EFFECT OF DIAMETER RATIOS ON FLOW THROUGH INLET VALVES OF INTERNAL COMBUSTION ENGINES

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May 22, 1941

Professor George W. Swett
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Dear Sir:

In accordance with the requirements for the degree of Bachelor of Science, we herewith respectfully submit a thesis entitled, "Effect of Diameter Ratios on Flow Through Inlet Valves of Internal Combustion Engines".

Sincerely yours,

Richard G. Falls

Stephen W. James

Acknowledgements

The authors wish to acknowledge their indebtedness to Professor A. R. Rogowski, Professor C. F. Taylor, Mr. English, Mr. Barker and the instructors of the machine tool laboratory for their assistance and advice on construction of the apparatus and in conducting this investigation.

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PART I

Introduction

It has been suspected for some time that because of the sharp intersection of the inlet port with the valve seat in internal combustion engines, a condition of severe turbulent flow is created which adversely affects the engine breathing capacity with a consequent reduction in the output power. The purpose of this investigation was to determine whether, by fairing a somewhat smaller port into a standard seat, the flow through the valve could be appreciably improved, and whether the ratio of port to seat diameter was critical for normal valve lifts or could be varied over a moderate range and still give improved flow.

We were familiar with the fact that over the past several years a series of theses had been performed relating to the effect of valve-shape and combustion chamber-valve head clearance on the mixture flow in internal combustion engines. The present subject was recommended to us by Professor C. F. Taylor as the one phase of that problem which had still to be investigated. Since accurate information on the whole subject of mixture flow is becoming more and more urgently needed for the design of high performance engines, we undertook to examine this final portion of the field in the expection that the results of this and the several previous theses will be coordinated, and incorporated into a much needed addition to the literature on the entire subject by a member of the Institute staff.

There were no previous contributions available on our particular phase of the subject, with the result that we were obliged to make an "educated guess" as to a series of port diameter-valve seat diameter ratios which would enalbe us to determine the extent of the effect which we were studying. We were, however, greatly aided by the work of D. U. Hunter, and that of Barker and Thomas-Stahle, on the shape of valve for optimum flow, and the one used in our tests was designed and built by us to conform to their recommendations as much as possible.

Although there has been some speculation as to what might be the effect on the flow coefficients of a valve and port combination if the port diameter were reduced relative to the valve diameter but so faired into the valve seat as to provide for smoother flow, actual data prior to our investigation was not available so far as we could find.

PART II

Summary of Results

Our investigation shows conclusively that the turbulence in the mixture flow through a normal valve and port combination is so great as to materially reduce the rate of flow for the usual valve lift of L/D = .25 to a value lower than that through a port of .886 the normal diameter if the smaller port be faired into the normal seat with the arc of a circle which is tangent to both the port wall and the seat, and that the rate of flow through a port of .766 normal diameter port, although less than for the .866 normal diameter port, still is greater than that through the normal port. A comparison of the flow coefficients for the four diameter ratios tested at several representative valve lifts is shown in Plot #2 which is to be found in the Appendix. Plot #1 shows the flow coefficients for each port over the entire L/D range for which it was tested.

Design of Apparatus

Since there had apparently been no previous work done on this phase of the flow problem, there were several major questions which had to be answered before any progress could be made with actual testing. Our first step was to make a survey of available materials in the Sloan Laboratory which might be incorporated into our apparatus. What we found were an air metering barrel with a set of thin plate orifices for measuring the quantity of air flow, and a sort of air dome which had been used by Barker and Thomas-Stahle in their work on combustion chamber shape for controlling the valve lift from the top side of the valve. The test method we therefore decided on was to clamp the port being tested to a hole in one end of the barrel and fasten the air dome to the opposite end of the port section so that it would center the valve on its seat in the port section and that the valve could be controlled from outside the dome. A large pipe was to be run from this dome to a vacuum pump nearby in the laboratory. We decided to use the same valve for all the ports, rather than try to use the same size port with varying valve seat and valve diameters.

This immediately raised the question of a proper size for the valve. We knew that any errors in the dimensions of the ports would be relatively more important to the d/D ratio if the valve were small than if it were large, but the inside diameter of the air dome was a distinct limitation to the valve size since too large a valve would give too small a clearance between the valve and the dome wall. After conferring with Professor C. F. Taylor it was decided that an overall valve diameter of two and a quarter inches would be satisfactory. We had nothing on which to base our estimates of the proper diameters of the three smaller ports except to use diameters which seemed to give reasonable ratios of d/D.

The question of a material from which to make the ports now arose. The dental stone used in the earlier work on combustion chamber shape was considered impractical because of its expense and the molds required. Quite some thought was given to using a wooden port with a steel valve seat for d/D equal to 1, to be sleeved down with machined brass inserts for the smaller ratios. However, brass pipe or tubing was not available in a sufficiently large range of diameters. Finally it was decided to machine individual ports from cast iron bushings, each with an overall length of six inches and diameter of three inches so that they would all fit the same air barrel adapter. Professor Taylor had suggested that we use at least three different ports, but we considered that we should use four, and ordered four rough cast iron bushings from the Barbour-Stockwell Company of Cambridge from which to make them. Because of the national defense work in which the company is engaged there was some delay in receiving the bushings. In view of the difficulty of reproducing curves having a varying radius, we decided to use arcs of circles to fair the different port diameters into the standard size valve seat. It was immediately found, however, that there was not equipment available in the M.I.T. machine tool laboratory to reproduce even such arcs in cast iron and it was necessary to design individual tools to cut the faired portion of each port and make them, three in all, from tool steel which we machined, heat-treated, and ground ourselves. Once the tools had been made, we were able to go ahead whenever we could get a lathe and make up the ports. The production of the tools and the ports took a considerable time because it was often impossible to obtain the use of the necessary machines in the machine tool laboratory.

