THE MEASUREMENT OF HORSE-POWER.*

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The authors feel they need offer no apology for dealing with this question, as the importance of B.H.P. testing must be apparent to all, both in the case of the pass tests of the finished product and for the trying-out of improvements in design or new types of engines. The errors of measurement in the case of the former should not exceed 5 per cent, and in the latter 2 per cent or less. In both cases it is essentially the torque curve that it is desirable to examine, and in any form of brake in which the torque is proportional to the square of the speed, an error in counting is increased.

From time to time power results are published which are so superlative and so far beyond anything in the authors' experience that they are inclined to cast doubt, not on the good faith of those responsible, but on the accuracy of the apparatus employed.

In comparing results obtained on engines of different sizes it is advisable to reduce the figures to brake mean effective pressure and piston speed. Some results taken from the technical press are as follows:—

M. E. P. lb. per sq. in.	Piston speed. ft. per min.
130	2,000
127	2,000
115	2,760

It is obvious that with high-class automobile engines of the ordinary four-cycle type, having compression ratios not exceeding about 5, the maximum power available at any speed is directly

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proportional to the amount of oxygen the engine can burn at that speed, rather than in any way dependent on the amount of fuel, provided that there is sufficient fuel to completely utilize the oxygen.

Consequently the maximum horse-power is determined by piston displacement and volumetric efficiency. Tests in which the air has been measured, such as those by Dr. Watson, in London, and Dr. Riedler, in Berlin, show that 2 cu. ft. per B.H.P. is a fair figure.

So it may be taken that Max. B.H.P. $= (D^2SN \times$ revs. per min.)/9,500, where D and S are bore and stroke in inches respectively, and N the number of cylinders of a four-stroke engine, a volumetric efficiency of about 92 per cent being assumed. This

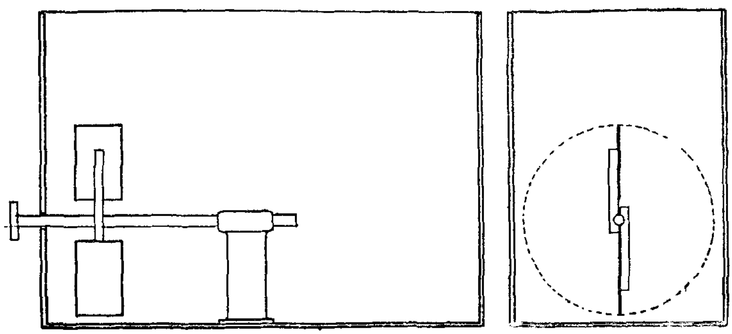


Fig. 1.

gives an equivalent mean effective pressure on the brake of 105 lb. per square inch. Any published figures which exceed this, especially at very high piston speeds, should be looked upon with suspicion.

The difference between this figure of 105 lb. per square inch as the probable mean effective pressure and the figures quoted above raise doubts as to the reliability of the brake used in measuring the horse-power of these engines. Generally in such reported performances no information is given about the dynamometer employed, but the high engine speeds attained suggest that some form of fan brake has been used. On account of its adaptability, cheapness and simplicity this brake is frequently used for high-speed work, and for reasons of safety is generally placed near a wall or in an alcove, or protected by a casing, see Fig. 1,

L L 2

which gives examples of the conditions under which the fan brake is actually used. As the horse-power absorbed by a fan brake is estimated from a formula, it is natural to suspect that environment must play an important part in the conditions of power absorption, and that the performance of a fan may vary with its position. This has been the experience of the authors, and they were inclined to write down the fan brake as hopeless, but its great convenience for various forms of test prompted them

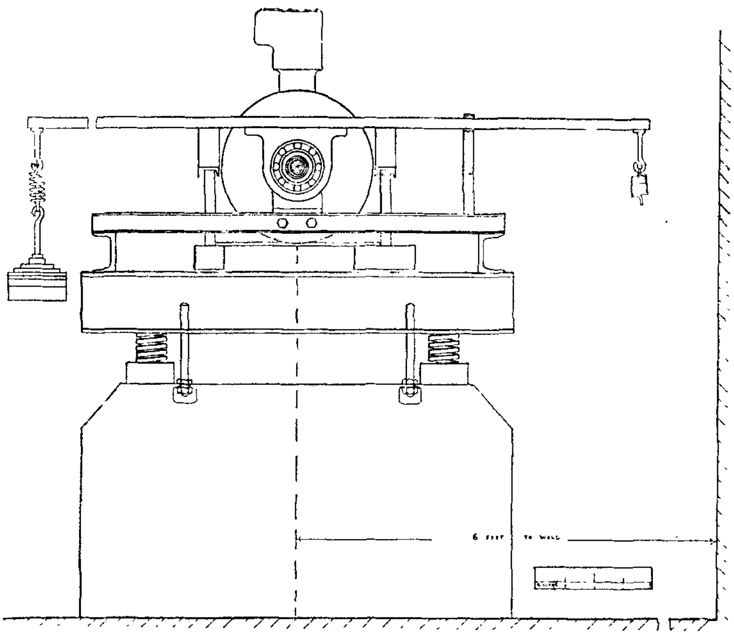


Fig. 2.

to investigate the limits within which it is reliable, and the experiments described below were carried out accordingly.

It may here be well to state the great advantages obtained by mounting the whole engine test bed on springs (see Figs. 2 and 3) instead of having it rigidly fixed to the floor. These springs were first used to minimize the amount of vibration transmitted to the floor; subsequently it was found that they presented such advantages for high-speed work that they were worth retaining on that account alone. A modern aluminum base chamber is frequently so flexible that considerable distortion must occur at high speeds, when bolted directly to a heavy cast-iron bed, cases being known in which the engine brackets have broken from this cause. These remarks are especially applicable to aeroplane engines.

It is now proposed to refer briefly to the merits and demerits of well-known types of absorption dynamometers.

(1) *The Solid Friction Brake*, whose main characteristic is that the torque is to a great extent independent of the speed.

