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First Interim Report on Fluid Diodes

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Summary

A description of the various forms of fluid diode and report of tests done on a breadboard unit leading to the manufacture and testing of a prototype 1¼" vortex diode.

This work was carried out under contract for Flight Refuelling Ltd. (ref. order no.D.15795 of 2.5.69) and is the first of a series to cover a preliminary study of fluidic and allied devices in aircraft low pressure fuel systems.

1.0 Introduction

The existence of devices with no moving parts that act as 'partial non return valves' has been known to at least some people for very many years. As with jet pumps much of the most detailed work seems to have been done in the nineteen thirties but it would also seem that few if any applications for fluid diodes have been suggested during the intervening years. However since the renewal of interest in other no moving part devices that started around 1960 many more people have become aware of the possibilities of such inherent simplicity. Nevertheless for one reason or another most of the effort has gone towards making smaller and smaller devices mainly of the wall attachment and flow interaction type, diodes and other devices possibly better suited to larger sizes continue to be neglected.

Work by Baker (Ref.1) on three forms of diode suggested that at least the vortex diode could be of use in aircraft systems. Of the others the 'cascade' diode would appear to be too expensive to manufacture although its performance is good. The scroll diode like the Tesla diode discussed by Paul (Ref.2) does not seem to have a very good performance and the latter would also be rather cumbersome. A simpler type useful when a low pressure drop and only a small pressure drop ratio are required is a plain 'bell mouth-gentle expansion' venturi. Although this could have a performance better than the scroll or Tesla it does not seem to have been mentioned at all in previous literature, possibly because it is too simple!

These five types of fluid diode are shown in Fig. 1a-e. Of these only the vortex diode has been tested and at present the venturi diode is the only other form for which further study if suggested.

2.0 Vortex diode development

2.1 Aims

The most apparent disadvantage of a vortex diode is the size of its vortex chamber. The principal aims of this programme were therefore to improve the performance of the diode and to either reduce the chamber diameter or to reshape it in order that the weight might be reduced. To facilitate this additional parts were made to fit the Department's first breadboard vortex unit which as in previous tests used aviation kerosine. Earlier results with this unit, described in Ref.3, showed that a pressure drop ratio (PDR) of around 50 was possible and since most of the proportions of this diode were similar to the best version of Zobel (Ref.4) it was decided to continue using the same tangential insert of approximately 0.6 inches diameter and the same chamber depth again of approximately 0.6 inches.

2.2 Results

2.2.1 Breadboard Unit

The first series of tests, runs 94 to 105 inclusive, kept the chamber diameter at its maximum value of 4.5 inches and varied the axial port insert. Since Zobel had done this a fully comprehensive series of tests was not considered necessary and after a few runs there was even less reason to suspect his findings than before (except possibly in the choice of angle α - see Fig.2 and Table 1). However the significance of cavitation was demonstrated by the sudden reduction in performance when using the smallest insert with a 0.4 inch diameter throat and what is probably a Reynolds Number effect on all sizes was noticed in a more gradual change in performance over the flow range used. The best result was that of run 100 using an old insert improved by partially 'belling' what was previously a 60° entry.

At this stage the PDR used was dictated by the pump characteristic (see Ref.3) since the pressure drops and flows used were the maxima obtainable, i.e. with all appropriate cocks fully open. Using this method the PDR for run 100 was 75.8. (This result is briefly referred to in Ref.5)

Later on it was realised that for consistency one should quote either the PDR at constant flow or the square of the flow ratio at constant pressure drop. Although these three values for the PDR are of the same order the differences may at times be significant. However at the time insufficient readings were taken to investigate these differences and the usual practice was to consider

$$Y_t = \frac{(P_t - P_a)^{1/2}}{Q_t} \quad \text{and} \quad Y_a = \frac{(P_a - P_t)^{1/2}}{Q_a}$$ for the maximum

Q_a and Q_t possible, the PDR used therefore being $\left(\frac{Y_t}{Y_a}\right)^2$

The next best results were from runs 98 and 105 using a new 0.6 inch axial insert. These gave PDR's of 68.5 and 68.8 (in the latter the insert had been smoothed off a little more but as can be seen the difference effected was insignificant).

Fig. 3 shows something of the effect of axial throat diameter d_a.

The second series of tests started by using the above 0.6 inch axial insert while varying the chamber diameter by means of perspex rings. It was initially possible to investigate effects of varying the chamber diameter from 4.5 inches down to 2.7 inches since it was considered that at the latter size the PDR would be reduced to only about 25. However in practice this combination (run 106) gave a PDR of over 43. This unexpectedly small reduction was due mainly to a reduction in Q_a there being only a small increase in Q_t, the effect that was expected to dominate the change.

Subsequently (run 109) a PDR of 46.2 was obtained with the 2.7 inch chamber and a 0.5 inch axial insert compared with 62.8 (run 102) with the full 4.5 inch chamber. It therefore appeared that the optimum axial port size decreases but this effect may be tied up with the flows from which the PDR is calculated.

Since it was clear that a reasonable performance could be expected with a very much smaller chamber another ring was made of 1.5 inch internal diameter and this time the expected reduction in performance was apparent, a PDR of about 17 being found. These results are shown in Fig.4.

Considering the tangential flow only these results suggested that increasing the chamber diameter up to about 2.7 inches brought about a decrease in Q_t but any further increase had little or no effect.