The final step in assembling the apparatus was the production of a valve of the proper size which incorporated the recommendations by the authors of the theses on valve-shape as much as possible, and the design of an air barrel adapter for the cast iron ports which would hold them and to which the air dome could be clamped. This adapter was designed by us but produced by a local pattern maker from built-up wood turned to size, being similar to those used in some of the recent research work done by some of the staff members in the Sloan

Laboratory. Drawings of the various parts of the apparatus are to be found in the Appendix to this thesis.

Testing Procedure

In making a test, the port to be tested was inserted into the air barrel adapter and the joints between the adapter and port were filled in with plasticene so as to make sure that there would be no leakage around the port. The air dome, incorporating the valve and the micrometer valve lift adjustment screw, was then clamped to the adapter and the seam between them was also filled in. The whole unit was then clamped to the air barrel and the manometer lead attached to the air dome. At all times during the test a constant pressure drop of ten inches of alcohol was maintained from the air barrel through the port to the dome. A measure of the rate of air flow through the apparatus was obtained by measuring the drop from atmospheric pressure to that in the barrel through a thin plate orifice by means of a manometer. By means of the micrometer screw, the valve opening was varied from L/D equal to zero up to L/D equal to 0.45 and back again to zero in L/D steps of 0.05, a manometer reading being taken at each step, and the constant pressure drop was maintained by varying the power supplied the pump and the valve in the vacuum line from the dome.

The discharge coefficient of the combination of valve and port was calculated by means of a formula derived from Moss' formula for flow of air through a rounded orifice. As derived by Hunter, this formula is

$$C_v = \frac{C_o D_o^2}{D^2} \sqrt{\frac{(P_1 - P_2)\ P_2}{(P_2 - P_3)\ P_3}} .$$

Using a two inch orifice with constant discharge coefficient, a valve of constant diameter, and assuming that $\frac{P_2}{P_3}$ is negligible for a constant value of $(P_2 - P_3)$ equal to ten inches of alcohol, the equation for the coefficient of the valve becomes

$$C_v = k \sqrt{\frac{P_1 - P_2}{P_2 - P_3}} = .5^{22} \sqrt{\frac{P_1 - P_2}{10}} .$$

The actual taking of data required very little time, and we wish that we might have had more time so that we could have made up several more ports, one or two larger and another slightly smaller than Port #2, so as to determine more closely the shape for optimum flow.

Discussion of Results

It was believed before we started our investigation that the flow coefficients for ports could be increased by using smaller ports with a faired surface joining them with the valve seat. From our runs this was shown to be true for diameter ratios which are not too small. From the data gathered, the results of the investigation are presented in the form of graphs. The graphs plotted are Flow Coefficient versus L/D for different diameter ratios and Flow Coefficient versus Diameter Ratio for different valve lifts. From these plots the true significance of the investigation is obvious. It is plain to see that for diameter ratios of about .87 a considerable increase in the flow through the valve-port unit is obtained. The three small valve-port combinations conformed very well to their supposed theoretical behavior, but the largest port could not be made to reach a maximum within the range of the experiment. On the whole the results proved satisfactory.

Suggestions for Future Investigation

For future investigation it is recommended that the same valve and ports be used in a system of greater capacity so that the true effects of the valve-port combination can be obtained uninfluenced by the limitations of the rest of the system. At the same time equations predicting the gains to be obtained by use of these ports should be worked out if possible. Perhaps the most important thing to be done next along this line is to set up an engine so that such variable ports can be inserted and then to see how much added power is obtainable by this method.

APPENDIX

BIBLIOGRAPHY

Barker, Wensley, Jr.............. *Effect of Cylinder-Head Clearance on Flow Through an Inlet Valve of an L-Head Egine*, M.I.T. Thesis, 1940.
Thomas-Stahle, J. I.

Hunter, D. U..................... *Effect of Valve and Port Shape on Air Flow Through Intake Valves, M.I.T.* Thesis, 1938.

EXPLANATION OF SYMBOLS

C_o	Coefficient of discharge of orifice.
C_v	Coefficient of discharge of valve-port unit.
D_o	Orifice diameter of flow meter.
D	Inside valve seat diameter.
d	Port diameter in straight section.
L	Valve lift.
P_1-P_2	Pressure drop across calibrated orifice.
P_2-P_3	Pressure drop across valve-port unit.
P_1	Atomospheric pressure.
P_2	Pressure in air barrel after orifice.
P_3	Pressure in dome above valve-port unit.

SAMPLE CALCULATIONS

For Cylinder No. 1, Run #1.

$$\frac{L}{D} = \frac{.108}{2.162} = .05$$

$P_1 - P_2 = 0.56$ inches alcohol

$P_2 - P_3 = 10$ inches alcohol

$D_o = 2$ inches

$D = 2.162$ inches

$d = 2.162$ inches

$$C_v = \frac{C_o D_o^2}{D^2} \sqrt{\frac{P_1 - P_2}{P_2 - P_3}} = k \sqrt{\frac{P_1 - P_2}{10}}$$

$$k = \frac{C_o D_o^2}{D^2} = \frac{.609 \times 4}{2.162 \times 2.162} = .522$$

$$C_v = .522 \sqrt{\frac{P_1 - P_2}{10}} = .522 \sqrt{\frac{.56}{10}}$$

$$C_v = .123$$

DATA SHEET

CYLINDER # 1

D = 2.162 inches d = 2.162 inches

$P_3 - P_2$ = 10 inches Alcohol

Run #	L	L/D	$P_1 - P_2$	C_v
1	.108	.05	0,56	.123
2	.216	.10	2.25	.247
3	.324	.15	5.40	.383
4	.432	.20	9.85	.517
5	.480	.222	12.05	.572
6	.541	.25	15.30	.645
7	.648	.30	20.95	.755
8	.757	.35	26.50	.849
9	.865	.40	31.80	.930
10	.973	.45	36.50	.997
11	.865	.40	32.40	.938
12	.757	.35	26.90	.856
13	.648	.30	21.20	.759
14	.541	.25	15.90	.657
15	.432	.20	10.20	.532
16	.324	.15	5.80	.397
17	.216	.10	2.30	.250
18	.108	.05	0.65	.133
19	.000	.00	0.00	.000

