PART II.

EXPERIMENTAL INVESTIGATIONS OF THE FLOW THROUGH OBSTRUCTED PASSAGES.

FOREWORD

(PART II.)

This Part deals with a series of flow tests which have been carried out on orifices and nozzles, of various diameters up to ½ inch. The apparatus used for this purpose was very simple, but effective for the purpose for which it was designed. Reliable values of the Discharge Coefficient (C_D) have been obtained for the various conditions under test.

The initial experiments made in this series consisted of a general calibration of nozzles of various sizes both in the normal projecting position and when placed so as to re-enter the tank ("Borda" Nozzles). It has been shewn, for the first time, by these tests that several types of flow may exist, independently of the flow criteria. In addition, the C_D for the re-entrant nozzles was found to be far greater than the theoretical 0.50. In all, these experiments show the importance of acquiring a full knowledge of the fundamental phenomena associated with the flow of fluids through apertures.

A series of experiments was then conducted on the effects of various methods of obstructing the flow of fluid to a pre-calibrated orifice or nozzle. These obstructions were intended to influence the flow of the jet into and through the orifice so that

(1) the approach stream contracted before entering the orifice,

(2) both contraction and expansion occured in the approach stream before entering the orifice, and

(3) the approach stream was not only contracted before entering the orifice but was also expanded either just before or just after entering the aperture.

The experiments showed that such interference with the approach stream actually caused definite increases in C_D (which in some cases actually became larger than 0.995). Several important methods of augmenting the flow, have been revealed by these experiments.

As a result of these tests, the conclusions have been drawn that obstructions of the type used do not appreciably affect the energy conditions but that they do help to restrict contraction of the jet. It has also been concluded that the production of low discharge coefficients is a difficult feat and that high values of C_D can be obtained by careful design.

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CHAPTER 6.

THE EXPERIMENTAL APPARATUS

25. **Requirements.** In the first place, as the apparatus was to be built up and all the parts purchased by the author it was necessary to design a method of orifice calibration which was simple, used standard materials and could be assembled with ordinary workshop tools, together with the assistance of a small lathe. Furthermore, an ordinary pipe line with an orifice was not entirely acceptable as it did not easily facilitate the inclusion of approach disturbances. A discharge vessel was therefore required from which the obstructions could be suspended.

It was necessary, while arranging the detailed design of this vessel or tank, to provide for a direct method of measuring the head of fluid over the inlet. In order that the correct dimensions of approach chamber in relation to the discharge orifice might be selected it was required to provide the widest variations possible in the Re of the approach. When finally built, the approach flow with a 1/2 inch nozzle covered the whole range from laminar, through transitory to turbulent flow, for the normal working range of head.

At the same time, although this was not entirely fulfilled in the final design, it was desired to prevent any abnormal flow disturbances from being introduced into the approach flow during the infiltration of make-up water. The temperature of the water was also required to be constant in order to ensure that the viscosity remained the same throughout the experiments.

To determine the rate of flow it was considered most reliable to measure the quantity of fluid discharged for a definite period and thereby obtain a direct reading of the discharge rate. In practice it is believed to be more accurate to measure the weight and deduce the volume by using the specific gravity given by a hygrometer. Scales were not available for this purpose, so that a measuring tank had finally, to be used.

26. <u>Description.</u> Liquid (water) was allowed to discharge freely under gravity from the jacketted tank apparatus, fig. 26.1.

The tank was made from a seamless pipe, 6" internal diameter, 24" long, which was of smooth internal surface. To this pipe a standard pipe flange 11" outside diameter was screwed and soldered at one end, while the other end was left open, all burrs being filed off. The flange was then faced off in a lathe while attached to the pipe, so that its face was smooth and normal to the axis of the pipe. (This heavy turning was carried out by local contractors). Eight holes each $\frac{17"}{32}$ diameter, were drilled into this flange on a pitch-circle $9\frac{1}{4}"$ diameter. These holes were required for the 1/2" bolts holding the orifice-plate to the tank. To make this orifice plate a piece of mild steel plate, 1/2" thick was cut out to 11" diameter, bolt holes drilled $\frac{17"}{32}$ diameter (using the flange as template) and then countersunk centrally fig. 26.2. to take the orifices or nozzles. Holes 1/2" diameter were drilled into the pipe in three rows, fig. 26.3. through which liquid could enter the tank from the surrounding jacket. These holes were considered to produce a low rate of infiltration for which the jet was ineffective and did not disturb the orifice approach flow. A mild steel plate, 1/8" thick was rolled to shape and welded to the tank to form a jacket, while a length of about 24" of steel tubing 3/8" bore was welded to the outer face of the 6" pipe in order to admit the water.

This tank was mounted on a tripod made of 1" angle bar and fitted with 3 adjustable feet which were made from bolts working inside nuts welded to the tripod base. Adjustment was made so that the discharge tank was vertical and the orifices in a horizontal plane.

A hook gauge, fig.26.4. was used to measure the head of liquid above the orifice inlet and consisted of a 3/8" diameter wire, 27" long threaded 22 T.P.I. with a flat along one side which enabled it to slide in the guide without turning. The guide was shaped to receive the rod by being bored with a 3/8" diameter hole and a slip of metal soldered into it, this mating with the flat face filed on the threaded wire — both filing the wire and inserting this slip of metal were difficult and tedious, but by constantly "fitting" them it was possible to provide for a good action. This was inserted through a hole drilled into a piece of plate fitted across the top of the tank and the whole lot secured by a back nut. Adjustment was obtained by fitting a knurled brass nut to the rod and bearing this against the face of the securing guide so that on rotating this nut the screw was lifted or lowered. The wire was reduced to about 1/8" diameter at its lower end, bent into a hook and sharpened off with a 45° point, i.e. included angle 90°. The flat made along the wire was marked off in inches by a ruler, checked by "counting the threads", re-checked by rotating the knurled nut and then a line etched across to show the length. The knurled nut was then divided into angles to enable a closer degree of height adjustment to be obtained.

A tank fitted with a "diverting flap" and divided into two parts, a waste tank and a calibrated tank, fig. 26.1. was used to receive the discharge from the orifice. The jet of fluid which came from this orifice was allowed to fall on to the flap and was diverted into the waste tank which was connected to a drain. When flow readings were required the flap was rotated to divert the flow into the calibrated tank.

A constant head tank in the roof used as the main source of water supply, (the true source being the ordinary water mains). From this source, the supply to the tank was regulated by a screwdown valve and then passed through a short length of rubber tubing to the orifice calibrating tank. The flow obtained in this way, was quite satisfactory.

27. <u>Calibration and Adjustment.</u> Vertical alignment of the orifice calibrating tank was obtained by using two plumb-lines tied at one end to the flange bolts and passed from the outside over the top to hang down inside the tank. These lines were spaced around the flange at about 90o so that the tank could be aligned in each of the vertical planes. Adjustment was carried out by means of the foot screws on the tripod, the setting being arranged so that the line was just parallel with the pipe wall. In order to verify this setting was correct, a builder's spirit level was placed across the flange face (a vertical attachment was made up for this purpose) and very slight adjustments made to bring the bubble central. It is considered that this true alignment was maintained throughout the tests.

The zero-head reading, from which to mark-off the hook gauge, was obtained by means of a yoke-plate, fig.27.1. This device was made up from two straight edges to which a flat cross plate was soldered, care being taken to ensure that the plate was in contact with the straight edges before soldering. By placing this yoke-plate against the bottom face of the flange with the cross plate on top it will be seen that the lower face of this plate must be in the plane of the flange face. The hook gauge was then lowered and the hook made to press against the cross plate. When the gauge had been adjusted to hold the yoke just against the flange, the pointer of the gauge was at the

the nominal bottom of the tank, i.e. at zero. At this setting a line was scratched across the flat face of the wire at the position of the top face of the knurled nut and using this as the initial or zero reading, the whole length was then marked off.

Known quantities of water were poured into the calibrated tank used for measuring the flow, in order to calibrate this tank. Before making this calibration however, the tank was cemented to the floor at three points in order to ensure that it did not move after having once been calibrated. When ready for calibration and the water had been poured in, the depth was marked on a scale behind the gauge glass, this reading being expressed in terms of volumetric capacity, cu. ft. Thus the apparatus was marked off in divisions of $\frac{1}{100}$ cubic feet, the distance between readings being about $\frac{1}{8}$" and so being sufficient to estimate with moderate accuracy, for 0.005 cu. ft.

When set up and in the initial stages, rough tests were made to examine the effect of the water entering the tank through the holes from the jacket. Aluminium powder was sprinkled on the surface of the water in the hope that this may indicate to some extent the disturbance caused by the entering jet. At low heads the whole surface rotated indicating a high degree of vorticity, this was however, caused by the efflux through the orifice, at the tank wall where the make-up water was admitted there were no abnormal disturbances. Under larger heads there was a very slight motion suggestive of a low velocity jet, which was observed most readily when the level of water corresponded with the centre of one of the inlet holes. From these rough checks it is considered that the make-up water entered under-laminar flow and that the jet — if any — was too insignificant in the large approach chamber.

28. Method of Use. Some amount of preliminary testing (accompanied occasionally by an unpleasant overflow of water) was necessary before the technique of using this apparatus could be mastered. As however, the only operative skill required was in calibrating the discharge it is considered that accurate results were soon produced.

(i) Obtaining the head. The head was at first obtained by opening up the valve from the constant head tank, measuring the head, gauging the flow, screwing the valve down one revolution, and repeating the experiment. This however, was not found to be satisfactory since (i) the head was difficult to measure exactly as the "micrometric adjustment" with a 22 T.P.I. thread involved some arithmetical calculations with each reading before the precise reading could be recorded and (ii) the head was never the same for any two consecutive experiments so that calculations were most laborious. It was therefore decided to adjust the head to certain values, 20", 19", 18".... etc... in order to regularise the experiments.

The hook gauge was set to the pre-determined level and the valve opened to a setting — as judged by experience — known to give approximately the correct head. Invariably, when starting an experiment for which the tank is initially empty, it took about 7 minutes for the head to reach 20" with a ½" diameter orifice which was not blocked but left free to discharge while the tank was being filled. (It was considered undesirable to block the orifice, even with "Plastecene" as any surplus material left near the orifice edge may effect the readings.) When approaching the required level slight adjustments were made to the valve so that the level would become correct. Final adjustments were made with a small clip on the rubber pipe. By this means the pre-determined heads were obtained accurately.

In reducing the head the hook gauge was adjusted to the new level and the valve closed slightly so that the tank head fell. Further adjustment was made with this valve and final adjustment obtained with the pipe clip. The time required to adjust the head depended upon the rate of flow, but was generally about 2 mins. for a 20" head, 3 mins. for a 6" head.

(ii) Measuring the head. When the hook just protruded through the surface of the water it was set — assuming the initial calibration to be accurate — to measure the height of fluid over the inlet.

The divisions on the scale gave the inch markings and a dot, the half-inch position, To set the hook at a certain head the nut was screwed down and its top made level with the inch marking while the zero-angle radian on this nut was set normal to the flat surface of the scale (an indicator at the circumference, secured to the base of the bar to which the hook gauge was fixed, was used as a datum for the radial markings.)

By adjusting to the conditions it was possible to obtain heads which remained constant for about the whole time of test. This head, as given by the hook gauge reading, was taken as the head of fluid above the inlet and causing discharge.

(iii) Measuring the discharge. During these operations of setting the head the orifice was allowed to discharge into the waste side of the measuring tank.

When the required head had been obtained and the flow settled down, the flap was moved over smartly and at the same time the stop watch was started. After the timing interval had elapsed (and this was as long as possible in order to reduce timing errors) the flap was again rotated to divert the jet, while at the same time the stop watch was stopped. It was essential to synchronise these movements as much as possible, but after some little practice this 2-handed technique was successfully mastered.

(iv) Emptying the measuring tank. A pipe was fitted between the bottom of the measuring tank and the waste tank with a cock fitted in between to allow the measuring tank drain to waste when the cock was opened.

It was found however that the head in the measuring tank was too small to allow drainage to take place rapidly. The very primitive method of "baling out" was therefore resorted to.

(v) Measuring the discharge. Since it was not possible to empty the tank completely of water it was necessary to remove as much as possible before commencing a new experiment. The initial reading was then noted and subtracted from the final in order to measure the quantity of water discharged.

29. <u>Estimated Accuracy of Tests.</u> Throughout the experiments the possible sources of error may be divided into (1) head, (2) discharge and (3) in the correct dimensioning of the orifice.

Errors involved in the measurement of the head may themselves be subdivided into calibration and manipulation errors, the former comprising such errors as arise in the basic calibration of the hook gauge and therefore exists during the whole range of measurement, while the latter includes only those errors which are involved in the operation of the gauge. Operational errors vary with each measurement.

Calibration errors arise from the following sources:-

Gauge out of vertical		nil
Thread of measuring screw worn	$\frac{-1"}{100}$ AT 6"	-0.16 %
		-0.16 %

Manipulation errors include:-

Unsteadiness of flow	$\frac{+1"}{-20}$ at 6"	±0.83 %
Irregularity of surface	$\frac{-1"}{100}$ at 6"	-0.16 %
Inaccurate use of gauge	$\pm\frac{1"}{50}$ at 6"	±0.32 %
		+ 0.99% - 1.31 %

Similarly the measurement of the discharge may be assessed in the following manner:-

Time to turn flap to measure	$\pm\frac{1}{10}$ sec. in 25 secs.	±0.40%
Time to use watch	$\pm\frac{1}{10}$ sec. in 25 secs.	±0.40%
Duration of flow	$\pm\frac{1}{50}$ sec. in 25 secs.	±0.08%
Time to turn flap to waste	$\pm\frac{1}{5}$ sec. in 25 secs.	±0.80%
Time to use watch	$\pm\frac{1}{10}$ sec. in 25 secs.	±0.40%
		±2.08%

Actually measuring the discharge includes the following:-

Initial calibration errors ———	-0.005 cu.ft.at 0.40 c.f —	-1.25%
Paralax error ————————	-0.001 cu.ft.at 4.40 c.f.—	-0.25%
		-1.50%

It may be presumed that the $\frac{1}{2}$" diameter orifice was produced to within ±0.0005", i.e. with a maximum error of ± 0.10%. The error in other dimensions was not directly comparable with the results, e.g. champfer, and no estimate is possible of the error involved.

The aggregate error from each stage may be taken as follows:-

(1) head, error = -0.16% + 0.99% or - 1.31% = 0.83% or -1.47%

(2) discharge, $Q^1 = \frac{V^1}{t_1} = \frac{0.985\ V}{(1.0208 \text{ or } 0.98)t} = 0.965\ Q \text{ or } 1.00\ Q.$

error = -3.5% or 0.

The effect of these errors on C_D may be evaluated in the following manner:-

$$\text{true } C_D = K \frac{Q}{A\sqrt{H}} \qquad \text{false } C_D = C_{D1} = K \frac{Q_1}{A_1\sqrt{H}}$$

Assuming $A_1 = M.A.$, $Q_1 = N.Q.$, $H_1 = O.H.$

$$C_{D1} = \frac{K}{M.A.} \cdot \frac{N.Q.}{\sqrt{O.H}} = \frac{N}{M.\sqrt{O}} \cdot C_D$$

$$\therefore \text{Error} = \frac{C_D - C_{D1}}{C_D}$$

$$= 1 - \frac{N}{M\sqrt{O}} \qquad \text{------------------------- } 54.1$$

Substituting, M = 100.83% or 98.53%

N = 100% or 96.50%

O = 100.1% or 99.90%

the extremes of error may therefore lie between,

$$\text{Error} = 1 - \frac{1}{1.0083\sqrt{1.001}} = -0.01 \text{ , i.e. } -1\%$$

and

$$\text{Error} = 1 - \frac{0.965}{0.9853\sqrt{0.999}} = 0.021 \text{, i.e. } 2.1\%$$

These calculations indicate that in general, the results for C_D will tend to be high. The maximum and overall error does however tend to be very small even when based on a rather harsh analysis and is therefore considered to be within the tolerable degree of experimental error. It will be noted that the greatest error occurs in the actual measurement of the discharge, for further research with apparatus of the type it would be advisable to use a larger capacity, tall tank fitted with a vernier adjustment and eye-piece for measuring the head reading. Head it will be noticed, is only important with respect to the square-root power and the error is therefore minimised.

CHAPTER 7

CALIBRATION OF ORIFICES AND NOZZLES.

In this chapter, tests are described which have been carried out to determine the discharge of orifices of various proportions when operating under various heads. This research has been initiated with a three-fold purpose

(1) to determine the fundamental discharge characteristics of the apertures in order to compare the results with those obtained when the approach is obstructed,
(2) compare the characteristics of the apertures as determined from these experiments, with those published by other workers,
(3) estimate, if possible, any effects of the apparatus itself on the flow under these conditions.

30. Experiment No. 1. "To determine the effect of length on the C_D of $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{1}{2}$" ins bore nozzles at various heads. Normal sharp-edge entry."

30.1. Description. A nozzle of the shape shown in figure 30.1 was prepared by turning up the whole body in a lathe, from an ordinary piece of brass rod. The jet passage was carefully bored out and the hole reamered out to remove any interior roughness, so that the surface could be as smooth as possible. Particular care was taken to smooth off the approach flange by taking very small cuts and traversing the tool slowly. This was completed by grinding. When this was completed, the approach was considered to be as sharp-edged as possible under normal conditions..

In order to ensure that the approach and jet surface conditions remained constant throughout the whole series of tests, the same nozzle was used throughout the experiment, variations in length being obtained by cutting off pieces from the back or exit end when required. By this means the nozzle was gradually shortened. It was necessary to ensure that no burrs were left on the jet after the nozzle had been shortened. It is considered that by carrying out a series of experiments in this manner, that the results obtained give a true indication of the effects of change in length.

30.2. Calibration of the orifices. It was necessary to ensure (1) the jet diameter, and (2) the nozzle length were accurately known. In order to measure the internal diameter measurements of two diameters at right angles, both for the entrance and exit apertures, were taken by means of internal verniers. This is not an entirely satisfactory calibration as the nozzles may be "barreled" inside; since, however, the walls are fairly thick it is probable that the inaccuracy is very small, and as it is considered sufficient to use the nominal diameter, further accuracy of calibration is considered unnecessary. The length measurement was checked by means of ordinary verniers.

Accuracy of centering of the jet with respect to the tank flange, was checked by placing the nozzle inlet face downwards on a face-plate and then lining up with a square. Since the nozzle was turned up to this inlet face it was not surprising (since the chuck was new and true) that the inaccuracies were not measurable; the setting of the nozzles is believed to have been in true vertical alignment.

30.3. Temperature. The completed tests reported in this thesis were usually conducted between the hours of 18.00 and 22.00 from the spring to the autumn. Throughout this period, although both the air and water temperatures were taken they did not vary much from 11.5 to 12.5°C. Since the change in viscosity over this range is so very small it was decided to use, for purposes of calculation an assumed constant temperature of 12°C.

30.4. Determination of the true head. In attempting to decide upon the standard from which to take the true head as a basis for theoretical calculations it was found that a very conflicting number of circumstances was involved.

(i) In the first place, it would not be correct to use the head above the orifice face, as this ignored the effect of the orifice length and at very low heads this would (for long orifices) represent an appreciable source of potential energy. On the other hand the conditions in the approach chamber and in the nozzle are far from similar, the approach may be laminar, the nozzle turbulent, there is also a loss of head in the throat of the nozzle when the jet re-expands to the pipe walls.

(ii) Another difficulty experienced in determining the true theoretical head arose when the length fell below a certain value described in Section 13, usually equal to the orifice diameter, when thin-plate effects predominated. It is obvious that the short length orifices do not derive any benefit from their length and that this should not be used when determining the true head.

(iii) For long orifices another point arises in that the boundary layer may become separated from the pipe walls, an occurrence which has already been described in section 18. When this occurs the true head is obviously that which exists above the point of separation.

From all this it became clear that a definite code was required upon which to base the theoretical calculations. It was decided, after much thought, that the following code covered all contingencies:-

"That the flow was to be assumed to completely fill the bore of the nozzle at all times."

The theoretical head was therefore taken as that from the surface of the liquid to the exit mouth of the nozzle, hence

Theoretical true head = H + L

30.5. Formula for the theoretical discharge (in cubic feet/second) of orifices $\frac{1}{8}$", $\frac{1}{4}$" & $\frac{1}{2}$" diameter when H & L are measured in inches.

Diameter $\frac{1}{2}$" $\qquad Q = A.V.$

$$A = \pi/4 \left(\tfrac{1}{2}\right)^2 \qquad V = \sqrt{2g\,(H+L)/12}$$

$$= 0.1963 \text{ sq.ins.} \qquad = 2.31\sqrt{H+L} \text{ ft/sec}$$

$$= 0.00136 \text{ sq.ft.}$$

$$\therefore Q = 0.00136 \times 2.31\sqrt{H+L}$$

$$= 0.00314\sqrt{H+L}$$

$$= \underline{314.10^{-5}\sqrt{H+L}} \text{ cu.ft./Sec.}$$

Diameter $\frac{1}{4}$" $\qquad Q = 78.5.10^{-5}\sqrt{H+L}$ cu.ft./Sec.

Diameter $\frac{1}{8}$" $\qquad Q = 19.63.10^{-5}\sqrt{H+L}$ cu.ft./Sec.

30.6. <u>Calculations — variation of C_D with orifice length.</u>
By relating the theoretical discharge determined in the foregoing to the experimental results listed in Appendix I (Experiment No.1.) the coefficient of discharge was obtained. To simplify calculation, checking and to ensure as high a degree of accuracy as possible the process was divided into four stages (1) the summation of H + L (ii) determination of $\sqrt{H + L}$ (iii) multiplication by the appropriate factor to obtain the theoretical discharge (over the same period of time as that taken in the experimental determination of the discharge) and then (iv) finally, in another series of calculations, the division of the measured by the theoretical discharge to give C_D. These calculations were made for orifices 1/8", 1/4" and 1/2" diameter, for each of the various lengths, at each of the measuring heads.

For each of these orifices, the C_D was plotted fig.30.2,3,4, (Appendix II) against the orifice length, for the even heads 20, 18..........6. This was achieved by using a base line from one of the ordinates and from this base line using a further set of ordinates to represent C_D, this base line being ascribed the value C_D = 0.70. It should be stated that the odd heads 19, 17, 15......7 were neglected in order to abbreviate the process; it was intended to use these values for reference to any dubious plottings.

30.7. Observations — variation of C_D with orifice length.

A general survey of the three sets of curves, figs 30.2.3.4, indicates a large variation between them.

I. In fig 30.2. for the 1/8" diameter orifice the following stages of development as the orifice length is increased, are well defined:-

(i) the C_D increases very suddenly from a low value to a very high value which is reached at an orifice length of 0.275" approx., i.e. $\frac{l}{d} = 2.20$, a value which appears to be constant for all heads,

(ii) from the maximum reached in stage (i) the C_D drops fairly rapidly to a minimum at an orifice length of about 0.55", i.e. $\frac{l}{d} = 4.40$. The actual value appears to vary according to the head,

(iii) with further increase of the orifice length the C_D increases to a second maximum at an orifice length of approximately 1", i.e. $\frac{l}{d} = 8.00$,

(iv) further increase in orifice length causes C_D to diminish (the slope of this stage varies but may be equal to that in ii).

The points fell ~~fell~~ very nicely upon the plotted curve except those for the 3/4" long orifice ($\frac{l}{d} = 6.0$) for which the values for C_D were consistently 5.0% (approx) high. It should also be noted that the slopes throughout are approximately the same for all stages.

II. In fig.30.3. for the 1/4" diameter orifice, the following may be observed:-

(i) the C_D increases very suddenly from a low value to a maximum at an orifice length of 0.35" approx., i.e. $\frac{l}{d} = 1.40$,

(ii) the C_D falls from this maximum, to a minimum at an orifice length of 1.375", i.e. $l/d = 5.50$ (the slope of this stage for the 1/4" orifice is less than is this stage for the 1/8" orifice.)

(iii) from this minimum the C_D increases rapidly to a second maximum when the orifice is about 1.625" long, i.e. $\frac{l}{d} = 6.50$.

(iv) for longer orifices the C_D falls. (The slope of this curve is, again, almost equal to that of stage (ii).

The points for this figure were scattered and si 'mean' curves had to be drawn through them.

III. In fig. 30.4. for the 1/2" orifice the stages are fairly well defined.

(i) before increasing to the first maximum as in the previous, the curve first of all falls to a minimum C_D with the characteristics listed in the following

TABLE 30.1.

HEAD ins	20	18	16	14	12	10	8	6
ORIFICE length for minimum C_D ins.	0.375	0.470	0.575	0.503	0.375	0.670	0.500	0.575
C_D, MINIMUM	0.665	0.645	0.655	0.648	0.638	0.604	0.635	0.645

when these values are plotted, it will be seen that

(a) the orifice length for minimum C_D is very erratic but in general, it appears to shorten from a length of 0.70" ($\frac{l}{d} = 1.40$) to 0.40" ($\frac{l}{d} = 0.80$).

(b) the value of the minimum C_D varies with the head and is lowest at a head of 10". Under these conditions it acquires a value of 0.604. (It should be noticed, however, that the above values of C_D require further analysis because the C_D above is calculated on a basis of true head = measured head + orifice length, whereas since sharp-edged flow is occurring the results are biased to lower with the long orifices than with the short ones.)

(ii) As the orifice length is increased the C_D rises very sharply to a maximum, as in stage (i) for the two previous orifices. The value of this maximum C_D and the corresponding orifice length vary with the head as in the following table.

TABLE 30.2.

HEAD ins.	20	18	16	14	12	10	8	6
ORIFICE LENGTH for maximum C_D ins.	0.88	1.08	1.18	0.86	0.83	1.23	0.90	0.95
C_D, MAXIMUM	0.89	0.88	0.87	0.88	0.88	0.87	0.87	0.89
Alternatives l					1.38		1.43	1.68
Alternatives C_D					0.86		0.87	0.87

when plotted,

(a) none of the results for the orifice length at C_D, MAX, are at all consistent, but in general the length shortens from 1.6" ($\frac{l}{d}$ = 3.2) to 0.95" ($\frac{l}{d}$ = 1.9) as the head is increased (using the alternative plotting).

(b) the C_D max. decreases to a minimum of approximately 0.859 under a head of 10.8"

(It is significant that the conclusions (ii) a,b, above correspond very closely with those of (i) a.b.)

(iii) Further lengthening of the orifice caused C_D to fall (at the larger heads) but under low heads the C_D levelled off without any decrease. This effect was not consistent when using all the results obtained and therefore in plotting the results recourse was made to the alternative charting shown by the dotted lines in fig. 30.4. After considering the results as a whole and the agreement reached when they were subsequently replotted for the above secondary observations, it has been decided that the alternative dotted curve, is most representative of the flow phenomena.

(iv) A second maximum is reached by the curve at a point which is later described as the "break-a-way". The characteristics of this point are tabulated as follows:-

TABLE 30.3.

HEAD, ins	20	18	16	14	12	10	8	6
ORIFICE LENGTH at Breakaway	3.0	3.1	2.62	3.9	3.0	2.25x	2.5x	2.5x
C_D	0.85	0.85	0.86	0.854	0.855	---	---	---

x These values are very approximate as the change is difficult to detect accurately under the low heads.

From the above observations the follwwing characteristics may be observed:-

(a) The breaking length decreased with decrease of head, varying from 3.0 ($\frac{l}{d}$ = 6.0) down to 2.25 ($\frac{l}{d}$ = 4.50).

(b) The C_D at which breakaway occurs is constant at 0.855.

(v) The slope of the graphs with further increase in length of the orifice appears to be the same for all heads.

30.8. Analysis - variation of C_D with orifice length. In the first instance it must be admitted that there is a marked difference between the shapes of the three graphs, figs.30,2,3,4. It will, however, be noticed from the values of Re given in a subsequent part of this section that the dynamical conditions during these experiments are quite different, and it is therefore considered that these differences influence the curves under revie.

The region of low C_D with short orifices, exists when the flow contracts on leaving the orifice and does not subsequently expand to refill the orifice. These are the conditions of sharp-edged flow. The actual variations of C_D under these conditions can only be studied from the experiments on the

1/2" orifice as the other experiments gave few results in this range. Although a minimum C_D is reached even in this region of low C_D, the calculations are biased (for the reasons previously mentioned) and are really too small. The effect is, however, too small to influence the general results and it must therefore be concluded that the foregoing deductions apply to the other orifices, namely

(a) that the orifice length for minimum C_D is variable, but in general that it shortens from a length of 0.70 ($\frac{l}{d} = 1.40$) to 0.40 ($\frac{l}{d} = 0.80$) as the head is increased.

(b) the minimum C_D has a least value with a head of 10".

It is considered that these results are in some way related to the position of the vena-contracta. Thus, if the jet had re-expanded a vena-contracta would have formed, possibly at a distance of about 1 pipe-diameter downstream. At the critical length for the minimum C_D, the flow just did not re-expand (although it was then very unstable), the length for these conditions corresponding very closely with the position of the vena-contracta. This supposition is confirmed by the existence of complete instability (as shewn by the steepness in slope of figs. 30) in the following part of the curve. Despite this, the author has been unable to develope an explanation for the shortening of this critical length as the head is increased.

The orifice length at which full flow takes place (i.e. the fluid issues from a nozzle, as distinct from a sharp-edged orifice) is distinguished by the high C_D, and varies with the orifice diameter in the manner tabulated below:-

TABLE 30.4.

Orifice Diameter(d)	Length (x)	$\frac{x}{d}$
$\frac{1}{8}$	0.275	2.20
$\frac{1}{4}$	0.350	1.40
$\frac{1}{2}$	0.88 to 1.68	1.76 to 3.36

It is evident therefore that this distance does depend upon the orifice size and the flow velocity. Since the value of 'x' for the $\frac{1}{8}$" reading was only taken from one reading and was multiplied by a high value, the final value of $\frac{x}{d}$ is liable to a large error. The true $\frac{x}{d}$ is considered to be less than 1.40, so that the distance increases with orifice and decreases with increase of head. The author's experiments confirm that the value of the maximum C_D at the full flow head increased with Re, as shown in fig. 13.1.

The reduction of C_D with increase in orifice length beyond the "full-flow" for both the $\frac{1}{8}$" and $\frac{1}{4}$" orifices, appears to have the same slope. ($-\frac{C_D}{l}$) for all heads, thereby indicating that the loss of C_D is not directly due to "pipe"-wall friction losses. The only explanationswhich the author can conceive are (1) that the jet, after expanding, is "reflected" from the walls (this is rather artificial and founded upon no evidence that such a phenomena does exist), and (2) that there is a length in which the flow changes from laminar to turbulent, an "inlet-length" effect, in fact, which causes some disruption of the normal flow so that C_D diminishes. It is sufficient to note that the position of the minimum which is reached under these conditions, (which appears to be independent of the head) increases from $\frac{l}{d} = 4.40$ for the ⅛" orifice, to $\frac{l}{d} = 5.50$ for the ¼" orifice, and that the slope of the curve, $-\frac{C_D}{l/d}$ is approximately 0.05 for the ⅛" orifice and 0.03 for the ¼" orifice.

The reasons for the increase in slope of the curve with further increase of l is also a matter of conjecture. The approximate slope $\frac{C_D}{l/d}$ is 0.017 for the ⅛" orifice and (although shorter and therefore more difficult to determine) 0.04 for the ¼" orifice.

The second maximum C_D is considered to occur at the point of "break-a-way" or separation, of the flow. Reference to the foregoing shows that the position of this point varies with orifice size and head in the following manner:-

TABLE 30.5.

d	l	$\frac{l}{d}$
⅛	1	8.0
¼	1.63	6.5
½	3.0 to 2.25	6.0 to 4.5

This shows that (1) with increase in orifice diameter the flow separates from the orifice more readily than with small diameters, (2) increase in the discharging head throws the separation point further from the orifice.

On further increasing the orifice length there is a drop in C_D. (Although this effect is magnified by using H+L for the calculations of C_D.) This decrease is considered to be caused by the re-contraction of the jet after breakaway, involving a new "vena-contracta" and fresh losses of head. In order to determine the precise effects of using H+L in the calculations, it was decided to evaluate the actual C_D for the 20" head condition, assuming breakaway to occur (from the faired curve) at 3·2 ins. Hence, for any longer nozzles the head producing the discharge will be 20 + 3·2 = 23·2 ins. On this basis, the correct theoretical discharge must be calculated as

$$Q = 15.7.10^{-2} \times \sqrt{23.2}$$

$$= 0.754 \text{ cu. ft.}$$

Since the original full flow is considered to be reduced by the formation of a vena-contracta after breaking, then, we may assume (not entirely correctly since it implies $C_{V2} = 1.0$)

$$C_{D1} = C_D \cdot C_{C2}$$

$$\text{i.e. } C_{C2} = C_{D1} / C_D$$

where C_{C2}, C_{V2} refer to the assumed contraction after breakaway,

C_{D1} = coefficient obtained by using H+3.2

C_D = coefficient obtained by using H+L.

The values of these coefficients are given in the following table,

TABLE 30.6.

ORIFICE LENGTH ins.	$3\frac{1}{4}$	$3\frac{3}{8}$	$3\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{3}{4}$	$3\frac{7}{8}$	4"	$4\frac{1}{8}$
(True) C_{D1}	0.849	0.842	0.844	0.849	0.841	0.811	0.799	0.804

Assume that C_D = 0.855 ______ this value being representative for the orifice length 3.1 ins.

ASSUMED C_{C2}	0.999	0.990	0.993	0.999	0.989	0.954	0.940	0.947

The following points must be watched with regards to this table,

1) between the lengths $3\frac{1}{8}$ ins. to $3\frac{3}{4}$ ins., C_D varies between 0.841 and 0.849. This represents a very small fluctuation from the mean (0.844) which may be accepted as lying within the limits of experimental error. It is therefore confirmed that breakaway does actually occur and for these readings under a 20" head, it occurs at an orifice length of 3.20 ins.

2) It is also shown by the above table that the "C_C" whose existence is suspected, has a very high value which is in keeping with the gentle change of section such as "breakaway" would involve.

3) The drop in "true C_D", C_{D2}, for lengths of $3\frac{7}{8}$" and more may be due to the formation of an airlock or vortex inside the nozzle. This argument is based on the fact that with the lengths involved there would be an unwetted length of 3.875-3.200 = 0.675 ins. This is quite appreciable and therefore the contraction of the jet at exit would be quite large. In these circumstances a large, empty annulus may surround the jet and may be responsible for the reduction of C_D at lengths greater than $3\frac{7}{8}$ ins.

<u>30.9. Reynolds Number of the Flow.</u> In order to understand the flow through the orifices under the experimental conditions it was considered necessary to tabulate Re for the conditions involved

For the orifice, $\frac{1}{2}$"diameter, $Re = \frac{v.d}{\nu} = \frac{(\frac{Q'}{a})d.}{\nu} = \frac{4.Q.d}{\pi.d^2.\nu}$

$$= \frac{4.Q'}{\pi.d.\nu}$$

where Q'= rate of discharge.

Assuming that Q' is measured in ft^3/sec.,

$$\nu = 1.23.10^{-5} \text{ sq.ft./sec., } d = \tfrac{1}{2} \text{ ins.} = \tfrac{1}{24} \text{ ft.}$$

$$\therefore \text{Re} = \frac{4.Q^1}{\pi\left(\frac{1}{24}\right).\ 1.23.10^{-5}}$$

$$= 2,490,000\ Q' \quad \text{\_\_\_\_\_\_\_\_\_ for the ORIFICE.}$$

But the diameter ratio $m = \left(\frac{\frac{1}{2}}{6}\right)^2 = \left(\frac{1}{12}\right)^2$

i.e. $\sqrt{m} = \frac{1}{12}$.

Hence, from equation 5.2. for the approach flow,

$$\text{Re} = \frac{1}{12} .\ 2,490,000\ Q'$$

$$= 207,500\ Q' \quad \text{\_\_\_\_\_\_\_\_\_ for the APPROACH.}$$

For the orifice, $\frac{1}{4}$" diameter,

Re = 4,980,000 Q' _________ for the ORIFICE.

$\sqrt{m} = \frac{1}{24}$

Re = 207,500 Q' _________ for the APPROACH.

For the orifice, $\frac{1}{8}$" diameter,

Re = 9,960,000 Q' _________ for the ORIFICE

$\sqrt{m} = \frac{1}{48}$

Re = 207,500 Q' _________ for the APPROACH

Using the volume Q actually measured in time t seconds, for the calculations,

$d = \frac{1}{2}$ ins. t = 50 secs. Re orifice = $2,490,000 \frac{Q}{50} = 49,800\ Q$

Re approach = $207,500\ \frac{Q}{50} = 4,150\ Q$

$d = \frac{1}{4}$"ins. t =50 secs. Re orifice = $4,980,000 \frac{Q}{50} = 99,600\ Q$

Re approach = $207,500 \frac{Q}{50} = 4,150\ Q$

$d = \frac{1}{8}$ ins. t = 500 secs. Re orifice = $9,960,000 \frac{Q}{500} = 19,920\ Q$

Re approach = $207,500 \frac{Q}{500} = 415\ Q.$

Using these equations and the values of Q given in Appendix I, the following values for Re may be obtained:-

TABLE 30.7.

	$\frac{l}{d}$	1.0			6.0		
	H ins	20	12	6	20	12	6
$\frac{1}{8}$"	Re Approach	0.129	0.102	0.076	0.150	0.119	0.085
	Re orifice	6.170	4.88	3.64	7.19	5.71	4.08
$\frac{1}{4}$"	Re approach	0.613	0.486	0.344	0.581	0.465	0.349
	Re orifice	14.70	11.65	8.26	13.95	11.15	8.37
$\frac{1}{2}$"	Re approach	1.99	1.52	1.04	2.64	2.13	1.63
	Re orifice	23.9	18.2	12.5	31.9	25.5	19.5

All these values should be multiplied by 10^3 to give Re.

This table shows,

1) that with $\frac{1}{8}$" orifice the flow in the approach is laminar, and in the orifice it is turbulent,

2) with the $\frac{1}{4}$" orifice the flow in the approach is also laminar (although of much larger Re than for the $\frac{1}{8}$" orifice) while the orifice is definitely

turbulent.

3) with the $\frac{1}{2}$" orifice the approach flow is very nearly turbulent as well as the orifice flow.

4) it will also be noted that these conditions exist with both long ($\frac{l}{d} = 6.0$) and short ($\frac{l}{d} = 1.0$) orifices.

From the values plotted in this table it is clear that a transitory zone exists at the entrance to the orifice which has some influence upon the C_D. The author believes that the "inlet" length in which the flow changes to turbulent is responsible for the fall in C_D after the "full-flow" length has been passed.

30.10. Calculations - The Effect of Head on C_D. In view of the conclusions reached in section 8 it was decided to plot C_D against $H_1^{-\frac{1}{2}}$, where H, is the effective head i.e. H+l.

To simplify this process it was decided to use a scale of absiccae based on $H_1^{-\frac{1}{2}}$ but actually noted in terms of H_1, an orifice commonly used with logarithmic plotting. The whole series of graphs for each size of orifice are plotted on one sheet, as in figs.30,5,6,7 respectively. It was found, after plotting fig.30.5 and part of fig.30.6. that it was unnecessary to plot all the varying conditions and consequently only a few typical values were selected for the $\frac{1}{2}$" orifice and plotted in fig.30.7.

30.11. Observations - the effect of head on the C_D. The points which were plotted in the foregoing manner showed no consistency whatsoever, only in a very limited number of cases was it possible to draw anything approaching a straight-line through the points. In these cases, the results were very erratic Co lying between 0.75 and 0.95, and the constant k between -0.050 and -0.300. With the shorter orifices there is a tendency for the curves to be normal, i.e., Co to approach 0.610 and k positive, but even with these nozzles the effect was only noticeable at heads less than 12".

<u>30.12. Analysis - The effect of Head on C_D.</u> Since the results obtained in an attempt of correlate the observations of section 8 to the readings obtained in this experiment are scattered and do not fluctuate far from the mean for any one orifice size, it was considered that <u>under the conditions for this experiment,</u> the effects of head on the C_D at each particular orifice length are negligible and that a mean value (arithmetical) may be used.

<u>30.13. Effect of orifice size.</u> In order to determine the effect of orifice size it was first considered necessary to use geometrically similar orifices, i.e., orifices with the same $\frac{1}{d}$ ratio. It was realised that by comparing the orifices on such a basis of similarity that the progressive effects of breakaway, full-flow, etc., which occur at different values of $\frac{1}{d}$ for different orifices diameters, may have important influence on the results. The considerations in subsections 30.10,11,12 above, of the effects of head on the C_D were taken to indicate that it was not necessary to obtain dynamical similarity in order to satisfactorily compare the effects of size on the C_D. For this reason

the mean C_D of all the readings at the selected $\frac{l}{d}$ ratio, was used.

TABLE 30.8

l/d	1	4	8
⅛"	0.725	0.751	0.800
¼"	.0.850	0.806[x]	0.754
½"	0.659	0.852	0.783

[x] Mean value from the readings of the 7/8" and 1⅛" nozzles.

The values given in table 30.8. above show that size may have some effect on the C_D of the orifices used. With $\frac{l}{d} = 1.0$ it has been previously stated that the ⅛" orifice has a low C_D, i.e. is influenced by thin-plate flow, similarily for the ½" orifice. With the ¼" orifice, however, a maximum C_D is reached with this value of the orifice ratio. The comparative results in table 30.8, are not surprising.

With $\frac{l}{d} = 4.0$ the flow through the orifice should be quite normal. It will be seen that under these conditions the value of C_D increases with orifice diameter.

When $\frac{l}{d} = 8.0$ there is a tendency for the flow to break awa away from the orifice walls. This effect is most marked with the ¼" orifice since this shows a tendency to breakaway at shorter orifice lengths than either of the other orifices; this is possibly reflected in the low value of C_D with $\frac{l}{d} = 8.0$, for this orifice.

In order to investigate the effect of orifice size on more rational lines, it was decided to record the values of C_D at each of the important flow-change points, namely, at(1) the "full-flow" maximum (2) the "approach-flow transition" mimimum, and (3) breakaway. These values are taken from the curves, fig.30 2,3 and 4, and (since $\frac{1}{d}$ for the various flow changes varies) were naturally taken at different values of $\frac{1}{d}$. [It should be recorded in support of the deductions made at sub-section 30.12. above, that when tabulating the values of C_D, it was found that for all the heads used, the variations from the mean were very slight.]

TABLE 30.9.

Diameter ins.	Full Flow maximum	Flow Transition Minimum	Breakaway
$\frac{1}{8}$	0.850	0.751	0.803
$\frac{1}{4}$	0.852	0.772	0.793
$\frac{1}{2}$	0.854	—	0.851

For the "full-flow" maximum there is a progressive (if slight) increase in C_D with orifice diameter; this increase may also occur with the flow-transition minimum, but the absence of satisfactory value for the $\frac{1}{2}$" orifice leaves the answer in doubt. At breakaway there is a slight drop from the C_D of the $\frac{1}{8}$" orifice to that of the $\frac{1}{4}$", and then a large jump to the value for the $\frac{1}{2}$" orifice. The true effects of orifice size are still in doubt, but from this analysis the author has formed the opinion that in general, the C_D tends to increase with orifice diameter.

Since the diameter ratio (m) for these orifices is so very small it is surprising that any marked increase in C_D should be observed for the "stable" values at $\frac{l}{d} = 4.0$. It is believed that these variations in C_D are due to C_c being made to vary with the orifice diameter. The variations in C_C themselves depend upon the depression 'x' of the jet, to which referrence was made, in section 2 . It will be noticed that these experiments relate to a free jet and for that reason the value of the depression x may be more important than in a suppressed flow.

<u>30.14. Conclusions.</u> These results have been discussed at considerable length since the values so obtained have been subsequently used as a basis for the comparison of the flow through apertures under other conditions.

31. Experiment No.2. "To determine the effect of head on the C_D of orifices of 0.050 and 0.030 ins. bore."

31.1. Description. Holes of the above diameters were drilled by a watchmaker into brass discs each 1" diameter, $\frac{1}{8}$" thick. These orifices were then placed in the apparatus and the discharge determined in exactly the same manner as in experiment No.1.

31.2. Calibration A measuring-microscope was used to measure the diameters of these holes and to check their roundness. The following diamensi ons were taken:-

TABLE 31.1.

0.050"	TOP	0.048	0.045
Orifice	Bottom	0.050	0.047
0.030"	Top	0.031	0.026
Orifice	Bottom	0.029	0.027

This shows that there was a certain amount of ovalling of the hole, but that was less than might have been expected in view of their size. (Both drills were obviously worn slightly undersize). It was not considered that these imperfections caused any serious inaccuracies in the results. It was decided to use the nominal diameters of these orifices for purposes of calculation.

The length of orifices were checked by means of a micrometer, they were 0.127 ins (0.030") and 0.125 ins. (0.050") respectively.

<u>31.3. Theoretical Discharge.</u> This was determined in the same manner as in sub-section 30.5, using the full-flow head H + L.

Diameter 0.050 ins. $A = \frac{\pi}{4}(0.050)^2$, $V = \sqrt{2g(H+L)/12}$

$= 19.61.10^{-4}$ sq.ins $\quad = 2.31\sqrt{H+L}$ ft./sec.

$= 0.136.10^{-4}$ sq.ft.

$Q = 0.136.10^{-4} \times 2.31 \sqrt{H + L}$

$= \underline{0.314.10^{-4} \sqrt{H + L}}$ cu.ft./sec.

Diameter 0.030 ins.

$\underline{Q = 0.113.10^{-4} \sqrt{H + L}}$ cu.ft./sec.

<u>31.4. Calculations.</u> The C_D for these orifices was determined in exactly the same manner as in subsection 30.6. and was plotted against $\frac{1}{\sqrt{H}}$ in fig.31.1. in exactly the same manner as in Experiment No.1.

<u>31.5. Observations.</u> The value of C_D for both the 0.050" orifice and the 0.030" orifice decreases with head in a manner which is definitely not proportional to $\frac{1}{H^{\frac{1}{2}}}$;

The value of C_D over the range of readings taken varied between 0.75 and 0.80. Since this was a fairly small, and not particularly systematic variation, the same conclusions must be reached as those given in sub-section 30.12. To characterise the C_D for each orifice, a mean value was calculated from the whole series obtained during this experiment.

<u>31.6. Analysis.</u> It will be seen that these mean values of C_D are very nearly the same. Since the diameters are small this indicates a fairly high degree of accuracy.

The values of $\frac{l}{d}$ for these experiments are respectively 2.5 and 4.0. Under these conditions the flow through the 0.050" orifice is in a state of transition (i.e. where the entry-length effects prevail), while for the 0.030" orifice the flow lies between transitory and breakaway. It is therefore considered that the Reynolds Number of the flow will provide some indication of the importance of the "Transition" effects according to the Re in the approach and in the orifice.

