EXPERIMENTAL STUDY OF VELOCITY INDICATOR

by

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UNCLASSIFIED

Report

Project Number Sig. 0-131

DEVELOPMENT OF A MINIATURE AIR VELOCITY INDICATOR

- - -

Experimental Study to

Determine Sensitivity of New Designs

by

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Fort Monmouth, New Jersey

August 1954

UNCLASSIFIED

ACKNOWLEDGMENTS

The writers wish to thank Dr. D. F. Peterson, Head, Department of Civil Engineering, Colorado A & M College for making the facilities within the Hydraulic Laboratory of that Department available for the work described in this report. The assistance of Ralph Asmus, Supervisor of Shops, in the Hydraulic Laboratory during construction of equipment is especially appreciated.

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LIST OF SYMBOLS

The following symbols are used throughout this report. Symbols not appearing in this list but used in the text will be defined where they first appear. The letters L, M, T, and t under dimensions stand for length, mass, time, and temperature respectively.

Symbol	Definition	Dimensions
b	atmospheric pressure	$ML^{-1}T^{-2}$
d	diameter of nose on modified Prandtl tube	L
k	dynamic pressure coefficient	---
p	$b - p_S$	$ML^{-1}T^{-2}$
p_a	$b - p_s$	$ML^{-1}T^{-2}$
p_s	static pressure	$ML^{-1}T^{-2}$
p_S	total slot pressure = $kq + p_s$	$ML^{-1}T^{-2}$
q	dynamic pressure = $\frac{\rho U^2}{2}$	$ML^{-1}T^{-2}$
s	sensitivity = $\frac{k_0 - k_A}{A}$* (A measured in degrees)	---
A	angle-of-yaw	---
B	angle-of-pitch	---
C	angle-of-twist	---
D	diameter of downstream portion of modified Prandtl tube	L
L	nose length of modified Prandtl tube (distance from tip to upstream edge of slot)	L
P	$b - (p_S)_0$	$ML^{-1}T^{-2}$

*A subscript 0 indicates a quantity measured at $A = 0$ and the subscript A indicates a quantity measured at an angle-of-yaw A.

Symbol	Definition	Dimensions
P_T	total pressure --- $kq + p_s$	$ML^{-1}T^{-2}$
S	slot width	L
U	mean ambient velocity	LT^{-1}
μ	dynamic viscosity	$ML^{-1}T^{-1}$
ν	kinematic viscosity	L^2T^{-1}
ρ	mass density of air	ML^{-3}

Chapter I

INTRODUCTION

In many experimental studies, the measurement of air speed and direction is often necessary. Particularly in subsonic wind tunnel studies of air flow through model cities, near model aircraft, and over model terrain features are such measurements of extreme significance. For some cases measurements made by photographing smoke in the air stream or fine threads tied to slender supports at critical locations may yield the desired information. However, in a majority of cases measurements made at a point with greater accuracy than by photographic methods are desirable.

Several instruments which use the pressure differential principle have been developed for making measurements of both air speed and direction. Among these are the pitot sphere for 3-dimension flow, the pitot cylinder for 2-dimensional flow and the 2 or 4-probe pitot claw for either 2 or 3-dimensional flow respectively. The work described in this report was for the purpose of finding an improved design from the standpoint of having greater sensitivity to direction.

The project was divided into two phases in the initial planning. The first phase consisted of a systematic investigation to determine a new design which would yield both air speed and direction from measurements of pressure differences and pressure maxima or minima. The initial approach was to find a design having greater sensitivity to direction change than conventional designs. The second phase was to begin after a satisfactory design had been achieved and was to have included miniaturization of the design and development of a system to turn the device while in operation and indicate the direction with respect to a reference frame.

Only work pertaining to the first phase of the proposed project is presented in this report. Details of the designs tested, description of the test arrangement and auxiliary instruments, results of the tests and an evaluation of the results as they pertain to an air speed and direction measuring instrument are included herein.

Chapter II

REVIEW OF EXISTING DESIGNS

The object of this Chapter is to review briefly some of the basic instruments used for the determination of air speed and direction. Particular emphasis is placed on the evaluation of the sensitivity s for the various instruments. For this report, the sensitivity s has been adopted for purposes of comparison of the response of the various designs when subjected to yaw. The number of instruments cited for comparison in this Chapter is rather limited because data necessary for the evaluation of s are not readily available.

Stagnation Tube

This instrument is basically an open-end cylinder. When the axis of the stagnation tube coincides with the direction of the moving fluid and the open end of the cylinder is upwind, the pressure indicated as existing at the open end is termed the total pressure P_T. Up to about 11° of yaw (4:12), the value of P_T is not sensibly affected. As the angle-of-yaw is increased, the pressure as measured by the stagnation tube decreases. At an angle-of-yaw of approximately 63°, the value of P_T becomes equal to the static pressure p_s and beyond this angle, the total pressure is less than p_s. This angle of 63° is called the pressure reversal point. Since the rate of pressure decrease at the pressure reversal point is substantial and the value of $P_T - P_s$ changes sign, this point is rather well defined. The bisector of the angle between the two pressure reversal points defines the direction of flow. The authors believe that this device may be used to measure wind direction in the outlined manner within several degrees without any great difficulty. One advantage of the stagnation tube stems from the point by point measurements which can be made with it since only a very restricted zone of flow is involved. The mechanical arrangement for rotating the stagnation tube may present some difficulty when wind directions at a point are sought. The stagnation tube has the disadvantage that the readings are not sufficient within themselves to indicate speed. The sensitivity as defined in this report has a value of 0.034 per degree.

Prandtl Pitot Tube

The Prandtl pitot tube is an improvement over the stagnation tube in that the velocity can be ascertained from measurements made with it. The velocity as indicated by this device can be determined within an accuracy of 1% (3:251). The Prandtl pitot tube can be used in a fashion similar to that for the stagnation tube to determine the wind direction within about the same limits of accuracy. The difficulties encountered with the stagnation tube in making direction determinations will also be encountered with the Prandtl tube. The sensitivity of this instrument was found to be 0.05 as determined from data contained in Refs. 1:272, 2, and 3:238.

Pressure Claw

This instrument is made up of five pressure tubes. One tube is used to measure a pressure which is a function of both the static pressure and the velocity. The remaining four tubes are placed so that the axes of the tubes are inclined toward the axis of the instrument at such an angle that the change in pressure per increment of change in pitch or yaw is the greatest. These stagnation tubes are spaced equally about the axis of the instrument. Wind directions can be determined through a movement of the instrument until opposing stagnation tubes indicate identical pressures. According to data contained in Ref. 1:278, the sensitivity of the pressure claw is 0.041 per degree.

Pitot Cylinder

The pitot cylinder is an instrument which can be used to measure both the direction and speed of a moving fluid in 2-dimensional flow. Two pitot cylinders at right angles to each other can be used for speed and direction measurements in 3-dimensional flow. The instrument is made from a cylindrical tube having two pressure taps about 90° apart in a plane normal to the tube axis. The principle utilized for direction indication is the same as that for a pressure claw. The sensitivity of this instrument is high compared with those previously mentioned. The data contained in Refs. 1:275 and 9:8 indicate that the sensitivity of the pitot cylinder is 0.11 per degree.

Chapter III

PHYSICAL BASIS FOR DESIGN AND EXPERIMENTAL PROGRAM

In the following paragraphs an effort is made to describe how boundary layer development along the longitudinal axis of a modified Prandtl tube may be utilized to allow determination of air stream direction. Whether the anticipated designs will be of practical value can only be determined after experimental studies yield the magnitude of the effects to be described.

Flow near the end of a separation tube of a particular design is also considered.

<u>Boundary Layer Development on a Standard Prandtl Tube</u>

The pitot tube as modified by Prandtl (3:248) consists of a circular tube of diameter d, about 13d in length and having a stagnation tap 0.3d in diameter coaxial with the cylinder. The end of the tube containing the stagnation tap is made hemispherical in form and the opposite end is perpendicularly connected to a stem which serves as support for the tube and also as a means to transmit the stagnation and static pressures to a manometer. Either a circumferential slot or a group of four to six radially drilled pressure taps equally spaced around the circumference of the tube at a section of distance 3d from the hemispherical nose is used to measure the static pressure. Ordinarily the tube is employed to determine fluid speed by measuring the difference between the static and stagnation pressures.

At zero angle-of-yaw, flow over the tube becomes axially symmetrical over a length not affected by the support

2. From the point of tangency of the hemispherical nose with the main tube, continued growth of the layer will be as that for a flat plate.

Under these assumptions and using Fig. 10.5 in (8:159) and Eq. 7.38 in (8:104), an expression for δ becomes

$$\delta \doteq 1.84\sqrt{\frac{\nu d}{U}} + 5\sqrt{\frac{\nu x}{U}} \qquad (1)$$

where x is measured parallel to the tube axis from the point of tangency. If a value of x is taken to be 2d, the expression for δ becomes

$$\delta \doteq 8.94\sqrt{\frac{\nu d}{U}}. \qquad (2)$$

Using 1/4 in. for d (1/4 in. is used for d in this experimental study), $\delta \doteq 0.006$ in. for $U = 10$ ft/sec and $\delta \doteq 0.002$ in. for $U = 100$ ft/sec. In the event transition of the boundary layer from laminar to turbulent flow should occur at the point of tangency, δ will be greater than that given by the foregoing calculations.

Upon introducing a small angle-of-yaw, the flow field near the forward portion of the tube will no longer be axially symmetrical. Instead, the flow field will then only be symmetrical with respect to a horizontal plane passing through the tube axis. Along the intersection of this plane with the upstream tube surface, one would expect the boundary layer to decrease in thickness. While on the opposite side, the boundary layer should become turbulent and increase in thickness. As the angle-of-yaw is increased to 90°, the upstream intersection of the plane and the tube becomes a stagnation line and separation occurs on the downstream surface with the flow becoming oscillatory--Plates 31 and 32, Ref. 3. The flow field change with angle-of-yaw and the accompanying changes in boundary layer characteristics will have considerable effect upon pressure distribution over the tube and the heat transfer characteristics of heat flow from a heated tube to the flowing air.

<u>Flow Characteristics of Modified Prandtl Tube</u>

As shown in Fig. 2, the modified Prandtl tube proposed for study differs from the original in the location of the circumferential slot cut into the body of the tube. A second difference is that the tube diameter of the upstream portion of the tube is d which is different from D on the order of $\pm 2\delta$.

When $d < D$ and the angle-of-yaw is zero, the tube of diameter d presents a circular lip at the slot which acts somewhat as a circle of stagnation. In this case, no flow would take place through the slot. As the angle-of-yaw varies slightly from zero, one would expect a pressure increase at the upstream symmetry line and a decrease in pressure on the opposite side of the slot. Such a pressure difference will cause fluid to flow through the slot and cause a secondary modification of the boundary layer in the vicinity of the slot. The exact nature of the variation in average slot pressure p_s in going from $A = 0$ to $A > 0$ cannot be predicted accurately since it will depend upon the geometry of the slot and the relative slot distance from the nose. However, in the case of $d < D$ one might expect the slot pressure to decrease as A is varied from zero, since it seems reasonable that the flow entering the slot at the upstream symmetry line would exit through most of the remaining periphery and hence decrease the net stagnation effect.

For the case of $d > D$ and $A = 0$, a circular region of separation exists at the downstream end of the tube of diameter d. Consequently, the mean slot pressure should become less than for a similar case in which $d < D$. When A is varied from zero, the expected effect would be a decrease in pressure at the upstream symmetry line and an increase on the opposite side. This pressure difference across the slot must result in flow through the slot from the downstream symmetry line to the upstream symmetry line and also across the intervening periphery. Such a flow would tend to alleviate the separation and result in a net increase of slot pressure.

Use of Modified Prandtl Tube to Determine Flow Direction

From the previous discussion of flow characteristics for the modified Prandtl tube one can expect a minimum slot pressure to occur when $d > D$ with $A = 0$ and $B = 0$. For the case of $d < D$, a maximum slot pressure should exist for $A = B = 0$. By making use of either one or the other of these conditions, the feasibility of mechanically varying the yaw and pitch of the tube at a particular location to determine the flow direction seems good. If such a procedure is to prove satisfactory, the response (variation of slot pressure with A and/or B) must be such that the tube may be brought to within tolerable deviation from the true flow direction. Also the flow condition must be stable to allow reading small variations of pressure differential on a manometer.

Considerations for Experimental Study of Modified Prandtl Tube

In order to arrive at a design with the greatest possible sensitivity, an experimental program must be carried out to determine the effects of geometry upon the slot pressure. By use of dimensional analysis, a group of dimensionless parameters may be arrived at which may be varied in the experimental program to give significant information. For consideration in the dimensional analysis, the following variables are considered of prime importance:

$$F(d, D, L, S, A, B, \rho, \mu, P, p) = 0.$$

Following the procedure set forth by the Buckingham π-theorem, three of the variables may be chosen to combine with the remaining variables to form dimensionless parameters. If D, ρ, and P are chosen for this purpose, the following parameters result:

$$F_1\left(\frac{d}{D}, \frac{L}{D}, \frac{S}{D}, \frac{p}{P}, \frac{P\rho D^2}{\mu^2}, A, B\right) = 0 \qquad (3)$$

or

$$\frac{p}{P} = F_2\left(\frac{d}{D}, \frac{L}{D}, \frac{S}{D}, \frac{P\rho D^2}{\mu^2}, A, B\right). \qquad (4)$$

To facilitate the testing program, B may be maintained at zero and $\frac{P\rho D^2}{\mu^2}$ -- the square of a modified form of the

Reynolds number — may be kept essentially constant by testing under only one ambient air velocity. The experimental program then consists of collecting data to study the following function:

$$\frac{p}{P} = F_3 \left(\frac{d}{D}, \frac{L}{D}, \frac{S}{D}, A\right) . \qquad (5)$$

Fluid Flow near Tip of Separation Tube

A particular design for a separation tube is shown in Fig. 3. When the tube is oriented in a uniform ambient fluid stream such that a plane containing the tube axis and the major axis of the end elliptical area is parallel to the direction of ambient velocity, the flow pattern should be symmetrical with respect to the symmetry plane. If the plane of symmetry is made horizontal in a fluid stream in which the velocity is parallel to the horizontal, a change in the angle-of-yaw will change the symmetrical flow pattern at the tip. At zero angle-of-yaw (tube axis parallel to ambient velocity), a boundary layer will form on the piezometer tap side of the tube and the pressure as indicated will be equal to or slightly less than the ambient. As the angle-of-yaw is changed such that the piezometer tap is presented to the oncoming flow, the pressure will increase at the tap until at 90° yaw a stagnation condition will exist. Upon yawing in an opposite sense, the piezometer tap will be in a separation zone where the pressure is considerably below the static pressure.

Sensitivity Definition

For comparing the sensitivity of designs under consideration with existing designs, the following definition will be adopted:

$$s = \frac{(P - p_a) - (p - p_a)}{qA}. \tag{6}$$

By virtue of the definition for P, p_a and p,

$$P - p_a = k_o q \tag{7}$$

and

$$p - p_a = k_A q. \tag{8}$$

Using Eqs. 6, 7, and 8, s may be expressed as follows:

$$s = \frac{k_o - k_A}{A}. \tag{9}$$

Chapter IV

EXPERIMENTAL EQUIPMENT AND PROCEDURE

The apparatus necessary to carry on this work was not in an assembled or fabricated state when the project was iniated although the materials were on hand from which the required equipment could be made. Therefore, a portion of the time from 1950 to 1954 which was devoted to this project by the authors was utilized in the actual construction and modification of equipment. The precision machine work was done by a competent machinest.

Wind Tunnel

In order to carry on the experimental work, a small wind tunnel was fabricated, Plate 1. The entrance and the test section of the tunnel were made from 6-in.-diameter (o.d.) seamless plastic pipe. A special wooden form was made for the molding of the entrance section. The shape of the entrance section was designed on the basis of information contained in Ref. 7. The blower used to draw air through the tunnel was made by the North American Manufacturing Company and was rated as capable of delivering 575 CFM. When the blower was operating at design load, the velocity in the test section was approximately 53 ft/sec. A valve installed in the exhaust pipe was used to control the velocity of the air in the tunnel. Usually the flow of air was throttled to some extent so that the velocity under which tests were run was about 45 ft/sec. A protractor graduated to $1/4^{\circ}$ was mounted on a rod which projected into the tunnel to support the instrument being tested, Plate 2. This protractor was used to measure the angle-of-yaw between the axis of the mounted instrument and the direction of the flowing air. The object of this work was to develop an instrument which would be serviceable in flow of three dimensions. This goal was kept in mind in the design of the various devices tested although they were only tested under 2-dimensional conditions. Since these instruments were designed for three dimensions, the authors believe that the response in 3-dimensional flow would be similar to that under 2-dimensional conditions.

Experimental Direction Tube Designs

The first objective of this study was to develop an instrument which could be used to measure both wind speed and direction. The Prandtl pitot tube has been found to be a satisfactory device for measuring wind speed when the wind direction is known approximately. With this in mind, the authors confined most of their efforts with regard to creating a device for determining wind direction to that design which could be readily incorporated with the Prandtl pitot tube design. Therefore, the goal of this work was the development of a single device whereby the wind speed would be indicated by an arrangement similar to the Prandtl tube and wind direction could be determined from the response of the instrument due to a modification of the tube developed as a result of this study.

The authors designed, built, and tested several instruments which appeared promising from considerations of the changes in flow characteristics created by yawing. Each of the devices are described in the paragraphs that follow.

Modified Prandtl tube with circumferential slot.

Details of the modified Prandtl tube design can be found in Fig. 2, and Plate 3. This device was made so that L and S could be varied. Three noses, each having a different value of d, were made; this permitted the parameter d/D to have three separate values. The method of supporting the instrument in the tunnel permitted the angle-of-yaw to be varied. In testing this design, one of the noses was placed on the stem so that the parameter S/D had some preassigned value. The axis of the stem was positioned so that it was parallel to the direction of the flowing air. The pressure difference p was measured by means of a Wahlen gage — Plate 4. The Wahlen gage is a differential manometer capable of measuring pressure differences as small as 0.00003 lb/in.^{2} or the equivalent of 0.001 in. of alcohol. After this pressure difference had been measured, the axis of the stem holding the nose was moved so that the axis of the nose and stem was at some predetermined angle A to the direction of the flowing air. This angle, called the angle-of-yaw, usually was varied from 0° to 15° by increments of two degrees from 0° to 10° and by five degrees increments from 10° to 15°. After the differential pressure readings were measured for the various angles-of-yaw for a particular S/D, the distance S was changed to another predetermined value and the new values of p for the different angles of yaw were measured. This procedure was repeated for different values of S which usually was from 0.010 in. to 0.050 in. This was the procedure of investigating the characteristics of a nose for a particular value of L after which L was decreased and the procedure of measuring the differential pressures for different values of the angle-of-yaw and of S was repeated. During the course of this testing program, L was varied from 1.25 in. to 0.125 in. The data collected through the aforementioned variations of the angle-of-yaw, S, and L comprised the data for the investigation of a particular nose. This same procedure was followed with the other two noses.