DATA SHEET

CYLINDER # 2

D = 2.162 inches

d = 1.87 inches

$P_3 - P_2$ = 10 inches Alcohol

Run #	L	L/D	$P_1 - P_2$	C_v
1	.108	.05	0.80	.147
2	.216	.10	3.60	.314
3	.324	.15	8.85	.494
4	.432	.20	15.75	.655
5	.480	.222	19.90	.736
6	.541	.25	22.80	.789
7	.648	.30	25.60	.835
8	.757	.35	26.80	.855
9	.865	.40	28.30	.879
10	.973	.45	29.70	.900
11	.865	.40	28.60	.884
12	.757	.35	27.10	.860
13	.648	.30	25.50	.834
14	.541	.25	22.80	.789
15	.480	.222	19.50	.729
16	.432	.20	15.50	.650
17	.324	.15	8.80	.490
18	.216	.10	3.60	.314
19	.108	.05	0.80	.147
20	.000	.00	0.00	.000

DATA SHEET

CYLINDER # 3

$D = 2.162$ inches $d = 1.65$ inches

$P_3 - P_2 = 10$ inches Alcohol

Run #	L	L/D	$P_1 - P_2$	C_v
1	.108	.05	0.90	.157
2	.216	.10	3.80	.321
3	.324	.15	9.00	.496
4	.432	.20	15.20	.644
5	.480	.222	16.85	.674
6	.541	.25	17.70	.695
7	.648	.30	17.90	.699
8	.757	.35	18.10	.702
9	.865	.40	18.30	.706
10	.973	.45	18.70	.714
11	.865	.40	18.50	.710
12	.757	.35	18.20	.704
13	.648	.30	17.90	.699
14	.541	.25	17.80	.697
15	.480	.222	17.00	.681
16	.432	.20	15.20	.644
17	.324	.15	9.20	.498
18	.216	.10	3.90	.326
19	.108	.05	0.95	.162
20	.000	.00	0.00	.000

