AIR RESISTANCE OF CYLINDER COMBINATIONS

A THESIS

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C O N T E N T S

Air Resistance of Cylinder Combinations

The present experiments were undertaken to investigate the shielding effect of cylinders or wires which lie one behind the other such as found in practice in the bracing wires of aeroplanes.

1. Description of Apparatus:

The specimens employed were made in the form of wooden rods of three different diameters, viz., 1", 3/4" and 1/2", and all 18" in length, which length is considered most suitable for the four foot wind tunnel. In these experiments the specimens were mounted on an apparatus specially designed for the purpose (Fig. 1) It consists of a V-shaped frame made of 1/8" brass sheet. On the top of each arm of the frame is a horizontal cross piece about 10" long, which forms with the arm the letter T when viewed in the direction perpendicular to that of the wind. A slot 3/16" wide and about 8" in length is cut in the centre of each of these cross pieces; 3/16" screws projecting from the ends of the specimens fit into these slots, and are held in position by small nuts. The spacing or gap of a combination of two cylinders can thus be varied by unscrewing the nuts on one of them and sliding it along the slots. The frame has at its lower end a short spindle which connects it to the balance underneath the wind tunnel.

From the balance pivot to the centre of the slots or the centre of the cylinders the arm was 32.813". The balance was so constructed that the balance weights gave the resistance directly when the arm was 36". Hence an arm ratio correction of $\frac{36}{32.813}$ or 1.095 had to be applied to all resistance readings.

2. Determination of the Resistance of the Apparatus.

For this purpose the apparatus was mounted on the balance without the specimens, but with the small nuts stuck on to the cross-pieces. The resistance was then measured at different wind speeds. The results are tabulated as follows:

Table I

Wind speed M. P. H.	Wind speed ft./sec.	D_o	D_1	$D_s = D_1 - D_o$
35	51.33	.073	.1240	.0510
30	44.00	.073	.1115	.0385
25	36.67	.073	.1000	.0270
20	29.33	.073	.0930	.0175
16	23.40	.073	.0870	.0140
12	17.50	.073	.0825	.0095

Where D_o = zero reading without wind
D_1 = readings with wind
D_s = resistance of the apparatus without arm ratio correction

From all readings of resistance of cylinders and cylinder combinations D_s for the corresponding speed was subtracted. Correction was then made for the arm ratio and K calculated. Hence the actual resistance of the apparatus was of no interest

3. Alignment of Apparatus with the direction of the wind.

It is important that the apparatus should be placed exactly parallel to the axis of the wind tunnel in order that its resistance may be the same in each experiment. To determine the effect of small deviations from the exact parallel position, the apparatus was turned 2° to either side of the correct position, and readings were taken of its resistances at the deviated positions, and it was found that the increase in resistance was 8% in each case, or approximately 4% per degree. With this apparatus, adjustment could be made to within 1/4 of a degree without difficulty, and therefore error from this source would be within 1% of the resistance of the apparatus which was itself only about 15% of the average resistance recorded in this investigation. No appreciable error would therefore be introduced in our results due to this cause.

4. Resistance of Cylinder Combinations:

Four combinations of cylinders were tested, and they were made up as follows:-

(1) 1" and 3/4"

(2) 1" and 1/2"

(3) 3/4" and 1/2"

(4) 1/2" and 1/2"

The larger cylinder was placed in the foremost position in the slots in each case, and the smaller or the rear one was shifted progressively to the rear after each reading was taken. The distance between the cylinders was measured by a pair of callipers. Wind velocity throughout the experiments was 30 miles an hour.

Table 2 gives the values of K which was calculated from the expression

$$R = KDLV^2$$ where

R was the measured resistance in lbs.
D the diameter of the larger cylinder in feet.
L the length in feet (=1.5)
V the wind velocity in feet per second

In combinations (3) and (4) where the large diameters are 3/4" and 1/2" respectively, the values of K have been reduced to 1" dia. in the following manner:

From fig. 3 we find that at 30 miles an hour

K for 1" dia. = 0.00120; (DV = 3.66)
K " 3/4" " = 0.00123; (DV = 2.75)
K " 1/2" " = 0.00122; (DV = 1.83)

Therefore at 30 miles per hour,

$$K \text{ for } 1'' \text{ dia.} = 120/123 = 0.975 \text{ times that for } 3/4'' \text{ dia.}$$

$$\text{and} \quad = 120/122 = 0.984 \text{ times that for } 1/2'' \text{ dia.}$$

Therefore in combination (3)

$$K = R/DLV^2 \times 0.975$$

and in combination (4)

$$K = R/DLV^2 \times 0.984$$

The values of K for all the combinations in the table are now comparable with each other and with the 1" single cylinder. The values of K are also expressed in percentages of the value for 1" cylinder (table 2) and are plotted in fig. 2 against cylinder spacings. Cylinder spacings are measured between centres and are in terms of the diameter of the larger cylinder.