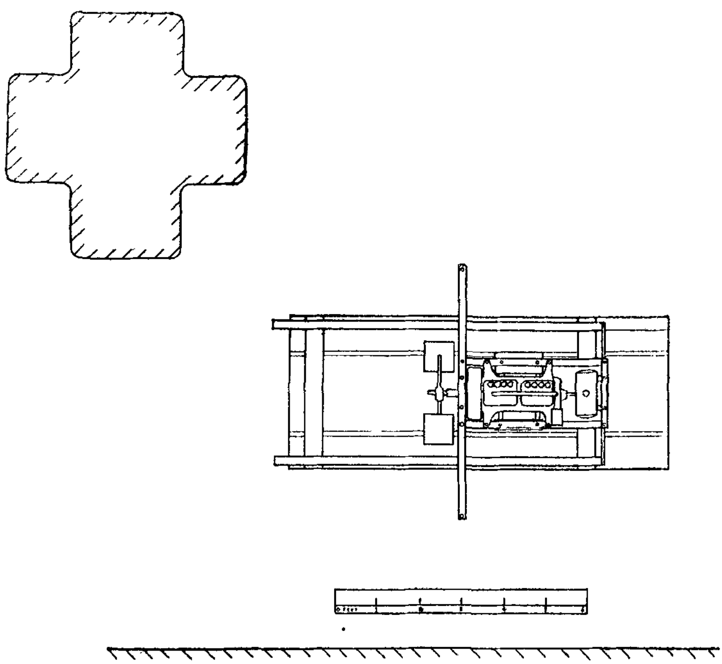


FIG. 3.

The ordinary rope brake may be taken as an example, being cheap in first cost and on the whole fairly accurate, but it requires a special internally-cooled flywheel and rather troublesome water outlet connections. It takes considerable skill in handling and at the best is liable to hunt, especially with a modern engine having a flat torque curve, as in Fig. 4. To take an example, suppose the engine is running at 1,100 revs. per min. with a torque of 156 lb. at 1 foot; if for any reason the engine torque decreases slightly, say 4 per cent, the engine will stop unless the brake is slackened to a torque of 150 lb. before the engine slows to 700 revs. per min., in which case the engine may speed up to 2,100 revolutions on recovering its full torque. In the case of brakes in which the torque varies as the square of the speed, the effect of a similar decrease of engine torque is only to reduce the speed from 1,100 to 1,078 revs. per min.

(2) *The Electrical Brake,* Dynamo Type.—Torque varies as speed. In general these are expensive in first cost, being specially designed with a small-diameter armature to allow of high peripheral speeds, and, as a rule, they are mounted on a rigid bed and

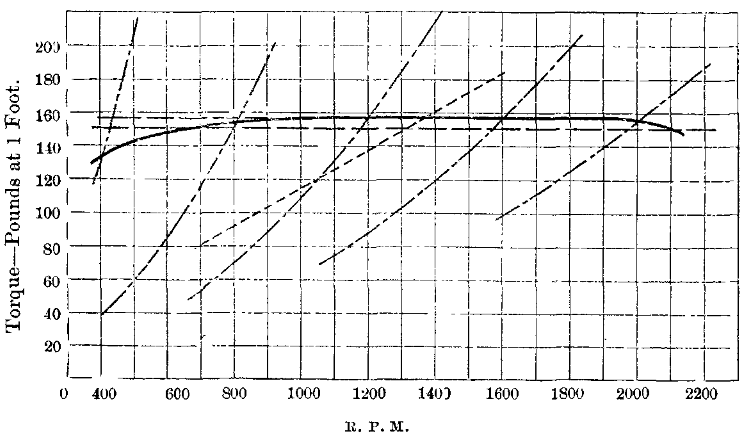


FIG. 4.

connected to the engine by some form of flexible coupling. They must be large enough to absorb the maximum power required. They certainly have the advantage of being able to drive the engine if necessary, but a much smaller and cheaper motor will do this satisfactorily. If the power is measured electrically, it involves a calibration of the apparatus, which calibration may easily be affected by external influences. A better method is that in which the field magnets are pivoted and the torque measured by hanging weights on an arm. This is not, as a rule, strictly accurate as it neglects windage and bearing friction, when absorbing power, and includes them when giving power. The windage, at any rate, is quite appreciable at high speeds.

(3) *The Eddy Current Brake,* which consists of one or more copper disks rotating between the poles of the pivoted electromagnets, the load being varied by means of the excitation. This is cheaper than the last named type and requires no electrical connections with the rotating parts, but it is not so suited to low-speed work as the two previous types. The copper disks are apt to overheat and warp in spite of means provided for ventilation, and the windage of these ventilators must be reckoned with.

(4) *The Water Brake* is very compact for the power it absorbs and has very few working parts to wear and get out of order, but is expensive and requires a flexible coupling. It is reported to be none too sensitive, but the authors have had no personal experience with it.

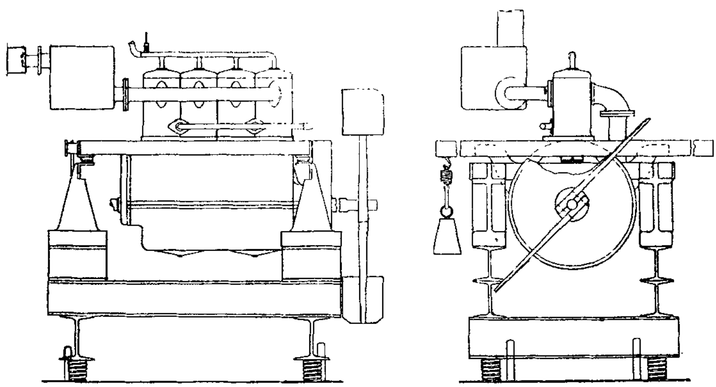


FIG. 5.

(5) *The Fan Brake* is exceedingly cheap and easy to fit direct, and enables one man to take charge of the engine as it keeps a very steady speed and prevents racing. Its defects are that it is unsuitable for low speeds on account of its bulk, it is noisy and the engine has to be stopped and the blades altered if it is desired to take full load tests at different speeds or different loads at the same speed. Its great disadvantage is that the horsepower reading is dependent on a formula in which the constant is very susceptible to changes of air pressure and temperature and to environment.

