TECHNICAL NOTES.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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PERFORMANCE OF A VANE-DRIVEN GEAR PUMP.

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R. H. Heald,
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The maintenance of an adequate and uniform supply of fuel for an aeronautical engine during flight is an important consideration in airplane design. In order to eliminate the uncertainty involved in feeding directly from the supply tank to the engine, the gasoline is frequently pumped upward to a smaller tank located within the upper wing from which it flows by gravity to the engine carburetor. The pump may be driven either (1) by the engine directly, or (2) by some type of wind wheel or rotor mounted so as to be in the relative air stream during flight. The purpose of this paper is to present the results of a test on a pumping unit of the latter type.

The test was conducted in the high speed wind tunnel at the Bureau of Standards on an Aeromarine Plane & Motor Corporation pump.

The driving unit consists of four hemispherical metal cups, 2 3/4 inches in diameter, mounted on a spider, the hub of which is threaded to take the connecting shaft of the pump. The unit may be mounted on the airplane so as to be either entirely in the air stream (Fig. 9) or partially enclosed in a sheet metal housing (Fig. 8).

The pump is of the gear type, the gears being enclosed in a metal casing cast in two sections. The gears have a 1-inch face and a pitch diameter of 3/4 inch. The bore of both the inlet and outlet pipes is 1/4 inch. The weight of this unit is 2.3 pounds, and the total weight of the equipment, including both driving and pumping units, is 3 pounds.

METHOD OF TESTING.

Wind Tunnel Test of Delivery.

Measurements of the quantity of fuel delivered per minute were made at various wind speeds, (1) with the housing in place and (2) with the vanes entirely exposed to the wind stream. Fig. 8 shows the mounting of the apparatus with the housing in place. The mounting with the housing removed is shown in Fig. 9. The wind speeds were determined from Pitot tube measurements, assuming a standard density of .00123 gms/cm^3.

Kerosene having a specific gravity of .817 was used in place of gasoline throughout the test, because of the necessity of mounting the pump in proximity to the switchboard controlling the wind tunnel motor.

The delivery of the pump when equipped with the wind-vane housing (Fig. 8) was measured at the wind speeds of 60, 80, 100 and 120 miles per hour, under the following conditions:

(a) With a constant intake head but with different discharge heads,

(b) With a constant discharge head but with different intake heads,

(c) With a constant intake and discharge head but with a different length of discharge hose,

(d) With a constant head and hose length but with elbow-equipped hose nipples or a tee equipped with hose nipples, attached to the end of the discharge hose.

The delivery of the pump was also determined with the vanes not enclosed for various discharge heads (Fig. 9). The rotational speed of the pump with constant discharge head and hose length, both with and without enclosed vanes was also measured for different wind speeds.

In all the tests the radii of the hose bends were fixed and the lengths of both the intake and discharge hose were maintained constant, except when determining the effect of the length of hose on the delivery of the pump. The bore of the rubber hose used in this test was 3/8 inch. The hose layout is shown in Fig. 10.

Test of Efficiency of Pump.

The efficiency of the pump was determined by driving it directly with a one-fourth HP, 220 volt, D.C. shunt motor. Measurements were made of the power supplied to the motor when running without load. The pump was then connected to the motor by means of a short extension shaft and the hose arranged so as to give conditions identical with those given in Table 1. As in the wind tunnel test, the amount of oil delivered by the pump was determined by weighing. At the same time, the electrical input to the motor and the rotational speed of the pump were determined.

Head Resistance of the Vanes.

In measuring the head resistance of the vanes, the bearing supporting them was mounted directly on the end of an upright stru-

of streamline form. The strut extended through the tunnel so that the lower end projected below the tunnel floor and was supported by a knife edge mounted on the floor of the tunnel. A weighing arm carrying knife edge and weighing pan was attached to the lower end of the strut at right angles to it and pointing up-stream. Suitable weights for counterbalancing were also provided. The pump was mounted on the strut outside of the tunnel and was connected to the driving vanes by means of the extension shaft. The hose was arranged for a discharge head of two feet using a three-foot length of hose on the discharge side and a two and one-half foot length on the intake side. The entire set-up was a duplicate of that indicated in Table 2.

In measuring the head resistance of the vanes when enclosed in the housing, it was necessary to modify somewhat the arrangement just described. The housing was placed in the side of the tunnel as for the delivery test (see Fig. 8), and the balance was supported from the floor of the room. Measurements were made of the head resistance of the vanes, with both the enclosed and unenclosed mounting for a range of wind speeds of from 20 to 120 miles per hour. Measurements were also made of the head resistance of a single vane projecting into the tunnel normal to the wind stream.

Performance and Characteristics of the Unit.

Table 1 and Fig. 1 give the delivery of the unit when wind driven, both with the vanes in the housing and with unenclosed

vanes. The effect of adding the housing is to increase the delivery at a given wind speed approximately 75 percent.

Table 1.

Discharge head 2.0 ft.
Intake head .22 ft.

Vanes unenclosed. Length discharge hose:21.5 ft.		Vanes in housing. Length discharge hose:3.0 ft.	
Air speed m.p.h.	Delivery gal/min.	Air speed m.p.h.	Delivery gal/min.
59.8	.68	60.2	1.31
80.5	.98	80.2	1.77
99.9	1.26	100.0	2.24
120.6	1.53	119.8	2.69

The delivery of the unit is proportional to the wind speed. The rotational speed of the pump shaft is also proportional to the wind speed. The inter-relationship of these quantities is shown in Fig. 2.

In Fig. 3 are presented the average results of a series of tests made for the purpose of determining the correction to be applied to the delivery rating for each additional foot of hose or foot of discharge head. The delivery is decreased approximately 1% for each foot of hose added.

The resistance of a tee is equal approximately to that of a foot of hose, and of an elbow to that of 2 ft. of hose.

Assuming the pump delivery to be the same for gasoline as for kerosene and assuming the fuel consumption of the engine to be 0.55 pounds per brake horsepower per hour, the pump with the vanes in the housing would deliver fuel for 1650 b.h.p. at an air speed of

100 miles per hour, with the short connections given in Fig. 1. With the vanes mounted entirely in the air stream, the conditions being the same, the pump would deliver sufficient fuel for 920 b.h.p. at an air speed of 100 m.p.h.

Performance of Pump when Motor Driven.

The delivery of the pump is directly proportional to the rotational speed of the shaft up to 2200 r.p.m., but above this speed the coefficient decreases slowly. The efficiency of the pump is low, the maximum efficiency (17%) occurring at the lowest angular speed (310 r.p.m.) at which observations were made. The efficiency decreases rapidly with increase in speed to slightly more than 1% at 2900 r.p.m. The efficiency and delivery of the pump are given in Fig. 4 and Table 2.

Table 2.

