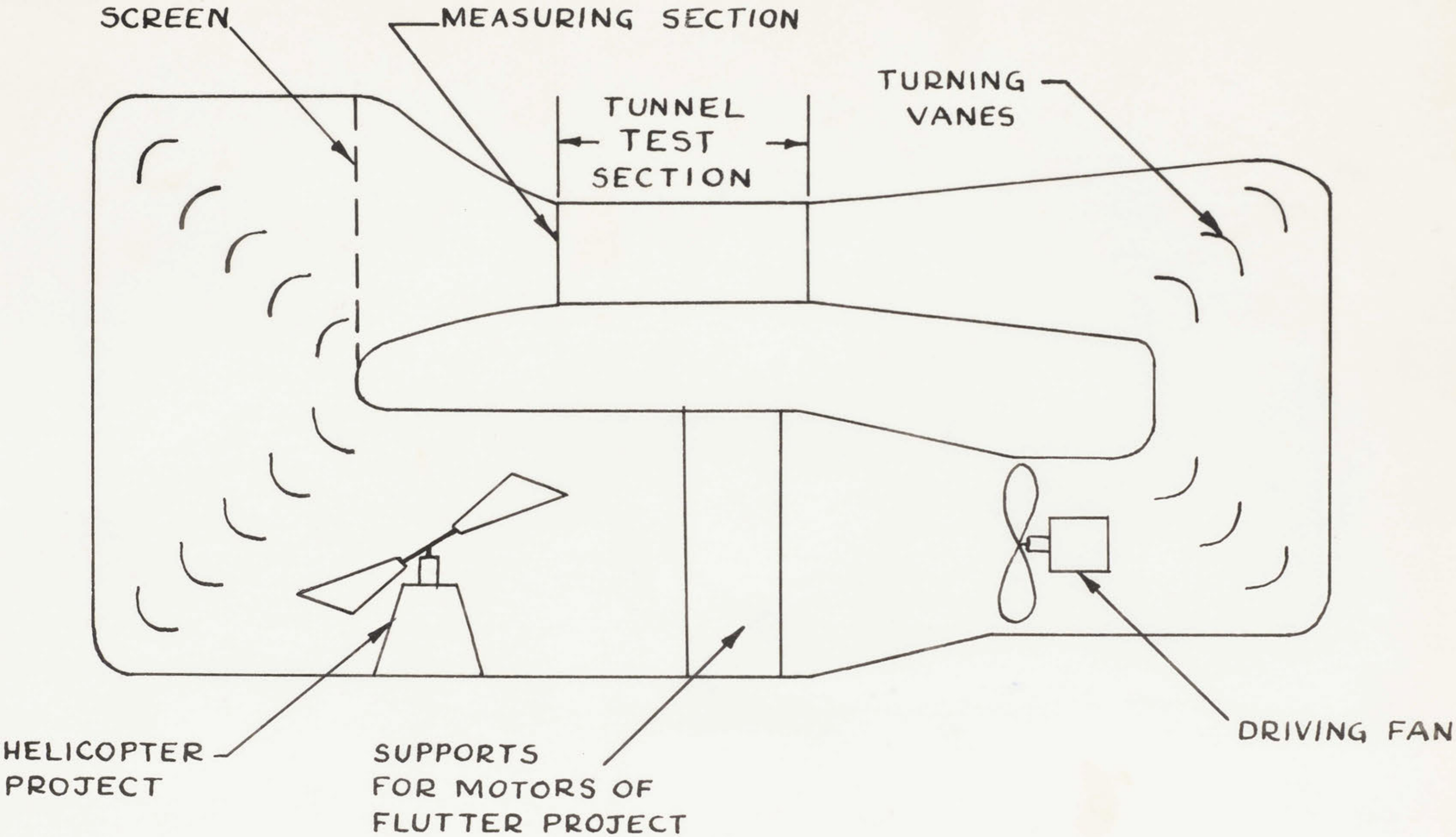


FIG. 14 - SCHEMATIC OF WIND TUNNEL