2.2.2 Prototype Unit

At this stage it was decided to build a prototype diode which would avoid the long 0.6 diameter passage through the ring and would therefore demonstrate more precisely the performance to be expected while at the same time showing the shape and size to be expected of a production unit. The general shape of this prototype diode is shown in Fig. 5. A chamber diameter of 1.8 inches was chosen since this allowed the outside diameter to be no bigger than that of a typical pipe connector to fit the 1¼" O/D ends. From Fig.4 a PDR of about 30 was expected.

Runs 129 and 132 used this prototype unit the latter in its finished state, although the axial throat was smoothed a little more in between runs, the improvement in performance was negligible.

It has already been mentioned that the PDR varies according to the actual values of Q_a and Q_t used, run 132 was the first to investigate this effect as fully as the characteristics of a single booster pump would allow. These results are shown in Figs. 6 and 7 from which it can be seen that whereas the PDR could, by taking the most favourable readings, be quoted as 38.1, more easily comparable and realistic values are obtained by considering the maximum PDR at constant flow or the PDR obtained by squaring the maximum flow ratio at constant pressure drop.

In practice one needs to know the complete performance and the 'useful' PDR will depend on the particular application

2.2.3 General Observations

Earlier incomplete series of readings with different diameter chambers confirm a peak Y_t at about 400 gph and a more or less level minimum Y_a between about 1000 gph and the cavitation point. A further, probably brief, series of tests is required to decide whether or not this is a simple Reynolds Number effect.

The cavitation point could only be reached with the smallest axial insert, 0.4 inch throat, with Q_a about 1200 gph. At this flow it was calculated that the pressure in the throat was about 5 psia which is around the value one would expect air to come rapidly out of solution. Such a condition will always provide a limit to the maximum value of Q_a.

It is interesting to note that with tangential flow the presence or lack of a core of air/vapour in the vortex did not affect the pressure drop, presumably because the flow down the core is in any case negligible.

Table 1 gives details of the axial inserts used in the diode and Table 2 brief details of all runs involving diodes up to the middle of October 1969.

3.0 Conclusions

A very useful performance can be obtained using a chamber no bigger than a normal pipe coupling.

Apart from the entry from the chamber to the tangential port no 'sensitive' region has been found and ordinary production methods and tolerances should prove perfectly acceptable.

4.0 Further Work

For small PDRs the venturi diode should be investigated.

Vortex diodes with a greater variety of throat/pipe diameter ratios should be studied since if sufficient pressure is available to prevent cavitation at high axial flows the throats and chamber can be made even smaller and it is possible that higher PDRs can be achieved.

Comparison should be made between the 1/4" prototype diode and the FR made 1/4" diode to see if a consistent K factor v. Reynolds Number relationship exists. If it does then subsequent design work should be fairly straightforward.

5.0 References

1. Baker, P. 'A comparison of fluid diodes' 2nd Cranfield Fluidics Conference, paper D6 (January 1967)
2. Paul, F.W. 'Fluid mechanics of the momentum flueric diode' IFAC Symposium on Fluidics, paper A1 (November 1968)
3. Taylor, A.F. 'Some experiments with fluidic devices in aviation kerosine' CoA Note Aero No.176 (April 1969)
4. Zobel, R. 'Experiments on hydraulic reversing elbow' Mitt.Hyd.Inst. Munich Vol.8, pp.1-47 (UKAEA Risley Trans.No.439)
5. Taylor, A.F. 'Vortex devices in aircraft fluid systems' paper submitted for 4th Cranfield Fluidics Conference (Sept. 1969)

Approximate dimensions of axial inserts

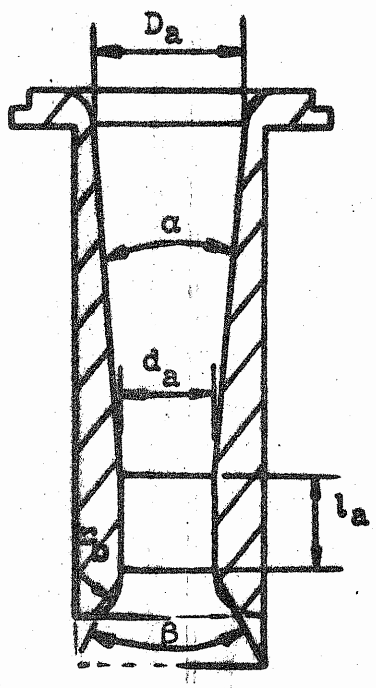


Table 1

Insert	d_a"	l"	D_a"	α°	β°	r_b"
Old 30°	0.50	0	0.95	14	30°	-
Old 60°	0.55	0	0.95	14	belled 60°	
5.1	0.50	0.50	0.80	14½	19	-
5.2	0.50	0.50	0.80	14½	B	0.25
5.3	0.50	0.50	0.80	8	B	0.25
5.4*	0.50	0.50	0.95	19	19	-
8.1	0.50	0.50	0.80	9½	B	0.25
8.2	0.40	0.40	0.80	9½	B	0.30
8.3	0.60	0.60	0.80	9½	B	0.20
Prototype	0.50	0	0.90	14	B	0.25