Discharge head 2.0 ft.
Intake head .22 ft.
Length discharge hose 3.0 ft.

R.P.M.	Delivery gal/min.	Efficiency %
310	.314	16.9
405	.411	11.0
500	.519	9.5
600	.623	7.9
700	.725	7.0
800	.823	6.2
900	.917	5.6
1000	1.01	5.1
1100	1.12	4.4
1200	1.22	4.0
1300	1.33	3.3
1400	1.43	3.0
1610	1.66	2.2
2330	2.36	1.3
2900	2.75	1.1

Resistance and Power Characteristics.

The power required for driving the unit with the vanes unenclosed at a speed of 120 m.p.h. is nearly 2 HP, while with the vanes in the housing the power required is slightly more than one-half horsepower. Fig. 5 and Table 3 give the values found for the head resistance of the vanes and the power required at the various wind speeds and emphasize the advantage to be obtained by enclosing the vanes in a housing.

Table 3.

Air speed m.p.h.	Vanes Unenclosed Drag (lbs.)	HP required	Vanes in housing. Drag (lbs.)	HP required
21.3	.184	.010	.057	.003
26.0	.275	.019	.075	.005
30.4	.377	.031	.106	.009
35.0	.501	.047	.130	.012
39.3	.630	.066	.168	.018
43.4	.763	.088	.201	.023
47.3	.906	.114	.250	.031
52.2	1.10	.153	.303	.042
56.5	1.29	.194	.355	.054
61.2	1.53	.249	.426	.069
65.5	1.77	.309	.487	.085
75.4	2.36	.475	.670	.136
85.0	2.97	.674	.864	.196
105.4	4.49	1.26	1.34	.376
122.2	6.09	1.98	1.79	.583

The dotted line in Fig. 5 represents the drag of a single vane held normal and concave to the wind. The data obtained in this test are in fair agreement with the results of Eiffel on a hemispherical cup 10 inches in diameter. Table 4 gives the comparative results.

Table 4.

Air speed m.p.h.	Drag lbs.	Values of K[1] Eiffel	Author's
29.6	.171		.0040
39.3	.302		.0040
43.9	.377		.0040
51.6	.522	.0034	.0040
65.1	.843		.0041
74.2	1.115		.0041
82.0	1.36		.0041
89.2	1.63		.0042
93.2	1.83		.0043
99.4	2.09		.0043

Combined Efficiency and Efficiency of the Vanes.

The term "Combined Efficiency" as used in this paper, is expressed as the ratio $\frac{P}{P_1}$, where P_1 is the power absorbed by the unit from the moving air stream (air speed × head resistance) and where P is the power output of the pump (delivery × total head pumped). The efficiency of the vanes is readily determined by dividing the combined efficiency of the unit by the efficiency of the pump. The results are summarized in Table 5, and the curves are given in Figs. 6 and 7.

1) The resistance may be expressed by the formula: $R = KAV^2$
Where R is the resistance of the body in pounds.
A is the area in square feet,
and V is the wind speed in feet per second.

Table 5.

Air speed m.p.h.	Efficiency of Vanes Unenclosed %	Efficiency of Vanes Enclosed %	Combined Efficiency Vanes unenclosed %	Combined Efficiency Vanes encl %
21.3	---	42.2	.43	4.66
26.0	---	38.5	.37	3.54
30.4	---	33.8	.31	2.66
35.0	2.13	31.2	.25	2.20
39.3	2.09	27.6	.21	1.72
43.4	2.02	24.4	.18	1.45
47.3	1.93	22.3	.16	1.21
52.2	1.81	22.0	.14	.97
56.5	1.67	21.4	.12	.82
61.2	1.58	21.2	.10	.71
65.5	1.49	20.8	.09	.61
75.4	1.37	20.2	.07	.47
85.0	1.36	19.5	.06	.34
105.4	1.39	17.7	.04	.30
122.2	1.37	16.4	.03	.17

These results again illustrate the decided advantage to be obtained by shielding the convex sides of the vanes from the air stream by some form of housing. At a wind speed of 60 m.p.h. the efficiency of the vanes is increased from 2% to 21% by the use of the housing, with a consequent increase in the combined efficiency of the unit from 0.1 to 0.7 percent.

The unit is working at a low efficiency throughout the range of airplane speeds. With the vanes in the housing the combined efficiency ranged from 0.7 to 0.2 percent for speeds from 60 to 120 m.p.h. The efficiency of the pump in this range is from 3 to 1 percent.

The efficiency of the pump is also very low. Some improvement may possibly be obtained by increasing the side of the outlet pipes. Since the pressure developed by the gears is small, any

reduction in the resistance of the inlet and outlet orifices should result in increased efficiency.

The efficiency of the drive can be improved either by gearing the pump directly to the engine shaft or by driving it with a small propeller. If practicable the former method is advisable since the efficiency of spur gears is from 93 to 96 percent. The efficiency of a small propeller is in the neighborhood of 70 percent. The dotted curve in Fig. 6 represents the efficiency of a small regulating air fan or propeller which is capable of delivering approximately one-fourth horsepower at wind speeds above 51 m.p.h.