DATA SHEET

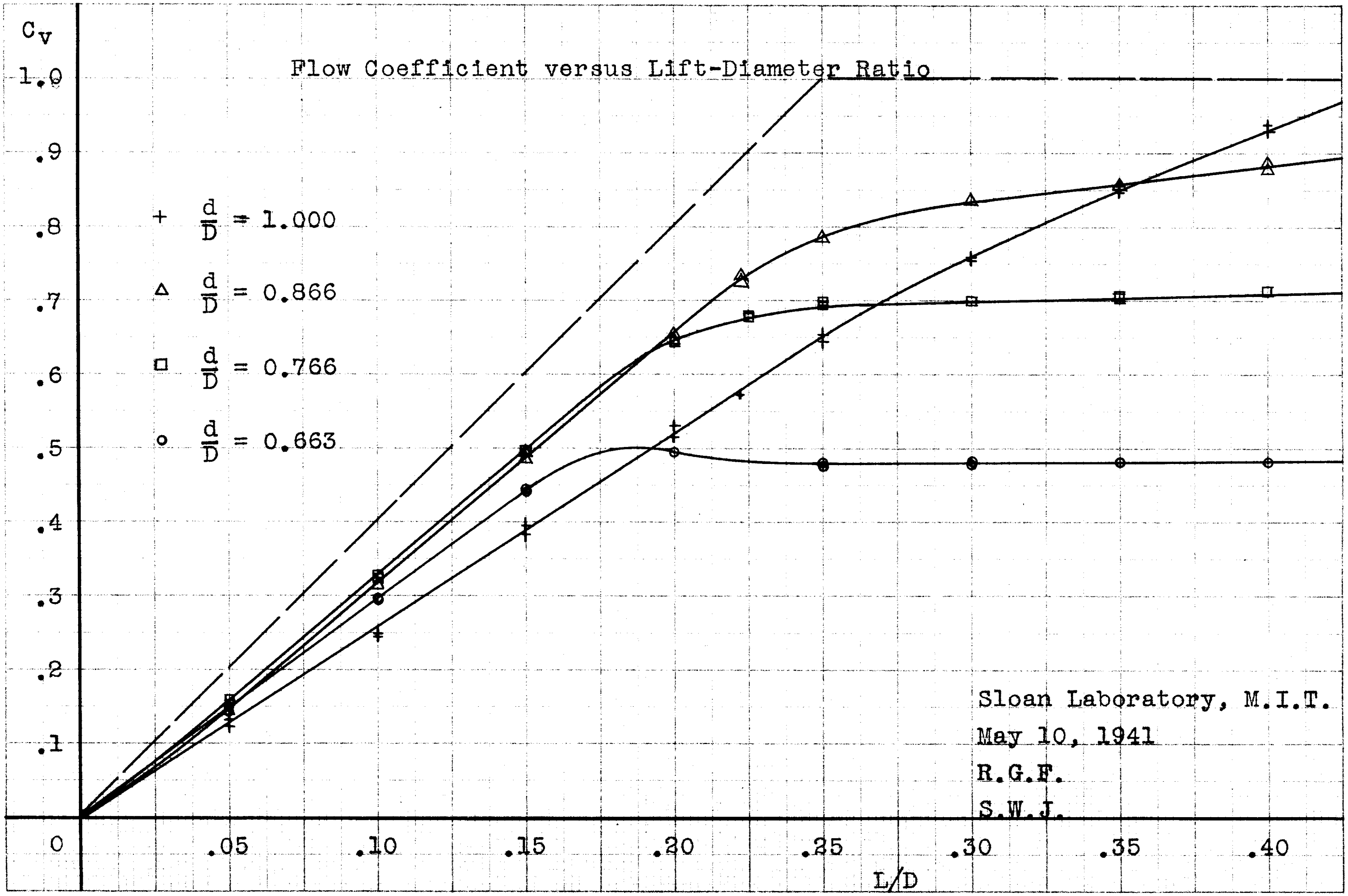
CYLINDER # 4

D = 2.162 inches

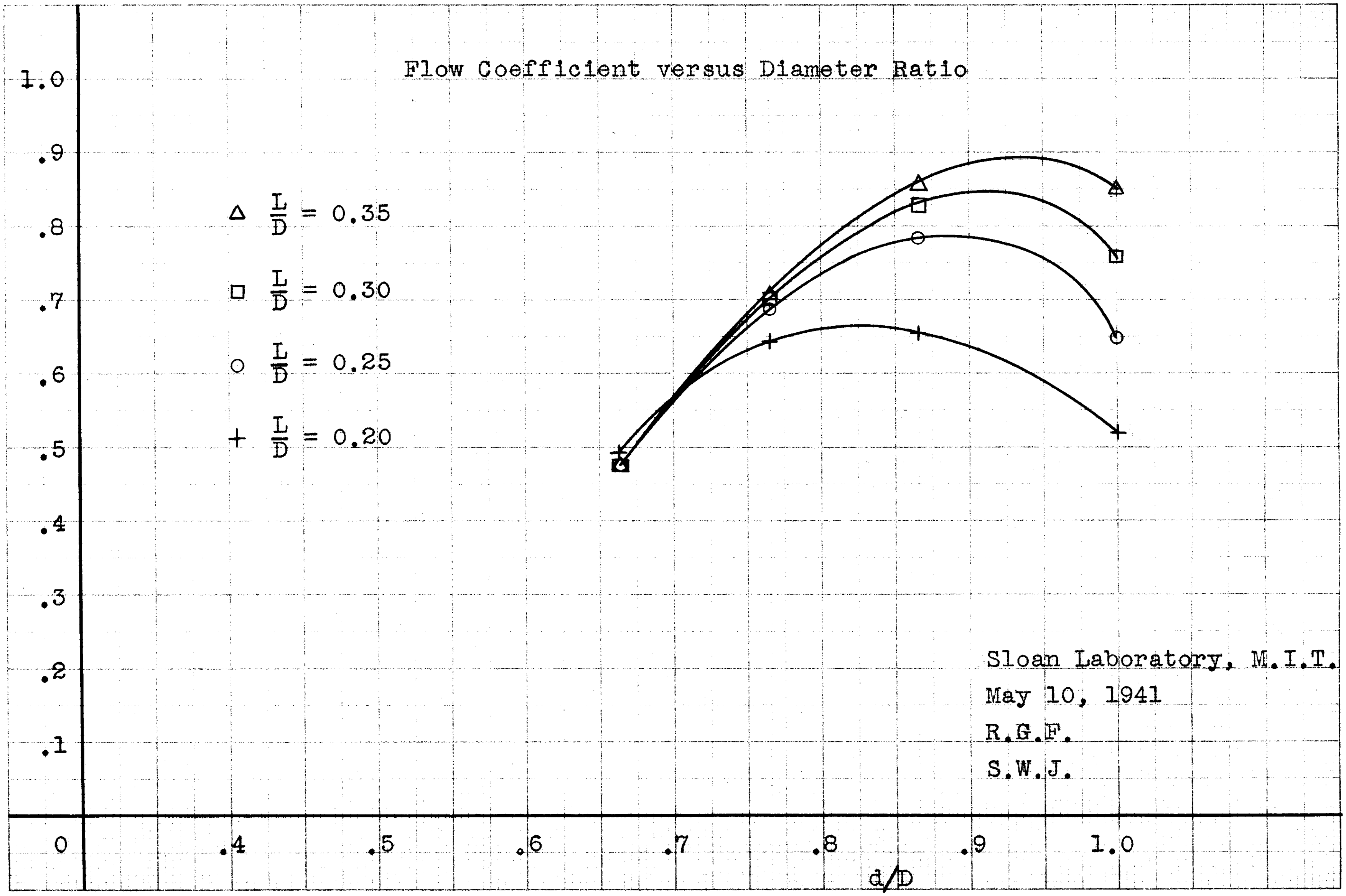
d = 1.43 inches

$P_3 - P_2$ = 10 inches Alcohol

Run #	L	L/D	$P_1 - P_2$	C_v
1	.108	.05	0.75	.143
2	.216	.10	3.20	.295
3	.324	.15	7.20	.440
4	.432	.20	9.00	.495
5	.541	.25	8.40	.478
6	.648	.30	8.50	.482
7	.757	.35	8.50	.482
8	.865	.40	8.60	.484
9	.973	.45	8.60	.484
10	.865	.40	8.55	.483
11	.757	.35	8.50	.482
12	.648	.30	8.40	.478
13	.541	.25	8.50	.482
14	.432	.20	9.10	.498
15	.324	.15	7.30	.447
16	.216	.10	3.30	.300
17	.108	.05	0.80	.147
18	.000	.00	0.00	.000

