# WINDAGE EXPERIMENTS WITH A MODEL OF THE ROTARY ENGINE B.R. 1.

By A. Fage, A.R.C.Sc., and H. E. Collins.

*Reports and Memoranda, No.* 448. *May,* 1918.

Summary.—(a) *Introductory.* (*Reasons for inquiry.*)—The present experiments were made at the request of the Technical Department of the Air Ministry to obtain data from which to calculate the windage losses in flight of the B.R. 1 engine mounted on the Sopwith "Camel."

The dependence of the windage horsepower on the area of the circular opening at the front of the cowling at the ordinary conditions of flight was also investigated.

Finally, the model engine was tested under conditions similar to those of the test-bed experiments at the Royal Aircraft Establishment.

(b) *Range of investigation.*—The experiments were made in No. 1 7-ft. channel, the scale of the models—engine, cowling, airscrew, and body—being one-third. The method of measuring the windage torque is given in detail in Report T. 1153. Experiments were made with the engine rotating (1) in a uniform wind, (2) in no wind, with and without the airscrew rotating, (3) in a uniform wind, with and without the airscrew rotating. In all three cases the windages were measured both with and without cowling, with the engine mounted in front of the body. The variation of the windage torque with the area of the circular opening at the front of the cowling was investigated over the working range of $(V/n)$ where "V" is the forward speed of the machine and "$n$" the rotational speed of the engine or airscrew. Finally, experiments were made with the engine model under conditions similar to those of the test-bed experiments at the Royal Aircraft Establishment.

(c) *Conclusions.*—It was found that the cowling reduces the windage torque of the engine, both with and without the airscrew rotating, the windage with the cowling being about 67 per cent. of the value without the cowling. At any forward speed the windage of the engine, both with and without the cowling, is reduced when the airscrew is mounted on the engine shaft. The windage losses when climbing and for maximum horizontal flight speed of the machine are 15·4 H.P. and 24·5 H.P. respectively at ground level, and are greater by about 12 per cent. and 37·5 per cent. than the values calculated from experiments in which the forward speed is zero.

The interference of the wings on the windage torque of the engine is practically negligible. Small changes of the circumferential shape of the cowling affects only slightly the windage torque. If the translational and the rotational speeds are constant, the windage losses increase fairly rapidly with the area of the circular opening at the front of the cowling up to a diameter of about 16 ins., above which the losses are not greatly affected by the area of this opening. By a suitable adjustment of the area of the circular opening it is possible to maintain the windage losses—and also the cooling—constant at all flying speeds. The windage losses, forward speed being zero, are reduced about 50 per cent. by closing the openings at the circumference and at the back of the cowling. The interference of the testing tunnel of the R.A.F. on the windage losses is small, when the engine is tested without any wind blast.

(d) *Applications and further developments.*—Experiments of a similar nature are to be made with a model of the B.R. 2 engine mounted in front of a model of the Sopwith "Snipe."

At the present time the windage losses of a rotary engine on an aeroplane in flight are of uncertain magnitude, and accordingly the present experiments were made, at the request of the Technical Department of the Air Ministry, to measure the windage losses on a model of the B.R. 1 engine, mounted in front of a model of the Sopwith "Camel" body, when rotating under conditions similar to those of practice. An investigation was also made of the dependence of the windage horsepower on the areas of the circular opening at the front and the air ducts at the back of the cowling. Finally the model engine was tested in place in a model of the engine testing tunnel of the Royal Aircraft Establishment.

*Descriptions of the models and of the method of measuring the windage torque.*—Experiments were made in the No. 1 7-ft. channel on the B.R. 1 engine mounted in front of the Sopwith "Camel" body, the scale of the models being one-third full size. The engine has nine cylinders, each of bore 120 mms., an overall diameter of 42 ins., and develops 150 H.P. at 1,250 r.p.m. A photograph of the model engine, which was made at the Royal Aircraft Establishment, is given in Fig. 6. The model was made almost entirely of wood. To take the high centrifugal loading each cylinder head was made of aluminium attached by a long steel bolt passing through the centre of the cylinder to a steel ring in the crankcase. All the experiments were made with the engine mounted in front of the Sopwith "Camel" body. A sketch of the model body which has air ducts at the bottom and at the sides is given in Fig. 2. A modified form of the body with air ducts at the sides of triangular shape, as shown in Fig. 2a, was used in some of the experiments. The model body was fitted with detachable wings. A sketch of the two-bladed airscrew, Drg. No. A.D. 644, mounted on the Camel machine is given in Fig. 1. It will be seen that the airscrew has a diameter of 2,590 mms. and also that the blade angles vary from 20° at the tip to 46° 40′ at the boss. The shape of the model cowling used in the experiments is shown by the sketches of Fig. 3. A large part of the undersurface at the back of the cowling was cut away. To allow sufficient clearance between the valve rocker supports at the head of each cylinder the cowling had a slight "bulge" at the circumference. The diameter of the circular hole at the front of the model cowling was 9·65 ins., the diameter at the back where the attachment to the body was made being $11\frac{5}{16}$ ins. A second cowling of slightly different shape, of which a sketch is given in Fig. 4, was used in a preliminary experiment. Experiments were also made to find the interference effect on the windage measurements of a model of the R.A.F. engine testing tunnel. A sketch of this model which was made of tin plate is given in Fig. 5, from which it will be seen that the overall length is 25·75 ins. and the diameters at the inlet and outlet 18·33 ins. and 12 ins. respectively.

It is not proposed to give a detailed description in the present report of the method of measuring the windage torque of the engine. This method is of general applicability, and accordingly, to facilitate future reference, a full description of the apparatus and of the method of measurement are given in a separate report, T. 1153, to which reference should be made in the present instance. It should perhaps be mentioned that the electric motor driving the model engine was completely encased in the model body, and was supported in such a manner as to allow a slight rocking motion about an axis parallel to the centre line of the channel. A spindle attached to the cradle carrying the electric motor was connected by a strut and "C" spring to the top of the channel balance, with which the measurements of the windage torque were made. The airscrew was mounted in front of the model engine on a separate shaft, which was driven independently from a second electric motor mounted on the top of the channel. The rotational speed of the airscrew was kept constant by a frequency meter working from the airscrew shaft.

Experiments were made with the engine rotating (*a*) in a uniform wind, (*b*) in no wind with and without the airscrew, (*c*) in a uniform wind with the airscrew rotating, the values of $(V/n)$ being similar to those of flight, where "V" is the forward speed of the machine and "$n$" the rotational speed of the airscrew or engine. In all cases the engine was mounted in front of the body, and the experiments were made with and without the engine cowling.

The variations of the windage torque with change in the area of the openings at the front and at the back of the cowling, and in the circumferential shape, were also investigated. Finally, the interference on the windage torque of a model of the engine testing tunnel of the R.A.E.—with no wind blast—was measured. The data of the tables at the end of the report are for the full-sized engine. The windage torque, Q in lbs./ft., may be calculated directly from the coefficient $(Q/\rho n^2)$ where $\rho$ is the mass density of the air in slugs per cubic foot, and is equal to 0·00237 at normal temperature and pressure, and $n$ the rotational speed is expressed in revolutions per second. With the values of $(V/n)$ of the report the forward speed V of the machine should be measured in feet per second.

*Discussion of the results of the experiments.*—The data calculated from the experiments made with the engine both with and without the cowling, (1) when rotating in a uniform wind without the airscrew, (2) when in a wind, rotating at the same speed but detached from the airscrew, and (3) when detached from and rotating at the same speed as the airscrew without any wind in the channel, are given in Tables 1 and 2 and shown graphically in Fig. 7.