In the course of investigating the circumferential slot principle, two variations of it were examined. The first consisted of a very thin flat circular plate mounted in place of the nose piece with a small annular space between the disc and the stem. The other involved the placement of a fine wire loop on the hemispherical nose so as to establish a turbulent boundary layer from a fixed point thereby eliminating to a certain extent Reynolds number effects. One loop was made of wire 0.001 in. in diameter and was placed approximately 0.06 in. upstream from the forward lip of the slot. Another loop made from 0.002 in. in diameter wire was placed about 0.02 in. from the forward lip of the slot.

<u>Separation nose.</u>

Details concerning what is called the separation nose are presented in Fig. 3 and Plate 5. Only one instrument of this type was tested. The testing procedure so far as varying the angle-of-yaw is concerned was similar to that followed for the modified Prandtl tube design. The separation nose type of design is thought to be best suited for measuring direction in 2-dimensional flow, but an arrangement similar to that of the 4-probe pitot claw would make the basic design useful in 3-dimensional flow.

Circumferentially-wound, heated-wire direction tube.

Details of the heated wire nose are presented in Fig. 4 and Plate 6. This design is based on the following reasoning. When the axis of a symmetrical streamlined body is parallel to the direction of the moving fluid in which it is immersed, a symmetrical boundary layer developes about the body. However, such is not the case when the axis of the body is askew to the direction of the moving fluid (see Chapter III). The changes in flow pattern caused by yawing will tend to change the net heat transfer rate from the nose to the air if the nose is heated by some means. However, if heat is supplied at an almost constant, rate, the temperature at which heat is transferred will vary with the angle-of-yaw. By supplying heat to the nose through a circumferential winding of fine wire having a high temperature coefficient of resistance, a change in temperature of the nose would cause a change in resistance of the winding. This change of resistance could be measured by means of a Wheatstone bridge. The function of the Wheatstone bridge in this case would be to detect changes of resistance (deviation from a null point) rather than the measurement of themagnitude of the change.

The heated wire nose diagramed in Fig. 4 was built and tested in an endeavour to ascertain if behaved according to the above speculations. One difficulty experienced in the construction of the instrument was the securing of wire having a high temperature coefficient of resistivity. Since a type of iron wire is supposed to have a high temperature coefficient of resistivity, an iron wire was used for these tests; but the value of the coefficient was unknown.

Chapter V

EXPERIMENTAL RESULTS AND DISCUSSION

In this Chapter, results of a systematic experimental study of a circumferentially-slotted direction tube are discussed. Results of an abbreviated study of a separation direction tube and a circumferentially-wound, heated-wire direction tube are also presented. Finally, the direction tubes investigated in this study are compared with those of conventional design in regard to sensitivity.

Circumferentially-slotted Direction Tube

The variation of the pressure-ratio p/P with angle-of-yaw A for a hemispherical nose was systematically studied by varying the slot-width ratio S/D, the nose-length ratio L/D and the nose diameter-stem diameter ratio d/D. Several tests were made to determine the effect of a fine wire loop placed on the hemispherical nose. Also a brief investigation was carried out to determine the pressure characteristics when a flat disc is substituted for the hemispherical nose.

Effect of d/D upon p/P.

Figs. 5-26 are ordered such that d/D increases from one figure to the next. For L/D = 0.512, Figs. 5, 12 and 20 show that p/P decreases with increasing A for d/D < 1 and increases with A for D/D > 1. This result appears to be in accord with the reasoning in Chapter III. Fig. 28 represents the results of a special test made with d/D reduced to 0.916 and L/D = 0.473. Again p/P decreases with increasing A but at a somewhat faster rate. As L/D is increased from 0.512 (Figs. 5-11, 12-19, and 20-26 are arranged in order of ascending L/D) the effect of d/D upon p/P becomes less pronounced until for $L/D \doteq 4$ no definite trend exists and p/P is greatly affected by S/D. At L/D of about 2 the pressure fluctuations became very strong indicating that the slot was probably in the region of transition from a laminar boundary layer to a turbulent boundary layer. Therefore, at $L/D > 2$ the boundary layer for the value of U used was in a turbulent state which would make the effect of δ/D less pronounced.

<u>Effect of L/D upon p/P.</u>

The effect of L/D is essentially a result of locating the slot in different regimes of the boundary layer. For values of L/D up to and including 1, the pressure fluctuations were small indicating that the boundary layer was still laminar. When L/D was either 1.5 or 2 the pressure flutuations were very large indicating an instability of the boundary layer and for $L/D = 4$ the pressure again became steady indicating the presence of a turbulent boundary layer. Figs. 8 and 23 show that the variation of p/P with A is greatest for $L/D \doteq 1$. This result is to be expected since the value of δ for this length of nose is more nearly equal to the value of $\left|\frac{d - D}{2}\right|$.

<u>Effect of S/D upon p/P.</u>

For $L/D \geq 1$ and $A > 8^{\circ}$, the value of p/P consistently decreases with increasing S/D. For $A < 8^{\circ}$ and all L/D, the effect of S/D upon p/P appears to be less than the error of pressure measurement because no consistent trend is apparent. Another factor causing some scatter of the data may be that the slot edges were not consistently sharp and square. According to Ref. 6, rounding of the slot edges has considerable effect upon p_s.

Effects of special nose modifications.

In an effort to eliminate Reynolds number effects upon the variation of p/P with A, a fine wire loop was placed around the hemispherical nose -- $d/D = 0.916$; $L/D = 0.472$ -- so that the plane of the wire was perpendicular to the tube axis. Fig. 29 gives the results for a 0.002 in. diameter wire placed approximately 0.02 in. upstream from the slot. This arrangement greatly reduced the sensitivity of p/P to A. In Fig. 30 the results are given for a 0.001 in. diameter wire placed approximately 0.06 in. upstream from the slot. These data indicate a fair sensitivity for $S/D = 0.16$. Further study to determine a wire size and location to form a turbulent boundary layer of thickness approximately $\frac{D-d}{2}$ should yield an arrangement which is stable, free from Reynolds number effects over a wide range of Reynolds number, and having a practical sensitivity.

A single test was made with the hemispherical nose replaced by a flat-disc such that $d/D = 1$ and $S/D = 0.06$. The results are shown in Fig. 31. The exploratory measurements were made with the anticipation of arriving at an arrangement which would be free of Reynolds number effects; however, instability of the flow discouraged further tests.

Sensitivity.

Only sensitivities for the most promising arrangements were calculated. These are given in the following table along with those for standard devices.

Nose	d/D	L/D	S/D	s
Hemispherical	0.955	0.512	0.20	0.006
"	0.973	1.008	0.20	0.018
"	1.028	1.005	0.08	0.008
"	0.916	0.472	0.04	0.007
Cylinder pitot				0.11
Pitot claw (2-probe)				0.04
Prandtl tube				0.05
Stagnation tube				0.034

Comparison of the values of maximum s for the circumferential-slot direction tube with the value of s for the cylinder pitot and the claw type instrument indicates that the sensitivity is not very satisfactory. This result alone is sufficient for rejection of the proposed design.

Separation Direction Tube

In an attempt to improve the sensitivity of a direction tube, a tip was designed to take advantage of the change in pressure within a region of separation as the geometry changes with yaw. The tube shown in Fig. 3 and Plate 5 was subjected to a parallel stream of air. The angle-of-yaw indicated in Fig. 32 is measured from the mean velocity vector to the tube axis. For $A < 0$ the piezometer tap faced upstream. In order to ascertain the effect of the plane containing the tube axis and major diameter of the end elliptical area (symmetry plane) not being in the plane of yaw, an angle-of-twist σ was introduced, Fig. 1.

For $C = 0$, the pressure ratio p/P varies rapidly with A in the vicinity of $A = 0$. For $A > 0$, the value of p/P is less than 1 and rapidly decreases since the orifice is in a separation zone and the change of flow direction at the tip becomes more abrupt with increasing A. With negative A the pressure ratio exceeds 1 because the piezometer tap is not in a zone of separation. Two sets of data are given for $C = 0$. Both sets have the same trend but the magnitude of p/P for a given A is different. The reason for this is believed to be in slightly different positions of the tube for the initial setting of $A = 0$.

The angle-of-twist C within 30° does not affect the value of p/P appreciably. However, as C approaches 90°, the tube becomes relatively insensitive to yaw.

Based upon a single separation tube of the given design a sensitivity of about 0.17 would result. If two similar tubes were used so that they would respond in opposition, the sensitivity could be increased to 0.34. This sensitivity is about 3 times greater than the cylinder pitot -- see table on page 23. The pressure fluctuations experienced when testing this instrument were not very great. Because of this high sensitivity, the stability of the pressure, and the adaptibility for 3-dimensional use, further development of the design is desirable.

<u>Circumferentially-wound, Heated-wire Direction Tube</u>

Details of this device can be found in Fig. 4 and Plate 6. Only one instrument of this nature was made and was fabricated with a fine iron wire. The temperature coefficient of this wire was unknown. This instrument was tested in the same manner as the modified Prandtl tube. The results were not conclusive but they indicated that the device was sensitive to changes of wind direction. The authors did not have the opportunity of investigating this instrument further although they believe that through the combined efforts of a metalurgist (wire development) and an aerodynamic or hydraulic engineer a practical instrument may be developed. An instrument of this nature may find military and commercial value in the field of aviation where snow and ice may make unheated instruments ineffective.

Chapter VI

CONCLUSIONS

The study described in this report centered about an experimental determination of pressure variations measured by two basic types of direction tubes when subjected to yaw. From a fundamental point-of-view, the tubes examined may be classified as follows:

1. Circumferential-slot on a modified Prandtl tube
2. Separation tube.

In addition, a preliminary investigation was begun to investigate the possibilities of development of a circumferentially-wound, heated-wire direction tube.

On the basis of data collected, the following conclusions were arrived at:

1. Because of relatively low sensitivity, the circumferentially-slotted, modified Prandtl tube does not constitute a satisfactory direction tube.

2. Because of relatively high sensitivity, pressure stability, and possible adaptation for 3-dimensional use, the separation tube affords a means to an improved direction tube.

3. The circumferentially-wound, heated-wire direction tube appears to be sensitive to changes of wind direction. A large amount of additional work must be done before a satisfactory instrument is developed.

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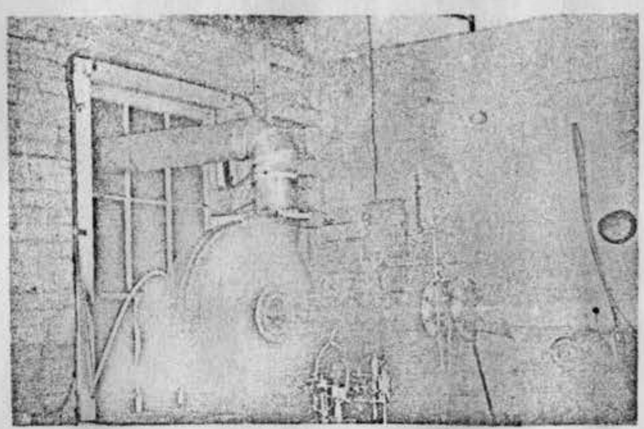

Plate 1. Wind tunnel.

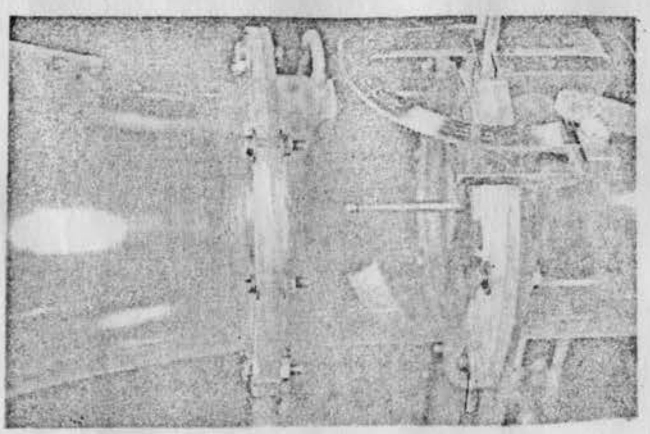

Plate 2. Close-up of wind tunnel.

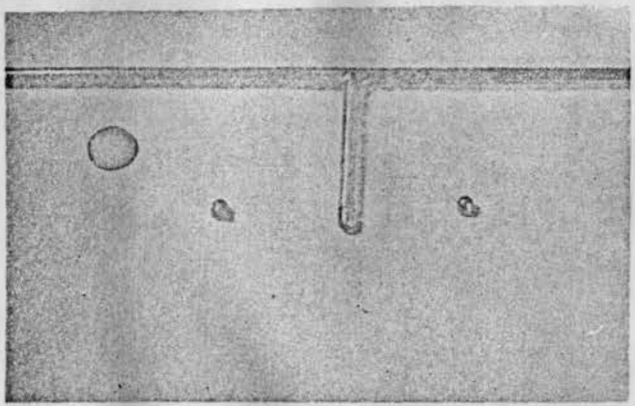

Plate 3. Circumferential slot direction tube.

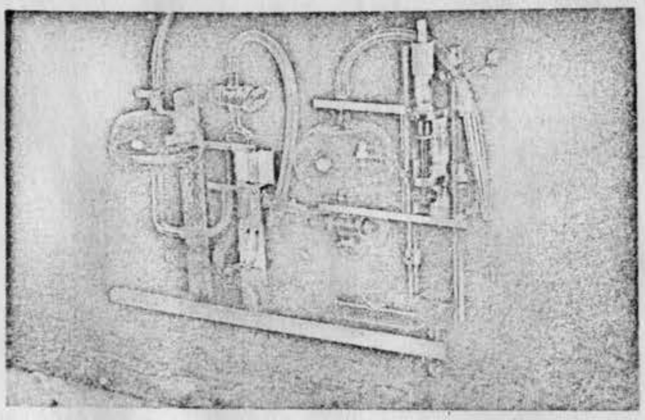

Plate-4. Wahlen gage.

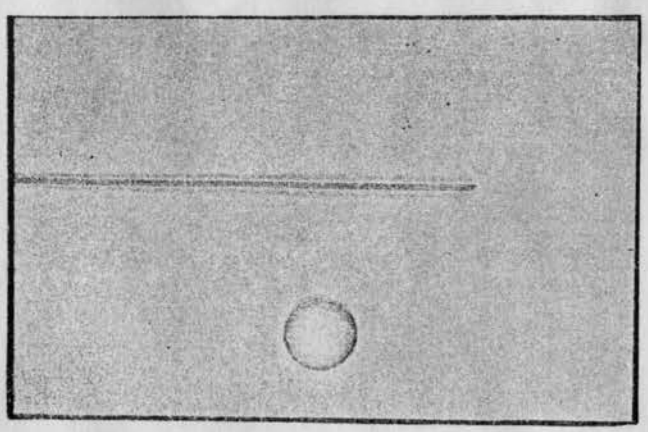

Plate 5. Separation direction tube.

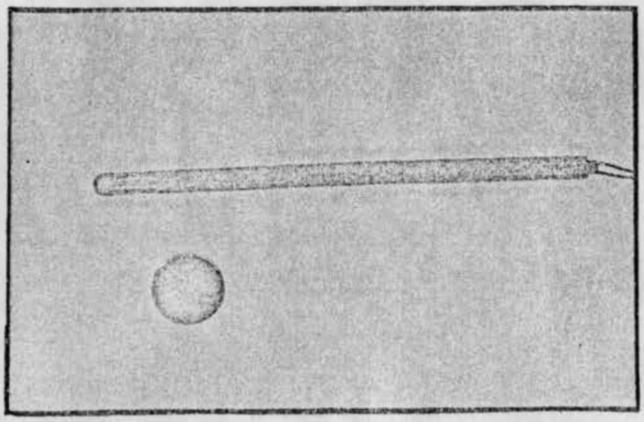

Plate 6. Circumferentially-wound heated-wire direction tube.

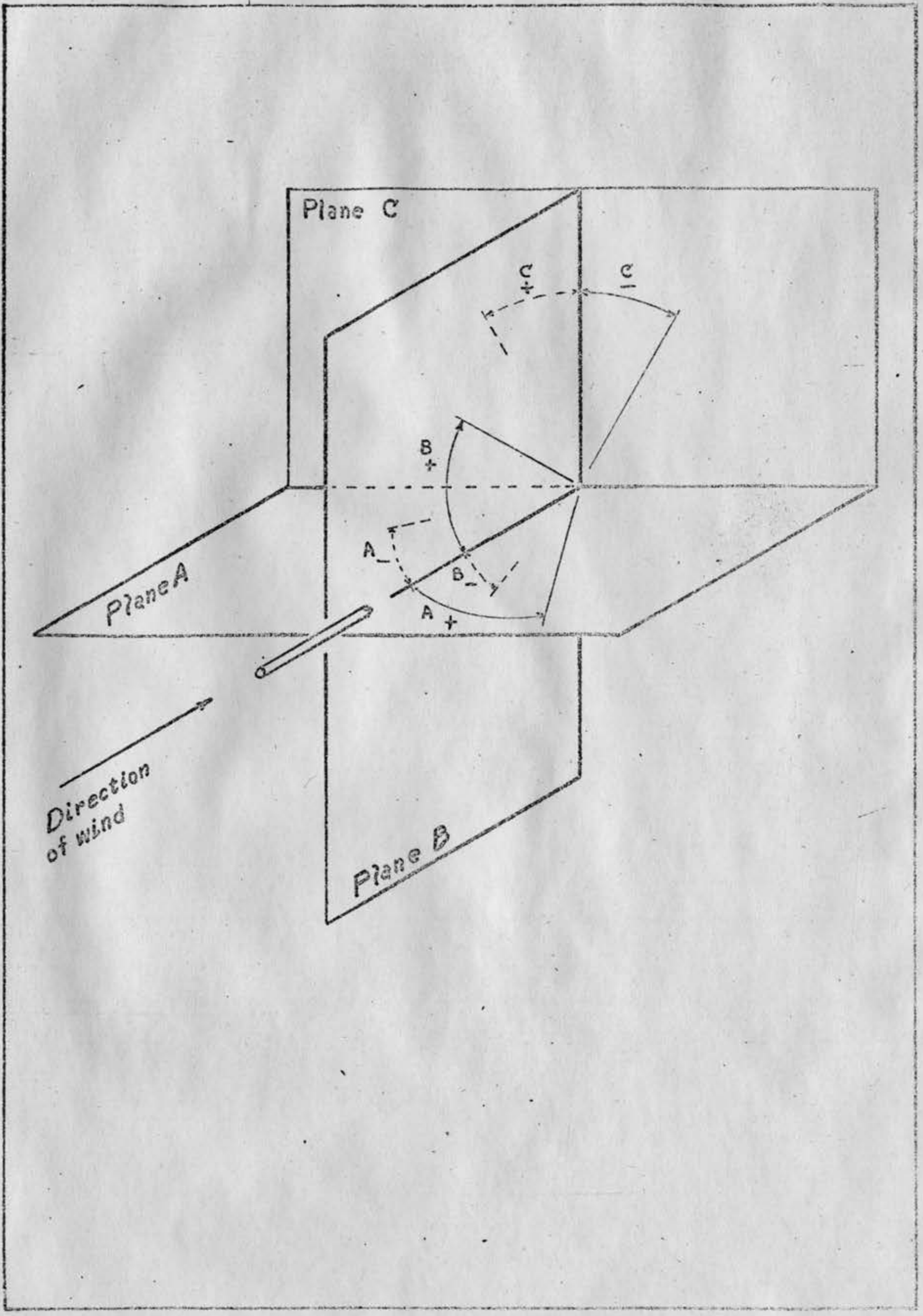

Fig. 1. Definition sketch.