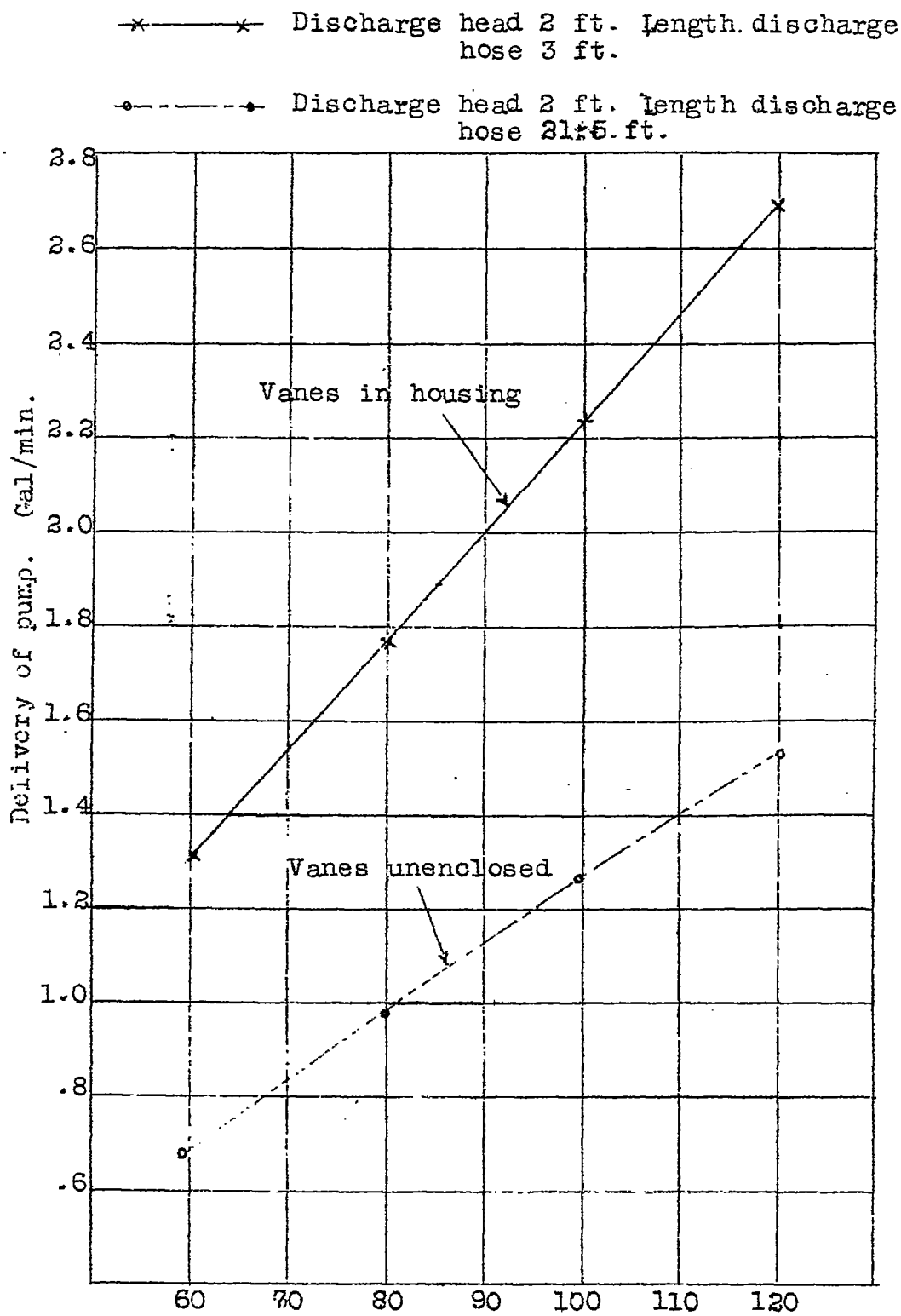

Discharge head 2 ft. Length discharge hose 3 ft.
Discharge head 2 ft. Length discharge hose 31.5 ft.
Vanes in housing
Vanes unenclosed
Delivery of pump. Gal/min.
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
60
70
80
90
100
110
120
Air speed - M.P.H.

Fig. 1

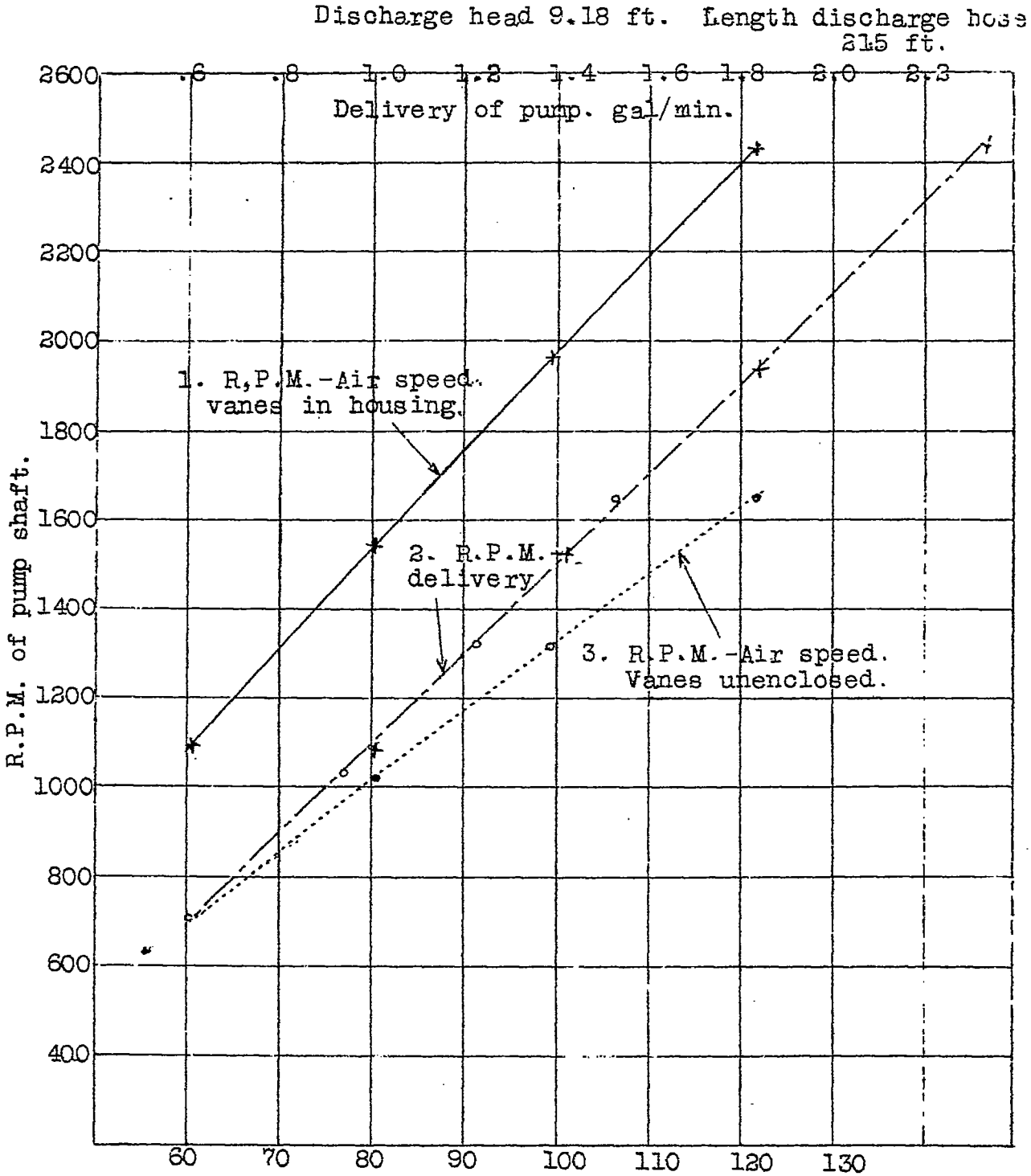

Discharge head 9.18 ft. Length discharge hose 215 ft.
.6 .8 1.0 1.2 1.4 1.6 1.8 2.0 2.3
Delivery of pump. gal/min.
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
R.P.M. of pump shaft.
1. R.P.M.-Air speed. vanes in housing.
2. R.P.M.-delivery
3. R.P.M.-Air speed. Vanes unenclosed.
60 70 80 90 100 110 120 130
Air speed M.P.H.

Fig. 2.