Owing to its many advantages, particularly with respect to aeroplane engines, which are so lightly built as not to be adapted to rigid mounting and coupling up, it was decided to make some tests as to the limitations of this particular form of brake. The method employed was that of measuring the counter torque of the engine, and the apparatus used is shown diagrammatically in Figs. 2 and 3. A hollow bracket mounted on the "dead" frame carries the inner race of a large ball bearing, an extension of the crankshaft, concentric with the ball race, passing through but not touching the bracket. This method of mounting is not essential (another arrangement is shown in Fig. 5), but in the case of driving the engine by means of an electric motor it removes the disturbing influence of the universal joint. The outer ball race fits in a housing which supports a transverse member, which

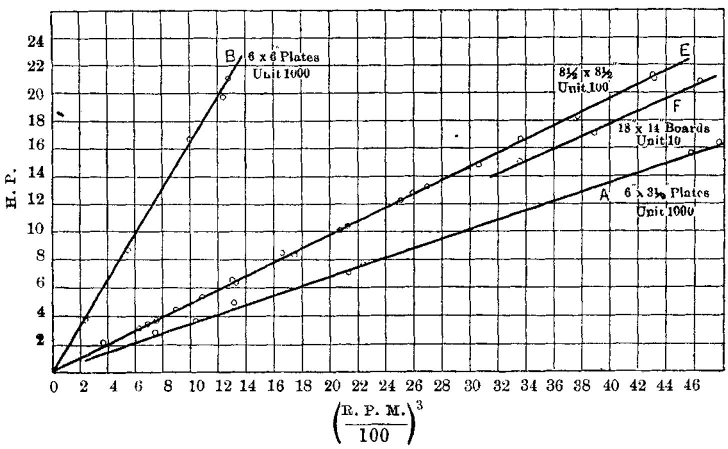


FIG. 6.

in the case of the flywheel end also forms the arm from which the weights are suspended. The petrol tank is mounted on the "live" frame and care is taken that the water connections cause no restraint. It is essential that the exhaust should discharge parallel to the axis of the engine and that the pipe should be in no way constrained, but should project some distance into a larger pipe. Counterweights are bolted to the "live" frame in order to bring the centre of gravity of the engine and frame in line with, but very slightly below, the axis of the supporting bearings. The sensitiveness of the apparatus mainly depends on the accuracy of this balancing. With the engine running, the bed shown in Fig. 2 would easily turn to $\frac{1}{2}$ oz. at a radius of 35 inches, this being equivalent to 0·017 horse-power at 1,000 revs. per minute.

The object of these experiments was:—

1. To examine the reliability of the formula

$$HP = CN^3$$

where $N =$ revolutions per minute.

2. To obtain, if possible, an expression for C in terms of fan dimensions.
3. To note the effect of adjacent objects.
4. To observe the effect of air currents.

THE RELIABILITY OF THE FORMULA $HP = CN^3$.

Experiments were conducted with fans of various areas at varying distances from the centre of rotation. A selected fan was run in a given position at as wide a range of speed as possible.

TABLE I.

Series.	Plates D × C	H. P. at 1,000 R. P. M.	$\frac{C^1}{A}$	Radius of Centre of Gravity l	Radius of Third Moment $= \sqrt[3]{\left(l^2+\frac{D^2}{4}\right)}$	Per Cent Error on Calculated Results Below	Above
	in.			in.	in.		
A	6 × 3½	0·353	8·42	6·27	6·76	13·7	....
		0·399	9·5	6·65	7·12	14·5	....
		0·662	15·75	8·15	8·54	20·6	....
		0·844	20·1	8·9	9·22	18·3	....
B	6 × 6	0·39	5·42	5·03	5·58	....	6·2
		0·774	10·76	6·53	6·96	....	4.5
		1·495	20·8	8·53	8·87	4·5	....
		2·54	36·2	10·53	10·80	7·6	....
		3·59	49·8	12·03	12·27	13·0	....
B′	....	1·625	22·6	9·03	9·36	....	....
		2·370	32·9	10·53	10·80	....	....
		3·36	46·6	12·03	12·27	....	....
C	6 × 8½	0·617	6·05	5·375	5·887	24·5	....
		0·728	7·06	5·75	6·225	6·2	....
		1·09	10·7	6·5	6·93	....	3·0
		1·495	14·65	7·25	7·64	....	5·0
		1·860	18·25	8·0	8·36	0	0

TABLE I.—*continued.*

Series.	Plates D × C	H. P. at 1,000 R. P. M.	$\frac{C^1}{A}$	Radius of Centre of Gravity l	Radius of Third Moment $= \sqrt[3]{\left(l^2+\frac{D^2}{4}\right)}$	Per Cent Error on Calculated Results Below	Above
	in.			in.	in.		
D	$8\frac{1}{2}\times 6$	0·79	7·75	5·375	6·316	1·4	....
		0·895	8·77	5·75	6·652	1·8	....
		0·920	9·02				
		1·235	12·1	6·5	7·32	1·0	....
		1·708	16·75	7·25	8·00	....	5·0
		2·17	21·25	8·0	8·69	....	3·8
E	$8\frac{1}{2}\times 8\frac{1}{2}$	1·56	10·83	6·283	7·12	4·0	....
		2·717	18·85	7·785	8·48	1·0	....
		3·88	25·0	8·785	9·416	4·0	....
		5·013	34·8	9·785	10·35	....	0·6
		6·48	45·0	10·785	11·29	....	....
		10·30	71·7	13·285	13·71	....	....
E′	....	5·13	35·6	9·785	10·35	....	....
		11·20	77·8	13·285	13·71	3·3	....
F	28 × 14	190·5	243·0	16·75	19·97	2·0	....
	26 × 16	167·0	201·0	15·75			
	26 × 14	149·0	204·5	15·75	18·73	0·25	....
	26 × 12	119·0	191·0	15·75			
	24 × 14	114·8	170·8	14·75	17·46	0	2·8
	24 × 12	95·6	166·0	14·75			0
	22 × 12	70·0	132·5	13·75	16·21	0·4	....
	21 × 14	69·5	118·0	13·25	15·60	0·3	....
	20 × 12	52·7	110·0	12·75	14·95	....	5·0
	18 × 14	40·5	80·3	11·75	13·70	0	0
	18 × 12	34·2	79·2	11·75			
	16 × 12	22·0	57·3	10·75	12·48	5·0	....
G1....	6 × 6	8·5	118·0	17·7	17·86	Poppe formula	
		11·1	154·0	19·7	18·85		
		14·3	198·0	21·7	21·83		
		18·0	250·0	23·6	23·73		
		22·2	308·0	25·6	25·71		

TABLE I.—*continued.*

Series.	Plates D × C	H. P. at 1,000 R. P. M.	$\frac{C^1}{A}$	Radius of Centre of Gravity l	Radius of Third Moment $=\sqrt[3]{\left(l^2+\frac{D^2}{4}\right)}$	Per Cent Error on Calculated Results Poppe formula
	in.			in.	in.	
G2....	$8\frac{1}{2}\times 8\frac{1}{2}$	20·2	140·0	17·7	18 02	
		26·1	181·0	19·7	20 0	
		33·0	230·0	21·7	21·97	
		41·2	286·0	23·6	23·85	
		50·5	350·0	25·6	25·78	
G3....	12 × 12	50·5	175·0	17·7	18·37	
		64·3	223·0	19·7	20·29	
		80·2	278·0	21·7	22·24	
		98·7	343·0	23·6	24·09	
		119·5	415·0	25·6	26·06	

TABLE II.