T A B L E 2

T A B L E 2

Comparative resistances and resistance Coefficients of Cylinder Combinations

Spacing bet. Centers in diam. of the larger Cylinder	Ratio of Cylinder diameters 1 : 1 — Resistance in % of that of one single cylinder	K $= \frac{R}{LDV^2}$	Ratio of Cylinder diameters 1 : 1-3/4 — Resistence in % of that of one single cylinder	K $= \frac{R_2}{LDV}$	Ratio of Cylinder Diameters 1 : 2/3 — Resistance in % of that of one single cylinder	K $= \frac{R}{LDV^2}$	Ratio of Cylinder Diameters 1 : 1/2 — Resistance in % of that of one single cylinder	K $= \frac{R}{LDV^2}$
3/4	- - -	- - -	- - -	- - - -	- - - -	- - - -	87.6	.001050
5/6	- - -	- - -	- - -	- - -	87.7	.000981	- - -	- - - -
7/8	- - -	- - -	77.8	.000935	- - -	- - - -	90.6	.001090
1-	38.4	.000446	72.6	.000872	83.7	.001005	90.3	.001085
1-1/8	- - -	- - -	- - -	- - -	- - -	- - - -	87.	.001045
1-1/4	50.0	.000580	73.4	.000880	76.1	.000914	85.3	.001025
1-1/2	51.1	.000592	74.5	.000895	73.3	.000881	83.6	.001005
1-3/4	53.7	.000624	- - -	- - -	70.9	.000850	80.7	.000970
2-	62.4	.000723	79.9	.000960	74.3	.000893	82.5	.000990
2-1/2	- - -	- - -	87.1	.001048	84.9	.001020	88.1	.001060
2-3/4	89.	.001030	- - -	- - - -	- - -	- - -	- - -	- - -
3	- - -	- - - -	97.4	.001170	102.7	.001232	106.5	.001280
3-1/2	118.	.001376	112.0	.001345	123.	.001473	121.6	.001460
4-	137.	.001580	128.-	.001540	130.	.001565	126.7	.001520
5-	142.	.001660	133.	.001595	133.8	.001605	- - -	- - -
6-	- - -	- - - -	137.	.001645	- - -	- - - -	129.	.001550
7-	152.	.001770	139.9	.001675	138.3	.001662	- - -	- - -
8-	- - -	- - -	143.9	.001724	- - -	- - -	132.5	.001590
9-	- - -	- - -	- - -	- - -	141.	.001691	- - -	- - - -
10-	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - - -
11-	163.	.001890	- - -	- - -	- - -	- - -	- - -	- - - -
12-	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - - -
15-	170.	.001970	- - -	- - -	- - -	- - -	- - -	- - - -

5. Determination of K for single cylinders :

"End effect" as commonly understood in connection with wire resistance experiments was not well defined in our case because the flow was not disturbed by the sharp corners of the ends, as they were not exposed to the air current with our apparatus. The coefficients K in table 2 had not therefore been corrected for this effect, but a separate series of experiments was carried out to determine the resistance of single cylinders on the same apparatus so that should any error be introduced in the actual coefficients of table 2, it would be eliminated as they were expressed in percentages of that for the single cylinders so determined.

The three sizes of cylinders were tested at speeds varying from 12 to 35 miles an hour. Tables 3, 4, and 5 give the values of K for each cylinder from three sets of experiments and these are all plotted against the product of diameter (in feet) and wind velocity (in feet per second) i.e., DV (fig. 3). Values of K for single cylinders used in preparing table 2 were taken from this curve.

The reason for plotting K against DV , or in other words for assuming that K is a function of D.V. is based on the principle of dynamical similarity by which it can be shown that for the same value of DV, the coefficients K is constant. The dimensional effect in our results is thus eliminated.

6. <u>Discussion of the preceeding results</u>:

On examining the curves in fig. 2, the first thing to be noticed is that all the combinations have, in general, the same trend in character. That is,- when the rear cylinder is being progressively displaced from a position immediately behind the front cylinder, the resistance of the combination decreases from about 90% of that of the front cylinder to less than 80% at about 2 diameters apart; it then increases rather rapidly up to about 3-1/2 to 4 diameters, after which it increases but very slowly as the rear cylinder is still further displaced down stream.

The first part of the curve for the 1 to 1 dia. ratio combination however, shows an exception to the above remark. The resistance in this case does not decrease with the increase of spacing between the cylinders at any point on the curve; and furthermore, when these cylinders are close together they have a resistance much less than any of the other combinations. Starting with about 40%, it increases to 80% at about 2-1/2 diameters apart. Except also for a part of this curve, all the curves lie very close together, crossing and recrossing each other at many points, showing that no one particular combination gives much less resistance than others. The 1 to 1 dia. ratio combination gives appreciably less resistance than the rest of the combinations when placed not more than 3 diameters apart, and a negligibly small amount more at other spacings. In practice then, no good purpose will be served by making the rear wire, where two wires are used, of a smaller diameter than the front one.

T A B L E 3 Resistance of 1" dia Single Cylinder

Wind Velocity M.P.H.	Wind Velocity Ft./Sec.	D V	$K = \frac{R}{DLV^2}$ (1)	(2)	(3)
12	17.5	1.46	- - -	- - -	.00107
16	23.4	1.95	- - -	- - -	.00110
20	29.3	2.44	.00120	.00111	.00115
25	36.7	3.06	.00119	.00117	.00117
30	44.0	3.66	.00118	.00119	.00117
35	51.3	4.27	.00118	.00117	.00116

T A B L E 4 Resistance of 3/4" dia Single Cylinder

Wind Velocity M.P.H.	Wind Velocity Ft./Sec.	D V	$K = \frac{R}{DLV^2}$ (1)	(2)	(3)
12	17.5	1.09	- - -	- - - -	.00101
16	23.4	1.46	- - -	- - - -	.00107
20	29.3	1.83	.00125	.00121	.00116
25	36.7	2.30	.00124	.00125	.00122
30	44.0	2.75	.00123	.00126	.00121
35	51.3	3.20	.00124	.00121	.00122

T A B L E 5 Resistance of 1/2" dia. Single Cylinder

Wind Velocity M.P.H	Wind Velocity Ft./Sec.	D V	$K = \frac{R}{DLV^2}$ (1)	(2)	(3)
12	17.5	0.73	- - -	- - -	.00092
16	23.4	0.975	- - -	- - -	.00106
20	29.3	1.22	.00125	.00117	.00116
25	36.7	1.53	.00126	.00122	.00123
30	44.0	1.83	.00126	.00127	.00124
35	51.3	2.14	.00126	.00124	.00124

N. B.

D = dia. of cylinder in ft.
L = length of cylinder in ft.
= 1.5 ft. for all cylinders
V = wind velocity in ft/sec.
R = resistance in lbs.

7: Experiments on the Resistance of Cylinder Combinations with filled in gaps:

It was thought probable that the resistance of any of the combinations would be reduced if we filled in the gap between the cylinders so as to form smooth sides between them. This may be done in practice by wrapping air tight fabric or tape round wires where they occur in pairs.

Four filled in gap combinations of spacings 2, 4,6 and 8 diameters were chosen for test from the 1 to 1 diameter ratio combination and also a filled in combination of ~~2~~ 4 diameters spacing from the 1 to ~~1/2~~ 3/4 diameter ratio combination to see whether such a refinement would improve the resistance by any larger amount.