From a comparison of the curves of Fig. 7 it will be seen that the windage torque of the engine with the cowling, both with the airscrew running and with no airscrew mounted, is about 67 per cent. of that without the cowling. Also at any forward speed of the machine there is a blocking-up effect due to the airscrew—

that is, the windage torque, both with and without the cowling is reduced when the airscrew is rotating in front of the engine. The airscrew has, however, only a small blocking-up effect when the forward speed of the machine is zero. The most important curve of Fig. 7 is perhaps No. 4, which shows how the windage torque of the engine varies with the forward speed of the aeroplane and the rotational speed of the airscrew and engine. The data of Table 5 give the windage horsepower of the engine, with and without cowling, when the machine is held stationary on the ground, when climbing and at maximum horizontal flight speed. It will be seen that the windage horsepower of the engine at ground level at maximum horizontal flight—the value of $(V/n)$ is taken to be 8·45, that is, when $V = 120$ miles per hour and $n =$ 1,250 r.p.m.—and at climbing where $(V/n) = 5{\cdot}35$ ($V = 70$ miles / hour and $n = 1{,}150$ r.p.m.) are 24·5 and 15·4 respectively. The windage losses at these rotational speeds, calculated from experiments in which no airscrew was mounted and in which the forward speed of the machine was zero, are 17·8 and 13·8 H.P. respectively.

It follows, then, that the windage losses of the engine at the maximum horizontal flight and at the climbing conditions of the machine are 37·5 per cent. and 12 per cent. greater than would be calculated from the ordinary test-bed experiments, with no wind blast.

The curves of Fig. 8 were plotted from the data of columns 4-7 of Tables 1 and 2, and show the variation of the windage torque $(Q/\rho n^2)$ with $(V/n)$ with the following arrangements of cowling and models. With these experiments the airscrew was not mounted in front of the engine.

*Arrangement* 1.—With cowling, wings and air ducts at the rear of cowling as in practice.

*Arrangement* 2.—With cowling and air ducts at the rear of cowling as in practice, but no wings mounted.

*Arrangement* 3.—With cowling and no wings as in the previous arrangement, but with additional triangular side openings in body as shown in Fig. 2a.

*Arrangement* 4.—Body with triangular side openings and no wings, but with the cowling, of which a sketch is given in Fig. 4. These are the only experiments in which this cowling was used.

Comparing the windage curves of arrangements (1) and (2) it will be seen that the interference of the wings on the windage torque of the engine is practically negligible. Also the additional triangular openings at the bottom of the sides of the body reduce the windage torque on an average by 2 per cent. over the range of $(V/n)$. Lastly, from the results of the experiments with the arrangements (3) and (4) it will be seen that the windage of the engine in the cowling of Fig. 4 is about 3 per cent. less than with the cowling of Fig. 3 which was used in all the other experiments, and which has a slightly different shape at the circumference.

A series of experiments was made to measure the dependence of the windage losses on the area of the circular opening at the front of the cowling. The areas of the circular openings of the model were such as to correspond with diameters of 29·0 ins., 22·2 ins., 18·0 ins., 12·0 ins., 9·0 ins. and 5·7 ins. on the full-sized cowling. The openings at the back of the cowling and in the body were the same as in practice and the measurements were made with the airscrew rotating at the same speed as the engine. The results of these experiments are collected in Table 3. In Fig. 9 the values of $(Q/\rho n^2)$ are plotted against the corresponding values of $(V/n)$. The data of Table 6, which were calculated from the curves of Fig. 9, show how the windage horsepower varies with the area of the circular opening at the front of the cowling, at the maximum horizontal flight at climbing, and at zero forward speed of the machine. The calculations were made for air density at ground level. The curves of Fig. 10 have been plotted from the data of Table 6. From Fig. 9 it will be seen that with circular openings of diameter 5·65 ins. and 9 ins. the windage torque is practically independent of the forward speed of the machine. In the latter case the opening is almost completely covered by the airscrew boss.

At constant values of V and $n$ the windage horsepower varies appreciably with the area of the circular opening at the front of the cowling up to a diameter of about 16 ins., but with openings of greater diameter the windage horsepower tends to become constant (see Fig. 10). It would seem, then, that there is a certain area of the circular opening which admits just the volume of air which can be conveniently dealt with by the engine. The quantity of air flowing through the circular opening appears to be limited with a small diameter to the area of the opening, but with a larger diameter to the " drawing in " capacity of the engine. With the present arrangement of engine and cowling it would seem that the cooling of the engine will not be greatly increased with any increase of the diameter from about 16 ins., if it be assumed that there is a definite connection between the cooling and windage losses of a rotary engine. Assuming the present engine can be efficiently cooled when the windage losses are 14 H.P. then the areas of the circular openings at maximum horizontal flight and at climbing would need to be 62 and 200 sq. ins. respectively.

The windage of the engine was measured under conditions similar to those of the test-bed experiments at the R.A.E. The results of these experiments are given in Table 4, from which it will be seen that when V = 0 the windage losses are reduced 50 per cent. if the openings in the circumference and at the back of the cowling are covered in so that the only opening is the circular hole of diameter 29 ins. at the front. With the additional interference due to the testing tunnel of the R.A.E. the windage losses are increased by about 3 per cent.

*Summary of the conclusions of the investigations.*—(*a*) The cowling reduces the windage torque of the engine. With the B.R. 1 engine the windage with the cowling is about 67 per cent. of the value without the cowling, both with and without the air-screw rotating.

(*b*) At any forward speed there is a blocking-up effect due to the rotating airscrew.

(*c*) At any rotational speed, the windage losses increase with an increase of the forward speed of the machine. With the engine of the present experiments the windage losses at maximum horizontal flight and at climbing are greater by about 37·5 per cent. and 12 per cent. respectively than the values calculated from experiments in which the forward speed is zero.

(*d*) The interference of the wings on the windage torque of the engine is practically negligible.

(*e*) The circumferential shape of the cowling does not greatly affect the windage torque.

(*f*) Keeping the values of the forward speed of the machine and rotational speed of engine and airscrew constant, there appears to be a certain area of the circular hole at the front of the cowling, below which the windage losses are dependent on the area of the circular opening, but above which the losses remain fairly constant, and depend on the "drawing-in" capacity of the engine.

(*g*) By varying the area of the circular opening at the front of the cowling the windage losses can be maintained constant at all speeds of flight.

(*h*) If the forward speed be zero, closing the openings at the circumference and at the back of the cowling so that the only opening is the circular hole at the front reduces the windage losses by about 50 per cent.

(*i*) The interference of the testing tunnel at the R.A.E. on the windage losses is very small when the engine is tested without any wind blast.

# TABLE 1.

## WINDAGE LOSSES ON B.R. 1 ENGINE. ENGINE MOUNTED IN FRONT OF "CAMEL" BODY.

Forward speed of machine zero ($V = 0$). $n$ = Rotational speed of engine in revs./sec.
$Q$ = Windage torque of engine in lbs./ft. $\rho$ = Density of the air in slugs/cu. ft.
( = 0·00237 slugs per cubic foot at a temperature of 15°·6 C. and a pressure of 760 mms.)

The data of the table are for the full-size engine.

| Engine alone. No cowling. No airscrew. No wings on body. | | Engine without cowling. With airscrew rotating at the same speed as engine. With wings. | | With cowling. With airscrew rotating at same speed as engine. Air ducts at rear of cowling as in practice. With wings on body. | | With cowling. No airscrew. Air ducts at rear of cowling as in practice. With wings on body. | | With cowling. No airscrew. Air ducts at rear of cowling as in practice. No wings on body. | | With cowling. No airscrew. With triangular openings in place of the side air ducts at rear of cowling. No wings on body. | | With a cowling of slightly different shape. (See Fig. 4.) No airscrew. With triangular openings in place of the side ducts at rear of cowling. No wings on body. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Value of $n$. | Value of $Q/\rho n^2$. | Value of $n$. | Value of $Q/\rho n^2$. | Value of $n$. | Value of $Q/\rho n^2$. | Value of $n$. | Value of $Q/\rho n^2$. | Value of $n$. | Value of $Q/\rho n^2$. | Value of $n$. | Value of $Q/\rho n^2$. | Value of $n$. | Value of $Q/\rho n^2$. |
| 16·0 | 104·0 | 15·4 | 98·0 | 18·35 | 68·2 | 22·3 | 72·6 | 11·2 | 71·1 | 11·4 | 69·6 | 23·6 | 64·5 |
| 18·7 | 102·0 | 12·5 | 99·6 | 16·15 | 69·5 | 13·6 | 73·7 | 14·0 | 69·0 | 16·1 | 69·5 | 22·1 | 64·7 |
| 19·7 | 103·5 | 9·1 | 101·2 | 15·10 | 69·1 | 15·8 | 71·8 | 16·0 | 70·4 | 17·9 | 69·7 | 20·5 | 64·1 |
| 22·1 | 101·0 | — | — | 12·70 | 69·1 | 19·2 | 73·2 | 17·7 | 72·0 | 19·7 | 69·5 | 18·5 | 65·4 |
| 23·0 | 102·0 | — | — | 8·40 | 67·9 | 20·8 | 73·0 | 19·5 | 71·3 | 21·3 | 69·6 | 19·5 | 64·8 |
| 23·4 | 103·5 | — | — | — | — | 22·4 | 71·7 | 21·0 | 70·9 | 22·7 | 69·4 | — | — |
| Mean value = 102·5 | | Mean value = 99·6 | | Mean value = 68·7 | | Mean value = 72·6 | | Mean value = 70·9 | | Mean value = 69·6 | | Mean value = 64·7 | |