Discharge head 2 ft. & 9 ft.
Length discharge hose 3 ft. & 21.5 ft.

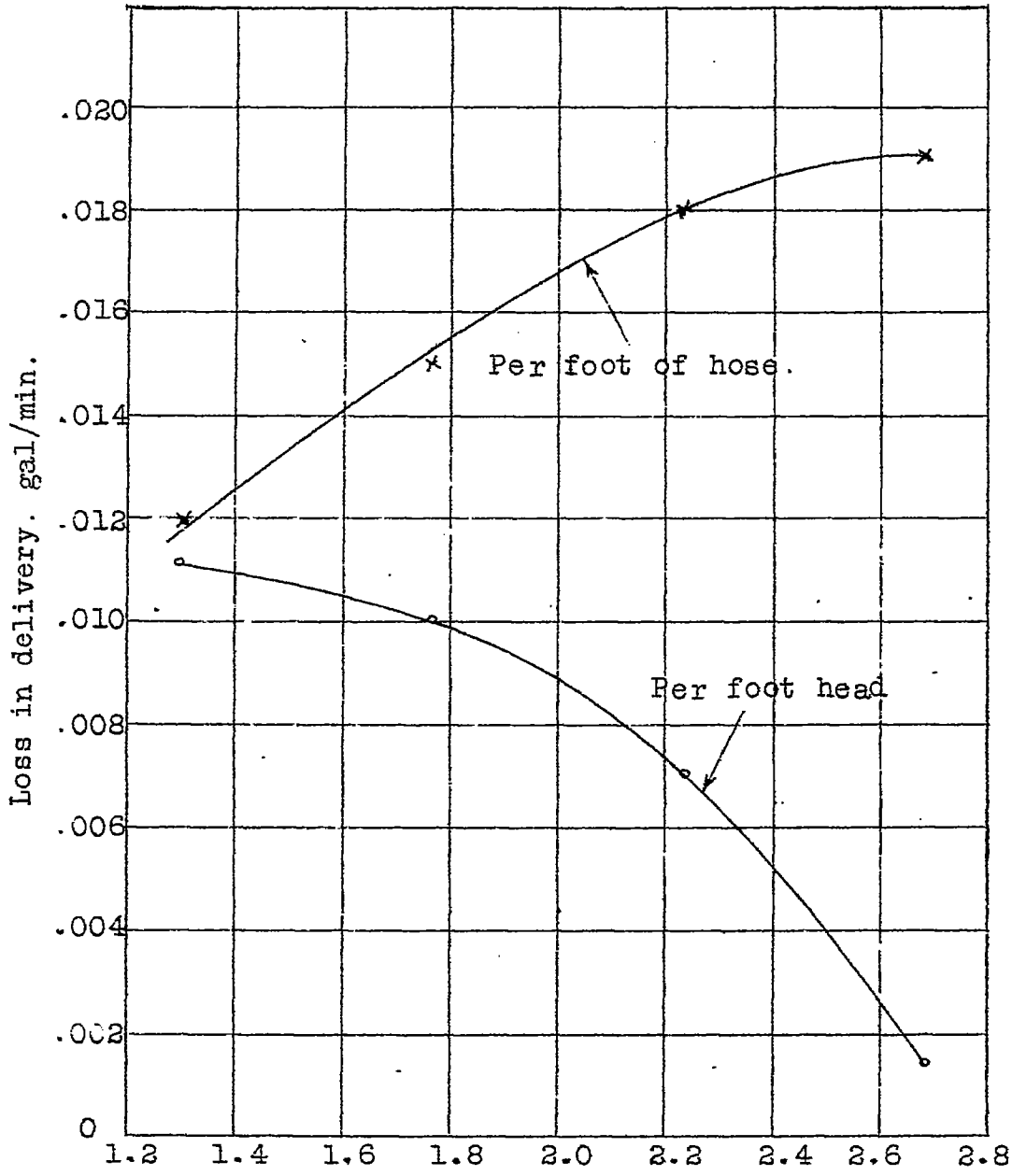


Fig. 3. Delivery of pump. gal/min.