Special specimens were made for this series of experiments, They were in the form of wooden boards with rounded edges. For the 1 to 1 diameter ratio combination the boards each had a uniform thickness of 1" and width of 3", 5", 7" and 9" representing spacings between centres of 2, 4, 6 and 8 diameters respectively. For the 1 to ~~1/2~~ 3/4 diameter ratio combination the board was tapered from 1" diameter at the front edge to ~~1/2"~~ 3/4" diameter at the rear. The lengths were as before all 18 inches. (fig. 4).

The uniform boards were all tested first with one edge facing the wind and then the other in order to eliminate errors in the mounting. It was found, however, that the readings taken from both mountings were in very close agreement.

T A B L E 6

Spacing between centers in diameters of the larger cylinder	Ratio of Cylinder diameters 1 : 1		Ratio of Cylinder diameters 1 : ~~1/2~~ 3/4	
	$K = \frac{R}{DLV^2}$	Resistance in % of that of one single cylinder	$K = \frac{R}{DLV^2}$	Resistance in % of that of one single cylinder
2	.000608	50.6	- - - -	- - -
4	.000604	50.3	.000543	45.2
6	.000640	53.3	- - - - -	- - -
8	..000606	50.5	0- - --	- - -

The values in table 6, are the means of four readings and they are, with the exception of the 1 to 1/2 diameter ratio, plotted in fig. 2. It will be seen that K for the 1 to 1 diameter ratio combination was practically constant for all the spacings on the curve and its value is only about 50% of that of the single cylinder. The resistance of the 1 to 1/2 diameter ratio combination is about 45% of that of a single cylinder, a slight improvement.

8. General conclusions and recommendations

From the results of the present investigation the following conclusions may be drawn:-

(1) When two cylinders either of equal diameters or different diameters are placed one behind the other (the larger cylinder in front in the latter case) in an air stream, the resistance of the combination is less than that of the front cylinder alone up to 3 diameters spacing.

(2) For spacings greater than 4 diameters the resistance of a combination of two cylinders one behind the other is only from 5% to 10% less, when the cylinder behind is of a smaller diameter, than that of a combination of equal diameters, provided the distances between centres are the same. For spacings less than 4 diameters the resistance is however from 10% to 30% more in the former case. Hence, as mentioned before, no good purpose will be served in practice by making a combination of two wires of different diameters.

(3) Above 4 diameters spacing, any further increase in the distance between centres is only accompanied by a very slight increase in resistance, about 2-1/2% per diameter spacing at the most.

(4) The resistance of any of the combinations is very much reduced when the gap between the cylinders is filled in, especially when the distance apart is more than 4 diameters of the larger cylinder.

Recommendations:

(1) The usual practice of using wires of equal diameters where two wires are needed should be adhered to as it is best both from resistance and strength considerations,

(2) Unless the wires are placed very close together (not more than 2 diameters apart between centres) it is absolutely essential that the gap between them should be filled in, either by wrapping air tight fabric or tape round them or by other means, as two-thirds of the resistance can be saved in this way. When wires are wrapped, their distance apart is of no importance as far as resistence is concerned, for the resistance is constant for all spacings.

As an illustration of the importance of filling in the gap between wires the following calculation is made for a typical tractor biplane.

Interplane bracing wires 3/15" dia., total length 450 ft.

The wires are arranged, as usual, one behind the other and their spacings between centres are 6 diameters of 1-1/8". Hence the length directly exposed to the wind is 225 ft.

Take the normal speed of the machine as 75 m.p.h.

Resistance of 3/16" single wire at 75 m.p.h.

$= 0.255$ lbs. per ft. run

From fig. 2, resistance for 6 dia. spacing double ~~wire~~ wire $=$ 145% the resistance of a single wire.

$\therefore$ total resistance of the wires $= 1.45 \times .255 \times 225 = 83$ lbs.

$$\text{H. P. expended} = \frac{83 \times 75 \times 1.46}{550} = 16.5$$

When the gaps are filled in, the resistance is only 53.3% the resistance of a single wire.

$$\text{power expended} = 16.5 \times \frac{.533}{1.45} = 6 \text{ H. P.}$$

$\therefore$ power saved $=$ 10-1/2 H.P.