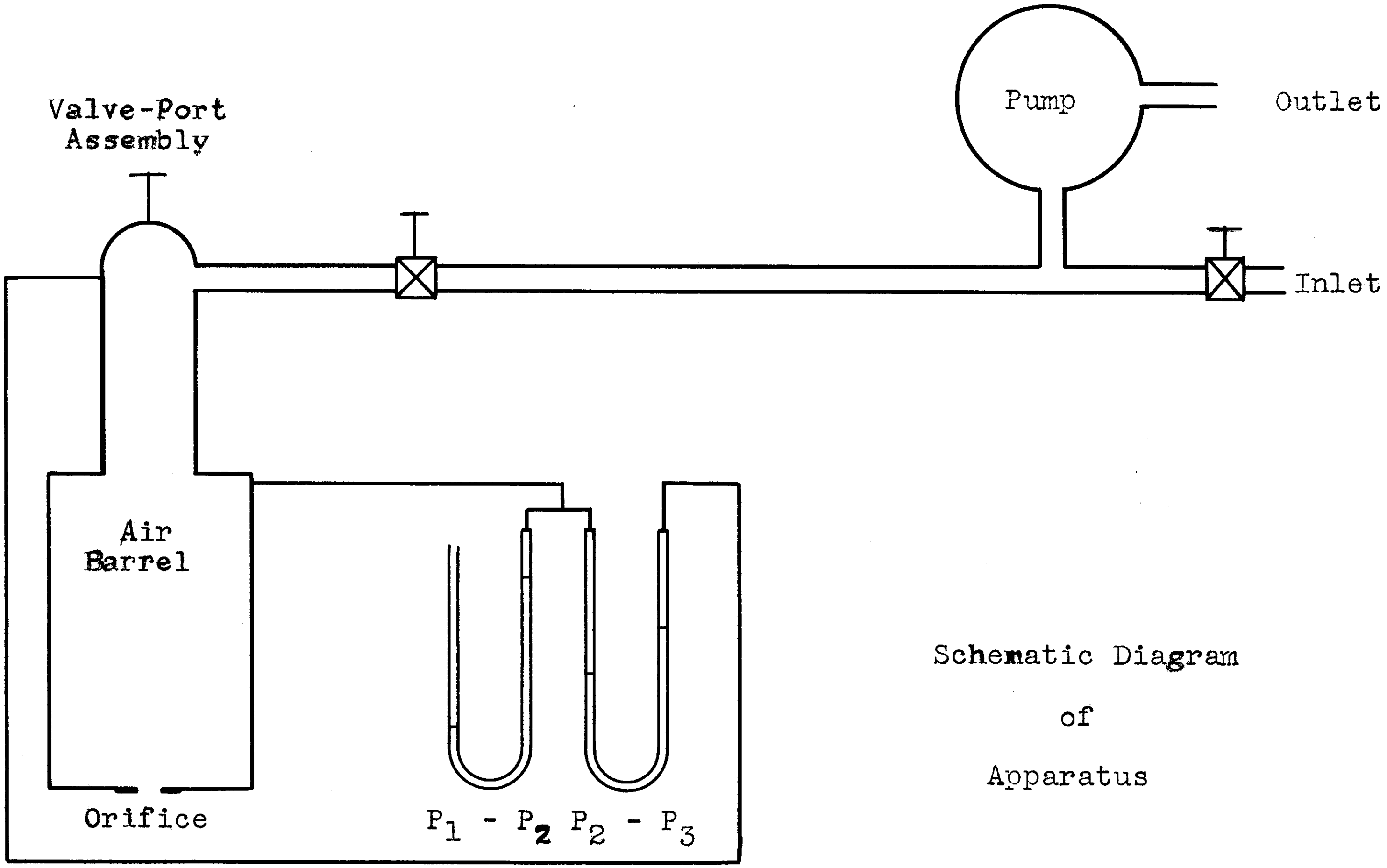

C_v
Flow Coefficient versus Lift-Diameter Ratio
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.05
.10
.15
.20
.25
.30
.35
.40
L/D
+ $\frac{d}{D}$ = 1.000
△ $\frac{d}{D}$ = 0.866
□ $\frac{d}{D}$ = 0.766
○ $\frac{d}{D}$ = 0.663
Sloan Laboratory, M.I.T.
May 10, 1941
R.G.F.
S.W.J.

Plot 1


Flow Coefficient versus Diameter Ratio

Sloan Laboratory, M.I.T.
May 10, 1941
R.G.F.
S.W.J.