H.P. Absorbed by Fan Arm.

Radius	Width	Depth	Speed	H.P.	Const.
in.	in.	in.			
12	1	0·75	1,800	1·02	0·175
10	1	0·75	3,500	3·29	0·0736
8	1	0·75	3,760	1·8	0·0338

TABLE III.

Rings on	Percentage too high
Nos. 1, 2, 3, 4, 5, 6,	11
1, 2, 3, 4,	10
1, 2, 3,	15
1, 2,	7·5
1,	5
0,	5
5, 6,	14
4, 5, 6,	21
3, 4, 5, 6,	14
2, 3, 4, 5, 6,	11
4,	19
0, (Fan clear 12 in. from frame)	0

Readings of horse-power consumed by this fan were taken at different speeds. This experimentally determined horse-power was for each case plotted against N^3 (Fig. 6). In each case the resulting graph is a straight line through the origin, that is

$$HP = CN^3$$

The value of C for each fan is given by the corresponding graph,

$$C = \tan \theta$$

where θ is the angle of inclination of the graph and the respective perpendicular and base lines are read to scale.

For any given fan at a given distance from the axis of rotation, the range of speed was usually two to one; over the whole of the fans employed the speed varied from 350 to 3,500 revs. per minute. In no case was there any suggestion that the formula $HP = CN^3$ failed to hold good.

It should be noticed that as each series of observations was taken continuously, atmospheric conditions did not change appreciably during any one series of tests, while the relative position of surrounding objects also remained unchanged. The experimental value of C thus obtained for a given fan was in all cases obtained as the result of a number of observations varying from 3 to 25. It is important to remember this, as afterwards, in an attempt to find some simple expression for C, these experimental constants are plotted against other quantities. In such case the plotted points may reasonably be expected to fall in a smooth curve, and any raggedness of arrangement must be put down to atmospheric or environment effects.

VALUE OF THE CONSTANT C.

It will be assumed, for the moment, that atmospheric conditions are constant, and that the fans are fairly removed from surrounding objects.

It has been shown that over very wide ranges of speed

$$HP = CN^3 \qquad (1)$$

C may be expressed in terms of other quantities, as

$$HP = 8\pi^3 aAR^3N^3 \qquad (2)$$

where

a = resistance constant of air per unit area,

A = area of plates,

R = radius of centre of pressure

equating (1) and (2)

$$CN^3 = 8\pi^3 aAR^3N^3$$

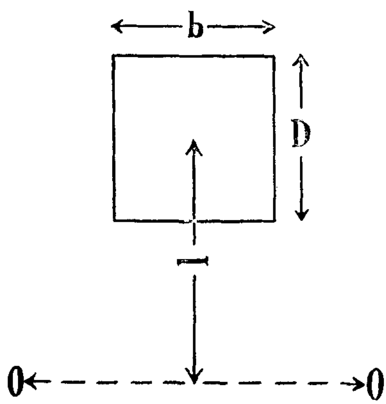
$$C = 8\pi^3 aAR^3$$

In this case, for all fans of equal radii of pressure centres, C would be directly proportional to A; the expression is better written

$$C/A = 8\pi^3 aR^3$$
$$= KR^3$$

where $K = 8\pi^3 a$

It is now necessary to find a value for R. If the air impinged normally on the plates, the radius of the centre of pressure would be as determined below.



Let $O\,O$ be the axis of rotation.

$l =$ the radius of centre of gravity.

$D =$ the depth of plate.

$b =$ the breadth of plate.

Then the HP absorbed by any element of surface $b.dx$ is

$$HP = KN^3 b.dx.x^3$$

where x is the distance of any element $b.dx$ from OO.

$$HP \text{ absorbed by whole fan} = KN^3 b \int_{e-(D/2)}^{e+(D/2)} x^3.dx.$$
$$= KN^3 bDl(l^2 + (D^2/4))$$

but from equation (2)

$$HP = KN^3 A R^3$$
$$\therefore R^3 = l\,(l^2 + (D^2/4))$$
$$\therefore R = \sqrt[3]{l(l^2 + (D^2/4))}$$
$$\therefore C/A = Kl(l^2 + (D^2/4)) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

This, then, would be the expected value of R if the air impinged normally on the fan plates. This, however, does not occur, for the air flows radially outwards through the fan and some displacement of the centre of pressure may occur. It now remains to be seen to what extent this formula (3) is correct.

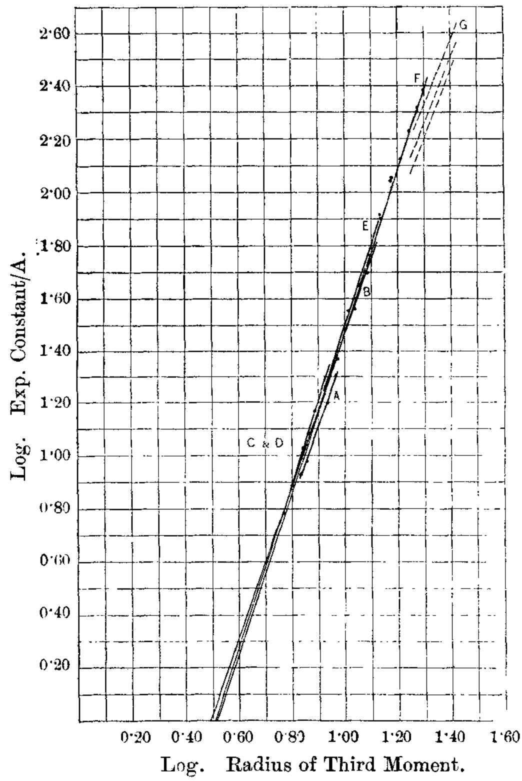


FIG. 7.

If $C/A = KR^3$

where $R = \sqrt[3]{l(l^2+(D^2/4))}$

Then $\log C/A = 3 \log R + \log K,$

which is of the form

$$y = 3x + C,$$

and shows that the graph obtained by plotting log C/A against log R is a straight line.

These experimental quantities log C/A obtained from a series of fans have been plotted against log $\sqrt[3]{l(l^2+(D^2/4))}$ in Fig. 7.

In the examination given above the possible effect of the arm carrying the fan has been ignored, and readings were taken to measure this effect. Only in the case of the smaller plates was the arm effect appreciable, and the *HP* results of these plates were corrected for this effect.