For the 0.050" orifice.

$$Re_{\text{orifice}} = 6{,}900\ Q$$

$$Re_{\text{approach}} = 57.6\ Q$$

For the 0.030" orifice,

$$Re_{\text{orifice}} = 11{,}500\ Q$$

$$Re_{\text{approach}} = 57.6\ Q$$

where Q is the discharge in cubic feet for the time under examination (3600 secs.) From the values given in Appendix I the following values have been obtained:-

<u>TABLE 31.2.</u>

ORIFICE DIAMETER	0.050"			0.030"		
HEAD ins	20	12	8	20	12	8
Re Approach	23.4	17.3	14.8	8.5	6.2	-
Re Orifice	2,800	2,070	1,725	1,710	1,250	-

From this table it is obvious that these orifices are operating under "transition" conditions for which the $\frac{l}{d}$ ratio plays a highly important part. For this reason it is not considered advisable to compare the values of C_D obtained in this experiment with those obtained in experiment No.1. [It should be added that the the author refrained from determining the discharge of these orifices when shortened as in experiment No.I. because the method of manufacturing these orifices was considered to be too inaccurate and the means of calibration not entirely suitable for work of this nature.]

32. Experiment No.3. "Re-entrant Nozzles. Determine the effect of length on the C_D of $\frac{1}{4}$" & $\frac{1}{8}$" nozzles at various heads."

32.1 Description. Before being shortened, each nozzle used for experiment No.1. was inverted so that a "re-entrant nozzle" effect might be obtained. The discharge was measure under these conditions and the C_D calculated. Values of the discharge were obtained for each of the orifice lengths used, and at various heads of the liquid above the orifice.

The discharge obtained under these circumstances is less consistent than that obtained with experiment No.1, because (a) the outlet of the nozzle used in experiment No.1., is the inlet for this experiment, and as this end is cut off each time the nozzle is shortened, any slight variations in sharpness may involve considerable discrepancies in CD, (b) the nozzles are only supported in a shallow recess, when inverted and for that reason they may not stand truly vertical. These effects reduce the consistency of the discharge from these nozzles.

32.2. Calibration. The nozzles were calibrated for experiment No.1. and so no special examination of the set-up was carried out before commencing this experiment.

32.3. Theoretical Discharge. The full flow assumption was again used. Under these conditions the effective head is independent of the nozzle since the outlet is always $\frac{1}{8}$" below the orifice plate. It was therefore convenient to use the theoretical discharge evaluated in experiment No.1. for the

$\frac{1}{8}$" thick orifice, as a basis of calculation.

32.4. Observations. - Effect of Length on C_D. It will be observed from the calculations tabulated in Appendix 2 that the C_D is everywhere greater than the theoretical value, 0.50 predicted by Borda.

With the $\frac{1}{4}$" orifice, C_D rises to a maximum and then decreases again as the length of the re-entrant nozzle is increased. The slope of the increasing gradient is equal to that of the decreasing part of the curve. The maximum C_D attained by the orifice occurs at lengths which increase as the head is increased. Approximate values of the $\frac{l}{d}$ for which the maximum C_D occurs are tabulated in the following

TABLE.32.1.

HEAD, ins	20	19	17	15	13	11	9	7
l	1.08	1.05	-	1.17	1.32	1.44	-	-
l/d	4.32	4.20	-	4.68	5.28	5.76	-	-
C_D max.	0.865	0.845	-	0.840	0.838	0.825	-	-

It is apparent also that the maximum C_D decreases with head.

For the $\frac{1}{2}$" inverted nozzle C_D increases very rapidly from a very low value (0.65 to 0.70), to a very hight value(about 0.85) when the length is increased up to $\frac{3}{4}$". For a length of about 2" there is a tendency (more marked under the low heads) for the C_D to remain constant. Further increase in length causes C_D to fall gradually, a very peculiar characteristic of these orifices is revealed by the results for the 7" and 8" heads. With these orifices the C_D remains

Low up to a length of 5/8" when it rises very rapidly to a maximum and afterwards decreases gradually. The slope of the diminishing C_D part of the curve is approximately the same at all heads. It should be added that the points plotted in this figure are very scattered, it has therefore been necessary to draw as fair a curve as possible through all these scattered points.

32.5. Analysis - Effect of Length on C_D

It will be seen from fig.32.1. that the C_D does not decrease to a low value until the nozzle length has been reduced to less than 3/8". Since the C_D at lengths less than this was not tested, and over the working the value of C_D was high, it is considered that conditions of full-flow (with possible breakaway) existed for the 1/4" orifice. That the C_D reached a maximum and then declined cannot be lightly explained. The decline is probably the result of breakaway, whereas the increasing portion — which would appear to be inconsistent with the characteristics of the outward-projection nozzle — is probably due to the re-entry of the nozzle; it is therefore probably affected by the external diameter of the nozzle and the distance which it projects into the tank. (This factor determining the ease with which fluid stream-line may rise and then deflect through the orifice.) On the other hand this may be due to champfer of the nozzle by causing the vena contracta and subsequent return of the fluid to full-flow, to occur much further downstream than with the sharp edged orifices. These are, of course, all mere conjectures and unconfirmed by fact.

At heads down to 8", the charactistics of the 1/2" orifices are very similar to those obtained from the outward projecting orifice except that transition effects are not encountered. With short nozzles, the plate flow takes place; for long lengths, full flow occurs and at lengths in excess of about 2", breakaway takes place. There is, however, no evidence of the flow-transition phenomena which were observed with the projection nozzles. A comparison of the maximum C_D for the 20" head ~~[illegible]~~ shows that the C_D for the re-entrant nozzle may be slightly less than for the projecting nozzle.

The peculiar characteristic of the discharge under 7" and 8" heads are obviously the result of ~~[illegible]~~ "thin plate" flow. The reasons for this condition cannot be inferred from quantitative results but are possibly related to formations of unstable conditions in the jet when the head above the inlet is small, as in these cases. It remains to be recorded that none of these tests reveal the existence of "Bord[illegible]" flow, with a C_D less than 0.50 such as would be assumed from simple theory, to exist and that the use of re-entrant nozzles under circumstances for which sharp-edged orifices are now used, should be carefully considered by all engineers.

<u>32.6. Observations - Effect of Head.</u> This effect is very slight, in fact within the limits of accuracy of these experiments it is not possible to reach any definite conclusions.
With the 1/4" nozzle, as shown in fig.32.3., the coefficient has a general tendency to rise slightly while with the 1/2" nozzle the predominating tendency is a reduction of C_D with reduction of head.

<u>32.7. Analysis - Effect of Head.</u> It is doubtful whether variations in head (over the range used) have any effect upon the coefficient of discharge.

33. Experiment No. 4. Determine the discharge through inverted nozzles, ½" bore but of various outside diameters.

33.1. Description. The procedure of the foregoing experiment was repeated, the length of the nozzle being kept constant at 2½" but the discharge for the nozzle of various outside diameters with a series of different heads was made.

To do this, one nozzle was made up and measurements taken for various outside diameters. After each test, the nozzle diameter was again turned down and further tests carried out. By this means the inlet, bore and outlet conditions remained the same for each test.

33.2. Calibration. The bore of the nozzle was measured by means of an internal vernier gauge at both the inlet and outlet. The following readings were obtained:-

Position	Diagonal	Measurement
Inlet	0.489	0.500
Outlet	0.501	0.503

There was therefore possibly a slight "coning" of the bore with the apex in the approach (on the other hand it is possible that the bore may have been slightly barrelled) but it is not considered — in view of the very slight differences from the mean — that these regularities were very large and certainly not very important as regards the flow.

33.3. Theoretical Discharge. Here again, assuming completely full flow through the nozzle so that the head for discharge was $H + \frac{1}{8}$, the previous equations for the $\frac{1}{2}$" bore case hold, namely,

$$Q\ 50 = 314.10^{-5}\sqrt{H + \frac{1}{8}}$$

<u>33.4. Calculations</u>. The theoretical discharge calculated for the various heads in experiment No. 1 was used to evaluate the coefficient of discharge of the nozzle from the readings given in Appendix 1. for this experiment. Actual evaluation was made by slide rule, set at the reciprocal theoretical discharge for each head and the C_D for each of the external diameters (for which the theoretical discharge at any one head is constant) read off. These calculations are tabulated in Appendix 2.

<u>33.5. Observations</u>. With the values obtained there are no systematic variations from the constant. From this it is concluded that the discharge coefficient of these orifices remains independent of their external diameter — over the range of sizes used.

<u>33.6. Analysis.</u> These observations indicate that the volume of fluid surrounding the orifices is "dead water" and has no influence upon the discharge. There is, it is therefore concluded, no upward movement of the water in this region which finally "sweeps" down into the nozzle (as may otherwise be the case, and [redacted] is assumed by many text-book writers.)

Such a statement as this conflicts with the author's previous conjectures in paragraph 1 of 32.5. Page.41 (This factor determining the ease with which the fluid streamlines may "rise" and then deflect through the orifice.) It appears that the increase in the C_D of the $\frac{1}{4}$" nozzle was not due to the size of the nozzle.

<u>33.7. Observations - Effect of Head.</u> Considering the table of results for this experiment it is evident that there is no systematic variation in the discharge according to the external diameter of the re-entrant nozzle.

<u>33.8. Analysis - Effect of Head.</u> It is concluded that the external diameter has no influence upon the C_D of the nozzle.

CHAPTER 8.

CONTROLLING INFLUENCE OF A CONTRACTING STREAM IN THE APPROACH TO AN ORIFICE.

In the following experiments, those obstructions have been used which will involve a contraction of the fluid stream. The effects of this contraction have been carefully studied.

34. Experiment No.5. "To determine the effect of bevelling the inlet on the C_D of ½" bore nozzle, 2⅛" long, and of an orifice ⅛" thick."

34.1. Description - 2⅛" long nozzle. A plain nozzle of average length 2⅛", bore ½", similar to that shown in fig.30.1. was turned up in a lathe. The edges were kept sharp and the bore smoothed out as in experiment No.1. For the first tests a champfer of included angle 150° (75° half angle) from the lathe slide) was turned out from the approach throat. This champfer was taken out so that the cone diameter on the nozzle inlet face was $\frac{9''}{16}$ — it being much easier to measure this dimension than any other. After this experiment had been completed, a champfer of included angle 120° (60° half included angle from the lathe slide) was turned into the inlet, again making a cone diameter of $\frac{9}{16}$".

34.1(a). Description — ⅛" long orifice. A piece of brass, approximately ⅛" thick was obtained, a hole ½" diameter drilled in the centre and a ½" bolt slipped through the hole and tightened up against a sleeve. This assembly was then placed into the lathe and the outside diameter of the metal turned down to $1\frac{1}{8}$". The $\frac{1}{2}$" hole was then reamered out smooth, the faces smoothed off and all burrs removed. This disc was then reset in the chuck, the jaws just gripping the edges of the disc. A bevel of included angle 150° was then turned on the inlet face to make a cone base diameter of 9/16". After a test on this orifice had been completed a bevel of included angle 120° was turned on the inlet face, and so on. It will be noticed that the results have been plotted in order for the half angles 15, 30, 45, etc., whereas the experiments were conducted in order for the angles 75°, 60°, 45° etc.

<u>34.2. Calibration</u>. The nozzle and orifice bores were measured for accuracy and found to be within a thousandth or two of the nominal size. The length of the nozzle was determined as 2.124 ins and the thickness of the orifice as 0.128 ins. Owing to the smallness of these descrepancies, the nominal figures of $2\frac{1}{8}$" and $\frac{1}{8}$" have been used in referring to the nozzles and orifice respectively.

It was not found possible to check the accuracy of the angle of orifice bevel and it was accordingly necessary to rely upon the accuracy of the lathe. This was a fairly old lathe, but there was little back-lash on any of the parts, the tool slide fitted well and the protractor was in good condition; the chuck was steady with good bearings and appeared to hold the metal central. It is therefore considered that errors in the angle of bevel could not have been very large.

<u>34.3. Theoretical Discharge.</u> It was again assumed that for a theoretically perfect nozzle with C_D = 1.0, the flow would completely fill the bore. Hence for the $2\frac{1}{8}$" nozzle the head causing discharge would be H + $2\frac{1}{8}$" and so the formula for the theoretical discharge would be the same as in experiment No. 1.

For the $\frac{1}{8}$" nozzle the head causing discharge would be H + $\frac{1}{8}$.

In practice, the author used the theoretical discharge tabulated for experiment No. 1., when the nozzle was $2\frac{1}{8}$" and $\frac{1}{8}$" long.

<u>34.4. Calculations.</u> The measured discharge was divided by the theoretical value taken from 34.3. above. Since the theoretical discharge did not vary with angle of bevel, the slide rule was set at the reciprocal, results read straight off and values of C_D recorded in Appendix 2.

<u>34.5. Observations - Variation of C_D with angle of bevel.</u>

For the $2\frac{1}{8}$" long nozzle the C_D gradually increases as the angle of bevel is increased and reaches a maximum at an included angle of about 95° (for a head of 20") and then decreases, gradually at first and then rapidly. The included angle corresponding to the maximum C_D decreases as the head increases as in the following table.

TABLE 34.1.

Head, ins	20	16	12	8	4
Angle for Max C_D	95	102	115	120	145
Max C_D	.955	.938	.948	.920	.935

The maximum C_D tends to decrease erratically with decrease of head.

An alternative plotting of the points on the C_D — of curve is shown dotted for the 16" and 12" heads, which breaks the curve up into two maximum C_D. It is, however, doubtful whether the points for the 120° included angle, plotted for these heads are correct and the alternative suggestion has not therefore received further consideration.

For the $\frac{1}{8}$" long orifice the C_D rises rapidly, as the champfer is increased, reaching a maximum at an included angle of champfer of about 55° (for the 20" head). Afterwards, the C_D falls gradually, the reduction in C_D with angle of champfer tending to fall off at included angles of champfer greater than 120°. Head again plays a part in the value of the included angle for maximum C_D, but this effect is less noticeable than it is for the longer nozzle, as the following table shows.

TABLE 34.2.

Head	20	16	12	8	6
Angle for Max. C_D	55	62	65	66	68
Max. C_D	.870	.885	.885	.895	.907

This shows that the max C_D tends to increase — almost linearly — with decrease in head.

34.6. Analysis - variation of C_D with angle of bevel. It is obvious from the preceding observations, that the characteristics of the long nozzle and short orifice are different in the following respects:-

(1) the included angle at which maximum C_D occurs, is generally much less for the $\frac{1}{8}$" orifice than for the $2\frac{1}{8}$" nozzle.

(2) the effect of head on the position of this maximum C_D, although generally similar for both orifices - i.e. with reduction of head the included angle for maximum C_D increases - is different in that for the long nozzle the effect is very sensitive at low heads, while for short orifice, variations of head have almost no effect at these low rates of flow.

(3) the maximum C_D decreases with decrease of head for the long nozzle; it increases for the short orifice.

(4) the maximum C_D for the long nozzle is much greater than that of the short orifice.

Before proceeding too far into the analysis of this experiment it should be noted from experiment No. 1. that under the conditions which exist with an $\frac{1}{2}$" nozzle $2\frac{1}{8}$" long, the flow is in a state of breakaway. The conditions at the inlet should, however, be those in which a slight vena contracta is formed followed by a subsequent re-expansion of the jet. For the $\frac{1}{8}$"

orifice, the flow should be sharp-edged, i.e. the formation of a vena contracta with no subsequent re-expansion in the nozzle.

The possible effects of increasing the champfer of an orifice have been discussed in Appendix 3. From the observations it would appear that considerably more contraction, or necking is involved in the long orifice, than with the short, thin plate. The two conditions are vastly different.

34.7. Variation of C_D with head. It will be seen that, as explained in 34.5. the maximum C_D for the $2\frac{1}{8}$" nozzle tends

(i) to decrease (erratically) with decrease head
(ii) angle corresponding to this maximum C_D decreases as the head increases.// For the $\frac{1}{8}$" orifice (i) the maximum C_D increases with decrease in head (ii) the angle corresponding to this maximum C_D decreases as the head increases. Thus, the main difference in the effects of head on the C_D is to cause the relationship between C_D and the head to be different between the two orifices.

With the conditions described in Appendix 3 it will be seen that for maximum C_D with the $2\frac{1}{8}$" long nozzle there will be a slight contraction at the throat, C_V will be very nearly unity. As the head decreases, the contraction increases so that C_C becomes smaller; also the C_V becomes correspondingly smaller. With the reduction in head, C_c and C_v decrease so that C_D is reduced. With the $\frac{1}{8}$" thick orifice it is possible that the contraction is almost complete before the jet leaves the orifice so that C_c becomes high. Head therefore has very little effect on the C_D except that as it decreases the contraction is less so that C_D (max) increases as the head decreases.

35. Experiment No. 6. "To determine the effect of depth of bevel on the C_D of a ½" bore nozzle 2⅛" long and om an orifice ⅛" thick."

35.1. Description. A nozzle and an orifice was constructed in exactly the same manner as in the preceding experiment. They were champfered with an included angle of 90° and with a circle 9/16" diameter on the inlet face. It was proposed to measure the discharge and calculate the C_D for the aperture under these conditions at various heads and then to deepen the champfer. Values of the C_D of the deepened champfer were then compared to analyse the effect of depth of champfer.

35.2. Calibration. The dimensions of the apertures were again checked as in Experiment No.5. The bores were again within reasonable limits of the nominal ½" and the lengths were found to be 2.126 and 0.128 ins. respectively. The diameters of the champfer circles on the inlet face were measured each time by means of a ruler. They were turned out to the values quoted.

35.3. Theoretical Discharges. Since the energy conditions had not been modified, the discharge equations given in 34.3 were used.

35.4. Calculation. The same procedure was adopted as in experiment No.5.

36.5. Observations. For the 2⅛" long nozzle, the C_D tends (generally) to increase rapidly between the inlet face diameter 9/16" to 5/8" and then very slightly between 5/8" and ¾". For the 1/8" thick orifice the CD generally decreases as the inlet face diameter increases, although the results for the orifice with a 5/8" inlet face diameter are consistently lower at all heads. It is thought that these results for the 5/8" orifice are false.

An additional series of tests for the 1/8" thick orifice with various inlet face circle diameters but with a champfer of 120^0 included angle also indicated a slight reduction in C_D as the depth of champfer was increased. The values of C_D for the 5/8" inlet face diameter case were again low.

35.6. Analysis. In the case of the $2\frac{1}{8}$" long nozzle with the 90^0 included angle case the C_D is almost maximum hence according to the foregoing theory, the jet would not touch the orifice until it just entered at the neck. Any increase in bevel merely reduces the curvature of the jet and so increases C_D.

With the 1/8" orifice, the conditions are such that the jet strikes the inlet face of the champfer, increasing the depth of champfer is not then likely to have much offset upon the C_D, other than by giving the jet more opportunity to stabilise and so allow it to contract when breaking away from the champfered face at the throat.

It is concluded that depth of champfer will influence the C_D, not according to the aperture thickness, but according to the angle of bevel.

36. Experiment No. 7. "To determine the influence of proximity on the discharge through four orifices spaced in a square."

36.1. Description. Four holes, each 1/8" ins. diameter were drilled ~~with~~ in a brass disc, $1\frac{1}{4}$" diameter, 1/8" thick, with their centres at the four corners of a square. Separate tests were made on different discs, for which the sides of the squares were $\frac{3}{16}$ ins., $\frac{1}{4}$ ins., $\frac{5}{16}$ ins., and $\frac{3}{8}$ ins long. Thus the distance between the edges of adjacent holes (the squared length-orifice diameter) were, $\frac{1}{16}$ ins, $\frac{1}{8}$ ins, $\frac{3}{16}$ ins and $\frac{1}{4}$ ins. for each of the above tests respectively.

To test the effect of proximity, each disc was used as an orifice, by placing it into the testing tank previously described and measuring its total (from all four orifices together) discharge. No attempt was made to collect the discharge from each hole, separately. It was thought that as the approach to each orifice would be distorted by the presence of the adjacent orifice, this distortion may reduce the contraction and so increase the C_D. These tests were designed to investigate this conjecture.

It should be noted that for each of the orifices individually, $\frac{l}{d} = \frac{1/8}{1/8} = 1.0$ for which, from experiment No.1. we understand that full flow occurs.

36.2. Calibration. The thickness of the plates was checked with a micrometer and it was found that the thickness was generally 0.125 ins. $\pm$ 1/1000 ins. The holes were not checked for diameter, but as a new drill was fitted, nominal sizes were accepted. The spacing between the holes was checked by a ruler across the diagonal holes. No values were recorded other than that the spacing was correct.

<u>36.3. Observations</u>. It was found that the discharge through the four separate orifices was unaffected by their spacing. No values of C_D were therefore calculated for this experiment.

Although the distance between adjacent holes was fairly large, it was noticed that their individual jets converged into one large jet as in fig.36.1. (Photograph). This amalgamation took place for the two closest spacings of the holes.

<u>36.4. Analysis.</u> Owing to the lack of influence of proximity on their C_D, it is considered that the approach streams to these small orifices are too weak to be influenced by their surroundings.

The amalgamation of the jets is possibly due to the holes being out of the perpendicular.

37. Experiment No. 8. "Determine the characteristics of the flow through an orifice ½" diameter, ⅛" thick with an obstructing aperture in the outlet."

37.1. Description. A disc of metal, 1⅛" outside diameter, ⅛" nominal thickness was produced from brass plate and bored to the shape shewn in fig.37.1, so as to consist of a ½" orifice with a diaphragm inserted to form an aperture of diameter d_1, thickness t. This orifice was placed into the testing tank and the discharge measured at various heads. After a series of head-discharge values had been obtained from these measurements, the diameter d_1 of the obstructing aperture was increased slightly by skimming it out on the lathe, so that a larger diameter d_2 was available, the obstructing aperture still having a thickness, t. The discharge for this orifice was again measured at different heads. This procedure was repeated, the obstructing aperture being gradually enlarged, but with the thickness maintained constant. The results are tabulated in Appendix I. Other orifices, with different diaphragm thicknesses, were tested in a similar manner.

From these tests it was hoped to determine (1) the effect of the obstructing aperture on the discharge from a sharp-edged, thin-plate orifice, ½" diameter, (2) the diameter of the aperture for which the jet from the ½" orifice was not touched by the inlet edge of the aperture.

37.2. Calibration. The discs, with aperture orifice, were turned up for the author on a watch maker's lathe. It is understood that the sizes were checked, (a) the diaphragm thickness by means of a depth gauge, after the plate thickness had been gauged by means of a micrometer, (b) the aperture, and ½" orifice diameter, by means of internal verniers. They were machined to the correct dimensions. The plate thickness was 0.125 ins. for all the discs used.

<u>37.3. Theoretical Discharge.</u> Full flow was assumed to occur with the theoretically ideal orifice. For these conditions, the area through which discharge occurs is $\frac{\pi}{4}(d_1)^2$, where d_1 is the aperture-orifice diameter. The head producing discharge is H + 1/8 ins, hence, with all dimensions given in inches, the theoretical discharge is

$$Q = \frac{\pi}{4}(d_1)^2 \cdot \sqrt{(H + 1/8)\, 2.g.} \text{ cu.ins/sec}$$

$$\text{where } g = 384 \text{ in/sec}^2$$

For simplicity of calculation of the theoretical discharge during the time of flow used in the experiment, the author took

$$Q_t = \left(\frac{d_1}{1/2}\right)^2 Q_t\left(\tfrac{1}{2}\right)$$

where $Q_t(\frac{1}{2})$ = theoretical discharge during the same interval of time for an unobstructed orifice ½" diameter under the same head.

It was thus possible to simplify calculation by breaking the process down into the multiplication of the theoretical discharge obtained in Experiment No. 1. by a factor given by $\left(\frac{d_1}{\frac{1}{2}}\right)^2$ with suitable modification of the calculations of Experiment No. 1. to allow for a time of discharge of 25 seconds and not 50 secs, as with the ½" orifice tests.

37.4. Observations - Variation of C_D with orifice diameter and aperture thickness.

Three stages in the development of the C_D ——— aperture diameter curves, figs. 37.2., 3, 4, 5, 6, can be readily observed. These are

(1) a certain "flatness" or constancy of C_D as the aperture diameter is gradually increased,

(2) a fairly sudden, sharp rise in C_D to a maximum, then

(3) an equally sharp drop in C_D.

It appears that the first stage (as obtained in tests 8/1, 8/2) persists up to an aperture diameter of about 0.33". During this phase, the C_D appears to have the same value for both of the diaphragms 0.020 and 0.040 ins. thick under similar heads.

In the second stage, the C_D increases almost linearly with increase in aperture diameter, the curves for all heads merging almost into one common curve. The line drawn through the average points has the following characteristics, assuming the general equations.

$$C_D = A + B\,(d_1)$$

where d_1 = aperture diameter.

TABLE 37.1.

Aperture thickness	0.020	0.040	0.060	0.080	0.100
A	-0.50	-0.45	-0.72	-2.32	-1.45
B	3.57	3.33	4.00	7.50	5.0

When plotted, it is seen that the negative value of A gradually increases as the diameter increases and that the positive value of B is similarly increased.

The maximum C_D is rather scattered, but for each diaphragm thickness, occurs at more or less the same aperture diameter, irrespective of head. The observed maxima are recorded in the following table.

TABLE 37.2.

Aperture Thickness	0.02	0.04	0.06	0.08	0.100
Aperture Diameter for C_D(max)	0.425	0.43	0.435	0.450	0.458
C_D (max)	0.955	0.96	0.985	0.97	0.87

These values are plotted as in fig. 37.7.

This shows that the aperture diameter corresponding to the maximum C_D, increases progressively as the aperture thickness is increased. [It will be noted that when this curve is extrapolated for the values of t, greater than 0.10, when the diaphragm thickness is 0.125 the aperture diameter for maximum C_D is 0.500.] As would be anticipated for the condition of a ½" nozzle without any discharge assage obstruction. The maximum C_D shews peculiar characteristics when plotted against the thickness, it rises to a maximum and then drops very suddenly as the aperture thickness is further increased.

In the third stage, further increase in aperture diameter causes the C_D to decrease, at first linearly and then less rapidly as the aperture diameter approaches ½".

37.5. Analysis - Variation of C_D with aperture diameter and diaphragm thickness.

During the first stage, the obstructing aperture inferfere with the jet from the ½" orifice so that the obstructing aperture runs full. Since C_D remains fairly constant, the loss of head between the ½" orifice and the aperture is not considered to be negligible; it is in fact possible that the jet from the ½" orifice is still contracting to its "vena-contracta" when it is again required to contract through the obstructing orifice. The absence of any large re-expansion of the stream indicates that loss of head due to change of velocity is restricted to the possible formation of an approach vortex at the walls in the vicinity of the obstructing diaphragm face.

That the C_D remains constant up to aperture diameter of 0.33 ins. indicates that this is approximately the effective diameter of the potential core, at least for the tests 8/1 and 8/2.

The maximum C_D is reached when the obstructing orifice does not touch the jet from the ½" nozzle. This indicates

(1) that under these conditions air cannot easily get between the jet and walls of the ½" portion of the orifice, hence a "vacuum" or depression of pressure occurs which allows the jet to swell out and so acquire a fairly high C_D,

(2) the aperture diameter corresponding to max C_D at each diaphragm thickness, gives the contour of the jet; (this must really be modified slightly owing to the suspected swelling of the jet, referred to above.)

The maximum C_D is influenced very considerably by the contraction of the jet, when the aperture orifice is some way from the ½" orifice, the jet is almost parallel and so the contraction of the stream when passing through the obstructing orifice is very slight, hence C_c tends to unity. The slight loss of head between the ½" and aperture orifices causes the diminution of C_D below 1.00. As the aperture diameter for max. C_D increases (with the increase in diaphragm thickness), so (1) the curvature of the jet increases (2) the loss of head decreases since the approach vortex becomes smaller, i.e. C_v increases. Hence, at first, the increase of C_v predominates and so C_D max. increases with increase of diaphragm thickness, but then, after a certain maximum C_D max. has been attained, the influence of the contracting jet predominates and so C_D decreases sharply with further increase in diaphragm thickness (t) as shown in fig.37.7. The controlling influence exercised by the ½" orifice upon the obstructing orifice should be carefully noticed. It will be of interest to designers to note that whereas the C_c for the obstructing orifices alone (undisturbed approach) would have been 0.610 approximately, the presence of the ½" orifice is sufficient to increase this C_D to as much as 0.99 (for the maximum C_D(max) case.)

The curve relating the aperture decimals for maximum C_D to the diaphragm thickness gives an indication of the C_c for a ½" orifice, since the ratio of (aperture diameter $\div$ ½)^2 for the diaphragm thickness at which the inlet face to the orifice corresponds with the vena contracta from the ½" orifice, gives the coefficient of contraction C_c. The plate was too thin for the obstructing aperture to be formed at the vena contracta, but it is thought that the following table relating these values for various diaphragm thicknesses will give some indication of this quantity.

Diaphragm thickness	0.020	0.540	0.060	0.080	0.100
C_c	0.723	0.740	0.757	0.810	0.839

When plotted roughly and extrapolated, the curve seemed likely to reach an asymptotic C_c of 0.650 approximately, with a diaphragm thickness of -0.090 ins. i.e. total distance of obstructing orifice inlet face from ½" orifice (which would correspond to the vena contracta) of 0.090 + 0.125 = 0.215 ins. Since the value of C_c = 0.650 is very roughly identical with the theoretical C_c (0.610) the author believes this conjecture may be very nearly correct.

37.6. Observations - Variation of C_D with head. In general, the curves for each of the heads seem to merge into each other. For those conditions under which some divergence can be observed, the following characteristics may be general:-

(i) when C_D is constant, the value is higher for the low heads than when the head is low.

(ii) when C_D is maximum, its value and the aperture diameter at which it occurs appear to vary with head, but no systematic variation is apparent.

(iii) when C_D decreases the value for the low heads still appears to be greater than for the high heads.

In view of the fairly crude methods used, it appears to be possible that head has very little influence upon these curves.

37.7. Analysis - Effect of head on C_D. The lack of importance is apparent from fig. 37.7. in that the improved C_v only introduces a slight increase in C_D whereas, the position of the diaphragm and its effect on C_c is most critical. Other than for its possible effects on the contraction, the head of water used in these experiments is not considered to have exerted a considerable controlling influence upon the characteristics recorded in the foregoing.

CHAPTER 9.

CONTROLLING INFLUENCE OF A STREAM WHICH CONTRACTS AND EXPANDS IN FLOWING THROUGH AN APERTURE.

Experiments are described in this chapter in which the obstructions to the flow of fluid throught an aperture involve either contration alone, or, under certain conditions, both contraction and expansion of the stream.

38. Experiment No.9. " Determine the characteristics of the flow through a nozzle ½" diameter, 2⅛" long with an obstructing aperture in the outlet.

38.1. Description. The procedure of the foregoing experiment was repeated with a nozzle 2⅛" long with an obstructing diaphragm 0.05 ins. thick placed at various distances from the inlet. A fresh nozzle was made for each position of the diaphragm and the tests carried out with various aperture diameters.

38.2. Calibration. The bores of the ½" inlet and outlet sections were calipered and skimmed out to the same bore, 0.500 ins. The positions of the diaphragms were measured by means of the depth gauge; it was not easy to place them accurately but in general the position lies within ± 0.005 ins. of the nomimal. A micrometer was used to measure the length of the nozzle, in all cases the nominal length, 2⅛" was recorded. The aperture was carefully turned out of the diaphragm, the diameter being obtained after micrometer adjustment of the tool rest. Owing to the difficulties involved in their measuxments these diameters were not checked.

38.3. Theoretical Discharge. Again full-flow conditions were assumed to exist for the nozzle. It was therefore found expedient to use the values tabulated for the $2\frac{1}{8}$" long nozzle, obtained for experiment No.1. These values of the calculated discharge were used to obtain the C_D from the observed discharge tabulated in the readings.

38.4. Observations - variation of C_D with aperture diameter and position.

Only two stages in the variation of C_D with aperture diameter can be readily identified, firstly, a fairly gradual increase of C_D with aperture diameter and then, secondly, a more rapid increase in C_D to a maximum after which the C_D remains fairly constant, as the aperture diameter increases to $\frac{1}{2}$"

The first stage is only shown clearly in fig.38.1. although there is a general tendency for this stage to exist shewn in the other figures.

This stage in general, persists up to an aperture diameter of 0.35 ins. Over the whole of this period, C_D has an exceptionally low value.

The sudden increase in C_D occurs at various diameters. The estimated point at which $\frac{d\,C_D}{d(d_1)}$ is maximum, is tabulated in the following table for the 20" head case.

TABLE 38.1.

Depth.	1/16	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$
Diameter for maximum slope.	.414	.364	.365	.353	.35
Slope.	11.9	14.6	17.6	13.6	12.6

With further increase in aperture diameter the C_D increases progressively to a maximum which has the following values (for the 20" head case) when interpolated up to the 0.050" aperture diameter case.

TABLE 38.2.

Depth	1/16"	$\frac{1}{4}$"	$\frac{3}{8}$"	$\frac{1}{2}$"	$\frac{5}{8}$"
$C_D$max.	.92	0.86	0.83	0.79	0.82

38.5. Analysis - Variations of C_D with aperture diameter and height.

That the values of C_D for the smaller aperture diameter are very small, far below 0.610, indicates either that an exceptionally high loss of energy is occurring or that the basis of calculation is inapplicable. It is believed in this case that the presence of the obstruction is insufficient to involve the considerable loss of energy indicated by those low values off C_D. The assumption is therefore made that the low values of C_D are due to the inaccurate basis of calculation.

A further series of calculations - for the 20" head case only - have been made and are recorded in appendix 2.

These values commence with quite normal values of C_D (0.70, etc.) for the small orifices but after a slight period of constancy rise very rapidly to give values in excess of 1.00. It would appear that these values represent the true C_D up to that aperture diameter for which C_D is about 1.00. Under these conditions the flow is flowing away from the edge of the obstructing orifice.

Thus the jet leaves the obstructing aperture orifice without re-expanding to fill the ½" nozzle. As the aperture orifice size is increased so does the C_D increase, hence the increase in C_D. It is probable that as the annulus area between the jet and the ½" nozzle walls is decreased with increase in the aperture diameter, so the air surrounding the jet is dragged away to form a vacuum in the vicinity of the vena contracta so that the jet area equals the orifice area and C_D approaches unity. With further increase of aperture diameter it is possible that the jet may re-expand slightly (but not sufficiently for it to touch the nozzle before it leaves) hence the jet area may exceed the aperture area at exit. Under these conditions the outlet portion of the nozzle <u>may</u> contribute to the head energy, as well as possess large area, hence the C_D based on plate flow will be greater than unity. With still further increase in aperture size the jet re-expands so as to strike the nozzle walls. Under these circumstances the curve based on plate flow is very steep, and it is considered that the point at which maximum slope occurs represents the transition from flow from the aperture orifice edge, to full flow. The following values, taken from the curves, indicate how this transition point varies with the position of the obstructing orifice:)-

TABLE 38.3

Depth	1/16	1/4	3/8	1/2	5/8
Transition point diameter ins.	.460	.383	.395	.365	.380

When the jet had re-expanded to the nozzle walls the C_D based on full flow (now the correct assumption) will be almost unity. The loss of head will however be faily high, owing to the losses caused by (1) by the contraction from the first ½" aperture (2) contraction and re-expansion of the jet from the aperture orifice. The C_V of this nozzle therefore varies directly as the aperture diameter; hence C_D increases with further increase in aperture diameter.

<u>38.6. Observations - Variation of C_D with head.</u> In general, the effect of head is very small. A tendency exists for C_D to decrease with decrese in head.

39. Experiment No.10. "Determine the effect on C_D of the flow through a precalibrated ½" diam.⅛" thick orifice with an obstructing orifice in the approach."

39.1. Description. This experiment was performed to examine the effects of the disturbances produced by an orifice placed in the approach to another orifice. A thin metal plate 6" diameter, soldered to three legs was drilled with an orifice in the centre and placed into the measuring tank. The flow through a precalibrated ½" diameter orifice, ⅛" thick was then measured at various values of H. After one such series of tests the diameter of the orifice in the centre of the plate was increased and the flow again measured with this disc/orifice combination in the approach to the precalibrated orifice. Following a series of flow measurements with the obstructing orifice at one distance from the pre-calibrated orifice, three longer legs were attached to other 6" discs and the tests repeated for various obstruction orifice diameters. In all, flow measurements were made for a series of aperture diameters at positions ⅝", 1⅛" and 4" from the precalibrated orifice.

39.2. Calibration. The 6" diameter discs were made to be reasonally good fits in the 6" diameter approach chamber, but no attempt was made to seal the joint at the circumference. Since the velocity at the walls, i.e. circumference of this disc, is normally very small the leakage due to slight clearances between the disc and pipe walls was considered to be insignificant. The centricity of the orifice was not verified since it was bored through the hole used for "centreing" the disc. Other enlargened holes were turned out and are not considered to have been more than a few thousnadths out-of-centre. The legs were sawn to size and soldered to the disc; the disc was then placed on a flat, face-plate and the height of the disc at each leg was checked.

39.3. Observations - Variations of C_D with approach orifice diameter and distance from outlet.

As the diameter of the disc, (situated at one constant height above the orifice inlet) is increased, so the C_D tends at first to rise to a maximum and then to decrease to a constant value as the diameter is still further increased.

The diameter at which maximum C_D occurs is given in the following table

TABLE 39.1.

HEAD	8"			20"		
Obstruction Height	$\frac{5}{8}$"	$1\frac{1}{8}$"	4"	$\frac{5}{8}$"	$1\frac{1}{8}$"	4"
Obstructing Orifice Diameter.	0.67	0.65	1.35	0.65	0.67	1.22
C_D max.	0.88	0.77	0.661	0.871	0.712	0.683

The C_D does not develope as constant value during the range of readings taken with the disc $\frac{5}{8}$" from the inlet. With the other disc positions the C_D attains the following constant values.

TABLE 39.2.

HEAD	8"		20"	
Obstruction Height	$1\frac{1}{8}$"	4"	$1\frac{1}{8}$"	4"
C_D (Constant)	.675	.650	.661	.638

39.4. Analysis - Variations of C_D with obstructing orifice diameter & height.

The approach to the precalibrated orifices will be required to contract through the obstructing orifice; expand into the "back" space between the disc and orifice plate, then recontract through the pre-calibrated orifice. This initial contraction of the jet has an important effect on the discharge through the precalibrated orifice, thus (1) the re-expansion into the back-space of fluid passing through the obstructing orifice will cause a loss of head before the flow reaches the precalibrated orifice. (2) the eddies formed by the obstructing orifice will influence the C_D of the precalibrated orifice.

When the obstructing orifice is smaller in diameter than the precalibrated orifice, liquid will pass through this obstructing orifice without re-expanding, and will subsequently fall through the precalibrated orifice. Under these conditions the C_D (measured on a full-flow basis) will be low, because the true head is less than the (H+L) used for the calculation of C_D. The air trapped in the "back space" will have a slight influence on the jet, possibly causing a slight vacuum as it is sucked out with the jet which will (a) increase the effective head and possibly (b) reduce the contraction at the sides of the jet, i.e. increase Cc. The actual influence of this "back space" air will depend upon the annulus between the jet and walls of the precalibrated orifice. Hence, as the obstructing orifice diameter increases so will, (1) the quantity of fluid passed through it will increase - and so therefore will C_D through the precalibrated orifice (based on "full-flow"), (2) the degree of "vacuum" of the air in the "back space". Both these effects, (of which the first is most important) cause the C_D based on the "full-flow" assumption to increase with the obstructing orifice diameter. It should be noted that the effect of the obstructing orifice will be to direct the jet out of the calibrated orifice with very little suppression at the sides as shewn in fig.39.4. So that under these conditions the jet is almost parallel when it leaves the plane of the precalibrated orifice. When the diameter of this orifice exceeds that of the precalibrated orifice the jet from the obstructing orifice will strike the sides of the pre-calibrated orifice. When this occurs, the C_D will acquire a maximum value since (i) the effective head will be H + L (ii) as shewn in fig.39.4.(b) there will be very little suppression of the jet, i.e. C_c will be almost unity, and (c) C_D will be very nearly equal to C_V.

It will be noticed that the diameter of the obstructing orifice for which C_D is maximum, gradually decreases as the disc is placed nearer the precalibrated orifice. A graph relating this orifice diameter to the position of the disc can be made almost linear if the obstructing orifice diameter is taken as 0.500 ins. when the disc coincides with the precalibrated orifice. This may serve as some indication of the shape of the jet from this obstructing orifice.

When the obstructing orifice diameter exceeds that for which the jet will just pass through the precalibrated orifice, the conditions of flow will be as shewn in fig.39.4.(c). The jet from the obstructing orifice will strike the orifice plate and expand to fill-up the "back space" with fluid. Hence (1) a fairly large degree of turbulence will occur at the inlet to the precalibrated orifice, (2) energy will be lost by the expansion, of the jet from the obstructing orifice (3) the jet through the precalibrated orifice will contract as it issues out and will therefore have a low Cc. Hence, as the obstructing diameter is increased so the C_D will decrease.

The effect of increasing the distance from the precalibrated orifice to the 6" disc is to increase the obstructing orifice diameter and the jet to pass through the precalibrated orifice without touching the walls.

It is believed that the decrease in C_D maximum as the distance from the 6" disc to the precalibrated orifice is increased, and which occurs when fluid flows from the obstructing ofifice —

full-flow through the precalibrated orifice — is due to the fact that C_V is the controlling factor for which the distance between the 6" disc and precalibrated orifice must be regarded as a "loss of head" when calculations are based on full flow up to the precalibrated orifice. This reduction is apparent from table 39.1. but the curve relating C_D max to the square-root of head over disc, is not linear as would be anticipated if this were the only factor. There is no doubt that this "effective head" aspect has an important influence upon the C_D, but other losses exist such as eccentricity of the orifices, etc., for which allowances must be made.

This analysis shows that when an appliance is designed in which two orifices are fitted in series, the orifice diameters and spacings can influence its operation very considerably.

<u>39.5. Effect of head.</u> The graphs plotting C_D against the obstructing orifice diameter show that with the disc $\frac{5}{8}$" and $1\frac{1}{8}$" away from the precalibrated orifice, C_D is higher at low (8") heads than at high (20") heads. When the disc is 4" away, the maximum C_D has a larger value for the 8" than for the 20" condition, but for other obstructing orifice diameters the C_D is higher for the 20" head than for the 8" head conditions. The calculations do not however, indicate any appreciably systematic variation of C_D with head so that the characteristics described above cannot be definitely ascribed to any particular method of discharge. No success has been achieved from attempts to analyse these variations of C_D with head.

40. <u>Experiment No.11.</u> <u>"Determine the variations in C_D of an orifice ½" diameter ⅛" thick, the approach to which is obstructed by a cone."</u>

<u>40.1. Description.</u> In view of the observations in the preceding experiments that the curve relating obstructing orifice diameter (for C_D max.) to the disc position was a straight line, it was considered of interest to study briefly the effect of placing a cone in the approach to the precalibrated orifice. This cone was designed to have the same angle of taper as the slope of the obstructing orifice — disc position curve.

A sheet of brass 1/32" thick was therefore marked out and soldered up along a seam so as to form a cone ½" and 1" dia, 2½" long which was mounted on three wire legs as shewn in fig.40.1. This was then placed with its axis coinciding with the axis of the precalibrated orifice so that the discharge was measured with this orifice at a certain distance (depending upon the length of the three legs) away. After a series of discharge tests at various heads had been completed the legs were shortened and the process repeated with the cone at positions nearer to the orifice.

<u>40.2. Calibration.</u> The dimensions of the cone were checked by means of a ruler, although not extremely accurate the sizes were correct to within ± 1/64". The inlet and

outlet of the cone were left sharp edged, smooth and coplanar and the bore was smoothed out with emery cloth, particular care being taken to level off the seam which had been soldered. The spacing of the legs was not checked but the height of the cone above a flat surface was measured by means of a ruler. It was reduced to the nominal values quoted by filing down the legs. Every care was taken to ensure that the legs were equal and the axis of the cone vertical, but no definite tests were applied; it looked vertical.

When placing it on the orifice plate the feet of the legs were placed on a circle and soldered down lightly. The position of the cone was then tested visually and slight adjustments made as necessary to bring it central. The height was again checked and found to be quite satisfactory.

40.4. Observations. The cone was found to have no influence whatsoever upon the discharge of the precalibrated orifice.

40.4. Analysis. It is therefore evident that the core of fluid which experiment No.10. showed to exist in the approach could not be controlled by means of the simple cone device used in this experiment. A definite contraction of the whole bulk of the approaching fluid must be made before the flow through the orifice will be increased.

CHAPTER 10.

CONTROLLING INFLUENCE OF A STREAM WITH A DEFINITE CONTRACTION AND EXPANSION IN THE APPROACH TO AN APERTURE.

Each of the obstruction upon which the experiments described in this Chapter, have been made, are designed to involve a contraction of the stream followed by a definite expansion prior to the flow of the stream through the orifice.

41. Experiment No.12. "Determine the effect on the C_D of a $\frac{1}{2}$" diameter orifice $\frac{1}{8}$" thick from placing a bar of rectangular section in the approach."

41.1. Description. In order to study the effect of a turbulence-producing obstruction it was decided to place a bar of rectangular section in the approach to the precalibrated orifice.

A bar, $5\frac{3}{4}$" long, $\frac{3}{4}$" wide, $\frac{3}{8}$" thick was therefore placed edgewise in the approach to the orifice, so that its central plane contained the axis of the orifice. Two holes, 3/16" diameter were drilled $\frac{5}{8}$" deep into the edge of this bar, the centres of these holes being $4\frac{1}{2}$" apart. Two holes were drilled and tapped 3/16" B.S.F. with their centres on a diameter of the orifice plate, and each $4\frac{1}{2}$" apart. Two 3/16" B.S.F bolts, 2" long were screwed through these tapped holes in the orifice plate, and engaged with the holes in the obstructing bar. By this means it was possible to raise and lower the bar accurately.

Tests were made with this bar (a) under various heads (b) at various positions in front of the orifice. The bar was then filed down (a very laborious process) so that a central length of 4" had a width (w); this reduction in width was obtained by filing a half off each side of the bar so that its central plane remained in the same position. Tests (a) and (b) were repeated with these thinner bars.

41.2. Calibration. The sides of the bar were filed off smooth and flat, and the edges left sharp. The dimentions and flatness of the bar were checked by means of a ruler. Prior to each test the position of the bar was adjusted by means of the screws so as to place it correctly in the position recorded. Adjustment was made against a ruler applied edge-on to the orifice plate. Centricity of the bar was checked by loosening the adjusting screws down until the bar rested upon the orifice plate. The distance was measured between the plate and the circumference of the orifice on each side; there were slight variations up to about ± 1/32", but these variations were considered to have little effect upon the discharge, through the orifice.