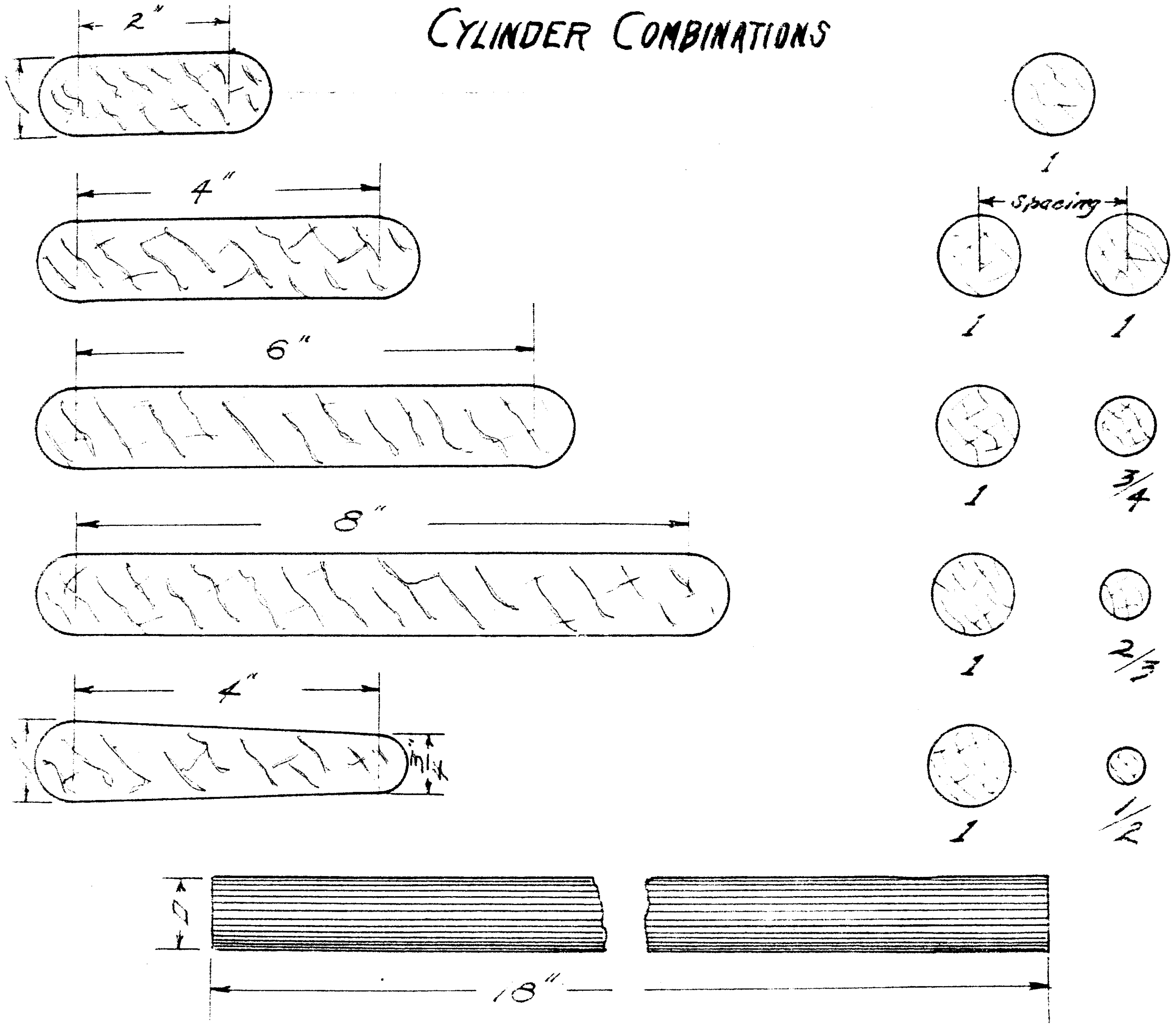
If one wire is used, for the same strength it has to be 1/4" in diameter.

Resistance of 1/4" wire $= .355 \times \frac{450}{2} = 80$ lbs.

$$\text{H. P. expended} = \frac{80 \times 75 \times 1.46}{550} = 16$$

$\therefore$ Power saved by using 3/16" filled in double wires $=$ 10 H.P.

CYLINDER COMBINATIONS



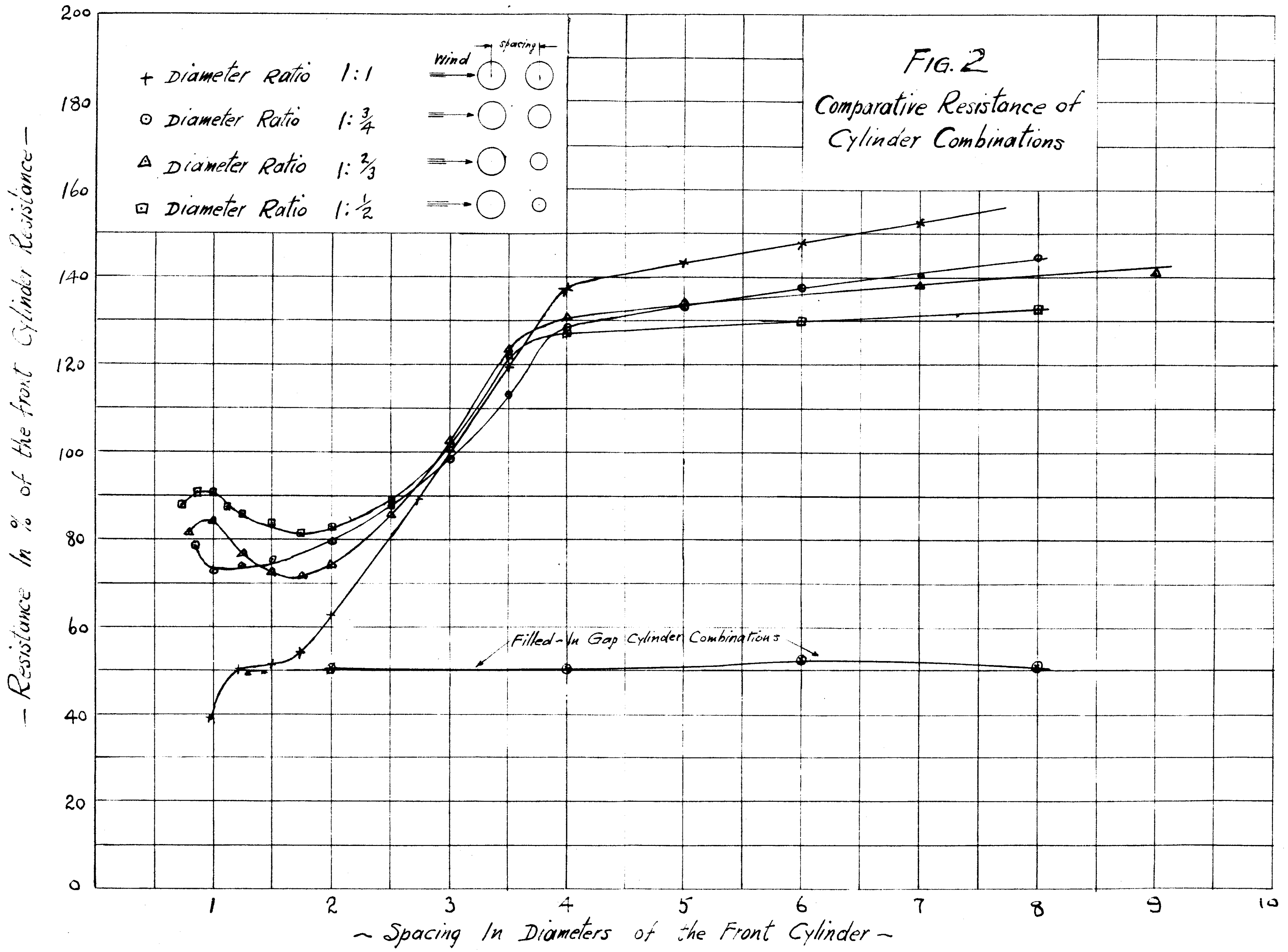


FIG. 2
Comparative Resistance of Cylinder Combinations
+ Diameter Ratio 1:1
⊙ Diameter Ratio 1:3/4
△ Diameter Ratio 1:2/3
⊡ Diameter Ratio 1:1/2
Wind
spacing
Filled-In Gap Cylinder Combinations
— Resistance In % of the front Cylinder Resistance —
— Spacing In Diameters of the Front Cylinder —
200
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10

