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SOME EXPERIMENTS WITH FLUIDIC DEVICES IN AVIATION KEROSENE

by

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DEPARTMENT OF AIRCRAFT DESIGN

Some experiments with fluidic devices in aviation kerosene

- by -

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SUMMARY

Comparatively little has been published on 'heavy current' fluidic devices yet their advantages suggest that they have a place in aircraft fluid systems. As a first brief step towards assessing their value to the aircraft fuel system designer several devices were tested, singly and in pairs, in aviation kerosene. Some of the results from these experiments are given and discussed and it is considered that further work could produce some extremely worthwhile information.

Contents

1. Introduction

As aircraft get larger and/or more complex, designers must continuously be on the lookout for the means to keep the systems and their components as simple, cheap, light and reliable as possible. Fluidic devices appeared to answer many of the designers' dreams and therefore a brief study was initiated, both to gain familiarity with the devices involved and to check the feasibility of their use in aircraft fuel systems.

Robson[1] carried out the first experimental work in the Department on a simple vortex valve and a Coanda (wall attachment) device. The experiments described here have used these same two basic units, shown in figures 1 and 2, in various forms; throughout these experiments pressure P is measured in psig and flow Q is measured in Imperial gallons per hour.

Work by Baker[2] on three forms of fluid diode suggested that the vortex diode as described by Heim[3] and Zobel[4] could be the most suitable so our vortex valve was modified accordingly and reverse to forward flow pressure drop ratios of around 50:1 were achieved.

Further work on the vortex valve with its one radial and one tangential inlet showed that in several configurations it was unstable due to a form of vortex switching. This confirmed that for some applications two radial inlets or an annular inlet would be required rather than a single radial one.

Work on the Coanda and proportional amplifier range of devices has only just begun but here one of the main criteria is pressure recovery and since this apparently conflicts with certain other requirements, notably load insensitivity, considerable work is likely to be required on the splitter shape and wall angles to give the best compromise for a particular application.

Combinations of Coanda device/vortex valve and proportional amplifier/ vortex valve have been investigated, the latter seeming particularly promising.

The test facilities used throughout have been those afforded by the fuel tanks and system of an Avro Canada CF-100 aircraft, these are shown diagrammatically in figure 3 and the aircraft booster pump characteristic is shown in figure 4.

It had proved difficult to predict performance from earlier reports since in nearly all cases at least one major parameter had been kept constant, a situation unlikely to occur in practice. No attempt therefore has been made to test under such convenient conditions, instead pressures and flows have been allowed to vary and hence special functions and ratios have had to be used to analyse the results obtained. It had been hoped that this method would show up any unexpected variations due to change of flow etc., in fact, remarkable consistency has been shown over a wide range of conditions and it seems surprising that the 'flow functions' adopted here have apparently not been extensively used in this field so far.

2. Experimental work

This has been mainly qualitative due to bad positioning of the pressure tappings in the original units. However, fairly accurate flow measurement has been possible and calculations based on these with the pressure readings available have been sufficiently consistent to inspire more confidence in the quantitative performance than had originally been expected. Nevertheless the curves presented should not be assumed to show more than general trends.

2.1 Vortex diode

The basic vortex element (fig. 1) was obviously a long way from the optimum shape and as neither Heim's nor Zobel's report was available at the start of these experiments, although their results were known from Baker's work, it was decided to modify the element stage by stage. Equal emphasis was given to keeping the pressure drop down in the forward flow direction and to pushing it up in the reverse direction. The technique was to change the vortex chamber depth by fitting metal or perspex discs to the bottom and top and to change the ports by means of 'inserts' made to fit inside the existing screwed adapters.

The most convenient way of assessing the performance was by means of a 'flow function' equal to flow divided by the square root of the pressure drop.

Early improvements raised the pressure drop ratio (equal to the square of the flow function ratio) from under 10 to over 20, the most significant factor however, which confirmed Zobel's findings, was shown to be the exit shape from the vortex body into the tangential outlet. When a new profiled tangential insert was used a few strokes of a file to round off the corners more than doubled the p.d. ratio to over 40 and subsequent refinements produced ratios of over 50.

The final configuration of the vortex diode is shown in figure 5, and its pressure drop/flow characteristics are shown in figure 6. It will be noted that in the high flow direction the pressure drop is very similar to that of a conventional non-return valve to fit the same sized (1 inch) pipe.

For a few tests a non-kerosene-resistant plastic cotton reel was used as a flow straightener in the axial port (dotted in figure 5), and was considered as being part of the diode. Before it distorted and began to disintegrate sufficient work was done to indicate that although, of course, the pressure drop with reverse flow was increased in the complete diode, the pressure drop in the system was unchanged. Thus the extra system p.d. previously due to the vortex continuing along the outlet pipe was equal to the p.d. across the flow straightener when fitted. It was thus convenient to add this extra p.d. to that across the diode during the majority of tests when the flow straightener was unfit for use.

The pressure measurements obtainable were considered insufficiently accurate to investigate further improvements or modifications to the diode so work was continued on the vortex valve instead.