41.3. Theoretical Discharge. The principles of full-flow, previously applied to these problems were also used for this case. The ~~critical~~ actual discharge deduced in Experiment No.1. for the $\frac{1}{8}$" long $\frac{1}{2}$" diameter orifice was therefore applied to this case.

41.4. Observations. C_D increases suddenly when the distance of the bar from the orifice is first increased. This rapid increase however soon decreased and acquires a constant value when the bar is placed at some short distance from the orifice as shewn in fig.41.1.

The position at which the constancy of C_D occurs has been determined (very approximately) and is recorded in the following

TABLE 41.1.

Width of Bar, ins.	$\frac{3}{8}$	7/32	$\frac{1}{8}$	1/16
Distance for C_D constant	0.375	0.255	0.220	0.085

It is evident that as the width of the bar decreases, so the conditions stabilise out much quicker and so the distance of the bar, from the orifice before C_D becomes constant and becomes smaller as the width of the bar is reduced.

The C_D acquires more or less the same constant value in all cases. This is roughly 0.625.

41.5. Analysis. It seems that as the C_D acquires more or less the same constant value for all thicknesses of the bar, the reduction in C_V due to loss of head must be very small, the eddies from the bar are probably weak in view of the low Reynolds Numbers of theapproach, deduced in Experiment No1. and since the contraction of the stream will also exert a further controlling influence. When the bar is near the

the orifice, it is considered that the loss of flow is due to a reduction of Co.

Theorising still further, the author believes it to be possible that the dead-water downstream of the obstructing bar causes a sort of cavity inside the jet in the vicinity of the orifice and so reduces the effective area. On this assumption we may equate

$$C_D' = C_D \times \left(\frac{d}{1/2}\right)^2$$

$$\therefore d^2 = 0.25 \times \frac{C_D'}{C_D}$$

$$= 0.40 \cdot C_D'$$

Where C_D' = value measured

C_D = constant value assumed 0.625

d = effective diameter of the jet.

Hence $0.50^2 - d^2$ is proportional to the area of the dead water at the orifice plate. From the values tabulated for the 20"head.

TABLE.41.2

Width of Bar	3/8"			7/32"			1/8"			1/16"		
Height of bar from orifice inlet.	0	0.1	0.2	0	0.1	0.2	0	0.1	0.2	0	0.1	0.2
$d^2 =$ [redacted] 0.40C_D'	0.05	0.16	0.232	0.148	0.214	0.244	0.196	0.230	0.244	0.216	0.244	0.24
$0.50^2 - d^2$	.20	.09	.018	.102	.036	.006	.054	.020	.006	.034	.006	.00

These values have been plotted in fig.42.3. It is considered that they give some indication of the degree of contraction of this dead water region behind arectangular plate. In view of the scarcity of further information, it is proposed to make no further comments on the shape of this dead water region.

42. <u>Experiment No.13</u> <u>"Determine the influence on the C_D of an orifice $\frac{1}{8}$" thick $\frac{1}{2}$" diameter by placing a disc of various diameters in the approach."</u>

<u>42.1. Description.</u> In order to apply an obstruction capable of making more powerful vortices than those produced by the bar in experiment No.12. it was decided to insert a disc in the approach to the orifice, this disc being placed at various distances before the orifice inlet and turned down to various diameters upon each of which a test was carried out.

A disc of mild steel 4" diameter was turned out of a piece of $\frac{1}{8}$" thick plate and soldered to three legs each 2" long and made from steel tubing $\frac{1}{4}$" diameter. The legs were soldered on a circle $1\frac{3}{4}$" diameter.

This disc was simply placed centrally on the orifice plate. No special precautions were taken to ensure that the plate was central, other than by measuring the distance between the circumferences of the disc and plate.

A series of tests were carried out on the 4" disc, the discharge, being taken for various heads. After each series of head-discharge tests the legs were shortened and a further series of head-discharge tests made. After repeating this for several positions of the disc ahead of the orifice, a fresh disc ofsmaller diameter, was made and the foregoing tests repeated with new legs.

<u>42.2. Calibration</u>. No special efforts were made to produce the disc accurately. The diameter of the disc and length of the legs was measured with a ruler.

<u>42.3. Theoretical Discharge</u>. The discharge through the orifice was taken from those obtained for the $\frac{1}{8}$" orifice in Experiment No.1.

<u>42.4. Observations</u>. C_D increases at first when the disc is placed away from the orifice. This increase is very considerable up to a distance 0.15" from the orifice, after which the rate of increase is more gradual. The C_D then acquires a maximum value and with further increase in the distance of the disc from the orifice there is a tendency for C_D to decrease slightly.

It was observed that the C_D was independent of the disc diameter, and varied only with its height from the orifice up to a distance of 0.15" from the orifice. As the distance from the orifice increases further there is a tendency for C_D to be influenced by the disc diameter.

<u>42.5 Analysis</u>. Since the "constant" values of C_D noted when the height of the back face of the plate from the inlet doesnot vary considerably either with (1) disc diameter or (2) position, it is not considered that the eddies from the disc have much influence upon the discharge. The controlling factors must therefore be either (a) loss of head in the approach, (b) variations in the Cc.

Since the disc diameter has very little effect on C_D it hardly seems as though the area at its circumference is of any importance in controlling the discharge. On studying the whole subject, it, seems as though <u>expansion</u> of the flow, will only occur when the flow reaches the circumference of the orifice, then, the disc must be placed at such a distance before the orifice, that the circumferential area is less than the orifice area

$$\text{i.e.} \quad \pi\left(\tfrac{1}{2}\right) x = \frac{\pi}{4}\left(\tfrac{1}{2}\right)^2$$

$$\text{i.e.} \quad \underline{x = 0.125 \text{ ins.}}$$

where x = height of the disc above the orifice.

It was observed that C_D increased very rapidly as the disc ~~positio~~ position was increased to 0.15 ins. in front of the orifice. The closeness of this observation with the value of x = 0.125 calculated above, lends support to the assumption that the principal loss of flow occurs in the loss of head during expansion of the flow at the circumference of the orifice.

Owing to the proximity of the disc to the orifice it will not be possible for the streamlines to deflect so easily as if the approach were unrestricted, hence C_D will be lower, the nearer the disc is to the orifice. This effect will persist for a greater distance of the disc from the orifice than will the loss of head influence previously discussed (which will, or should become zero, at x = 0.125 ins). Hence, C_D will not reach its maximum distance until the disc is some further distance from the arffice.

After this maximum C_D has been reached the circumference of the disc will commence to exert an influence upon the C_D since, as the height of the disc increases, the annulus of area between the disc and walls of the 6" tank will be less than the circumference area between the circumference of the disc and the orifice plate. Hence, a reexpansion of the flow will occur as the height of the disc is increased, with the result that C_D will fall slightly according to the amount of head lost during the reexpansion. The height for this expansion to commence is given by

Annulus area = Circumferental Area

$$\text{i.e.} \quad \frac{\pi}{4}\left[6^2 - D^2\right] = \pi D x.$$

$$\text{i.e.} \quad x = \frac{36 - D^2}{4D}$$

which acquires the following values.

D	4	3	2½
x	1.25	2.25	3.0

Reference to fig.42J. shows that the maximum C_D is reached at approximately 1" and 1.25" respectively. There must be remembered however, that a slight re-expansion will always occur when the flow enters the corner of the approach and this may have some influence upon the flow and bring the point of the disc for maximum C_D nearer to the orifice plate than the foregoing deductions would indicate.

In conclusion it should bu stated that although the vertices formed by the disc do not appear to have an influence on C_D due to the presence of the vortices themselves, the head lost in their formation does control C_V and C_D. The effect on Cc is probably insignificant.

CHAPTER 11.

GENERAL TESTS OF THE PRESSURE DISTRIBUTION IN THE FLUID STREAM.

It was considered desirable, before concluding this series of experiments, to investigate the distribution of pressure around the orifices used. In the absence of special instruments, the readings obtained were not expected to be extremely accurate. There is however very little doubt that the observations which have been made have assisted in framing a general idea of the characteristics of the flow through these apertures.

43. Experiment No.14. "Determine the static pressure along a nozzle $2\frac{1}{8}$" long."

43.1. Description. A nozzle, $\frac{1}{2}$" diameter, $2\frac{1}{8}$" long was made with 15 holes, $\frac{1}{8}$" diameter 2" long, bored axially through its shell, their centres lying on a circle $\frac{3}{4}$" diameter. Fifteen smaller holes ($\frac{1}{32}$" dia) were drilled radially, one through each of the axial holes, and each in a plane $\frac{1}{8}$" below the preceding hole. At the outlet face, the axial holes were all counterbored, $\frac{5}{32}$" diameter, $\frac{3}{16}$" deep and short lengths of copper tube inserted and soldered. The radial hole $\frac{1}{8}$" from this face was rebored. The radial holes on the outside of the nozzle were then blanked off with small solder 'blobs' and smoothed down. The inlet face holes were similarly blanked off. The finished nozzle is shown in fig.43.2.

A direct connection from the small hole in the wall of the jet to the axial hole in the wall and to the small piece of copper tubing therefore enabled fluid to be forced through to a glass tube connected to the copper tubing by rubber hose. The level, above datum, of the water in this glass tube was intended to measure the static pressure.

43.2. Calibration. The tapping holes, both axial and radial, were all carefully drilled. No special checks were made of their positions.

The glass tubing was clipped to the wall with a piece of graph paper behind it. The nozzle was placed in the tank, pressure connections made, outlet blanked off with a piece of plasticene, and the tank then filled to 20". The level of the water in the glass tube was then marked on the graph paper. As a general test, the outlet of the nozzle was unblocked to discharge the water from the tank, then reblocked and the tank filled to 4". The position of the 4" level in the tube was exactly 16" below the 20" mark. It was therefore considered satisfactory to mark down 20" from the 20" - mark on the graph paper to obtain the position corresponding to the nozzle inlet. The level of each tapping point was then marked off the graph paper by measuring down each $\frac{1}{8}$".

43.3. Observations. The water was made to issue from the nozzl at various heads and the fluid level in the tapping tubes noted. It was observed that no fluid entered the tapping tubes with th water level at all heads in the tanks. This was observed, desp: the glass tubes being extended to read - 6" below their datum positions.

44. <u>Experiment No.15.</u> "<u>Determine the distribution of static pressure on the inlet face of the orifice.</u>"

<u>44.1. Description.</u> The orifice plate was drilled with 3 holes, $\frac{1}{32}$" diameter, spaced radially $\frac{3}{4}$", $1\frac{1}{2}$" and $2\frac{1}{4}$" respectively, from the centre. These holes were each counter-bored 5/32" diameter, $\frac{1}{4}$" deep on the outer face of the orifice plate and short lengths of copper tubing soldered in. Each piece of tubing was connected by rubber hose to the glass tube secured to the wall for experiment No.14. The same calibrations were used. By this means, it was intended to measure the static pressure on the face plate of the orifice to investigate what effect the curvature of the approach had upon this pressure.

<u>44.2. Calibration.</u> The spacing of the holes were checked with a ruler. The $\frac{3}{4}$" and $1\frac{1}{2}$" positions were satisfactory but the other hole was placed at $2^5/16$ " from the centre.

<u>44.3, Observations.</u> Tests were made (1) upon an orifice, $\frac{1}{2}$" diameter $\frac{1}{8}$" thick, (2) $\frac{1}{2}$" diameter $2\frac{1}{8}$" long, and (3) $\frac{1}{4}$" diameter 1" long. In all cases, the static pressure on the face plate was equal to the head 'H'.

<u>44.4. Analysis.</u> It is concluded that the approach velocity was so low that the 'kinetic' head was too small to have any appreciable influence upon the static head at the orifices.

45. Experiment No.16. "Determine the total pressure of the central filament through an orifice $\frac{1}{2}$" diameter, $\frac{1}{8}$" thick at various distances downstream from the inlet."

45.1. Description. A piece of small-bore brass tubing was soldered to the orifice plate and bent, downwards - then upwards to make a U - S bend about 2" diameter, so that its central stem projected axially through the centre of the jet with its end face flush with the orifice inlet.

This brass tubing was connected by rubber hose to the glass tube, clipped up for Experiment No.14, Tests were made, measuring the total head of the central filament of the jet as measured by this tube. After one series of readings had been taken for various values of H with the tapping tube flush with the orifice inlet, the tapping tube was bent back so that the top was $\frac{1}{8}$" from the orifice inlet. Tests were repeated on the jet with the tap at this position and then the tube was again adjusted with the tap $\frac{1}{4}$" below the inlet and the process repeated.

45.2. Calibration. The position of the pressure tapping was checked before each test with the orifice plate removed, by means of a depth gauge and the appropriate action taken to bring it to the correct position. The axial position of this tapping point was ascertained by measuring across a diameter of the orifice. It is considered that the position was correct to within $\pm$ 1/64", but that in any case the velocity profile was probably sufficiently "flat" to permit small deviations from the co-axial to exist without involving any appreciable inaccuracy in the results.

The pressure gauge on the wall had been previously calibrated in the manner dscribed in Experiment No.14. No further calibration was undertaken.

The face of the pressure tapping was left flat and no attempt was made to "stream line" it off as for some pitot tubes since the pressure/velocity exchange generally takes place before the flow reaches the tapping tube.

45.3. Observations. The total pressure appears to be the same at all positions of the pressure tube (subject of course, to slight variations arising from individual causes, particularly at the high heads). As the head falls, so the ratio measured total pressure.: head H, varies in the following manner:-

TABLE 45.1.

HEAD H	20	16	12	8	4
Ratio of heads.	.979	.986	.978	.971	.970

Mean values of the measured total pressure have been used for H = 20 and H = 16.

45.4. Analysis. That the position of the pressure tube had no effect upon the total pressure reading indicates that the change in energy has completed before the stream has contracted to the inlet of the orifice. The square root of the ratio of heads is equal to the coefficient of velocity, thus,

TABLE 45.2.

HEAD H	20	16	12	8	6
C_v	.988	.993	.987	.986	.986

There appears to be a general decrease in C_v as the head H falls, but the author believes that owing to the "primitive" manner in which the pressure readings were taken it is more probable that the accuracy of recording decreased as the Head H fell with the foregoing results.

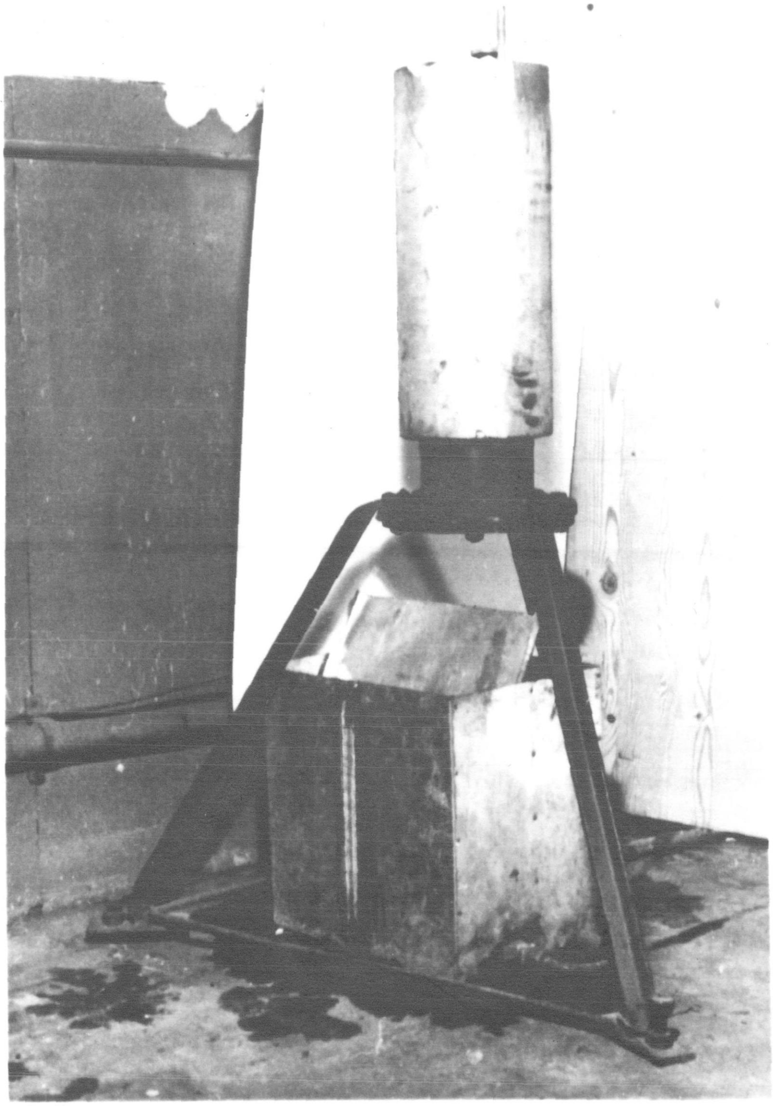


Fig.26.1. The Experimental Apparatus.

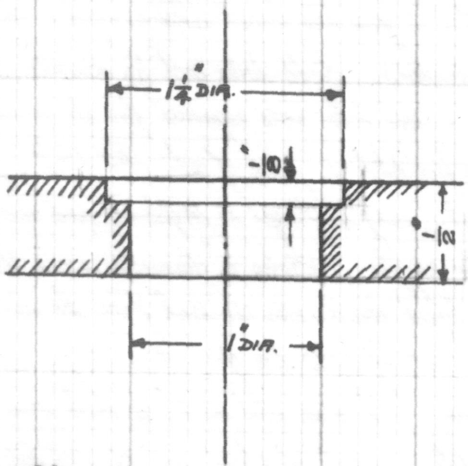


FIG. 26.2. HOLE IN ORIFICE PLATE

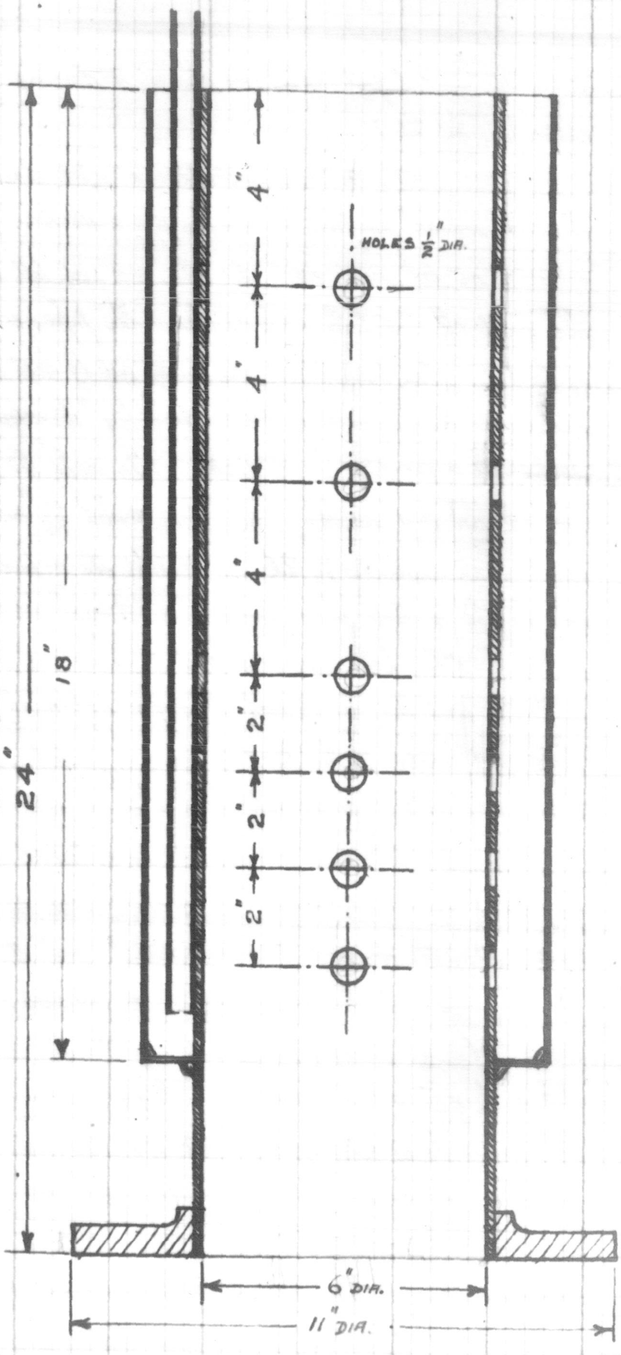


FIG. 26.3. TANK FOR ORIFICE CALIBRATION.

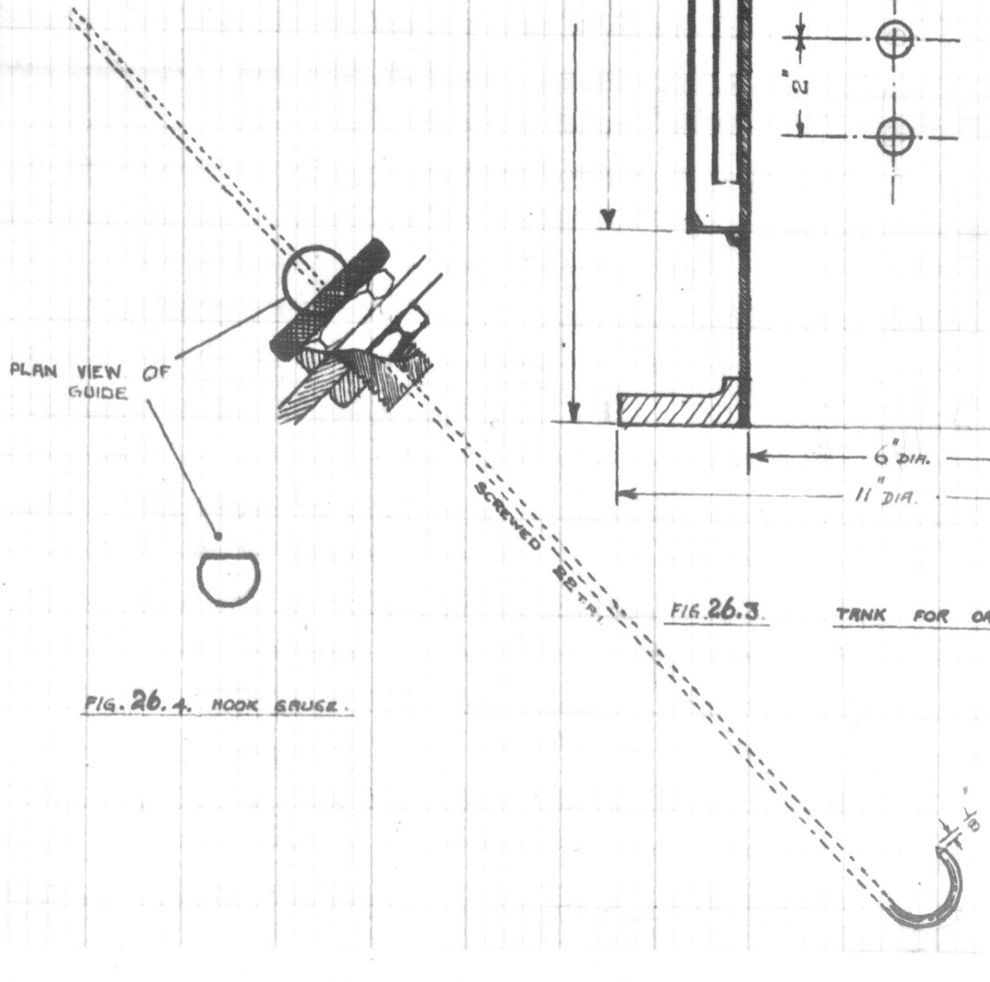


FIG. 26.4. HOOK GAUGE.

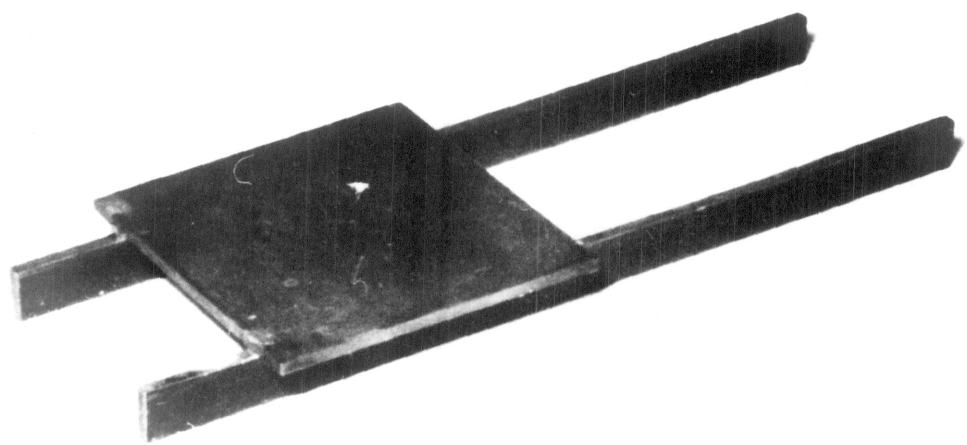


Fig.27.1. Yoke for calibrating Hook Gauge.

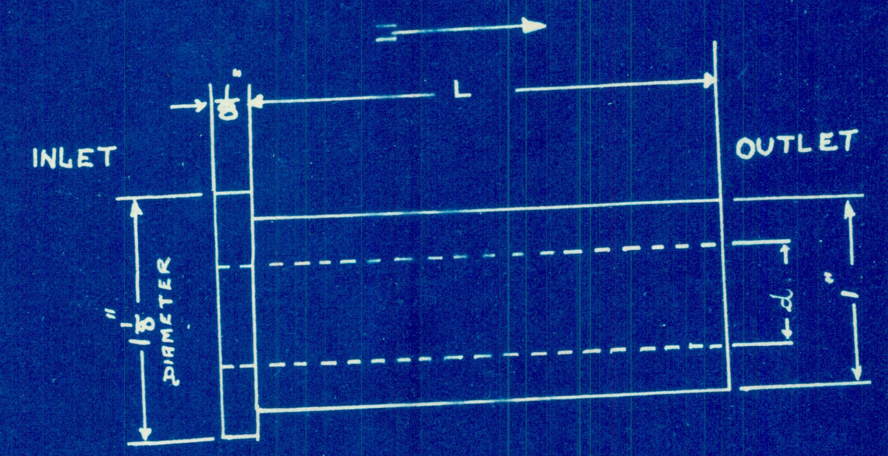


FIG. 30.1. BRASS NOZZLE - GENERAL DIMENSIONS.

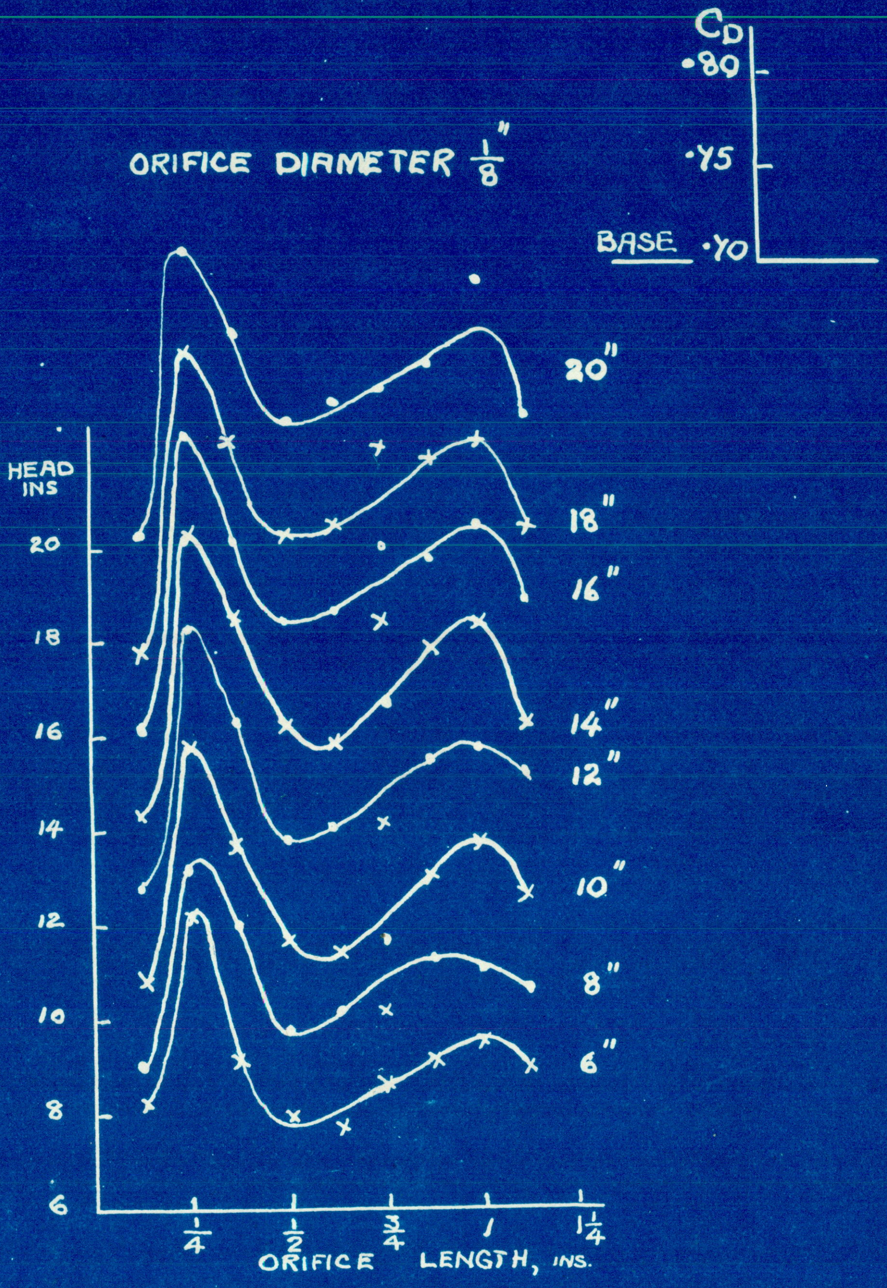


FIG. 30.2. EFFECT OF LENGTH ON CD OF AN 1/8" NOZZLE.

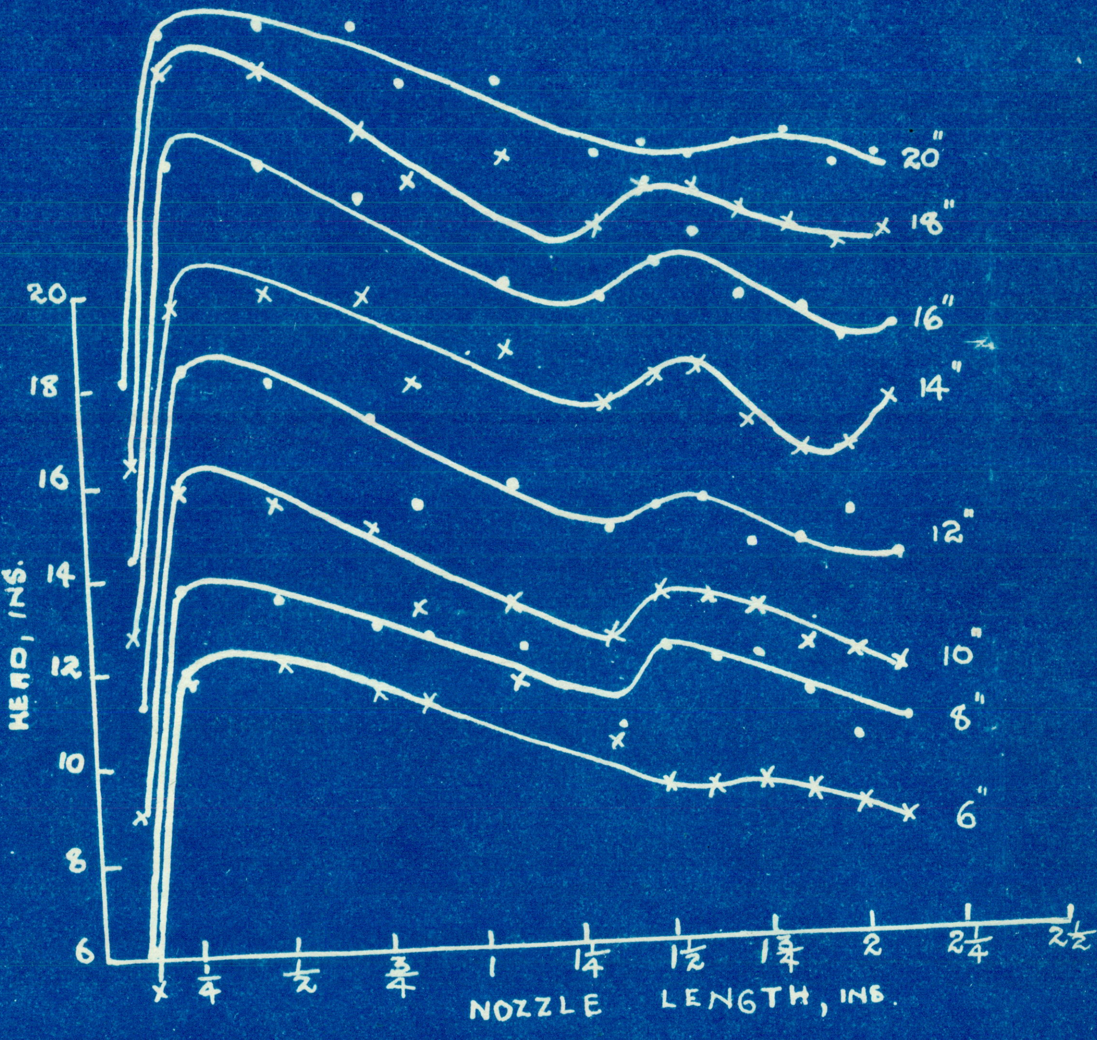


FIG.30.3. EFFECT OF LENGTH ON C_D OF NOZZLE $\frac{1}{4}$" BORE.

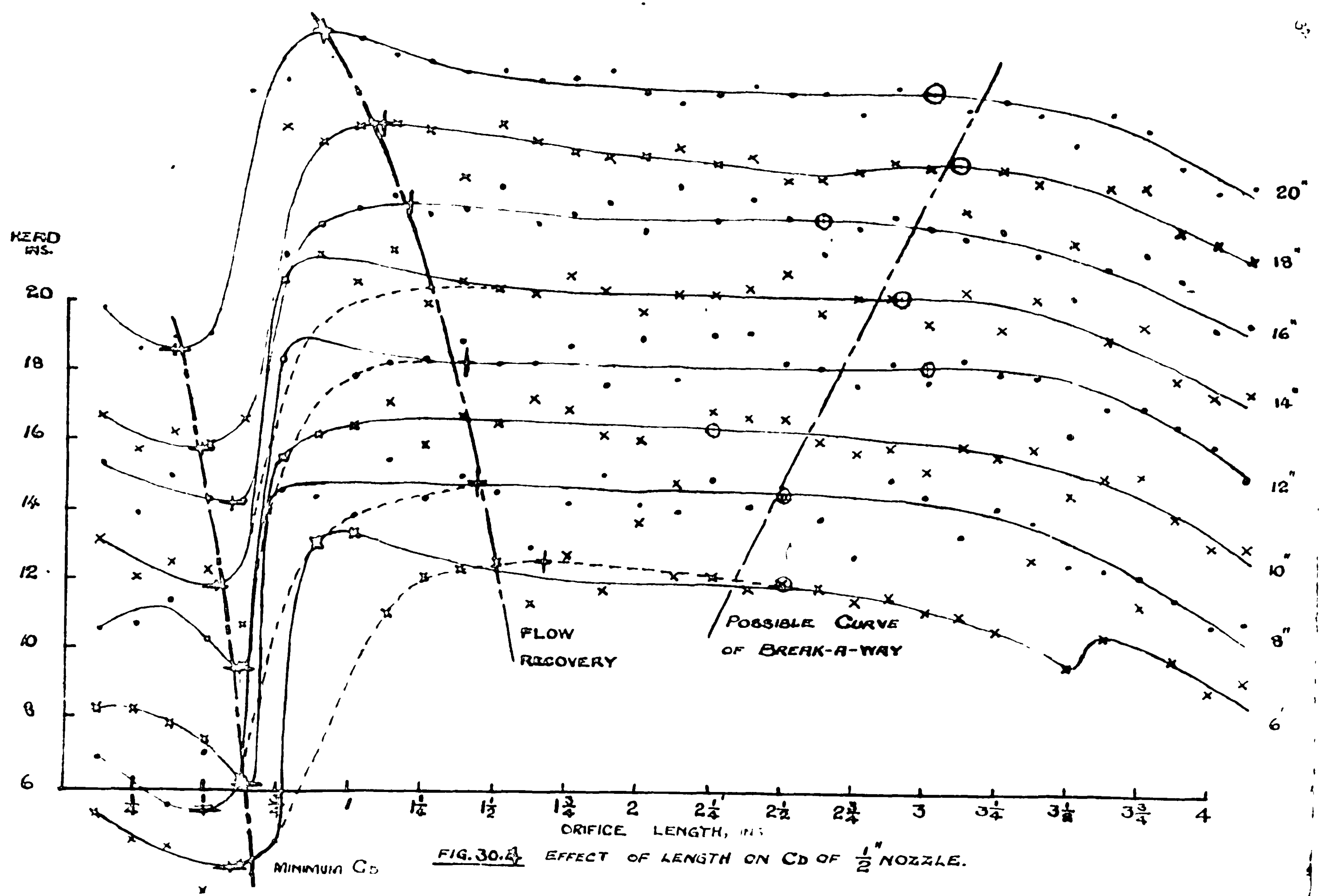


FIG. 30.A EFFECT OF LENGTH ON C_D OF $\frac{1}{2}$" NOZZLE.

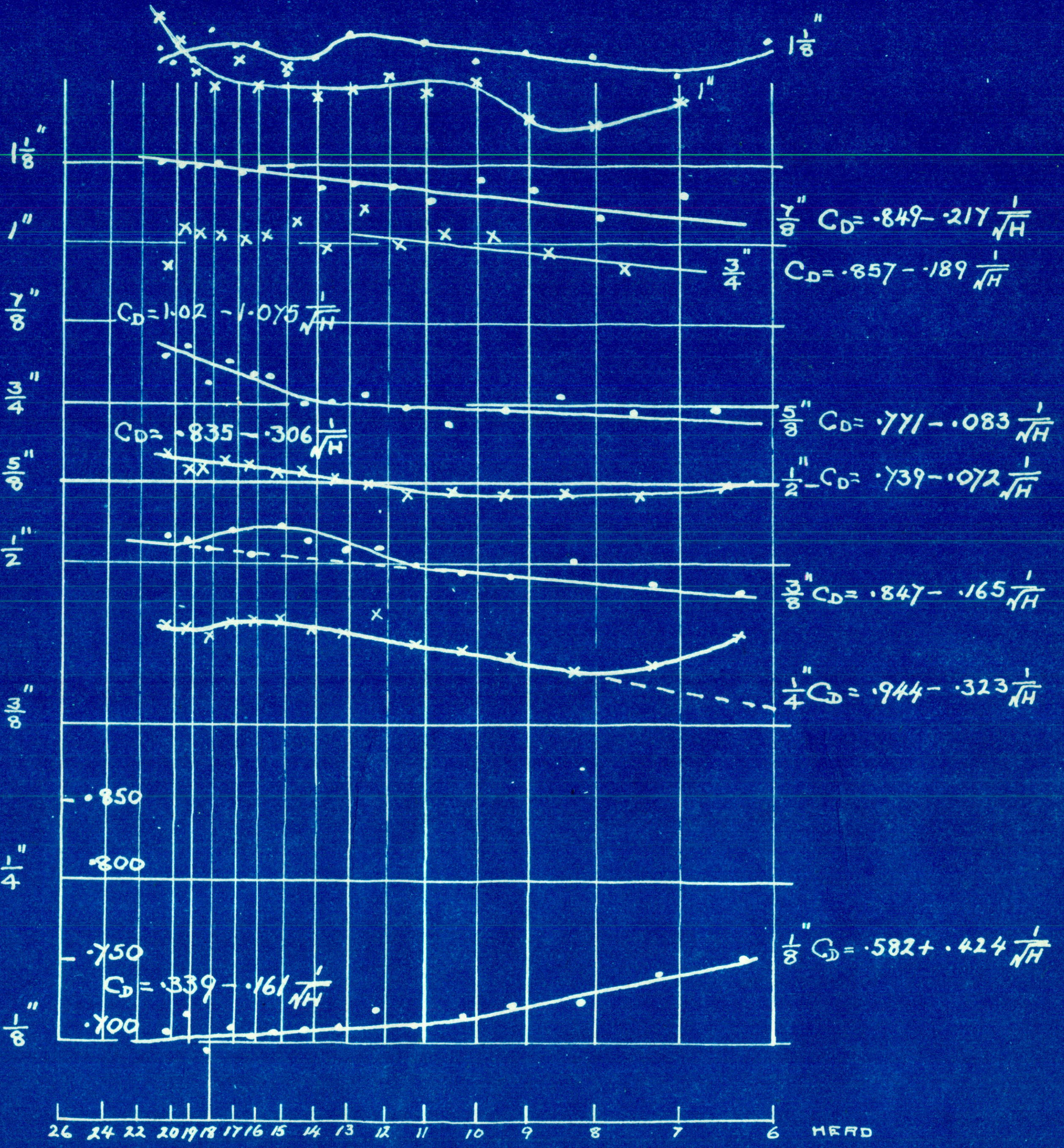


FIG. 30.5. EFFECT OF HEAD ON C_D OF 1/8" NOZZLE.

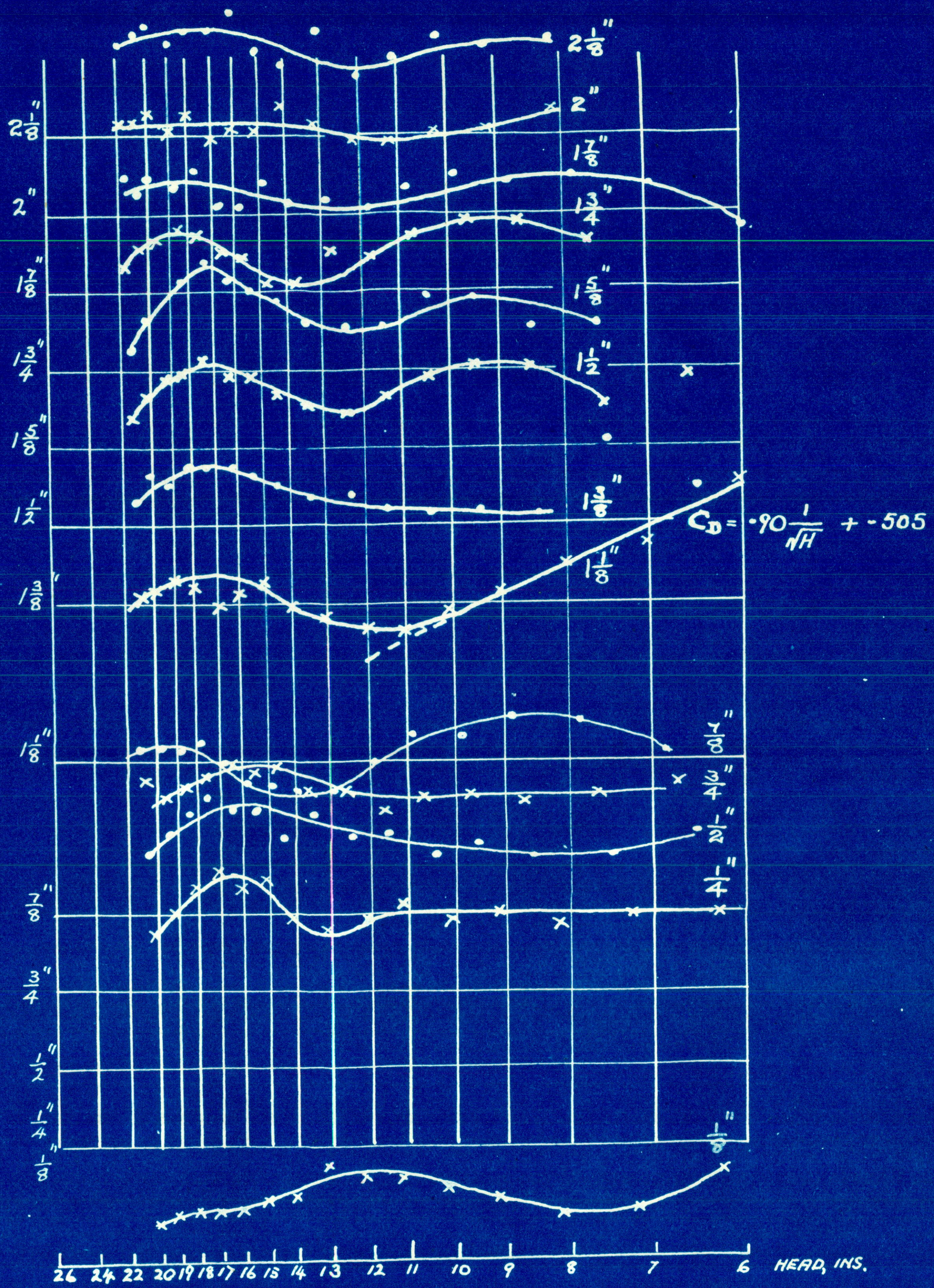


FIG. 30.6. EFFECT OF HEAD ON CD OF 1/4" NOZZLE.