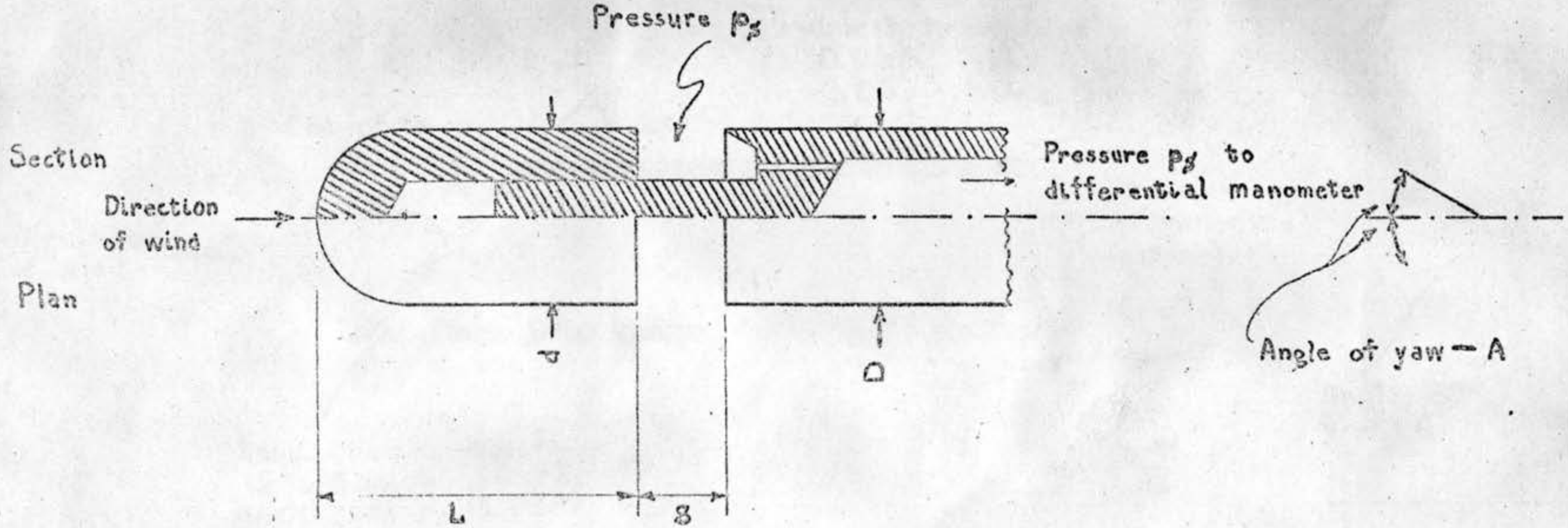

Fig. 2. Circumferential slot direction tube.

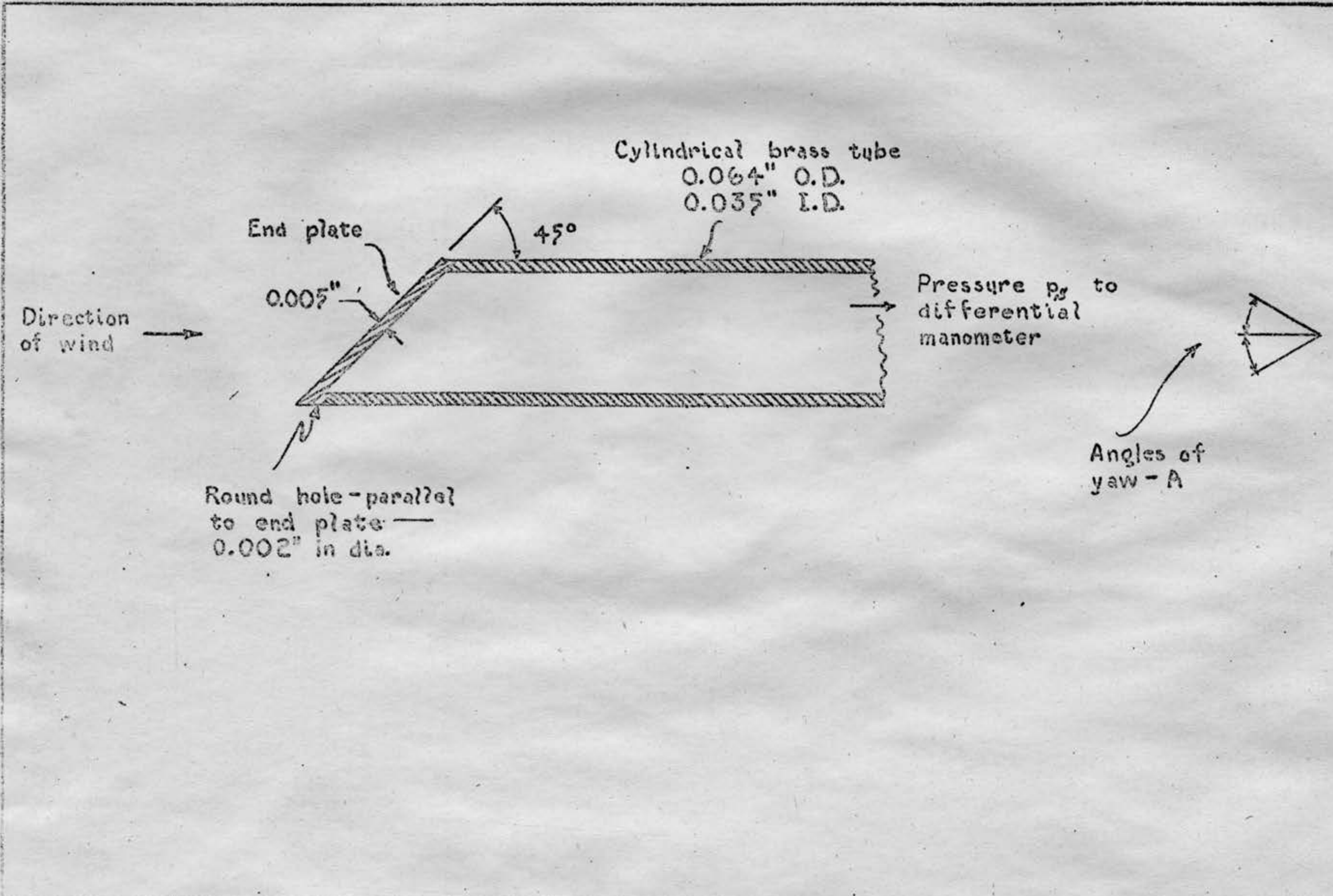

Fig. 3. Separation direction tube.

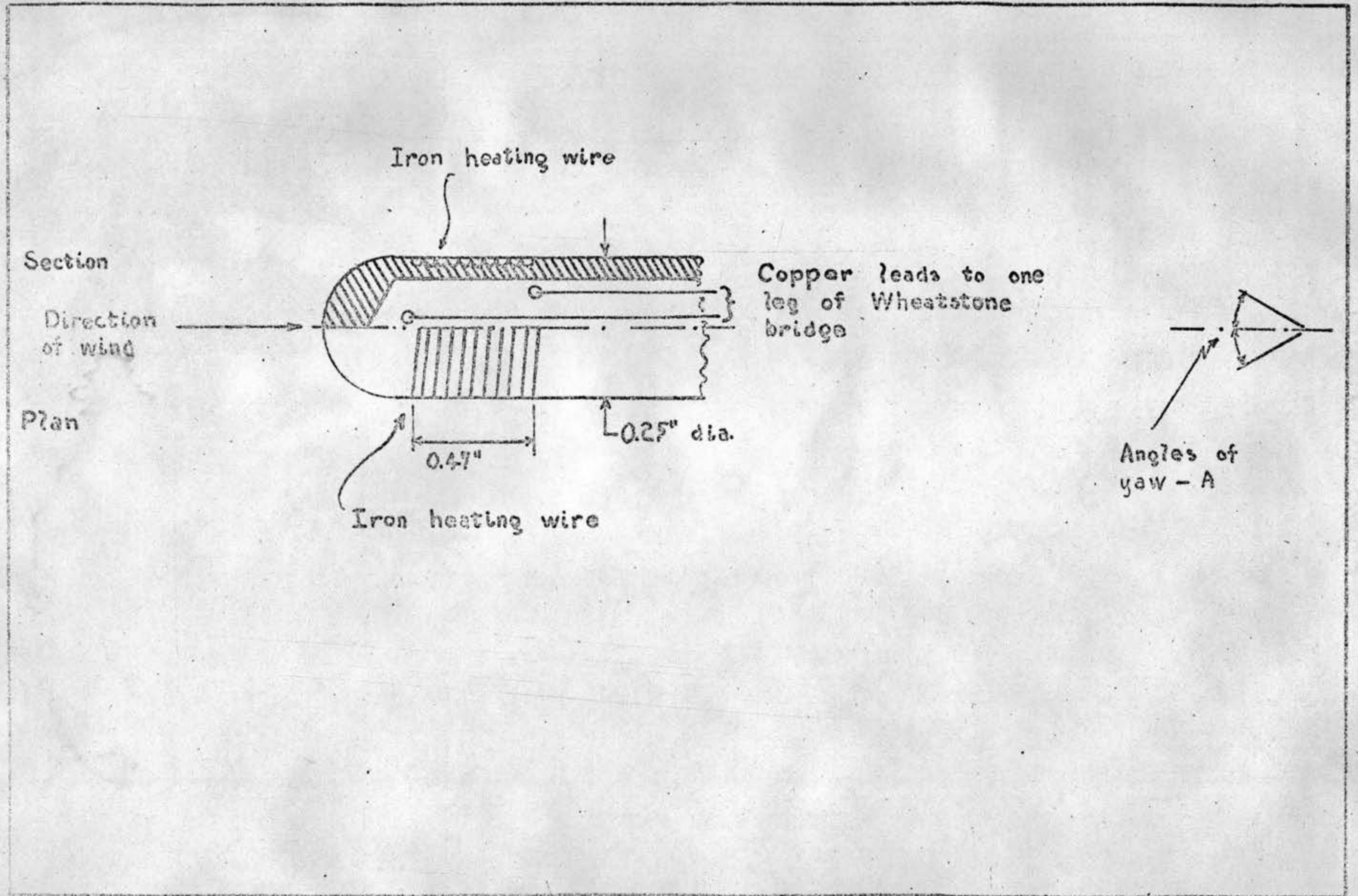

Fig. 4. Circumferentially-wound heated wire direction tube.