2.2 Vortex valve

Unlike the diode one is here interested not only in the tangential to radial p.d. ratio (i.e. the TDR or turn down ratio) but with the conditions in between, that is, when there is flow into the vortex chamber through both the radial and the tangential inlet ports. In presenting this overall performance the same flow function as used for the diode was found to be convenient and since flow measurements were far more accurate than pressure measurements this was plotted against the ratio $\frac{Q_R}{Q_T}$. Other research workers seem to have favoured plots against inlet pressure difference so, to see if this would make any difference to the basic shape of the curves produced, $\frac{Q_R}{Q_T}$ was plotted against a function of the pressure difference $\frac{|P_T - P_R|^{\frac{1}{2}}}{Q_T}$ (using the sign of P_T-P_R). Since, despite the inaccuracy inherent in taking the small difference between two larger quantities, this turned out to be virtually a straight line, figure 7, there is every justification for continuing to use $\frac{Q_R}{Q_T}$. It can be seen that $Q_R = Q_T$ when $P_R = P_T$ which reflects the fact that for this series of tests both inlets were the same size (0.6 inches diameter).

In this and in other curves where $\frac{Q_R}{Q_T}$ becomes negative fuel is entering only through the tangential port and is leaving through both the axial port and the radial port, a situation usually ignored.

Early tests showed that the vortex valve was extremely sensitive to pressure difference changes between the inlets. In fact, it was soon realised that a form of vortex switching was occurring, thus confirming the recommendation of Syred, Royle and Tippetts[5] that a single radial inlet should not be used. However, it was not convenient to modify the valve at the time, so further tests were carried out with different sized axial outlets and it was found that with a 1 inch outlet the valve did not exhibit this switching characteristic. It was also felt that the smaller sizes would be better if used with sharp edged radial and tangential ports instead of the faired off ports developed during the vortex diode tests; this will be the subject of future investigations.

Figure 8 shows some typical results and from these can be derived the TDRs (turned down ratios) - in this case around $4\frac{1}{2}$ for the flow TDR and around 20 for a pressure drop TDR. (Note that both are useful measures of performance, as indeed is the power index used by Gebben[6], but care must be taken to avoid the ambiguity noted in some reports).

A limited and so far inconclusive series of tests has been carried out to try and ascertain the optimum axial port size, from a TDR point of view, to go with the 0.6 inch inlets and 4.5 inch diameter, 0.6 inch deep chamber. It would appear at this stage that 0.5 inch diameter (the same as for the diode) is fairly near the optimum and figure 9 shows the shape of curve to be expected.

Syred, Royle and Tippetts[5] also show the improvements on performance that might be expected by having both two radial ports and two axial ports.

2.3 Coanda device

The basic unit used by Robson[1] was found to have too large a supply nozzle for the power available from a single CF-100 booster pump and was narrowed accordingly. At the same time the parallel section of the nozzle was shortened to reduce the pressure drop. Initial tests with different lengths of splitter verified some of the geometry effects described by Robson[1] and figures 10 and 11 are taken from this report (although both were themselves derived or taken from earlier reports). While the exact transition points were not confirmed, and will probably vary to some extent anyway, it is felt that these two figures give a very good 'rule of thumb' guide to geometry effects. Other dimensions were chosen 'by eye' but with regard to known angles of expansion to give reasonable pressure recovery.

Switching was very easy to achieve with the control ports supplied from the inlet side of the device so further tests were carried out with them connected to the outlets. With the pressure recovery being achieved at the time, only about 30%, switching was distinctly more difficult. This was found to be due to the comparatively low back pressures used, in some cases switching could not be achieved until the appropriate outlet cock had been slightly closed.

When testing with no outlet rotameters and with the outlets joined by a 'Y' piece, it was noted that considerable recirculation took place (as used by Montgomery and Floyd[7] for Serck's self cleaning filter); this caused an additional pressure drop through the system.

By adjusting the outlet cock setting it was possible to establish various switching delays (i.e. time between opening the control cock and switching taking place) from about 1 second up to about 7 seconds with good repeatability. However no attempt has yet been made to see how this delay varies with flow, or any other parameter, so neither its usefulness nor its significance has been established.

Due to the undesirable pressure drop characteristics of the rotameters and since a Coanda device/vortex valve combination was of interest anyway, most tests were carried out with the vortex valve fitted and only a single rotameter in the supply pipe. As switching within the vortex valve would have complicated things the 1 inch diameter axial port was used in all the tests.

2.4 Coanda device/vortex valve combination

The performance of the Coanda device was in no way affected by having a variable pressure drop device downstream of it since the resulting back pressures change in both legs simultaneously.

However the vortex valve proved very useful in deriving the flow in each leg, knowing the total flow and the relevant static pressures the 'flow function' for the vortex valve could be calculated thus giving the ratio $\frac{Q_R}{Q_T}$ and hence Q_R and Q_T.

Further testing is planned for this combination but at this stage the Coanda device was changed into a proportional amplifier by fitting a very long pointed splitter block.

2.5 Proportional amplifier/vortex valve combination.

Although this series of tests was directed at establishing the performance of a simple proportional amplifier the above heading is used since no tests have yet been carried out with 'free' outlets from the amplifier. As explained earlier, joining the outlet legs at the vortex valve determines the back pressures in a particular way and some change in the amplifying characteristics might be expected with no such communication between the outlets.

The long splitter used was slightly assymetric near its tip and this may have helped create the convenient bias to the right hand outlet which fed the radial inlet of the vortex valve. The control port on the right hand side was considerably narrower than the supply nozzle and was fed from upstream of the amplifier, thus an increase in control flow would be expected to increase the flow in the left hand (tangential) leg at the expense of the right hand (radial) leg thus increasing the back pressure due to the vortex valve. This worked very well in the first and only arrangement tried before a pressure tapping stub failed and brought the tests to an early end.

During these tests flow rate was measured in the supply line and in the control line and derived in the two outlets from the vortex valve characteristics. Figure 12 shows the variation in the outlet leg flows with increasing control flow although the smallest rotameter available was not small enough to record below about 26 gpm and therefore a certain amount of extrapolation is necessary. Figure 13 shows both the variation of the differences between these output flows with increasing control flow and the resulting 'flow gain',

$$\frac{\Delta(Q_T-Q_R)}{\Delta Q_C}$$

which is remarkably high.