B = bellmouth

* modified 5.1

Table 2. Summary of Diode Results

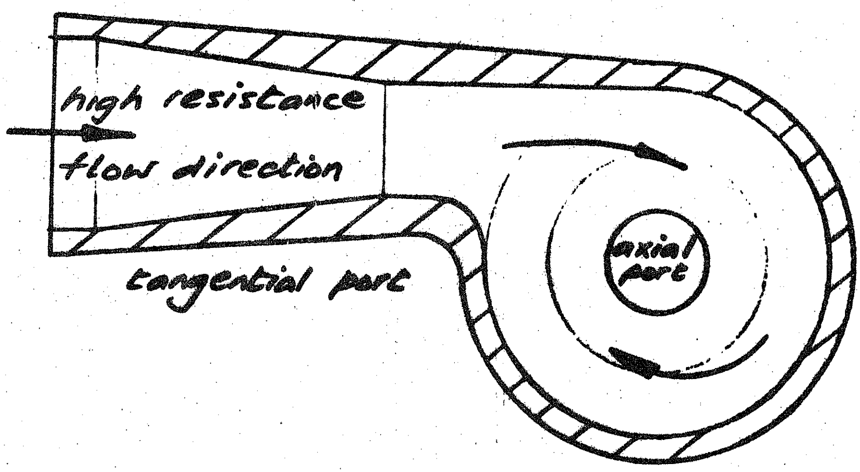
*Run No.	Date	Chamber dia. *	Axial insert	PDR+	Remarks
94	26.8.69	4.5	5.1	53.4	
95	'	4.5	5.3	58.6	
96	'	4.5	8.2	47.5	for Q_a below cavitation flow
97	'	4.5	old 30°	67.3	
98	'	4.5	8.3	68.5	
99	27.8.69	4.5	None	39.4	ie.1" with bellmouth at top
100	'	4.5	old 60°	75.8	best!
101	'	4.5	5.4	about 49	worse than 94
102	'	4.5	8.1	62.8	
103	'	4.5	old 30°	67.0	insert smoothed off more, see 97
104	'	4.5	5.2	55.6	
105	28.8.69	4.5	8.3	68.8	smoother bellmouth, see 98
106	'	2.7	8.3	43.9	
107	'	3.9	8.3	58.0	
108	'	3.3	8.3	51.7	
109	'	2.7	8.1	46.2	
108x	30.8.69	2.7	8.2	42.4	for Q_a below cavitation flow
109x	2.9.69	1.5	5.2	16.5	5.2 used in error
110	3.9.69	1.5	5.2	16.5	flow straightener moved
111	'	1.5	8.1	16.6	
112	'	1.5	8.3	16.8	
115	4.9.69	4.5	old 60°	27.0	'True' tangential insert, <u>sharp</u>
116	5.9.69	4.5	old 60°	38.9	' ' ' rounded
129	10.9.69	1.8	-	32.2	Prototype (unfinished)
132	16.9.69	1.8	-	32.2	' (finished)

* The 1st run using fluidic devices carried out by the author was in October 1968, run 94 on 26th August 1969 was the first to use parts manufactured under the F.R. contract.

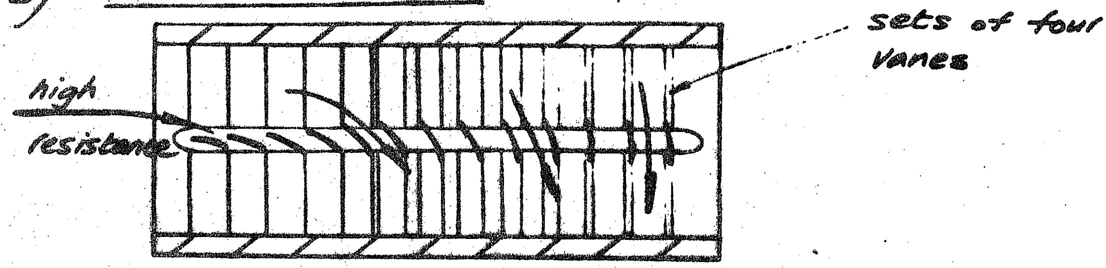
+ PDR based on maximum flows possible, see page 3.

x Numbers wrongly allocated.