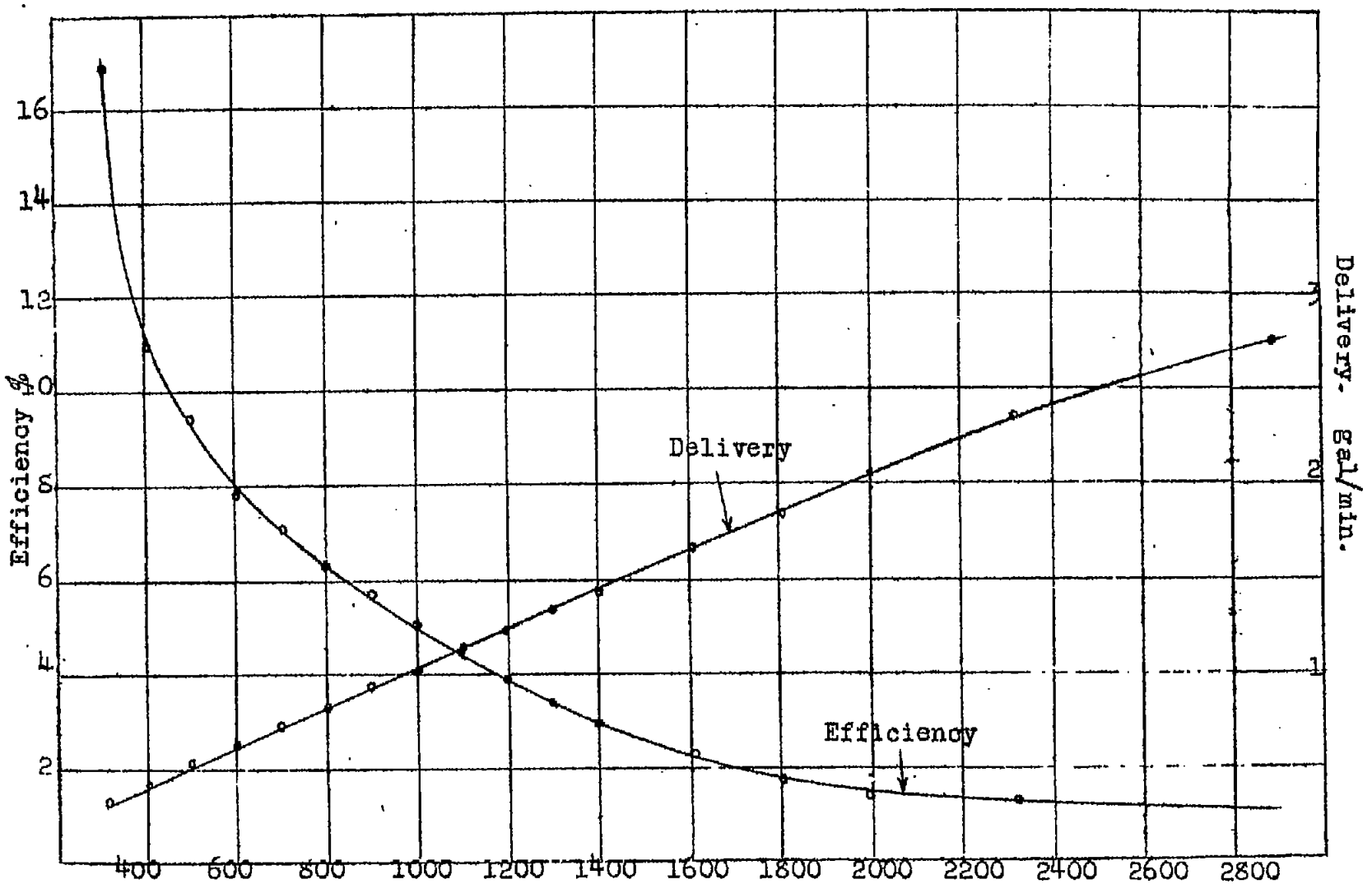

Efficiency %
16
14
12
10
8
6
4
2
Delivery
Efficiency
Delivery. gal/min.
3
2
1
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
R.P.M. of pump shaft

Fig. 4.

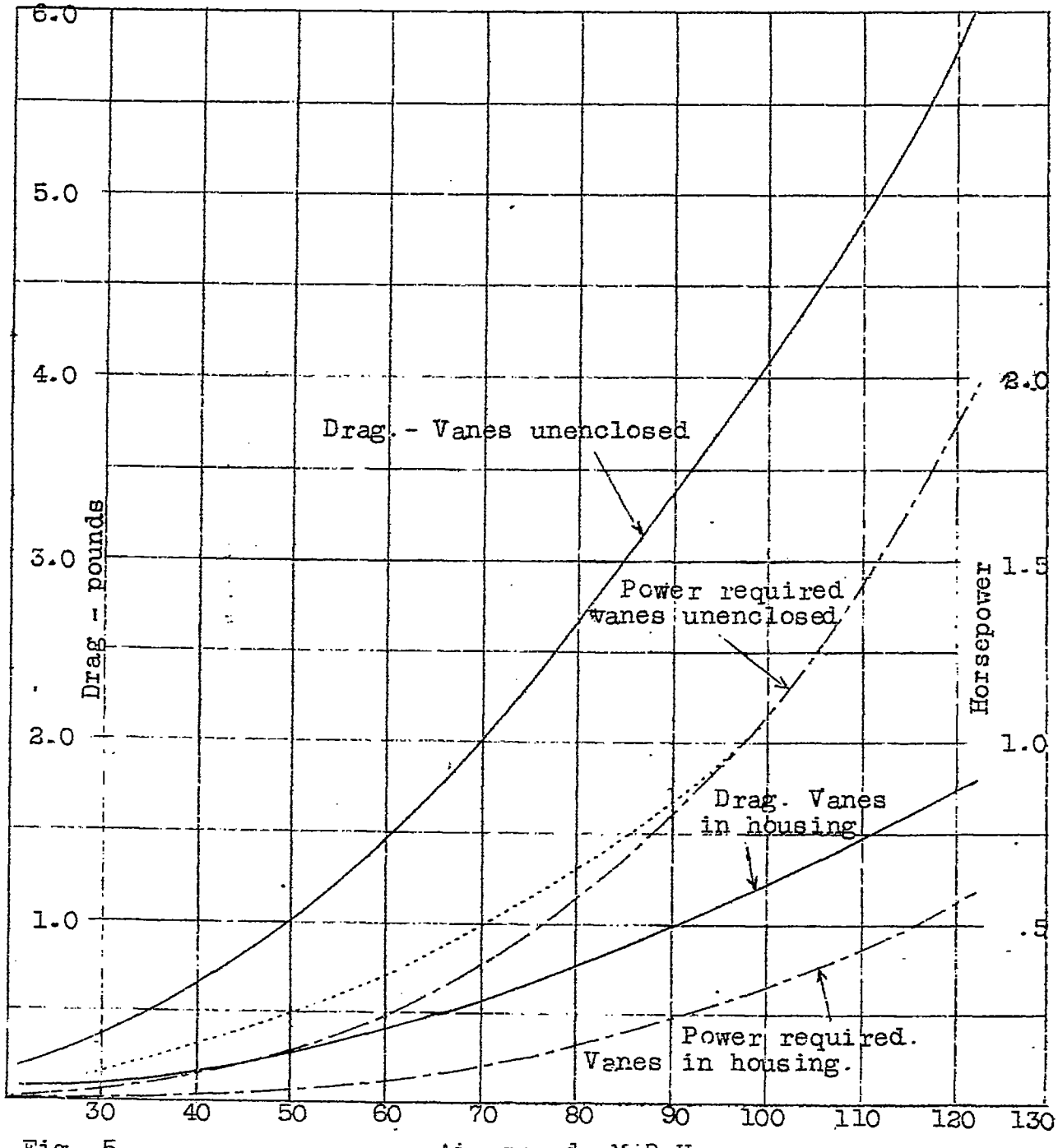

6.0
5.0
4.0
3.0
2.0
1.0
Drag - pounds
2.0
1.5
1.0
.5
Horsepower
Drag. - Vanes unenclosed
Power required
Vanes unenclosed
Drag. Vanes
in housing
Power required.
Vanes in housing.
30
40
50
60
70
80
90
100
110
120
130
Air speed. M.P.H.

Fig. 5.