To eliminate the effect of the supply pump characteristic, figure 14 shows the variation of outlet flow ratios with control flow and figure 15 shows how this affects the flow function of the vortex valve and the amplifier/vortex valve combination.

Certain shortcomings of the arrangement used can be seen from figures 14 and 15; firstly it must be remembered that the vortex valve used gave nowhere near the optimum TDR to be expected, secondly the amplifier although sensitive over part of the range did not reduce the Q_R to Q_T ratio as far as was hoped and thirdly the pressure drop across the amplifier was high and therefore reduced the overall TDR of the combination. Further work will aim to remedy these shortcomings.

3. Conclusions

Any experiments carried out only at sea level on devices that may find application in aircraft are obviously of limited value. However the results obtained are encouraging and a measure of familiarity has already been achieved that would have been impossible from just reading other people's reports. The fact that reasonable results were obtained with devices designed almost entirely by eye and by feel was particularly valuable in removing some of the mystery that may daunt a newcomer to fluidics. It has also opened up many further avenues which it is hoped can be explored in the near future.

4. References

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2. Baker, P. — 'A Comparison of Fluid Diodes', Second Cranfield Fluidics Conference paper D6, January 1967.

3. Heim, R. — 'An Investigation of the Thoma Counterflow Brake', Trans. of the Hyd. Inst. of the Munich Tech. Univ., Bult. 3 pp13-28 of Translation published by ASME, 1935.

4. Zobel, R. — 'Experiments on a Hydraulic Reversing Elbow', Mitt. Hydraul. Inst. Munich, Vol. 8, pp 1-47 (UKAEA Risley Translation 439).

5. Syred, N., Royle, J.K. and Tippetts, J.R. — 'Optimization of High Gain Vortex Devices', Third Cranfield Fluidics Conference, paper J3, May 1968.

6. Gebben, V.D. — 'Vortex Valve Performance Power Index', Technical paper proposed for presentation at Symposium on Fluidics sponsored by ASME and HDL May 1967.

7. Montgomerie, G.M. and Floyd, T.J. — 'Heavy Current Fluidic Devices', Second Cranfield Fluidics Conference, paper K4, January 1967.

Figure 1 <u>Basic vortex unit</u>

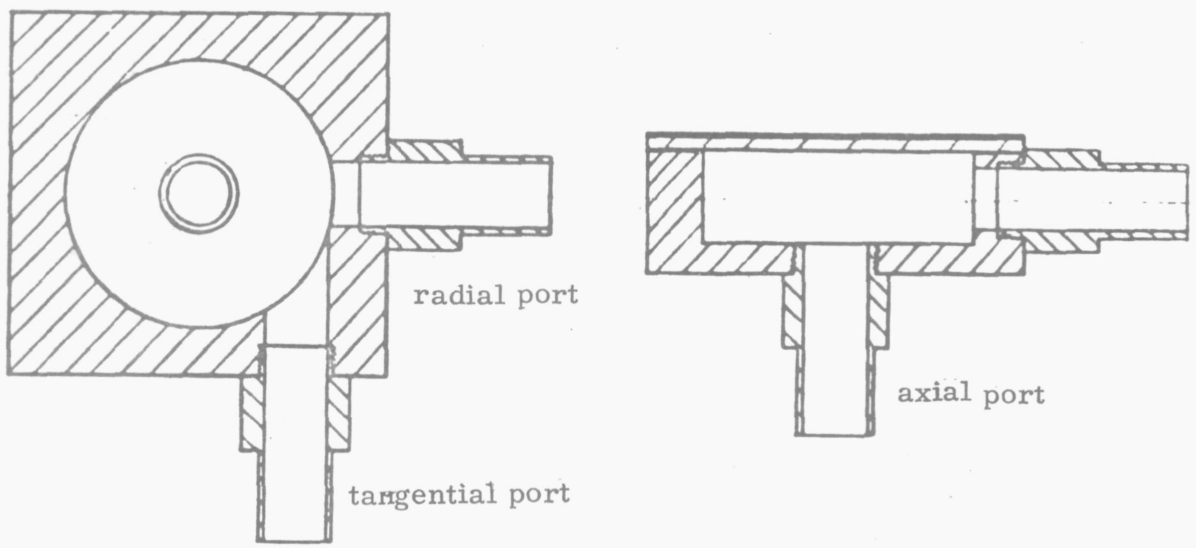
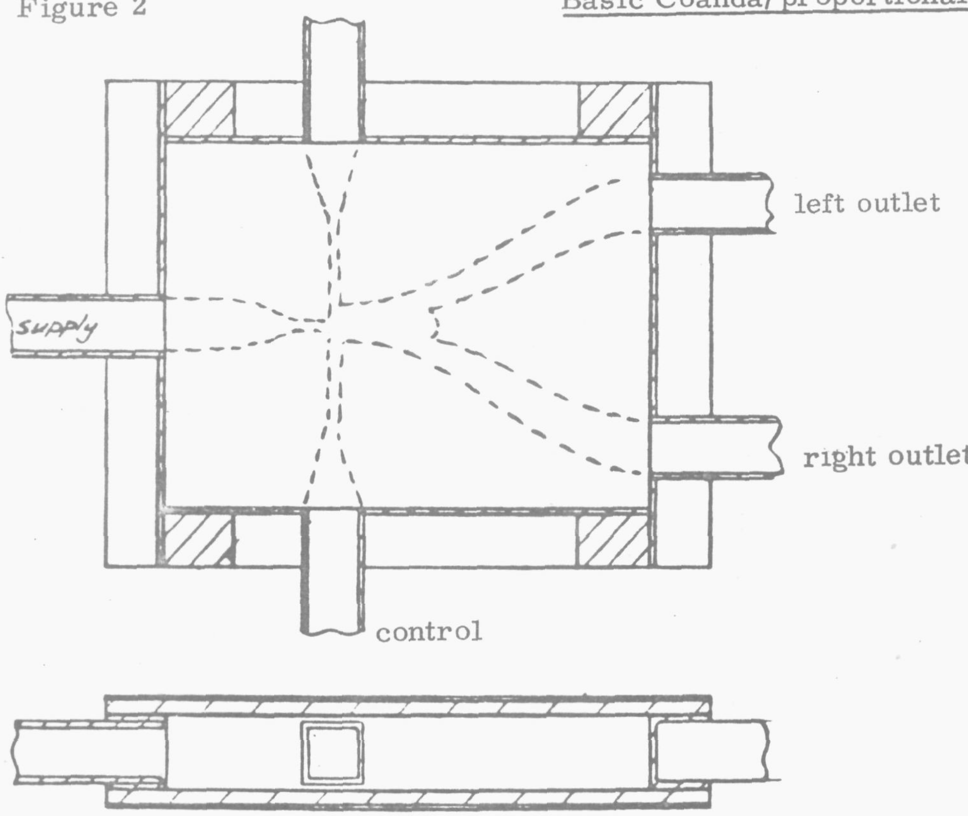