a) vortex diode



b) cascade diode



c) scroll diode

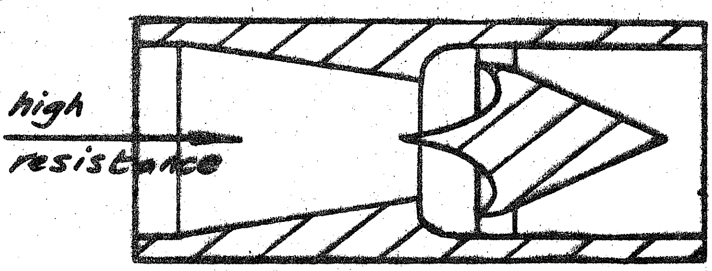
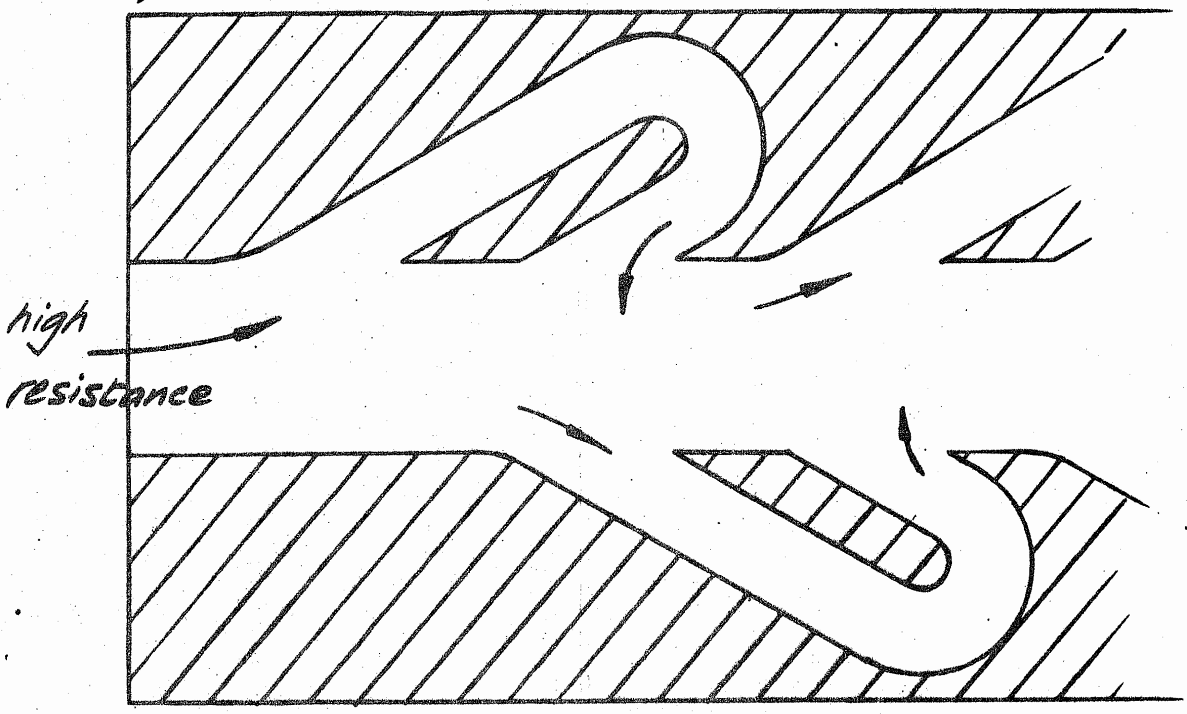


Figure 1 a) b) & c)

d) Tesla diode



e) venturi diode

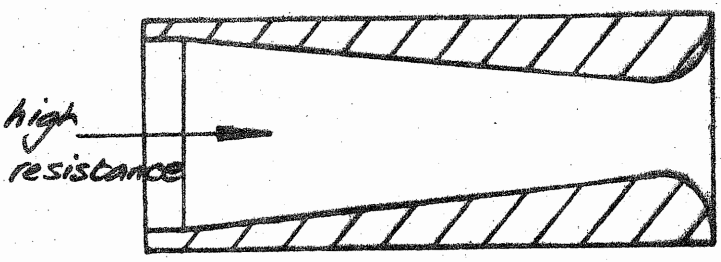


Figure 1 d) & e)