Plot 2



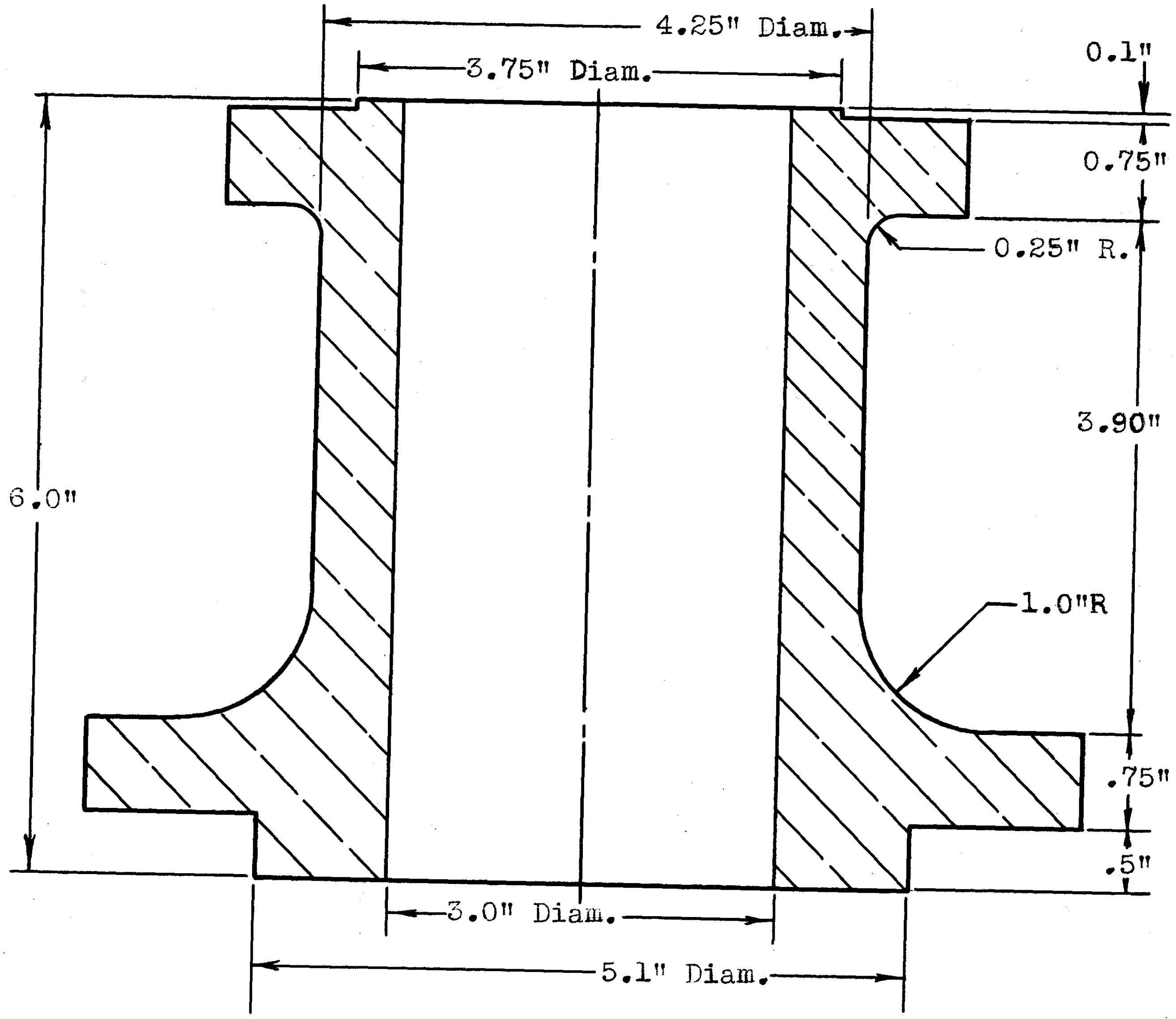
Schematic Diagram

of

Apparatus

R.E.G.
L.W.J.
5/15/41

AIR BARREL ADAPTER



R.G.F.