Figure 2 <u>Basic Coanda/ proportional unit</u>

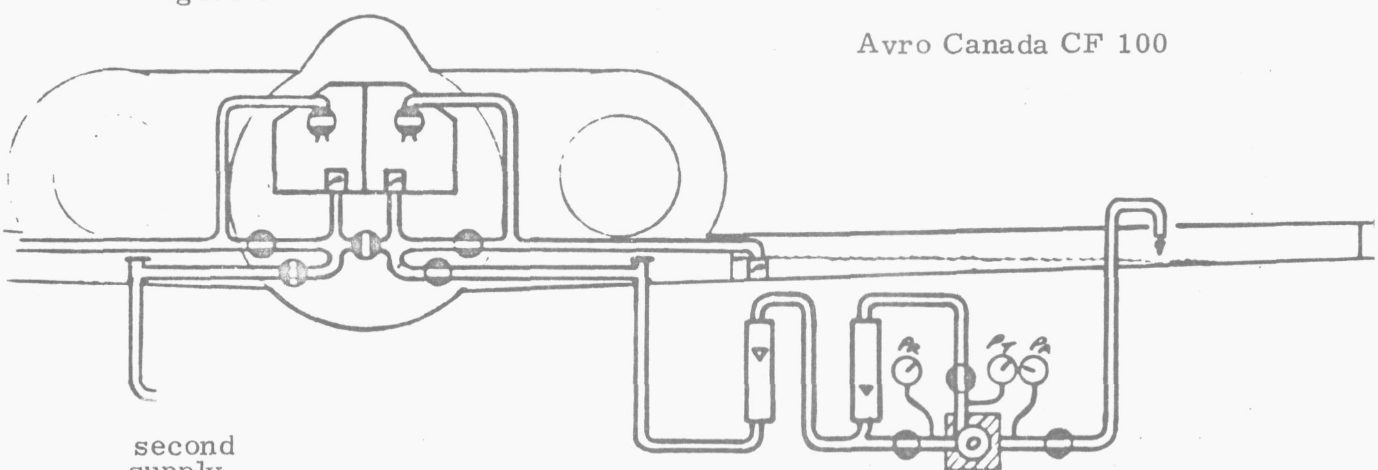


Scale: one third full size

FIGURES 1 and 2

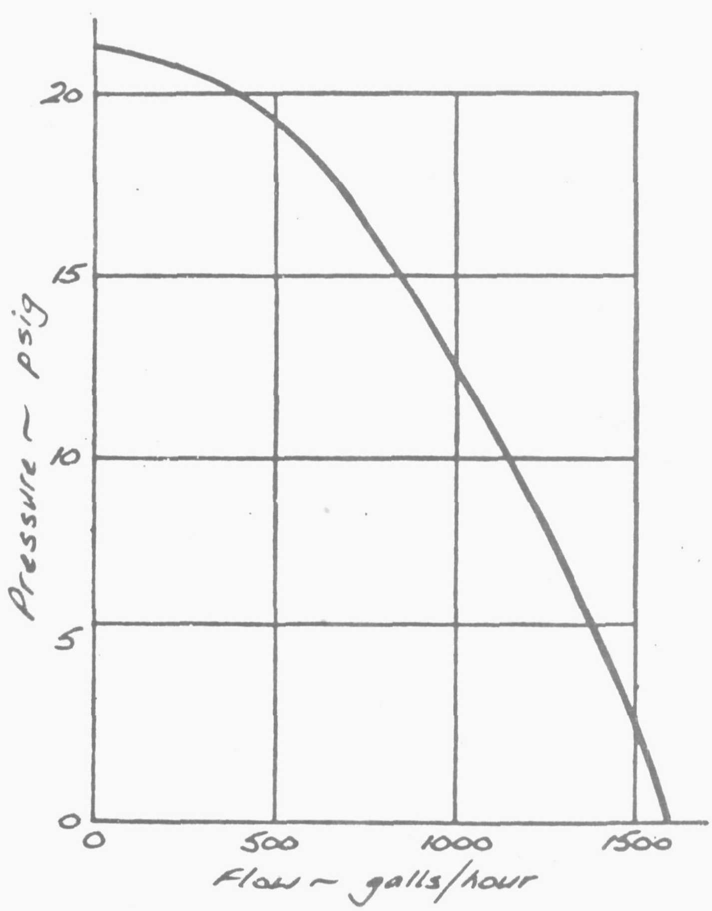
Test facilities

Figure 3



Avro Canada CF 100

Figure 4



Fuel pump characteristic

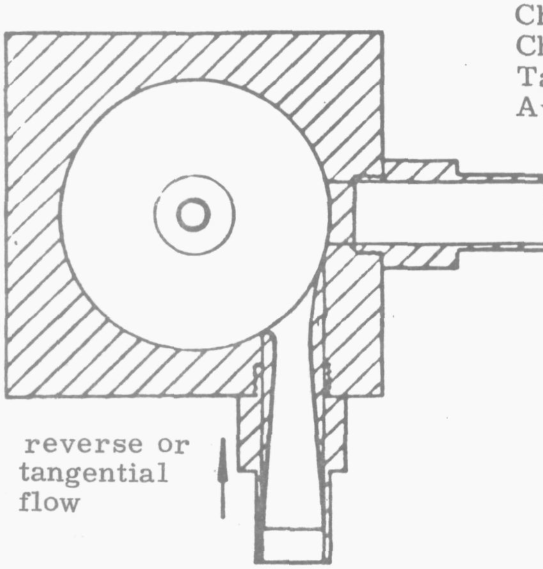