The constants given by a large number of fans have been con-

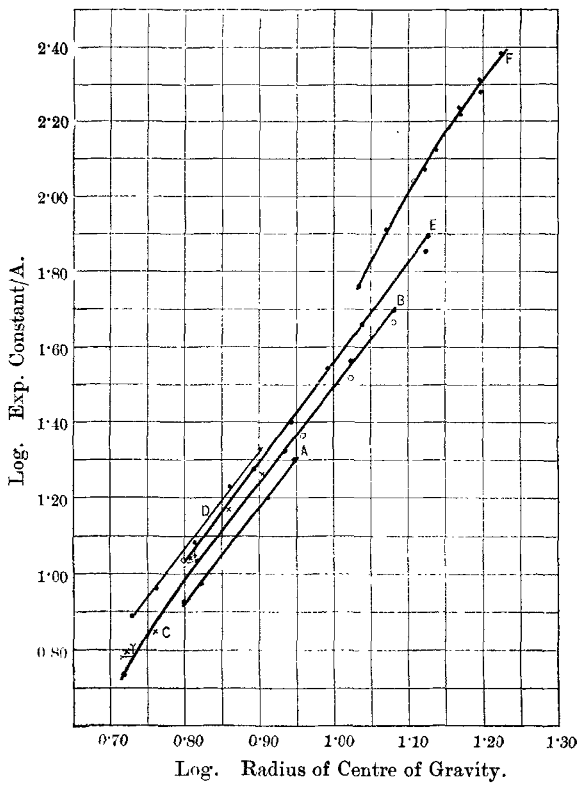


Fig. 8.

sidered, see Table I., p. 537. Groups A, B, C, D, E have been obtained from different plates by altering the radii of the centre of gravity. Group F contains the results obtained from a large assortment of plates, but with little variation of the radius of the centre of gravity for each plate. In every case, however, the value of C^1/A has been calculated from a series of observations.

The graphs plotted in Fig. 7 may fairly be taken as straight lines of the form $y = mx + c$ and with the exception of graph of A appear to lie well about some common axis.

Examining each graph separately, it is at once seen that no graphs obey the $C/A = KR^5$ formula exactly.

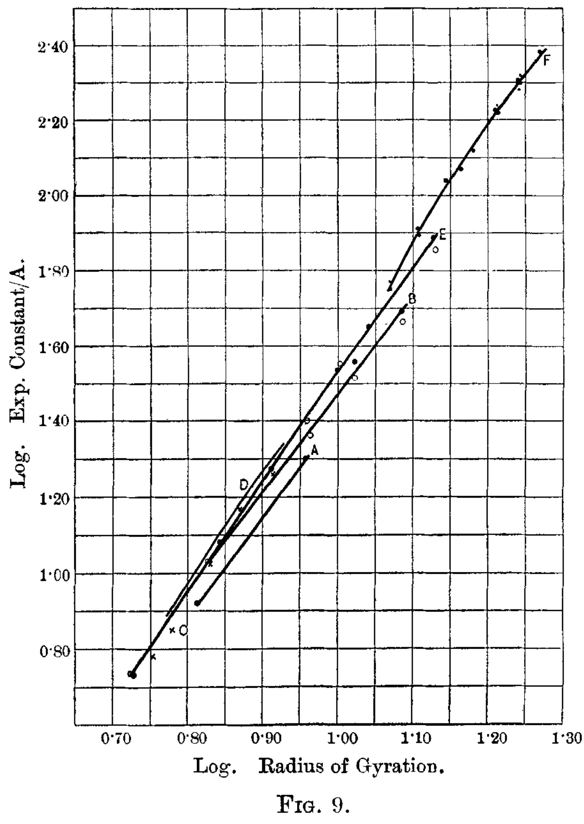


FIG. 9.

Indeed, this is to be expected, and it is clear that no simple general expression for C/A may be obtained.

If, however, a fair approximation to accuracy is accepted it is found that the formula

$$C^1/A = R^5 \times 312 \times 10^{-1}$$

gives a fairly satisfactory expression in cases C, D, E and F, and in case B up to a value 9 in. for the radius of the centre of gravity, but is badly out for case A.

Figs. 8 and 9 show log C^1/A plotted respectively against log radius of the centre of gravity of the plate, and against log radius of gyration. These values for R are obviously impossible. Figs. 10 and 11 show log *given constant*/A plotted against log

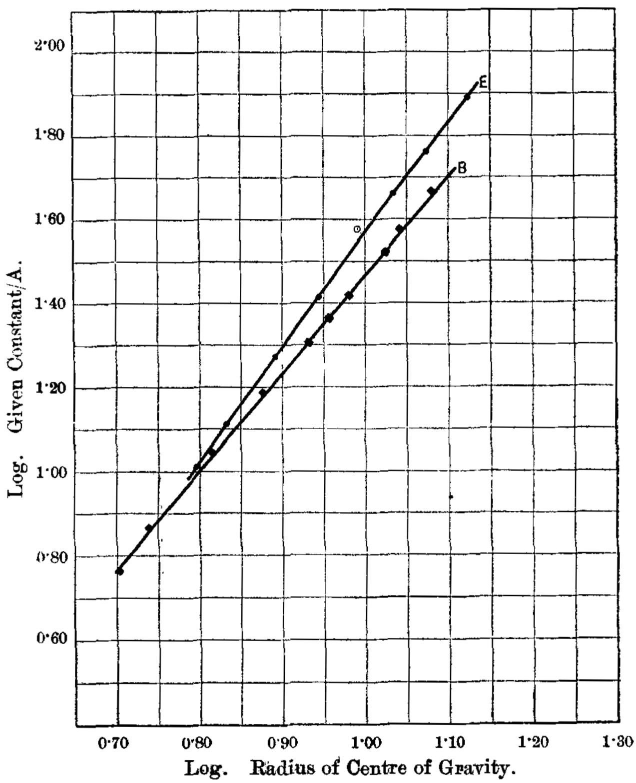


FIG. 10.

radius of the centre of gravity and against log radius of the third moment. In all cases the experimental constant is taken as the HP absorbed at 1,000 revs. per minute, and $C^1/A = (constant \times 1{,}000)/area\ of\ both\ blades$. The curves G, in Fig. 9, are worked out from a formula given by Mr. Poppe for square plates.

$$HP = AR^3N^3/4{,}010.$$

A = area in square centimetres.

R = radius of outer edge in decimetres.

$$N = R.P.M./1{,}000.$$

r = radius of centre of gravity (given as 5·5 decimetres).