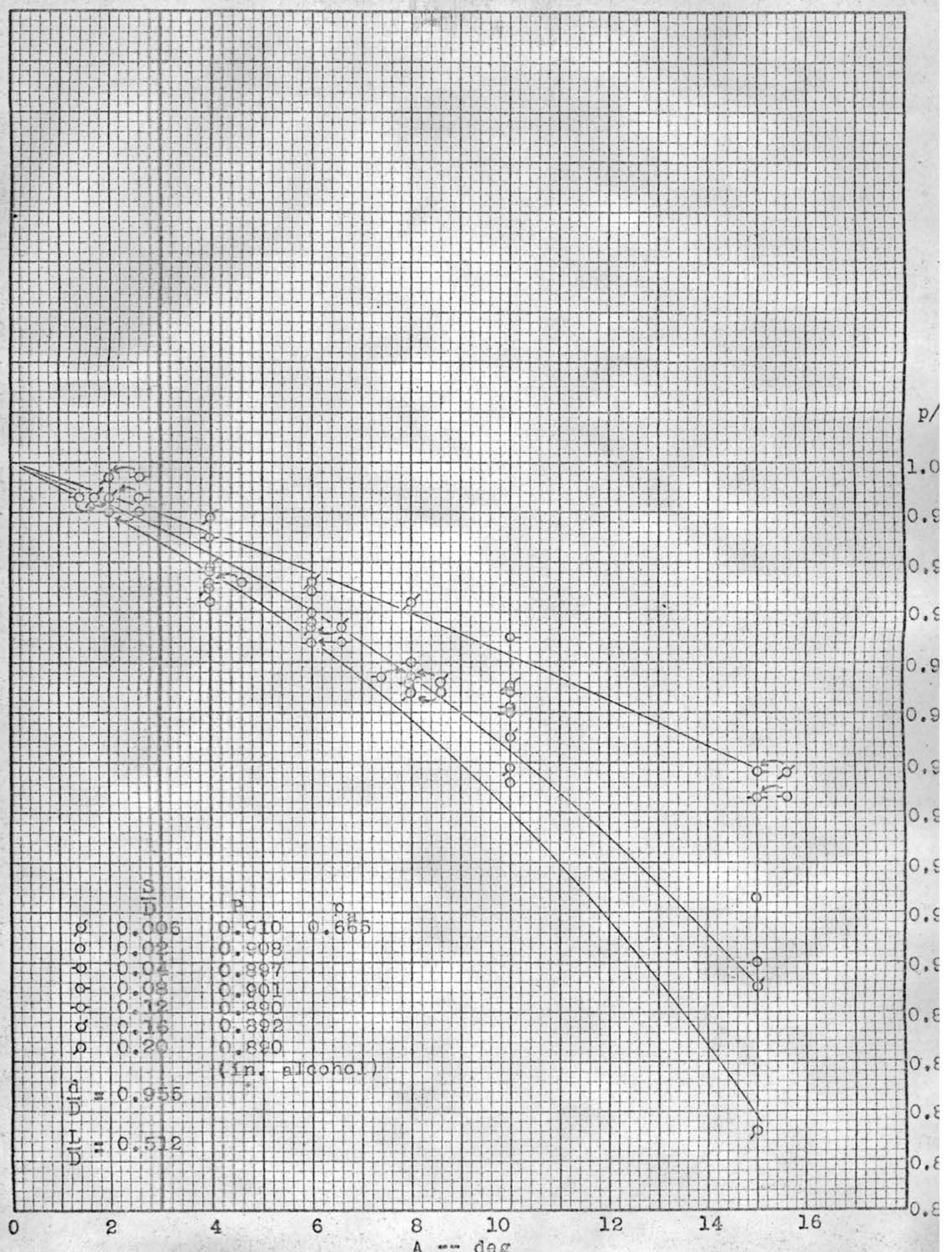

Fig. 5. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

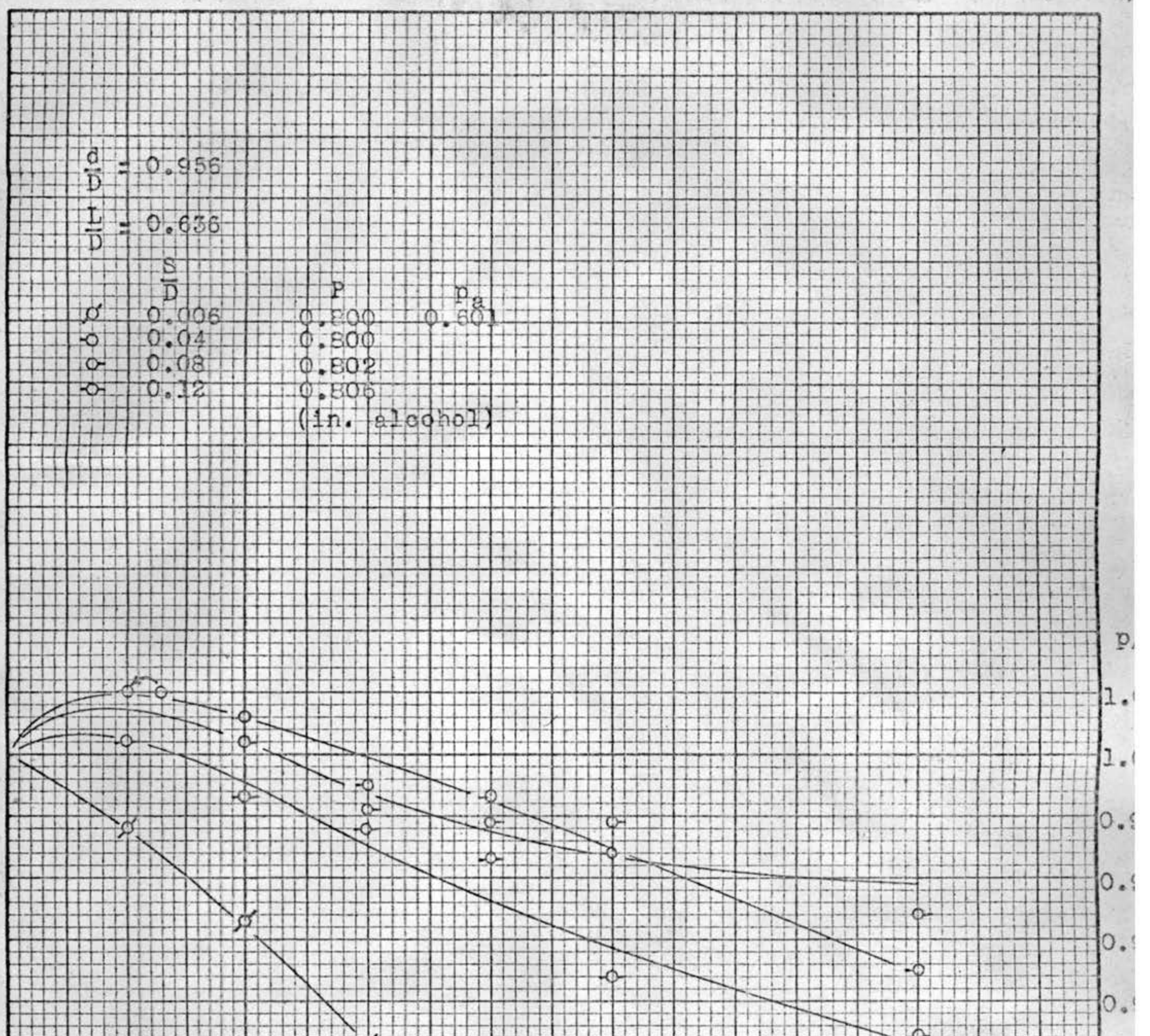

Fig. 6. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

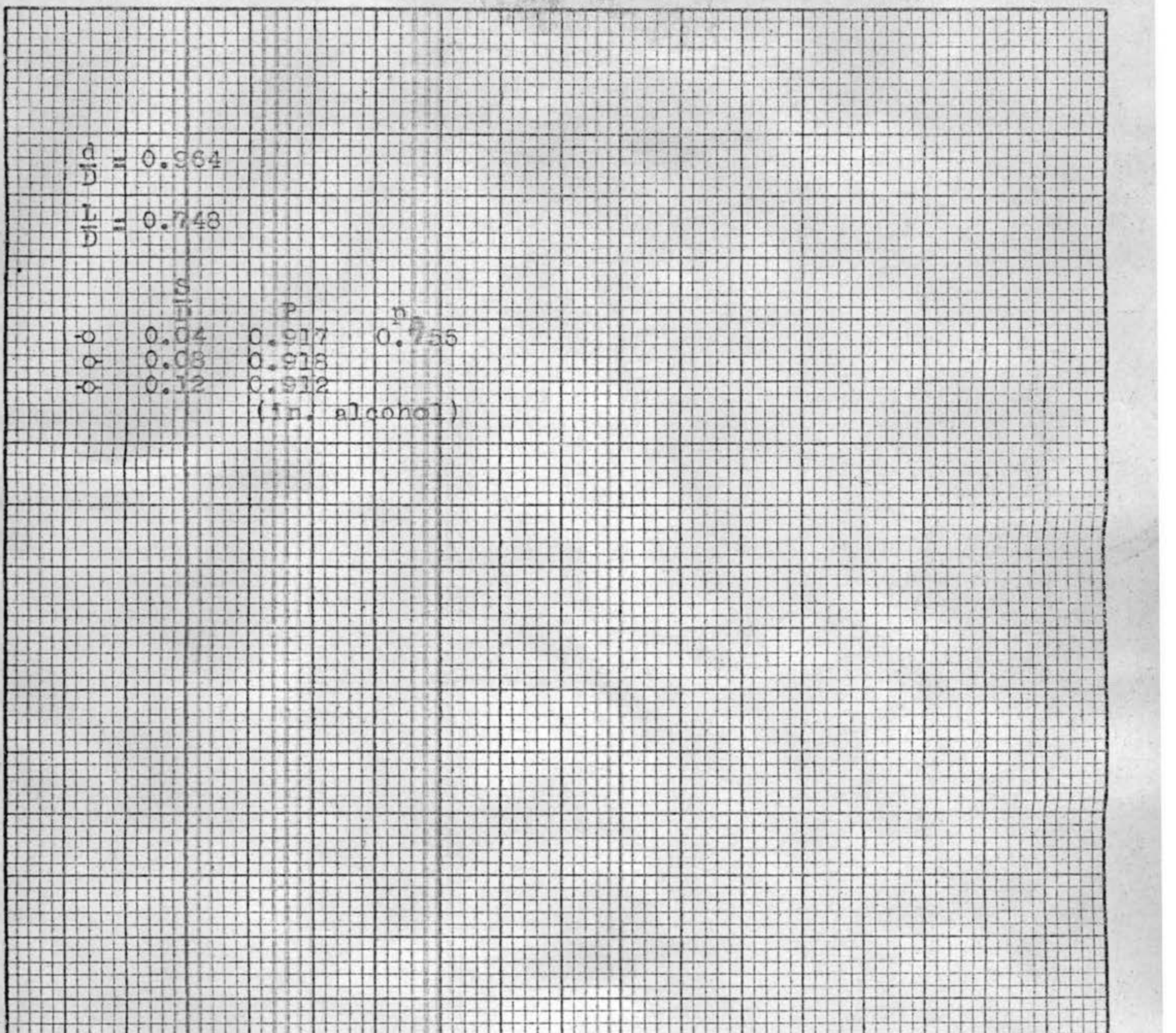

Fig. 7. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

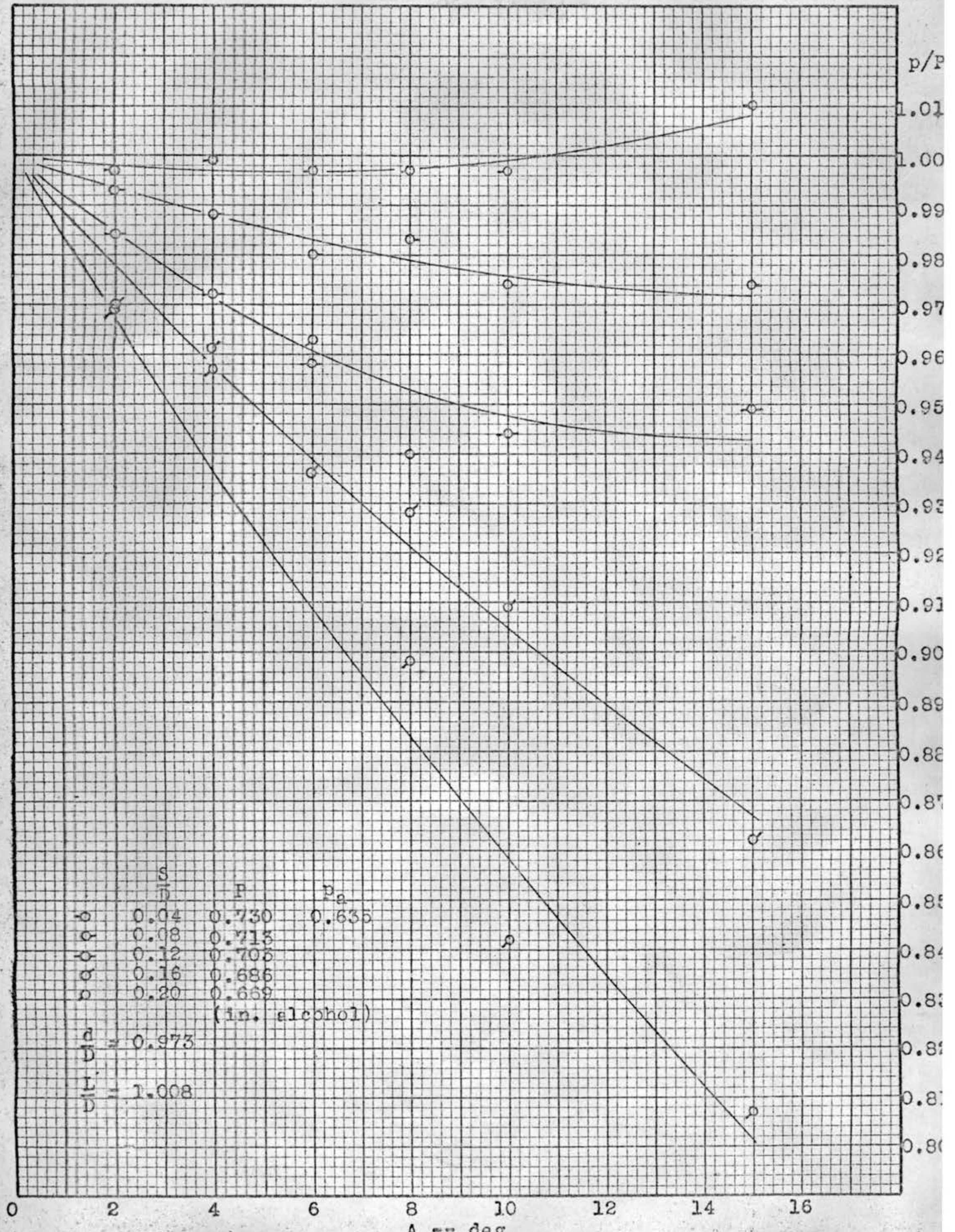

Fig. 8. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

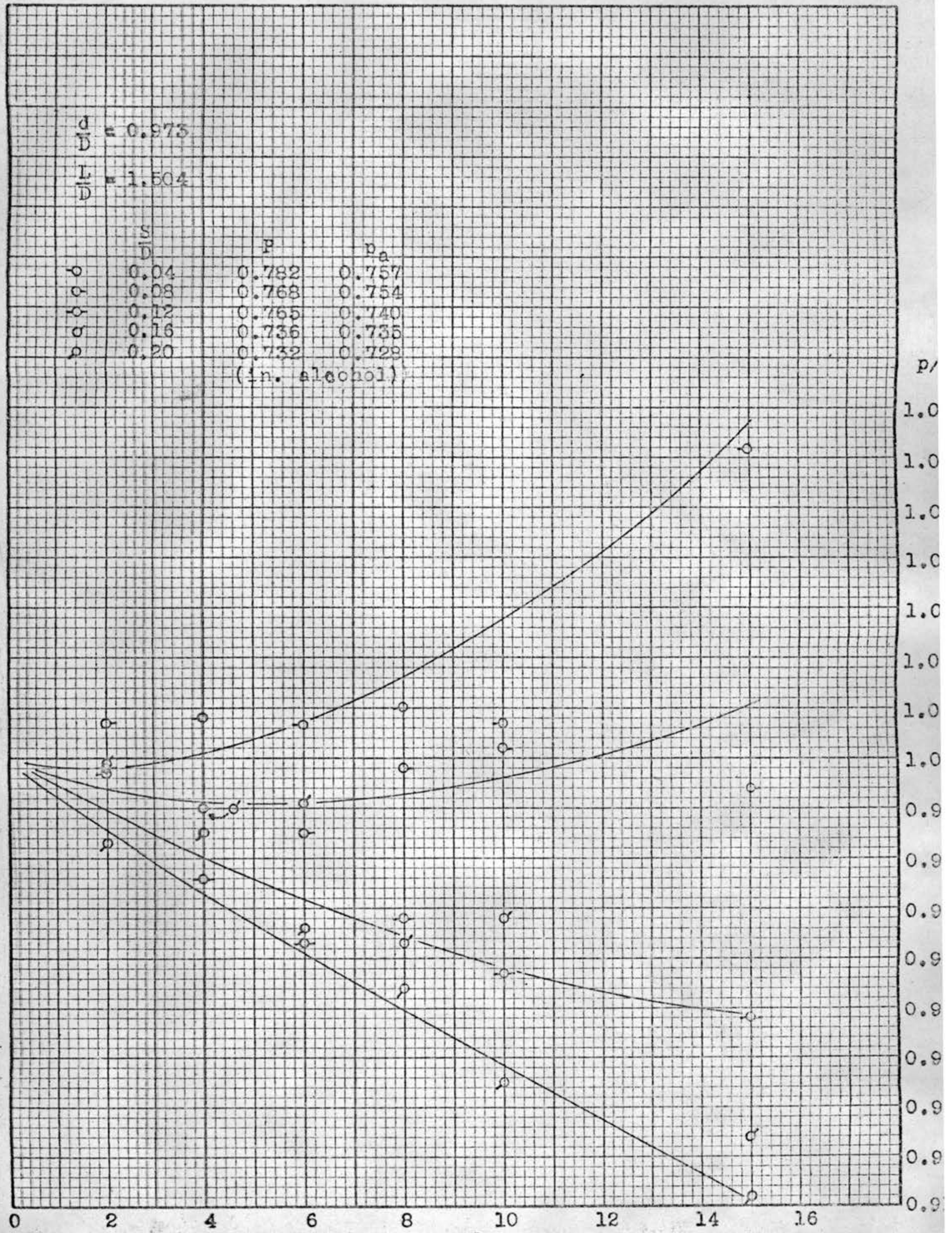

Fig. 9. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

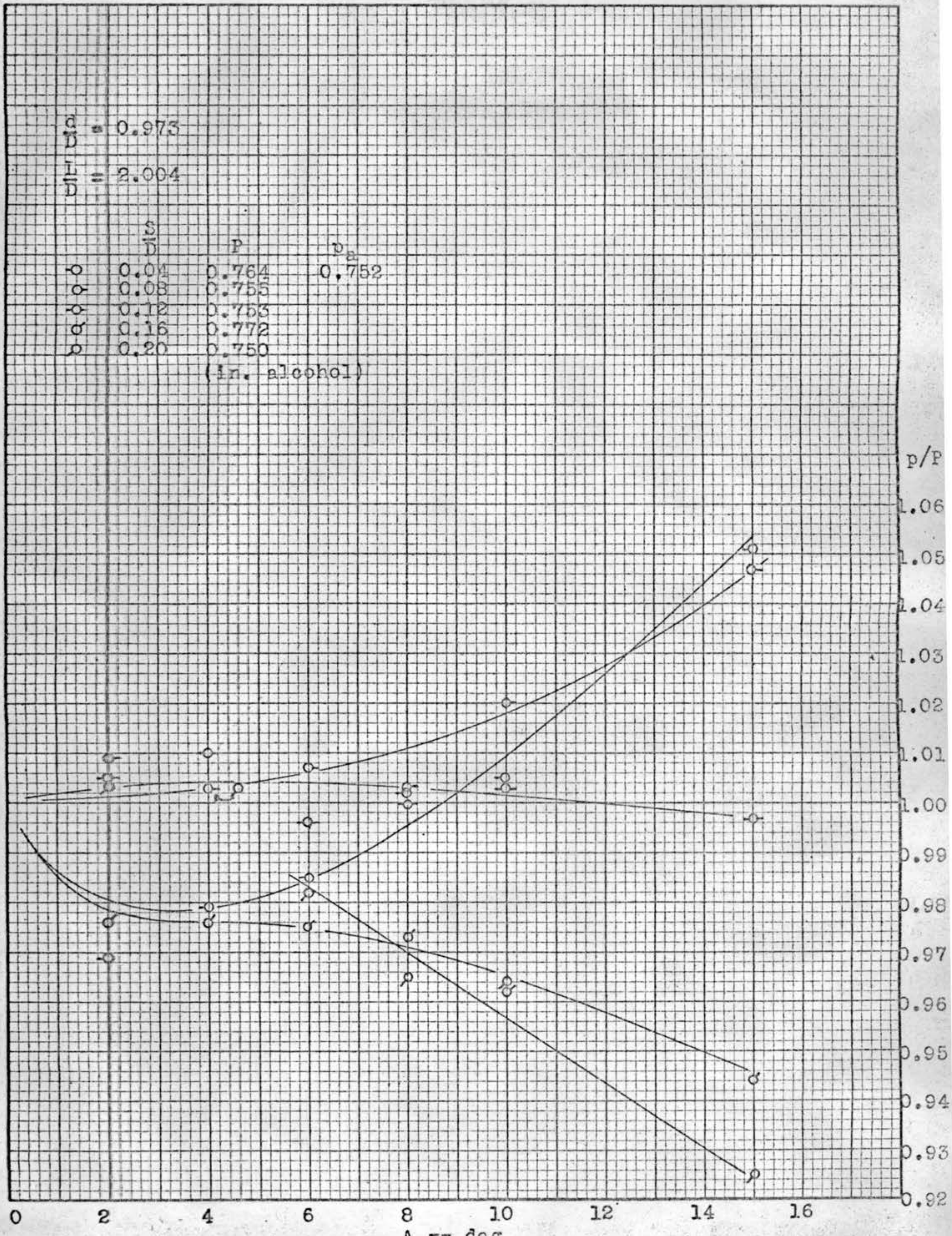