Pressure measured downstream of rotometer

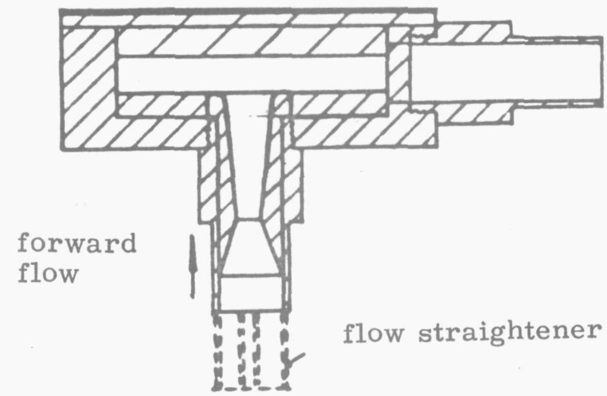
FIGURES 3 and 4

Vortex diode

Figure 5

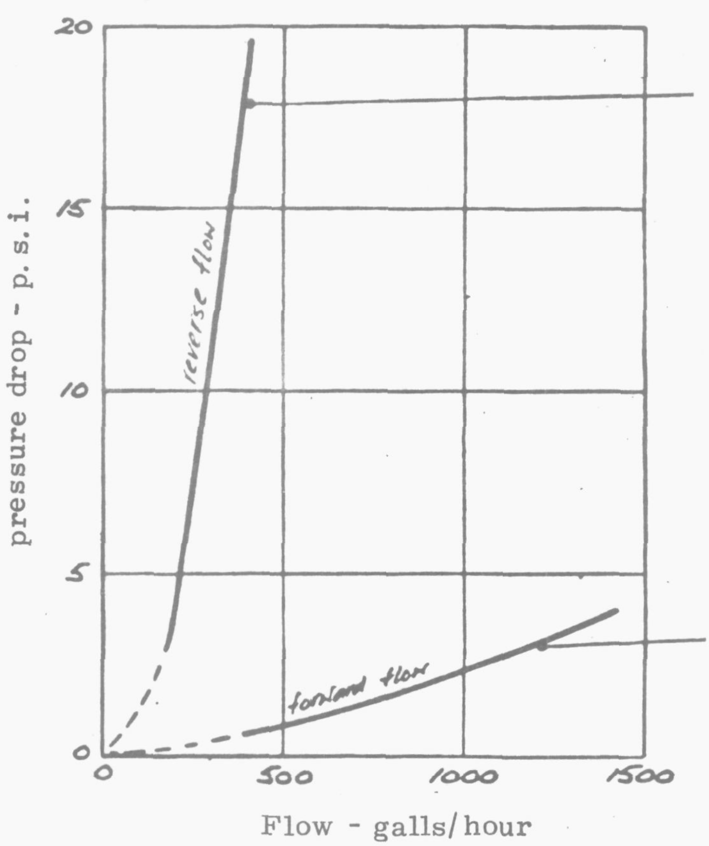
Chamber diameter	4. 5 inches
Chamber depth	0. 6 inches
Tangential nozzle	0. 6 inches diameter
Axial port throat	0. 5 inches diameter