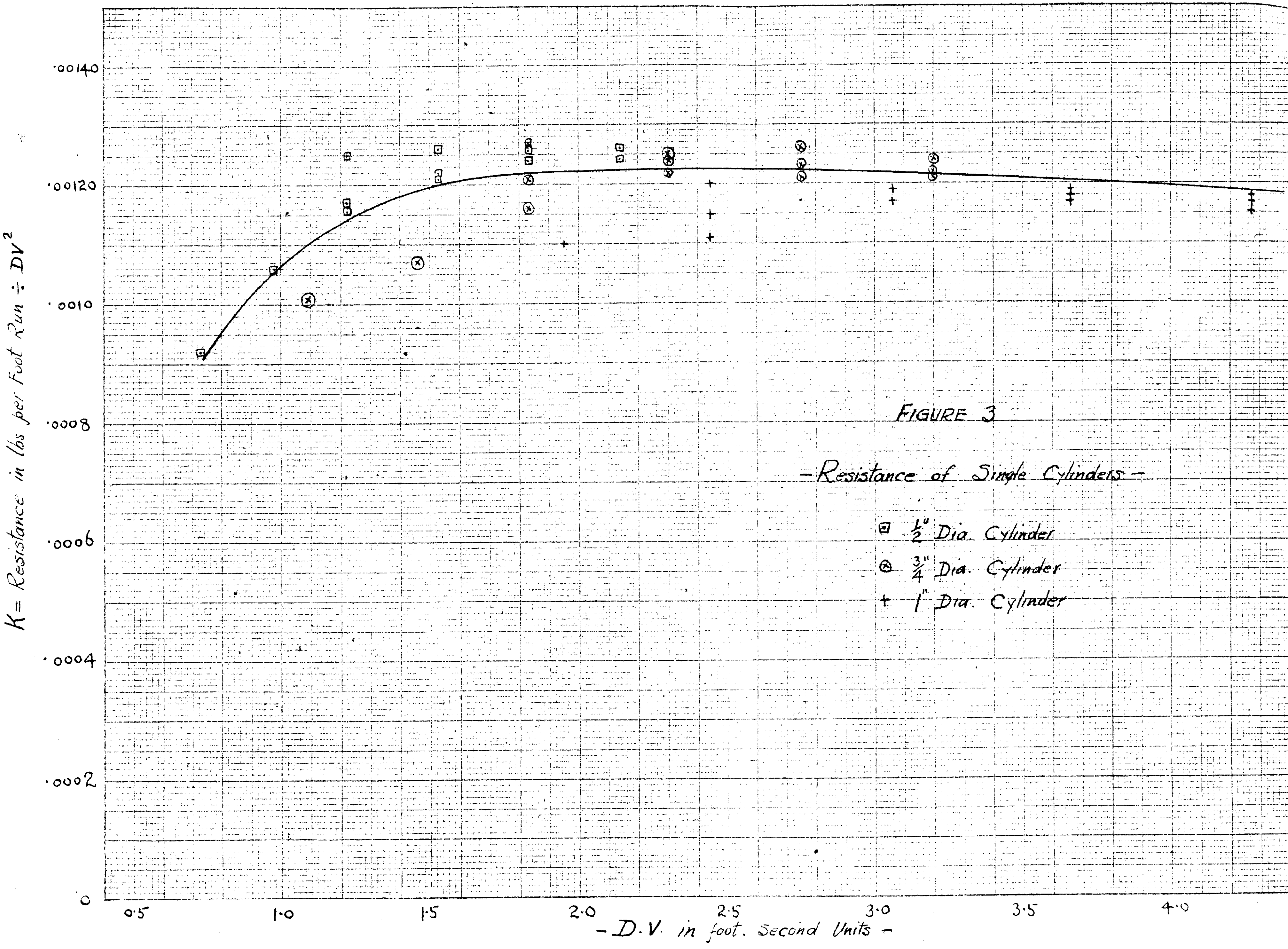
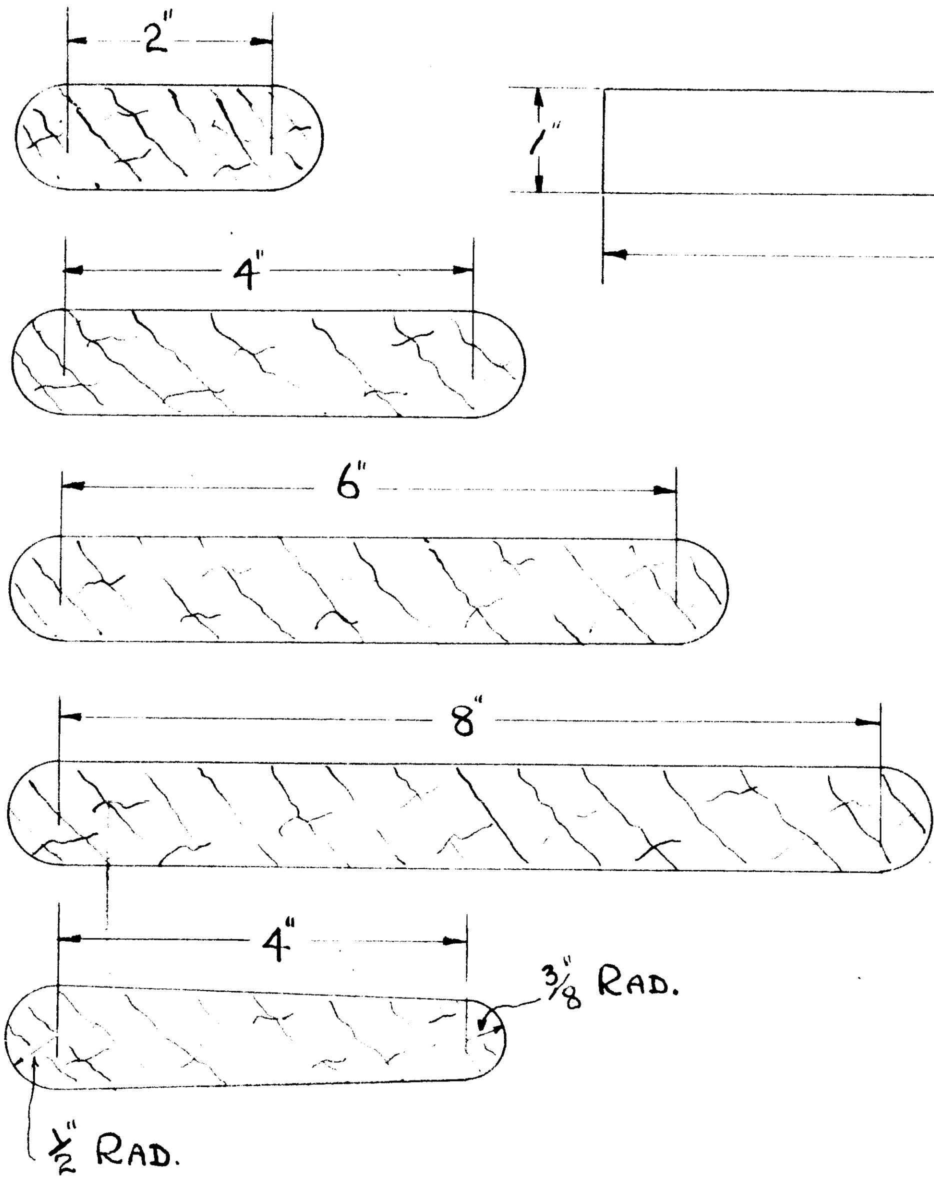