It will be observed that they fall below the results of F blades,

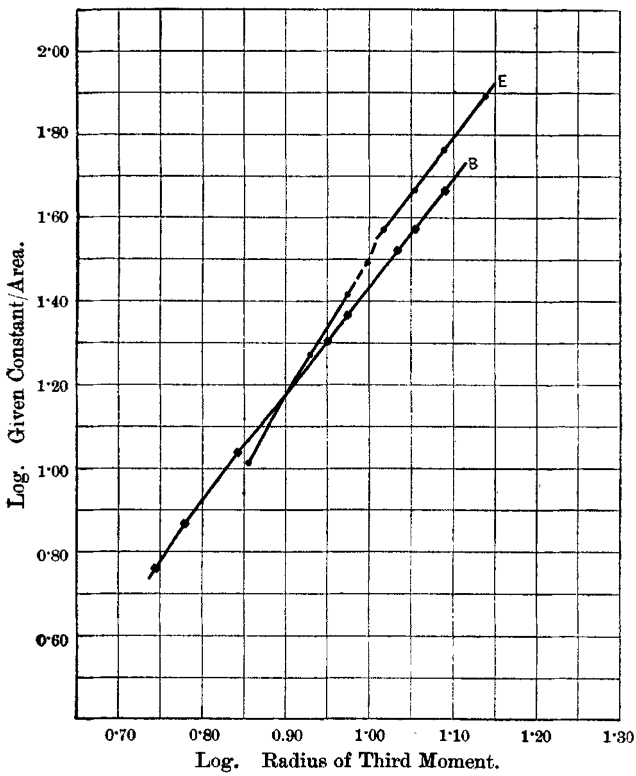


FIG. 11.

but under the environment conditions in which they are employed doubtless give fairly correct results.

The sizes worked out were 6 in. × 6 in., $8\frac{1}{2}$ in. × $8\frac{1}{2}$ in., and 12 in. × 12 in., the latter line being nearest F. The great danger in using this formula lies in the temptation to apply it for dimensions differing widely from those given.

Some of the first experiments on the type of bed shown in Fig. 5 were made to test the effect on the accuracy of the fan, of shrouding one side of the fan by means of various rings and disks, as shown in Fig. 12. Table III., p. 539, gives the results obtained, the left-hand column giving the numbers of the rings put on, and the right-hand column the percentage by which the horse-power from the formula CN^3 exceeds the measured horse-power. It is interesting to note that with the fan close to the flywheel there

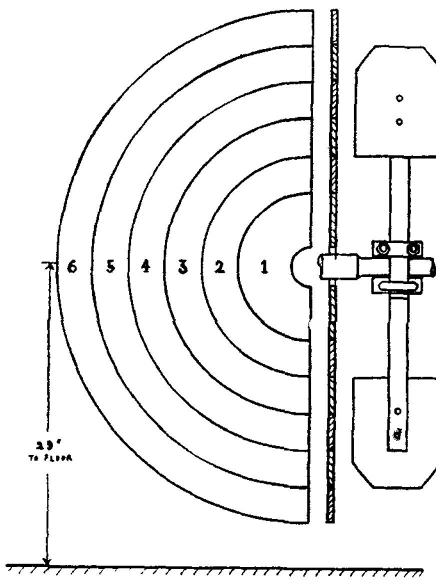


FIG. 12.

is an error of 5 per cent, and with one ring (No. 4) on, at about the radius of the centre of the blade, the error is 20 per cent. It was next thought that it might be possible to calibrate a fan in a box of stated dimensions in order to cut out the environment factor.

Fig. 13 shows the effects observed in building up the box, the floor forming the bottom.

(1) First a board, 42 in. × 36 in., forming the back was inserted. The apparent horse-power was then 10 per cent too high.

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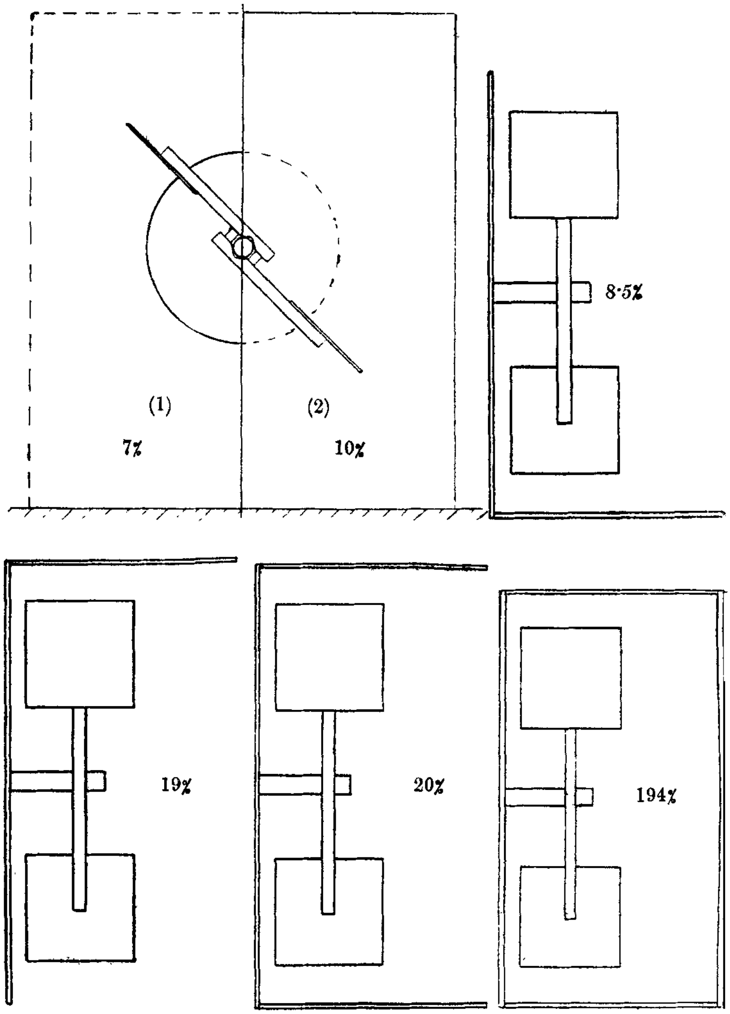
(2) One side, 42 in. × 18 in., was arranged on the side towards which the top of the flywheel was moving; this appeared to



