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THE AIR RESISTANCE OF RACING CYCLISTS

by

T. NONWEILER

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T. Nonweiler, B.Sc.

SUMMARY

Tests in a closed-section wind-tunnel on three different cyclists mounted on a racing bicycle are described, and figures quoted for the recorded air resistance. Some comments are also included on the implications of the results concerning the power-output of racing cyclists.

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1. Introduction

Interest recently displayed in the problem of human-powered flight has revealed the dearth of information which exists concerning the power attainable by a human-being. As a contribution to such limited data, which is of interest to physiologists, tests were undertaken to determine the air resistance of some amateur racing cyclists mounted on their bicycles in a closed section wind-tunnel. After describing the experimental method and the results obtained, we shall examine briefly the way in which such data determine the useful power-output of a cyclist.

2. Experimental Method

A stripped-down racing cycle, as used by one of the subjects tested, was suspended in the vertical centre plane of the closed working section of the tunnel by wires attached to an overhead balance. In addition, two heavy weights were hung at the end of wires passing through the floor of the tunnel, and attached to the wheel axles, so as to stabilise the bicycle. This was necessary of course as no part of the machine could contact the floor of the tunnel if a true balance reading of air drag were to be obtained.

The subjects to be tested mounted the cycle, and the tunnel was switched on to provide air streams of various speeds between 40 and 55 ft./sec. It did not prove practical to allow the subjects to pedal whilst the drag was recorded, as even if they remained deliberately 'at rest', their movement and that of the bicycle was enough to make it difficult to obtain a steady reading from the drag balance. Nor was it practical to conduct tests with the cycle yawed to the wind direction.

Figure 1 is a drawing of the bicycle rigged in the tunnel, with a subject mounted on it, whose dimensions correspond with those of 'Subject B' of this report.

Figure 2 consists of photographs further illustrating the rig.

3. Subjects Tested and their Posture

Three subjects were tested, known hereafter as 'A', 'B' and 'C' who are amateur members of a local cycling club. In view of the difficulty of defining accurately the dimensions and posture of a human subject, only the barest details relevant to this subject will be given. Indeed, it seems doubtful whether any use would be served by trying to do more than this.

The approximate height and weights of the subjects are as follows:

'A' :	height	5ft.7½in.;	weight	144lb.
'B' :	'	5ft.10½in.;	'	150lb.
'C' :	'	6ft.0½in.;	'	179lb.

Unless otherwise stated they wore singlets, shorts and special shoes as normally used by racing cyclists. Subject 'B' (see figure 1) may be regarded as corresponding closely in most vital statistics with a 'standard' man as defined by the well-known surveys.

Two different positions were adopted in the tests by each subject, which are posed and defined in most essentials by subject 'A' in fig. 3; these will hereafter be termed the 'racing' and 'touring' positions. No more upright position than the latter (figure 3b) could be adopted owing to the proximity of the tunnel roof.

4. Accuracy of Results and Corrections Applied

Only figures for air resistance were measured: owing to the unsteadiness of the subject already referred to it would be impossible to expect that the drag data could be read from the balance recorder with an accuracy of any more than about ± 1 oz. (in a total varying between 6lb. and 17lb.) Calibration of the tunnel balance in this range suggested errors due to non-linearity in response and hysterisis effects in the recording mechanism of the same magnitude. Further there was a tendency for the bicycle sometimes suddenly to yaw a little, so that some of the results may suffer in this respect. Again of course it was impossible to guarantee that the subjects posture was always identical as the tunnel speed was changed. Repeated tests on subject 'A' suggested that the overall accuracy of drag measurement was about ± 3 per cent.

Corrections were applied for solid blockage using the expression:[1]

$$\frac{\text{effective increase in speed}}{\text{tunnel speed}} = \frac{0.65\ (\text{model volume})}{(\text{tunnel x-section area}) \times (\text{breadth})}$$

where the 'model volume' included an assessment of the subjects volume by assuming his specific gravity was unity. The wake blockage was assessed by the formula:[2]

$$\frac{\text{effective increase in speed}}{\text{tunnel speed}} = \frac{1}{4}\ \frac{\text{drag area}}{\text{tunnel x-section area}}$$

Typically solid blockage accounted for a 0.4 per cent increase in effective speed, and wake blockage for a 2 per cent increase. The tare drag of the supporting wires was measured independently by separate experiment and formed about 4 per cent of the total.