Fig. 10. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

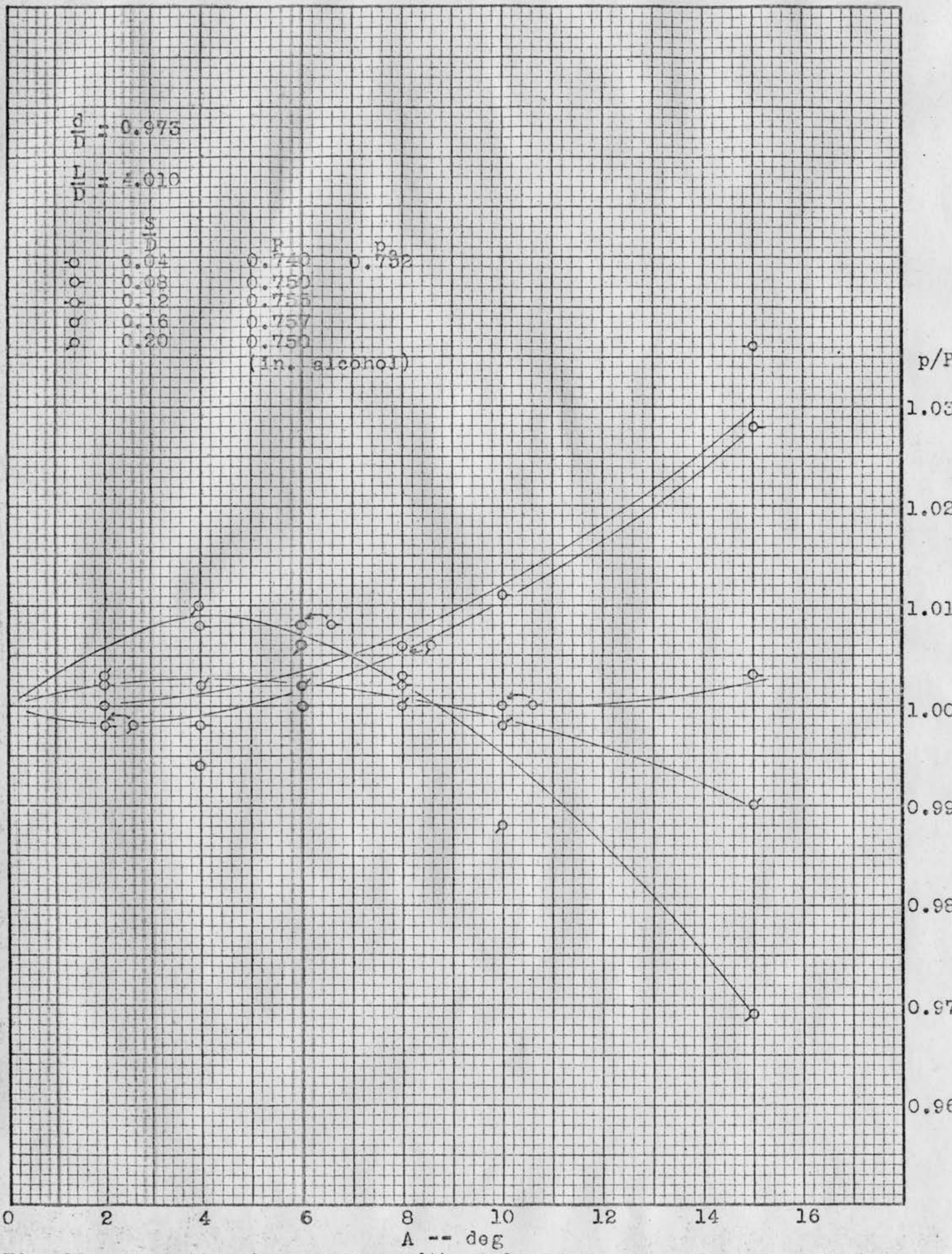

Fig. 11. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

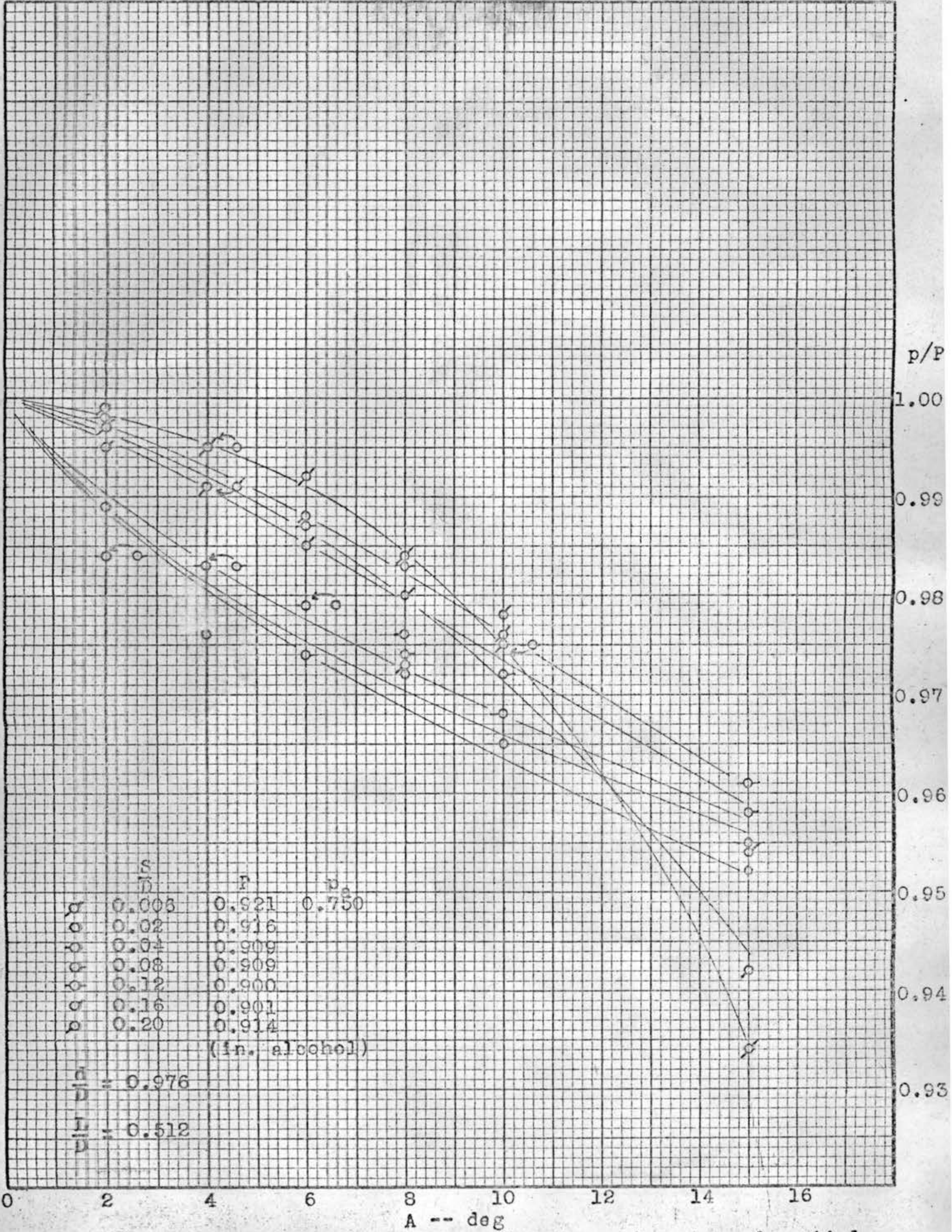

Fig. 12. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

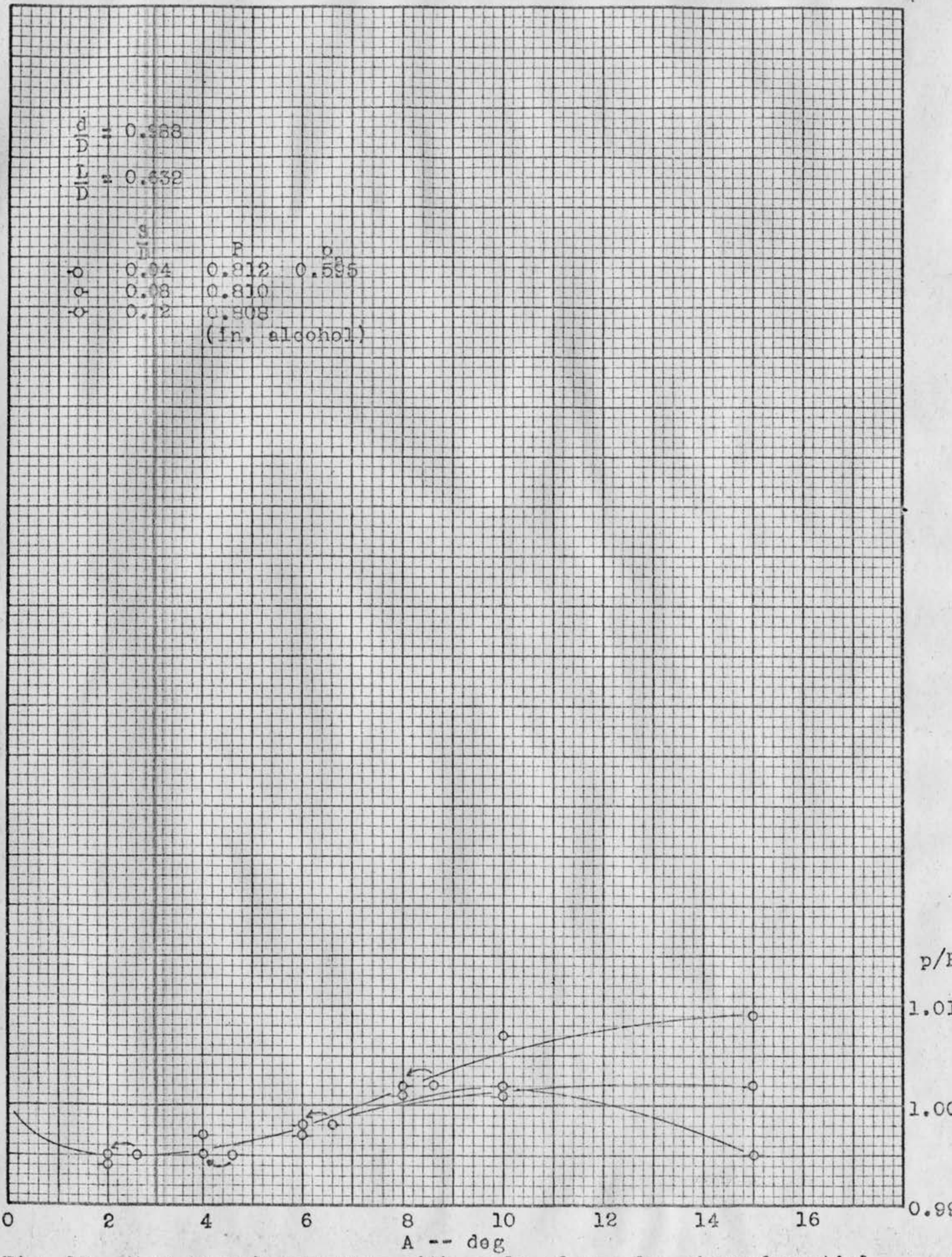

Fig. 13. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

Fig. 14. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

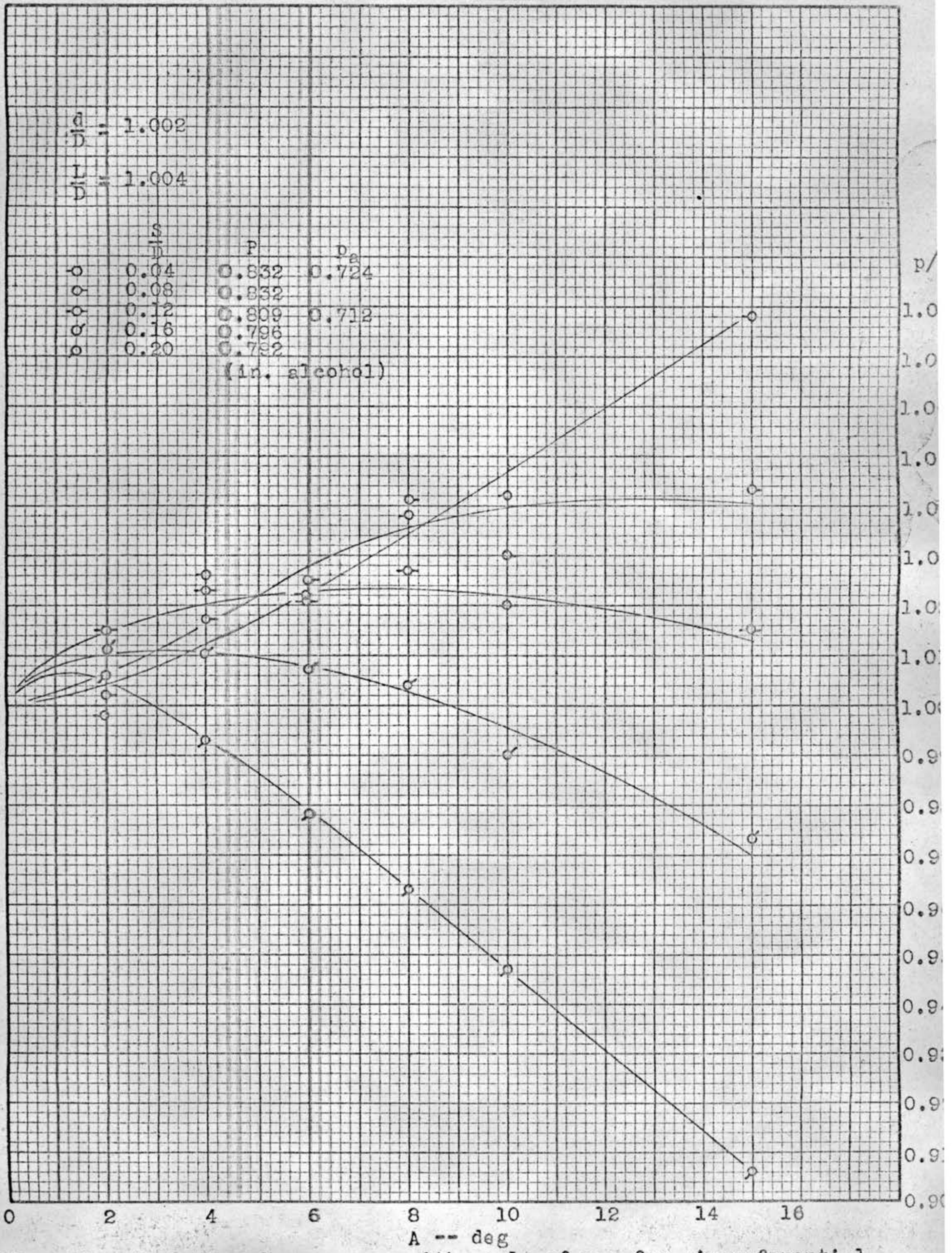

Fig. 15. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

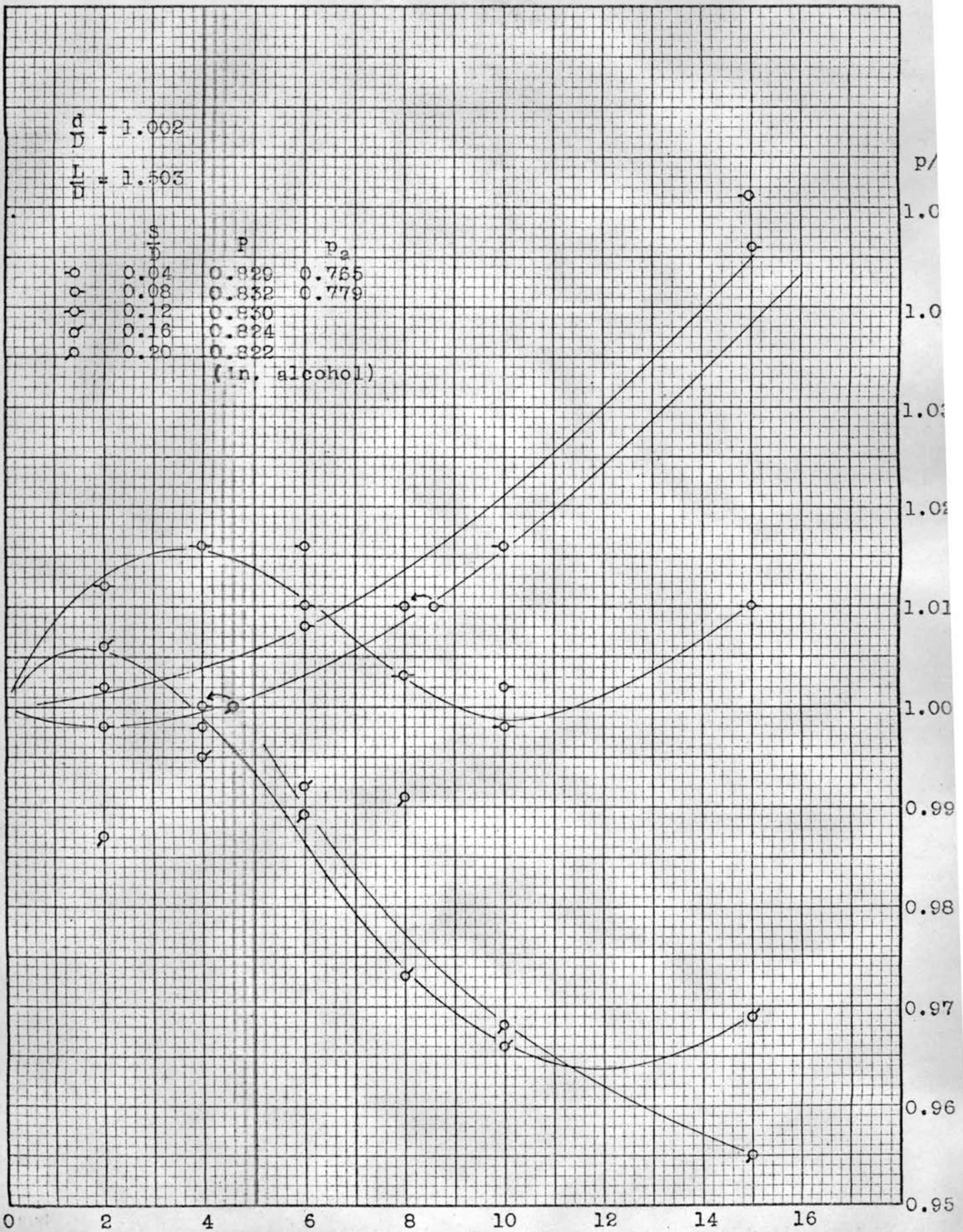