Scale: One third full size

Figure 6



flow function $\frac{Q_T}{(P_T - P_A)^{\frac{1}{2}}} = 93$

flow function $\frac{Q_A}{(P_A - P_T)^{\frac{1}{2}}} = 700$

FIGURES 5 and 6

Vortex valve

Figure 7

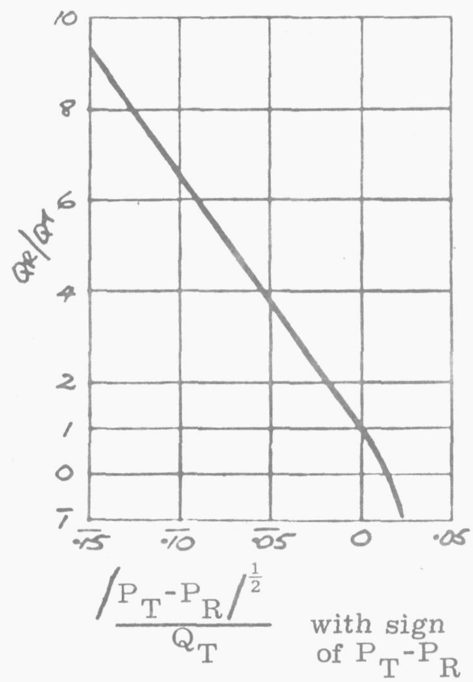
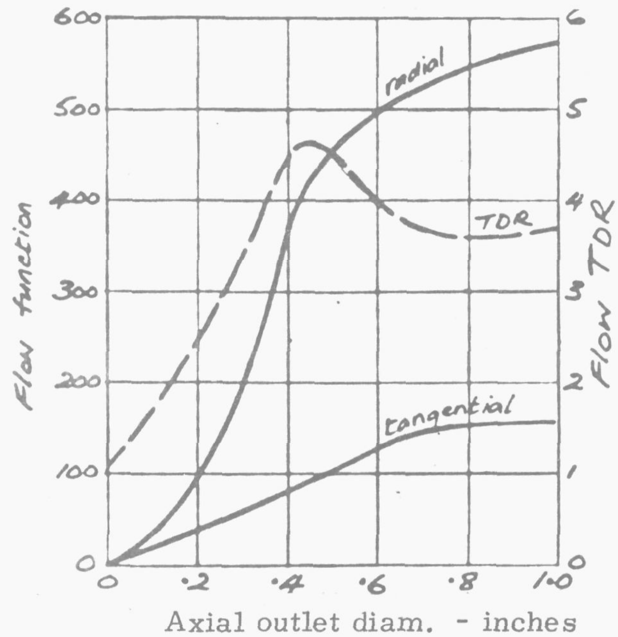