It will be apparent that these corrections provide a means of converting the data into those relevant to the 'model' in mid-air. No effort has been made to allow for the 'ground effect' which would exist in practice: it is considered that it is likely to be negligible.

5. Discussion of Results

The air resistance of the subjects in the 'touring' and 'racing' positions is detailed in Tables I and II.

TABLE I

Resistance in the Touring Position

Subject 'A'	Speed:	35.5ft./sec.	Drag area:	4.03sq.ft.
		46.6ft./sec.		4.00sq.ft.
Subject 'B'		33.9ft./sec.		4.02sq.ft.
		41.8ft./sec.		3.96sq.ft.
		44.9ft./sec.		3.90sq.ft.
Subject 'C'		37.2ft./sec.		3.91sq.ft.
		47.8ft./sec.		3.94sq.ft.

TABLE II

Resistance in the Racing Position

Subject 'A'	Speed:	39.2ft./sec.	Drag area:	3.17sq.ft.
		43.9ft./sec.		3.16sq.ft.
		47.4ft./sec.		3.07sq.ft.
		50.2ft./sec.		3.17sq.ft.
		53.3ft./sec.		3.25sq.ft.
		54.1ft./sec.		3.05sq.ft.
Subject 'B'		39.3ft./sec.		3.39sq.ft.
		45.8ft./sec.		3.33sq.ft.
		53.3ft./sec.		3.34sq.ft.
Subject 'C'		38.9ft./sec.		3.50sq.ft.
		48.1ft./sec.		3.48sq.ft.

The term 'drag area' used here refers to the quotient (drag/dynamic head)*; this concept is obviously to be preferred as no easy reference area for the formation of coefficients is available. (As a matter of interest, the frontal area of subject 'B' was estimated as 3.6sq.ft. in the racing position, so that his drag coefficient based on this area would be about 0.93).

* As this report may be used by those unacquainted with aerodynamic terminology, it should be pointed out that the dynamic head is defined as $\frac{1}{2}\times$(density of the air)$\times$(speed)^2. Under standard sea-level conditions this equals $25.6(V/100)^2$ lb./sq.ft., where V is in m.p.h. Thus drag = $0.00256\,V^2 \times$(drag area) lb.

The results tabulated above show that in the 'touring position' all subjects had (surprisingly) about the same drag, but that in the 'racing position' there is some positive correlation with the size of the subject tested. The mean drag areas for the subjects are

A: 3.15sq.ft. ; B: 3.35sq.ft.; C: 3.50sq.ft.,

A being the shortest and lightest subject, and C the tallest and heaviest of those tested. These data reveal a variation of $\pm$ 5 per cent about the figure of 3.33 sq.ft., whereas for example the height of the three subjects varied $\pm 3\frac{1}{2}$ per cent about a central figure. The lack of similar variation in the figures relating to the more upright 'touring' position probably results from the constraint exercised by the proximity of the tunnel roof in taking up of this position. There is apparently no significant variation of drag area with speed (i.e. the air resistance varies directly with the square of the speed) much as one might anticipate.

One or two other test results of interest may be quoted. The 'drag area' of the bicycle without cyclist was measured as 1 sq.ft., which is remarkable high. Of course it cannot be assumed that the air pressure on the cyclist provided only the extra 2 sq.ft. or so of drag area, because his presence would shroud part of the bike structure.

In another test the subject 'A' was clothed in jacket and flannel trousers: his drag area in the racing position then increased by 30 per cent to 4.09sq.ft. Subject 'B' experimented with various positions, unusual for him, and one of these (photographed in fig. 2c) yielded a drag area 0.18sq.ft. (5 per cent) lower than that of his normal racing position. The elbows were kept closer in and the head lower in this attitude. However similar modifications by subject 'A' resulted in an increased drag. Time did not allow variations of saddle and handlebar position to be tried, and of course it is not known in what way these modifications in posture affect the efficiency of muscular operation.

Finally it is worth pointing out that side forces and yawing moments were recorded by the balance, though no record of these was taken. The lift force was always negligible. So far as was possible the bicycle was maintained in an attitude facing the oncoming wind, so these side forces presumably arise from the asymmetric leg position. Aerodynamically speaking, the 'model' even with the physical constraint supplied by the rig, had poor stability characteristics in yaw, and this contributed sometimes to the difficulty of steadying the balance readings. This fact however would not seem to have any practical significance.