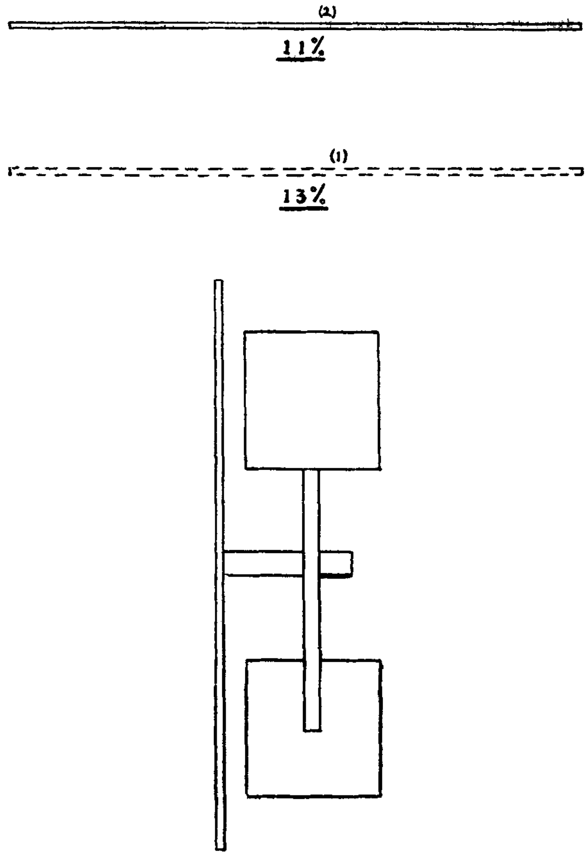
Group A, B, C, D, E.
FIG. 13.

reduce the effect of the back only, and gave a figure of 8·5 per cent too high.

(3) The side, as in (2), was removed and placed opposite—19 per cent too high.

(4) Both sides on—20 per cent too high; very similar to (3).

(5) Back, front and two sides—top open—194 per cent too high; that is to say, the apparent horse-power is nearly three times greater than the real horse-power.



Group C and G.
FIG. 14.

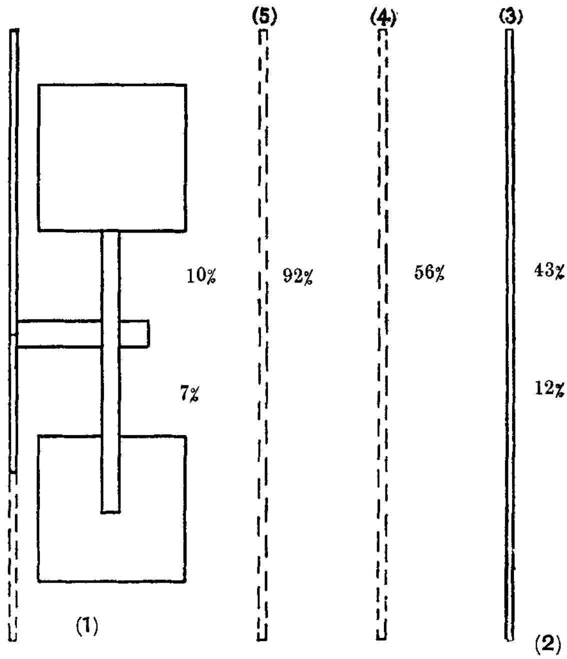
Fig. 14.—*Side Wall Effects.*

(1) Board at back, as in Fig. (1), and 42 in. × 36 in. board at side, as shown, $11\frac{1}{2}$ in. from outer edge of blade .... 13 per cent too high.

(2) Similar to (1), but 21 in. away............ 11 ,, ,,

Fig. 15.—*End Effects.*

(1) Disk of same diameter as flywheel, at back, apparent horse-power	7	per cent too high.
(2) As in (1), but 42 in. × 36 in. board parallel to disk $28\frac{1}{2}$ in. away	12	„ „
(3) Board at back, as in Fig. 15, (1) and similar board in front $28\frac{1}{2}$ in. apart......	43	„ „
(4) As in (3), but 21 in. apart..................	56	„ „
(5) As in (3 and 4), but 14 in. apart.........	92	„ „



Group F.

Fig. 15.

Edge Effect.—In order to test whether the ratio of area to perimeter or edge exposed exercised any effect, a pair of $8\frac{1}{2}$ in. × $8\frac{1}{2}$ in. plates were made perforated with a large number of holes ($\frac{1}{2}$ in. diameter), but the ratio C/A was found to be unaltered.

Barometer Effect.—This is shown in Fig. 16, and over the range observed during these experiments is almost double that which might be expected.

Temperature Effect.—It is difficult to measure the temperature of the air actually taken by the fans, as a considerable portion is drawn past the hot engine. For instance, in one case the experimental constant determined directly after the engine was started up was 105, after ten minutes' run it had decreased to

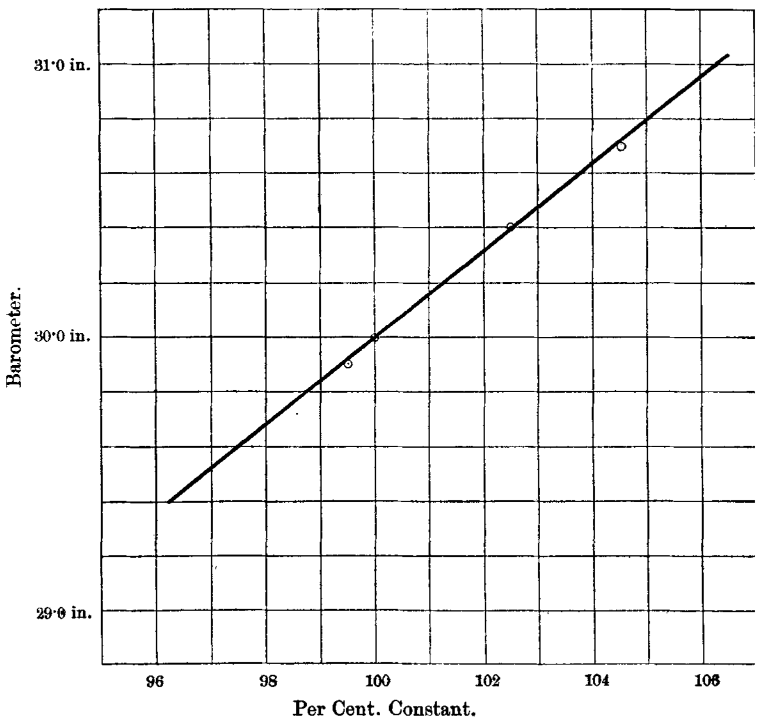


Fig. 16.

100, the room temperature meanwhile increasing from 14° C. to 17° C.

Draught Effect.—An electric fan was arranged to blow air on to the rotating blades; this was tried at different angles, but in no case was any effect observable.