L.W.J.
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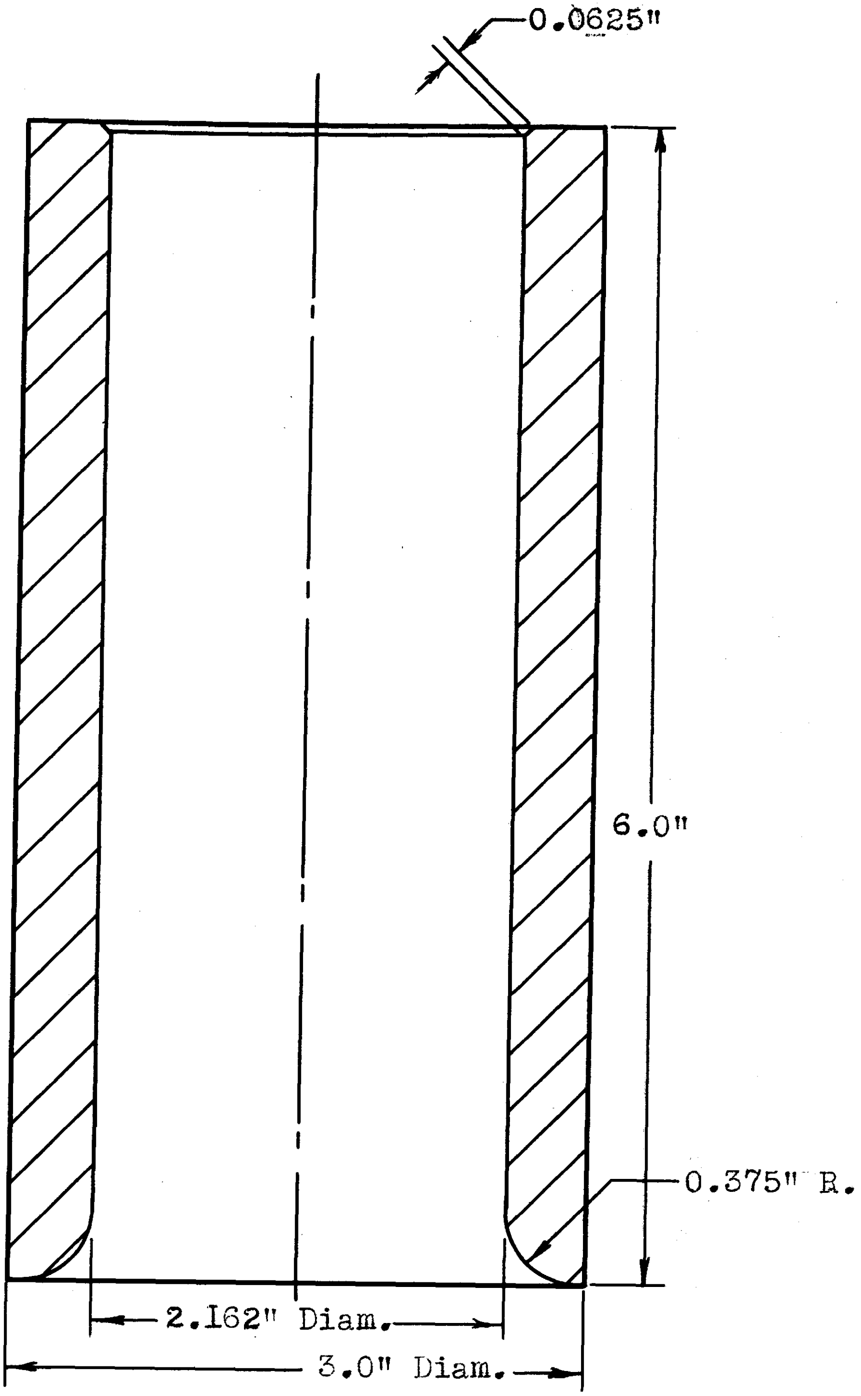
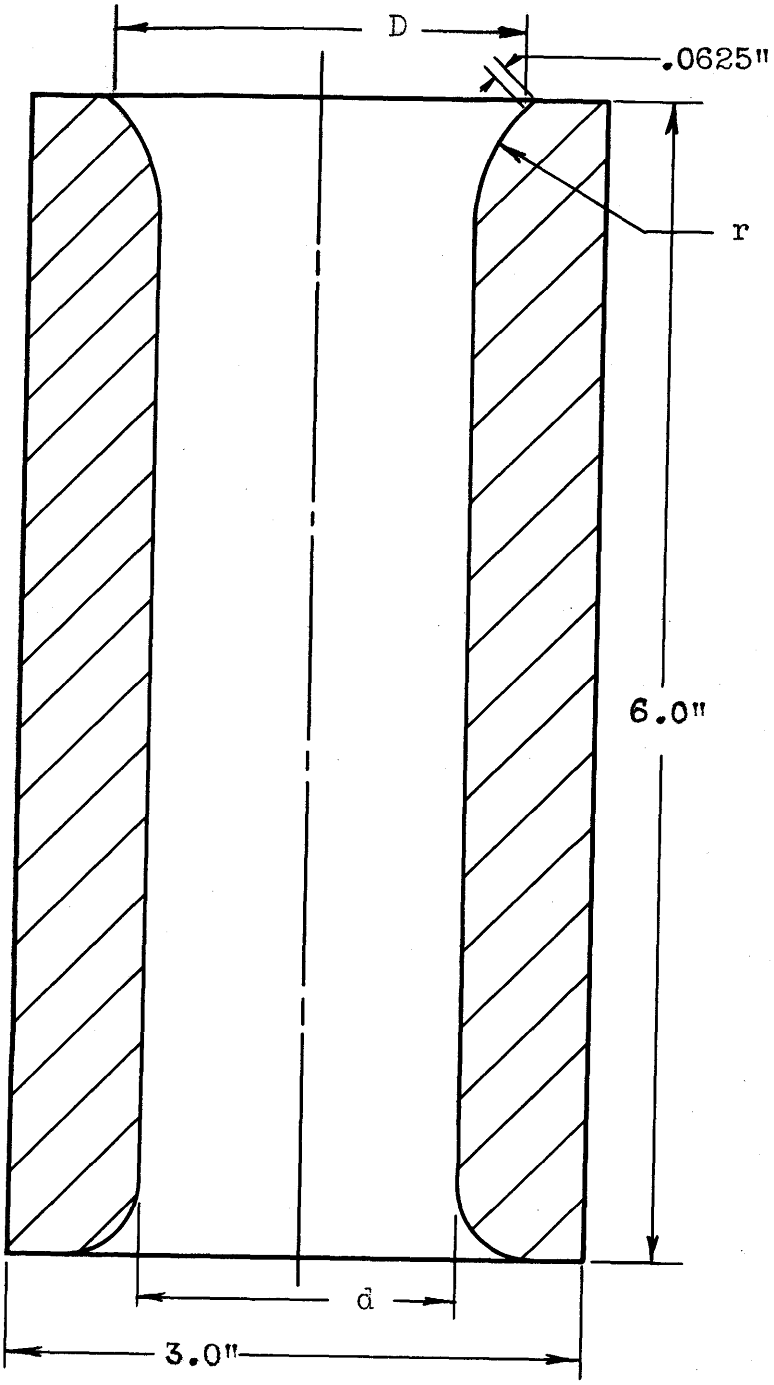