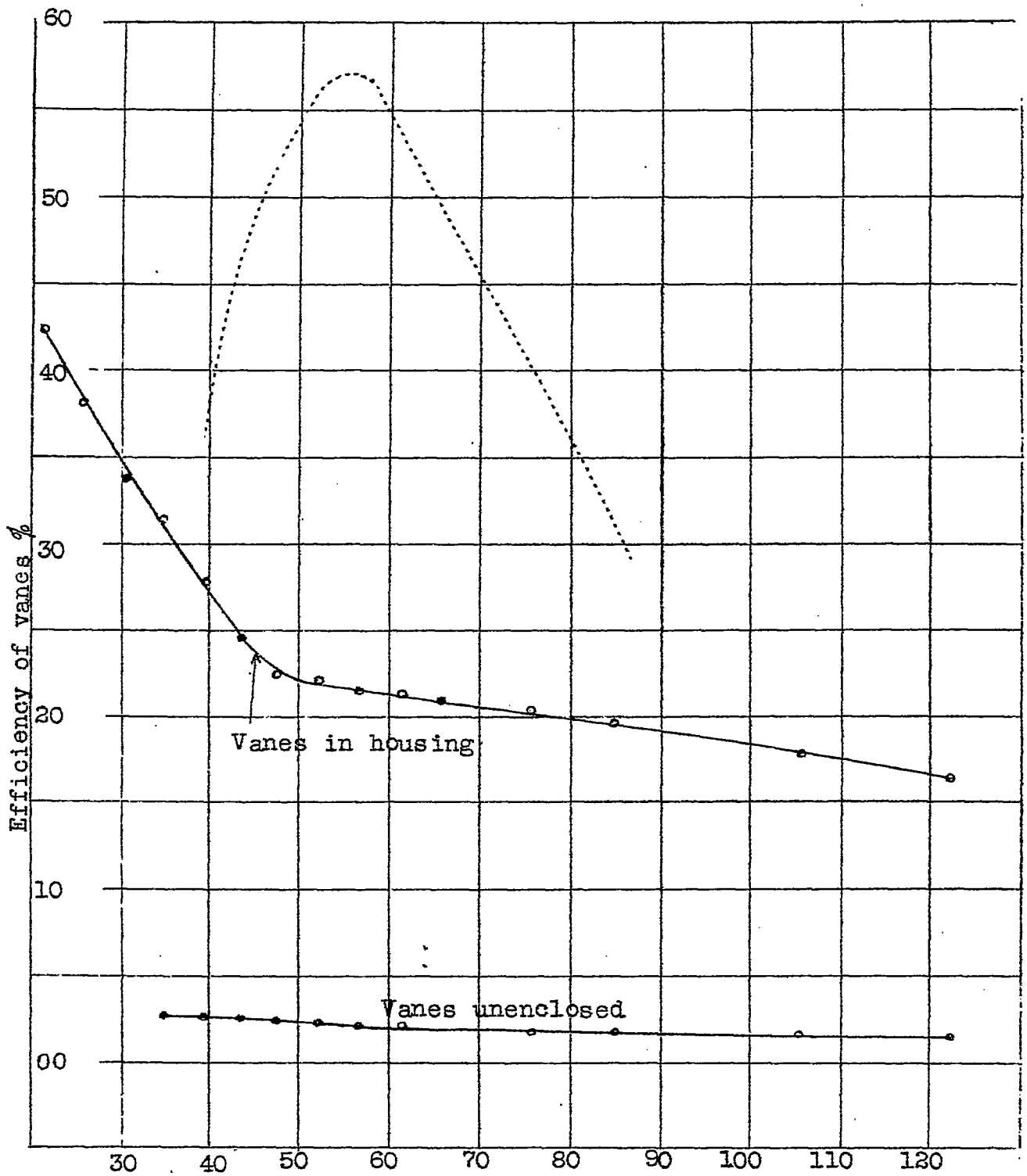

60
50
40
30
20
10
00
Efficiency of vanes %
Vanes in housing
Vanes unenclosed
30
40
50
60
70
80
90
100
110
120
Air speed. M.P.H.

Fig. 6.

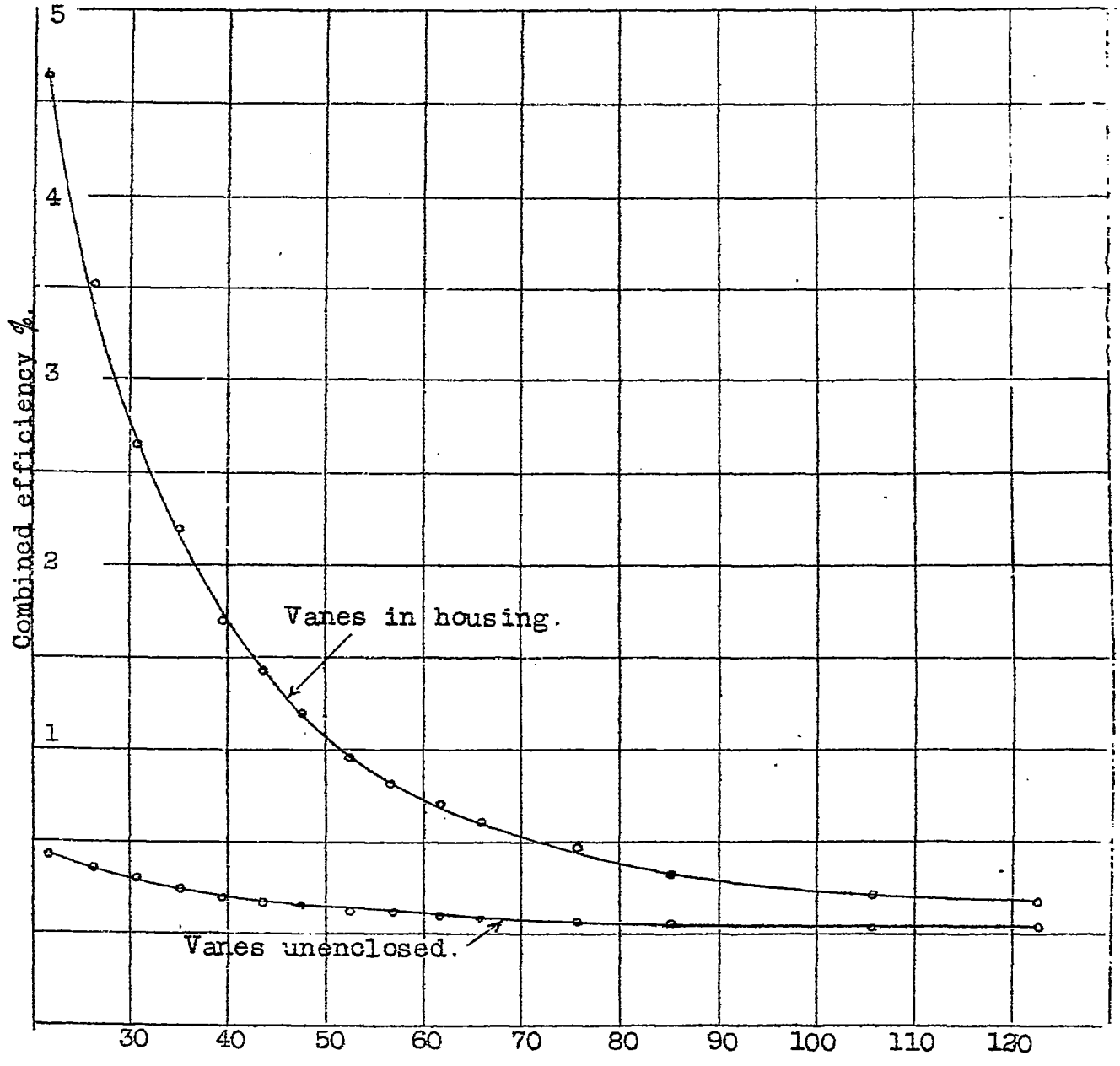

5
4
3
2
1
Combined efficiency %.
Vanes in housing.
Vanes unenclosed.
30
40
50
60
70
80
90
100
110
120
Air speed - M.P.H.