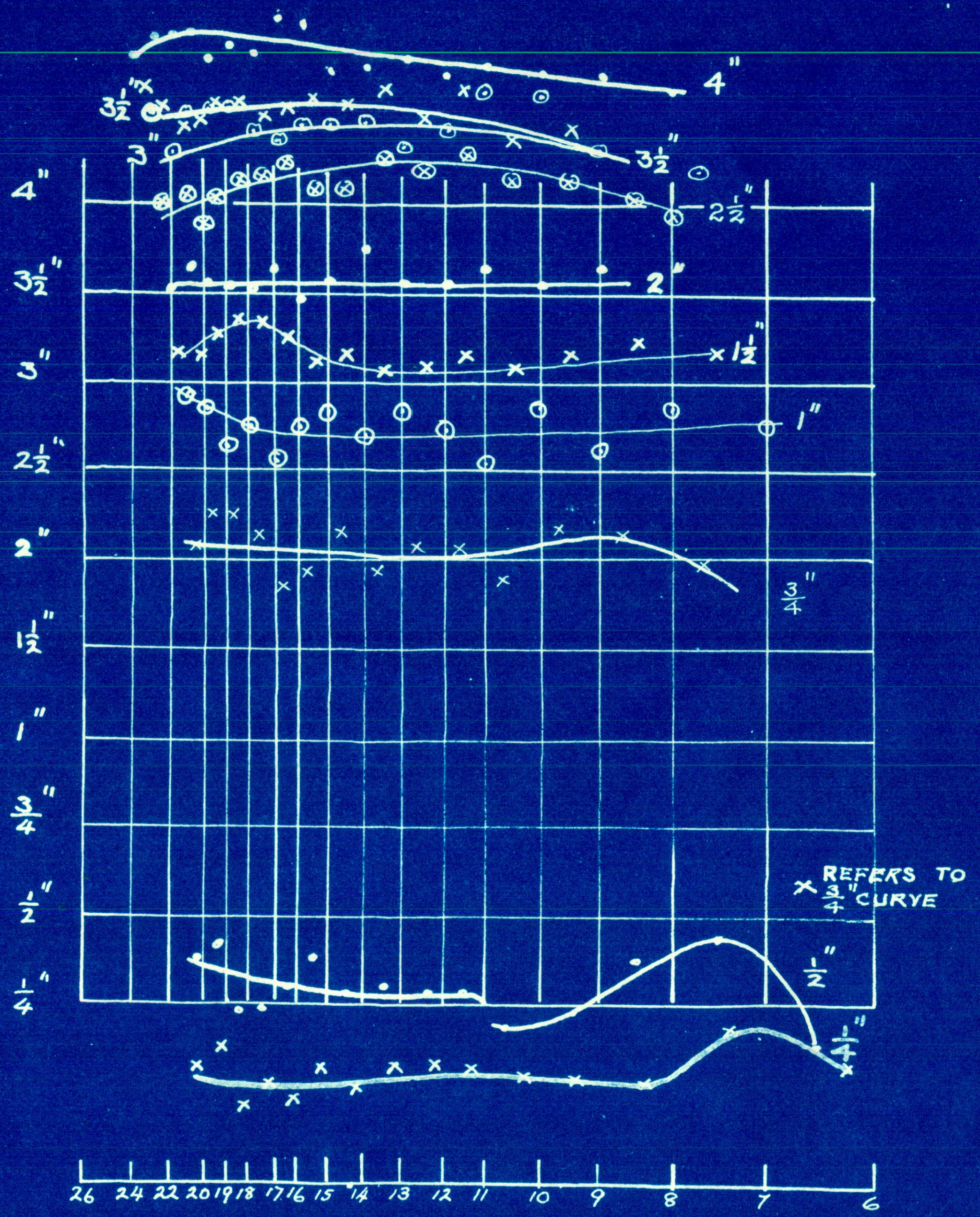


FIG. 30.7. EFFECT OF HEAD ON C_D OF ½" NOZZLE.

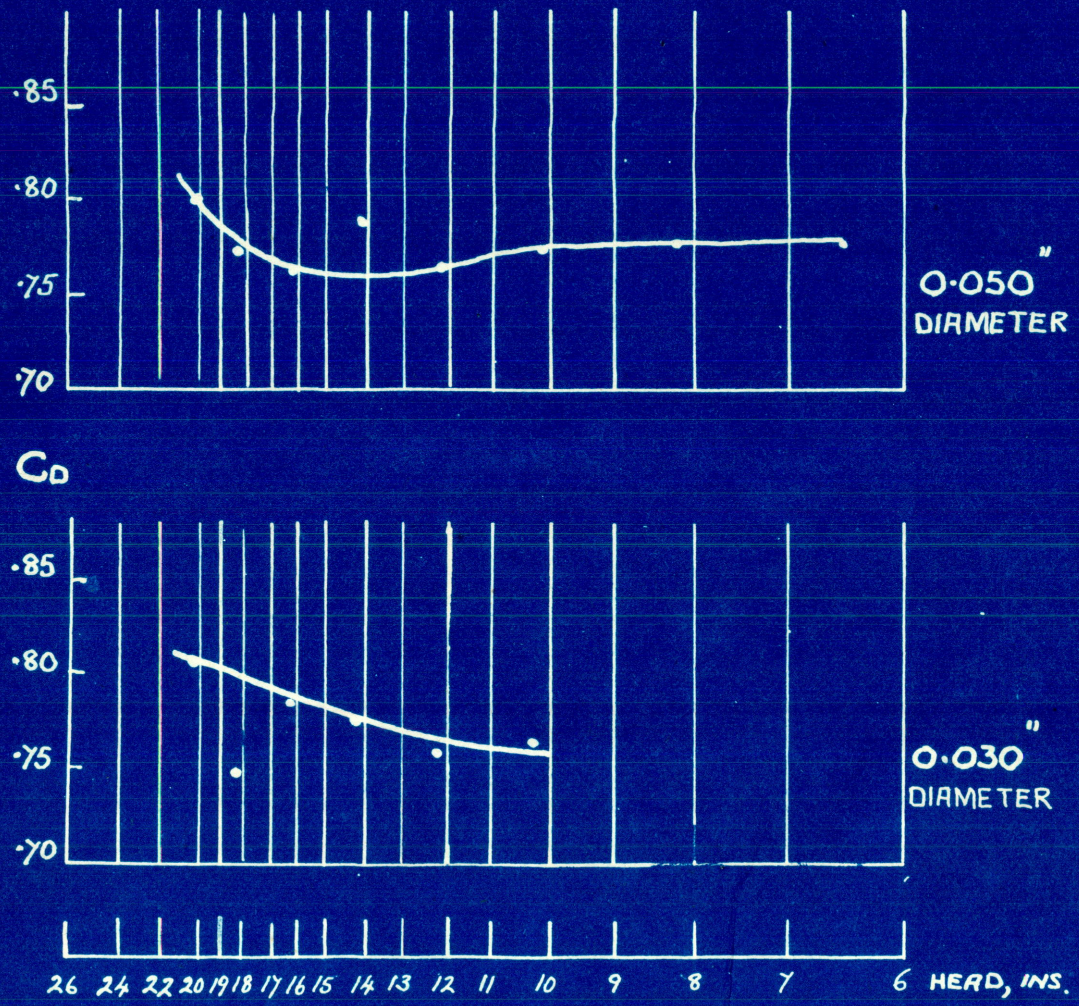


FIG.31.1. EFFECT OF HEAD ON THE C_D OF ORIFICES 0·030 AND 0·050 INS. DIAMETER.

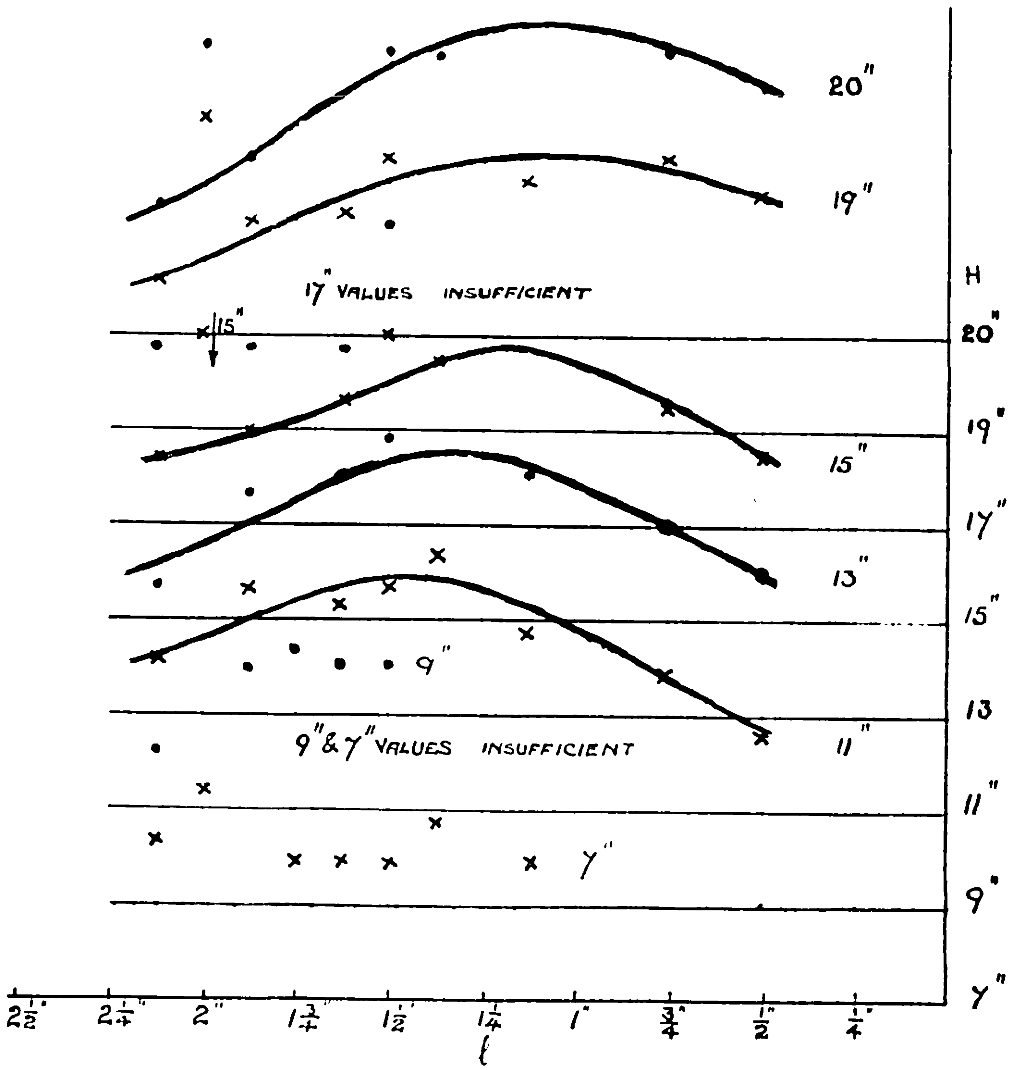


FIG. 32.1. EFFECT OF LENGTH ON C_D OF INVERTED ¼" NOZZLE.

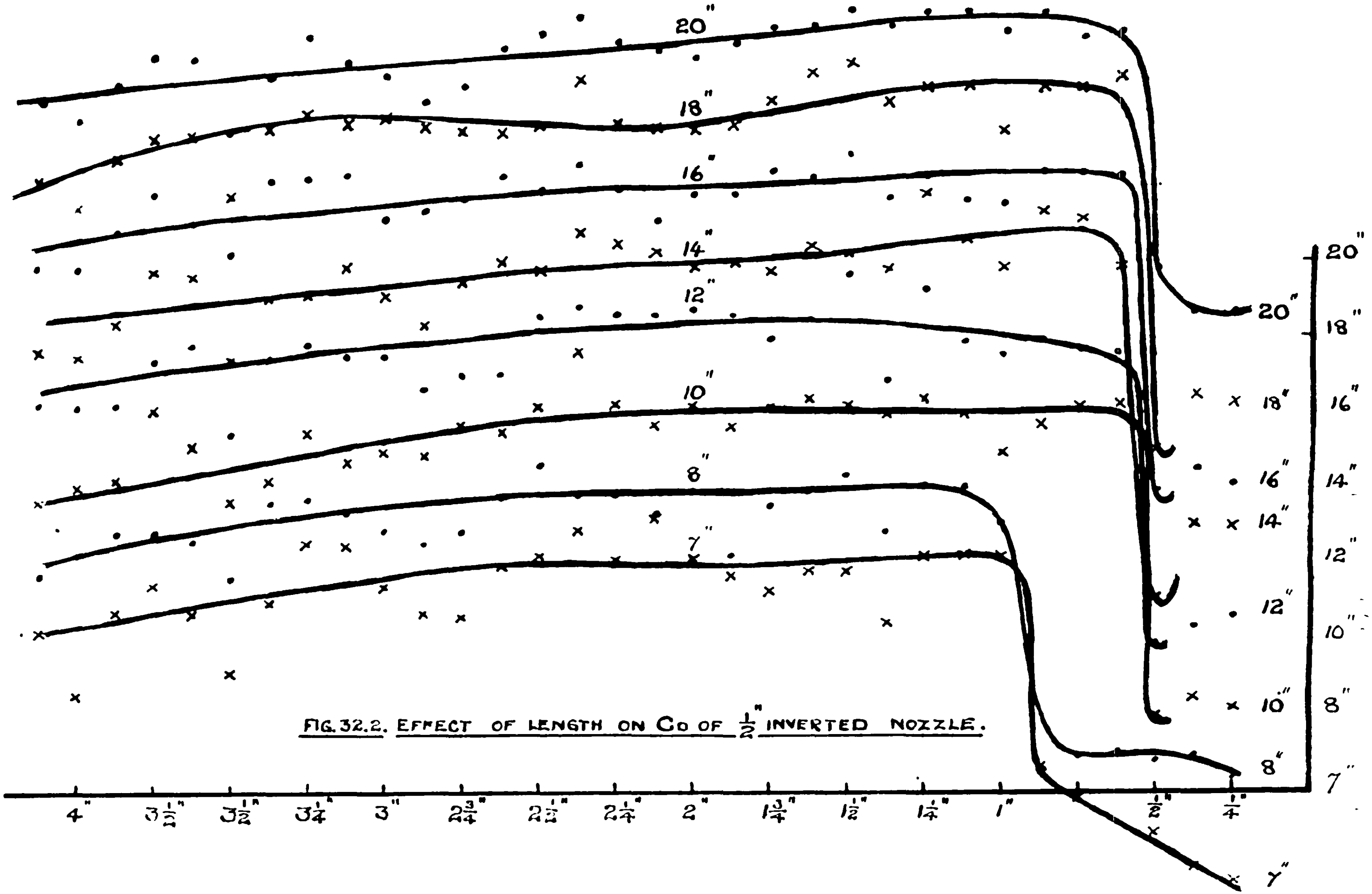


FIG. 32.2. EFFECT OF LENGTH ON C_D OF ½" INVERTED NOZZLE.

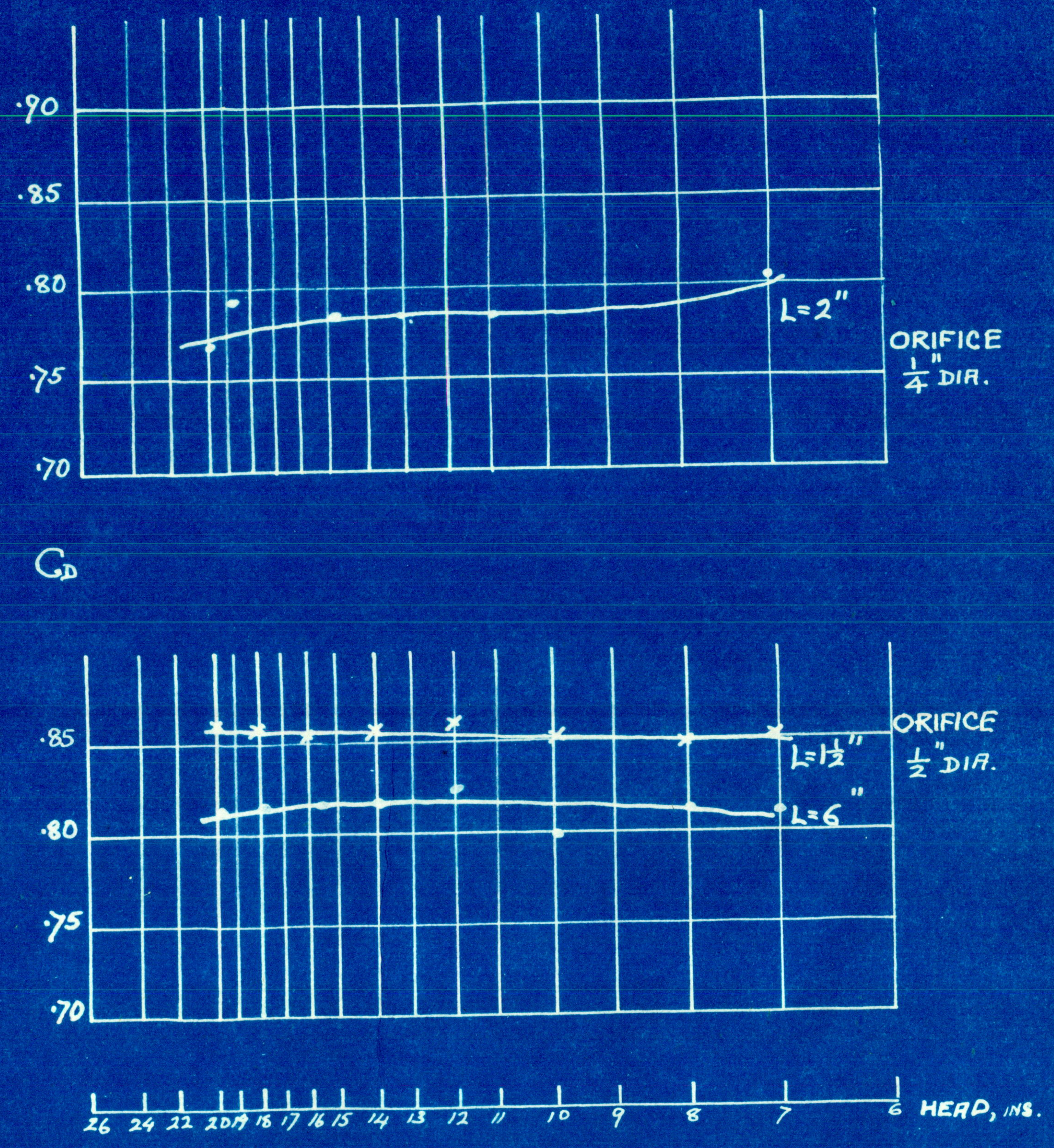


FIG. 32.3. EFFECT OF HEAD ON THE CD OF RE-ENTRANT NOZZLES.

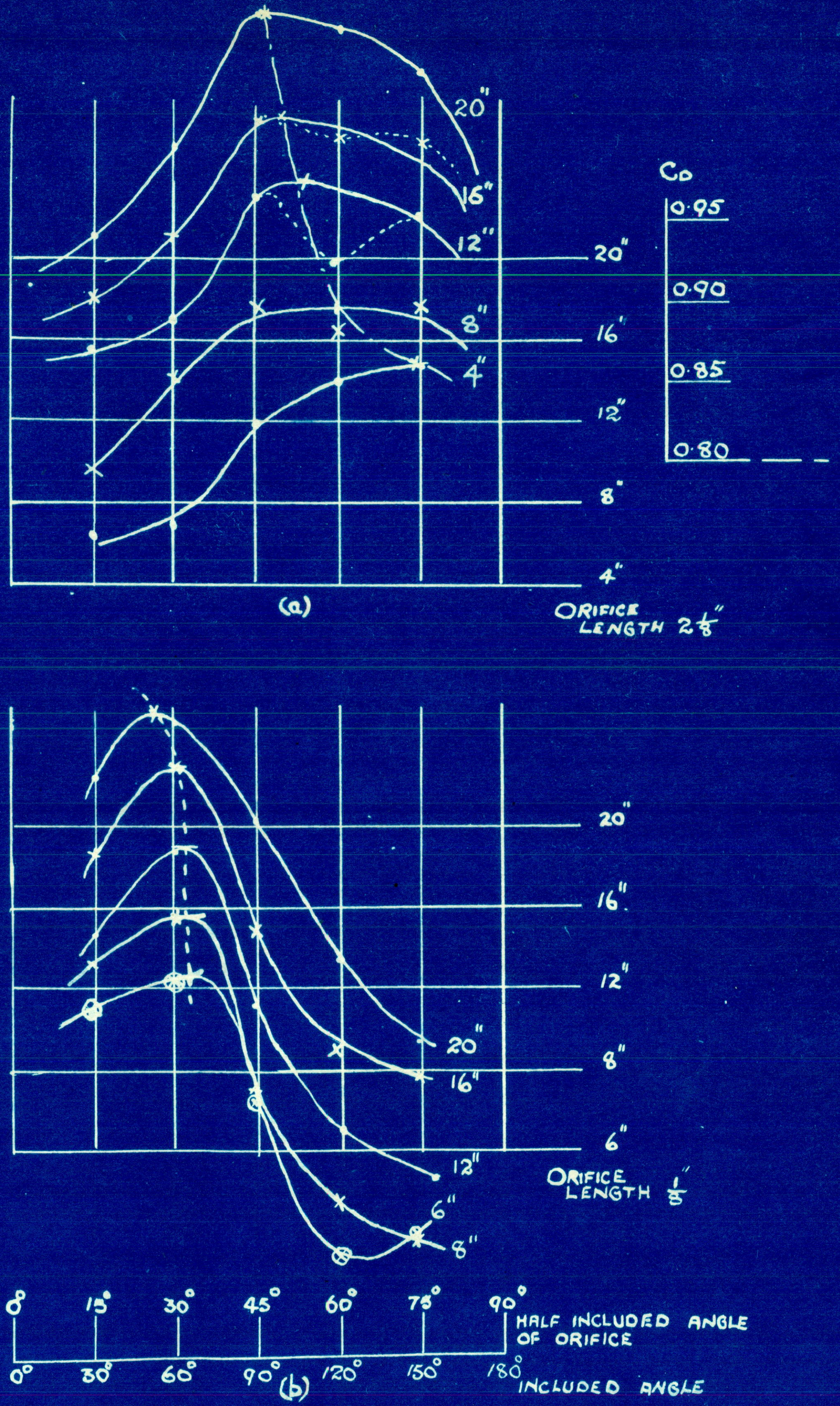


FIG. 34.1. EFFECT OF CHAMPFER ON THE C_D OF A NOZZLE.

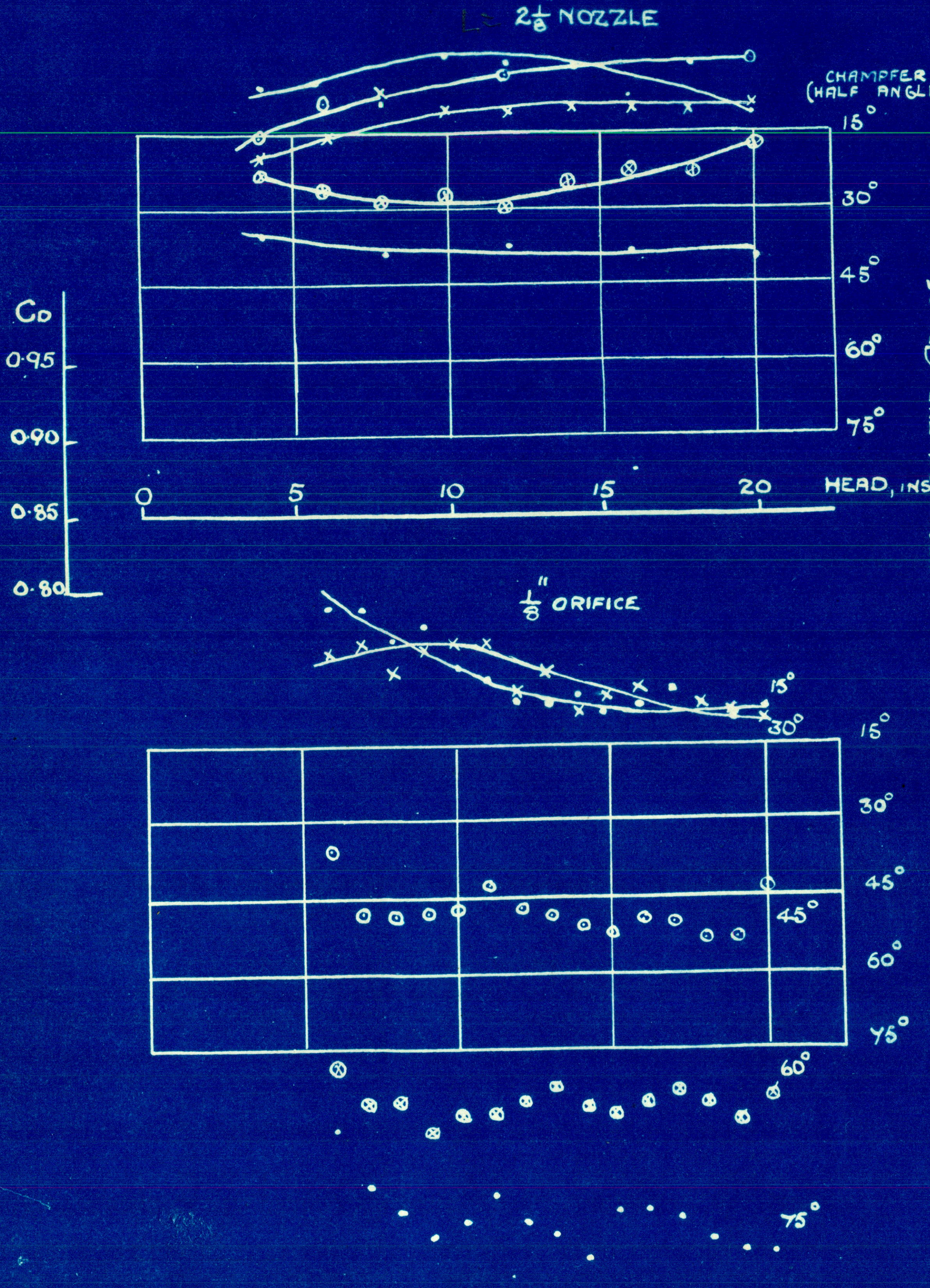


FIG. 34.2. EFFECT OF HEAD ON THE CD OF A CHAMPFERED ORIFICE.

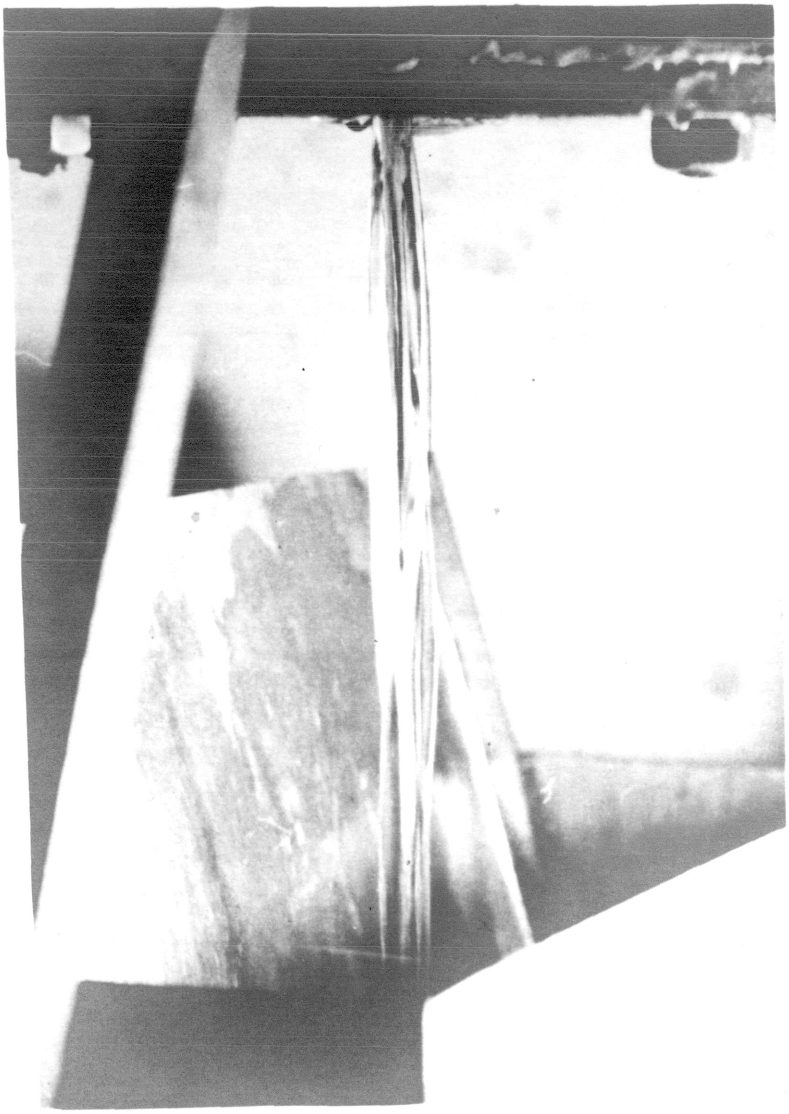
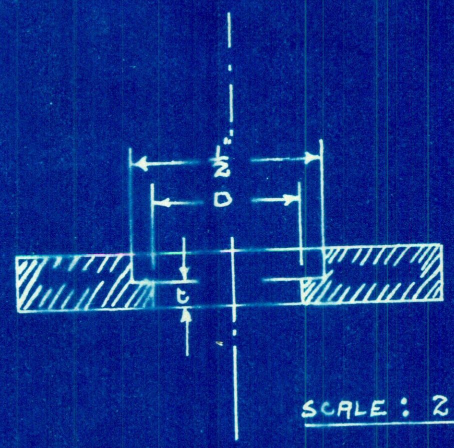


Fig. 36.1. Jet from orifices in close proximity.



SCALE: 2 X FULL SIZE

FIG. 3Y. 1. ORIFICE WITH OBSTRUCTING DIAPHRAGM.

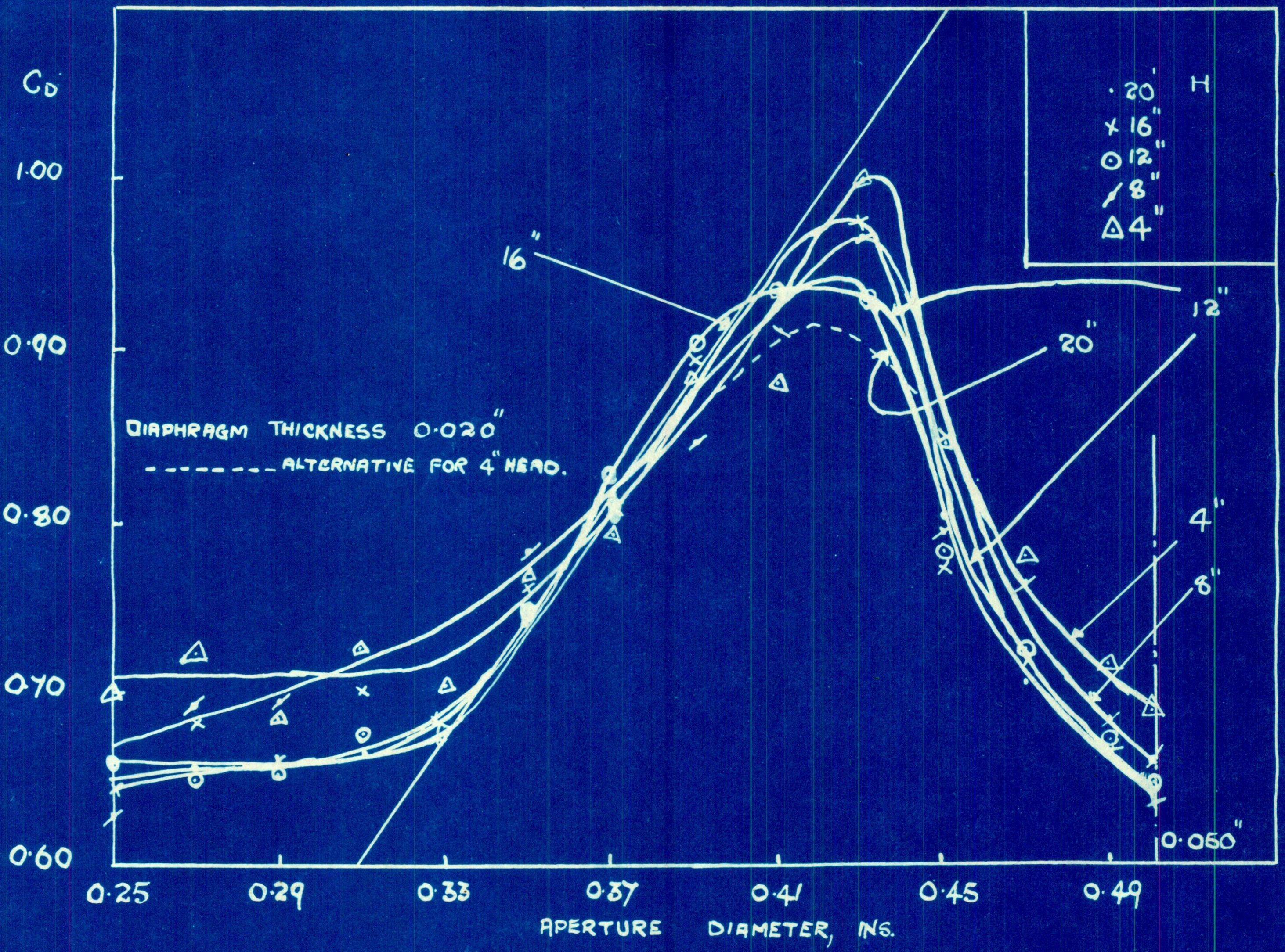


FIG 37. 2 VARIATION OF C_D WITH APERTURE DIAMETER.

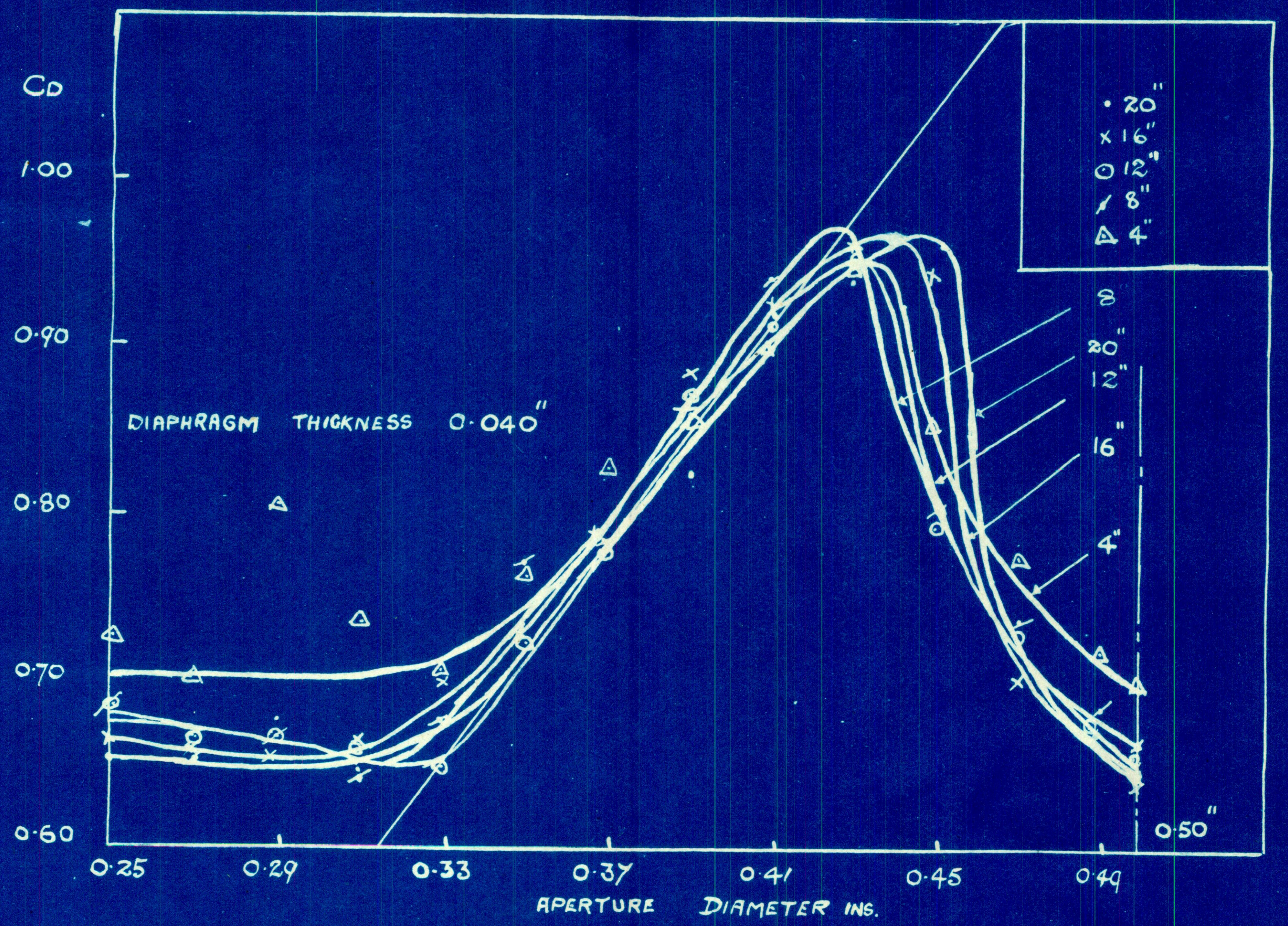


FIG. 37.3. VARIATION OF CD WITH APERTURE DIAMETER

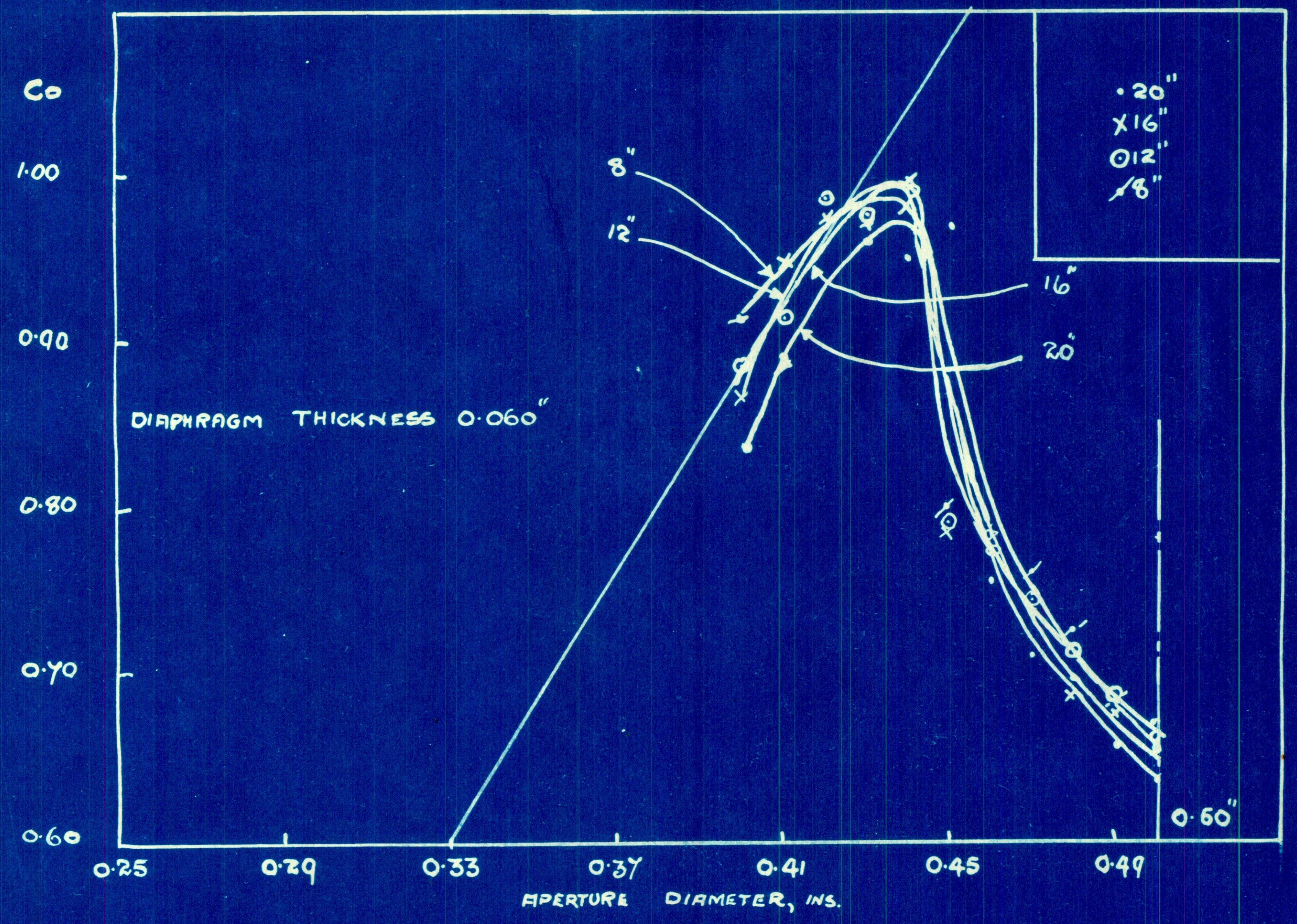


FIG. 3Y. 4. VARIATION OF C_D WITH APERTURE DIAMETER.

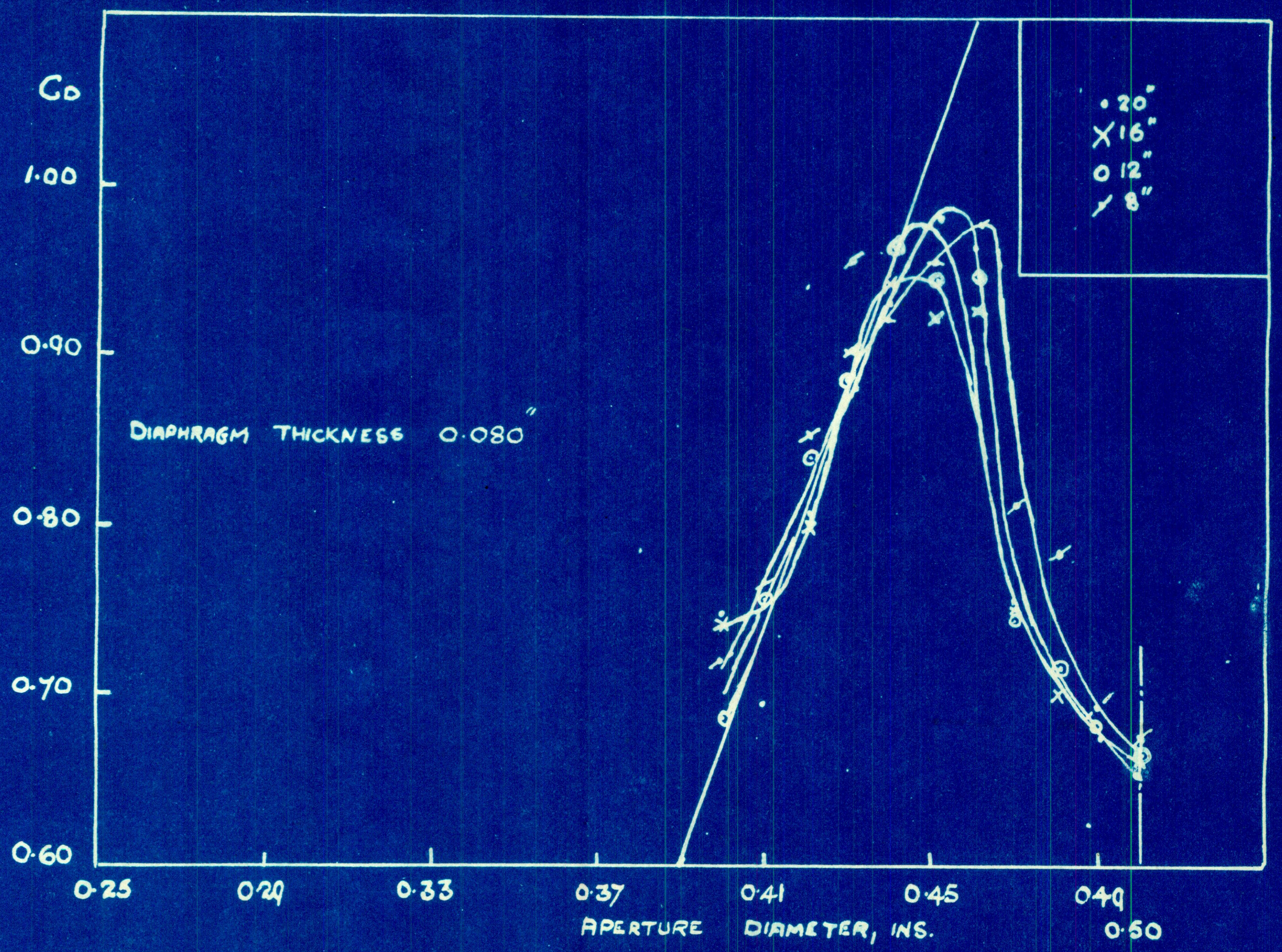


FIG. 37 5. VARIATION OF C_D WITH APERTURE DIAMETER.

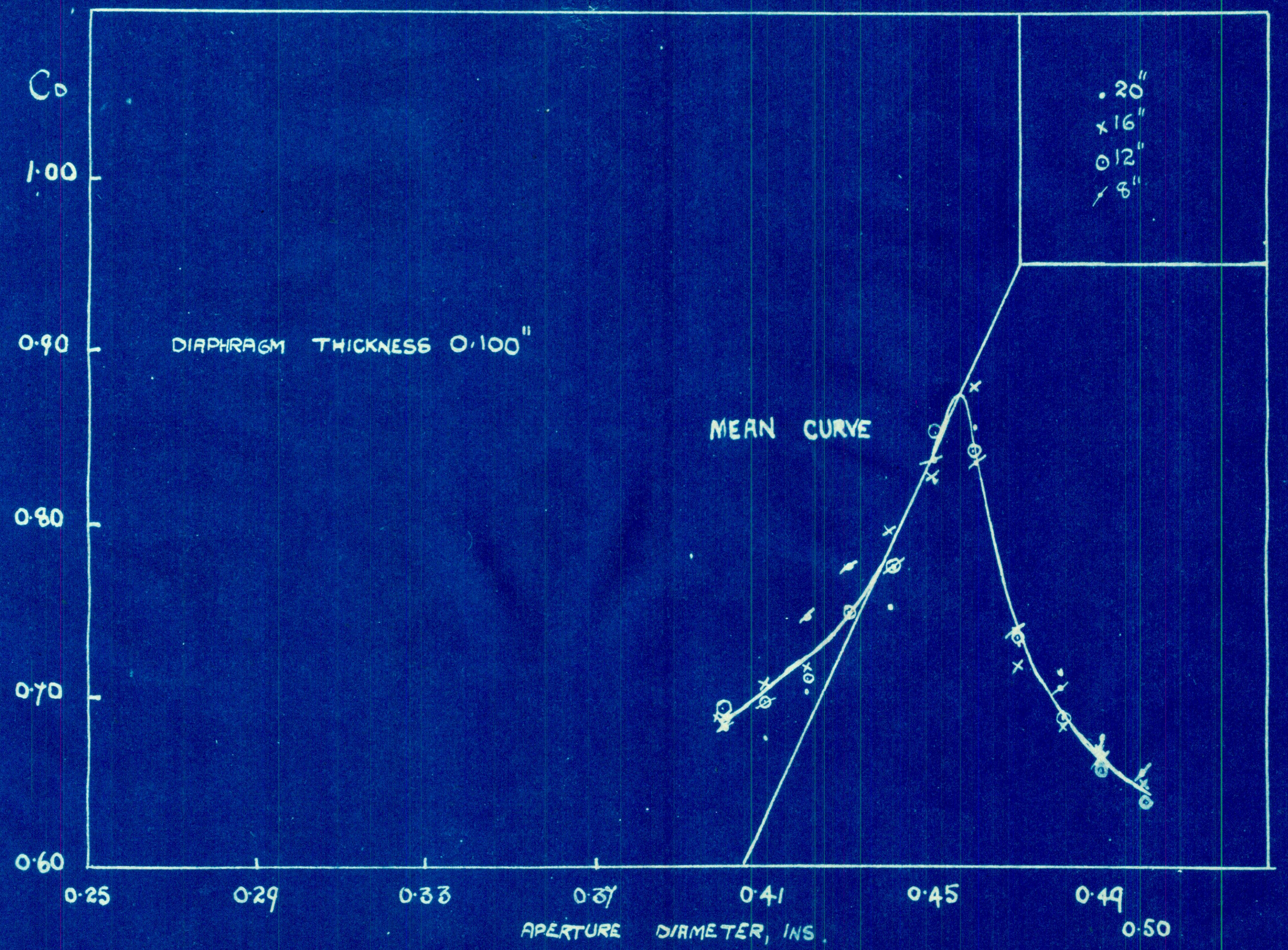


FIG. 37. 6. VARIATIONS OF C_D WITH APERTURE DIAMETER.