Fig. 16. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

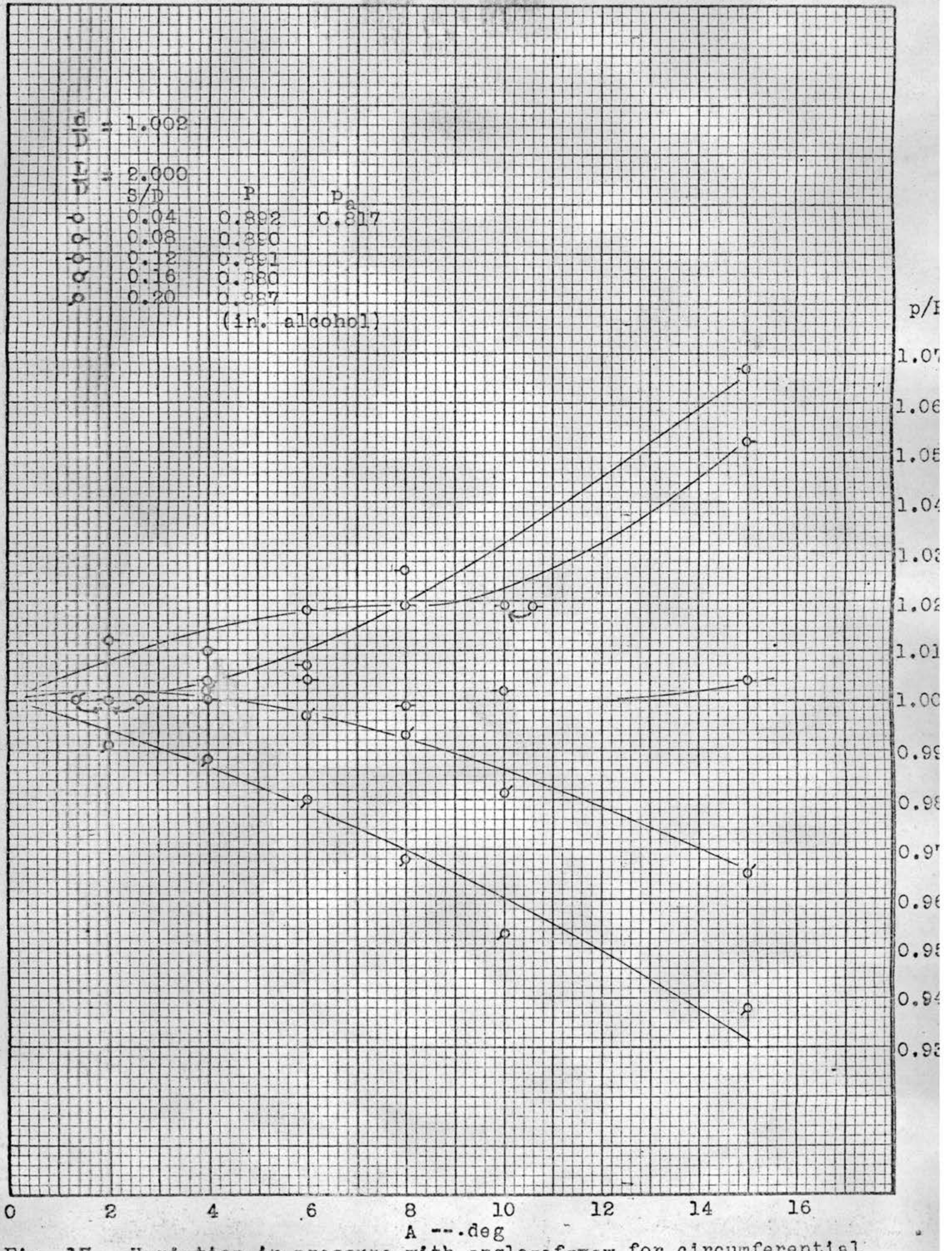

Fig. 17. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

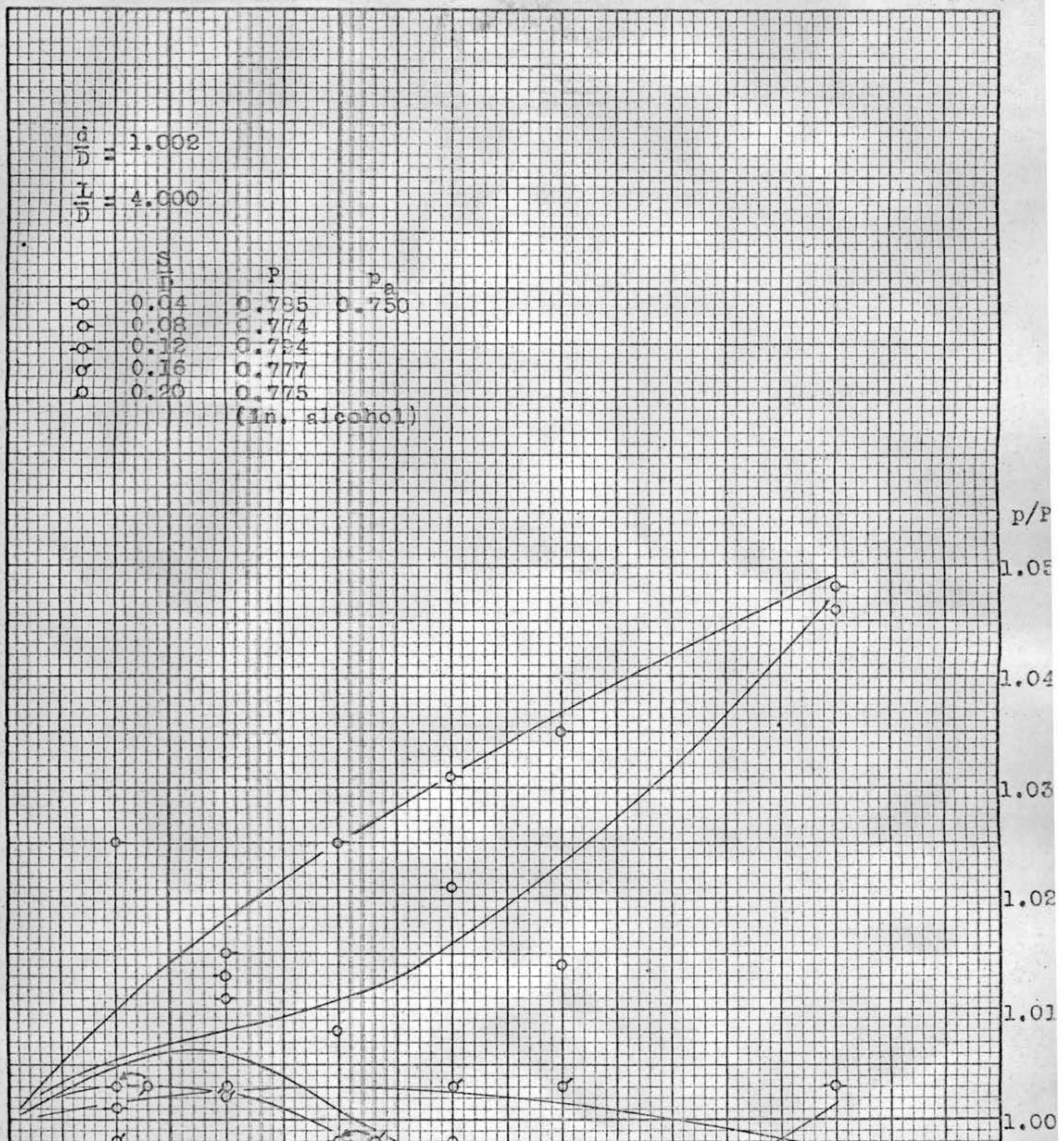

Fig. 18. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

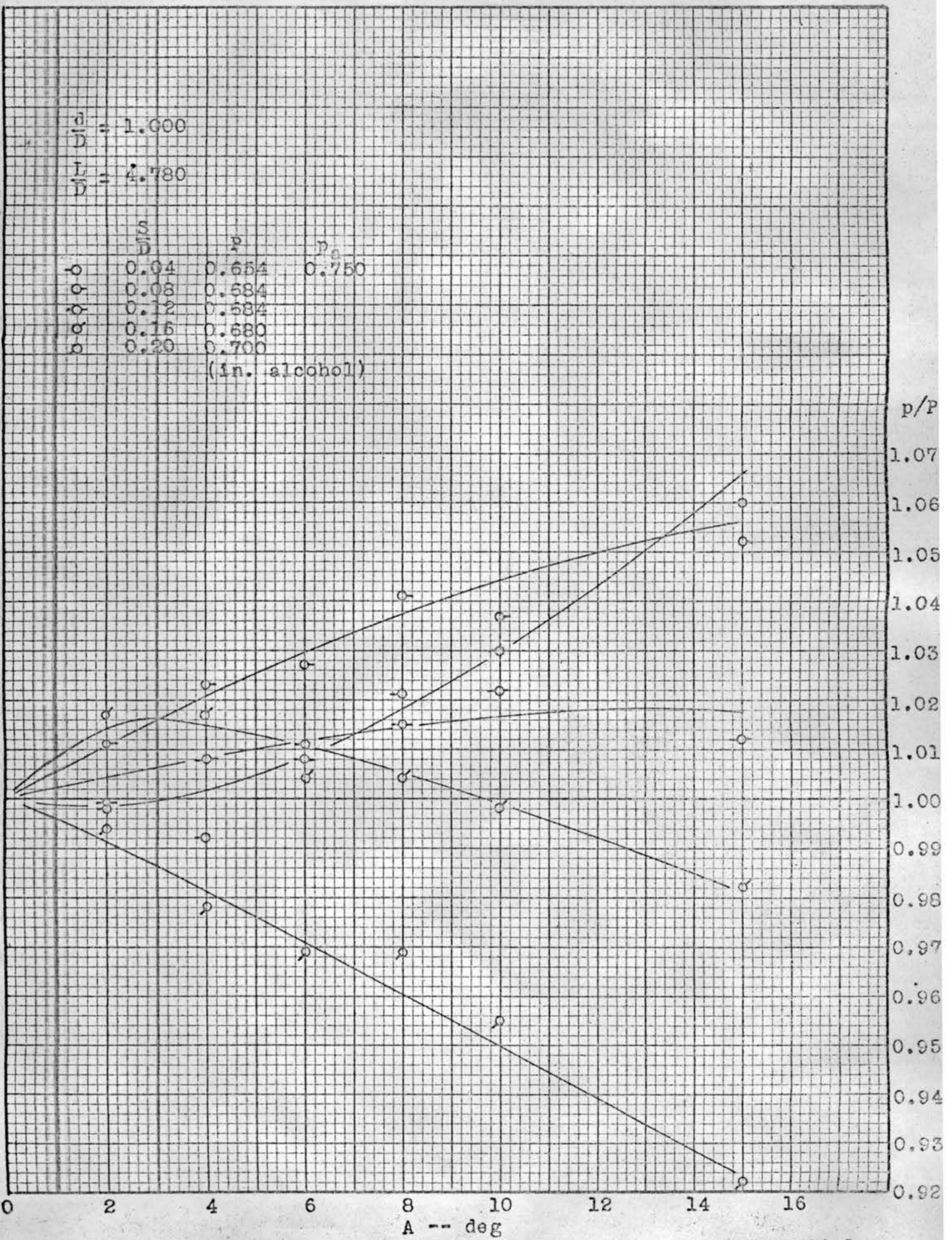

Fig. 19. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

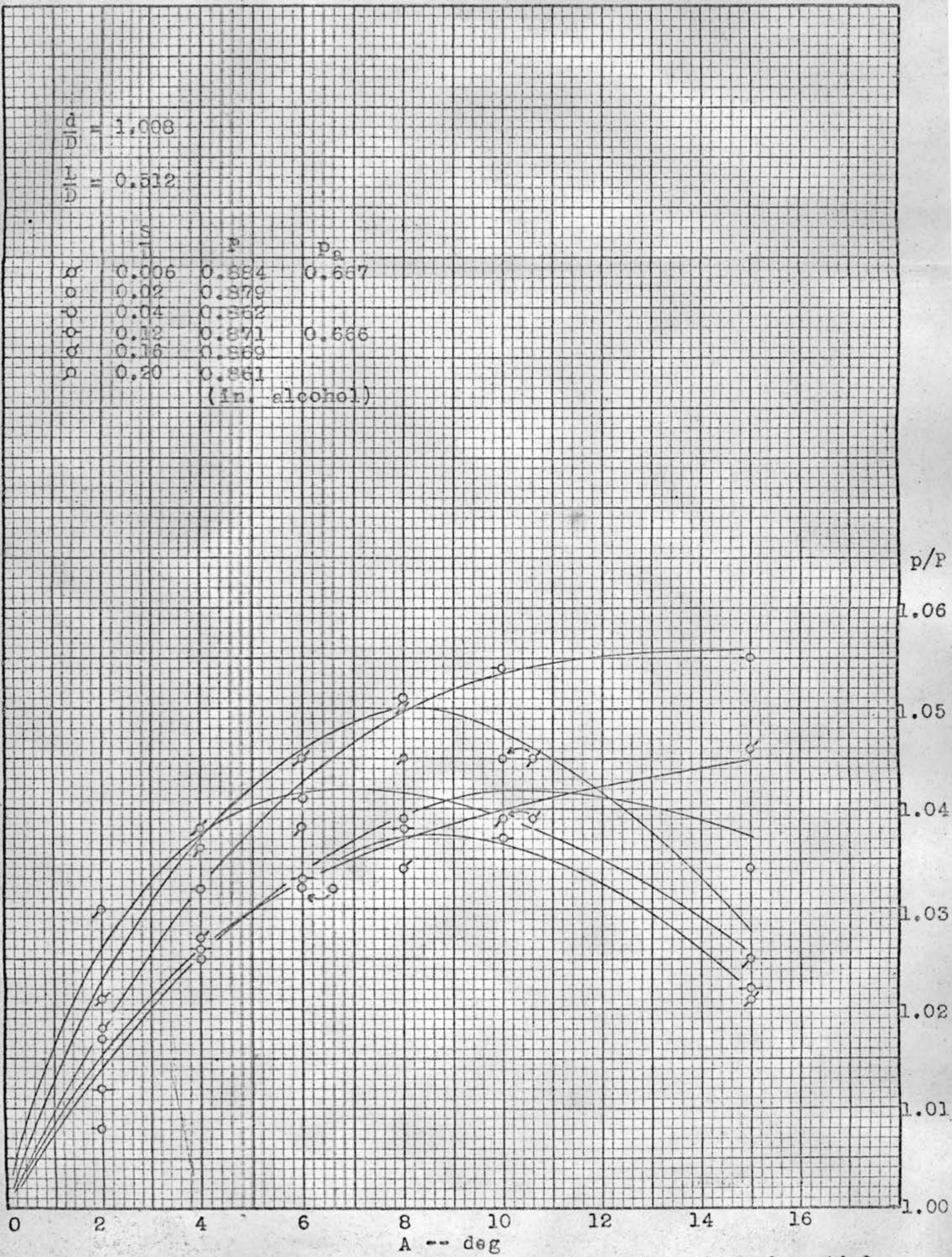

Fig. 20. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

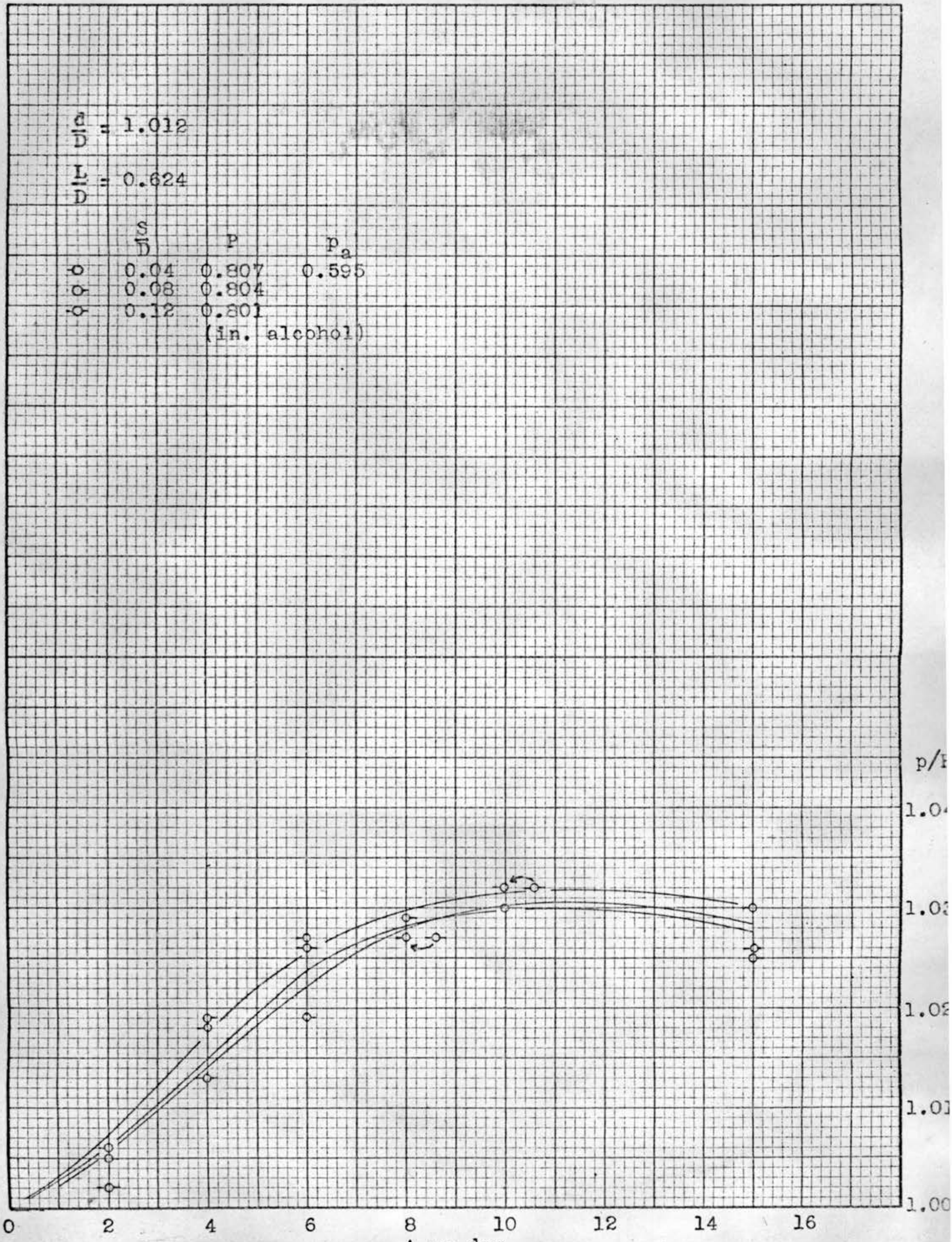

Fig. 21. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

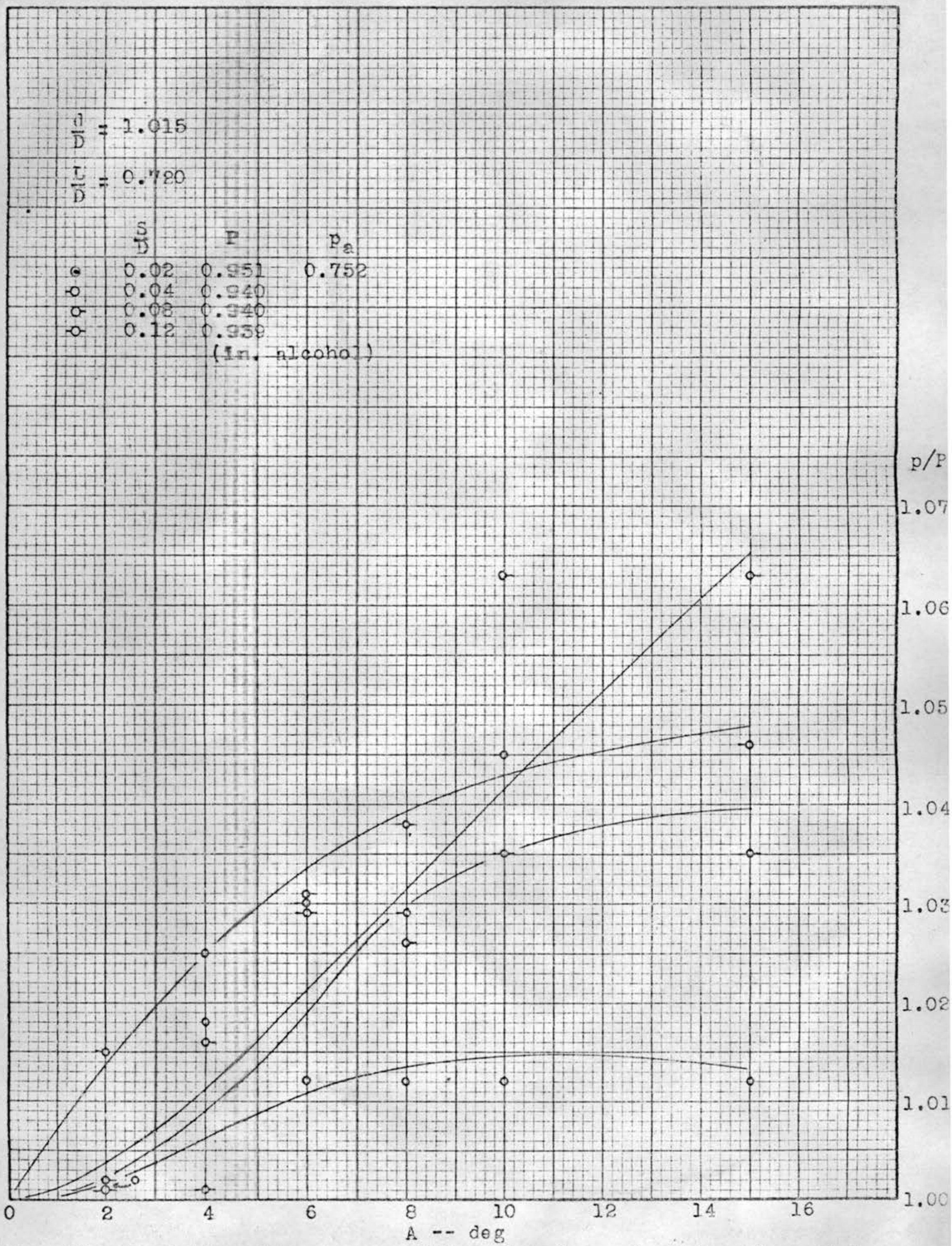