## Table 2.

### WINDAGE LOSSES ON B.R. 1 ENGINE. ENGINE MOUNTED IN FRONT OF "CAMEL" BODY.

V = Forward speed of machine in feet per second. Q = Windage torque of engine in lbs./ft.
$n$ = Rotational speed in revolutions per second. $\rho$ = Density of the air in slugs per cu. ft.
( = 0·00237 slugs per cubic foot at a temperature of 15°·6 C. and a pressure of 760 mms.)

The data of the table are for the full-size machine.

| Engine alone. No cowling. No airscrew. No wings on body. | | Engine without cowling. With airscrew rotating at same speed as engine. With wings. | | With cowling. With airscrew, Drg. No. A.D. 644 rotating at same speed as engine. Air ducts at rear of cowling as in practice. With wings on body. | | With cowling. No airscrew. Air ducts at rear of cowling as in practice. With wings on body. | | With cowling. No airscrew. Air ducts at rear of cowling as in practice. No wings on body. | | With cowling. No airscrew. With triangular openings in place of side air ducts at rear of cowling. No wings on body. | | With cowling of slightly different shape. (See Fig. 4.) No airscrew. With triangular openings in place of air ducts at rear of cowling. No wings on body. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Value of $V/n$ | Value of $Q/\rho n^2$. | Value of $V/n$. | Value of $Q/\rho n^2$. | Value of $V/n$. | Value of $Q/\rho n^2$. | Value of $V/n$. | Value of $Q/\rho n^2$. | Value of $V/n$. | Value of $Q/\rho n^2$. | Value of $V/n$. | Value of $Q/\rho n^2$. | Value of $V/n$. | Value of $Q/\rho n^2$. |
| 0·0 | 102·5 | 0·0 | 99·6 | 0·0 | 68·7 | 0·0 | 72·6 | 0·0 | 70·9 | 0·0 | 69·6 | 0·0 | 64·7 |
| 4·2 | 134·5 | 5·40 | 121·6 | 4·9 | 78·6 | 3·8 | 84·0 | 3·9 | 84·0 | 4·1 | 84·4 | 4·0 | 80·2 |
| 5·1 | 145·5 | 5·90 | 130·9 | 5·4 | 81·4 | 4·9 | 91·2 | 4·5 | 88·2 | 4·4 | 86·5 | 4·3 | 82·5 |
| 6·0 | 157·5 | 7·25 | 145·0 | 5·95 | 84·3 | 6·0 | 101·0 | 5·3 | 95·7 | 4·8 | 90·3 | 4·6 | 83·2 |
| 6·5 | 160·0 | 9·90 | 175·1 | 7·20 | 90·6 | 6·6 | 109·0 | 6·0 | 101·0 | 5·4 | 95·3 | 5·9 | 97·5 |
| 7·0 | 164·5 | 10·80 | 188·0 | 10·75 | 118·0 | 7·2 | 116·0 | 6·2 | 105·0 | 6·0 | 99·5 | 6·4 | 103·5 |
| 8·5 | 182·0 | — | — | — | — | 8·2 | 125·2 | 7·3 | 118·0 | 8·9 | 131·5 | 7·1 | 111·0 |
| 10·4 | 199·0 | — | — | — | — | 9·6 | 143·0 | 9·6 | 143·0 | — | — | 7·6 | 116·0 |
| 11·9 | 221·0 | — | — | — | — | 10·6 | 158·0 | 11·8 | 173·0 | — | — | 8·2 | 124·5 |
| — | — | — | — | — | — | 11·8 | 172·5 | — | — | — | — | 9·5 | 141·0 |
| — | — | — | — | — | — | — | — | — | — | — | — | 11·8 | 173·0 |

TABLE 3.

## DEPENDENCE OF WINDAGE ON THE SIZE OF THE CIRCULAR OPENING AT THE FRONT OF THE COWLING.

Engine mounted in front of "Camel" body. Airscrew mounted in front of and rotating at the same speed as the engine. Openings at the back of the cowling the same as in the machine.

$V$ = Forward speed of machine in feet per second. $Q$ = Windage torque of engine in lbs./ft.
$n$ = Rotational speed in revolutions per second. $\rho$ = mass density of air in slugs per cubic feet.
(= 0·00237 at a temperature of 15°·6 C. and a pressure of 760 mms.)

**The data of the table are for the full-sized engine.**

| With 29″ diameter opening.* | | With 22″·2 diameter opening. | | With 18″ diameter opening. | | With 12″ diameter opening. | | With 9″ diameter opening. | | With 5″·65 diameter opening. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Value of $V/n$. | Value of $Q/\rho n^2$. | Value of $V/n$. | Value of $Q/\rho n^2$. | Value of $V/n$. | Value of $Q/\rho n^2$. | Value of $V/n$. | Value of $Q/\rho n^2$. | Value of $V/n$. | Value of $Q/\rho n^2$. | Value of $V/n$. | Value of $Q/\rho n^2$. |
| 0·0 | 68·7 | 0·0 | 69·0 | 0·0 | 69·2 | 0·0 | 62·8 | 0·0 | 55·4 | 0·0 | 51·7 |
| 4·92 | 78·6 | 5·42 | 76·7 | 4·92 | 74·3 | 5·46 | 63·0 | 5·36 | 56·3 | 5·52 | 53·5 |
| 5·41 | 81·4 | 5·92 | 77·6 | 5·34 | 75·2 | 5·91 | 63·8 | 5·92 | 56·5 | 8·81 | 53·3 |
| 5·96 | 84·3 | 7·14 | 82·8 | 5·91 | 77·0 | 7·17 | 65·4 | 7·15 | 56·0 | 9·96 | 53·5 |
| 7·20 | 90·6 | 9·80 | 93·7 | 7·11 | 80·8 | 9·80 | 70·4 | 9·85 | 56·2 | — | — |
| 10·74 | 118·0 | 10·75 | 99·1 | 8·78 | 87·5 | 10·78 | 73·0 | 10·70 | 57·5 | — | — |
| — | — | — | — | 10·74 | 93·0 | — | — | — | — | — | — |

* This is the diameter of the opening in the cowling as fitted in the machine.

TABLE 4.

## EXPERIMENTS WITH A MODEL OF THE ENGINE TESTING TUNNEL OF THE R.A.E.

Tunnel mounted in place in front of the B.R. 1 engine.

$n$ = rotational speed of engine in revolutions per second.

$Q$ = windage torque of engine in lbs./ft.

$\rho$ = mass density of air in slugs per cubic foot.

( = 0·00237 at a temperature of 15°·6 C. and a pressure of 760 mms.)

$V = 0$. No airscrew.