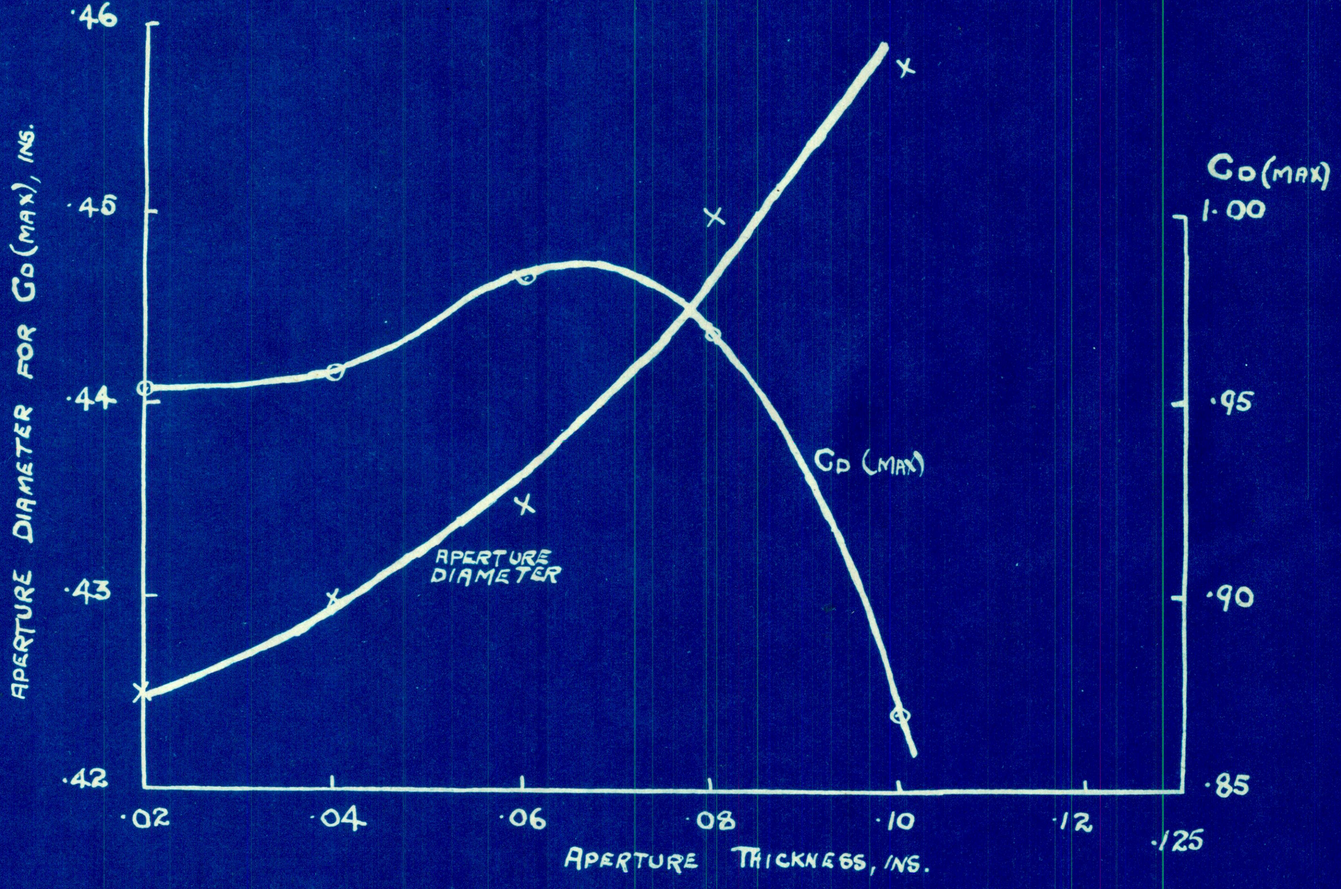


FIG. 3Y. 7. MAXIMUM C_D CHARACTERISTICS.

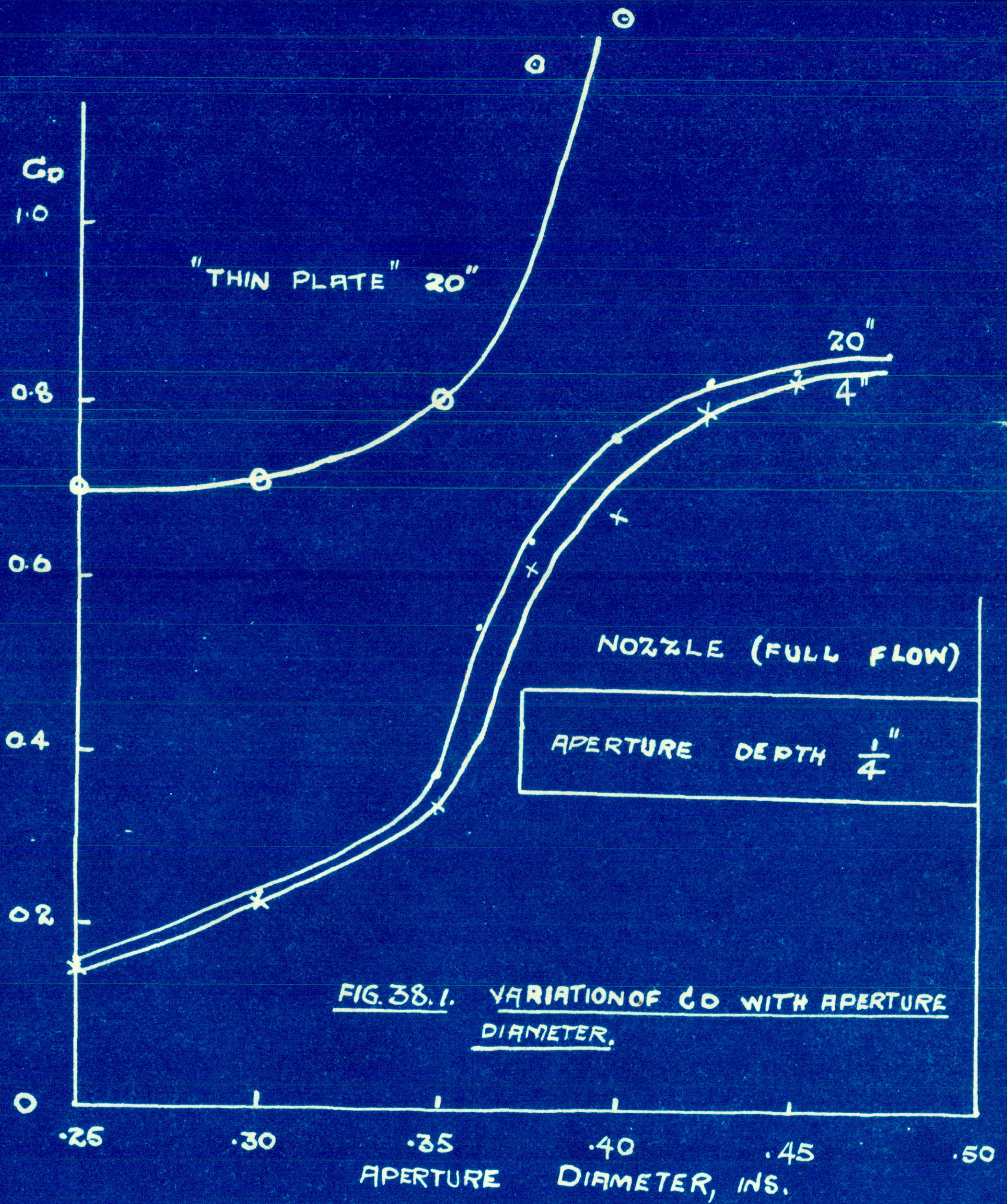


FIG. 38.1. VARIATION OF C_D WITH APERTURE DIAMETER.

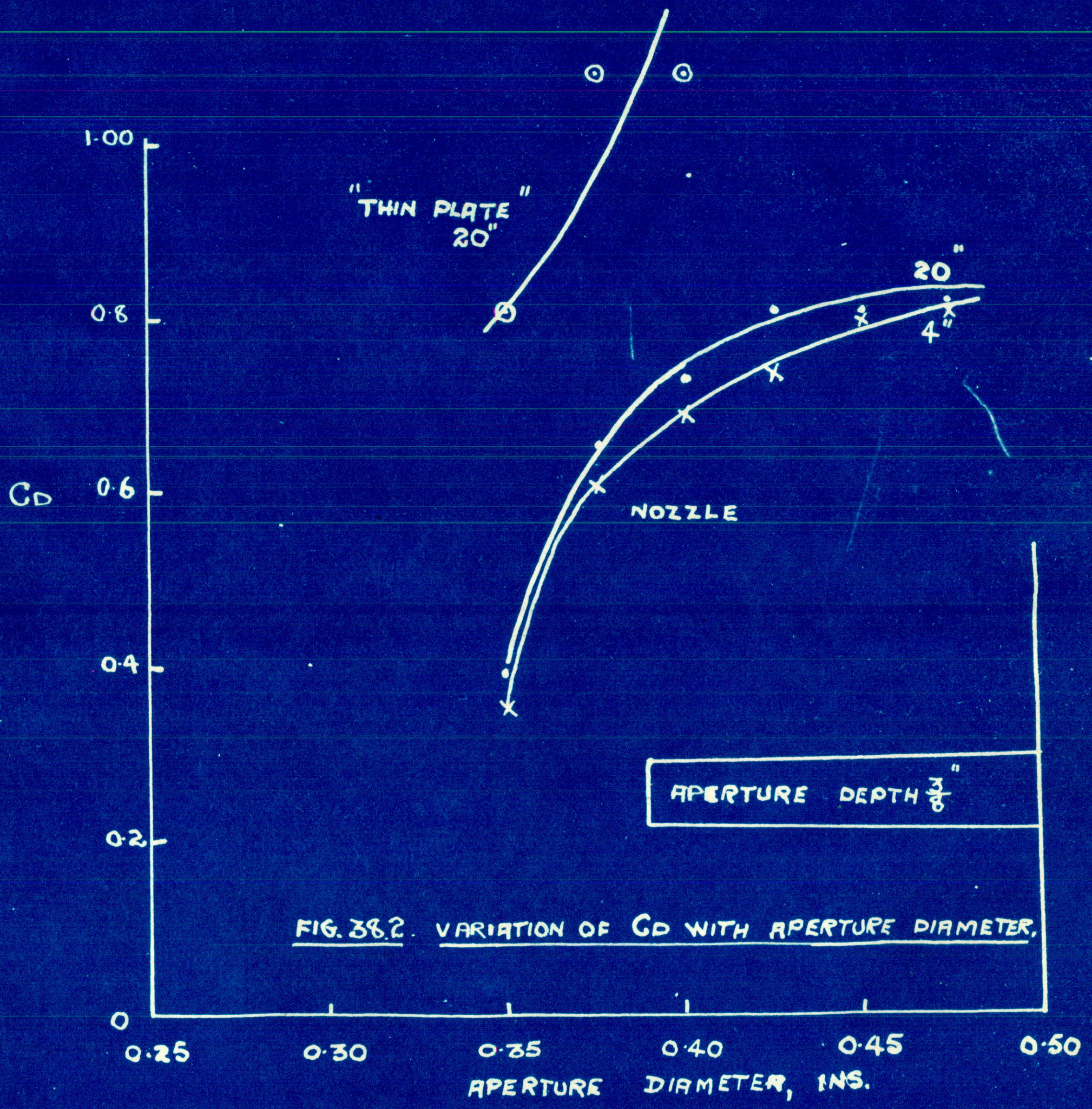


FIG. 38.2. VARIATION OF CD WITH APERTURE DIAMETER.

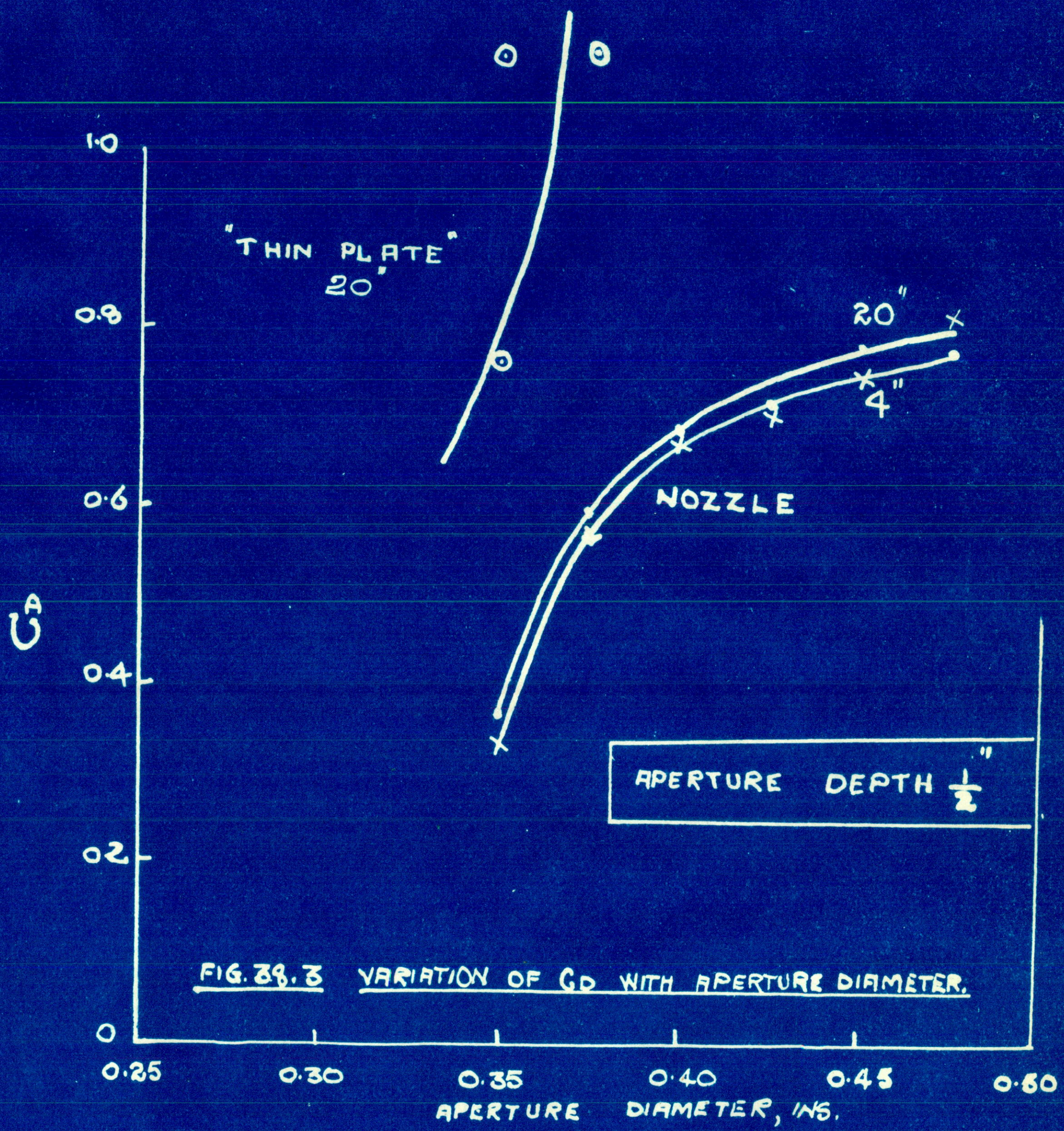


FIG. 38.3 VARIATION OF C_D WITH APERTURE DIAMETER.

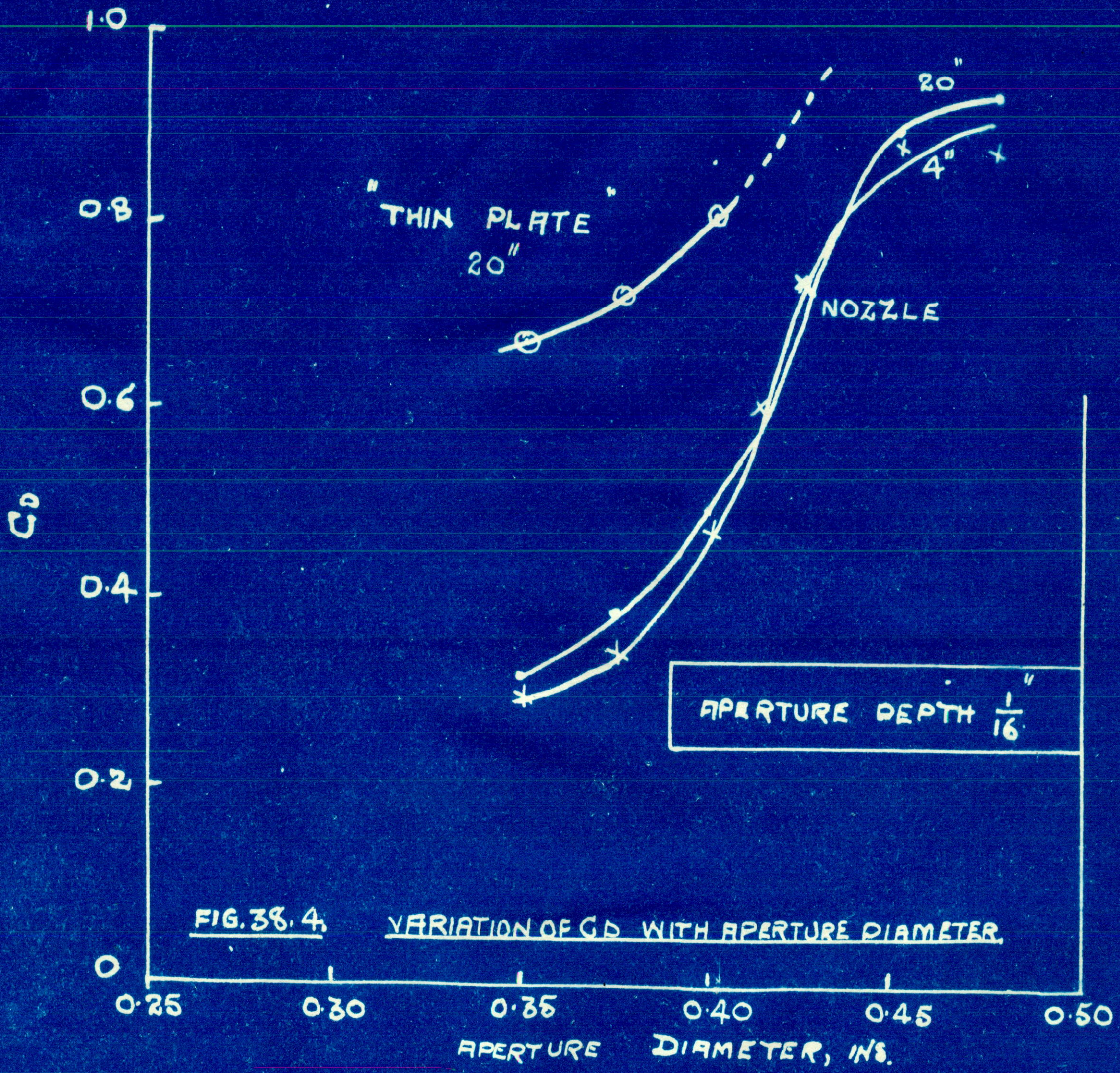


FIG. 38.4. VARIATION OF C_D WITH APERTURE DIAMETER.

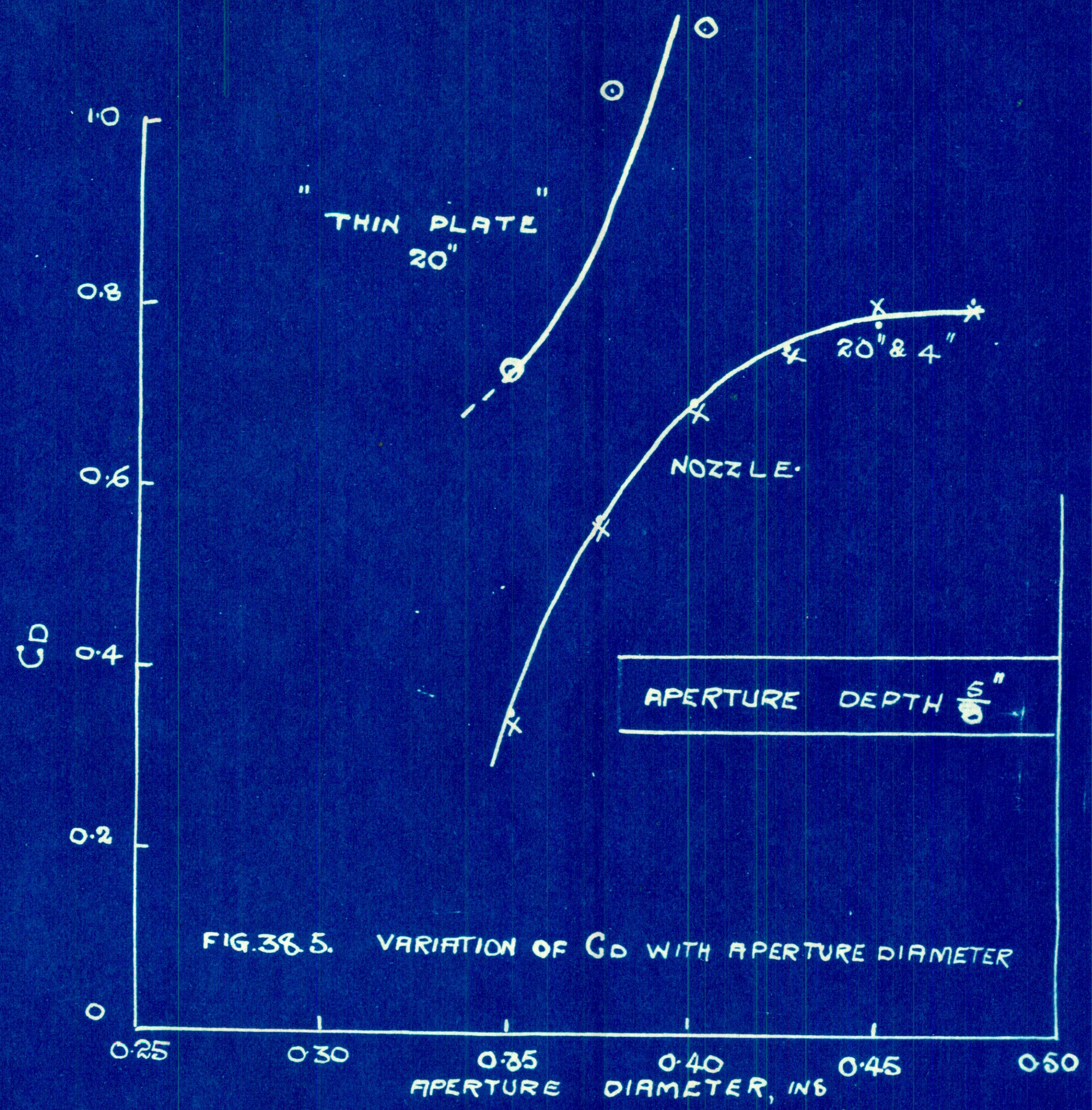


FIG. 38.5. VARIATION OF C_D WITH APERTURE DIAMETER

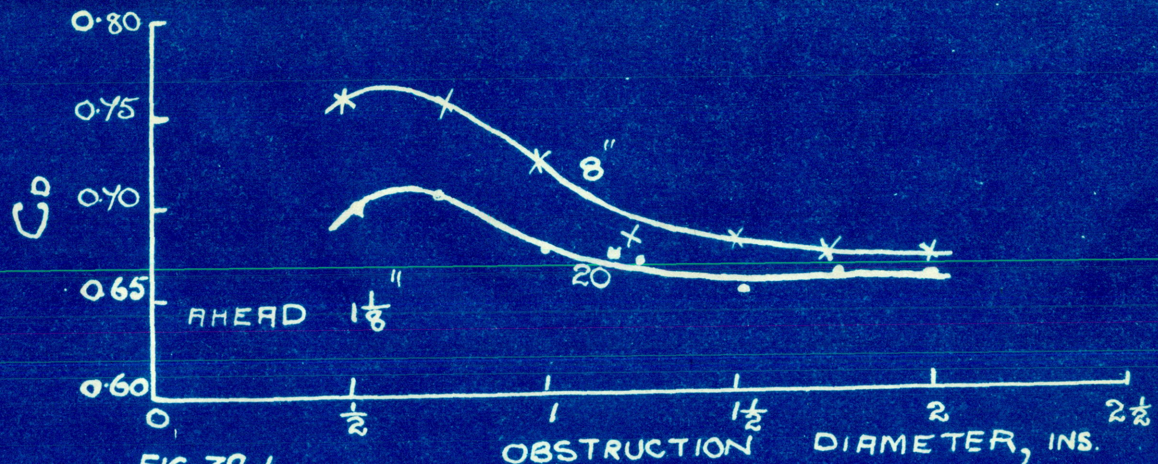


FIG. 39.1.

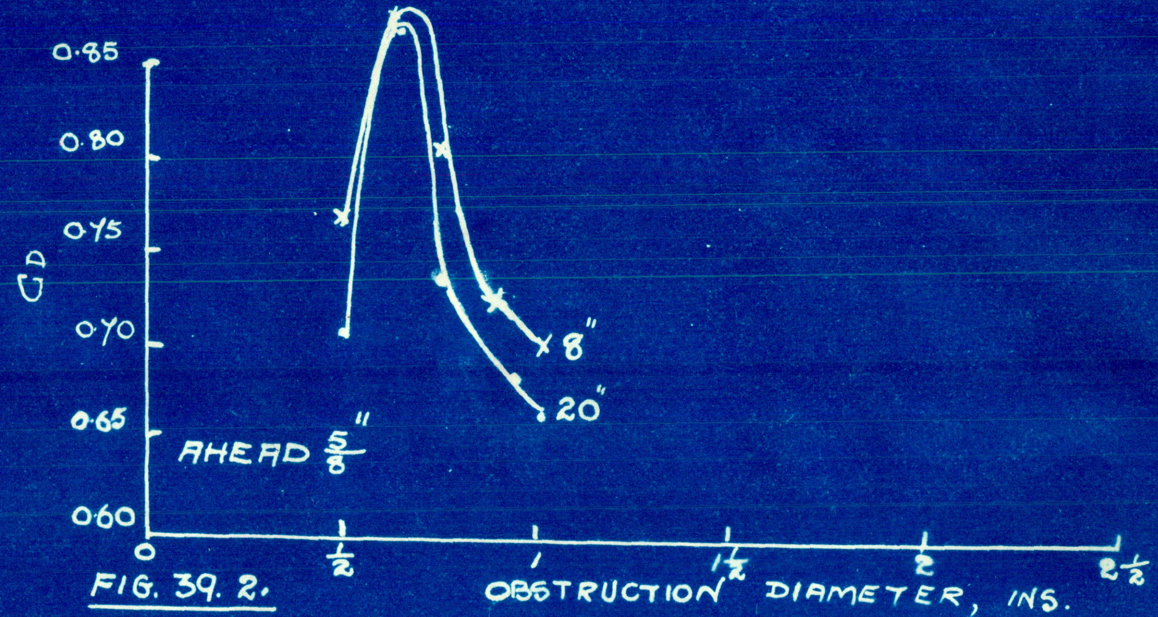


FIG. 39.2.

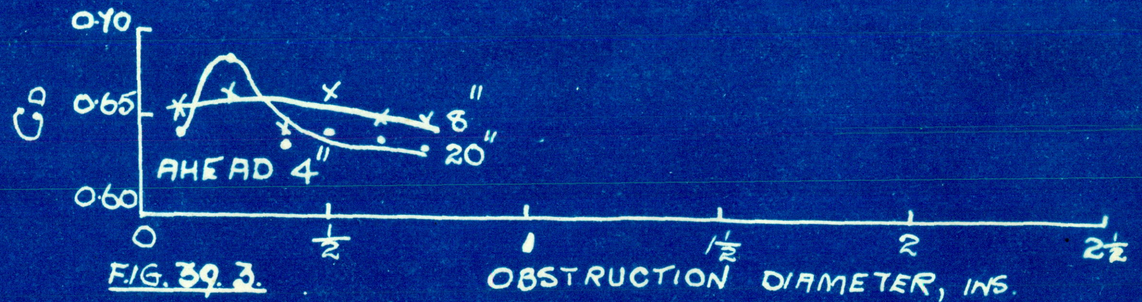


FIG. 39.3.

FIGS. 39. THE EFFECT ON C_D OF AN OBSTRUCTING ORIFICE IN THE APPROACH TO A PRE-CALIBRATED ORIFICE.

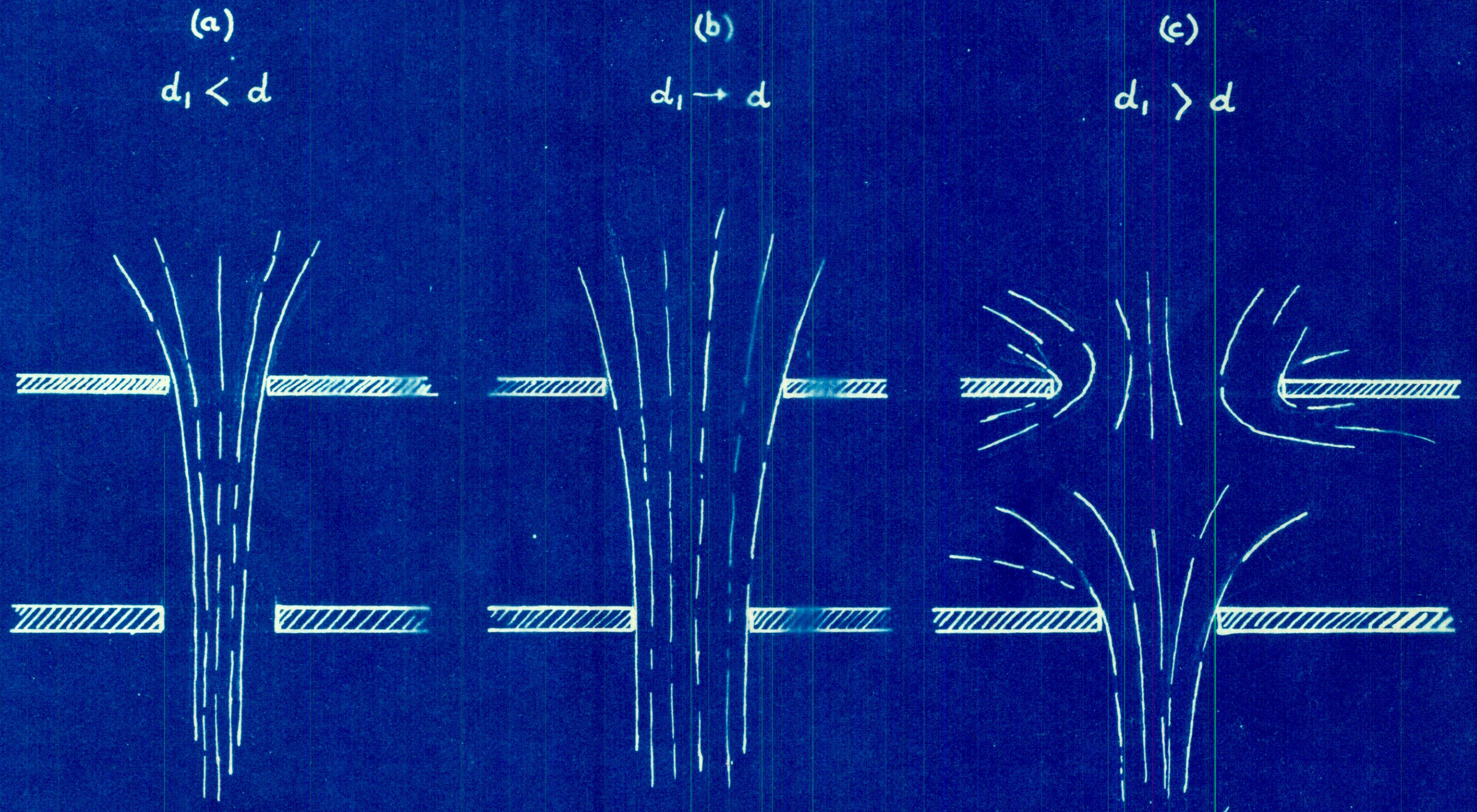


FIG. 39.4. JET THROUGH TWO ORIFICES IN SERIES.

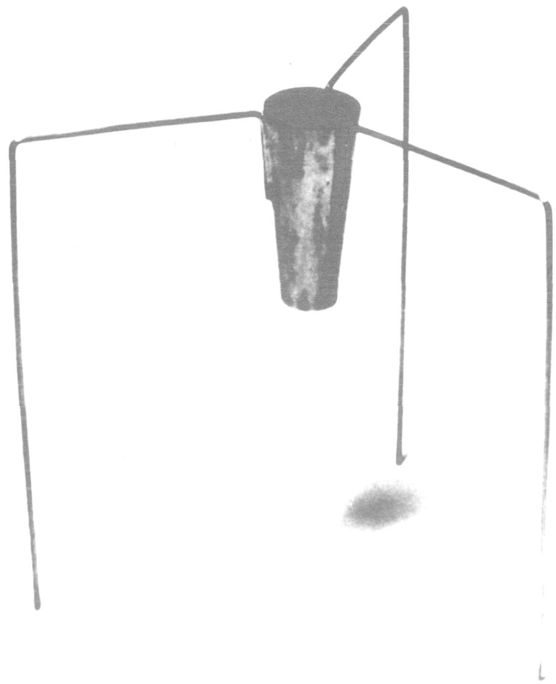


Fig.40.1. Cone mouted on wire legs for Experiment No.11.

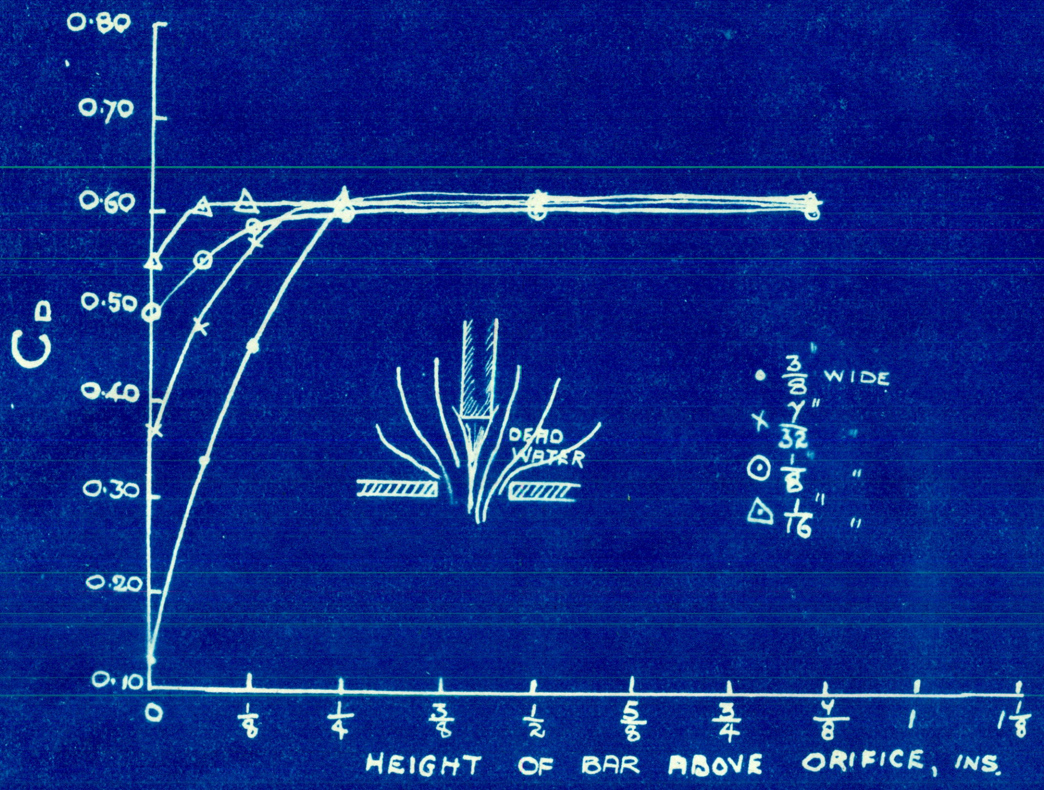


FIG. 41.1. EFFECT OF A BAR IN THE APPROACH TO AN ORIFICE.

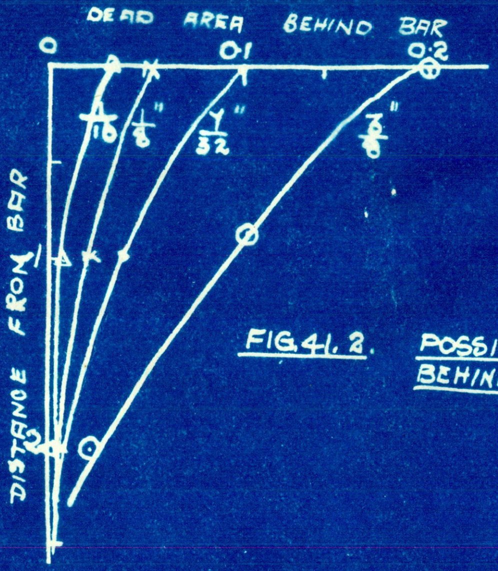


FIG. 41.2. POSSIBLE DEAD-WATER BEHIND BAR.

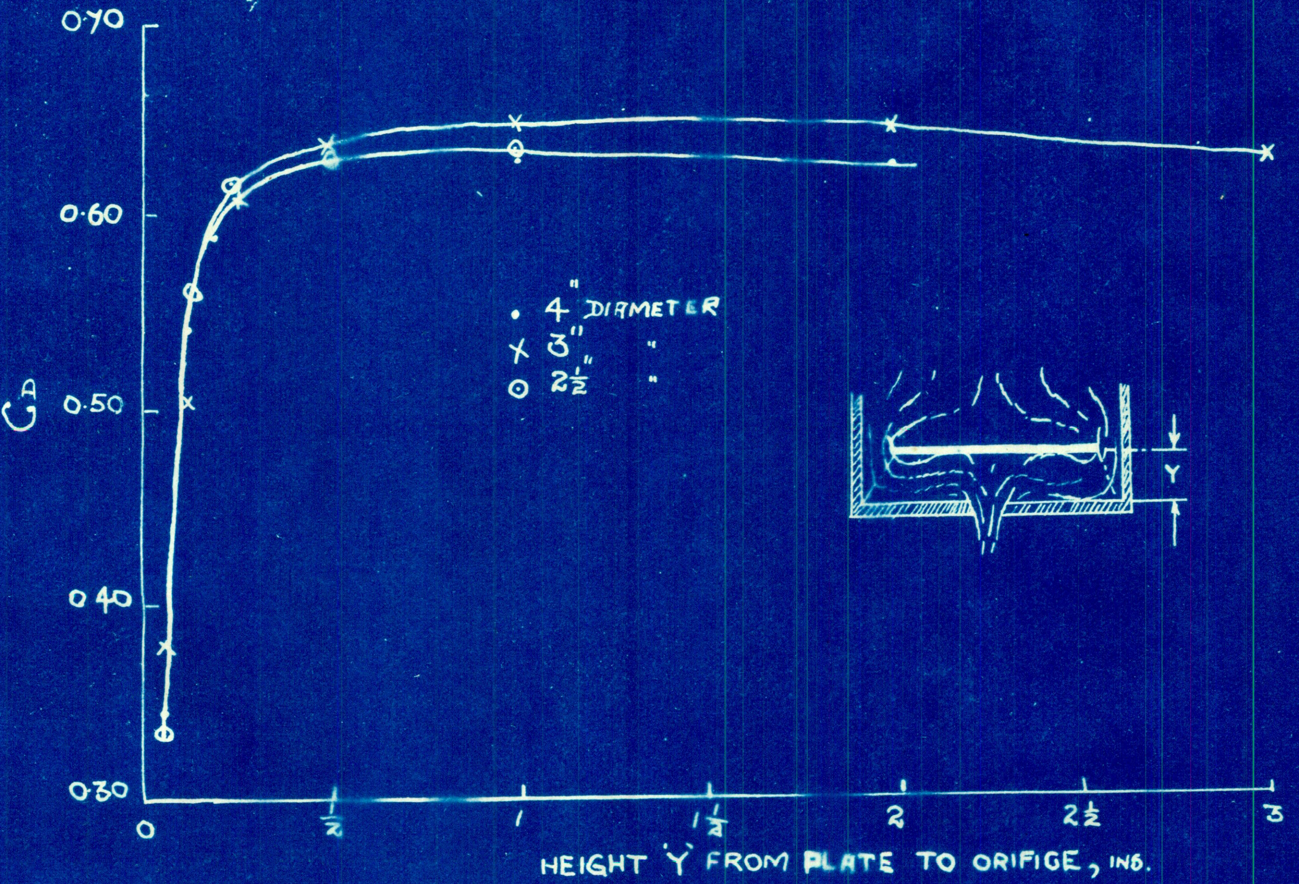


FIG. 421 EFFECT OF A DISC IN THE APPROACH TO AN ORIFICE.

APPENDIX I

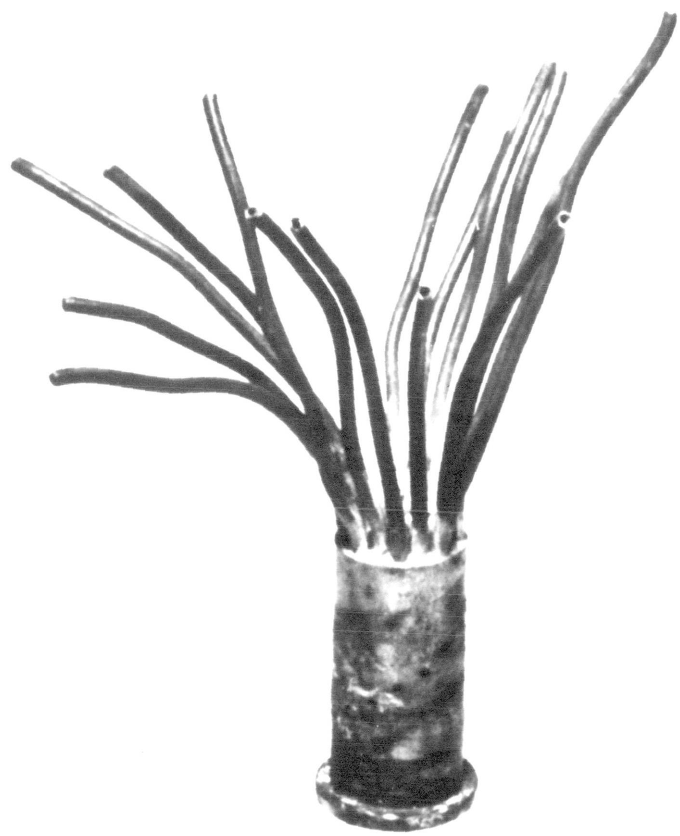


FIG. 43.1. NOZZLE WITH STATIC PRESSURE TAPS

APPENDIX NO. 1. -----RESULTS.

EXPERIMENT NO.I.

PURPOSE: "Determine the effect of length on the C_D of $\frac{1}{8}$", $\frac{1}{4}$", $\frac{1}{2}$" nozzles at various heads." Normal sharp-edged entry.

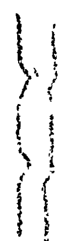
TEST No. 1/1

TIME OF FLOW 500 secs. ORIFICE DIAMETER $\frac{1}{8}$"

DISCHARGE cu.ft.

HEAD H INS.	LENGTH OF ORIFICE									
	$1\frac{1}{8}$"	1"	7/8"	$\frac{3}{4}$"	$\frac{5}{8}$"	$\frac{1}{2}$"	$\frac{3}{8}$"	$\frac{1}{4}$"	$\frac{1}{8}$"	
20	.347	.377	.358	.361	.347	.340	.360	.379	.310	
19	.343	.363	.349	.352	.340	.329	.350	.370	.307	
18	.335	.352	.340	.341	.323	.320	.340	.361	.290	
17	.326	.331	.330	.331	.318	.312	.335	.351	.286	
16	.313	.328	.319	.321	.307	.303	.319	.340	.276	
15	.304	.313	.310	.312	.298	.291	.315	.330	.270	
14	.289	.307	.301	.306	.281	.282	.302	.318	.261	
13	.283	.290	.287	.290	.275	.270	.290	.305	.252	
12	.277	.281	.277	.287	.262	.259	.280	.298	.245	
11	.265	.273	.265	.269	.250	.247	.264	.279	.233	
10	.251	.258	.251	.259	.235	.236	.250	.265	.224	
9	.240	.248	.243	.246	.226	.224	.237	.250	.214	
8	.227	.228	.228	.230	.218	.212	.228	.234	.203	
7	.212	.215	.211	.213	.201	.199	.210	.221	.194	
6	.203	.205	.200	.205	.188	.187	.194	.209	.183	
5	.185		.184	.	.175		.180		.175	
4	.169		.163	.	.162		.165		.161	
3	.155		.149							
2										
1										

OBSERVATIONS It was observed the jet for the $\frac{1}{8}$" long orifice was not round and cylindrical but was constricted by dimples shewn



R. A. COLLACOTT.

TEST No. 2/1

TIME OF FLOW **50 secs.** ORIFICE DIAMETER ¼"

DISCHARGE cu.ft.