Figure 9



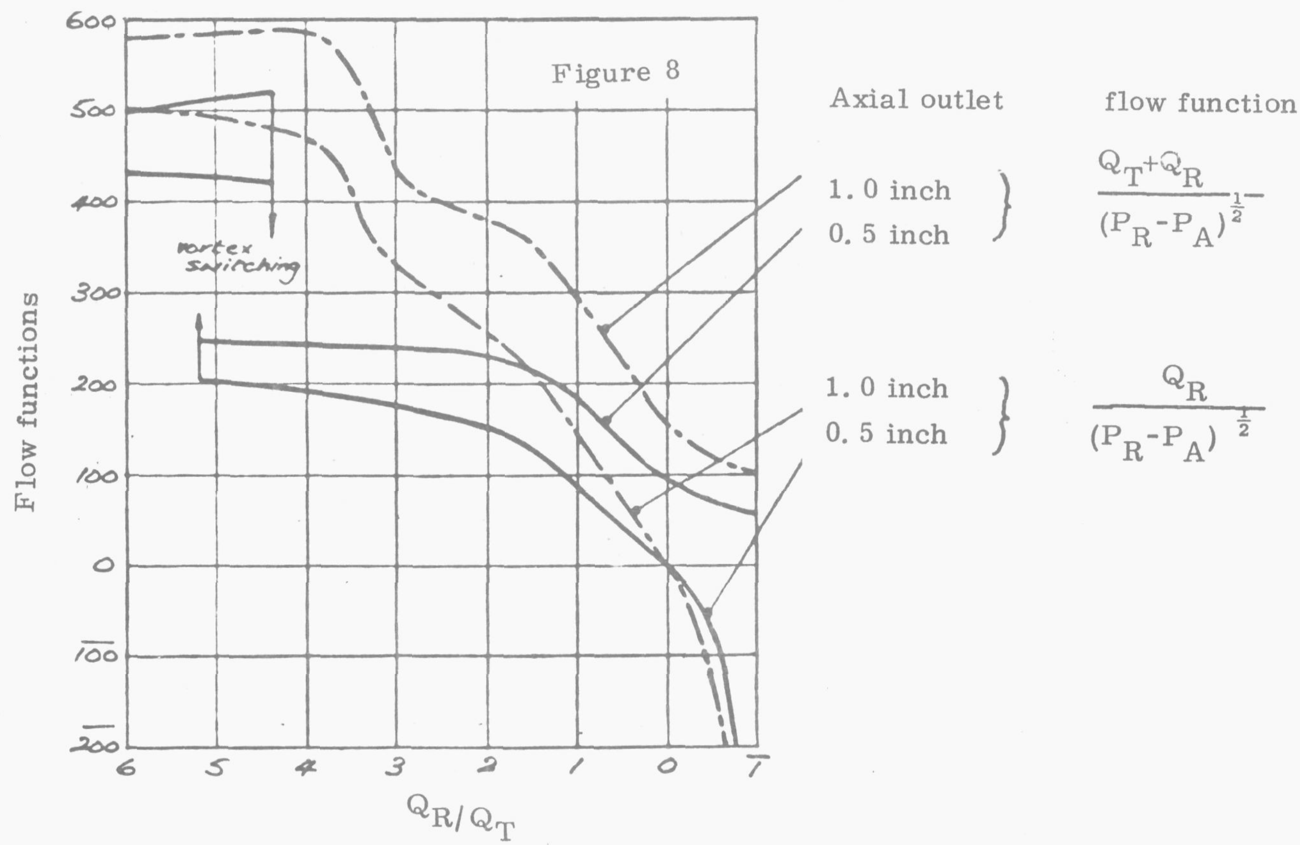
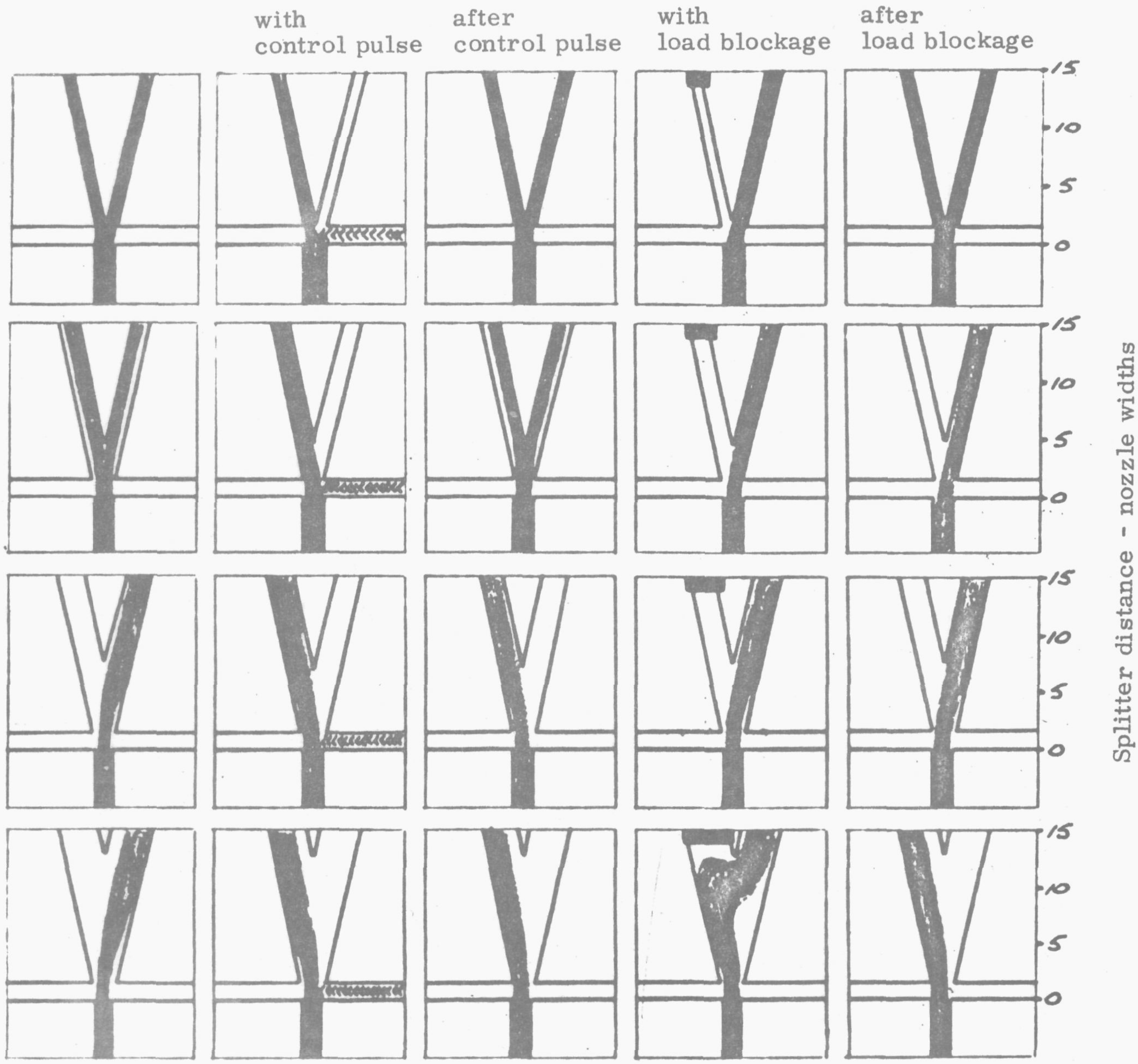