Fig. 7.

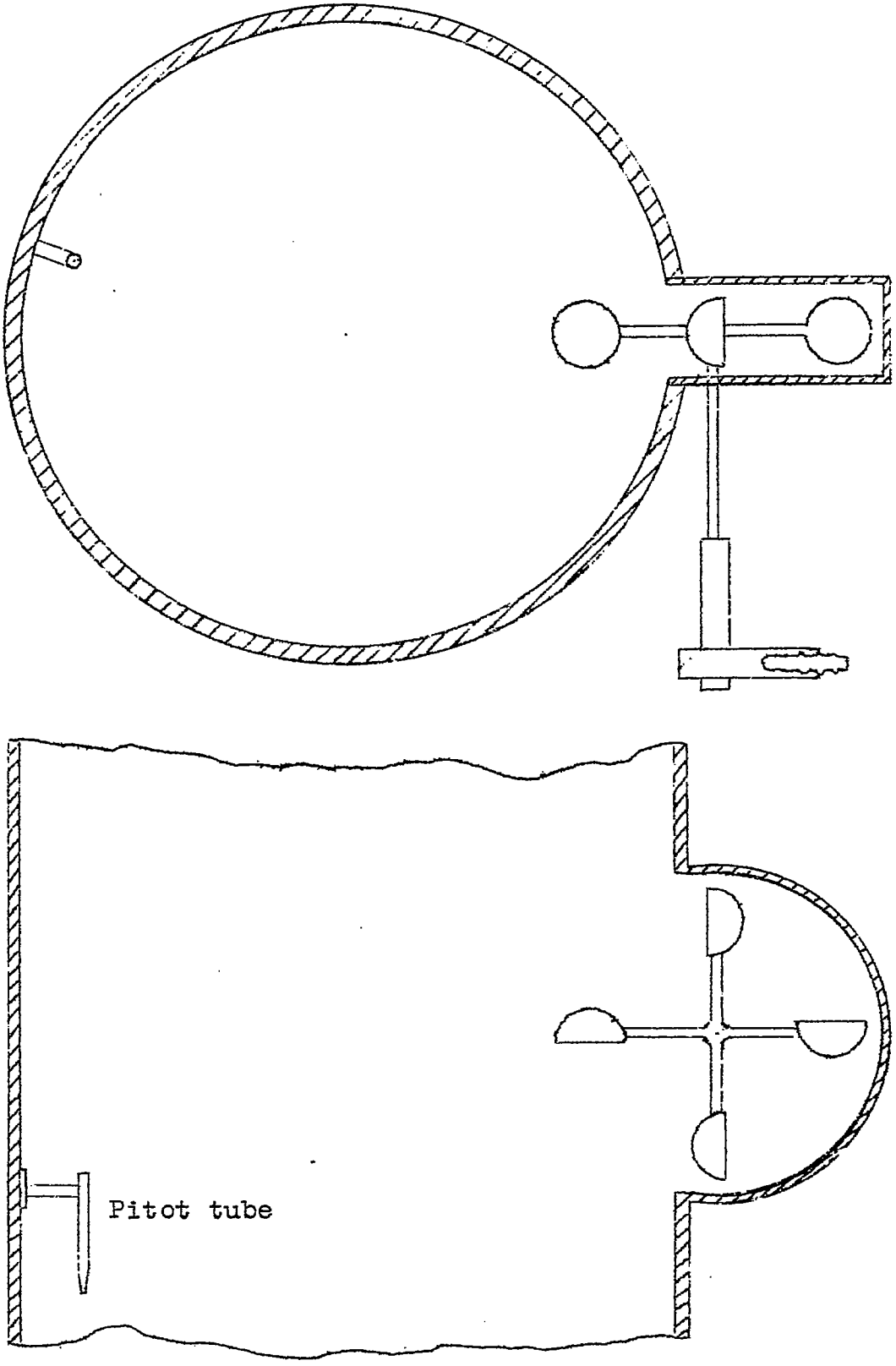


Fig. 8

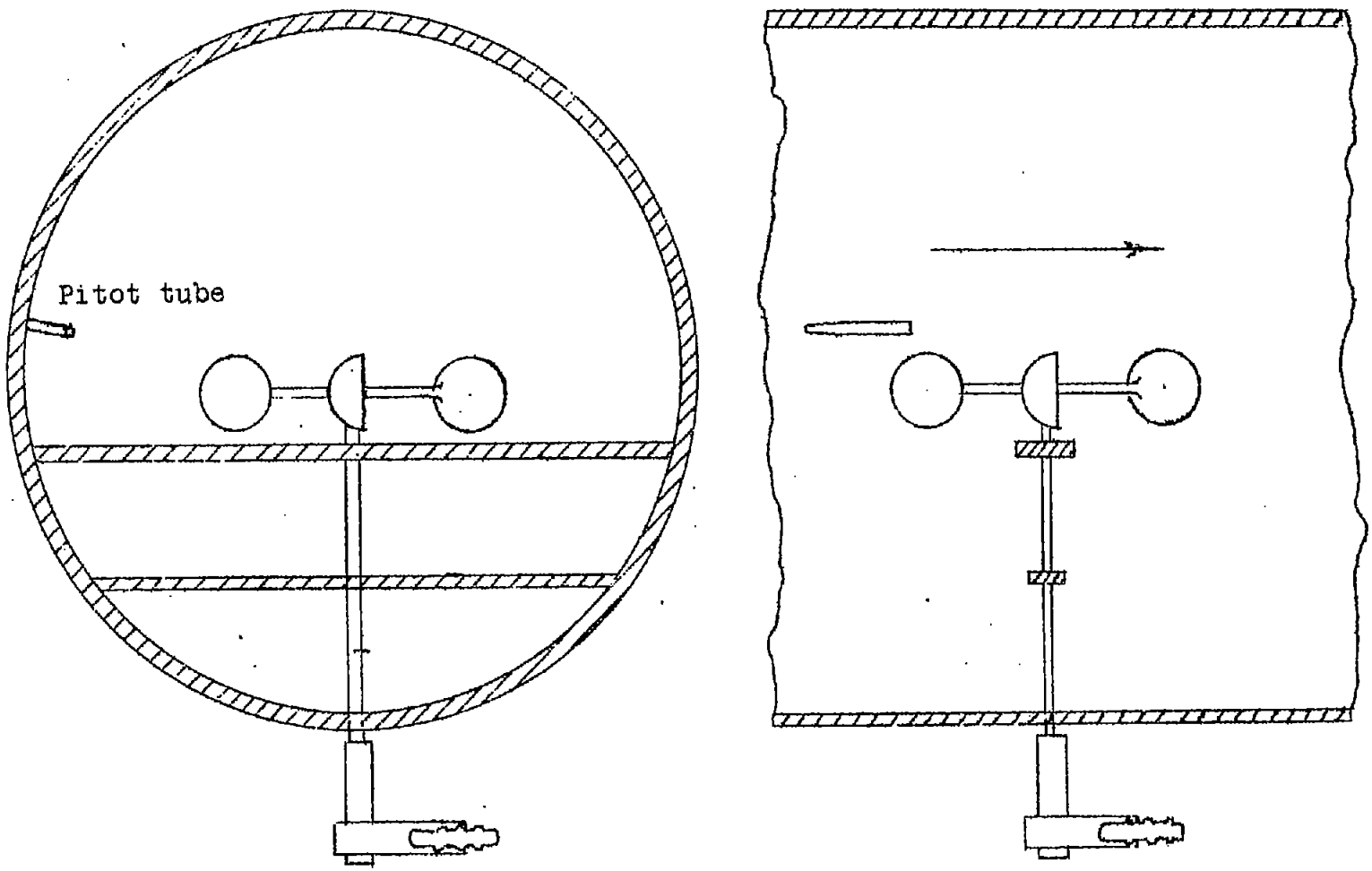
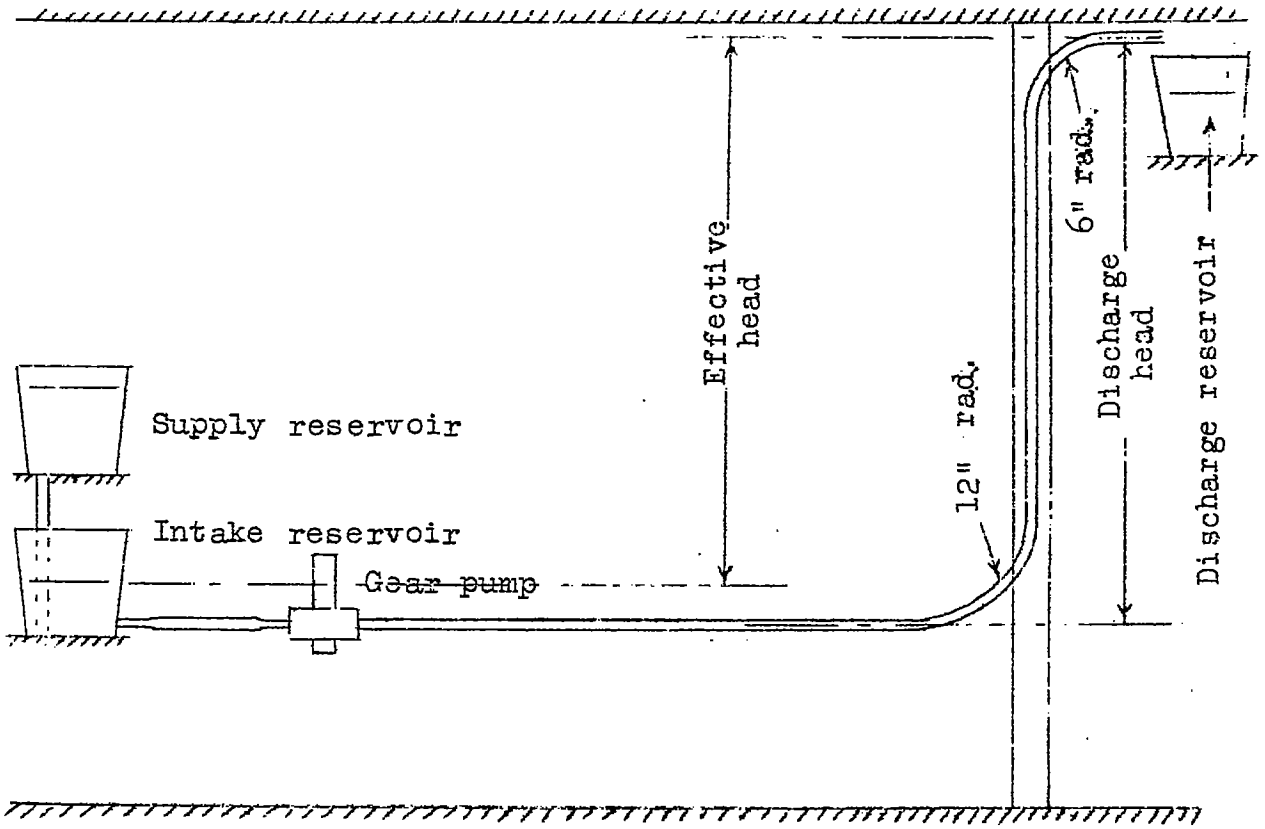


Fig. 9.


Supply reservoir