HEAD H INS.	LENGTH OF ORIFICE									
	2⅛"	2"	1 7/8"	1¾"	1⅝"	1½"	1⅜"	1¼"	1⅛"	1"
20	.140	.139	.142	.140	.139	.140	.139	.	.145	
19	.138	.136	.137	.139	.139	.139	.138		.143	
18	.136	.134	.135	.136	.138	.138	.134		.140	
17	.130	.129	.131	.134	.137	.135	.133		.136	
16	.128	.127	.129	.130	.135	.132	.129		.130	
15	.125	.121	.121	.124	.130	.127	.125		.127	
14	.123	.118	.118	.120	.124	.123	.120		.124	
13	.115	.114	.116	.114	.119	.117	.115		.118	
12	.110	.113	.111	.110	.113	.112	.110		.112	
11	.109	.107	.107	.108	.109	.107	.106		.107	
10	.101	.101	.102	.104	.104	.104	.101		.102	
9	.098	.097	.099	.101	.102	.101	.096		.100	
8	.095	.093	.095	.097	.097	.097	.091		.096	
7	.090	.089	.090	.092	.090	.092	.086		.092	
6	.085	.085	.085	.085	.084	.084	.081		.088	
5			.079		.075	.	.077		.085	
4			.070		.070		.072		.076	
3			.065		.068		.064		.067	
2			.059		.058		.053		.054	
1			.051		.049		.046		.047	

R. A. COLLACOTT.

TEST NO. 2/1 (Contd.1)

TIME OF FLOW 50 secs. ORIFICE DIAMETER 1/4"

DISCHARGE cu.ft.

HEAD H INS.	LENGTH OF ORIFICE									
	7/8"	3/4"	5/8"	1/2"	3/8"	1/4"	1/8"			
20	.145	.149		.149		.148	.115			
19	.141	.143		.148		.147	.113			
18	.137	.141		.146		.145	.110			
17	.134	.138		.143		.143	.107			
16	.129	.136		.138		.138	.104			
15	.123	.131		.134		.134	.102			
14	.121	.127		.127		.126	.099			
13	.115	.121		.124		.120	.097			
12	.110	.116		.118		.117	.093			
11	.106	.110		.113		.113	.089			
10	.101	.106		.106		.106	.084			
9	.098	.101		.102		.102	.079			
8	.095	.095		.096		.095	.073			
7	.090	.090		.090		.090	.069			
6	.085	.085		.085		.083	.066			
5	.079	.079		.079		.075	.062			
4	.070	.070		.070		.067	.060			
3										
2										
1										

TEST No. 3/1

TIME OF FLOW 50secs. ORIFICE DIAMETER ½"

DISCHARGE cu.ft.

HEAD H INS.	LENGTH OF ORIFICE									
	4⅛"	4"	3⅞"	3¾"	3⅝"	3½"	3⅜"	3¼"	3⅛"	3"
20	.606	.600	.612	.634	.638	.620	.634	.640	.634	.640
19	.590	.596	.610	.616	.611	.596	.630	.623	.617	.611
18	.579	.586	.590	.611	.609	.576	.607	.612	.589	.609
17	.570	.572	.580	.600	.590	.568	.600	.595	.588	.595
16	.554	.548	.574	.583	.574	.559	.576	.587	.581	.584
15	.548	.539	.557	.566	.560	.544	.561	.564	.565	.559
14	.527	.522	.529	.551	.543	.525	.558	.541	.558	.541
13	.519	.519	.514	.537	.532	.511	.540	.529	.544	.528
12	.490	.502	.510	.515	.514	.500	.523	.523	.525	.512
11	.469	.470	.487	.496	.501	.481	.502	.494	.494	.497
10	.458	.456	.467	.482	.479	.468	.487	.481	.482	.471
9	.436	.441	.449	.457	.456	.444	.450	.462	.461	.456
8	.422	.418	.428	.435	.434	.431	.445	.449	.437	.449
7	.409	.405	.415	.424	.425	.397	.421	.427	.418	.427
6	.390	.383	.393	.408	.395	.382	.418	.389	.391	.391
5		.366	.385							
4		.340	.351							
3										
2										
1										

R. A. COLLACOTT.

TIME OF FLOW 50secs. ORIFICE DIAMETER $\frac{1}{2}$"

DISCHARGE cu.ft.

HEAD H INS.	LENGTH OF ORIFICE									
	$2\frac{7}{8}$"	$2\frac{3}{4}$"	$2\frac{5}{8}$"	$2\frac{1}{2}$"	$2\frac{3}{8}$"	$2\frac{1}{4}$"	$2\frac{1}{8}$"	2"	$1\frac{7}{8}$"	$1\frac{3}{4}$"
20	.640	.627	.634	.632	.634	.630	.621	.626	.637	.630
19	.619	.611	.619	.621	.612	.621	.616	.619	.615	.613
18	.611	.605	.599	.597	.605	.600	.608	.600	.597	.597
17	.600	.595	.585	.591	.592	.590	.599	.583	.588	.588
16	.587	.580	.566	.582	.589	.577	.590	.565	.579	.571
15	.574	.563	.564	.567	.569	.561	.567	.559	560	.567
14	.551	.548	.541	.555	.547	.542	.541	.531	.538	.542
13	.543	.522	.528	.529	.532	.529	.525	.522	.524	.517
12	.520	.507	.513	.512	.521	.520	.499	.514	.491	.506
11	.503	.498	.500	.503	.491	.490	.469	.483	.472	.491
10	.478	.471	.473	.484	.480	.479	.448	.464	.464	.470
9	.463	.451	.447	.467	.453	.460	.437	.450	.439	.453
8	.453	.422	.432	.438	.432	.439	.426	.423	.432	.419
7	.429	.417	.400	.416	.419	.421	.403	.406	.400	.395
6	.393	.389	.390	.389	.385	.389	.382	.395	.372	.380
5					.362					
4					.358					
3										
2										
1										

R. A. COLLACOTT.

TEST No. 3/1 (Contd 2)

TIME OF FLOW 50 secs. ORIFICE DIAMETER ½"

DISCHARGE cu.ft.

HEAD H INS.	LENGTH OF ORIFICE									
	1⅝"	1½"	1⅜"	1¼"	1⅛"	1"	7/8"	¾"	⅝"	½"
20	.626	.630	.626	.630	.631	.637	.639	.620	.605	.480
19	.614	.616	.615	.615	.620	.615	.617	.609	.472	.474
18	.603	.609	.580	.600	.602	.598	.590	.595	.450	.436
17	.591	.597	.577	.583	.580	.583	.581	.570	.448	.426
16	.564	.579	.569	.563	.571	.561	.551	.533	.420	.420
15	.557	.558	.557	.540	.550	.545	.547	.524	.400	.419
14	.530	.531	.532	.521	.540	.523	.534	.520	.370	.393
13	.516	.517	.516	.499	.508	.511	.509	.496	.360	.380
12	.495	.492	.501	.491	.487	.479	.499	.480	.354	.365
11	.479	.478	.477	.477	.479	.464	.471	.459	.336	.350
10	.471	.461	.459	.446	.460	.469	.442	.431	.310	.325
9	.443	.441	.440	.423	.440	.406	.437	.425	.307	.311
8	.400	.417	.420	.410	.420	.398	.402	.400	.300	.308
7	.397	.398	.396	.390	.384	.381	.390	.371	.284	.295
6	.361	.372	.367	.359	.347	.359	.360	.270	.262	.250
5									.248	
4									.220	
3									.210	
2									.182	
1									.140	

TEST No. 3/1 (Contd 3)

TIME OF FLOW 50secs. ORIFICE DIAMETER $\frac{1}{2}$"

DISCHARGE cu.ft.

HEAD H INS.	LENGTH OF ORIFICE									
	$\frac{3}{8}$"	$\frac{1}{4}$"	$\frac{1}{8}$"							
20	.476	.470	.490							
19	.469	.467	.470							
18	.440	.430	.447							
17	.431	.426	.439							
16	.428	.411	.430							
15	.422	.407	.419							
14	.393	.386	.400							
13	.381	.379	.377							
12	.378	.367	.363							
11	.350	.348	.359							
10	.327	.330	.328							
9	.323	.314	.311							
8	.291	.295	.300							
7	.280	.288	.287							
6	.260	.260	.265							
5										
4										
3										
2										
1										

OBSERVATIONS:- i. At L = $\frac{3}{4}$" it was observed that the flow was very translucent at H = 6 ins.

ii. At L = $\frac{5}{8}$" the jet was very smooth at H = 6 ins and H = 5 ins but at lower heads the "standing waves" made the jet less clear.

iii. At L = $\frac{1}{2}$" and $\frac{3}{8}$" the jet tended to rotate spasmodically in a clockwise direction at all heads, but with less violence as the head decreased.

R. A. COLLACOTT.

EXPERIMENT No. 2.

PURPOSE: "Determine the effect of head on C_D for orifices of 0.050" & 0.030" "bore".

TEST No. 1/2 & 2/2

TIME OF FLOW 60 mins = 3600 secs.

ORIFICE DIAMETER Test 1/2 — $\frac{50}{1000}$ ins

Test 2/2 — $\frac{30}{1000}$ ins

DISCHARGE cu.ft.

HEAD H INS.	1/2	2/2								
20	.406	.140								
19										
18	.372	.131								
17										
16	.346	.129								
15										
14	.335	.119								
13										
12	.303	.108								
11										
10	.278	.099*								
9										
8	.250									
7										
6	.217									
5										
4	.175									
3										
2										
1										

OBSERVATIONS:- The jet from the orifice 1/2 ($\frac{50}{1000}$ ins diameter) is about 3 - 4 ins long before breaking-up into drops.

* Discharge at lower heads too small for accurate measurement.

R. A. COLLACOTT.

EXPERIMENT No. 3.

PURPOSE: "Re-entrant Nozzles. Determine the effect of length on the C_D of $\frac{1}{4}$" & $\frac{1}{2}$" nozzles at various heads.

TEST NO. 1/3

TIME OF FLOW 50 secs. ORIFICE DIAMETER OUTSIDE / INSIDE ¼"

DISCHARGE cu.ft.

HEAD H INS.	LENGTH									
	2⅛"	2"	1 7/8"	1¾"	1⅝"	1½"	1⅜"	1¼"	1⅛"	1"
20	.136	.151	.140			.150	.150			
19	.134	.149	.139	.159	.140	.145			.143	
18	.131	.148	.135				.140		.133	
17	.129	.143	.129	.145	.129	.140				
16	.125	.136	.128				.132		.129	
15	.120	.130	.122	.139	.125	.130	.128			
14	.113	.125	.119							
13	.109	.121	.116	.125	.117	.120	.120		.117	
12	.107	.119	.111							
11	.102	.114	.107	.119	.106	.107	.109		.104	
10	.096	.107	.102							
9	.094	.101	.098	.099	.098	.098				
8	.087	.096	.096				.093		.090	
7	.082	.085		.081	.081	.081	.083		.081	
6		.079								
5				.072		.074				
4				.064		.066				
3				.057		.059				
2				.046		.050				
1										

OBSERVATIONS: (1) To determine head over base of nozzle ADD ⅛" to 'H'
(2) To determine head over inlet to nozzle SUBTRACT length of nozzle from head given by (1)
(3) The following values additional to those above were obtained for the 2" long nozzle to study the viscous flow:-

H	5	4½	4	3½	3	2½	2¼	2⅛	2 1/16	2 1/32	2
Discharge 50 secs.	.075	.067	.065	.062	.058	.053	.049	.045	.044	.044	.040

R. A. COLLACOTT.

TEST No. 1/3 (Contd 1)

TIME OF FLOW 50 secs.

OUTSIDE
ORIFICE DIAMETER
INSIDE ¼"

DISCHARGE cu.ft.

HEAD H INS.	LENGTH									
	7/8"	3/4"	5/8"	½"						
20		.150		.147						
19		.145		.142						
18										
17										
16										
15		.124		.120						
14										
13		.114		.110						
12										
11		.101		.097						
10										
9										
8		.091		.091						
7										
6										
5										
4		.061		.067						
3										
2										
1										

R. A. COLLACOTT.

TEST No. 2/3

TIME OF FLOW 50 secs. ORIFICE DIAMETER OUTSIDE

INSIDE ½ ins.

DISCHARGE cu.ft.

HEAD H INS.	LENGTH									
	4⅛"	4"	3 7/8"	3¾"	3⅝"	3½"	3⅜"	3¼"	3⅛"	3"
20	.570	.560	.575	.583	.588	.552	.580	.598	.586	.580
19	.556	.556	.569	.569	.570	.544	.571	.583	.577	.579
18	.538	.527	.549	.557	.558	.531	.561	.569	.563	.566
17	.521	.518	.531	.546	.542	.514	.554	.548	.549	.541
16	.503	.504	.518	.533	.521	.506	.538	.539	.541	.522
15	.489	.490	.487	.514	.507	.485	.511	.522	.512	.510
14	.468	.466	.479	.499	.496	.463	.487	.489	.500	.489
13	.459	.450	.469	.478	.476	.459	.468	.478	.482	.478
12	.440	.439	.441	.455	.461	.428	.455	.460	.457	.457
11	.414	.411	.428	.436	.428	.406	.433	.449	.441	.435
10	.395	.400	.403	.425	.414	.395	.402	.418	.409	.411
9	.382	.374	.383	.399	.389	.377	.391	.398	.396	.398
8	.354	.361	.367	.367	.365	.353	.376	.377	.373	.367
7	.336	.319	.342	.350	.342	.326	.346	.363	.361	.350
6	.318	.300			.323					
5	.284	.296			.293					
4		.205			.262					
3										
2										
1										

OBSERVATIONS:- 1) The following additional values were taken

4⅛" long

H	6½	5½
Q	.320	.294

4" long

6½	5½
.307	.297

R. A. COLLACOTT.

TEST No. 2/3 (Contd 1)

TIME OF FLOW 50 secs. ORIFICE DIAMETER OUTSIDE / INSIDE $\frac{1}{2}$ ins

DISCHARGE cu.ft.

HEAD H INS.	LENGTH									
	$2\frac{7}{8}$"	$2\frac{3}{4}$"	$2\frac{5}{8}$"	$2\frac{1}{2}$"	$2\frac{3}{8}$"	$2\frac{1}{4}$"	$2\frac{1}{8}$"	2"	$1\frac{7}{8}$"	$1\frac{3}{4}$"
20	.567	.576	.592	.599	.608	.596	.592	.590	.596	.604
19	.564	.575	.583	.581	.598	.578	.571	.577	.577	.586
18	.562	.560	.559	.562	.584	.563	.560	.560	.563	.575
17	.538	.543	.541	.541	.553	.552	.554	.555	.552	.553
16	.525	.530	.539	.535	.546	.535	.522	.533	.532	.544
15	.503	.508	.533	.521	.544	.515	.517	.511	.511	.528
14	.477	.494	.502	.497	.514	.509	.506	.500	.501	.497
13	.460	.477	.474	.480	.500	.486	.475	.483	.489	.480
12	.445	.450	.451	.471	.475	.471	.471	.474	.471	.463
11	.428	.435	.427	.455	.451	.453	.446	.442	.442	.450
10	.410	.420	.418	.428	.444	.427	.420	.427	.419	.426
9	.381	.393	.400	.400	.423	.408	.400	.391	.398	.393
8	.363	.367	.378	.387	.376	.378	.372	.379	.360	.375
7	.342	.341	.356	.358	.365	.357	.369	.358	.353	.348
6										
5										
4										
3										
2										
1										

R. A. COLLACOTT.

TEST No. 2/3 (Contd 2

TIME OF FLOW 50 secs. ORIFICE DIAMETER OUTSIDE / INSIDE ½"

DISCHARGE cu.ft.

HEAD H INS.	LENGTH									
	1⅝"	1½"	1⅜"	1¼"	1⅛"	1"	7/8"	¾"	⅝"	½"
20	.605	.611	.603	.610	.610	.600	.610	.599	.600	.490
19	.593	.596								
18	.587	.590	.574	.580	.580	.560	.580	.580	.584	.420
17	.562	.571								
16	.541	.550	.531	.541	.530	.529	.543	.541	.540	.409
15	.529	.530								
14	.509	.506	.500	.530	.510	.500	.521	.519	.500	.371
13	.488	.498								
12	.470	.486	.447	.481	.462	.458	.463	.460	.458	.353
11	.442	.444								
10	.429	.428	.424	.429	.423	.411	.4[illegible]0	.426	.427	.324
9	.400	.403								
8	.379	.384	.367	.380	.380	.370	.399	.300	.301	.289
7	.355	.354	.340	.358	.359	.359	.300			.281
6										
5										
4										
3										
2										
1										

R. A. COLLACOTT.

TEST No. 2/2 (Contd 3)

TIME OF FLOW 50 secs. ORIFICE DIAMETER OUTSIDE INSIDE ½ ins.

DISCHARGE cu.ft.

HEAD H INS.	LENGTH									
	3/8"	1/4"								
20	.470	.470								
19										
18	.444	.440								
17										
16	.418	.411								
15										
14	.400	.398								
13										
12	.360	.363								
11										
10	.330	.325								
9										
8	.300	.293								
7	.272	.268								
6										
5										
4										
3										
2										
1										

R. A. COLLACOTT.

EXPERIMENT No. 4.

PURPOSE: "Re-entrant Nozzles. Determine the effect of outside diameter on the C_D ofa 4" long nozzle, $\frac{1}{2}$" bore".

TEST No. 1/4

TIME OF FLOW 50 secs. ORIFICE DIAMETER ½ ins.

DISCHARGE cu. ft.

HEAD H INS.	OUTSIDE DIAMETER									
	4"	3"	2"	1"						
20	.556	.560	.560	.560						
19										
18	.538		.538							
17										
16	.512	.498	.500	.500						
15										
14	.476		.480							
13										
12	.448	.440	.440	.440						
11										
10	.396									
9										
8	.360	.350	.350	.350						
7										
6	.308	.298	.306	.304						
5	.234									
4										
3										
2										
1										

R. A. COLLACOTT.

EXPERIMENT No. 5.

PURPOSE: "Determine the effect of bevelling the inlet on the C_D of a $\frac{1}{2}$" bore nozzle $2\frac{1}{8}$" long and of an orifice $\frac{1}{2}$" bore $\frac{1}{8}$" thick."

TEST No. 1/5

TIME OF FLOW 25 secs.

ORIFICE LENGTH $2\frac{1}{8}$"

DISCHARGE cu. ft. DIAMETER $\frac{1}{2}$"

HEAD H INS.	HALF INCLUDED ANGLE OF BEVEL									
	15°	30°	45°	60°	75°					
20	.301	.321	.351	.348	.339					
19										
18	.298	.305	.	.320						
17										
16	.276	.289	.312	.309	.308					
15										
14	.266	.273	.	.290						
13										
12	.249	.254	.277	.265	.273					
11										
10	.232	.236	.	.248						
9										
8	.205	.219	.230	.226	.230					
7										
6	.187	.189	.	.204						
5										
4	.162	.163	.175	.180	.182					
3										
2										
1										

OBSERVATIONS: Cone of champfer forms a circle $\frac{9}{16}$" diameter on inlet face.

R. A. COLLACOTT.

TEST No. 2/5

TIME OF FLOW 50 secs.

ORIFICE LENGTH $\frac{1}{8}$"

DIAMETER $\frac{1}{2}$"

DISCHARGE cu. ft.

HEAD H INS.	HALF INCLUDED ANGLE OF BEVEL									
	15°	30°	45°	60°	75°					
20	.580	.610	.567	.506	.470					
19	.559	.595	.530	.480	.458					
18	.553	.586	.517	.479	.451					
17	.544	.565	.509	.459	.449					
16	.522	.559	.496	.451	.438					
15	.501	.537	.474	.431	.423					
14	.491	.513	.461	.420	.391					
13	.468	.508	.446	.411	.386					
12	.453	.482	.431	.391	.375					
11	.440	.470	.423	.371	.369					
10	.423	.455	.394	.352	.343					
9	.415	.431	.374	.329	.321					
8	.388	.400	.351	.316	.310					
7	.372	.383	.334	[illegible]	.297					
6	.345	.351	[illegible]	[illegible]	.290					
5										
4										
3										
2										
1										

OBSERVATIONS: Cone of champfer forms a circle $\frac{9"}{16}$ diameter on inlet face.

R. A. COLLACOTT.

EXPERIMENT No. 6.

PURPOSE. "Determine the effect of depth of bevel on the C_D of $\frac{1}{2}$" bore nozzle $2\frac{1}{8}$" long and an orifice $\frac{1}{8}$" thick."

TEST No. 1/6

TIME OF FLOW 25 secs.

ORIFICE LENGTH $2\frac{1}{8}$"

DIAMETER $\frac{1}{2}$"

DISCHARGE cu. ft.

HEAD H INS.	CIRCLE AT INLET DIAMETER INCHES Half Angle 45°									
	9/16	5/8	3/4							
20	.340	.351	.348							
19										
18										
17										
16	.313	.312	.312							
15										
14										
13										
12	.271	.277	.276							
11										
10										
9										
8	.225	.230	.230							
7										
6										
5										
4	.170	.175	.175							
3										
2										
1										

R. A. COLLACOTT.

TEST No. 2/6

TIME OF FLOW 50 secs.

ORIFICE LENGTH 1/8"

DIAMETER 1/2"

DISCHARGE cu. ft.

HEAD H INS.	CIRCLE AT INLET. DIAMETER INCHES Half Angle 45°					Half Angle 60°				
	9/16	5/8	11/16	3/4		9/16	5/8	11/16	3/4	
20	.562	.547	.560	.558		.520	.495	.503	.499	
19	.534	.528	.530	.529		.497	.483	.486	.484	
18	.518	.514	.521	.517		.489	.472	.478	.474	
17	.513	.508	.513	.506		.460	.460	.455	.459	
16	.502	.485	.501	.500		.455	.449	.447	.450	
15	.488	.469	.471	.470		.429	.433	.431	.433	
14	.465	.459	.459	.461		.422	.420	.419	.420	
13	.451	.442	.446	.446		.408	.409	.408	.407	
12	.437	.423	.435	.433		.382	.397	.396	.389	
11	.429	.419	.423	.422		.373	.370	.370	.370	
10	.404	.388	.391	.392		.347	.359	.349	.352	
9	.390	.363	.375	.377		.331	.328	.330	.330	
8	.368	.347	.350	.352		.316	.317	.316	.316	
7	.341	.329	.331	.335		.294	.300	.301	.301	
6	.327	.318	.323	.326		.287	.288	.288	.286	
5										
4										
3										
2										
1										

R. A. COLLACOTT.

EXPERIMENT No. 7.

PURPOSE. "Determine the influence of proximity on the discharge through four orifices spaced in a square."

FOUR(4) ORIFICES AT CORNER OF SQUARE

TIME OF FLOW 100 secs.

ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft. (AGGREGATE DIAMETER 1/4")

HEAD H INS.	DISTANCE BETWEEN HOLES									
	3/16"	1/4"	5/16"	3/8"						
20	.225	.224	.222	.228						
19										
18										
17										
16	.205	.205	.202	.207						
15										
14										
13										
12	.189	.186	.178	.179						
11										
10										
9										
8	.152	.151	.149	.150						
7										
6										
5										
4	.110	.120	.115	.115						
3										
2										
1										

OBSERVATIONS: Jets from the 3/16" and 1/4" nozzles joined when water dribbled between them. Separate columns of fluid issued from the other sets of nozzles.

R. A. COLLACOTT.

EXPERIMENT No. 8.

PURPOSE: "Determine the characteristics of the flow through an orifice $\frac{1}{2}$" Diameter $\frac{1}{8}$" thick with an obstructing Aperature of varying diameter and thickness in the outlet."

TEST No. 1/8

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft. APERTURE-ORIFICE THICKNESS 0.020"

HEAD H INS.	APERTURE DIAMETER									
	.250	.270	.290	.310	.330	.350	.370	.390	.410	.430
20	.055	.0675	.0775	.090	.110	.128	.155	.190	.220	.243
19	.054	.067								
18										
17										
16	.031	.063	.070	.085	.100	.118	.139	.172	.194	.227
15										
14	.049		.066							
13										
12	.045	.052	.060	.071	.086	.100	.124	.150	.173	.190
11										
10	.0415									
9										
8	.0370	.045	.052	.0615	.071	.086	.100	.115	.139	.160
7										
6	.0340									
5										
4	.028	.034	.037	.045	.052	.060	.070	.086	.095	.118
3										
2	.020									
1										

R. A. COLLACOTT.

TEST No. 1/8 (Contd)

TIME OF FLOW 25 secs

ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft. APERTURE-ORIFICE THICKNESS 0.020"

HEAD H INS.	APERTURE DIAMETER									
	.450	.470	.490	.500						
20	.228	.221	.225	.226						
19										
18										
17										
16	.197	.201	.201	.200						
15										
14										
13										
12	.173	.176	.177	.176						
11										
10										
9										
8	.144	.152	.149	.148						
7										
6										
5										
4	.109	.110	.110	.110						
3										
2										
1										

TEST No. 2/8

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft. APERTURE-ORIFICE THICKNESS 0.040"

HEAD H INS.	APERTURE DIAMETER									
	.250	.270	.290	.310	.330	.350	.370	.390	.410	.430
20	.0575	.0675	.080	.087	.110	.126	.153	.177	.220	.246
19	.0573									
18										
17										
16	.0525	.0605	.069	.080	.102	.113	.138	.170	.198	.225
15										
14										
13										
12	.0465	.053	.061	.069	.082	.098	.116	.145	.165	.193
11										
10										
9										
8	.0385	.0425	.050	.055	.070	.085	.097	.118	.143	.160
7										
6										
5										
4	.029	.033	.0435	.0455	.052	.060	.073	.083	.098	.112
3										
2										
1										

R. A. COLLACOTT.

TEST No. 2/8 (Contd)

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft. APERATURE-ORIFICE THICKNESS 0.040"

HEAD H INS.	APERTURE DIAMETER									
	.450	.470	.490	.500						
20	.275	.225	.226	.226						
19										
18										
17										
16	.240	.196	.201	.200						
15										
14										
13										
12	.175	.176	.178	.178						
11										
10										
9										
8	.145	.146	.149	.148						
7										
6										
5										
4	.109	.109	.110	.111						
3										
2										
1										

R. A. COLLACOTT.

TEST No.3/8

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft. APERATURE-ORIFICE THICKNESS 0.060"

HEAD H INS.	APERTURE DIAMETER									
	.400	.410	.420	.430	.440	.450	.460	.470	.480	.490
20	.188	.211	.240	.251	.260	.276	.225	.222	.225	.223
19										
18		.209							.215	
17										
16	.175	.202	.217	.226	.244	.200	.209	.206	.205	.206
15										
14		.190								
13										
12	.155	.169	.190	.197	.211	.175	.180	.180	.180	.181
11										
10		.158								
9										
8	.131	.134	.153	.163	.171	.145	.148	.151	.150	.149
7										
6	.111	.120	.131	.137	.145	.130	.1 30	.130	.128	.129
5										
4										
3										
2										
1										

R. A. COLLACOTT.

TEST No. 3/8(Contd)

TIME OF FLOW 25 secs

ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft. APERTURE-ORIFICE THICKNESS 0.060"

HEAD H INS.	APERTURE DIAMETER									
	.500									
20	.224									
19										
18										
17										
16	.206									
15										
14										
13										
12	.180									
11										
10										
9										
8	.149									
7										
6	.129									
5										
4										
3										
2										
1										

TEST No. 4/8

TIME OF FLOW 25 secs. ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft. APERTURE-ORIFICE THICKNESS 0.080"

HEAD H INS.	APERTURE DIAMETER									
	.400	.410	.420	.430	.440	.450	.460	.470	.480	.490
20	.169	.165	.200	.229	.256	.280	.288	.235	.230	.229
19										
18										
17										
16	.150	.160	.178	.210	.231	.235	.247	.209	.209	.208
15										
14										
13										
12	.130	.140	.162	.179	.205	.209	.220	.181	.180	.181
11										
10										
9										
8	.103	.116	.135	.159	.162	.173	.185	.152	.152	.152
7										
6	.091	.100	.111	.135	.140	.149	.136	.135	.135	.136
5										
4										
3										
2										
1										

R. A. COLLACOTT.

TEST NO. 4/8(Contd)

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft. APERTURE-ORIFICE THICKNESS 0.080"

HEAD H INS.	APERTURE DIAMETER									
	.500									
20	.230									
19										
18										
17										
16	.209									
15										
14										
13										
12	.181									
11										
10										
9										
8	.151									
7										
6	.135									
5										
4										
3										
2										
1										

TEST No. 5/8

TIME OF FLOW secs.

ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft. APERTURE-ORIFICE THICKNESS 0.100"

HEAD H INS.	APERTURE DIAMETER									
	.400	.410	.420	.430	.440	.450	.460	.470	.480	.490
20	.155	.160	.175	.196	.206	.235	.255	.228	.230	.229
19		.	.172							
18	.150		.171							
17			.169							
16	.139	.151	.160	.174	.195	.211	.235	.200	.203	.202
15			.156							
14			.153							
13										
12	.121	.129	.137	.151	.164	.189	.196	.177	.173	.173
11										
10	.110		.130							
9										
8	.098	.105	.118	.129	.135	.152	.158	.146	.145	.145
7										
6	.085	.092	.100	.111	.125	.135	.150	.124	.122	.121
5										
4										
3										
2										
1										

R. A. COLLACOTT.

TEST No. 5/8(Contd)

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"

DISCHARGE cu ft. APERTURE-ORIFICE THICKNESS 0.100"

HEAD H INS.	APERTURE DIAMETER									
	.500									
20	.228									
19										
18										
17										
16	.203									
15										
14										
13										
12	.174									
11										
10										
9										
8	.146									
7										
6	.122									
5										
4										
3										
2										
1										

R. A. COLLACOTT.

EXPERIMENT No. 9.

PURPOSE. "Determine the characteristics of the flow through a nozzle ½" diameter 2⅛" long with an obstructing aperture 0.050" thick but of varying diameter at various positions about the vena-contractor."

TEST No. 1/9

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"

DISCHARGE cu.ft. APERTURE DEPTH FROM INLET 1/4"

HEAD H INS.	APERTURE DIAMETER									
	.250 x	.300 x	.350 x	.375	.400	.425	.450	.475		
20	.062	.0905	.140	.236	.283	.300	.309	.312		
19										
18	.056	.086					.301			
17										
16	.0535	.082	.1295	.212	.196	.270	.280	.283		
15										
14		.079					.269			
13										
12	.0465	.0725	.114	.190	.164	.233	.251	.256		
11										
10	.042	.067				.221				
9										
8	.038	.060	.0945	.161	.140	.201	.211	.211		
7										
6		.054					.189			
5										
4	.030	.0445	.066	.117	.130	.152	.160	.161		
3										
2										
1										

OBSERVATIONS: x The flow for aperture diameter 0.250, 0.300, 0.350 ins. was so small that it was measured for a period of 50 secs. and the reading halves.

R. A. COLLACOTT.

TEST No. 2/9

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft. APERTURE DEPTH FROM INLET 3/8"

HEAD H INS.	APERTURE DIAMETER									
	.350	.375	.400	.425	.450	.475				
20	.141	.240	.270	.297	.298	.300				
19										
18										
17										
16	.129	.216	.247	.256	.271	.272				
15										
14										
13										
12	.110	.191	.214	.222	.237	.239				
11										
10										
9										
8	.095 x	.161	.179	.191	.200	.202				
7										
6										
5										
4	.068 x	.118	.133	.142	.155	.157				
3										
2										
1										

OBSERVATIONS: For heads of 8" and 4" with aperture diameter 0.350 the flow was obtained over 50 seconds and the reading halved.

R. A. COLLACOTT.

TEST No. 3/9

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft. APERTURE DEPTH FROM INLET 1/2"

HEAD H INS.	APERTURE DIAMETER									
	.350 x	.375	.400	.425	.450	.475	.			
20	.1345	.221	.253	.269	.294	.293				
19										
18										
17										
16	.120	.202	.234	.239	.269	.271				
15										
14										
13										
12	.105	.177	.203	.211	.235	.239				
11										
10										
9										
8	.091	.149	.168	.189	.193	.203				
7										
6										
5										
4	.065	.110	.132	.138	.147	.160				
3										
2										
1										

OBSERVATIONS: All readings for the 0.350 ins. aperture diameter were taken over 50 seconds and then halved.

R. A. COLLACOTT.

TEST No. 4/9

TIME OF FLOW 25 secs. ORIFICE DIAMETER ½"
APERTURE DEPTH FROM INLET 1/16"

DISCHARGE cu.ft.

HEAD H INS.	APERTURE DIAMETER									
	.350	.375	.400	.425	.450	.475				
20	.117	.141	.181	.262	.326	.340				
19										
18										
17										
16	.105	.127	.166	.238	.285	.299				
15										
14										
13										
12	.094	.113	.131	.209	.252	.271				
11										
10										
9										
8	.079	.095	.121	.178	.212	.230				
7										
6										
5										
4	.058	.066	.091	.142	.170	.168				
3										
2										
1										

R. A. COLLACOTT.

TEST No. 5/9

TIME OF FLOW 25 secs. ORIFICE DIAMETER ½"

DISCHARGE cu.ft.

APERTURE DEPTH FROM INLET 5/8"

HEAD H INS.	APERTURE DIAMETER									
	.350	.375	.400	.425	.450	.475				
20	.129	.210	.255	.281	.290	.300				
19										
18										
17										
16	.115	.191	.234	.252	.256	.271				
15										
14										
13										
12	.103	.167	.208	.224	.229	.240				
11										
10										
9										
8	.088	.141	.174	.190	.189	.200				
7										
6										
5										
4	.063	.109	.135	.146	.158	.158				
3										
2										
1										

R. A. COLLACOTT.

EXPERIMENT No. 10.

PURPOSE. "Determine the effect on the C_D of flow through a pre-calibrated $\frac{1}{2}$" diameter $\frac{1}{8}$" thick orifice with an obstructing orifice of variable diameter at various distances from the pre-calibrated orifice."

TEST No. 1/10

TIME OF FLOW 25 secs.

ORIFICE DIAMETER $\frac{1}{2}$"

DISCHARGE cu. ft. OBSTRUCTION. DISTANCE AHEAD $1\frac{1}{8}$"

HEAD H INS.	OBSTRUCTING ORIFICE DIAMETER									
	$\frac{1}{2}$"	$\frac{3}{4}$"	1"	$1\frac{1}{4}$"	$1\frac{1}{2}$"	$1\frac{3}{4}$"	2"			
20	.245	.249	.238	.236	.231	.233	.233			
19										
18	.244									
17										
16	.233	.223	.213	.213	.208	.210	.210			
15										
14	.220	.219								
13										
12	.192	.193	.190	.184	.184	.183	.181			
11										
10	.181									
9										
8	.170	.170	.162	.153	.153	.152	.151			
7										
6	.145									
5										
4			.113	.111	.113	.111	.112			
3										
2										
1										

OBSERVATIONS: The jet obtained with the obstructing orifice $\frac{1}{2}$" diameter was very "ragged" at all heads.

R. A. COLLACOTT.

TEST No. 2/10

TIME OF FLOW 25 secs. ORIFICE DIAMETER $\frac{1}{2}$"
DISCHARGE cu. ft. Obstruction. DISTANCE AHEAD $\frac{5}{8}$"

HEAD H INS.	OBSTRUCTING ORIFICE DIAMETER									
	$\frac{1}{2}$"	$\frac{5}{8}$"	$\frac{3}{4}$"	$\frac{7}{8}$"	1"					
20	.249	.306	.260	.245	.235					
19										
18	.240									
17										
16	.226	.275	.240	.220	.213					
15										
14	.213									
13										
12	.203	.241	.211	.195	.180					
11										
10										
9										
8	.170	.195	.180	.163	.157					
7										
6	.151									
5										
4	.094	.137	.130	.120	.119					
3										
2										
1										

R. A. COLLACOTT.

TEST No. 3/10

TIME OF FLOW 25 secs.

ORIFICE DIAMETER $\frac{1}{2}$"

DISCHARGE cu. ft. OBSTRUCTION. DISTANCE AHEAD 4"

HEAD H INS.	OBSTRUCTING ORIFICE DIAMETER									
	$1\frac{1}{8}$"	$1\frac{1}{4}$"	$1\frac{3}{8}$"	$1\frac{1}{2}$"	$1\frac{5}{8}$"	$1\frac{3}{4}$"				
20	.226	.229	.224	.226	.225	.224				
19										
18										
17										
16	.206	.210	.202	.206	.205	.205				
15										
14										
13										
12	.178	.180	.172	.176	.177	.177				
11										
10										
9										
8	.147	.148	.144	.149	.146	.146				
7										
6										
5										
4										
3										
2										
1										

R. A. COLLACOTT.

EXPERIMENT No. 11.

PURPOSE. "Determine the variations in the C_D of an orifice $\frac{1}{2}$" diameter $\frac{1}{8}$" thick the approach to which is obstructed by a cone."

TEST No. 1/11

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft.

HEAD H INS.	HEIGHT OF CONE TOP ABOVE ORIFICE										
	5"	4"	3"								
20	.224	.228	.227								
19											
18											
17											
16	.203	.207	.208								
15											
14											
13											
12	.172	.175	.175								
11											
10											
9											
8	.147	.148	.147								
7											
6											
5											
4											
3											
2											
1											

R. A. COLLACOTT.

EXPERIMENT No. 12.

PURPOSE. "Determine the effect on the C_D of an $\frac{1}{2}$" diameter $\frac{1}{8}$" thick orifice by placing a bar of rectangular section to divide up the approach."

TEST No. 1/12

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft. WIDTH OF BAR 3/8"

HEAD H INS.	HEIGHT OF BOTTOM OF BAR ABOVE ORIFICE INLET									
	0[x]	1/8"	1/4"	1/2"	7/8"					
20	.043	.162	.215	.220	.221					
19										
18	.042									
17										
16	.041	.154	.185	.220	.200					
15										
14	.038									
13										
12	.035	.140	.167	.172	.173					
11										
10	.030									
9										
8	.025	.114	.140	.145	.148					
7										
6	.024									
5										
4	.019	.077	.102	.106	.106					
3										
2										
1										

OBSERVATIONS. [x] To obtain the discharge under these conditions the flow was measured for 100 seconds and the answer divided by 4.

R. A. COLLACOTT.

TEST No. 2/12

TIME OF FLOW [illegible] secs.

ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft. WIDTH OF BAR 7/32"

HEAD H INS.	HEIGHT OF BOTTOM OF BAR ABOVE ORIFICE INLET									
	0	$\frac{1}{16}$	[illegible]	[illegible]	$\frac{1}{2}$	$\frac{7}{8}$				
20	.130	.168	.204	.[illegible]14	.219	.220				
19										
18										
17										
16	.112	.150	.189	[illegible]	.199	.199				
15										
14										
13										
12	.097	.137	.16[illegible]	.171	.176	.178				
11										
10										
9										
8	.081	.111	[illegible]	.1[illegible]4	.146	.147				
7										
6										
5										
4	.057	.077	.10[illegible]	.110	.111	.112				
3										
2										
1										

R. A. COLLACOTT.

TEST No. 3/12

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft. WIDTH OF BAR 1/8"

HEAD H INS.	HEIGHT OF BOTTOM OF BAR ABOVE ORIFICE INLET									
	0	$\frac{1}{16}$"	$\frac{1}{8}$"	$\frac{1}{4}$"	$\frac{1}{2}$"	$\frac{7}{8}$"				
20	.172	.193	.208	.213	.215	.219				
19										
18										
17										
16	.153	.175	.187	.192	.198	.200				
15										
14										
13										
12	.132	.153	.165	.168	.173	.177				
11										
10										
9										
8	.110	.129	.134	.143	.147	.152				
7										
6										
5										
4	.083	.094	.100	.105	.111	.113				
3										
2						.087				
1						.070				

R. A. COLLACOTT.

TEST No. 4/12

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"

DISCHARGE cu. ft.   WIDTH OF BAR 1/16"

HEAD H INS.	HEIGHT OF BOTTOM OF BAR ABOVE ORIFICE INLET									
	0	1"/16	1"/8	1/4	1/2"	7"/8				
20	.192	.214	.215	.217	.219	.220				
19										
18										
17										
16	.177	.195	.199	.199	.200	.201				
15										
14										
13										
12	.155	.170	.175	.178	.179	.179				
11										
10										
9										
8	.126	.140	.144	.147	.149	.149				
7										
6										
5										
4	.091	.108	.110	.112	.114	.115				
3										
2										
1										

R. A. COLLACOTT.

EXPERIMENT No. 13.

PURPOSE. "Determine the influence on the C_D of an orifice $\frac{1}{8}$" thick $\frac{1}{2}$" diameter by placing a disc of various diameters at various distances upstream of the orifice."

TEST No.1/13

TIME OF FLOW 25 secs. ORIFICE DIAMETER ½"
DIAMETER OF DISC 4"

DISCHARGE cu.ft.

HEAD H INS.	HEIGHT BETWEEN BACK FACE AND ORIFICE INLET									
	⅛"	3/16"	5/16"	½"	1"	2"	1/16"			
20	.191	.209	.221	.225	.224	.221	.120			
19										
18		.200		.209						
17										
16	.176	.198	.199	.200	.203	.204	.109			
15										
14				.188						
13										
12	.149	.167	.178	.178	.177	.175	.095			
11										
10		.151								
9										
8	.128	.137	.150	.147	.144	.138	.078			
7										
6		.117								
5										
4	.091	.098	.105	.104	.105	.099	.058			
3										
2										
1										

R. A. COLLACOTT.

TEST No. 2/13

TIME OF FLOW 25 secs. ORIFICE DIAMETER ½"
DIAMETER OF DISC 3"

DISCHARGE cu.ft.

HEAD H INS.	HEIGHT BETWEEN BACK FACE AND ORIFICE INLET									
	1/16"	1/8"	¼"	½"	1"	2"	3"			
20	.133	.130	.215	.225	229	.227	.222			
19										
18							.209			
17										
16	.120	.160	.188	.199	.208	.199	.200			
15										
14					.191	.184				
13										
12	.105	.145	.163	.175	.177	.173	.176			
11										
10										
9										
8	.087	.118	.135	.146	.148	.142	.145			
7										
6						.121				
5										
4	.060	.085	.099	.110	.113	.104	.110			
3										
2										
1										

TEST No 5/15

TIME OF FLOW 25 secs.

ORIFICE DIAMETER $\frac{1}{2}$"

DIAMETER OF DISC $2\frac{1}{2}$"

DISCHARGE cu.ft.

HEAD H INS.	HEIGHT BETWEEN BACK FACE AND ORIFICE INLET									
	1/16"	$\frac{1}{8}$"	$\frac{1}{4}$"	$\frac{1}{2}$"	1"					
20	.117	.199	.217	.222	.223					
19										
18										
17										
16	.105	.175	.189	.200	.201					
15										
14										
13										
12	.091	.153	.168	.174	.174					
11										
10										
9										
8	.072	.127	.136	.146	.147					
7										
6										
5										
4	.055	.091	.099	.105	.105					
3										
2										
1										

R. A. COLLACOTT.

EXPERIMENT No. 14.

PURPOSE: "Determine the static pressure along a nozzle $2\frac{1}{8}$" long.

RESULTS: There was little success as the water would not flow through the pressure tubes. Obviously the static pressure is so low that it was unable to move the fluid against the friction forces of the small-bore pressure tubing.

EXPERIMENT No. 15

PURPOSE: "Determine the distribution of static pressure on the inlet face of the orifice."

RESULTS: For all the positions measured the pressure on the inlet face was equal to the "head of water".

EXPERIMENT No. 16.

PURPOSE: "Determine the total pressure of the central filament through an orifice ½" diameter ⅛" thick at various distances downstream from the inlet."

RESULTS. The following readings were taken

TOTAL PRESSURE, INS.			
Head H ins.	DISTANCE BELOW INLET.		
	0	8"	¼"
20	19.89	19.38	19.50
18			
16	15.88	15.75	15.73
14			
12	11.75	11.75	11.75
10			
8	7.77	7.77	7.77
6			
4	3.88	3.88	3.88
-			

APPENDIX NO. 2. ----- CALCULATIONS.

EXPERIMENT No. 1.

Test No. 1/1

TIME OF FLOW: 500 secs.

ORIFICE DIAMETER 1/8"

DISCHARGE cu. ft. (Theoretical)

Head over Inlet	H+L	1⅛" H+L	1⅛" Q	H+L	1" H+L	1" Q	H+L	7/8" H+L	7/8" Q
20	21.13	4.60	.451	21.00	4.58	.449	20.88	4.57	.448
19	20.13	4.49	.440	20.00	4.47	.438	19.88	4.46	.437
18	19.13	4.37	.428	19.00	4.36	.427	18.88	4.35	.426
17	18.13	4.26	.418	18.00	4.24	.416	17.88	4.23	.414
16	17.13	4.14	.406	17.00	4.12	.404	16.88	4.11	.403
15	16.13	4.02	.394	16.00	4.00	.392	15.88	3.99	.391
14	15.13	3.89	.382	15.00	3.87	.379	14.88	3.86	.378
13	14.13	3.76	.369	14.00	3.74	.367	13.88	3.73	.366
12	13.13	3.62	.355	13.00	3.61	.354	12.88	3.59	.352
11	12.13	3.48	.341	12.00	3.46	.339	11.88	3.45	.338
10	11.13	3.34	.328	11.00	3.32	.325	10.88	3.30	.323
9	10.13	3.18	.312	10.00	3.16	.310	9.88	3.14	.308
8	9.13	3.02	.296	9.00	3.00	.294	8.88	2.98	.292
7	8.13	2.85	.280	8.00	2.83	.278	7.88	2.81	.276
6	7.13	2.67	.262	7.00	2.65	.260	6.88	2.62	.257
5	6.13	2.48	.243	6.00	2.45	.240	5.88	2.43	.238
4	5.13	2.27	.223	5.00	2.24	.220	4.88	2.21	.217
3	4.13	2.03	.199	4.00	2.00	.196	3.88	1.97	.193
2	3.13	1.77	.174	3.00	1.73	.170	2.88	1.70	.167
1	2.13	1.46	.143	2.00	1.41	.138	1.88	1.37	.134

Observations: Basic equation used for calculations is

$$Q = 9.820.10^{-2} \sqrt{H+L}$$

R.A. COLLACOTT

Test No. 1/1(Contd)

TIME OF FLOW: 500 secs.

ORIFICE DIAMETER 1/8"

DISCHARGE cu.ft.(Theoretical)

Head over Inlet	¾"			⅝"			½"		
	H+L	H+L	Q	H+L	H+L	Q	H+L	H+L	Q
20	20.75	4.56	.448	20.63	4.54	.446	20.50	4.53	.444
19	19.75	4.44	.436	19.63	4.43	.435	19.50	4.42	.434
18	18.75	4.33	.425	18.63	4.32	.434	18.50	4.30	.422
17	17.75	4.21	.413	17.63	4.20	.412	17.50	4.18	.410
16	16.75	4.09	.401	16.63	4.08	.400	16.50	4.06	.399
15	15.75	3.97	.389	15.63	3.95	.388	15.50	3.94	.386
14	14.75	3.84	.377	14.63	3.83	.376	14.50	3.81	.374
13	13.75	3.71	.364	13.63	3.69	.362	13.50	3.67	.360
12	12.75	3.57	.350	12.63	3.55	.348	12.50	3.54	.347
11	11.75	3.43	.337	11.63	3.41	.335	11.50	3.39	.333
10	10.75	3.28	.322	10.63	3.26	.320	10.50	3.24	.318
9	9.75	3.12	.306	9.63	3.10	.304	9.50	3.08	.302
8	8.75	2.96	.290	8.63	2.94	.289	8.50	2.92	.286
7	7.75	2.78	.273	7.63	2.76	.271	7.50	2.74	.269
6	6.75	2.60	.255	6.63	2.58	.253	6.50	2.55	.250
5	5.75	2.40	.236	5.63	2.37	.233	5.50	2.35	.231
4	4.75	2.18	.214	4.63	2.15	.211	4.50	2.12	.208
3	3.75	1.94	.191	3.63	1.91	.188	3.50	1.87	.184
2	2.75	1.66	.163	2.63	1.62	.159	2.50	1.58	.155
1	1.75	1.32	.130	1.63	1.28	.126	1.50	1.23	.121

R. A. COLLACOTT

Test No. 1/1 (Contd)

TIME OF FLOW: 500 secs.