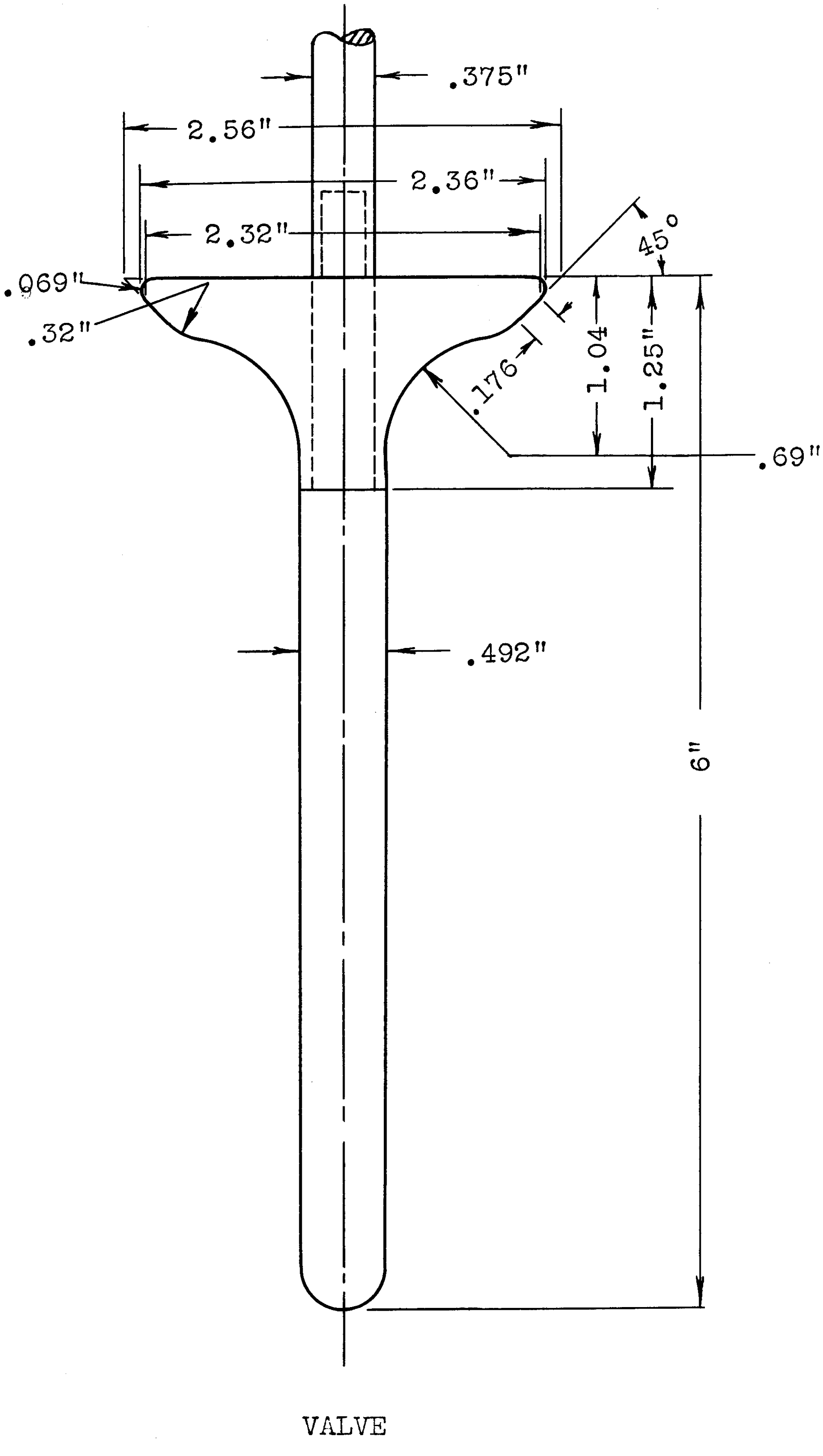
CYLINDER # 1

R.G.G.
L.W.J.
5/15/41



CYLINDER #	D	d	r
2	2.162"	1.869"	0.50"
3	2.162"	1.649"	0.875"
4	2.162"	1.429	1.25"

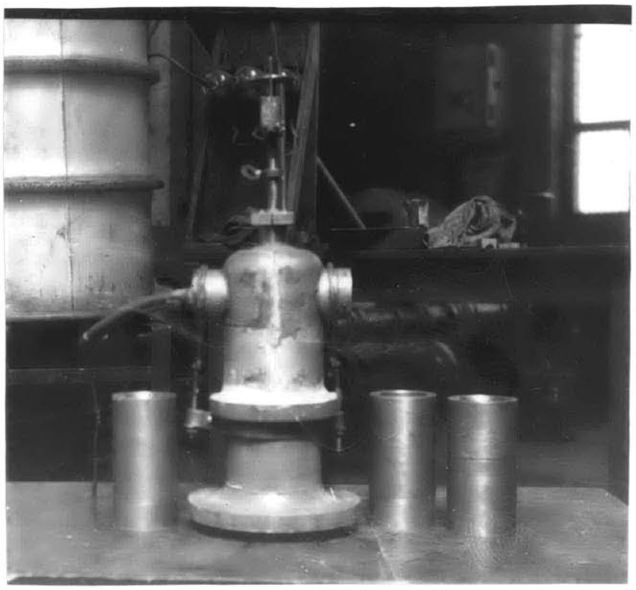
R.G.T.
S.W.J.
5/15/41



VALVE

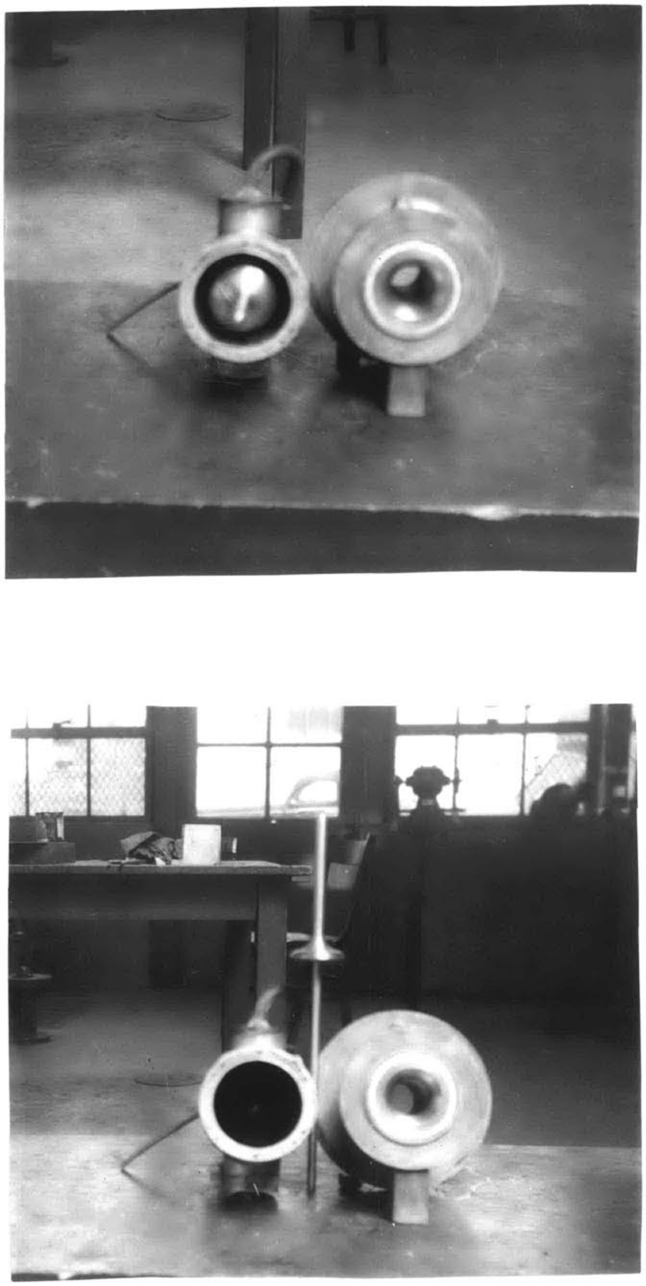
5/15/41

APPRARATUS



VALVE-PORT ASSEMBLY, AND PORTS

ADAPTER, AND PORTS



DOME, VALVE, ADAPTER, AND PORT