Axial port dimensions

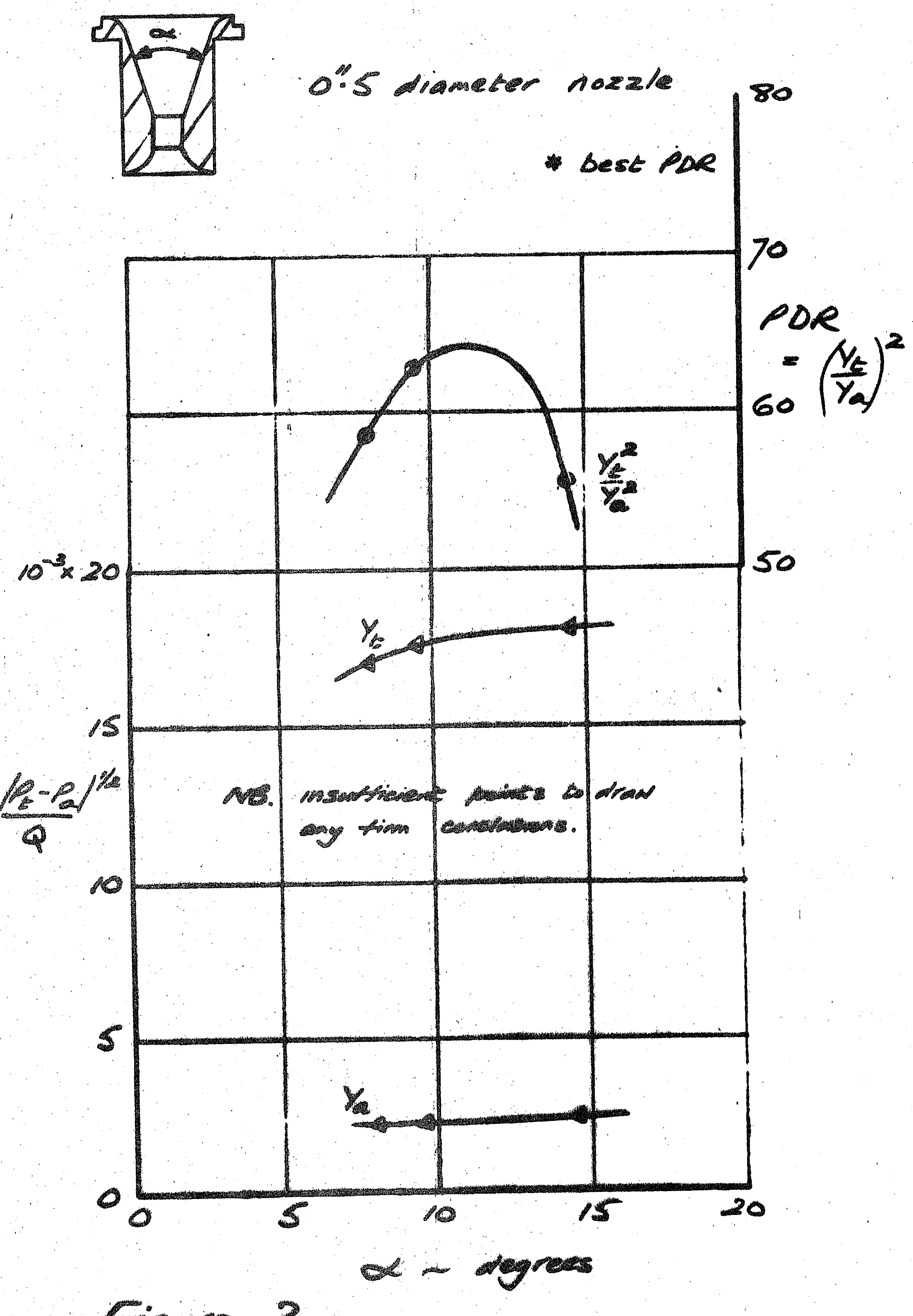


Figure 2

Axial port dimensions

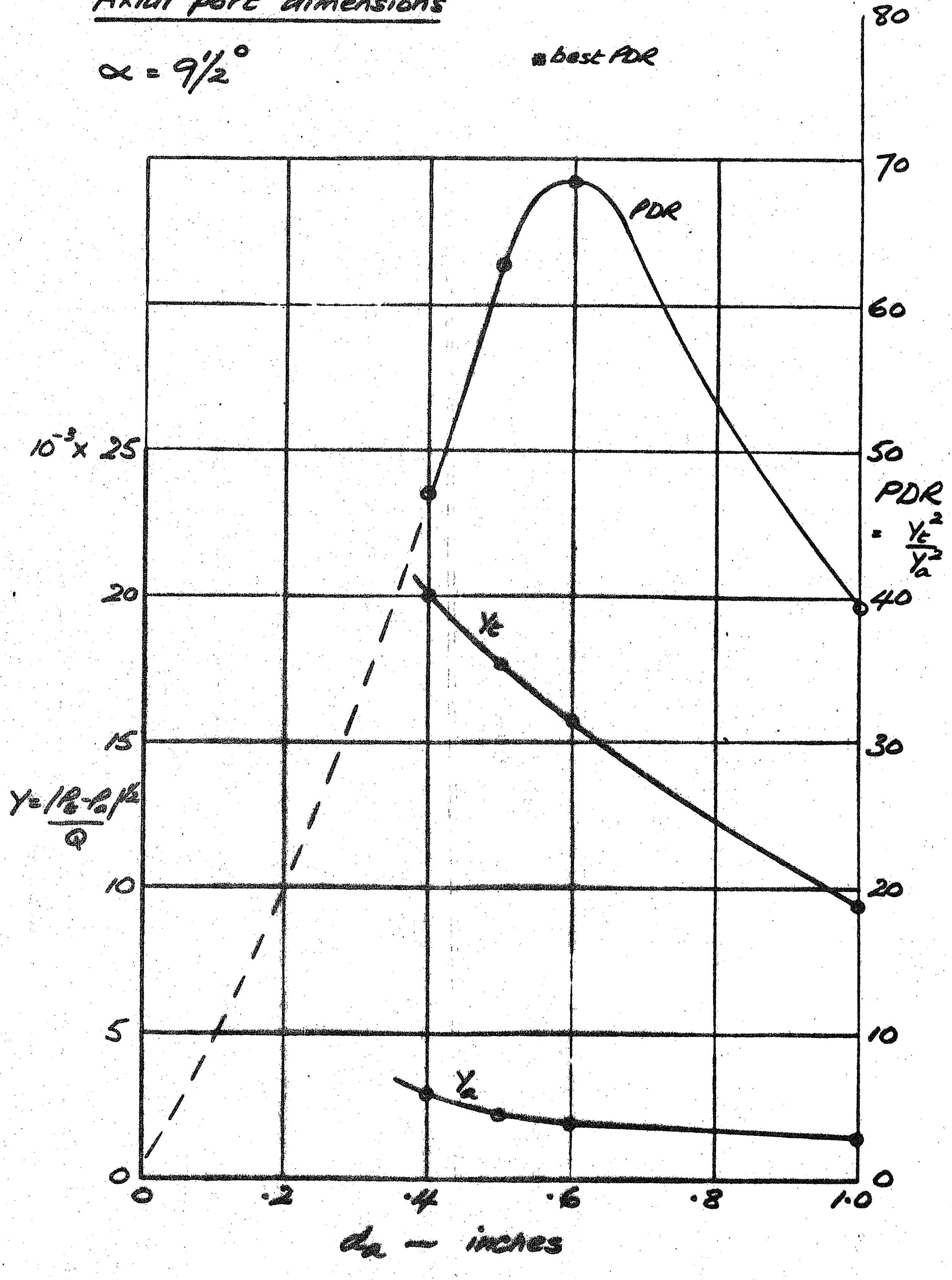


Figure 3