ORIFICE DIAMETER 1/8"

DISCHARGE cu.ft. (Theoretical)

Head over Inlet		3/8"			1/4"			1/8"	
	H+L	H+L	Q	H+L	H+L	Q	H+L	H+L	Q
20	20.38	4.51	.442	20.25	4.50	.441	20.13	4.49	.440
19	19.38	4.40	.432	19.25	4.39	.431	19.13	4.37	.429
18	18.38	4.29	.421	18.25	4.27	.419	18.13	4.26	.418
17	17.38	4.17	.409	17.25	4.15	.408	17.13	4.14	.407
16	16.38	4.05	.397	16.25	4.03	.395	16.13	4.02	.394
15	15.38	3.92	.384	15.25	3.91	.383	15.13	3.89	.382
14	14.38	3.79	.372	14.25	3.78	.371	14.13	3.76	.369
13	13.28	3.66	.359	13.25	3.64	.357	13.13	3.62	.355
12	12.38	3.52	.346	12.25	3.50	.344	12.13	3.48	.341
11	11.38	3.37	.331	11.25	3.35	.329	11.13	3.34	.328
10	10.38	3.22	.316	10.25	3.20	.314	10.13	3.18	.312
9	9.38	3.06	.300	9.25	3.04	.298	9.13	3.02	.296
8	8.38	2.90	.285	8.25	2.87	.282	8.13	2.85	.280
7	7.38	2.72	.267	7.25	2.69	.264	7.13	2.67	.262
6	6.38	2.53	.249	6.25	2.50	.245	6.13	2.48	.243
5	5.38	2.32	.228	5.25	2.29	.225	5.13	2.27	.223
4	4.38	2.09	.206	4.25	2.06	.202	4.13	2.03	.199
3	3.38	1.84	.131	3.25	1.80	.177	3.13	1.77	.174
2	2.38	1.54	.151	2.25	1.50	.147	2.13	1.46	.143
1	1.38	1.18	.116	1.25	1.12	.110	1.13	1.06	.104

R.A. COLLACOTT

TEST No. 1/1 (Contd)

TIME OF FLOW 500 secs. ORIFICE DIAMETER 1/8"

DISCHARGE COEFFICIENT

HEAD H INS.	Orifice Length								
	1 1/8"	1"	7/8"	3/4"	5/8"	1/2"	3/8"	1/4"	1/8"
20	.770	.840	.799	.784	.778	.767	.816	.859	.704
19	.760	.826	.799	.808	.782	.758	.811	.858	.717
18	.761	.805	.798	.803	.761	.759	.808	.852	.694
17	.781	.796	.799	.802	.772	.761	.819	.860	.708
16	.771	.812	.792	.800	.768	.760	.803	.861	.701
15	.772	.799	.793	.802	.768	.754	.821	.862	.706
14	.757	.810	.796	.812	.748	.755	.812	.858	.707
13	.768	.790	.784	.797	.749	.750	.808	.854	.709
12	.780	.793	.787	.820	.753	.746	.809	.868	.719
11	.778	.805	.784	.798	.747	.741	.798	.848	.710
10	.765	.793	.778	.805	.734	.742	.791	.844	.718
9	.769	.800	.789	.804	.743	.741	.790	.840	.723
8	.767	.776	.781	.793	.754	.742	.800	.830	.725
7	.758	.773	.765	.782	.742	.740	.787	.838	.741
6	.775	.789	.779	.804	.743	.749	.780	.853	.754
5	.762		.773		.751		.790		.755
4	.758		.751		.769		.806		.809
3	.779		.773						
2									
1									

R. A. COLLACOTT.

Test No. 2/1

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/4"

DISCHARGE cu.ft.(Theoretical)

Head over Inlet		2⅛"			2"			1⅞"	
	H+L	H+L	Q50	H+L	H+L	Q50	H+L	H+L	Q50
20	22.13	4.70	.186	22.00	4.69	.184	21.88	4.68	.184
19	21.13	4.60	.181	21.00	4.58	.180	20.88	4.57	.180
18	20.13	4.49	.177	20.00	4.47	.176	19.88	4.46	.175
17	19.13	4.37	.172	19.00	4.36	.172	18.88	4.35	.171
16	18.13	4.26	.167	18.00	4.24	.167	17.88	4.23	.166
15	17.13	4.14	.163	17.00	4.12	.162	16.88	4.11	.161
14	16.13	4.02	.158	16.00	4.00	.157	15.88	3.99	.151
13	15.13	3.89	.153	15.00	3.87	.152	14.88	3.86	.151
12	14.13	3.76	.148	14.00	3.74	.147	13.88	3.73	.141
11	13.13	3.62	.142	13.00	3.61	.142	12.88	3.59	.141
10	12.13	3.48	.137	12.00	3.46	.136	11.88	3.45	.136
9	11.13	3.34	.131	11.00	3.32	.130	10.88	3.30	.129
8	10.13	3.18	.125	10.00	3.16	.124	9.88	3.14	.123
7	9.13	3.02	.119	9.00	3.00	.118	8.88	2.98	.117
6	8.13	2.85	.112	8.00	2.83	.111	7.88	2.81	.110
5	7.13	2.67	.105	7.00	2.65	.104	6.88	2.62	.103
4	6.13	2.48	.098	6.00	2.45	.096	5.88	2.43	.095
3	5.13	2.27	.089	5.00	2.24	.088	4.88	2.21	.087
2	4.13	2.03	.080	4.00	2.00	.079	3.88	1.97	.077
1	3.13	1.77	.070	3.00	1.73	.068	2.88	1.70	.067

<u>Observations:</u> Basic equation used for calculations is

$$Q = 3.93.10^{-2} H + L$$

R.A.COLLACOTT

Test No. 2/1 (Contd)

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/4"

DISCHARGE cu.ft. (Theoretical)

Head over Inlet	H+L	1¾" H+L	Q50	H+L	1⅝" H+L	Q50	H+L	1½" H+L	Q50
20	21.75	4.66	.183	21.63	4.65	.183	21.50	4.64	.182
19	20.75	4.56	.179	20.63	4.54	.178	20.50	4.53	.178
18	19.75	4.44	.174	19.63	4.43	.174	19.50	4.42	.174
17	18.75	4.33	.170	18.63	4.32	.170	18.50	4.30	.169
16	17.75	4.21	.166	17.63	4.20	.165	17.50	4.18	.164
15	16.75	4.09	.161	16.63	4.08	.161	16.50	4.06	.160
14	15.75	3.97	.156	15.63	3.95	.155	15.50	3.94	.155
13	14.75	3.84	.151	14.63	3.83	.150	14.50	3.81	.150
12	13.75	3.71	.146	13.63	3.69	.145	13.50	3.67	.144
11	12.75	3.57	.140	12.63	3.55	.140	12.50	3.54	.139
10	11.75	3.43	.135	11.63	3.41	.134	11.50	3.39	.133
9	10.75	3.28	.129	10.63	3.26	.128	10.50	3.24	.127
8	9.75	3.12	.122	9.63	3.10	.122	9.50	3.08	.121
7	8.75	2.96	.116	8.63	2.94	.116	8.50	2.92	.115
6	7.75	2.78	.109	7.63	2.76	.108	7.50	2.74	.108
5	6.75	2.60	.102	6.63	2.58	.101	6.50	2.55	.100
4	5.75	2.40	.094	5.63	2.37	.093	5.50	2.35	.092
3	4.75	2.18	.086	4.63	2.15	.085	4.50	2.12	.083
2	3.75	1.94	.076	3.63	1.91	.075	3.50	1.87	.074
1	2.75	1.66	.065	2.63	1.62	.064	2.50	1.58	.062

R.A. COLLACOTT

Test No. 2/1(Contd)

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/4"

DISCHARGE cu.ft. (Theoretical)

Head over Inlet	H+L	$1\frac{3}{8}$" H+L	Q50	H+L	$1\frac{1}{4}$" H+L	Q50	H+L	$1\frac{1}{8}$" H+L	Q50
20	21.38	4.62	.182	21.25	4.62	.181	21.13	4.60	.181
19	20.38	4.51	.177	20.25	4.50	.177	20.13	4.49	.177
18	19.38	4.40	.173	19.25	4.39	.173	19.13	4.37	.172
17	18.38	4.29	.169	18.25	4.27	.168	18.13	4.26	.168
16	17.38	4.17	.164	17.25	4.15	.163	17.13	4.14	.163
15	16.38	4.05	.159	16.25	4.03	.159	16.13	4.02	.158
14	15.38	3.92	.154	15.25	3.91	.154	15.13	3.89	.153
13	14.38	3.79	.149	14.25	3.78	.149	14.13	3.76	.148
12	13.38	3.66	.144	13.25	3.64	.143	13.13	3.62	.142
11	12.38	3.52	.138	12.25	3.50	.138	12.13	3.48	.137
10	11.38	3.37	.133	11.25	3.35	.132	11.13	3.34	.131
9	10.38	3.22	.127	10.25	3.20	.126	10.13	3.19	.126
8	9.38	3.06	.120	9.25	3.04	.120	9.13	3.02	.119
7	8.38	2.90	.114	8.25	2.87	.113	8.13	2.85	.112
6	7.28	2.72	.107	7.25	2.69	.106	7.13	2.67	.105
5	6.38	2.53	.100	6.25	2.50	.098	6.13	2.48	.097
4	5.38	2.32	.097	5.25	2.29	.090	5.13	2.27	.089
3	4.38	2.09	.082	4.25	2.06	.081	4.13	2.03	.080
2	3.38	1.84	.072	3.25	1.80	.071	3.13	1.77	.070
1	2.38	1.54	.062	2.25	1.50	.059	2.13	1.46	.057

R.A. COLLACOTT

Test No. 2/1 (Contd)

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/4"

DISCHARGE cu.ft. (Theoretical)

Head over Inlet	H+L	1" H+L	Q50	H+L	7/8" H+L	Q50	H+L	¾" H+L	Q50
20	21.00	4.58	.180	20.88	4.57	.180	20.75	4.56	.179
19	20.00	4.47	.176	19.88	4.46	.175	19.75	4.44	.174
18	19.00	4.36	.171	18.88	4.35	.171	18.75	4.33	.170
17	18.00	4.25	.167	17.88	4.23	.166	17.75	4.21	.165
16	17.00	4.12	.162	16.88	4.11	.162	16.75	4.09	.161
15	16.00	4.00	.157	15.88	3.99	.157	15.75	3.97	.156
14	15.00	3.87	.152	14.88	3.86	.152	14.75	3.84	.151
13	14.00	3.74	.147	13.88	3.73	.147	13.75	3.71	.146
12	13.00	3.61	.142	12.88	3.59	.141	12.75	3.57	.140
11	12.00	3.46	.136	11.88	3.45	.136	11.75	3.43	.135
10	11.00	3.32	.130	10.88	3.30	.130	10.75	3.28	.129
9	10.00	3.16	.124	9.88	3.14	.123	9.75	3.12	.123
8	9.00	3.00	.118	8.88	2.98	.117	8.75	2.96	.116
7	8.00	2.83	.111	7.88	2.81	.111	7.75	2.73	.109
6	7.00	2.65	.104	6.88	2.62	.103	6.75	2.60	.102
5	6.00	2.45	.097	5.88	2.43	.096	5.75	2.40	.094
4	5.00	2.24	.088	4.88	2.21	.087	4.75	2.18	.086
3	4.00	2.00	.079	3.88	1.97	.078	3.75	1.94	.076
2	3.00	1.73	.068	2.88	1.70	.067	2.75	1.66	.065
1	2.00	1.41	.056	1.88	1.37	.054	1.75	1.32	.052

R.A. COTTACOTT

Test No.2/1(Contd)

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/4"

DISCHARGE cu.ft.(Theoretical)

Head over Inlet	5/8"			1/2"			3/8"		
	H+L	H+L	Q50	H+L	H+L	Q50	H+L	H+L	Q50
20	20.63	4.54	.178	20.50	4.53	.178	20.38	4.51	.177
19	19.63	4.43	.174	19.50	4.42	.174	19.38	4.40	.173
18	18.63	4.32	.170	18.50	4.30	.169	18.38	4.29	.169
17	17.63	4.20	.165	17.50	4.18	.164	17.38	4.17	.164
16	16.63	4.08	.160	16.50	4.06	.160	16.38	4.05	.159
15	15.63	3.96	.156	15.50	3.94	.155	15.38	3.92	.154
14	14.63	3.83	.151	14.50	3.81	.150	14.38	3.79	.149
13	13.63	3.69	.145	13.50	3.67	.144	13.38	3.66	.144
12	12.63	3.55	.140	12.50	3.54	.139	12.38	3.52	.138
11	11.63	3.41	.134	11.50	3.39	.133	11.38	3.37	.133
10	10.63	3.26	.128	10550	3.24	.127	10.38	3.22	.127
9	9.63	3.10	.122	9.50	3.08	.121	9.38	3.06	.120
8	8.63	2.94	.116	8.50	2.92	.115	8.38	2.90	.114
7	7.63	2.76	.108	7.50	2.74	.108	7.38	2.72	.107
6	6.63	2.58	.101	6.50	2.55	.100	6.38	2.53	.100
5	5.63	2.37	.093	5.50	2.35	.092	5.38	3.32	.091
4	4.63	2.15	.085	4.50	2.12	.083	4.38	2.09	.082
3	3.63	1.91	.075	3.50	1.87	.074	3.38	1.84	.072
2	2.63	1.62	.064	2.50	1.58	.062	2.38	1.54	.061
1	1.63	1.28	.050	1.50	1.23	.048	1.38	1.18	.046

R.A. COLLACOTT

Test No. 2/1 (Contd)

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/4"

DISCHARGE cu.ft.(Theoretical)

Head over Inlet	H+L	¼" H+L	Q50	H+L	⅛" H+L	Q50
20	20.25	4.50	.177	20.13	4.49	.177
19	19.25	4.39	.173	19.13	4.37	.172
18	18.25	4.27	.167	18.13	4.26	.167
17	17.25	4.15	.163	17.13	4.14	.163
16	16.25	4.03	.159	16.13	4.02	.158
15	15.25	3.91	.154	15.13	3.89	.153
14	14.25	3.78	.149	14.13	3.76	.148
13	13.25	3.64	.143	13.13	3.62	.142
12	12.25	3.50	.138	12.13	3.48	.137
11	11.25	3.35	.132	11.13	3.34	.131
10	10.25	3.20	.126	10.13	3.18	.125
9	9.25	3.04	.120	9.13	3.02	.119
8	8.25	2.87	.113	8.13	2.85	.112
7	7.25	2.69	.106	7.13	2.67	.105
6	6.25	2.50	.098	6.13	2.48	.097
5	5.25	2.29	.090	5.13	2.27	.089
4	4.25	2.06	.081	4.13	2.03	.080
3	3.25	1.80	.071	3.13	1.77	.070
2	2.25	1.50	.059	2.13	1.46	.057
1	1.25	1.12	.044	1.13	1.06	.042

R.A. COLLACOTT

TEST No. 2/1 (Cond)

TIME OF FLOW 50 secs. ORIFICE DIAMETER 1/4"

DISCHARGE COEFFICIENT

HEAD H INS.	ORIFICE LENGTH									
	$2\frac{1}{8}$	2"	$1\frac{7}{8}$"	$1\frac{3}{4}$"	$1\frac{5}{8}$"	$1\frac{1}{2}$"	$1\frac{3}{8}$"	$1\frac{1}{4}$"	$1\frac{1}{8}$"	
20	.757	.756	.771	.766	.760	.769	.764		.801	
19	.763	.758	.761	.777	.781	.781	.780		.808	
18	.769	.762	.772	.781	.793	.793	.774		.814	
17	.756	.750	.767	.789	.807	.799	.788		.810	
16	.767	.761	.778	.784	.819	.806	.787		.798	
15	.767	.747	.752	.771	.808	.794	.787		.804	
14	.779	.752	.752	.770	.800	.793	.780		.811	
13	.751	.750	.769	.756	.793	.781	.772		.798	
12	.743	.769	.756	.754	.779	.778	.765		.789	
11	.768	.754	.759	.772	.779	.770	.768		.781	
10	.738	.743	.751	.771	.777	.782	.759		.779	
9	.749	.746	.768	.783	.797	.796	.757		.794	
8	.760	.760	.773	.796	.795	.801	.759		.807	
7	.757	.753	.769	.794	.777	.800	.754		.822	
6	.759	.765	.773	.780	.778	.778	.801		.838	
5			.766		.742		.770		.877	
4			.738		.753		.791		.854	
3			.747		.800		.781		.838	
2			.767		.774		.736		.771	
1			.762		.767		.768		.825	

R. A. COLLACOTT.

TEST No. 2/1 (Contd)

TIME OF FLOW 50 secs. ORIFICE DIAMETER 1/4"

DISCHARGE COEFFICIENT

HEAD H INS.	ORIFICE LENGTH									
	1"	7/8"	3/4"	5/8"	1/2"	3/8"	1/4"	1/8"		
20		.805	.833		.838		.837	.650		
19		.806	.823		.850		.849	.658		
18		.802	.830		.864		.868	.659		
17		.808	.838		.872		.877	.657		
16		.798	.845		.863		.868	.659		
15		.783	.840		.865		.870	.667		
14		.797	.841		.847		.845	.669		
13		.783	.829		.862		.839	.683		
12		.781	.829		.849		.847	.679		
11		.779	.815		.850		.856	.679		
10		.778	.822		.836		.842	.672		
9		.797	.822		.843		.850	.664		
8		.813	.820		.835		.840	.652		
7		.811	.826		.833		.849	.657		
6		.827	.834		.850		.848	.681		
5		.823	.841		.859		.834	.698		
4		.805	.814		.844		.828	.750		
3										
2										
1										

R. A. COLLACOTT.

Test No. 3/1

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/2"

DISCHARGE cu.ft. (Theoretical)

Head over Inlet	$4\frac{1}{8}$" H+L	H+L	Q50	4" H+L	H+L	Q50	$3\frac{7}{8}$" H+L	H+L	Q50
20	24.13	4.91	.771	24.00	4.90	.769	23.88	4.89	.766
19	23.13	4.81	.755	23.00	4.80	.754	22.88	4.78	.751
18	22.13	4.70	.738	22.00	4.70	.738	21.88	4.68	.735
17	21.13	4.60	.722	21.00	4.58	.719	20.88	4.57	.718
16	20.13	4.49	.705	20.00	4.47	.702	19.88	4.46	.701
15	19.13	4.37	.686	19.00	4.36	.683	18.88	4.35	.682
14	18.13	4.26	.669	18.00	4.24	.665	17.88	4.23	.664
13	17.13	4.14	.650	17.00	4.12	.646	16.88	4.11	.645
12	16.13	4.02	.631	16.00	4.00	.628	15.88	3.99	.626
11	15.13	3.89	.610	15.00	3.87	.607	14.88	3.86	.606
10	14.13	3.76	.590	14.00	3.74	.587	13.88	3.73	.585
9	13.13	3.62	.568	13.00	3.61	.565	12.88	3.59	.563
8	12.13	3.48	.546	12.00	3.46	.543	11.88	3.45	.541
7	11.13	3.34	.524	11.00	3.32	.521	10.88	3.30	.518
6	10.13	3.18	.499	10.00	3.16	.496	9.88	3.14	.493
5	9.13	3.02	.474	9.00	3.00	.471	8.88	2.98	.467
4	8.13	2.85	.447	8.00	2.83	.444	7.88	2.81	.441
3	7.13	2.67	.419	7.00	2.65	.416	6.88	2.62	.411
2	6.13	2.48	.389	6.00	2.45	.385	5.88	2.43	.382
1	5.13	2.27	.356	5.00	2.24	.352	4.88	2.21	.347

<u>Observations:</u> Basic equation used for calculations is

$$Q = 15.7.10^{-2} \quad H + L$$

R.A. COLLACOTT

Test No. 3/1 (Contd)

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/2"

DISCHARGE cu.ft. (Theoretical)

Head over Inlet		3¾"			3⅝"			3½"	
	H+L	H+L	Q50	H+L	H+L	Q50	H+L	H+L	Q50
20	23.75	4.89	.766	23.63	4.86	.764	23.50	4.85	.761
19	22.75	4.77	.749	22.63	4.76	.748	22.50	4.74	.744
18	21.75	4.66	.731	21.63	4.65	.730	21.50	4.64	.729
17	20.75	4.56	.716	20.63	4.54	.712	20.50	4.53	.711
16	18.95	4.44	.697	19.63	4.43	.696	19.50	4.43	.696
15	18.75	4.33	.680	18.63	4.32	.679	18.50	4.30	.675
14	17.75	4.21	.661	17.63	4.20	.659	17.50	4.18	.657
13	16.75	4.09	.642	16.63	4.08	.641	16.50	4.06	.638
12	15.75	3.97	.623	15.63	3.95	.620	15.50	3.94	.619
11	14.75	3.84	.602	14.63	3.83	.601	14.50	3.81	.598
10	13.75	3.71	.582	13.63	3.69	.579	13.50	3.67	.576
9	12.75	3.57	.560	12.63	3.55	.557	12.50	3.54	.556
8	11.75	3.43	.539	11.63	3.41	.535	11.50	3.39	.532
7	10.75	3.28	.515	10.63	3.26	.511	10.50	3.24	.509
6	9.75	3.12	.490	9.63	3.10	.487	9.50	3.08	.484
5	8.75	2.96	.465	8.63	2.94	.461	8.50	2.92	.458
4	7.75	2.78	.437	7.63	2.76	.433	7.50	2.74	.430
3	6.75	2.60	.408	6.63	2.58	.405	6.50	2.55	.400
2	5.75	2.40	.377	5.63	2.37	.372	5.50	2.35	.369
1	4.75	2.18	.342	4.63	2.15	.338	4.50	2.12	.333

R.A. COLLACOTT

Test No. 3/1 (Contd)

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/2"

DISCHARGE cu.ft.(Theoretical)

Head over Inlet		3⅜"			3¼"			3⅛"	
	H+L	H+L	Q50	H+L	H+L	Q50	H+L	H+L	
20	23.38	4.84	.760	23.25	4.82	.757	23.13	4.81	.755
19	22.38	4.73	.743	22.25	4.72	.741	22.13	4.70	.737
18	21.38	4.62	.725	21.25	4.61	.723	21.13	4.60	.722
17	20.38	4.51	.708	20.25	4.50	.706	20.13	4.49	.705
16	19.28	4.40	.690	19.25	4.39	.689	19.13	4.37	.686
15	18.38	4.29	.673	18.25	4.27	.670	18.13	4.26	.669
14	17.38	4.17	.654	17.25	4.15	.651	17.13	4.14	.650
13	16.38	4.05	.636	16.25	4.03	.633	16.13	4.02	.631
12	15.38	3.92	.616	15.25	3.91	.615	15.13	3.89	.610
11	14.38	3.79	.596	14.25	3.78	.593	14.13	3.76	.591
10	13.38	3.66	.575	13.25	3.64	.571	.13.13	3.62	.568
9	12.38	3.52	.552	12.25	3.50	.549	12.13	3.48	.546
8	11.38	3.37	.529	11.25	3.35	.526	11.13	3.34	.524
7	10.38	3.22	.506	10.25	3.20	.503	10.13	3.19	.501
6	9.38	3.06	.481	9.25	3.04	.477	9.13	3.02	.474
5	8.38	2.90	.455	8.25	2.87	.451	8.13	2.85	.447
4	7.38	2.72	.427	7.25	2.69	.423	7.13	2.67	.419
3	6.38	2.53	.397	6.25	2.50	.393	6.13	2.48	.389
2	5.38	2.32	.364	5.25	2.29	.360	5.13	2.27	.356
1	4.38	2.09	.328	4.25	2.06	.325	4.13	2.03	.319

R.A. COLLACOTT

Test No. 3/1 (Contd)

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/2"

DISCHARGE cu.ft (Theoretical)

Head over Inlet	H+L	3" √H+L	3" Q50	2⅞" H+L	2⅞" √H+L	2⅞" Q50	2¼" H+L	2¼" √H+L	2¼" Q50
20	23.00	4.80	.753	22.88	4.78	.750	22.75	4.77	.749
19	22.00	4.69	.736	21.88	4.68	.735	21.75	4.66	.732
18	21.00	4.58	.719	20.88	4.57	.717	20.75	4.56	.716
17	20.00	4.47	.701	19.88	4.46	.700	19.75	4.44	.696
16	19.00	4.36	.684	18.88	4.35	.682	18.75	4.33	.680
15	18.00	4.24	.666	17.88	4.23	.664	17.75	4.21	.661
14	17.00	4.12	.647	16.88	4.11	.645	16.75	4.09	.642
13	16.00	4.00	.628	15.88	3.99	.626	15.75	3.97	.624
12	15.00	3.87	.607	14.88	3.86	.606	14.75	3.84	.603
11	14.00	3.74	.587	13.88	3.73	.586	13.75	3.71	.583
10	13.00	3.61	.567	12.88	3.59	.564	12.75	3.57	.560
9	12.00	3.46	.543	11.88	3.45	.541	11.75	3.43	.539
8	11.00	3.32	.521	10.88	3.30	.518	10.75	3.28	.515
7	10.00	3.16	.496	9.88	3.14	.493	9.75	3.12	.490
6	9.00	3.00	.471	8.88	2.98	.468	8.75	2.96	.464
5	8.00	2.83	.444	7.88	2.81	.441	7.75	2.78	.437
4	7.00	2.65	.416	6.88	2.62	.411	6.75	2.60	.408
3	6.00	2.45	.385	5.88	2.43	.382	5.75	2.40	.377
2	5.00	2.24	.352	4.88	2.21	.347	4.75	2.18	.342
1	4.00	2.00	.314	3.88	1.97	.309	3.75	1.94	.305

R.A.COLLACOTT

Test No.3/1 (Contd)

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/2"

DISCHARGE cu.ft. (Theoretical)

Head over Inlet		2 5/8"			2 1/2"			2 3/8"	
	H+L	H+L	Q50	H+L	H+L	Q50	H+L	H+L	Q50
20	22.63	4.76	.747	22.50	4.74	.744	22.38	4.73	.742
19	21.63	4.65	.730	21.50	4.64	.729	21,38	4.62	.725
18	20.63	4.54	.713	20.50	4.53	.712	20.38	4.51	.708
17	19.63	4.43	.695	19.50	4.42	.693	19.38	4.40	.691
16	18.63	4.32	.679	18.50	4.30	.675	18.38	4.29	.674
15	17.63	4.20	.659	17.50	4.18	.656	17.38	4.17	.655
14	16.63	4.08	.641	16.50	4.06	.638	16.38	4.05	.636
13	15.63	3.95	.620	15.50	3.94	.619	15.38	3.92	.616
12	14.63	3.83	.601	14.50	3.81	.598	14.38	3.79	.594
11	13.63	3.69	.579	13.50	3.67	.576	13.38	3.66	.575
10	12.63	3.55	.557	12.50	3.54	.556	12.38	3.52	.552
9	11,63	3.41	.535	11.50	3.39	.532	11.38	3.37	.529
8	10.63	3.26	.512	10.50	3.24	.509	10.38	3.22	.506
7	9.63	3.10	.486	9.50	3.08	.484	9.38	3.06	.481
6	8.63	2.94	.461	8.50	2.92	.458	8.38	2.90	.455
5	7.63	2.76	.433	7.50	2.74	.430	7.38	2.72	.427
4	6.63	2.58	.405	6.50	2.55	.400	6.38	2.53	.397
3	5.63	2.37	.372	5. 50	2.35	.369	5.38	2.32	.364
2	4.63	2.15	.338	4.50	2.12	.333	4.38	2.09	.329
1	3.63	1.91	.300	3.50	1.87	.294	3.38	1.84	.289

R.A. COLLACOTT

Test No. 3/1 (Contd)

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/2"

DISCHARGE cu.ft.(Theoretical)

Head over Inlet	H+L	2¼"		2½"			2"		
		H+L	Q50	H+L	H+L	Q50	H+L	H+L	Q50
20	22.25	4.72	.741	22.13	4.70	.738	22.00	4.69	.736
19	21.25	4.61	.724	21.13	4.60	.722	21.00	4.58	.719
18	20.25	4.50	.706	20.13	4.49	.705	20.00	4.47	.701
17	19.25	4.39	.689	19.13	4.37	.686	19.00	4.36	.685
16	18.25	4.27	.671	18.13	4.26	.669	18.00	4.24	.665
15	17.25	4.15	.651	17.13	4.14	.649	17.00	4.12	.647
14	16.25	4.03	.634	16.13	4.02	.631	16.00	4.00	.629
13	15.25	3.91	.614	15.13	3.88	.610	15.00	3.87	.608
12	14.25	3.78	.593	14.13	3.76	.590	14.00	3.74	.588
11	13.25	3.64	.571	13.13	3.62	.568	13.00	3.61	.566
10	12.25	3.50	.549	12.13	3.48	.546	12.00	3.46	.544
9	11.25	3.35	.526	11.13	3.34	.524	11.00	3.32	.521
8	10.25	3.20	.503	10.13	3.19	.501	10.00	3.16	.496
7	9.25	3.04	.477	9.13	3.02	.474	9.00	3.00	.471
6	8.25	2.87	.450	8.13	2.85	.447	8.00	2.83	.444
5	7.25	2.69	.423	7.13	2.67	.419	7.00	2.65	.416
4	6.25	2.50	.393	6.13	2.48	.389	6.00	2.45	.385
3	5.25	2.29	.360	5.13	2.27	.357	5.00	2.24	.352
2	4.25	2.06	.323	4.13	2.03	.319	4.00	2.00	.314
1	3.25	1.80	.283	3.13	1.77	.278	3.00	1.73	.272

R.A. COLLACOTT

Test No. 3/1 (Contd)

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/2"

DISCHARGE cu.ft.(Theoretical)

Head over Inlet	H+L	$1\frac{7}{8}$" H+L	Q50	H+L	$1\frac{3}{4}$" H+L	Q50	H+L	$1\frac{5}{8}$" H+L	Q50
20	21.88	4.68	.735	21.75	4.66	.732	21.63	4.65	.730
19	20.88	4.57	.718	20.75	4.56	.716	20.63	4.54	.713
18	19.88	4.46	.700	19.75	4.44	.697	19.63	4.43	.696
17	18.88	4.35	.683	18.75	4.33	.681	18.63	4.32	.679
16	17.88	4.23	.665	17.75	4.21	.661	17.63	4.20	.659
15	16.88	4.11	.645	16.75	4.09	.642	16.63	4.08	.641
14	15.88	3.99	.626	15.75	3.97	.623	15.63	3.95	.620
13	14.88	3.86	.606	14.75	3.84	.603	14.63	3.83	.601
12	13.88	3.73	.585	13.75	3.71	.583	13.63	3.69	.579
11	12.88	3.59	.564	12.75	3.57	.560	12.63	3.55	.558
10	11.88	3.45	.541	11.75	3.43	.538	11.63	3.41	.535
9	10.88	3.30	.518	10.75	3.28	.515	10.63	3.26	.511
8	9.88	3.14	.473	9.75	3.12	.490	9.63	3.10	.487
7	8.88	2.98	.468	8.75	2.96	.464	8.63	2.94	.461
6	7.88	2.81	.441	7.75	2.78	.437	7.63	2.76	.433
5	6.88	2.62	.411	6.75	2.60	.408	6.63	2.58	.405
4	5.88	2.43	.381	5.75	2.40	.377	5.63	2.37	.372
3	4.88	2.21	.347	4.75	2.18	.342	4.63	2.15	.337
2	3.88	1.97	.309	3.75	1.94	.304	3.63	1.91	.300
1	2.88	1.70	.267	2.75	1.66	.260	2.63	1.62	.254

R.A. COLLACOTT

Test No. 3/1 (Contd)

TIME OF FLOW: 50 secs ORIFICE DIAMETER 1/2"

DISCHARGE cu.ft.(Theoretical)

Head over Inlet	H+L	1½" H+L	1½" Q50	H+L	1⅜" H+L	1⅜" Q50	H+L	1¼" H+L	1¼" Q50
20	21.50	4.64	.729	21.38	4.62	.725	21.25	4.61	.724
19	20.50	4.53	.712	20.38	4.51	.708	20.25	4.50	.707
18	19.50	4.42	.694	19.38	4.40	.691	19.25	4.39	.689
17	18.50	4.30	.675	18.38	4.29	.674	18.25	4.27	.671
16	17.50	4.18	.657	17.38	4.17	.655	17.25	4.15	.652
15	16.50	4.06	.638	16.28	4.05	.636	16.25	4.03	.634
14	15.50	3.94	.618	15.38	3.92	.616	15.25	3.91	.613
13	14.50	3.81	.599	14.38	3.79	.595	14.25	3.78	.593
12	13.50	3.67	.576	13.38	3.66	.575	13.25	3.64	.571
11	12.50	3.54	.556	12.38	3.52	.552	12.25	3.50	.549
10	11.50	3.39	.533	11.38	3.37	.529	11.25	3.35	.526
9	10.50	3.24	.509	10.38	3.22	.505	10.25	3.20	.502
8	9.50	3.08	.483	9.38	3.06	.480	9.25	3.04	.477
7	8.50	2.92	.458	8.38	2.90	.455	8.25	2.87	.451
6	7.50	2.74	.430	7.38	2.72	.427	7.25	2.69	.422
5	6.50	2.55	.400	6.38	2.53	.397	6.25	2.50	.393
4	5.50	2.35	.369	5.38	2.32	.364	5.25	2.29	.360
3	4.50	2.12	.332	4.38	2.09	.328	4.25	2.06	.323
2	3.50	1.87	.293	3.38	1.84	.289	3.25	1.80	.283
1	2.50	1.58	.248	2.38	1.54	.242	2.25	1.50	.236

R.A. COLLACOTT

Test No. 3/1 (Contd)

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/2"

DISCHARGE cu.ft. (Theoretical)

Head over Inlet	1⅛" H+L	H+L	Q50	1" H+L	H+L	Q50	7/8" H+L	H+L	Q50
20	21.13	4.60	.722	21.00	4.58	.719	20.88	4.57	.718
19	20.13	4.49	.705	20.00	4.47	.702	19.88	4.46	.700
18	19.13	4.37	.686	19.00	4.36	.685	18.88	4.35	.683
17	18.13	4.26	.669	18.00	4.24	.666	17.88	4.23	.664
16	17.13	4.14	.650	17.00	4.12	.647	16.88	4.11	.645
15	16.13	4.02	.631	16.00	4.00	.628	15.88	3.99	.626
14	15.13	3.89	.610	15.00	3.87	.607	14.88	3.86	.606
13	14.13	3.76	.590	14.00	3.74	.587	13.88	3.73	.585
12	13.13	3.62	.569	13.00	3.61	.566	12.88	3.59	.564
11	12.13	3.48	.546	12.00	3.46	.543	11.88	3.45	.541
10	11.13	3.34	.524	11.00	3.32	.521	10.88	3.30	.518
9	10.13	3.19	.501	10.00	3.16	.496	9.88	3.14	.493
8	9.13	3.02	.474	9.00	3.00	.471	8.88	2.98	.468
7	8.13	2.85	.447	8.00	2.83	.444	7.88	2.81	.441
6	7.13	2.67	.419	7.00	2.65	.417	6.88	2.62	.411
5	6.13	2.48	.389	6.00	2.45	.385	5.88	2.43	.382
4	5.13	2.27	.356	5.00	2.24	.352	4.88	2.21	.347
3	4.13	2.03	.319	4.00	2.00	.314	3.88	1.97	.309
2	3.13	1.77	.278	3.00	1.73	.272	2.88	1.70	.267
1	2.13	1.46	.229	2.00	1.41	.221	1.88	1.37	.215

R.A. COLDICOTT

Test No. 3/1 (Contd)

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/2"

DISCHARGE cu.ft. (Theoretical)

Head over Inlet	H+L	¾"		⅝"			½"		
		H+L	Q50	H+L	H+L	Q50	H+L	H+L	Q50
20	20.75	4.56	.716	20.63	4.54	.713	20.50	4.53	.712
19	19.75	4.44	.697	19.63	4.43	.696	19.50	4.42	.693
18	18.75	4.33	.680	18.63	4.32	.678	18.50	4.30	.675
17	17.75	4.21	.661	17.63	4.20	.659	17.50	4.18	.657
16	16.75	4.09	.641	16.63	4.08	.640	16.50	4.06	.638
15	15.75	3.97	.623	15.63	3.95	.620	15.50	3.94	.619
14	14.75	3.84	.603	14.63	3.83	.601	14.50	3.81	.599
13	13.75	3.71	.583	13.63	3.69	.579	13.50	3.67	.576
12	12.75	3.57	.560	12.63	3.55	.557	12.50	3.54	.556
11	11.75	3.45	.538	11.63	3.41	.535	10.50	3.39	.532
10	10.75	3.28	.515	10.63	3.26	.512	10.50	3.24	.509
9	9.75	3.12	.490	9.63	3.10	.487	9.50	3.08	.484
8	8.75	2.96	.464	8.63	2.94	.461	8.50	2.29	.458
7	7.75	2.78	.437	7.63	2.76	.433	7.50	2.74	.430
6	6.75	2.60	.408	6.63	2.58	.405	6.50	2.55	.400
5	5.75	2.40	.377	5.63	2.37	.372	5.50	2.35	.369
4	4.75	2.18	.342	4.63	2.15	.338	4.50	2.12	.333
3	3.75	1.94	.305	3.63	1.91	.300	3.50	1.87	.293
2	2.75	1.66	.260	2.63	1.62	.254	2.50	1.58	.248
1	1.75	1.32	.207	1.63	1.28	.201	1.50	1.23	.193

R.A. COLLACOTT

Test No. 3/1(Con)

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/2"

DISCHARGE cu.ft.(Theoretical)

Head over Inlet	H+L	3/8" H+L	Q50	H+L	1/4" H+L	Q50	H+L	1/8" H+L	Q50
20	20.38	4.51	.708	20.25	4.50	.707	20.13	4.49	.705
19	19.38	4.40	.691	19.25	4.39	.690	19.13	4.37	.686
18	18.38	4.29	.673	18.25	4.27	.671	18.13	4.26	.670
17	17.38	4.17	.655	17.25	4.15	.651	17.13	4.14	.650
16	16.38	4.05	.636	16.25	4.03	.634	16.13	4.02	.631
15	15.38	3.92	.615	15.25	3.91	.614	15.13	3.89	.610
14	14.38	3.79	.595	14.25	3.78	.593	14.13	3.76	.591
13	13.38	3.66	.574	13.25	3.64	.571	13.13	3.62	.568
12	12.38	3.52	.553	12.35	3.50	.550	12.13	3.48	.546
11	11.38	3.37	.529	11.25	3.35	.526	11.13	3.34	.524
10	10.38	3.22	.506	10.25	3.20	.503	10.13	3.18	.499
9	9.38	3.06	.481	9.25	3.04	.477	9.13	3.02	.474
8	8.38	2.90	.455	8.25	2.87	.450	8.13	2.85	.447
7	7.38	2.72	.427	7.25	2.69	.422	7.13	2.67	.419
6	6.38	2.53	.397	6.25	2.50	.393	6.13	2.48	.389
5	5.38	2.32	.364	5.25	2.29	.359	5.13	2.27	.356
4	4.38	2.09	.328	4.25	2.06	.323	4.13	2.03	.319
3	3.38	1.84	.289	3.25	1.80	.283	3.13	1.77	.278
2	2.38	1.54	.242	2.25	1.50	.236	2.13	1.46	.229
1	1.38	1.18	.185	1.25	1.12	.176	1.13	1.06	.167

R.A. COLLACOTT

TEST No. 3/1 (Contd)

TIME OF FLOW 50 secs. ORIFICE DIAMETER 1/2"

DISCHARGE COEFFICIENT

HEAD H INS.	ORIFICE LENGTH									
	4⅛"	4"	3⅞"	3¾"	3⅝"	3½"	3⅜"	3¼"	3⅛"	
20	.786	.781	.799	.828	.837	.815	.836	.845	.839	
19	.782	.791	.812	.822	.817	.802	.848	.840	.837	
18	.784	.794	.803	.835	.833	.791	.837	.846	.816	
17	.790	.797	.808	.839	.829	.797	.848	.842	.833	
16	.786	.781	.819	.837	.825	.803	.834	.852	.847	
15	.799	.789	.816	.833	.825	.806	.833	.842	.845	
14	.788	.785	.797	.833	.824	.799	.853	.831	.859	
13	.798	.803	.798	.837	.830	.801	.848	.834	.862	
12	.777	.800	.814	.828	.828	.809	.848	.850	.860	
11	.768	.774	.803	.824	.834	.805	.843	.833	.836	
10	.777	.777	.799	.828	.827	.813	.848	.841	.849	
9	.767	.780	.799	.816	.819	.797	.815	.841	.844	
8	.773	.770	.790	.808	.811	.813	.843	.853	.833	
7	.701	.778	.801	.823	.832	.781	.832	.849	.834	
6	.781	.772	.798	.833	.811	.790	.867	.816	.826	
5		.772	.823							
4		.760	.796							
3										
2										
1										

R. A. COLLACOTT.

TEST No. 3/1 (Contd)

TIME OF FLOW 50 secs. ORIFICE DIAMETER 1/2"

DISCHARGE COEFFICIENT

HEAD H INS.	ORIFICE LENGTH									
	3"	2 7/8"	2 3/4"	2 5/8"	2 1/2"	2 3/8"	2 1/4"	2 1/8"	2"	
20	.850	.853	.838	.849	.850	.855	.849	.842	.850	
19	.829	.842	.836	.848	.852	.844	.850	.853	.862	
18	.848	.851	.844	.839	.839	.854	.850	.862	.856	
17	.849	.858	.856	.842	.853	.857	.858	.873	.853	
16	.853	.862	.853	.833	.862	.874	.860	.883	.850	
15	.840	.865	.851	.858	.864	.869	.861	.874	.864	
14	.836	.853	.853	.843	.871	.860	.857	.857	.844	
13	.842	.868	.837	.851	.851	.863	.863	.861	.858	
12	.843	.858	.840	.854	.858	.879	.878	.845	.873	
11	.847	.859	.855	.865	.873	.854	.858	.828	.853	
10	.830	.848	.842	.851	.869	.869	.872	.821	.852	
9	.840	.857	.838	.836	.878	.857	.874	.835	.863	
8	.861	.875	.819	.843	.861	.853	.874	.850	.858	
7	.861	.870	.851	.823	.866	.871	.831	.852	.862	
6	.829	.841	.839	.847	.850	.846	.855	.854	.891	
5						.847				
4						.902				
3										
2										
1										

TEST No. 3/1 (Contd)

TIME OF FLOW 50 secs. ORIFICE DIAMETER 1/2"

DISCHARGE COEFFICIENT

HEAD H INS.	ORIFICE LENGTH									
	1 7/8	1 3/4"	1 5/8"	1 1/2"	1 3/8"	1 1/4"	1 1/8"	1"	7/8"	
20	.867	.861	.859	.866	.863	.871	.874	.888	.890	
19	.857	.851	.861	.866	.869	.870	.880	.876	.882	
18	.853	.857	.865	.878	.839	.872	.878	.873	.864	
17	.862	.862	.871	.885	.856	.869	.868	.878	.875	
16	.871	.863	.857	.882	.868	.865	.878	.868	.884	
15	.868	.883	.869	.874	.874	.852	.872	.867	.873	
14	.859	.870	.855	.860	.864	.848	.886	.862	.881	
13	.864	.858	.859	.863	.867	.841	.862	.871	.869	
12	.840	.860	.856	.854	.871	.859	.857	.846	.882	
11	.839	.877	.858	.858	.866	.870	.877	.854	.871	
10	.856	.874	.881	.864	.869	.848	.879	.861	.864	
9	.848	.882	.868	.857	.872	.843	.879	.819	.887	
8	.876	.865	.822	.864	.875	.859	.887	.845	.860	
7	.855	.852	.861	.870	.870	.865	.859	.858	.883	
6	.843	.870	.833	.865	.859	.851	.826	.884	.876	
5										
4										
3										
2										
1										

R. A. COLLACOTT.

TEST No. 3/1 (Contd)

TIME OF FLOW 50 secs.   ORIFICE DIAMETER 1/2"

DISCHARGE COEFFICIENT

HEAD H INS.	ORIFICE LENGTH									
	3/4"	5/8"	1/2"	3/8"	1/4"	1/8"				
20	.853	.849	.674	.672	.663	.696				
19	.874	.679	.683	.679	.677	.696				
18	.874	.664	.646	.654	.641	.667				
17	.862	.671	.643	.658	.654	.676				
16	.832	.657	.659	.673	.648	.682				
15	.841	.645	.673	.687	.864	.688				
14	.863	.616	.657	.661	.651	.678				
13	.842	.622	.660	.663	.654	.664				
12	.858	.636	.657	.683	.668	.664				
11	.854	.629	.658	.663	.661	.687				
10	.838	.607	.635	.646	.657	.658				
9	.867	.630	.644	.670	.658	.658				
8	.863	.651	.673	.639	.656	.671				
7	.848	.657	.637	.656	.683	.637				
6	.662	.648	.626	.656	.662	.682				
5		.667								
4		.651								
3		.701								
2		.713								
1		.697								

R. A COLLACOTT.

EXPERIMENT No. 2.