The data of the table are for the full-sized engine.

| | Value of $Q/\rho n^2$. | Horsepower at ground level. | |
|---|---|---|---|
| | | $n$ = 1,150 r.p.m. | $n$ = 1,250 r.p.m. |
| (a) Without testing tunnel. Cowling as in practice with air ducts at the rear and at the bottom of the cowling. | 70·9 | 13·5 | 17·4 |
| (b) Without testing tunnel. Cowling completely enclosing the engine with the exception of the opening at the front of diameter 29 ins. No hole in the periphery of the cowling and blocked up at the back. | 31·5 | 6·0 | 7·8 |
| (c) With testing tunnel, but otherwise as in (b) above. | 32·5 | 6·2 | 8·0 |

TABLE 5.

## CALCULATIONS OF WINDAGE HORSEPOWER AT GROUND LEVEL FOR VARIOUS CONDITIONS OF FLIGHT.

Engine mounted in front of "Camel" body.

| | Forward speed V of machine zero. | | Climbing. | Horizontal Flight. |
|---|---|---|---|---|
| | | | V = 70 miles per hour. | V = 120 miles per hour. |
| | $n$ = 1,150 r.p.m. | $n$ = 1,250 r.p.m. | $n$ = 1,150 r.p.m. $\left(\frac{V}{n}\right) = 5{\cdot}35.$ | $n$ = 1,250 r.p.m. $\left(\frac{V}{n}\right) = 8{\cdot}45.$ |
| Engine with no cowling. Without airscrew. No wings on body. | 19·55 | 25·2 | 28·1 | 44·5 |
| Engine with no cowling. With airscrew running. With wings on body. | 18·95 | 24·4 | 23·4 | 38·8 |
| Engine with cowling. Without airscrew. With wings on body. | 13·8 | 17·8 | 18·1 | 31·6 |
| Engine with cowling. With airscrew running. With wings on body. | 13·1 | 16·9 | 15·4 | 24·5 |