Chamber dimensions

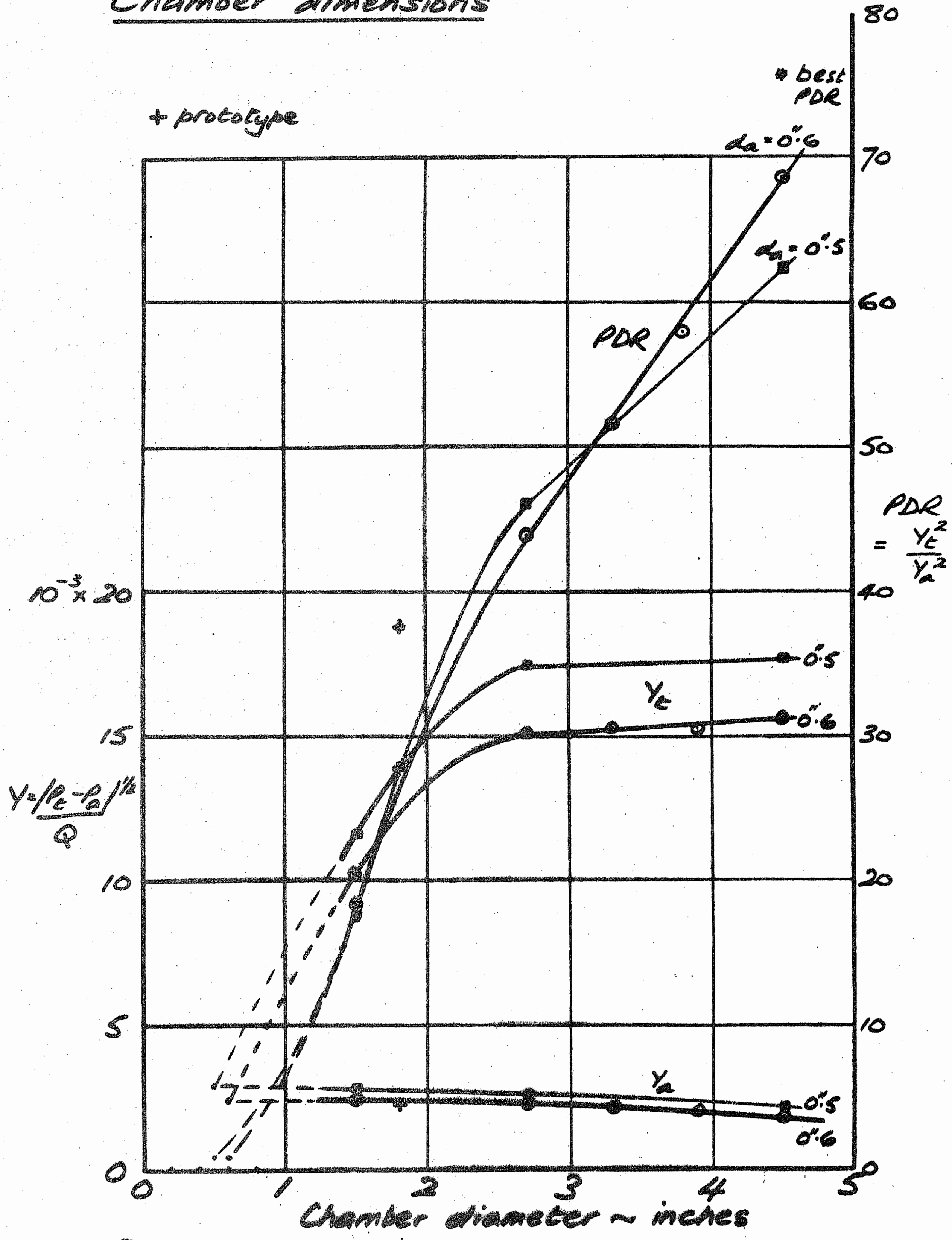


Figure 4

Prototype 1¼" vortex diode

approx. full size

tangential nozzle 0".6 diameter