Figure 8

FIGURES 7, 8 and 9

Coanda device

Figure 10

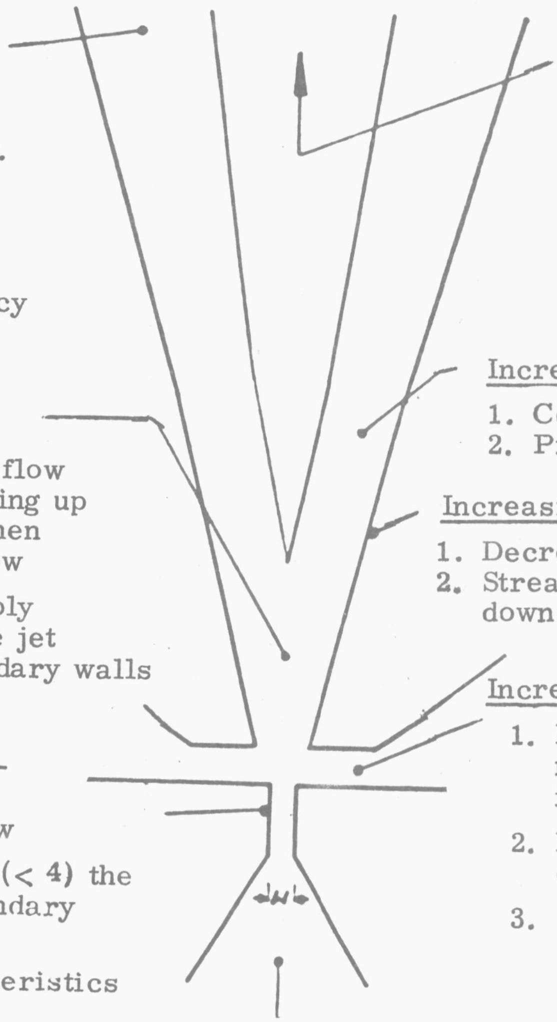


Effect of splitter distance on behaviour

FIGURE 10

Coanda device

Figure 11



Effects of geometry

FIGURE 11

<u>Proportional amplifier/ vortex valve combination</u>

Figure 12

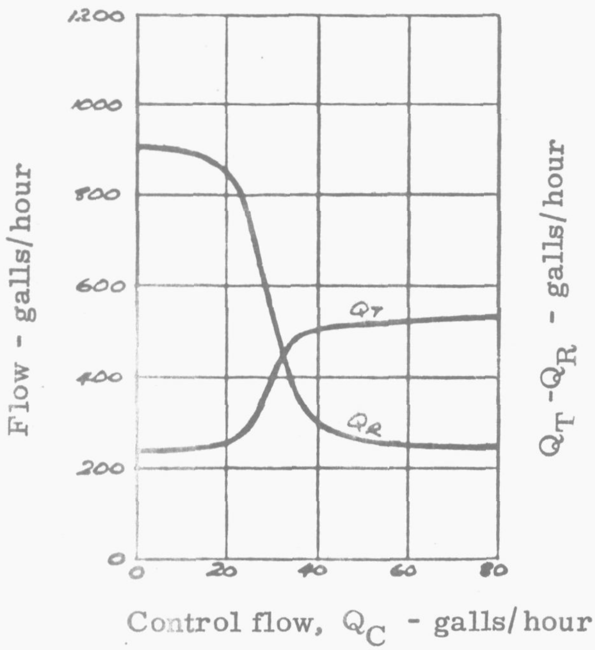


Figure 13

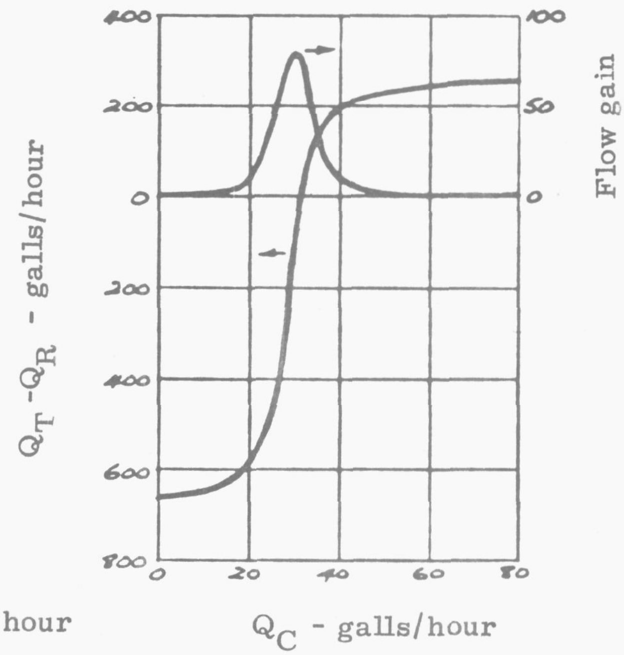


Figure 14

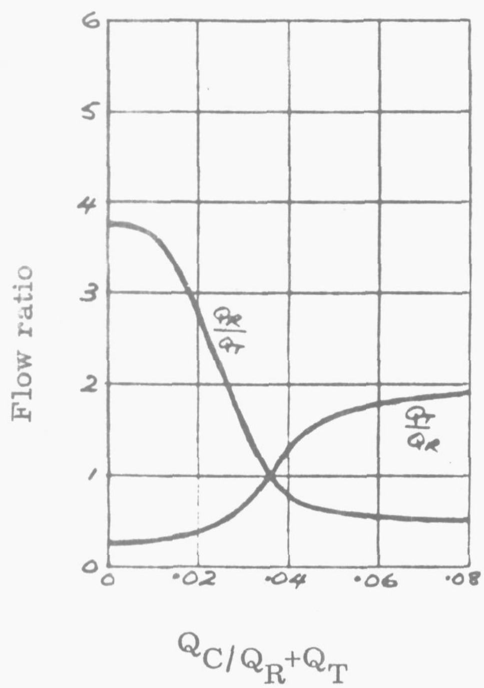
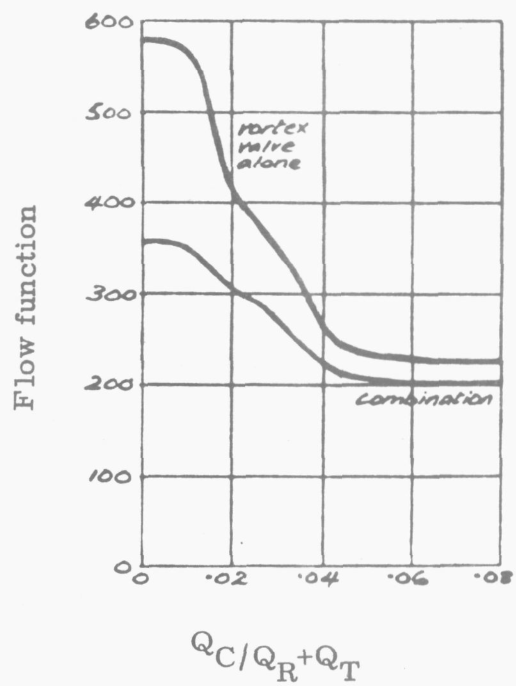


Figure 15



FIGURES 12, 13, 14 and 15.