Intake reservoir
Gear pump
Effective head
12" rad.
6" rad.
Discharge head
Discharge reservoir

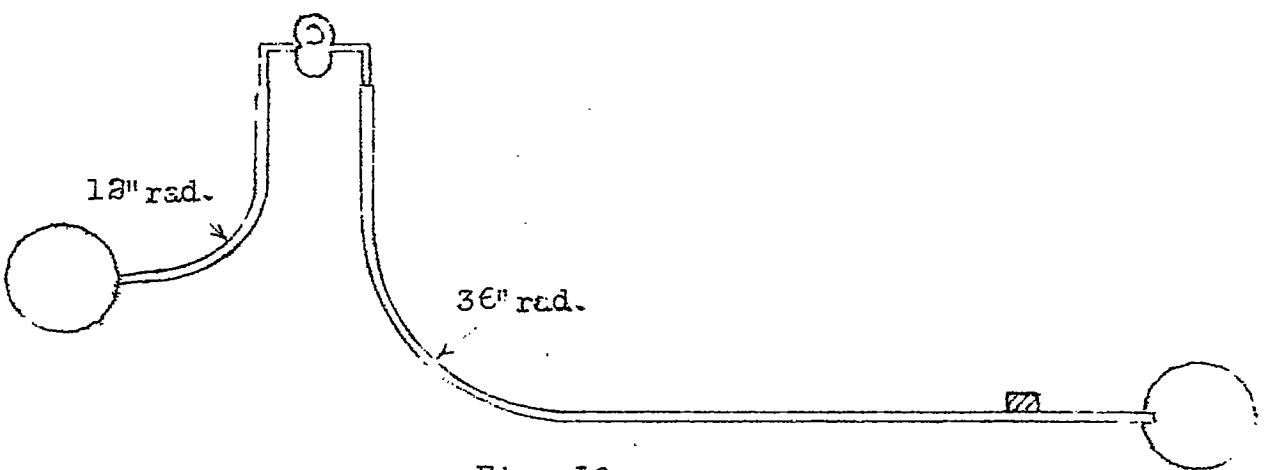

12" rad.
36" rad.

Fig. 10.