FIGURE 3

– Resistance of Single Cylinders –



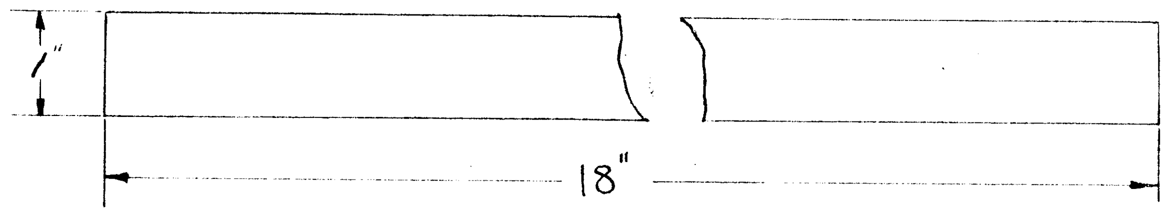
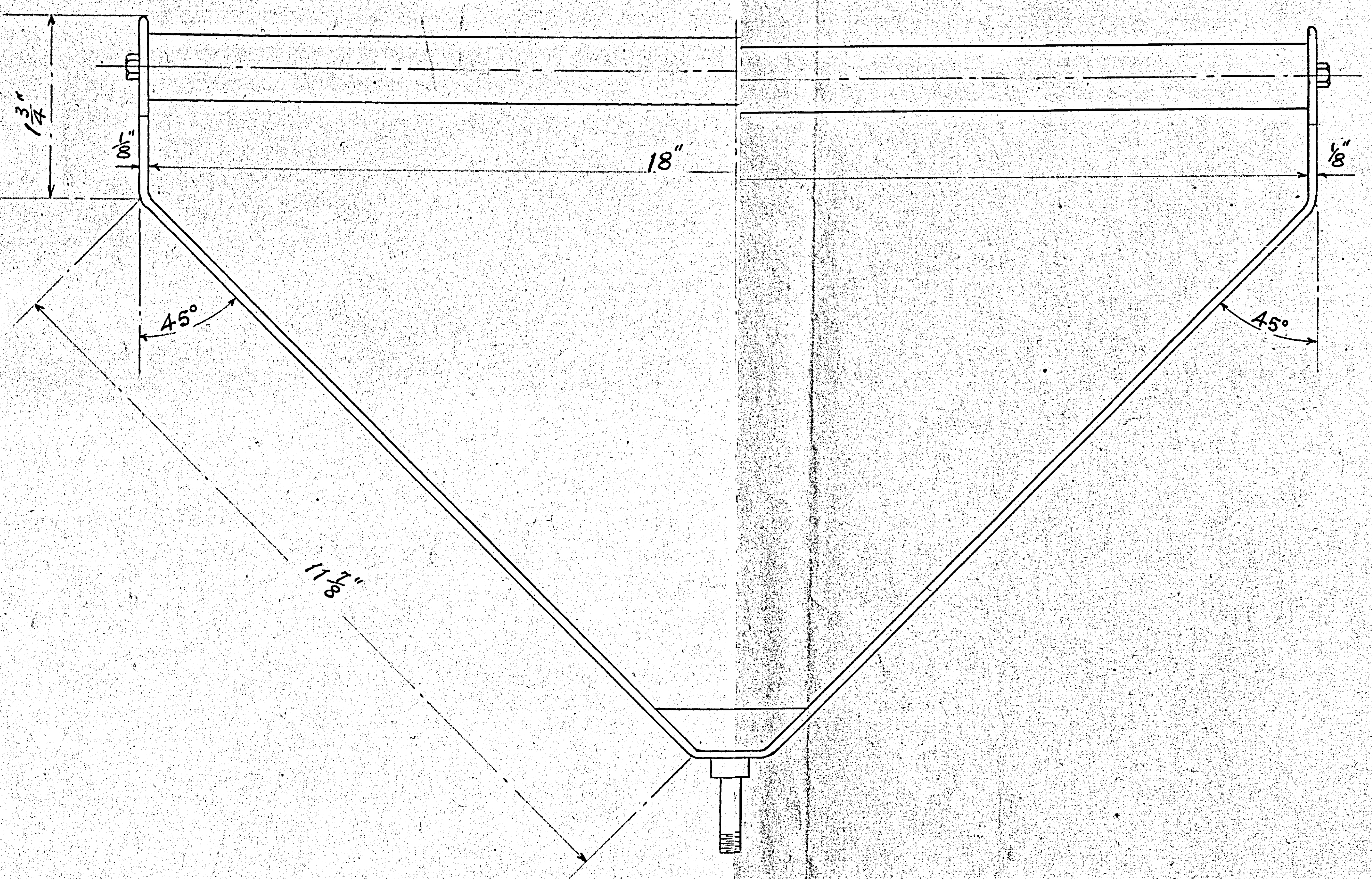
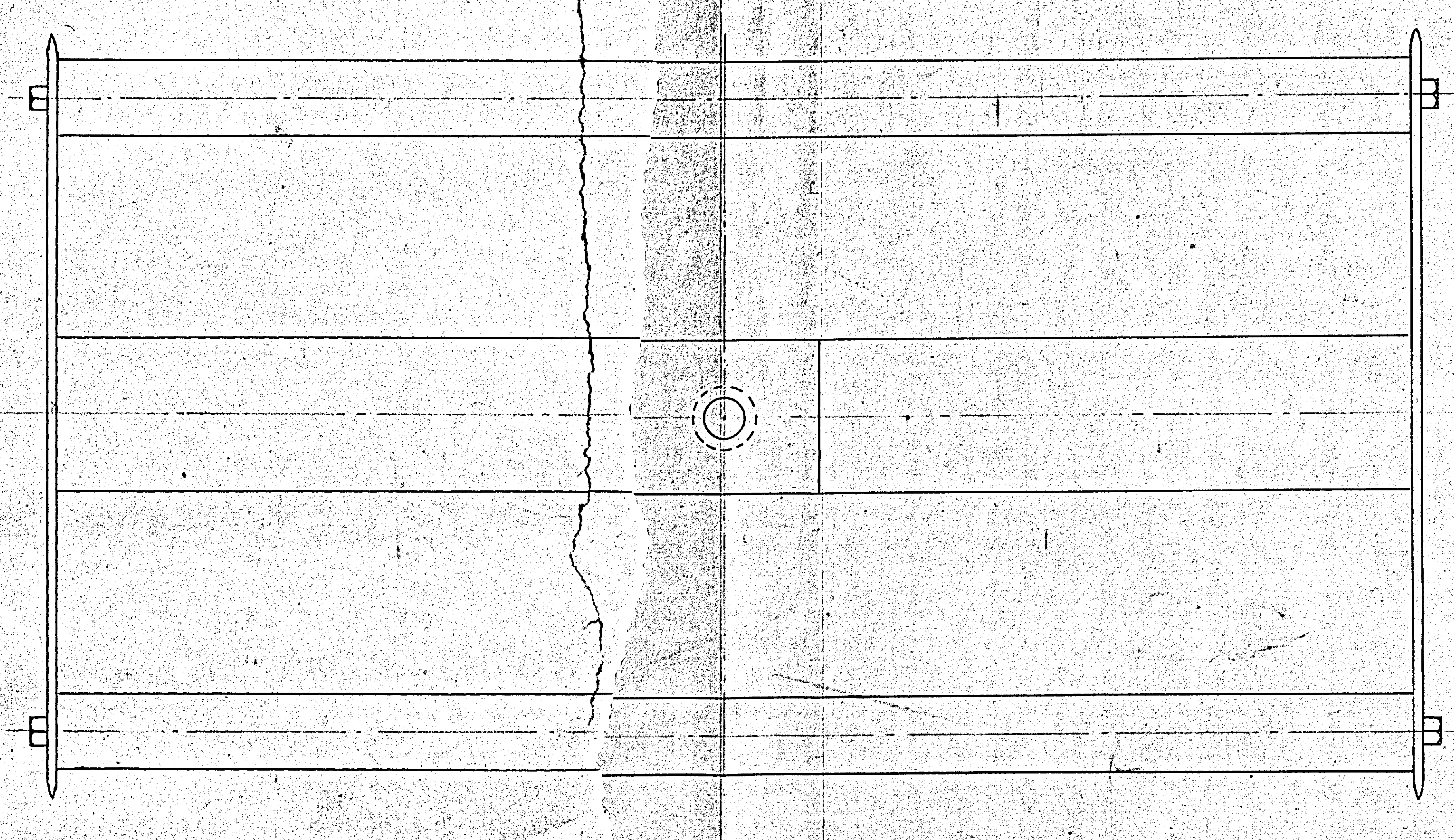