# WINDAGE MEASUREMENTS OF B.R.1. ENGINE

## Two bladed airscrew A.D. 644

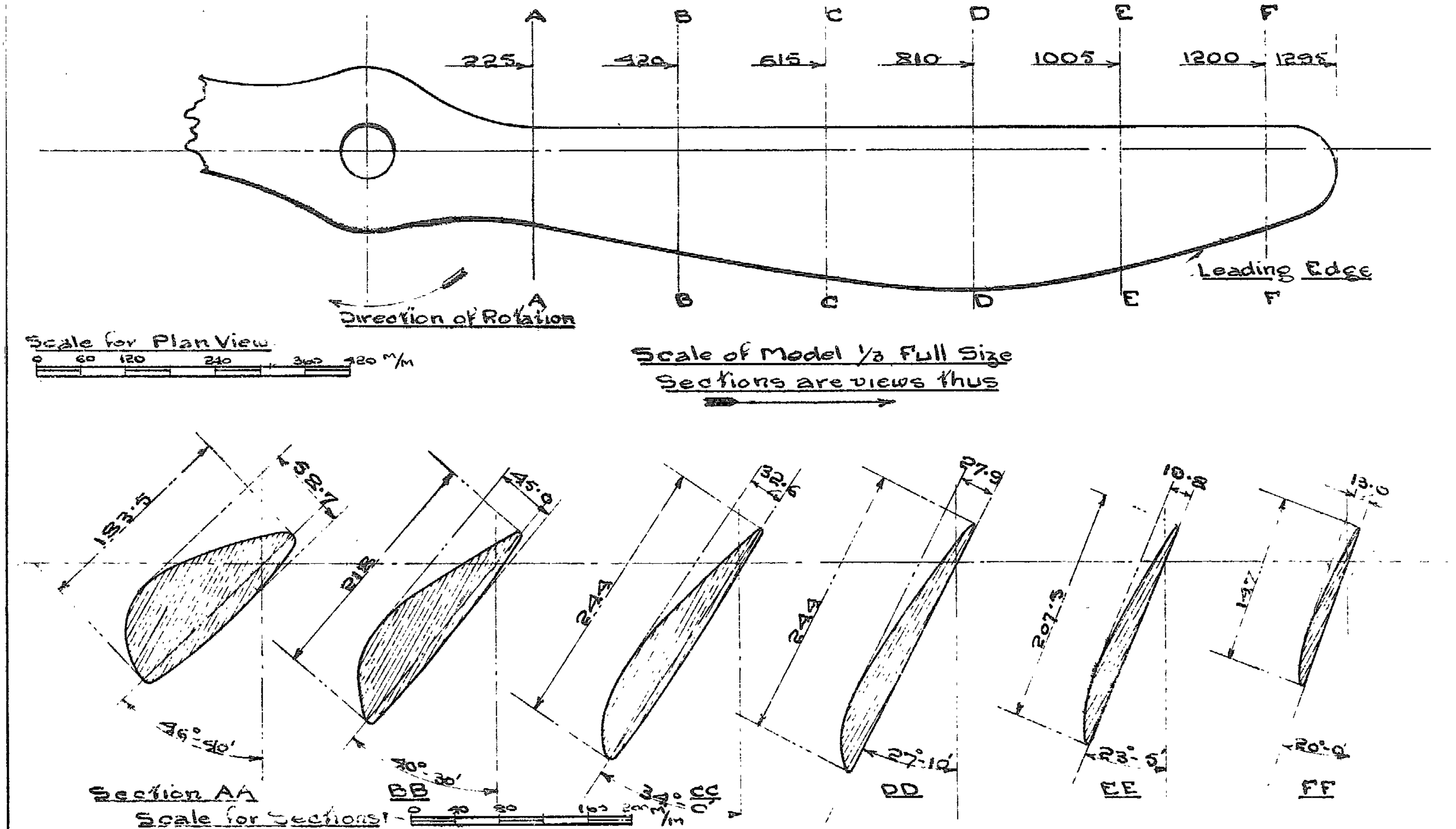



FIG. 1

# - WINDAGE MEASUREMENTS of B.R.1. ENGINE -

## Sketch of 1/3 scale model of Sopwith "Camel" Body

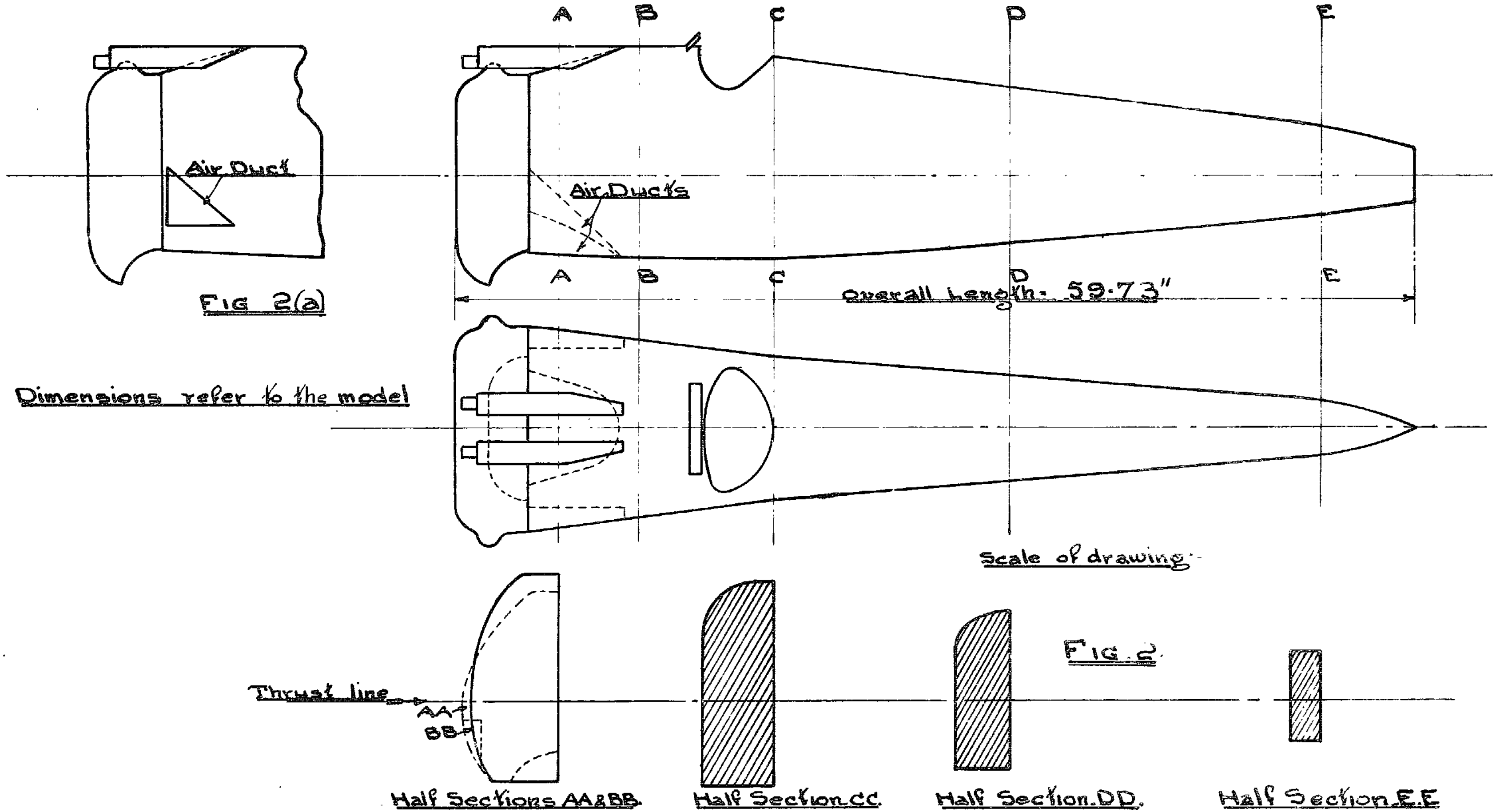
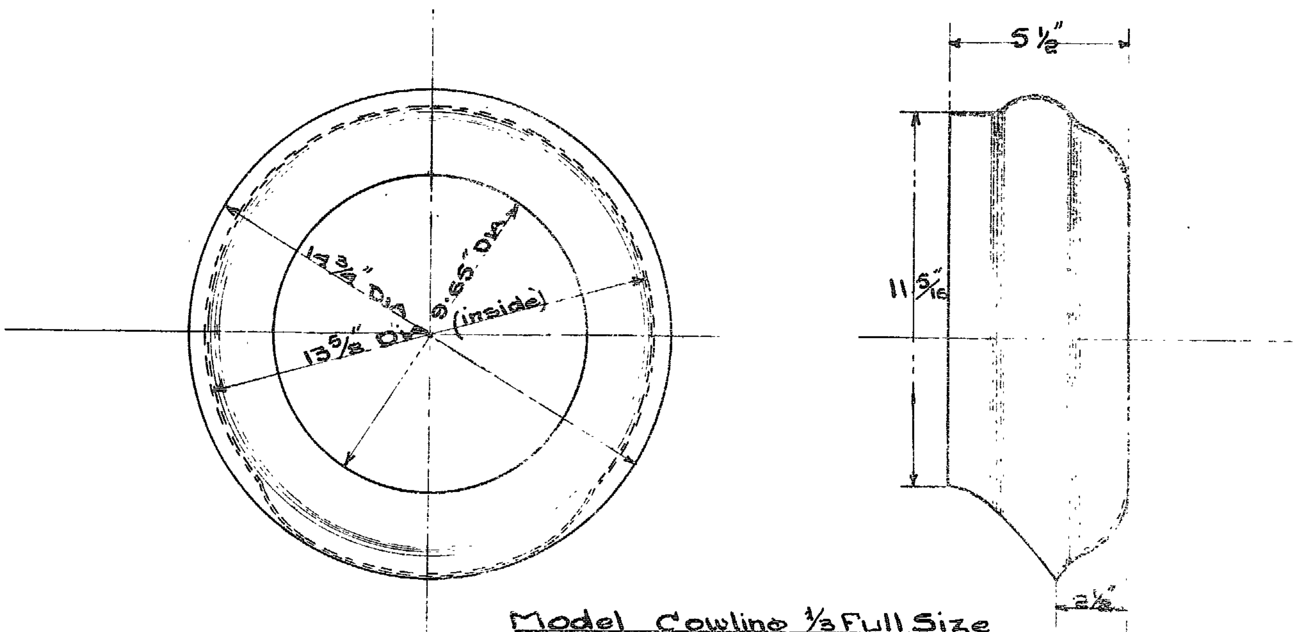



FIG 2(a)

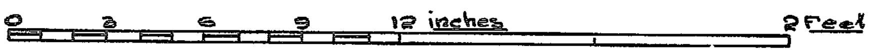
FIG. 2.

# — WINDAGE MEASUREMENTS OF B.R.1 ENGINE —

## Sketch of a model of the cowling mounted on the Sopwith Camel.




Model Cowling 1/3 Full Size



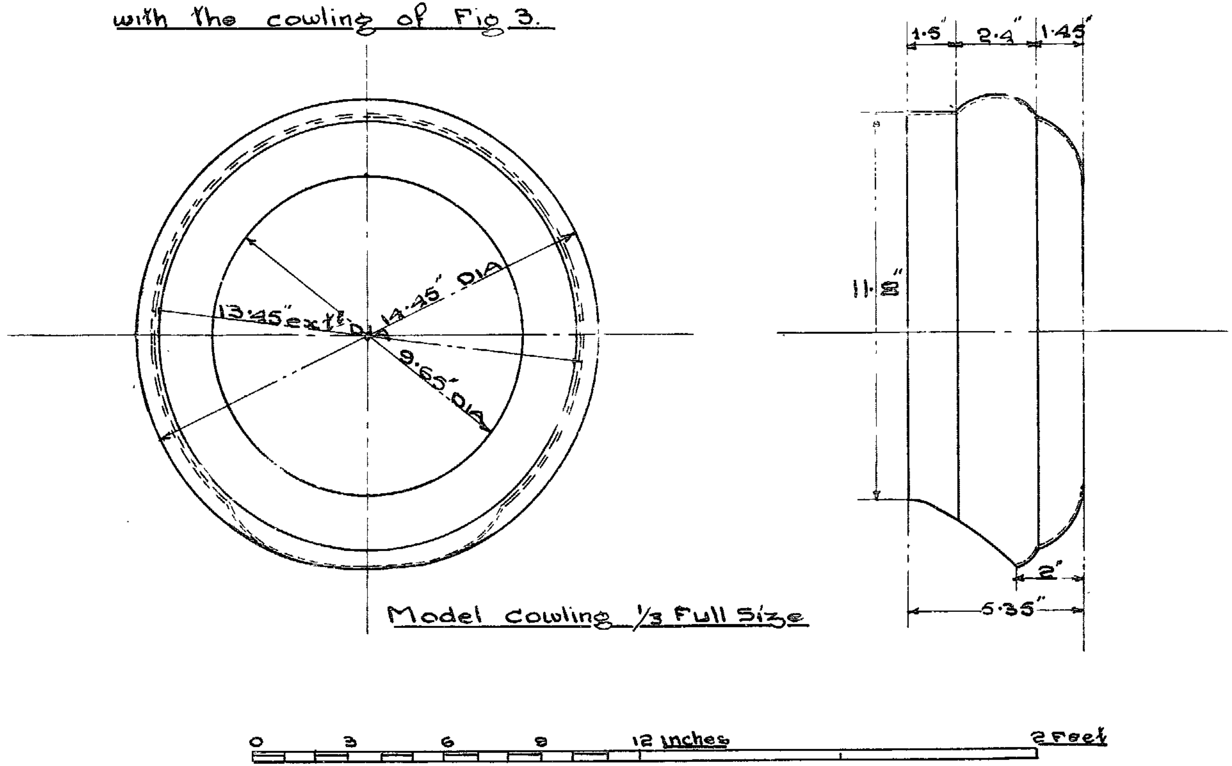

Scale for drawing:- 3" = 1 foot

FIG. 3.

# — WINDAGE MEASUREMENTS OF B.R.1. ENGINE —

## Sketch of model cowling used in preliminary experiments

Results of experiments with this cowling are given in the last columns of tables 1 & 2. All other experiments made with the cowling of Fig 3.




Model cowling 1/3 Full Size

REPORT No 448.

FIG 4.