Fig. 22. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

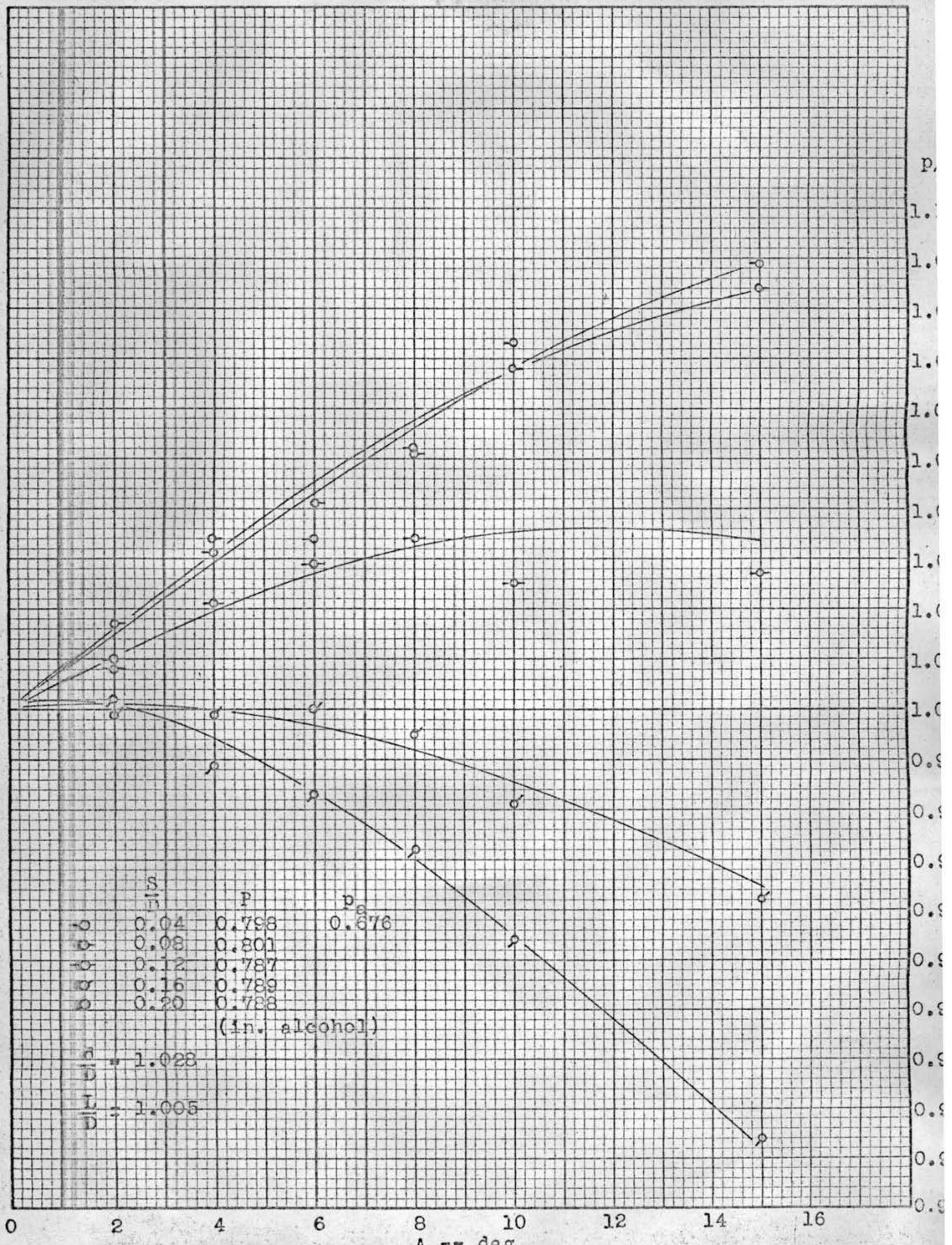

Fig. 23. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

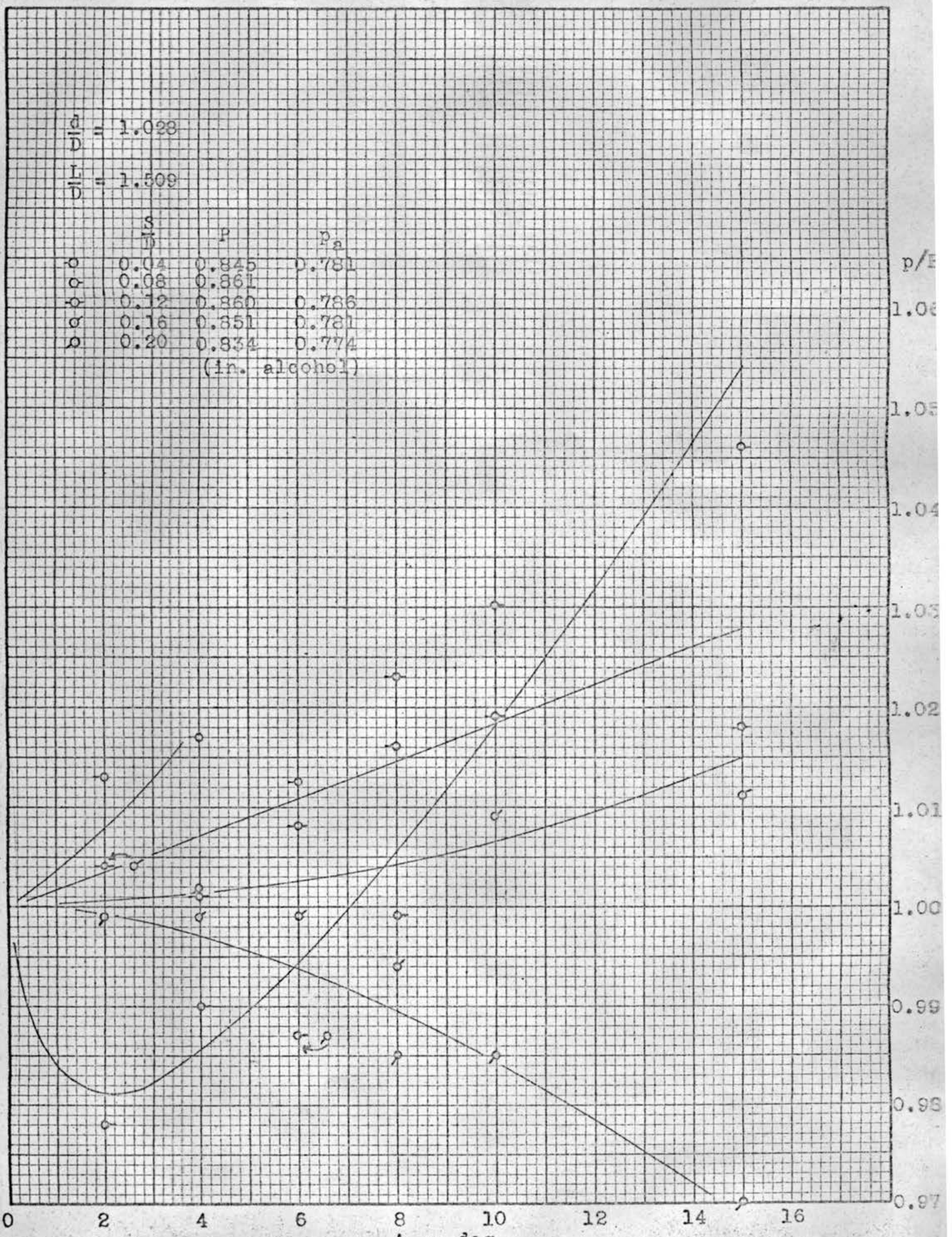

Fig. 24. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

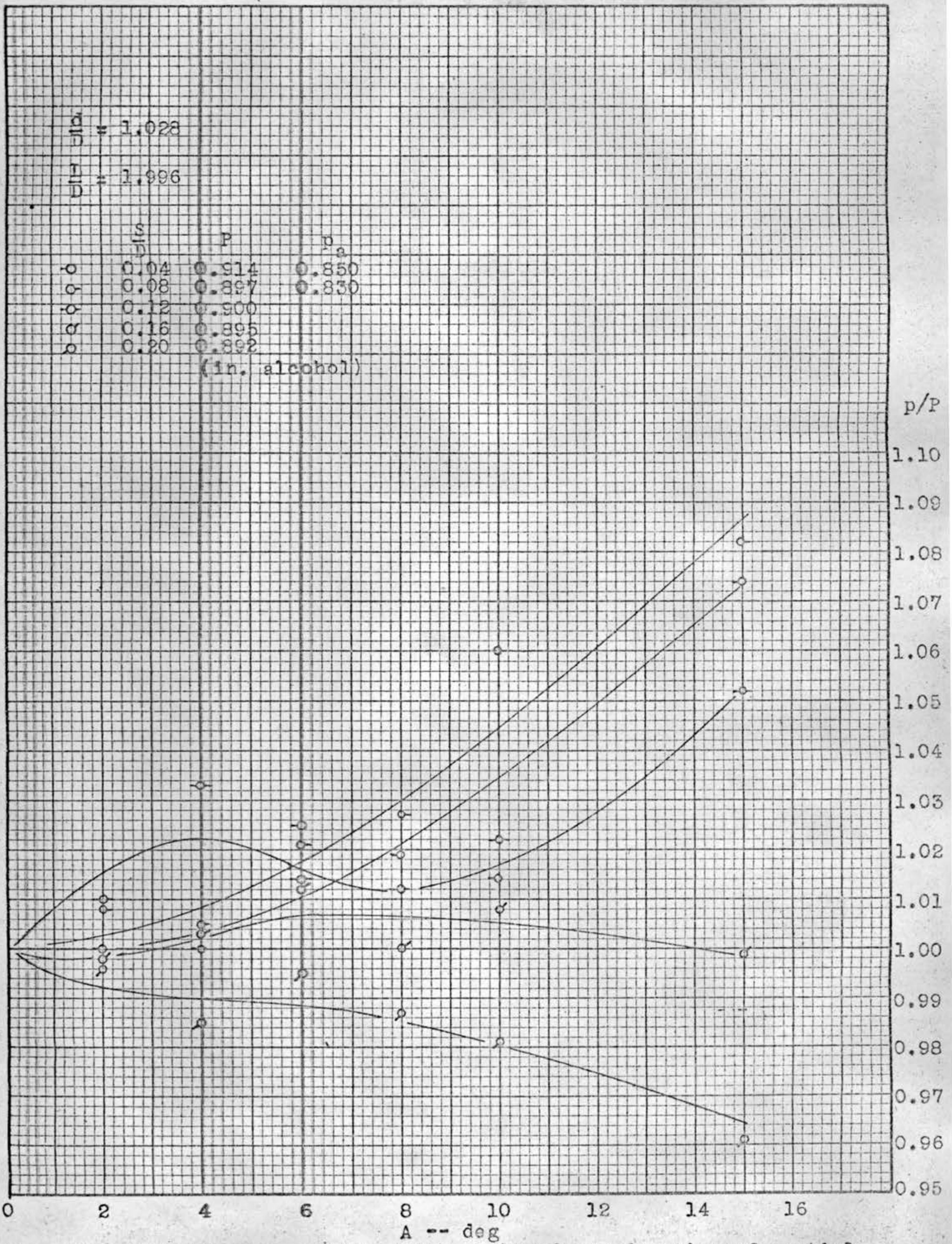

Fig. 25. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

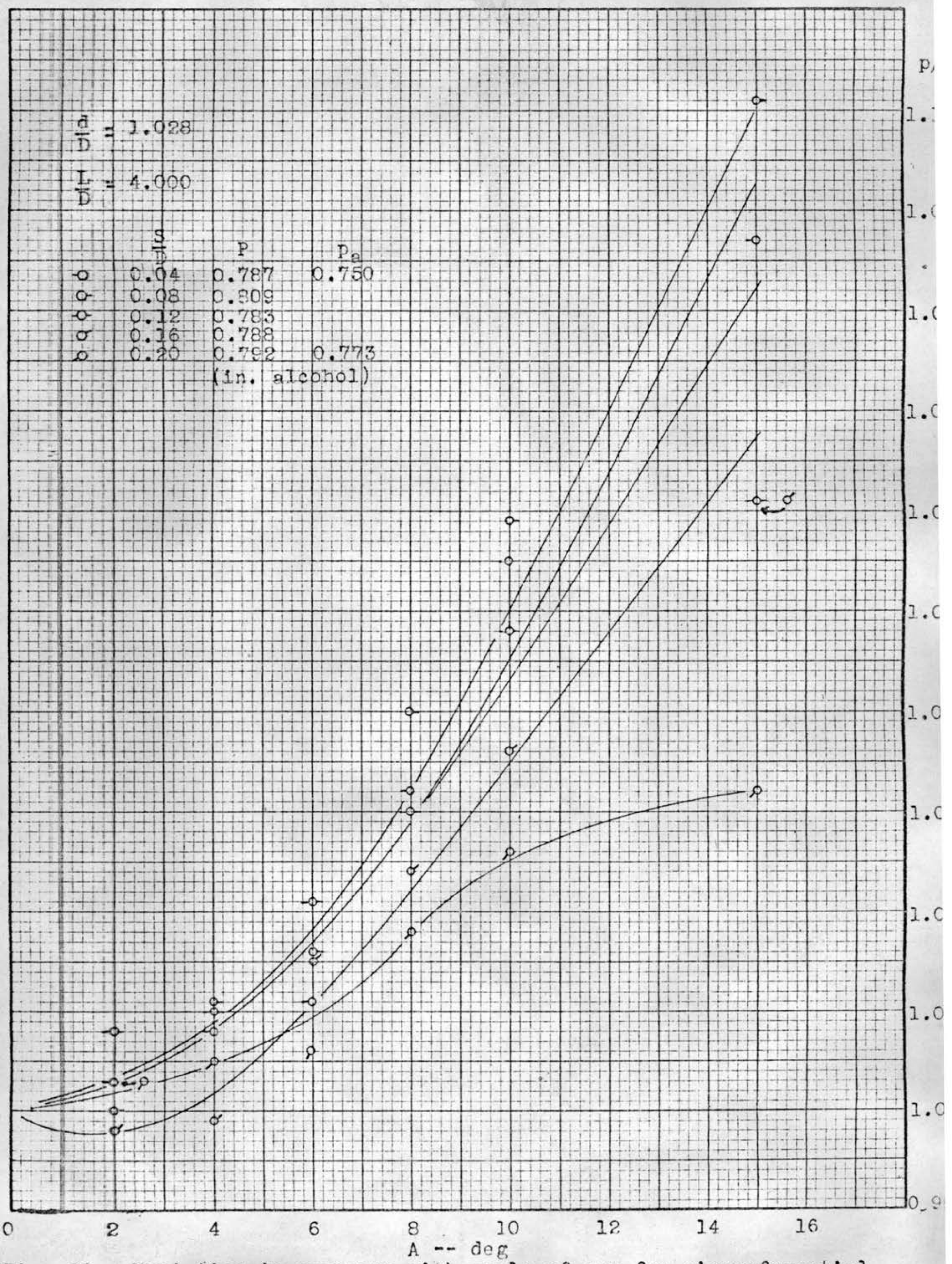

Fig. 26. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

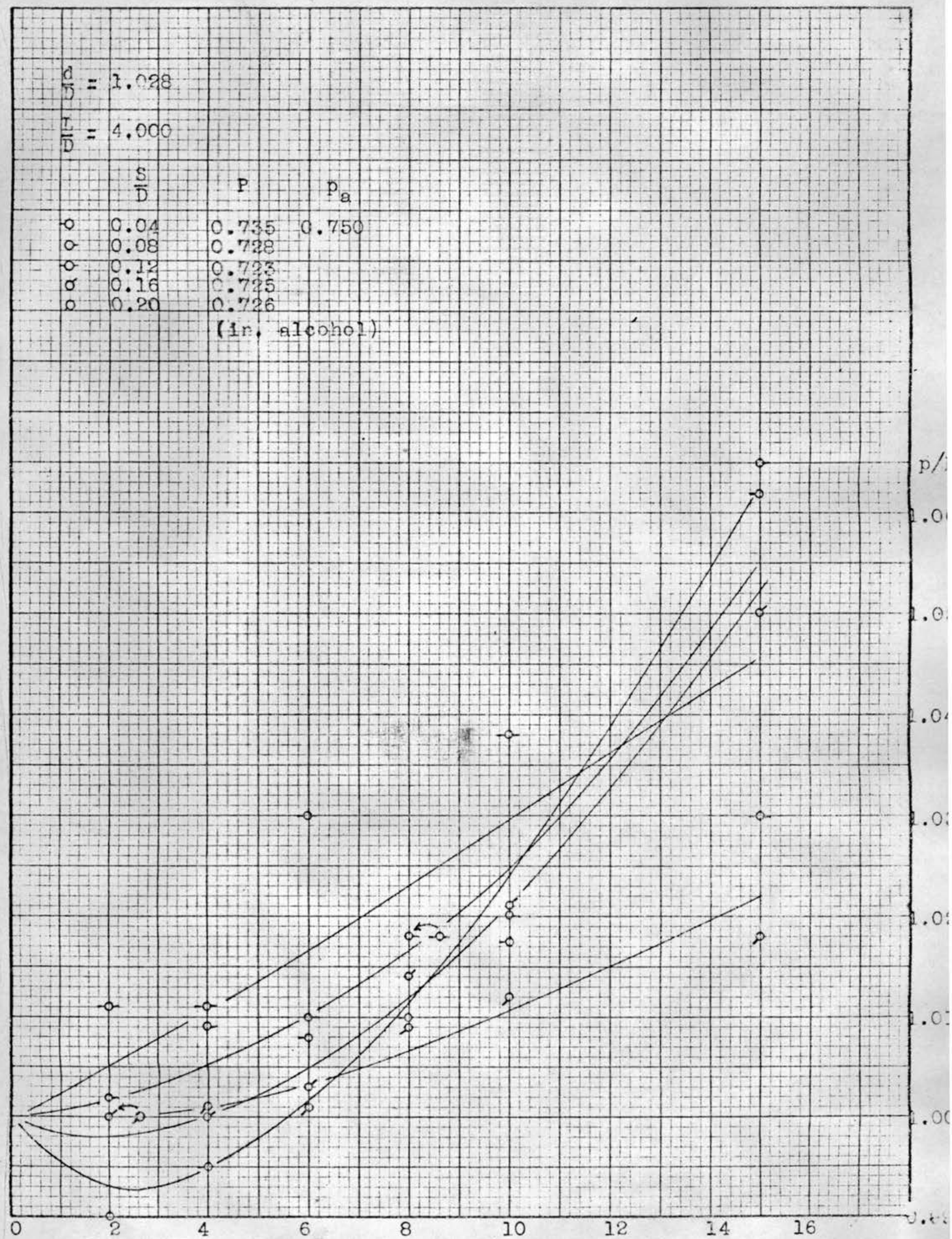

Fig. 27. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