axial nozzle 0".5 diameter
chamber 1".8 diameter

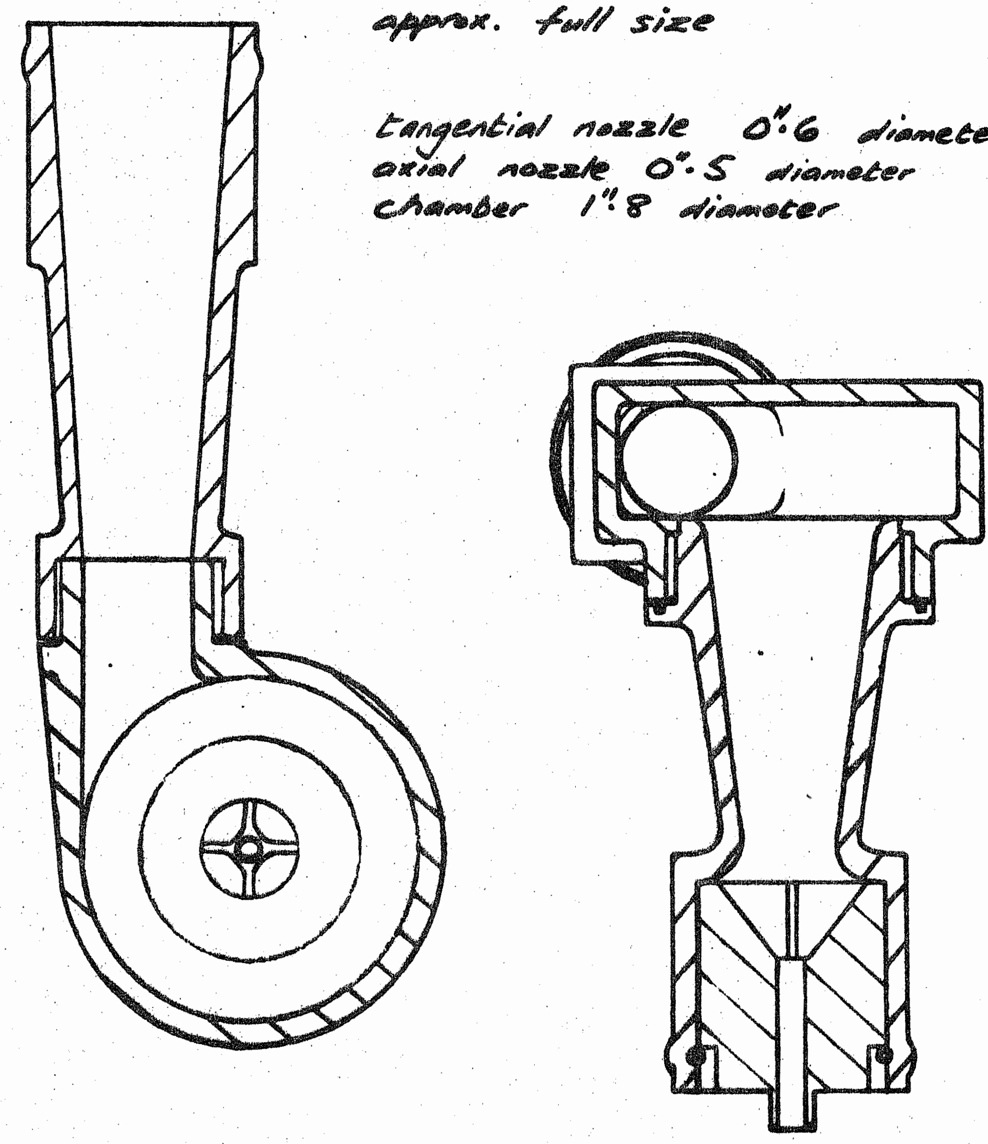


Figure 5

Prototype 1¼" vortex diode

Variation of PDR with flow.