REPORT N° 448.

# SKETCH OF MODEL OF R.A.F. ENGINE TESTING TUNNEL

## Scale of model = ⅓ Full Size

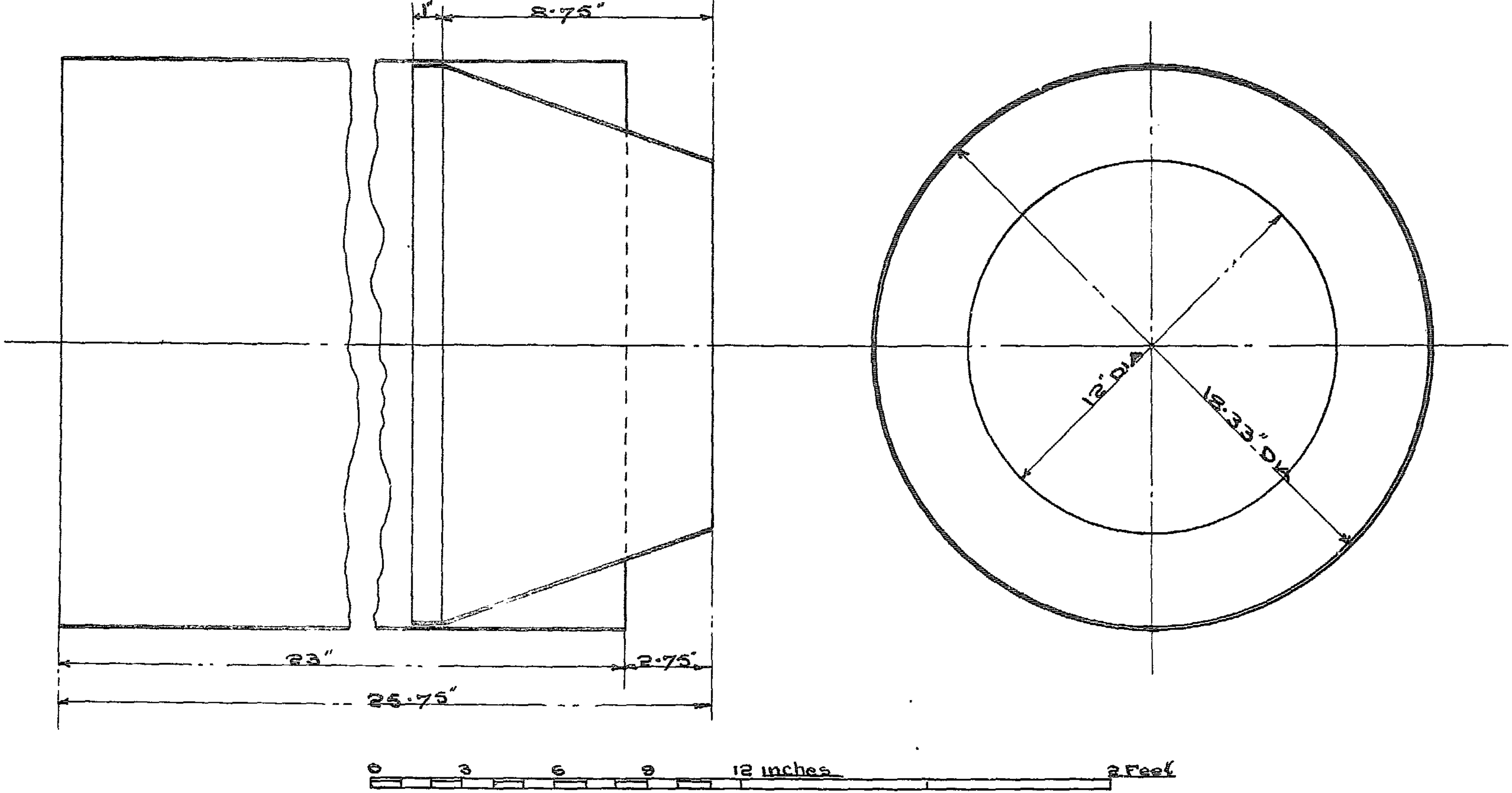
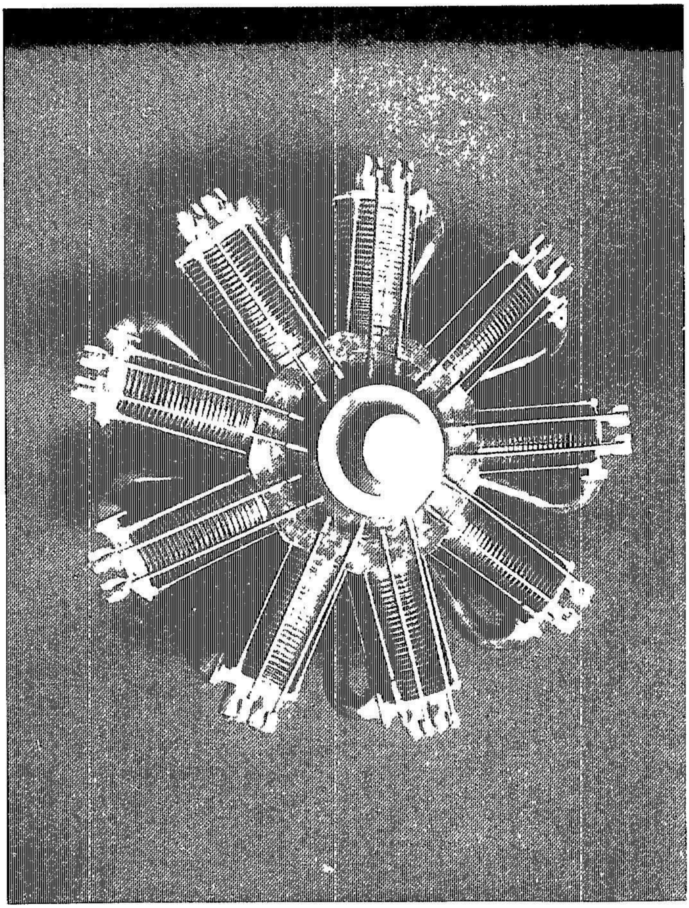



FIG 5.



Photograph of Model BR. 1 Engine.

REPORT No. 448.

WINDAGE MEASUREMENTS OF B.R.I. ENGINE.