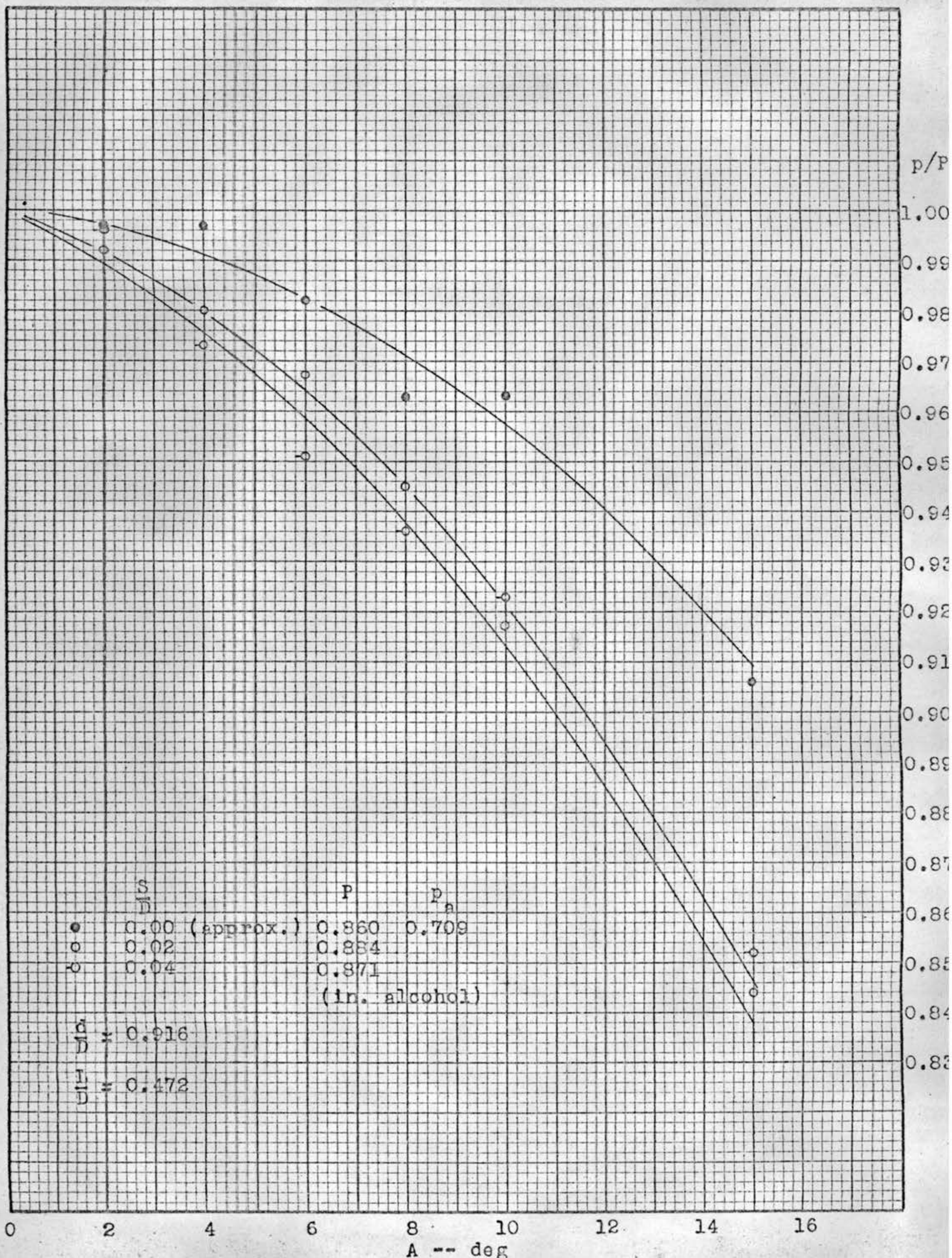

Fig. 28. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

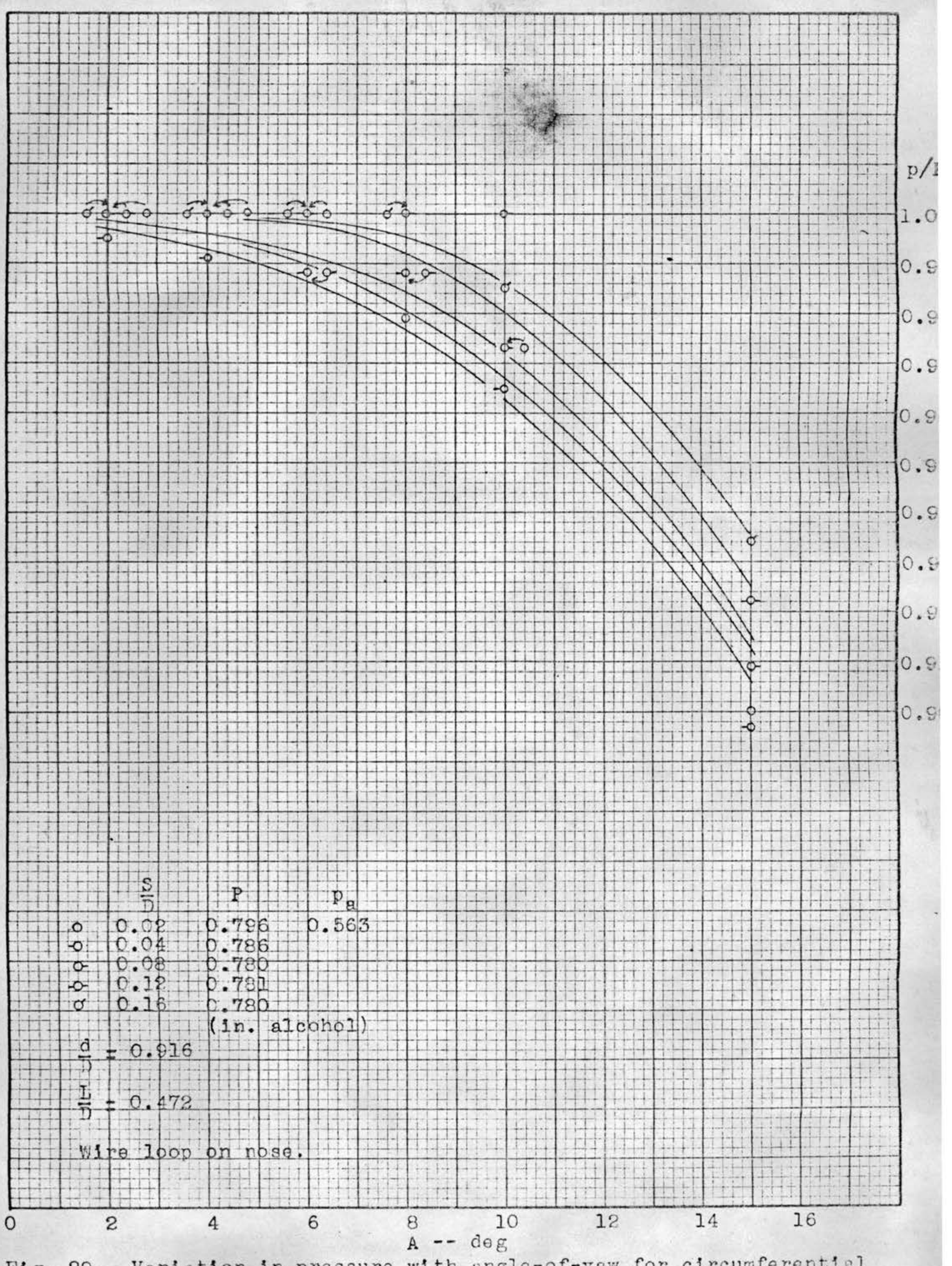

Fig. 29. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

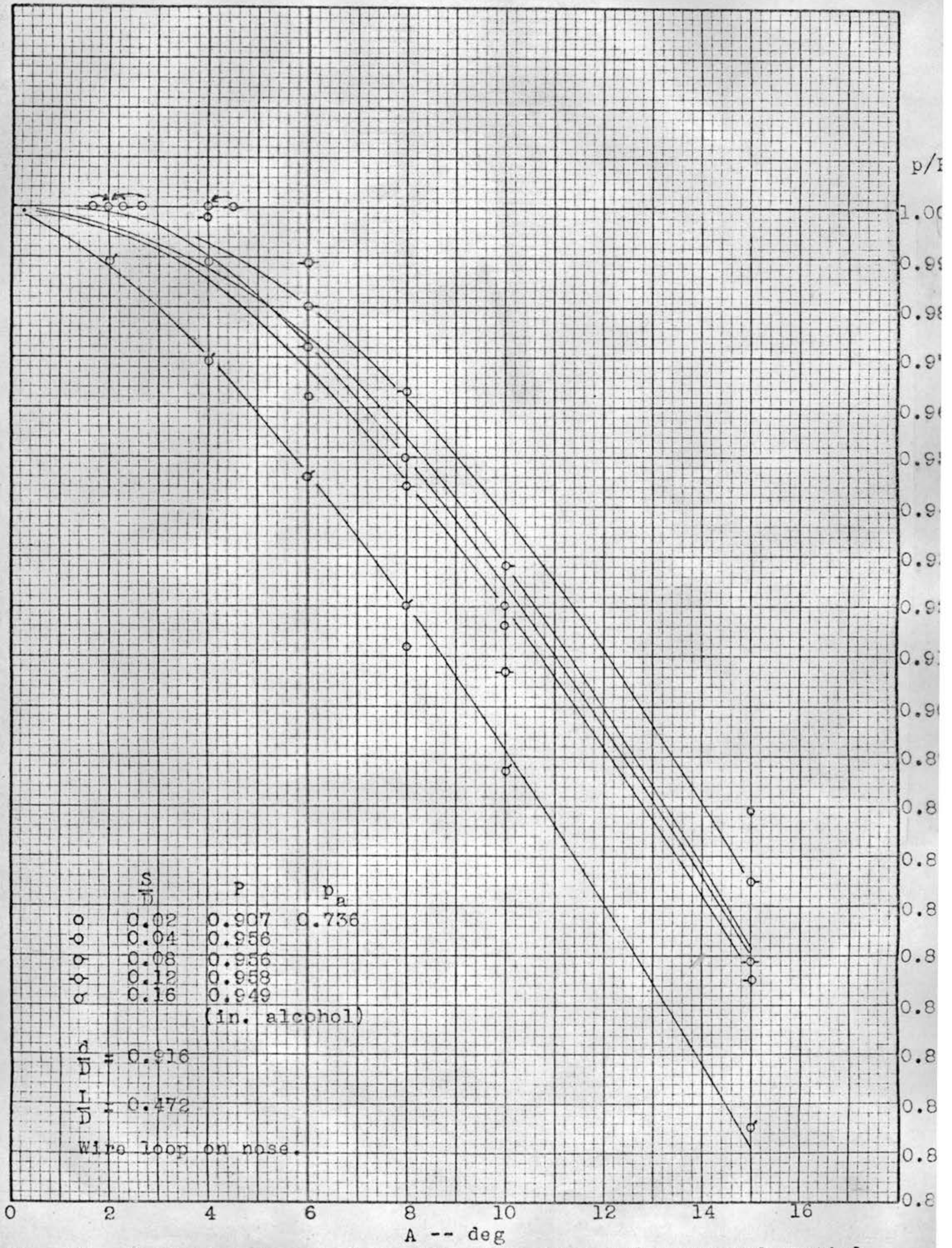

Fig. 30. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

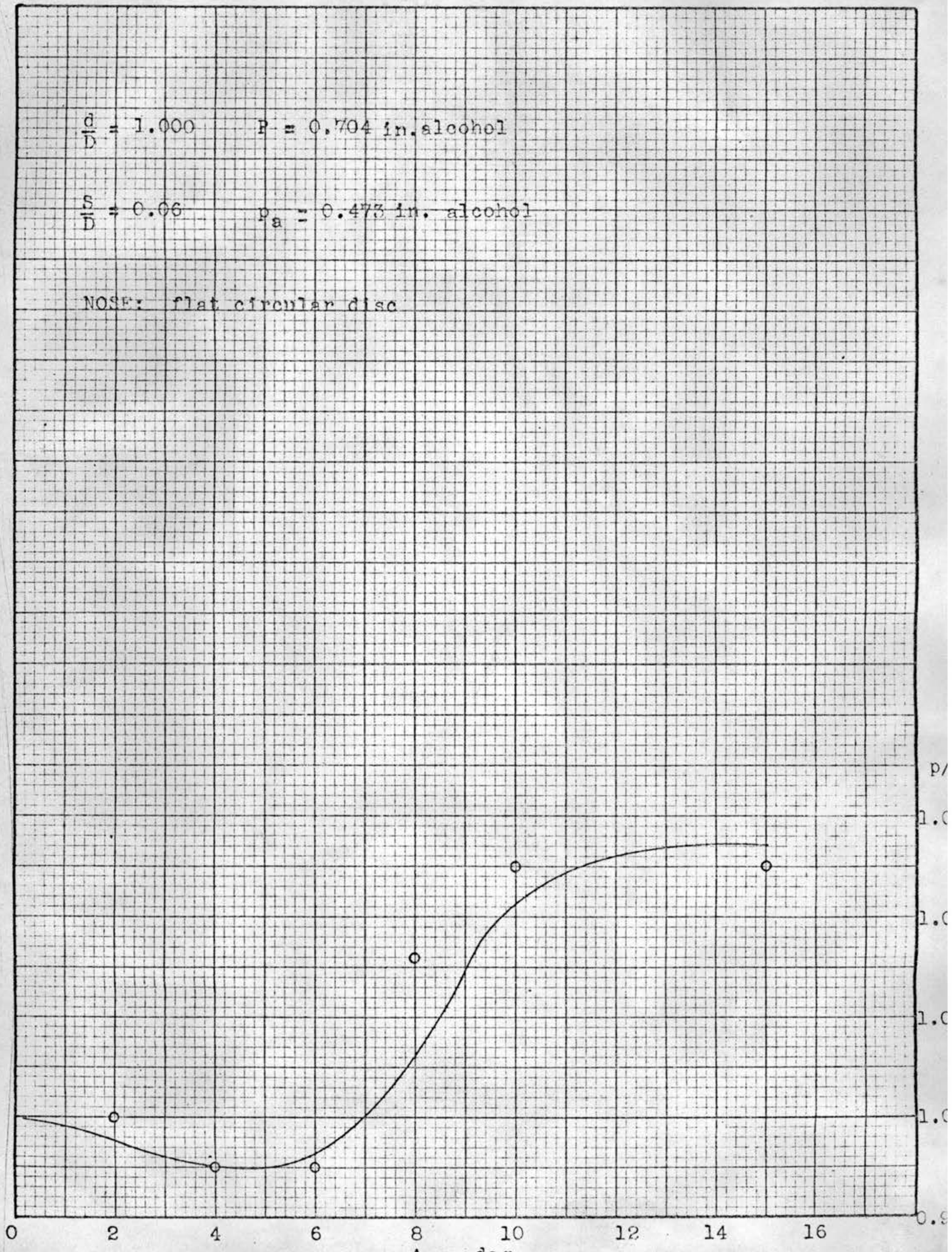

Fig. 31. Variation in pressure with angle-of-yaw for circumferential slot direction tube.

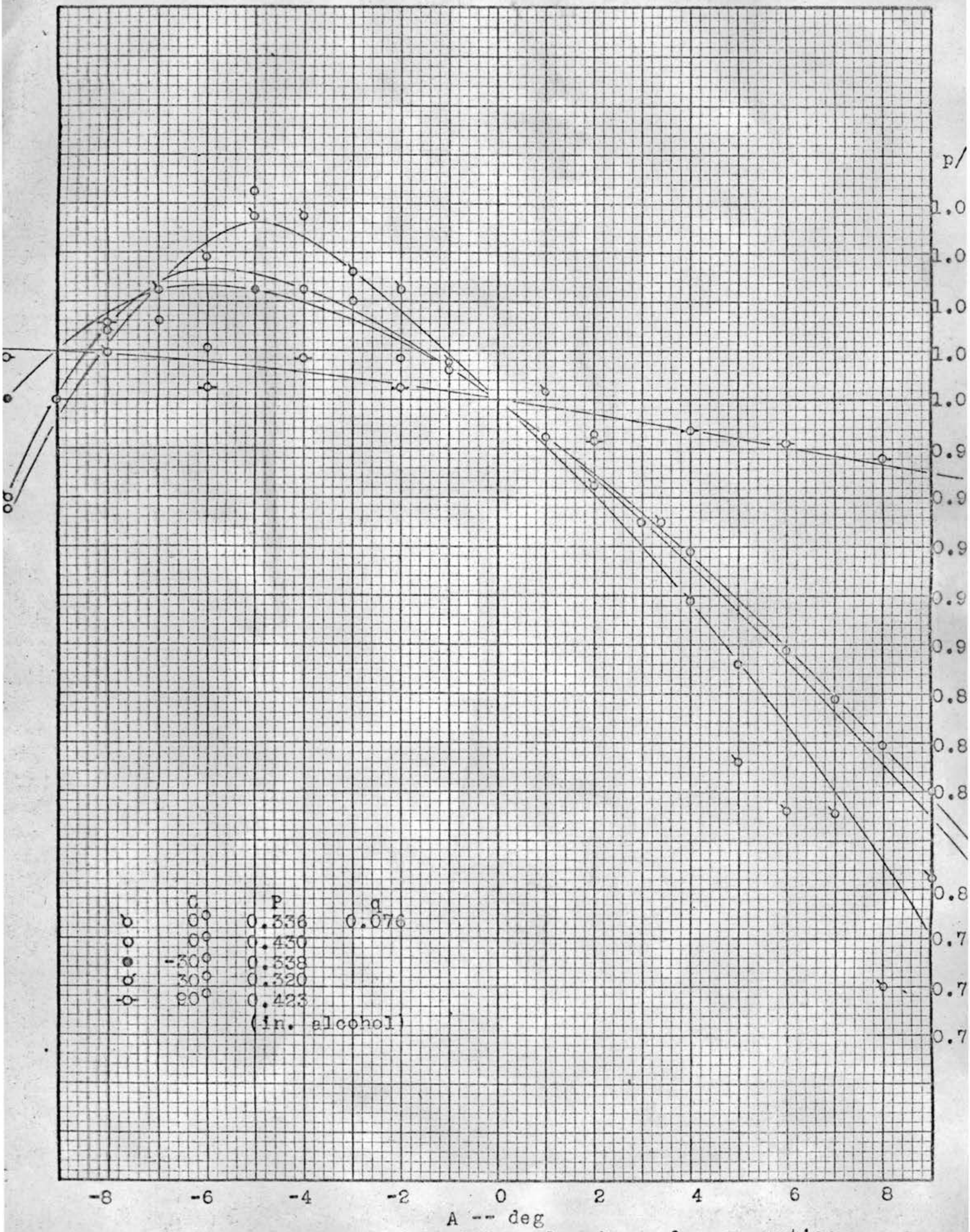

Fig. 32. Variation in pressure with angle-of-yaw for separation direction tube.