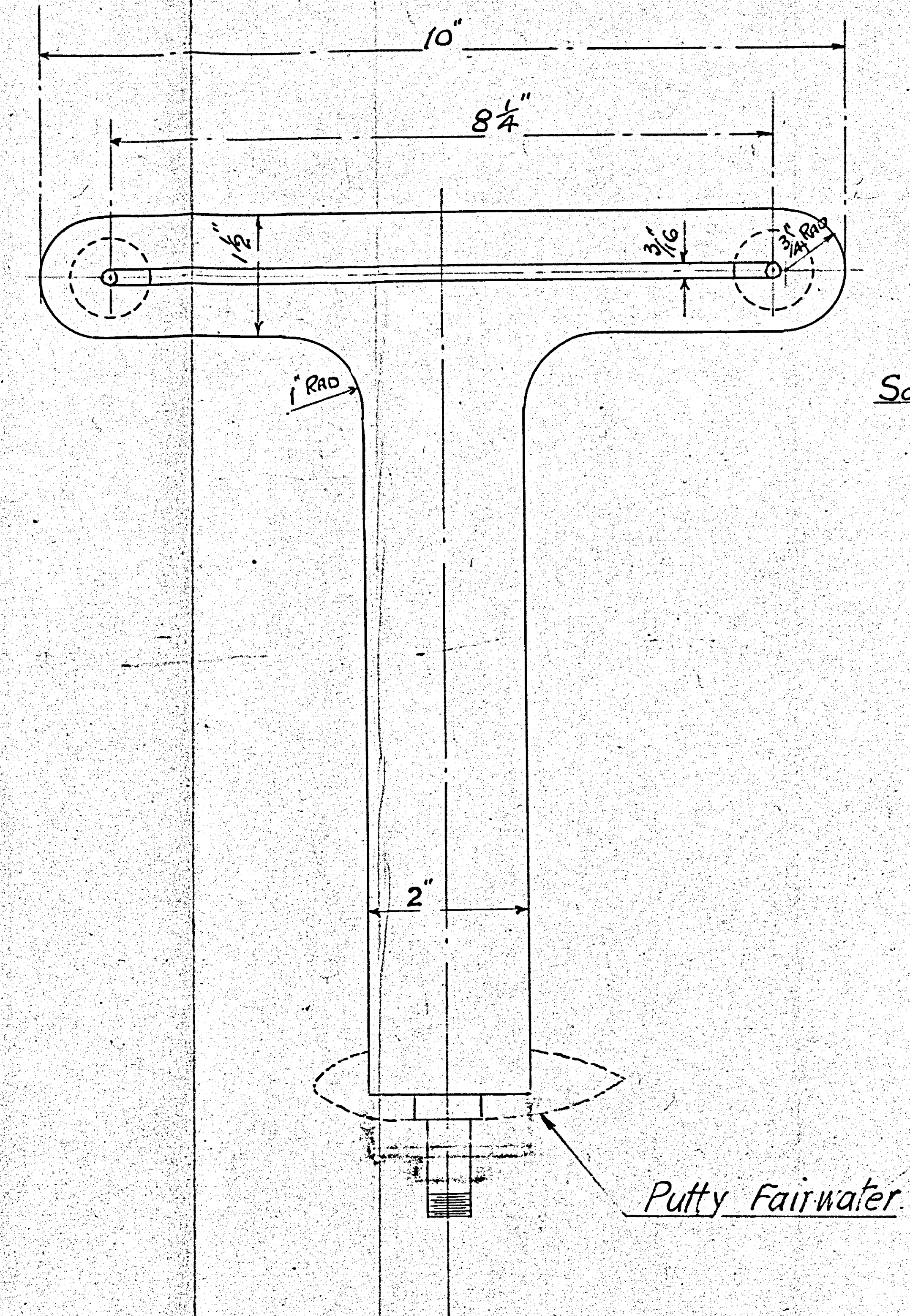
FIGURE 4

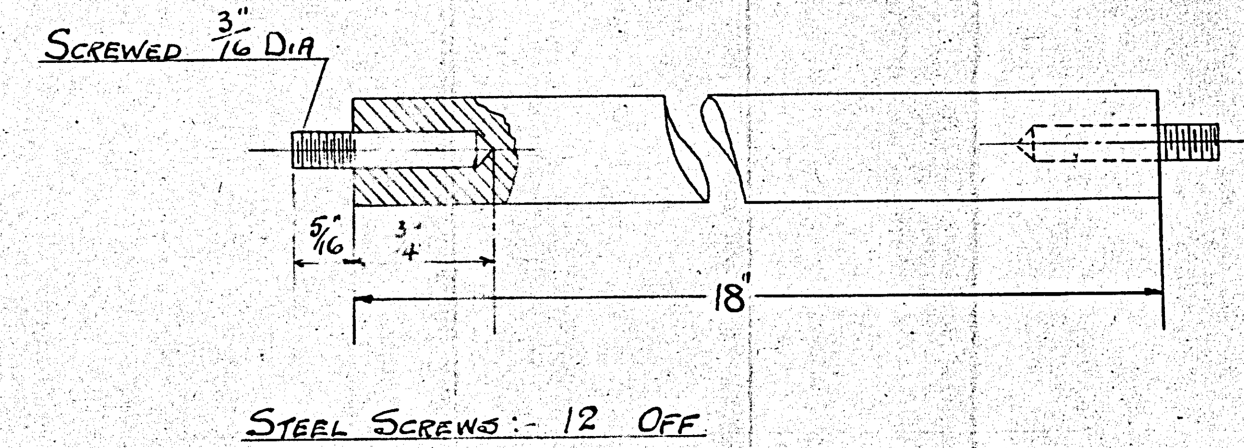
FILLED IN GAP

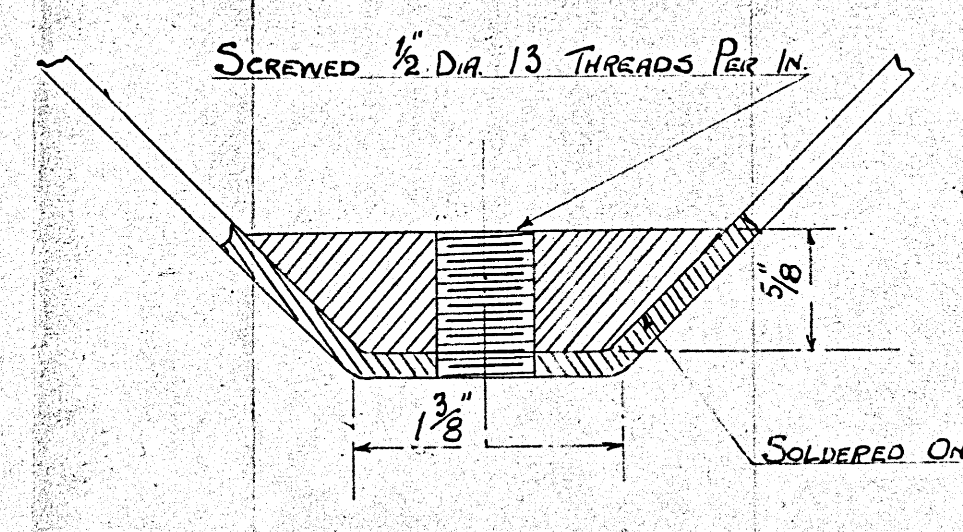
CYLINDER COMBINATIONS











FULL SIZE VIEW OF JOINT

FIGURE 1

APPARATUS FOR THE MEASUREMENT OF RESISTANCE OF CYLINDER COMBINATIONS

SCALE :- 1/2 SIZE