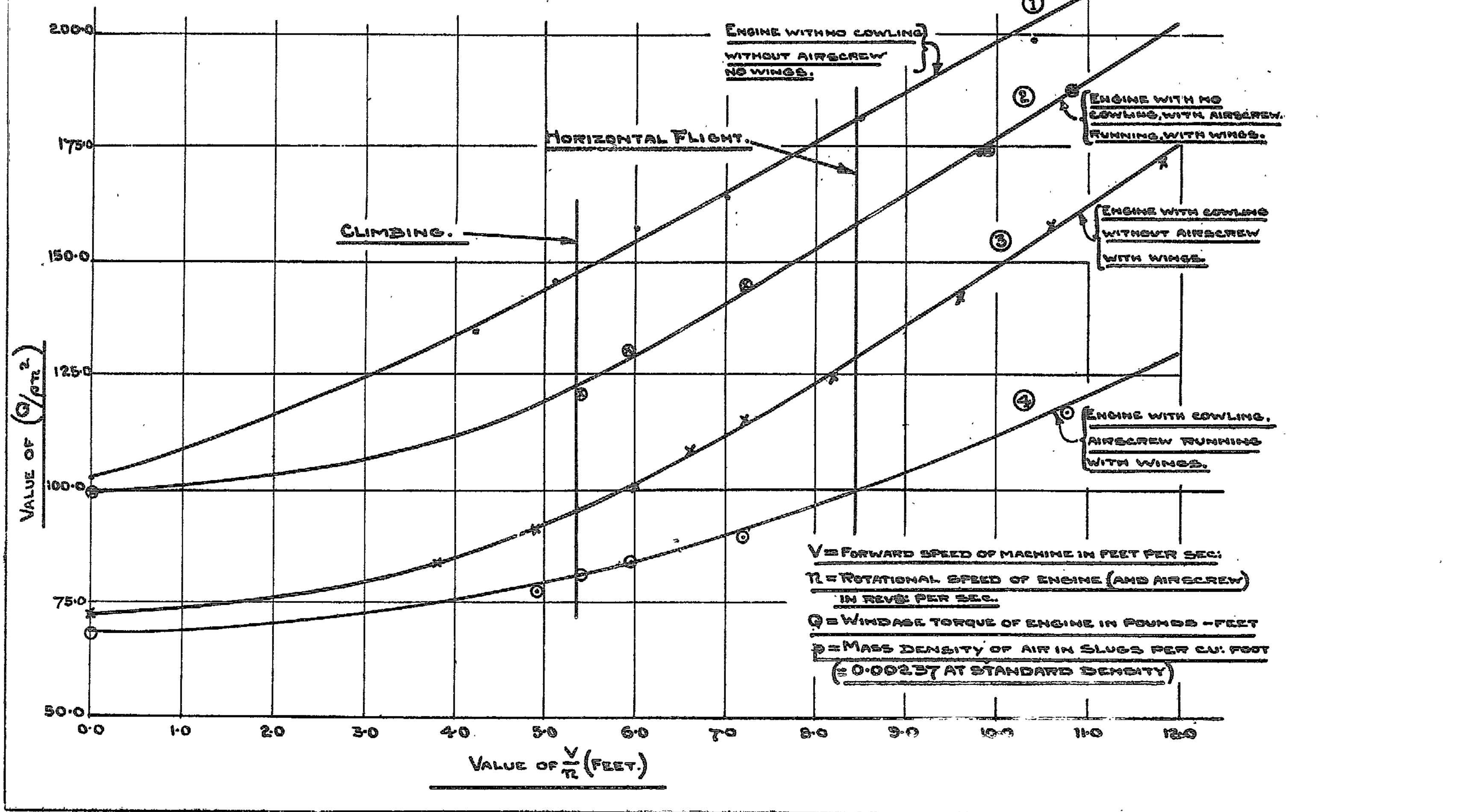
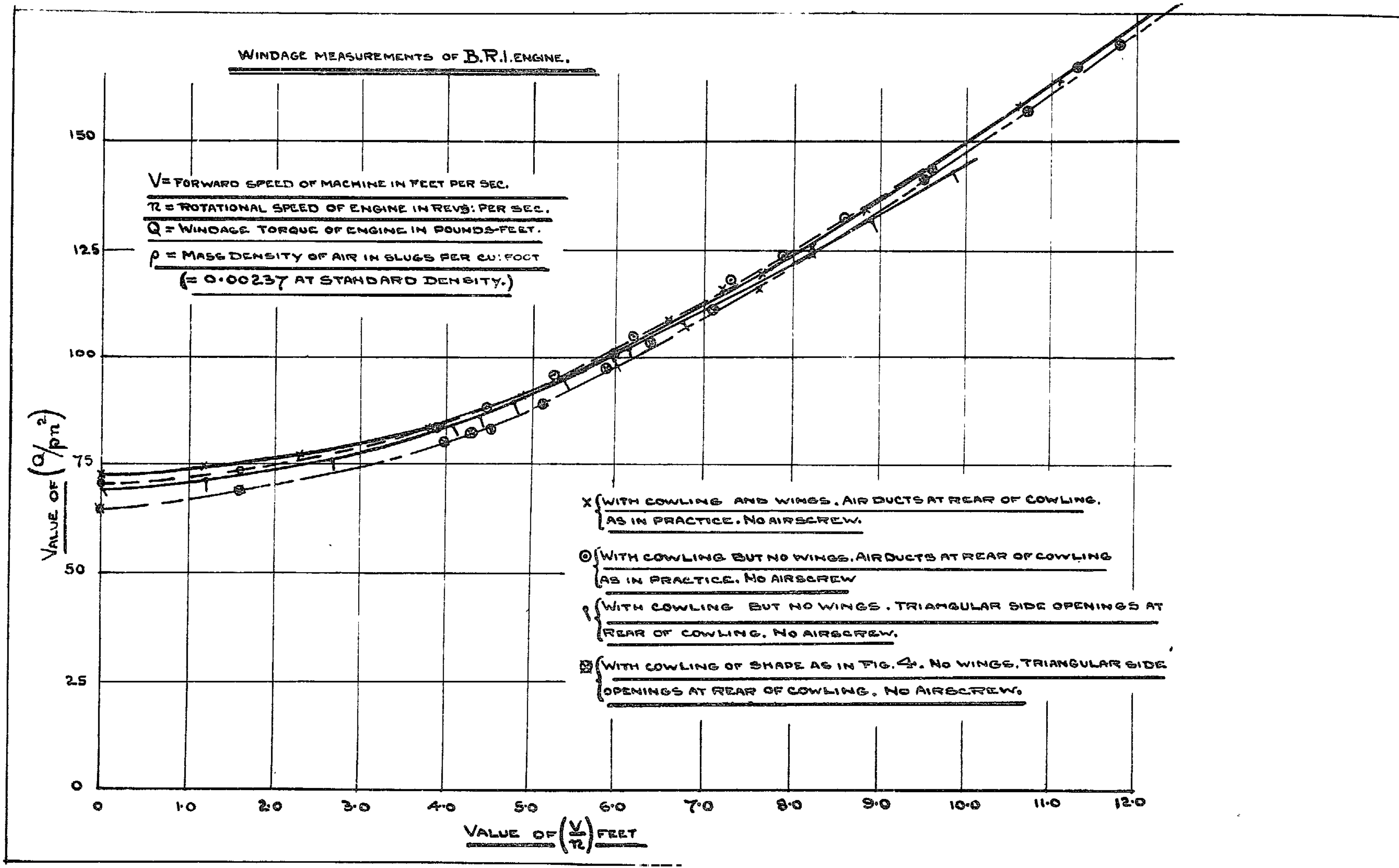



FIG 7.




REPORT No 448.