Tests Nos. 1/2 & 2/2

TIME OF FLOW: <u>60 mins = 3600 secs.</u>

Head over Inlet H	H+L	0.050" H+L	Q	C_D	0.030" H+L	H+L	Q	C_D
20	20.13	4.49	.508	.800	20.13	4.49	.184	.805
19	19.13	4.37	.494	.773	19.13	4.37	.179	
18	18.13	4.26	.481	.773	18.13	4.26	.175	.748
17	17.13	4.14	.468		17.13	4.14	.170	
16	16.13	4.02	.455	.761	16.13	4.02	.165	.783
15	15.13	3.89	.440		15.13	3.89	.159	
14	14.13	3.76	.425	.789	14.13	3.76	.154	.773
13	13.13	3.62	.409		13.13	3.62	.148	
12	12.13	3.48	.393	.764	12.13	3.48	.143	.758
11	11.13	3.34	.377		11.13	3.34	.137	
10	10.13	3.18	.359	.775	10.13	3.18	.130	.761
9	9.13	3.02	.341		9.13	3.02	.124	
8	8.13	2.85	.322	.777	8.13	2.85	.117	
7	7.13	2.67	.302		7.13	2.67	.110	
6	6.13	2.48	.280	.776	6.13	2.48	.102	
5	5.13	2.27	.257		5.13	2.27	.093	
4	4.13	2.03	.230	.752	4.13	2.03	.083	
3	3.13	1.77	.200		3.13	1.77	.073	
2	2.13	1.46	.165		2.13	1.46	.060	
1	1.13	1.06	.120		1.13	1.06	.044	

<u>Observations:</u> Basic equation for calculation of Q is:

Diameter 0.050" $Q = 3600 \times 0.314.10^{-4}$ H+L

$= 0.113$ H+L cu.ft.

Diameter 0.030" $Q = 3600 \times 0.113.10^{-4}$ H+L

$= 0.041$ H+L cu.ft.

EXPERIMENT No. 3.

Test No. 1/3

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/4"

THEORETICAL DISCHARGE AND THE DISCHARGE COEFFICIENT

Head over Inlet	$H+\frac{1}{8}$	$H+\frac{1}{8}$	Q50	LENGTH (CD) $2\frac{1}{8}$"	2"	$1\frac{7}{8}$"	$1\frac{3}{4}$"	$1\frac{5}{8}$"
20	20.13	4.49	.177	.769	.854	.791		
19	19.13	4.37	.172	.779	.866	.809	.924	.814
18	18.13	4.26	.167	.784	.886	.809		
17	17.13	4.14	.163	.791	.878	.791	.890	.791
16	16.13	4.02	.158	.791	.861	.811		
15	15.13	3.89	.153	.785	.850	.799	.909	.818
14	14.13	3.76	.148	.764	.845	.804		
13	13.13	3.62	.142	.767	.852	.816	.880	.824
12	12.13	3.48	.137	.781	.869	.811		
11	11.13	3.34	.131	.779	.870	.817	.908	.809
10	10.13	3.18	.125	.767	.856	.816		
9	9.13	3.02	.119	.780	.849	.824	.832	.824
8	8.13	2.85	.112	.777	.857	.857		
7	7.13	2.67	.105	.781	.810		.771	.771
6	6.13	2.48	.097		.814			
5	5.13	2.27	.089				.809	
4	4.13	2.03	.080				.800	
3	3.13	1.77	.070				.814	
2	2.13	1.46	.057				.807	
1	1.13	1.06	.042					

<u>Observations:</u> (1) Basic equation used for calculations is

$$Q50 = 3.93.10^{-2}\ H+\tfrac{1}{8}$$

(2) Following table of the additional results for 2" long nozzle:-

H	5	$4\frac{1}{2}$	4	$3\frac{1}{2}$	3	$2\frac{1}{2}$	$2\frac{1}{4}$	$2\frac{1}{8}$	$2\frac{1}{16}$	$2\frac{1}{32}$	2
$H+\frac{1}{8}$	5.13	4.63	4.13	3.63	3.13	2.63	2.38	2.25	2.19	2.16	2.13
$H+\frac{1}{8}$	2.27	2.15	2.03	1.91	1.77	1.62	1.54	1.50	1.48	1.47	1.46
Q50	.089	.885	.080	.075	.070	.064	.061	.059	.058	.058	.057
C_D	.844	.788	.813	.827	.829	.829	.803	.763	.759	.759	.702

TEST No. 1/3

TIME OF FLOW 50 secs. ORIFICE DIAMETER 1/4"

DISCHARGE COEFFICIENT

HEAD H INS.	LENGTH									
	1½"	1⅜"	1¼"	1⅛"	1"	⅞"	¾"	⅝"	½"	
20	.849	.849					.849		.831	
19	.843			.831			.843		.826	
18		.839		.796						
17	.859									
16		.836		.816						
15	.850	.836					.811		.784	
14										
13	.845	.845		.824			.800		.771	
12										
11	.818	.832		.794			.772		.740	
10										
9	.824									
8		.831		.804			.813		.813	
7	.771	.791		.771						
6										
5	.831									
4	.825						.762		.838	
3	.842									
2	.878									
1										

Test No. 2/3

TIME OF FLOW: 50 secs. ORIFICE DIAMETER 1/2"

THEORETICAL DISCHARGE AND THE DISCHARGE COEFFICIENT

Head H Ins	H+⅛	H+½	Q50	LENGTH (C_D) 4⅛	4	3⅞	3¾	3⅝
20	20.13	4.49	.705	.809	.795	.818	.835	.835
19	19.13	4.37	.686	.811	.811	.829	.829	.831
18	18.13	4.26	.670	.804	.788	.820	.831	.833
17	17.13	4.14	.650	.801	.796	.816	.840	.834
16	16.13	4.02	.631	.797	.798	.820	.845	.825
15	15.13	3.89	.610	.800	.803	.799	.840	.831
14	14.13	3.76	.591	.791	.789	.810	.844	.840
13	13.13	3.62	.568	.809	.798	.825	.841	.839
12	12.13	3.48	.546	.806	.804	.807	.834	.844
11	11.13	3.34	.524	.790	.785	.818	.833	.818
10	10.13	3.18	.499	.791	.801	.806	.851	.829
9	9.13	3.02	.474	.807	.789	.808	.841	.821
8	8.13	2.85	.447	.792	.808	.821	.821	.817
7	7.13	2.67	.419	.805	.764	.819	.857	.819
6	6.13	2.48	.389	.816	.771			.831
5	5.13	2.27	.356	.796	.831			.823
4	4.13	2.03	.319		.642			.821
3	3.13	1.77	.278					
2	2.13	1.46	.229					
1	1.13	1.06	.167					

TEST NO. 2/3

TIME OF FLOW 50 secs. ORIFICE DIAMETER 1/2"

DISCHARGE COEFFICIENT

HEAD H INS.	Length									
	$3\frac{1}{2}$	$3\frac{3}{8}$	$3\frac{1}{4}$	$3\frac{1}{8}$	3	$2\frac{7}{8}$	$2\frac{3}{4}$	$2\frac{5}{8}$	$2\frac{1}{2}$	
20	.783	.823	.849	.831	.822	.804	.817	.840	.850	
19	.791	.831	.849	.341	.844	.820	.837	.850	.346	
18	.793	.839	.849	.840	.845	.839	.836	.835	.840	
17	.790	.851	.843	.845	.832	.829	.835	.832	.832	
16	.803	.852	.855	.359	.827	.832	.840	.854	.848	
15	.795	.837	.854	.839	.836	.825	.833	.873	.354	
14	.784	.826	.828	.846	.828	.809	.836	.850	.842	
13	.309	.825	.842	.349	.841	.810	.840	.835	.846	
12	.785	.834	.843	.838	.838	.816	.825	.826	.863	
11	.775	.828	.856	.341	.830	.817	.330	.815	.869	
10	.791	.806	.839	.819	.824	.821	.842	.838	.857	
9	.796	.825	.840	.836	.840	.804	.830	.844	.844	
8	.790	.841	.843	.835	.821	.812	.821	.846	.866	
7	.779	.826	.866	.861	.835	.816	.814	.849	.854	
6										
5										
4										
3										
2										
1										

R. A. COLLACOTT.

TEST NO. 2/3

TIME OF FLOW 50 secs. ORIFICE DIAMETER 1/2"

DISCHARGE COEFFICIENT

HEAD H INS.	LENGTH									
	$2\frac{3}{8}$	$2\frac{1}{4}$	$2\frac{1}{8}$	2	$1\frac{7}{8}$	$1\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{1}{8}$	$1\frac{3}{8}$	
20	.863	.845	.839	.836	.845	.856	.858	.867	.856	
19	.871	.841	.831	.841	.841	.854	.865	.870		
18	.870	.840	.836	.836	.840	.858	.876	.881	.856	
17	.850	.849	.851	.854	.849	.850	.865	.879		
16	.865	.848	.828	.845	.844	.861	.858	.871	.841	
15	.890	.844	.847	.838	.838	.865	.866	.869		
14	.870	.861	.856	.846	.849	.842	.861	.856	.846	
13	.881	.856	.837	.851	.861	.846	.860	.878		
12	.870	.863	.863	.869	.863	.849	.861	.890	.820	
11	.860	.865	.851	.843	.843	.859	.843	.848		
10	.890	.856	.841	.855	.840	.854	.860	.857	.849	
9	.893	.861	.844	.826	.840	.830	.845	.851		
8	.846	.846	.832	.849	.806	.839	.848	.859	.821	
7	.871	.852	.880	.854	.842	.831	.846	.845	.811	
6										
5										
4										
3										
2										
1										

R. A. COLLACOTT.

TEST NO. 2/3

TIME OF FLOW 50 secs. ORIFICE DIAMETER 1/2"

DISCHARGE COEFFICIENT

HEAD H INS.	LENGTH									
	1¼	1⅛	1	⅞	¾	⅝	½	⅜	¼	
20	.868	.868	.851	.865	.849	.861	.605	.667	.667	
19										
18	.868	.868	.836	.865	.865	.871	.626	.661	.650	
17										
16	.858	.840	.839	.861	.859	.806	.649	.663	.651	
15										
14	.896	.864	.846	.882	.879	.846	.629	.677	.674	
13										
12	.881	.846	.839	.849	.842	.839	.647	.659	.665	
11										
10	.860	.849	.824	.841	.854	.856	.649	.661	.651	
9										
8	.850	.850	.828	.893	.671	.674	.669	.671	.656	
7	.854	.856	.856	.716			.671	.649	.639	
6										
5										
4										
3										
2										
1										

R. A. COLLACOTT.

EXPERIMENT No. 4.

No Calculations

EXPERIMENT No. 5.

TEST No. 1/5

TIME OF FLOW 25 secs.

ORIFICE LENGTH 2_8"
DIAMETER $\frac{1}{2}$"

DISCHARGE COEFFICIENT

HEAD H INS.	HALF INCLUDED ANGLE OF BEVEL									
	Q25		15°	30°	45°	60°	75°			
20	.369		.814	.870	.950	.941	.919			
19	.361									
18	.353		.845	.866		.924				
17	.343									
16	.334		.828	.866	.934	.925	.922			
15	.325									
14	.316		.841	.864		.918				
13	.305									
12	.295		.845	.861	.939	.900	.926			
11	.284									
10	.273		.850	.864		.909				
9	.262									
8	.250		.820	.876	.920	.903	.920			
7	.237									
6	.224		.835	.843		.911				
5	.209									
4	.195		.831	.836	.899	.923	.933			
3	.178									
2	.159									
1	.139									

R. A. COLLACOTT.

TEST No. 2/5

TIME OF FLOW 50 secs.

ORIFICE LENGTH $\frac{1}{8}$"
DIAMETER $\frac{1}{2}$"

DISCHARGE COEFFICIENT

HEAD H INS.	HALF INCLUDED ANGLE OF BEVEL									
			15	30	45	60	75			
20			.823	.865	.805	.718	.667			
19			.815	.868	.772	.700	.668			
18			.825	.875	.771	.715	.673			
17			.836	.870	.783	.721	.690			
16			.826	.885	.786	.715	.694			
15			.820	.880	.775	.706	.693			
14			.831	.869	.780	.710	.661			
13			.824	.895	.786	.723	.679			
12			.830	.882	.790	.715	.686			
11			.840	.916	.808	.707	.704			
10			.849	.913	.790	.706	.688			
9			.875	.910	.789	.694	.677			
8			.868	.895	.785	.716	.693			
7			.888	.915	.798	.714	.709			
6			.888	.903	.830	.738	.746			
5										
4										
3										
2										
1										

R. A. COLLACOTT.

EXPERIMENT No. 6.

TEST No. 1/6

TIME OF FLOW 25 secs.

ORIFICE LENGTH 2⅛"
DIAMETER ½"

DISCHARGE COEFFICIENT

HEAD H INS.	FACE CIRCLE DIAMETER C_D									
	025	9/16	5/8	3/4						
20	.369	.921	.950	.943						
19	.361									
18	.353									
17	.343									
16	.334	.938	.935	.935						
15	.325									
14	.316									
13	.305									
12	.295	.919	.940	.935						
11	.284									
10	.273									
9	.262									
8	.250	.901	.920	.920						
7	.237									
6	.224									
5	.209									
4	.195	.871	.898	.898						
3	.178									
2	.159									
1	.139									

1=2x45
= 90°

R. A. COLLACOTT.

TEST No. 2/6

TIME OF FLOW 50 secs.

ORIFICE LENGTH 1/8"
DIAMETER 1/2"

DISCHARGE COEFFICIENT

1 = 2x45 = 90° 1 = 2x60 = 120°

HEAD H INS.	FACE CIRCLE DIAMETER									
	050	9/16	5/8	11/16	3/4	9/16	5/8	11/16	3/4	
20	.705	.737	.775	.794	.791	.737	.702	.713	.708	
19	.686	.779	.769	.772	.770	.725	.704	.709	.705	
18	.670	.774	.767	.779	.772	.730	.705	.714	.707	
17	.650	.790	.781	.789	.779	.707	.707	.700	.706	
16	.631	.795	.767	.793	.790	.720	.710	.707	.712	
15	.610	.800	.769	.772	.770	.703	.710	.708	.710	
14	.591	.786	.775	.775	.779	.713	.709	.707	.709	
13	.568	.795	.779	.785	.786	.719	.720	.719	.716	
12	.546	.800	.775	.796	.792	.699	.726	.725	.711	
11	.524	.819	.799	.808	.806	.711	.706	.706	.706	
10	.499	.809	.777	.784	.786	.695	.719	.699	.706	
9	.474	.823	.766	.791	.795	.698	.693	.696	.696	
8	.447	.824	.776	.783	.787	.707	.709	.706	.706	
7	.419	.814	.785	.790	.800	.702	.716	.718	.718	
6	.369	.841	.818	.830	.838	.739	.741	.741	.736	
5	.356									
4	.319									
3	.278									
2	.227									
1	.167									

R. A. COLLACOTT.

EXPERIMENT No. 7

No Calculations

EXPERIMENT No. 8.

TEST No. 1/8

TIME OF FLOW 25 secs.

ORIFICE LENGTH $\frac{1}{8}$"
DIAMETER $\frac{1}{2}$"

APERTURE DISCHARGE COEFFICIENT

HEAD H INS.	APERTURE DIAMETER								
	.250	.270	.290	.310	.330	.350	.370	.390	.400
20	.088	.103	.118	.135	.164	.173	.194	.214	.226
19	.086	.100	.115	.132	.159	.168	.188	.209	.219
18	.084	.098	.113	.129	.155	.164	.184	.204	.215
17	.081	.095	.109	.125	.151	.159	.178	.198	.208
16	.079	.092	.106	.121	.146	.155	.173	.192	.202
15	.077	.089	.103	.117	.142	.149	.167	.186	.195
14	.074	.086	.099	.113	.137	.145	.162	.179	.189
13	.071	.083	.096	.109	.132	.139	.156	.173	.182
12	.068	.080	.092	.105	.127	.134	.150	.166	.175
11	.066	.077	.088	.101	.121	.128	.143	.159	.168
10	.062	.073	.084	.096	.116	.122	.137	.151	.160
9	.059	.069	.080	.091	.110	.117	.130	.145	.152
8	.056	.065	.075	.086	.104	.110	.123	.136	.143
7	.052	.061	.070	.080	.097	.103	.115	.127	.134
6	.049	.057	.066	.075	.090	.096	.107	.118	.125
5	.045	.052	.060	.068	.083	.087	.098	.108	.114
4	.040	.047	.054	.062	.074	.078	.088	.097	.102
3	.035	.041	.047	.053	.064	.068	.076	.085	.089
2	.029	.033	.038	.044	.053	.056	.063	.070	.073
1	.021	.024	.028	.032	.039	.041	.046	.051	.053

R. A. COLLACOTT.

TEST No. 1/8

TIME OF FLOW 25 secs

ORIFICE LENGTH 1/8"
DIAMETER 1/2"

THEORETICAL DISCHARGE

HEAD H INS.	APERTURE DIAMETER								
	.410	.420	.430	.440	.450	.460	.470	.480	.490
20	.237	.249	.261	.274	.285	.298	.312	.323	.339
19	.231	.242	.254	.266	.278	.290	.303	.315	.329
18	.226	.237	.249	.260	.272	.284	.297	.308	.322
17	.219	.230	.241	.252	.263	.275	.288	.299	.312
16	.213	.223	.233	.245	.256	.267	.279	.290	.303
15	.205	.215	.226	.237	.247	.258	.270	.281	.293
14	.199	.208	.218	.229	.239	.250	.261	.272	.283
13	.192	.200	.210	.220	.230	.240	.251	.261	.273
12	.185	.193	.202	.212	.221	.232	.242	.252	.263
11	.177	.185	.194	.203	.212	.222	.231	.241	.251
10	.168	.176	.184	.193	.202	.211	.220	.229	.239
9	.160	.168	.176	.184	.192	.201	.210	.218	.228
8	.151	.158	.166	.174	.181	.189	.198	.206	.216
7	.141	.148	.155	.162	.169	.177	.185	.193	.201
6	.131	.138	.144	.151	.158	.165	.172	.179	.187
5	.120	.136	.132	.138	.144	.151	.158	.164	.171
4	.108	.113	.118	.124	.129	.135	.141	.147	.153
3	.094	.098	.103	.108	.113	.118	.123	.128	.134
2	.077	.081	.085	.089	.093	.097	.101	.105	.110
1	.056	.059	.062	.065	.068	.071	.074	.077	.080

For all further calculations of the aperture-diameter = 0.500 ins. case the values of the theoretical discharge were taken from those calculated in test 3/1, length = 1/8".

R. A. COLLACOTT.

TEST No. 1/8

TIME OF FLOW 25 secs.

APERTURE ORIFICE LENGTH 0.020"
ORIFICE DIAMETER

DISCHARGE COEFFICIENT

HEAD H INS.	APERTURE DIAMETER									
	.250	.270	.290	.310	.330	.350	.370	.390	.410	
20	.625	.656	.657	.666	.679	.749	.890	.887	.928	
19	.628	.670								
18										
17										
16	.646	.683	.660	.701	.686	.761	.896	.895	.911	
15										
14	.663		.666							
13										
12	.661	.650	.652	.676	.677	.747	.827	.904	.934	
11										
10	.678									
9										
8	.661	.693	.694	.721	.682	.781	.813	.846	.922	
7										
6	.694									
5										
4	.700	.724	.686	.727	.703	.770	.796	.888	.890	
3										
2										
1										

R. A. COLLACOTT.

TEST No. 1/8

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
APERTURE-ORIFICE LENGTH 0.025"

DISCHARGE COEFFICIENT

HEAD H INS.	APERTURE DIAMETER									
	.430	.450	.470	.490	.500					
20	.933	.802	.708	.665	.640					
19										
18										
17										
16	.975	.773	.721	.664	.635					
15										
14										
13										
12	.942	.784	.728	.673	.646					
11										
10										
9										
8	.964	.796	.768	.684	.663					
7										
6										
5										
4	1.00	.846	.781	.719	.691					
3										
2										
1										

R. A. COLLACOTT.

TEST NO. 2/8

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
APERTURE-ORIFICE THICKNESS 0.040"

DISCHARGE COEFFICIENT

HEAD H INS.	APERTURE DIAMETER									
	.250	.270	.290	.310	.330	.350	.370	.390	.410	
20	.654	.655	.678	.644	.671	.729	.789	.827	.929	
19	.569									
18										
17										
16	.661	.656	.651	.661	.699	.729	.790	.886	.930	
15										
14										
13										
12	.624	.663	.633	.657	.646	.731	.773	.874	.892	
11										
10										
9										
8	.628	.654	.667	.640	.673	.772	.789	.867	.947	
7										
6										
5										
4	.725	.701	.806	.733	.702	.768	.830	.856	.906	
3										
2										
1										

R. A. COLLACOTT.

TEST No. 2/8

TIME OF FLOW 25 secs

ORIFICE DIAMETER 1/2"
APERTURE-ORIFICE THICKNESS 0.040"

DISCHARGE COEFFICIENT

HEAD H INS.	APERTURE DIAMETER									
	.430	.450	.470	.490	.500					
20	.943	.966	.721	.667	.641					
19										
18										
17										
16	.966	.940	.701	.663	.634					
15										
14										
13										
12	.956	.792	.728	.678	.652					
11										
10										
9										
8	.964	.801	.738	.683	.662					
7										
6										
5										
4	.950	.846	.774	.719	.697					
3										
2										
1										

R. A. COLLACOTT.

TEST No. 3/8

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
APERTURE-ORIFICE THICKNESS 0.060"

DISCHARGE COEFFICIENT

HEAD H INS.	APERTURE DIAMETER									
	.400	.410	.420	.430	.440	.450	.460	.470	.480	
20	.833	.889	.964	.962	.950	.970	.756	.711	.697	
19										
18		.926							.699	
17										
16	.866	.949	.972	.971	.996	.784	.783	.739	.688	
15										
14		.955								
13										
12	.886	.913	.9[illegible]6	.977	.995	.791	.776	.744	.714	
11										
10		.940								
9										
8	.916	.888	.968	.982	.982	.801	.703	.763	.728	
7										
6	.889	.917	.949	.951	.960	.823	.788	.756	.716	
5										
4										
3										
2										
1										

R. A. COLLACOTT.

TEST No. 3/8

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
APERTURE [illegible] C,060

DISCHARGE COEFFICIENT

HEAD H INS.	APERTURE DIAMETER									
	.400	.600								
20	.658	.635								
19										
18										
17										
16	.678	.653								
15										
14										
13										
12	.689	.651								
11										
10										
9										
8	.683	.668								
7										
6	.690	.664								
5										
4										
3										
2										
1										

R. A. COLLACOTT.

TEST No. 4/8

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"

APERTURE-ORIFICE DIAMETER 0.080"

DISCHARGE COEFFICIENT

HEAD H INS.	APERTURE DIAMETER									
	.400	.410	.420	.430	.440	.450	.460	.470	.480	
20	.743	.697	.804	.878	.934	.883	.968	.754	.713	
19										
18										
17										
16	.742	.752	.799	.901	.942	.922	.926	.750	.701	
15										
14										
13										
12	663	.757	.840	.887	.968	.945	.948	.748	.716	
11										
10										
9										
8	.721	.768	.854	.958	.931	.957	.980	.768	.739	
7										
6	.728	.763	.805	.938	.927	.944	.824	.785	.754	
5										
4										
3										
2										
1										

R. A. COLLACOTT.

TEST NO. 4/8

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
APERTURE-ORIFICE THICKNESS 0.080"

DISCHARGE COEFFICIENT

HEAD H INS.	APERTURE DIAMETER									
	.490	.500								
20	.675	.653								
19										
18										
17										
16	.689	.663								
15										
14										
13										
12	.688	.663								
11										
10										
9										
8	.693	.677								
7										
6	.723	.694								
5										
4										
3										
2										
1										

R. A. COLLACOTT.

TEST No. 5/8

TIME OF FLOW 25 secs

ORIFICE DIAMETER 1/2"
APERTURE-ORIFICE THICKNESS 0.100"

DISCHARGE COEFFICIENT

HEAD H INS.	APERTURE DIAMETER									
	.400	.410	.420	.430	.440	.450	.460	.470	.480	
20	.686	.675	.703	.751	.751	.826	.856	.731	.713	
19			.711							
18	.699		.722							
17			.735							
16	.689	.709	.718	.747	.797	.828	.880	.717	.681	
15			.725							
14			.736							
13										
12	.692	.698	.710	.749	.774	.855	.844	.732	.687	
11										
10	.688		.739							
9										
8	.686	.696	.748	.777	.776	.840	.838	.739	.703	
7										
6	.680	.701	.725	.771	.828	.856	.910	.721	.682	
5										
4										
3										
2										
1										

R. A. COLLACOTT.

TEST No. 5/8

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
APERTURE-ORIFICE THICKNESS 0.100"

DISCHARGE COEFFICIENT

HEAD H INS.	APERTURE DIAMETER									
	.490	.500								
20	.675	.647								
19										
18										
17										
16	.668	.648								
15										
14										
13										
12	.658	.638								
11										
10										
9										
8	.665	.654								
7										
6	.647	.628								
5										
4										
3										
2										
1										

R. A. COLLACOTT.

EXPERIMENT No.9

TEST No. 1/9

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
APERTURE DEPTH FROM INLET 1/4"

THEORETICAL DISCHARGE[x]

HEAD H INS.	APERTURE DIAMETER									
	.250	.300	.350	.375	.400	.425	.450	.475		
20	.163	.245	.379	.640	.767	.813	.837	.846		
19										
18	.159	.244					.854			
17										
16	.164	.246	.386	.634	.586	.808	.838	.846		
15										
14		.250					.853			
13										
12	.158	.246	.387	.644	.556	.790	.850	.868		
11										
10	.154	.246				.810				
9										
8	.152	.240	.379	.644	.560	.803	.825	.825		
7										
6		.241					.844			
5										
4	.155	.230	.379	.601	.669	.782	.824	.826		
3										
2										
1										

x Based on the assumption of "full-flow" through the nozzle, so that the theoretical discharge is the same as for a plain nozzle ½" bore 2⅛" long. (See calculations for experiment No. 1.)

R. A. COLLACOTT.

TEST No. 2/9

TIME OF FLOW 25 secs. ORIFICE DIAMETER 1/2"
APERTURE DEPTH FROM INLET 3/8"

DISCHARGE COEFFICIENT

HEAD H INS.	APERTURE DIAMETER									
	.350	.375	.400	.425	.450	.475				
20	.382	.650	.731	.805	.807	.813				
19										
18										
17										
16	.386	.646	.739	.766	.811	.813				
15										
14										
13										
12	.373	.647	.725	.752	.804	.810				
11										
10										
9										
8	.380	.644	.716	.765	.800	.809				
7										
6										
5										
4	.350	.607	.684	.731	.798	.809				
3										
2										
1										

R. A. COLLACOTT.

TEST No. 3/9

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
APERTURE DEPTH FROM INLET 1/2"

DISCHARGE COEFFICIENT

HEAD H INS.	APERTURE DIAMETER									
	.350	.375	.400	.425	.450	.475				
20	.363	.600	.686	.730	.796	.795				
19										
18										
17										
16	.359	.604	.700	.715	.804	.810				
15										
14										
13										
12	.356	.600	.688	.716	.797	.810				
11										
10										
9										
8	.354	.596	.672	.756	.773	.813				
7										
6										
5										
4	.335	.566	.679	.709	.756	.823				
3										
2										
1										

R. A. COLLACOTT.

TEST No. 4/9

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
APERTURE DEPTH FROM INLET 1/16"

DISCHARGE COEFFICIENT

HEAD H INS.	APERTURE DIAMETER									
	.350	.375	.400	.425	.450	.475				
20	.317	.381	.490	.710	.884	.922				
19										
18										
17										
16	.314	.380	.496	.712	.853	.894				
15										
14										
13										
12	.319	.383	.444	.709	.854	.919				
11										
10										
9										
8	.317	.380	.484	.711	.848	.921				
7										
6										
5										
4	.298	.340	.468	.730	.873	.861				
3										
2										
1										

TEST No. 5/9

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
APERTURE DEPTH FROM INLET 5/8"

DISCHARGE COEFFICIENT

HEAD H INS.	APERTURE DIAMETER									
	.350	.375	.400	.425	.450	.475				
20	.350	.570	.691	.760	.787	.814				
19										
18										
17										
16	.344	.572	.700	.761	.766	.811				
15										
14										
13										
12	.349	.568	.705	.761	.777	.813				
11										
10										
9										
8	.352	.565	.696	.759	.756	.801				
7										
6										
5										
4	.339	.562	.691	.752	.810	.810				
3										
2										
1										

R. A. COLLACOTT.

TABLE

Values of C_D based on full flow up to and through the aperture.

Values taken for the 20" head.

Aperture Diameter, ins.		.250	.300	.350	.375	.400
X		.125	.180	.246	.282	.322
Depth	Q25	.088	.127	.175	.199	.228
1/2"	C_D	.704	.713	.821	1.185	1.240
Depth	Q25	.088	.127	.175	.200	.228
3/8"	C_D			.806	1.080	1.080
Depth	Q25	.089	.127	.176	.200	.229
1/4"	C_D			.761	1.111	1.111
Depth	Q25	.089	.128	.176	.201	.230
1/8"	C_D			.733	1.045	1.111
Depth	Q25	.088	.127	.174	.198	.227
1/16"	C_D			.665	.712	.736

EXPERIMENT No. 10

TEST No. 1/10

TIME OF FLOW 25 secs

ORIFICE DIAMETER 1/2"
OBSTRUCTION - DISTANCE AHEAD $1\frac{1}{8}$"

DISCHARGE COEFFICIENT

HEAD H INS.	OBSTRUCTING ORIFICE DIAMETER									
	¼"	½"	1"	1¼"	1½"	1¾"	2"			
20	.695	.707	.676	.670	.655	.661	.661			
19										
18	.729									
17										
16	.739	.707	.675	.675	.660	.666	.666			
15										
14	.746	.742								
13										
12	.704	.707	.696	.674	.674	.671	.663			
11										
10	.724									
9										
8	.759	.759	.723	.683	.683	.679	.674			
7										
6	.743									
5										
4			.706	.684	.706	.684	.701			
3										
2										
1										

TEST No. 2/10

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
OBSTRUCTION - DISTANCE AHEAD 5/8"

DISCHARGE COEFFICIENT

HEAD H INS.	OBSTRUCTING ORIFICE DIAMETER									
	1/2"	5/8"	3/4"	7/8"	1"					
20	.706	.869	.738	.695	.667					
19										
18	.716									
17										
16	.717	.873	.761	.698	.676					
15										
14	.722									
13										
12	.744	.883	.774	.715	.660					
11										
10										
9										
8	.769	.871	.804	.728	.701					
7										
6	.775									
5										
4	.588	.857	.813	.750	.744					
3										
2										
1										

R. A. COLLACOTT.

TEST No. 3/10

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
OBSTRUCTION-DIAMETER AHEAD 4"

DISCHARGE COEFFICIENT

HEAD H INS.	OBSTRUCTING ORIFICE DIAMETER									
	1"	1 1/8"	1 3/16"	1 1/4"	1 5/16"	1 3/8"				
20	.642	.660	.637	.642	.639	.636				
19										
18										
17										
16	.654	.667	.641	.654	.652	.652				
15										
14										
13										
12	.652	.660	.630	.645	.649	.649				
11										
10										
9										
8	.656	.661	.643	.665	.651	.651				
7										
6										
5										
4										
3										
2										
1										

EXPERIMENT No. 11

No Calculations.

EXPERIMENT No. 12

TEST No. 1/12

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
WIDTH OF BAR 3/8"

DISCHARGE COEFFICIENT

HEAD H INS.	HEIGHT OF BOTTOM OF BAR ABOVE ORIFICE INLET									
	0	1/8"	1/4"	1/2"	7/8					
20	.122	.460	.610	.624	.627					
19										
18	.126									
17										
16	.130	.489	.619	.625	.635					
15										
14	.129									
13										
12	.128	.513	.612	.630	.633					
11										
10	.120									
9										
8	.100	.456	.560	.580	.580					
7										
6	.123									
5										
4	.119	.482	.637	.663	.663					
3										
2										
1										

TEST No. 2/12

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
WIDTH OF BAR 7"/32

DISCHARGE COEFFICIENT

HEAD H INS.	HEIGHT OF BOTTOM OF BAR ABOVE ORIFICE INLET									
	0	1/16	1/8	1/4	1/2	7/8				
20	.369	.477	.579	.607	.622	.623				
19										
18										
17										
16	.356	.477	.600	.606	.631	.631				
15										
14										
13										
12	.356	.501	.597	.626	.645	.652				
11										
10										
9										
8	.325	.444	.528	.576	.583	.587				
7										
6										
5										
4	.356	.481	.626	.688	.694	.701				
3										
2										
1										

R. A. COLLACOTT.

TEST No. 3/12

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
WIDTH OF BAR 1/8"

DISCHARGE COEFFICIENT

HEAD H INS.	HEIGHT OF BOTTOM OF BAR ABOVE ORIFICE INLET								
	0	1/16	1/8	1/4	1/2	7/8			
20	.489	.547	.591	.605	.610	.622			
19									
18									
17									
16	.486	.556	.594	.610	.620	.635			
15									
14									
13									
12	.484	.560	.604	.615	.635	.649			
11									
10									
9									
8	.440	.515	.536	.571	.588	.607			
7									
6									
5									
4	.519	.588	.626	.657	.694	.706			
3									
2									
1									

R. A. COLLACOTT.

TEST No. 4/12

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
WIDTH OF BAR 1/16"

DISCHARGE COEFFICIENT

HEAD H INS.	HEIGHT OF BOTTOM OF BAR ABOVE ORIFICE INLET									
	0	1/16	1/8	1/4	1/2	7/8				
20	.545	.607	.610	.616	.621	.624				
19										
18										
17										
16	.562	.619	.631	.631	.635	.638				
15										
14										
13										
12	.569	.623	.641	.652	.656	.656				
11										
10										
9										
8	.503	.559	.575	.587	.596	.596				
7										
6										
5										
4	.569	.676	.689	.701	.711	.719				
3										
2										
1										

R. A. COLLACOTT.

EXPERIMENT No. 13

TEST No. 1/13

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
DIAMETER OF DISC 4"

DISCHARGE COEFFICIENT

HEAD H INS.	HEIGHT BETWEEN BACK FACE AND ORIFICE INLET									
	1/8"	3/16	5/16	1/2	1"	2"	1/16			
20	.541	.593	.627	.639	.636	.628	.340			
19										
18		.597		.625						
17										
16	.559	.629	.631	.635	.645	.647	.346			
15										
14				.636						
13										
12	.545	.611	.631	.651	.648	.641	.348			
11										
10		.604								
9										
8	.571	.611	.670	.656	.643	.616	.348			
7										
6		.600								
5										
4	.569	.612	.656	.650	.656	.619	.362			
3										
2										
1										

R. A. COLLACOTT.

TEST No. 2/13

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
DIAMETER OF DISC. 3"

DISCHARGE COEFFICIENT

HEAD H INS.	HEIGHT BETWEEN BACK FACE AND ORIFICE INLET									
	1/16	1/8	1/4	1/2	1"	2"	3"			
20	.378	.511	.610	.639	.650	.644	.630			
19										
18							.626			
17										
16	.381	.509	.596	.631	.651	.632	.636			
15										
14					.547	.624				
13										
12	.384	.531	.596	.640	.648	.633	.644			
11										
10										
9										
8	.389	.527	.603	.652	.661	.634	.648			
7										
6						.621				
5										
4	.412	.556	.619	.683	.706	.650	.688			
3										
2										
1										

R. A. COLLACOTT.

TEST No. 3/13

TIME OF FLOW 25 secs.

ORIFICE DIAMETER 1/2"
DIAMETER OF DISC 2½

DISCHARGE COEFFICIENT

HEAD H INS.	HEIGHT BETWEEN BACK FACE AND ORIFICE INLET				
	1/16"	1/8"	1/4"	1/2	1"
20	.332	.565	.616	.330	.633
19					
18					
17					
16	.334	.555	.600	.635	.639
15					
14					
13					
12	.333	.560	.615	.637	.637
11					
10					
9					
8	.322	.569	.607	.652	.657
7					
6					
5					
4	.344	.569	.619	.656	.656
3					
2					
1					

EXPERIMENTS 14, 15, 16

No Calculations

APPENDIX 3.

Some notes regarding the possible influence of champfer on the C_D of an orifice.

When a sharp-edged orifice is champfered slightly, so that the included angle of champfer is fairly small, the breakaway of the jet occurs at the circumference of the champfer on the inlet face. This has the effect of allowing the fluid to enter through an area greater than the actual area of the or Hence the subsequent contraction of the jet may be such that on issuing from the orifice it has the same cross-sectional area as the orifice. (If this appears confusing, then it will be clarified by the subsequent illustrations). Under most conditions, however, this full-flow will not be obtained and hence the jet characteristics will vary with angle and size of champfer.

These variations in the characteristics of the jet from a champfered orifice are accompanied by marked variations in the discharge coefficients.

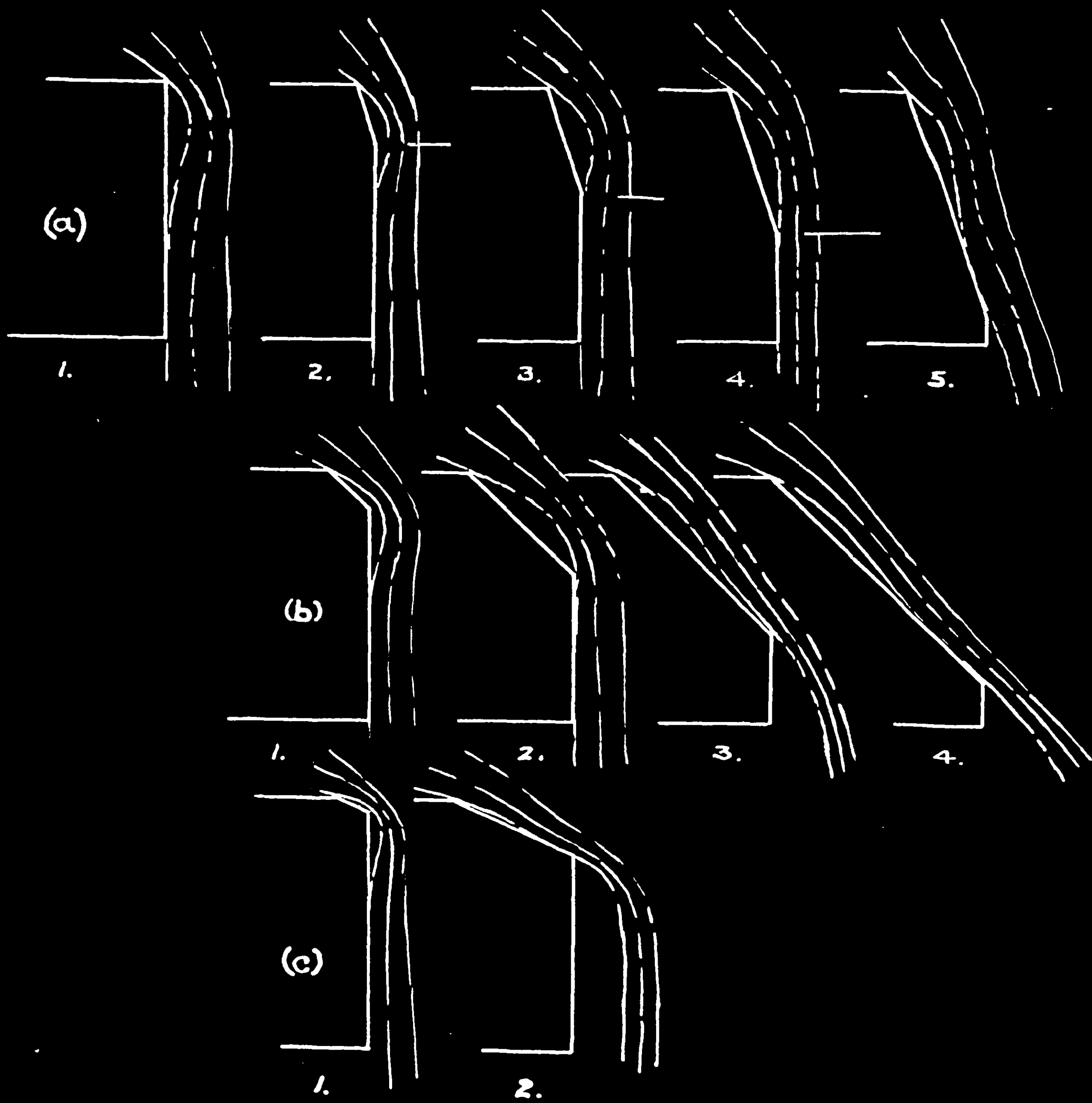
During the first stage, as the angle of champfer increases so the Cc increases owing to the greater development of the jet before leaving the orifice, and with this increase in Cc, the loss of head becomes smaller so that C_V is increased, hence C_D

increases as the angle increases.

For the conditions in which the jet either first re-expands into the throat of the aperture, as for a thin plate orifice, just contracts to the same cross section as the throat, the value of C_D will be a maximum. This will be due to the fact that Cc is then a maximum, and so also is Cv. It is not necessary under these conditions for the Cc to be unity, although it is very near this figure with the long nozzle; with a thin plate aperture, contraction of the jet may occur after the throat area has been reached, and so the issuing jet may have a cross section at the vena-contracta which is slightly smaller than that of the aperture.

When the jet strikes the sides of the conical champfer there will be a loss of head due to impact of the jet and a contraction of the jet due to its breakaway after a sloping entry into the throat causing Cc to decrease. Hence with increasing angle of champfer so the C_D would decrease.

These stages in the development of the flow through a champfered orifice are amplified in the following:-



FIGS. (I)

(a) <u>Angle acute.</u> Commencing with a shallow champfer (a.2.), as the depth of champfer is increased the contraction decreases and therefore Cc C_V and C_D increase. When, as in fig(a.4.) the depth reaches a certain maximum, the jet just issues with Cc approaching unity. Further increase in depth of champfer causes "coning" and a rapid drop in C_D, due to a reduction in both Cc and Cv.

(b), (c) Angle acute. As the acuteness of the angle of champfer is increased so does the depth for maximun C_D decrease in the manner indicated.

Combined Effects of Depth and Angle of Bevel.

These are identical in the following figure which is believed to be representative of the phenomena.

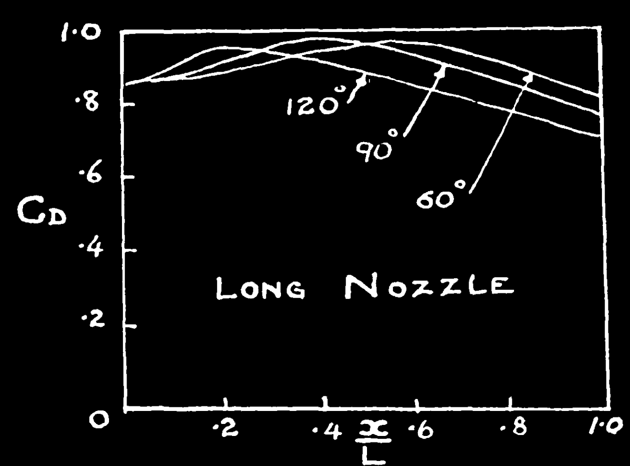


Fig.II.

Depth of Bevel $(\frac{x}{l})$

Thus, referring to Experiment No.6., 35.5. (p.53.) Observations With an included angle of bevel of 90° the maximum was probably reached with $\frac{x}{l}$ equal to between $\frac{5/8}{2\frac{1}{8}}$ and $\frac{3/4}{2\frac{1}{8}}$, i.e., $\frac{5}{17}$ or $\frac{6}{17}$, when the variation of C_D was very slight after a rapid increase between

$$\frac{x}{l} = \frac{9}{34} \text{ to } \frac{x}{l} = \frac{5}{17} \quad (\text{i.e. } \frac{10}{34}).$$

(b) THIN PLATE ORIFICES.

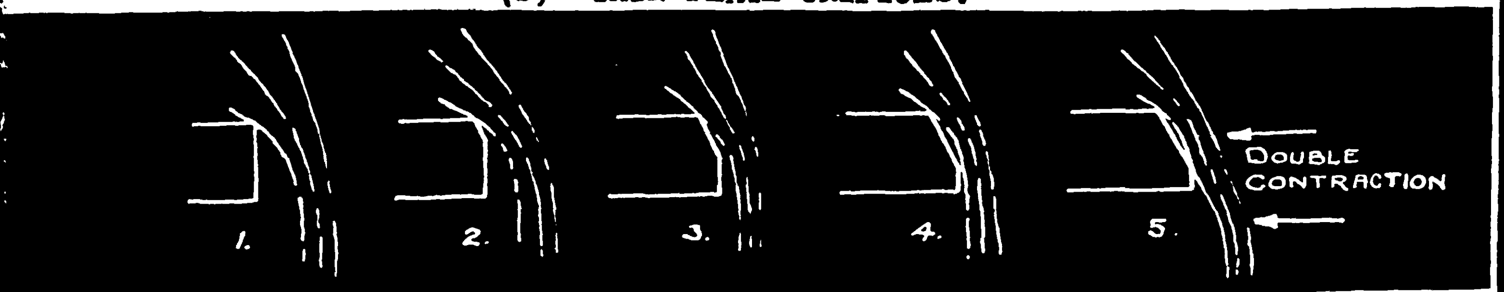
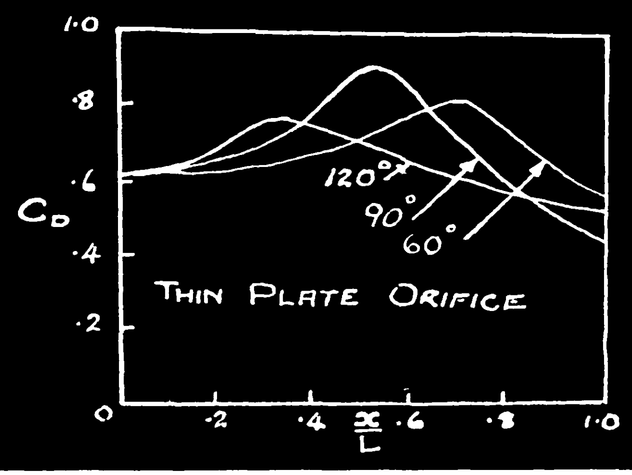


FIG.III.

(a) Angle acute. As in the foregoing discourse for the long nozzle, increasing the depth of champfer will cause C_D to increase to a maximum and then fall rapidly when "coning" occurs. Under these conditions, however, (i) the rise in C_D with increase in depth of champfer will be greater, (ii) the maximum C_D will possibly be much less than unity, depending upon the angle of bevel (iii) with further increase in the depth of bevel, C_D may fall below 0.610 (due to the "double contraction").

(b) Angle obtuse. Increasing the angle of bevel will cause the maximum C_D to be obtained with shallower bevels. This will result in (i) a rise in maximum C_D with angle of bevel, followed by a subsequent fall in C_D when 'critical' angle has been exceeded, (ii) a decrease in the mimimum C_D with very deep bevels, followed by a subsequent rise to 0.610 as the angle is still further increased up to 180°.

(c) Combined effects of depth and angle of bevel. An attempt to describe the foregoing is condensed into the following illustration



From Experiment No.6. it would appear as though the critical conditions occured for much smaller values of $\frac{x}{L}$ than they do with the long nozzle.

Design and Development Memoranda. These conjectures hint at the possibility of champfering causing, under certain circumstances, a reduction in C_D. Unfortunately these remarks were framed after the experimental work in this thesis had been completed and the apparatus dismantled. It is considered that a more extensive survey of this problem should be made.