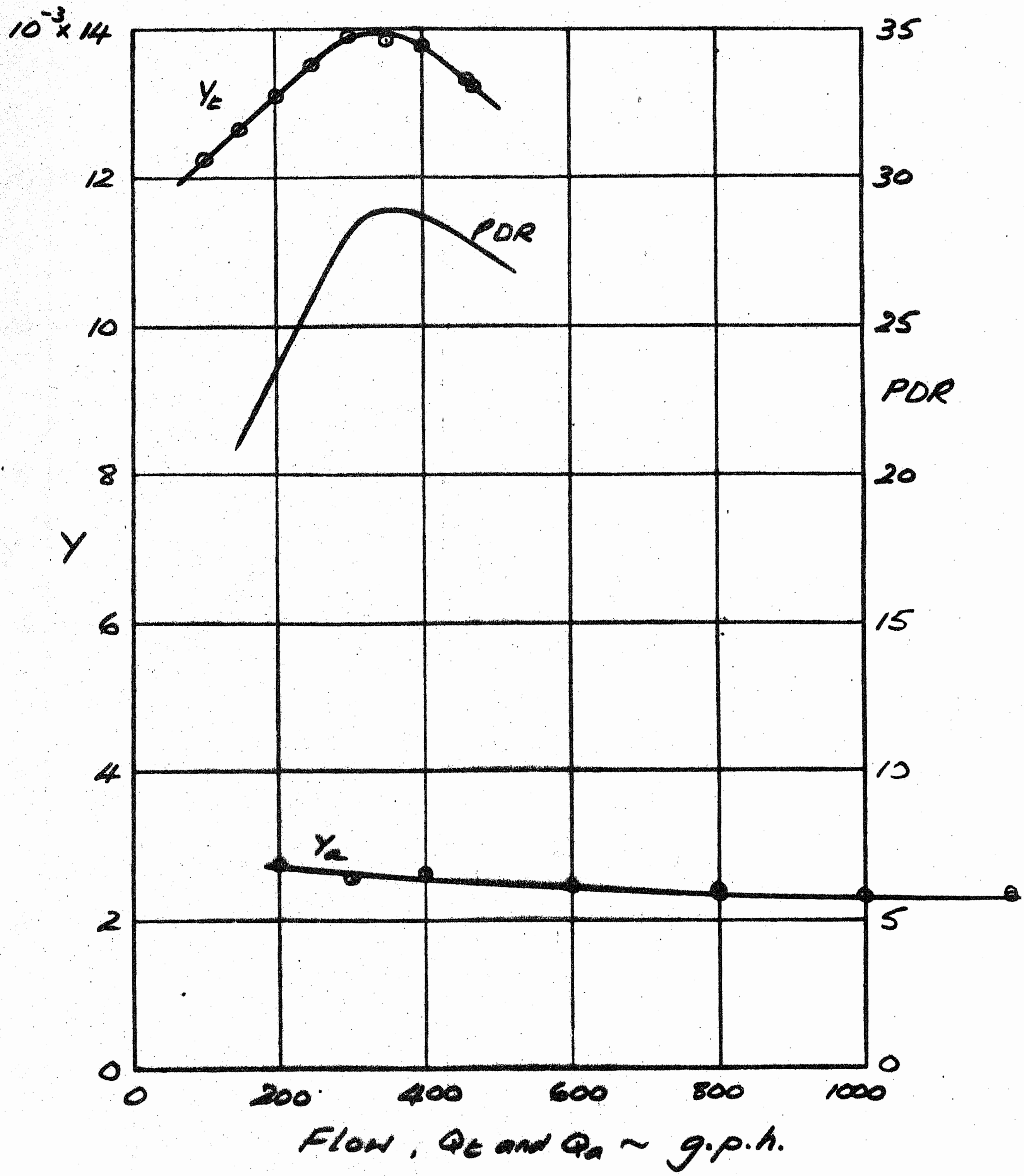


Figure 6

Prototype 1¼" Vortex diode

Variation of PDR with pressure drop.

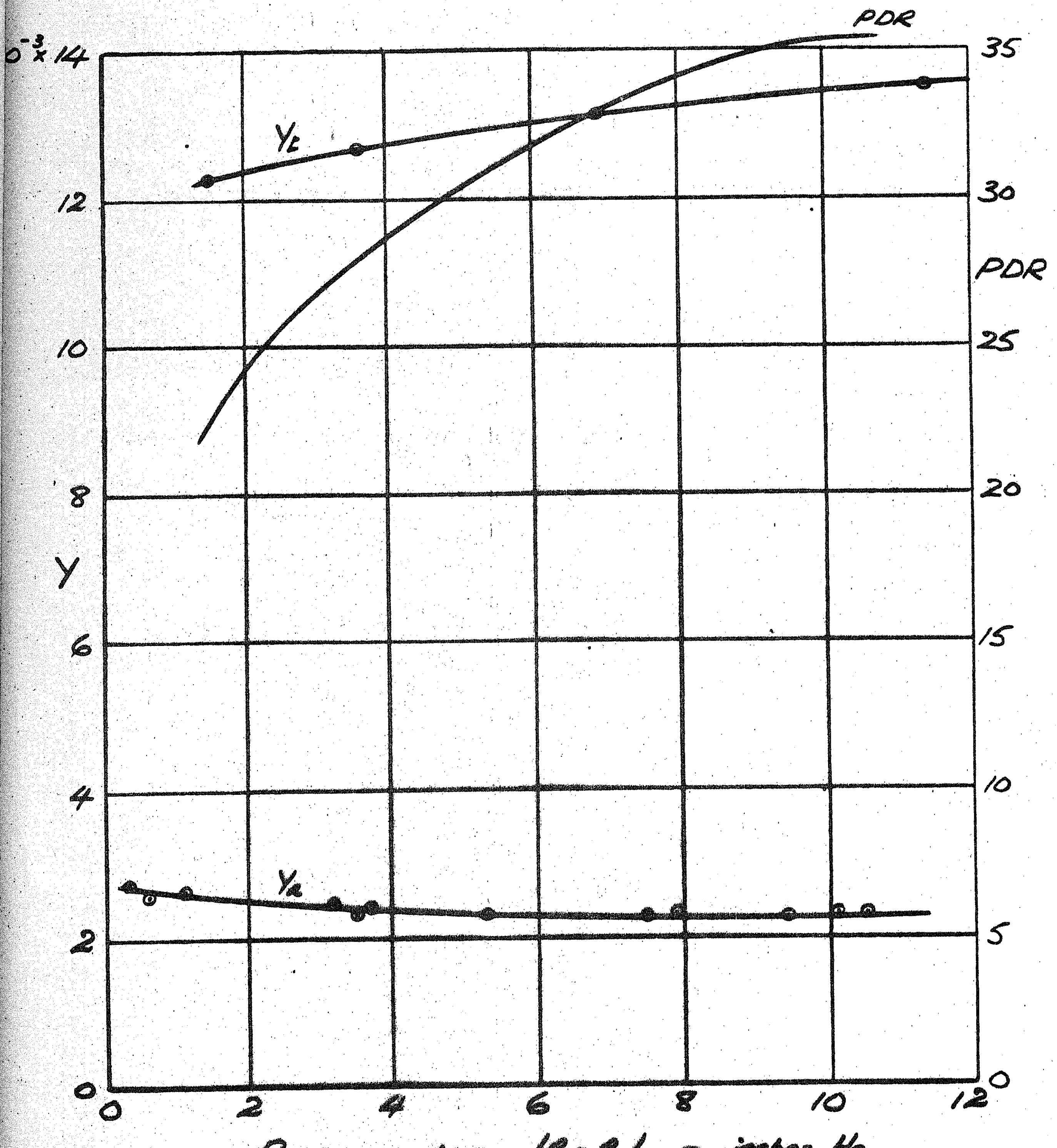


Figure 7