High Speed Tests.—With the smaller fans, *A* and *B*, a geared-up arrangement was used, speeds up to 3,700 revs. per minute being obtained. This gear was also used in determining the resistance of the arms, a pair of dummy wooden arms being shown in position.

DISCUSSION.

Mr. JOHN WILKINSON, in opening the discussion, said: I have had a great deal of experience with fan dynamometers, and I think I can bear out everything the author has said in regard to their use. I have found that for factory conditions it is a very satisfactory instrument to use, and it is a very easy instrument to use. I have never considered that fan dynamometers approach the extreme accuracy which is necessary for laboratory tests of various engines under the various conditions in which they must be tested, on account of the great variations in regard to environment, and have always been very careful that all our tests shall be made under perfectly similar conditions. The dynamometers should be calibrated accurately over all the ranges of speed which are to be used. Whenever I have had occasion to change the physical aspects of the testing room, I have found it necessary to make recalibrations. But where the conditions are kept uniform, the curves of horse-power will generally follow a definite law. As I remember, the power curves are always proportional, not to the cube of the speed, but to an exponent slightly under the cube of the speed, something like 2·97 or 2·98, varying slightly with the different sizes of plate used.

I would always be suspicious of any horse-power curves made on fan dynamometers where the speed relations are extreme, unless the dynamometer had been calibrated over the whole range of speed. But where the limits are definitely settled, I think that with proper care the results can be made accurate enough to meet the conditions of any manufacturer.

Mr. HERBERT CHASE: I have been very much interested in this paper. The statements the authors make are, I think, exactly in accordance with the facts as I have been able to observe them. The fan dynamometer, as stated, is a very cheap and very convenient form of dynamometer, but it must be used with exceptional care if accuracy in results is desired. I consider it one of the best forms for commercial use. It gives a steady load and does not require much attention from the operator. I speak particularly of "running-in" tests.

For exact scientific tests it seems to me most desirable that the fan brake should be used in connection with some means of measuring the torque reaction of the motor. That, also, the authors have indicated. If this is not done it is very easy to fall into some of the errors which they have pointed out, due to environment and to atmospheric conditions. I would like to call attention to the table of corrections for barometer and temperature change which Mr. Renard has published in a paper on the subject.

One of the great disadvantages of the fan dynamometer is that in almost all forms it is necessary to stop the dynamometer and alter the position of the blades in order to change the load. This fact alone makes it much less convenient than the electric cradle type, which I consider the most convenient of all. The saving in time alone over a period of two or three years seems to me sufficient to offset the great difference in first cost.

Mr. T. B. Browne: It may interest those present to know that the fan dynamometer is used a great deal in our factories in England for comparative tests. The more delicate work of testing a new model or setting the standard of an engine, that is, deciding the horse-power which shall be required from all engines of that model, is usually done with either the electric cradle dynamometer or rope friction dynamometer used in conjunction with a spring balance. The fan dynamometer, as the authors have said, is so very sensitive and liable to many corrections that I think it is not at all suitable for obtaining very fine results. But for comparative purposes and bringing the engine up to the standard required, I think there is nothing to beat it. It is very cheap and simple to fit; it is, of course, quite easy to arrange for each engine to be put on test under precisely the same conditions and surroundings; and it is not a very difficult matter to make temperature and pressure corrections. The electric dynamometer is, of course, an expensive outfit; some of our smaller makers have, therefore, confined themselves to the use of the rope dynamometer. In the hands of people who have had experience with it very accurate results can be obtained.

Mr. H. L. Horning: Inasmuch as the weight of the air determines the power absorbed, is it not necessary that the change in humidity of the air be noted in the readings?

Mr. E. B. Wood: We take readings with wet and dry bulb thermometers and really have not noticed any difference. But I would like to point out that the barometer and the thermometer together can within reasonable limits effect a variation of 20 per

(Mr. E. B. Wood.)

cent. I do not know whether that amount of variation need be allowed in commercial testing. I thought that 10 per cent would pass for testing.

Mr. F. JEHLE: I was very much interested in Mr. Wood's paper, and agree with him in nearly everything he has said. Being particularly interested in the eddy current magnetic absorption type of dynamometer, I do not quite agree with him as to that. I think this form of dynamometer, if any, may be made to handle high torque at low speeds: in fact, I have seen one in use that did this. Of course, where it has all the necessary refinements to do this, it is no longer a cheap dynamometer. Still, it possesses the advantage of being self-contained; that is, it has no resistance grids or switchboards. As far as the warping of the disk is concerned, I have known of no trouble that way. Of course, I used a water-cooled one.

The statement that the water brake is compact for power is true at comparatively high speeds only. I have never seen a water brake that could be used at very low speeds unless it was extremely large.

Mr. W. C. LAMKEN: From data given in the German Hütte handbook for engineers, I have developed the following formula, which seems to be sufficiently correct for commercial use:—

brake horse-power $\text{HP} = CmNn^3\left((B-b)(R^4-r^4)+bL^4\right)$

where

C = a constant.

m = the specific gravity of the air.

N = number of blades.

n = number of revolutions per min.

B = width of blade in in. measured parallel to the shaft.

b = width of beam in in. measured parallel to the shaft.

R = radial distance of outer edge of blade from centre of shaft, in in.

r = radial distance of inner edge of blade from centre of shaft, in in.

L = radial distance of outer edge of beam from centre of shaft, in in.

In three complete sets of curves on hand I found the following values of Cm:—

$$Cm = 6{\cdot}4 \quad 10^{-15}$$
$$Cm = 6{\cdot}4 \quad 10^{-15}$$
$$Cm = 7{\cdot}8 \quad 10^{-15}$$

With these values used in the above formula the figures obtained differed less than 5 per cent from those taken from the corresponding points of the original curves.

Mr. E. T. Birdsall: I would like to ask whether anybody has used circular instead of square blades. In all the data I have on fan dynamometers square blades are specified, and it has always seemed to me that there would be some effect due to the difference in the corner area relative to the total area of the blades which may account for the difference between small blades and large blades.

Mr. E. B. Wood: We made some experiments rather with the idea of testing what I have called edge effect, that is, the effect of altering the ratio of area to perimeter. In a pair of the $8\frac{1}{2}$ in. by $8\frac{1}{2}$ in. blades we drilled a lot of $\frac{1}{2}$ in. holes, reducing the area to about three-quarters of what it was previously, and increasing the length of the edges tremendously. On testing, it was found that C/A was as nearly as possible the same as that of the solid blade. Some of the F results are on rectangular blades and not necessarily on square blades I have not tried any circular ones.