FIG 8

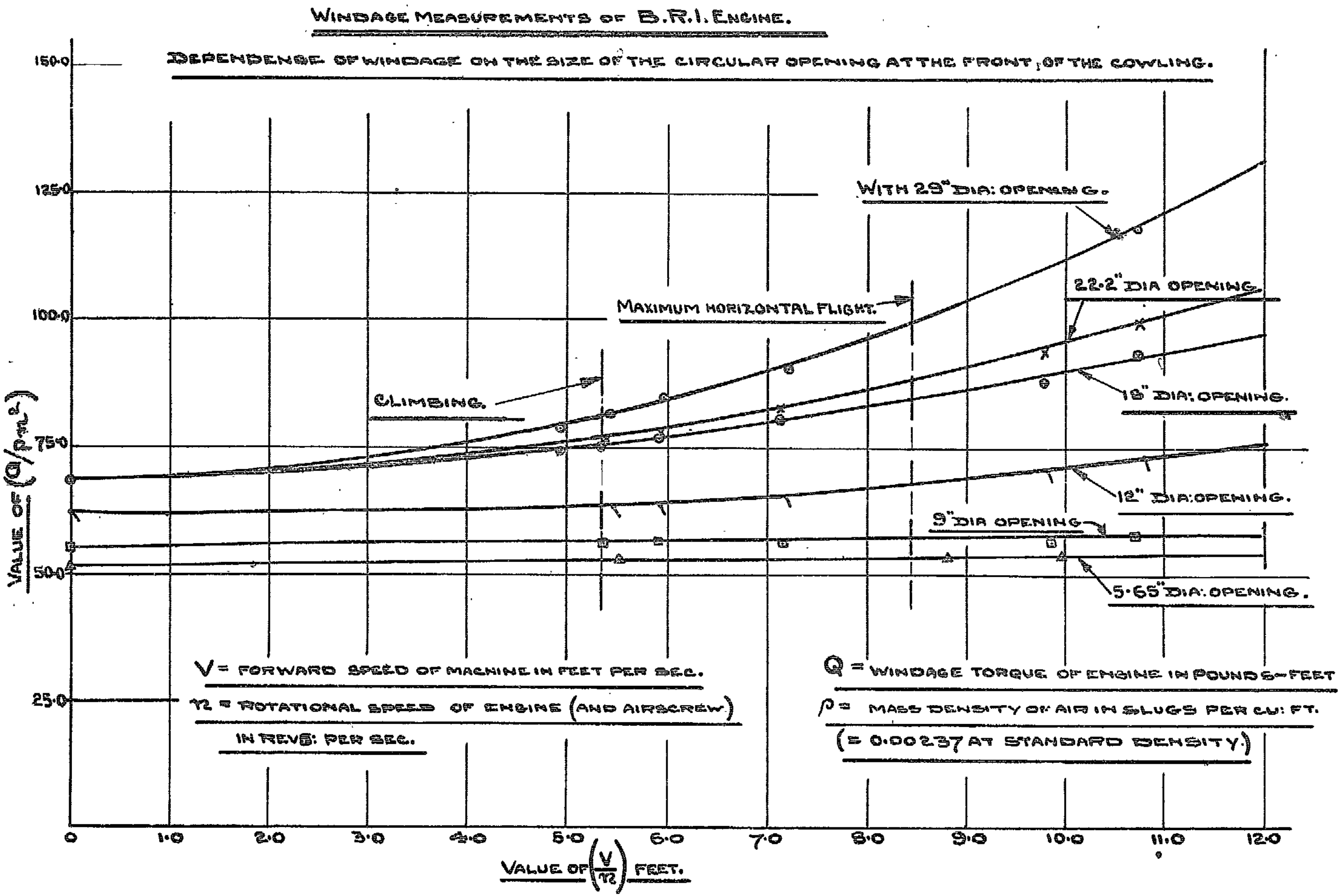

WINDAGE MEASUREMENTS OF B.R.I. ENGINE.
DEPENDENSE OF WINDAGE ON THE SIZE OF THE CIRCULAR OPENING AT THE FRONT OF THE COWLING.
WITH 29" DIA: OPENING.
22·2" DIA OPENING.
MAXIMUM HORIZONTAL FLIGHT.
CLIMBING.
18" DIA: OPENING.
12" DIA: OPENING.
9" DIA OPENING
5·65" DIA: OPENING.
V = FORWARD SPEED OF MACHINE IN FEET PER SEC.
n = ROTATIONAL SPEED OF ENGINE (AND AIRSCREW) IN REVS: PER SEC.
Q = WINDAGE TORQUE OF ENGINE IN POUNDS-FEET
ρ = MASS DENSITY OF AIR IN SLUGS PER CU: FT. (= 0.00237 AT STANDARD DENSITY.)
VALUE OF (Q/ρn²)
150·0
125·0
100·0
75·0
50·0
25·0
0
1·0
2·0
3·0
4·0
5·0
6·0
7·0
8·0
9·0
10·0
11·0
12·0
VALUE OF (V/n) FEET.

FIG 9.

REPORT No 448.

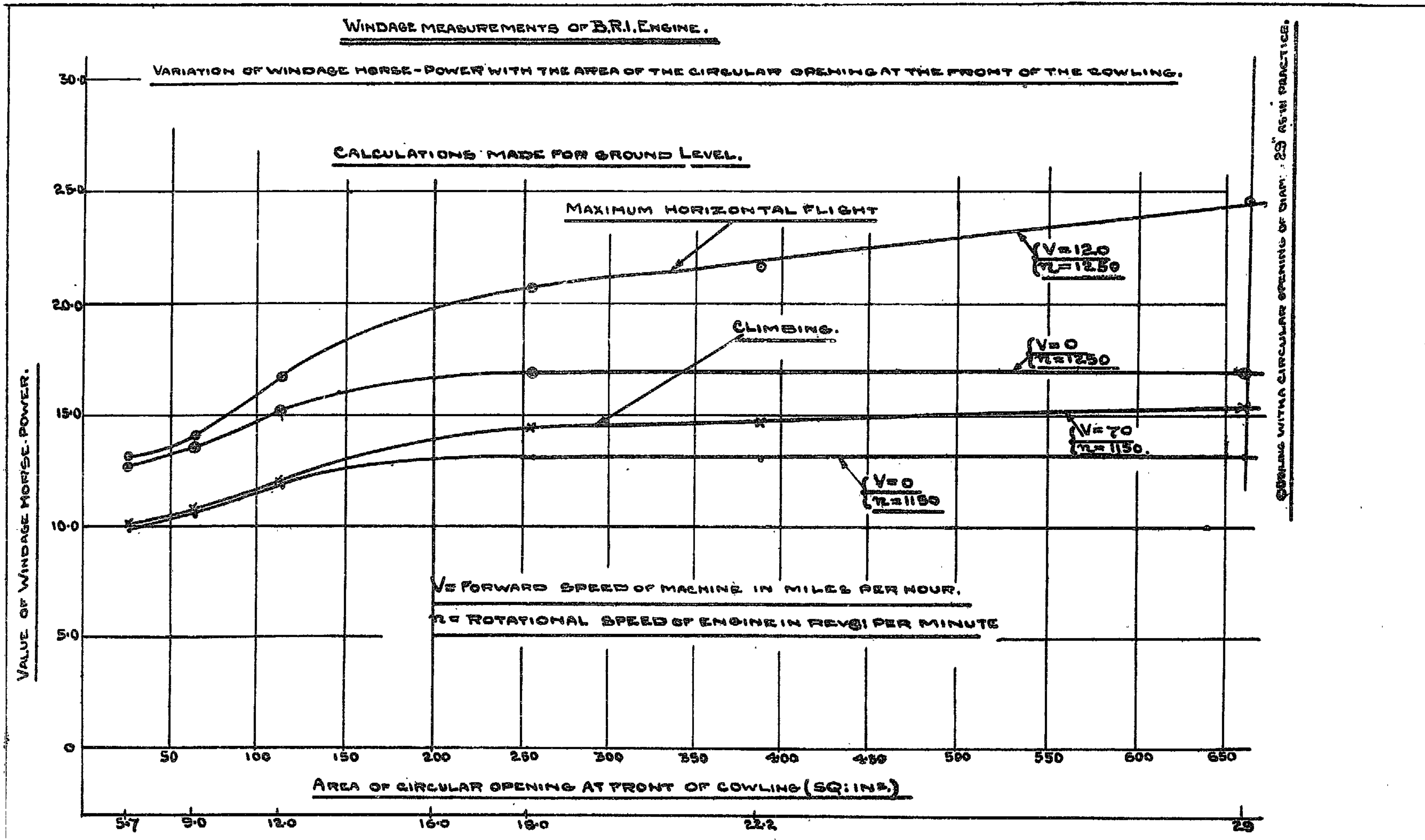



FIG. 10.

TABLE 6.

## VARIATION OF THE WINDAGE HORSEPOWER WITH THE AREA OF THE CIRCULAR OPENING AT THE FRONT OF THE COWLING.

Calculations made for the full-sized engine at the ground level.

Engine mounted in front of "Camel" body.

Airscrew mounted in front of and rotating at the same speed as the engine.

| Diameter of circular hole. | Area of circular hole. | Forward speed zero. | | Climbing. | Maximum horizontal flight. |
|---|---|---|---|---|---|
| | | Rotational speed $n = 1{,}150$ r.p.m. | Rotational speed $n = 1{,}250$ r.p.m. | Forward speed 70 m.p.h. Rotational speed = 1,150 r.p.m. | Forward speed 120 m.p.h. Rotational speed = 1,250 r.p.m. |
| Ins. | Sq. ins. | | | | |
| 29·0 | 660 | 13·1 | 16·9 | 15·4 | 24·5 |
| 22·2 | 387 | 13·1 | 16·9 | 14·7 | 21·6 |
| 18·0 | 255 | 13·1 | 16·9 | 14·4 | 20·7 |
| 12·0 | 113 | 11·9 | 15·2 | 12·1 | 16·7 |
| 9·0 | 63·5 | 10·6 | 13·6 | 10·8 | 14·0 |
| 5·7 | 25·2 | 9·9 | 12·7 | 10·1 | 13·1 |