6. Application of Data to deduce the Power of a Cyclist

Any applications of the data to estimate the useful power supplied by a cyclist are fraught with difficulty owing to the fact that whilst cycling a uniform speed is not preserved, the relative wind speed and direction is continually changing and the ground surface is not level. However, as most speed trials or distance races are conducted on a closed course it is permissible to assume that, on the average, these variations are unimportant; if anything it is not difficult to persuade oneself that their neglect will underestimate the average power output (defined as total work done ÷ time). Thus, figures for an 'average' power based on that needed to maintain the average speed in still air on level ground are not without interest or value. To calculate these a figure of 0.006 was used as a coefficient of friction (to include rolling and mechanical resistance), on the basis of information kindly supplied by Raleigh Industries Ltd.

The average powers attained for example by subject 'B' can in this way readily be deduced from his speeds over various distances, and his 'speed versus power' characteristics are shown in fig. 4. His best results on road races are given below in Table III: it is only fair to point out that he would not mind being classified as a good amateur middle-distance racing cyclist, without being perhaps an exceptional one.

TABLE III

Inferred 'average' power of Subject 'B'

Distance	Time			Mean Speed	Average power needed to overcome Friction	Air Drag	Total Resistance
miles	hrs.	mins.	secs.	m.p.h.	h.p.	h.p.	h.p.
10		23	17	25.72	0.062	0.389	0.451
25		59	52	25.05	0.060	0.351	0.411
30	1	14	15	24.24	0.058	0.318	0.376
50	2	7	12	23.43	0.056	0.294	0.350
100	4	30	53	22.15	0.053	0.248	0.301

In appreciating these power levels, it is interesting to note that climbing two 8in. stairs a second corresponds approximately to a useful output of about 0.35 h.p. As would be expected there is a steady drop in average power level with duration of effort.

These figures should be compared with the following list of the highest powers recorded in bicycle ergometer tests on trained cyclists during physiological experiments; the list has been composed by Dr. D.R. Wilkie of the University College, London, Dept. of Physiology, after examination of many references.*

TABLE IV

Highest Powers recorded in Ergometer Tests

Duration of effort, mins.	1	2	5	10	30	60	270
Highest recorded figure for average power } H.P.	0.54	0.47	0.41	0.38	0.34	0.28	0.19

These suggest not only lower powers but a more rapid dimunition of power with duration of effort; for a duration of $\frac{1}{2}$-hour the figure (from Table III) for subject 'B' is 30 per cent higher, and at the longest duration of effort (3 hours) it would be at least 75 per cent higher, than the data of the ergometer tests. There may well be many good reasons to explain this disparity, but it is important to note that it exists: no doubt the suitabilityof the posture of the subject tested on the laboratory machine, and his incentive for extreme effort, affect the answer. Moreover there would undoubtedly be a considerable difference between the performance of any one subject and another - even assuming both were trained cyclists, - and also for the same subject from one day to the next.

It is amusing to speculate that if subject 'B' could reach speeds corresponding to the record achievements at the distances quoted in Table III, his power output would have to be increased by at least 25 per cent (and by 50 per cent at the two extremes of distance quoted). Bearing in mind that he is a man of average size, and that changes in the essential racing posture have been found to have only a relatively small effect on the air resistance to be overcome, it is probable that this gives a fair idea of the actual power attainments of the record breakers. A tentative assessment of these attainments in shorter distance races is given, on this basis, in fig. 5.

* It is understood much higher powers have been recorded by professional cyclists working on ergometers in experiments conducted by bicycle manufacturers. These figures are not however published.

7. Conclusions

(i) A method of evaluating the drag of a cyclist on a bicycle has been evolved which gave results repeatable within ± 3 per cent.

(ii) The drag is found to vary as $(\text{speed})^2$, and to be only slightly influenced by the size of the subject and his posture in the generally adopted racing position.

(iii) The drag of the bicycle itself was recorded as about 30 per cent of the total recorded when mounted by a cyclist.

(iv) The results imply that road cyclists generate considerably higher powers than have been recorded by ergometer tests in physiological laboratories.

Acknowledgements

The subjects of these tests were Messrs. M. Buck, B. Fletcher, and M. Street of the St. Neots Cycling Club, whose enthusiastic cooperation in this work is most gratefully acknowledged. The unusual task of designing the rig for the bicycle in the tunnel was undertaken by Messrs. G. Holloway and S. Lilley.

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2. A. Thom — Blockage Corrections and Choking in the R.A.E. High Speed Tunnel. A.R.C., R. and M. No. 2033. (1943).

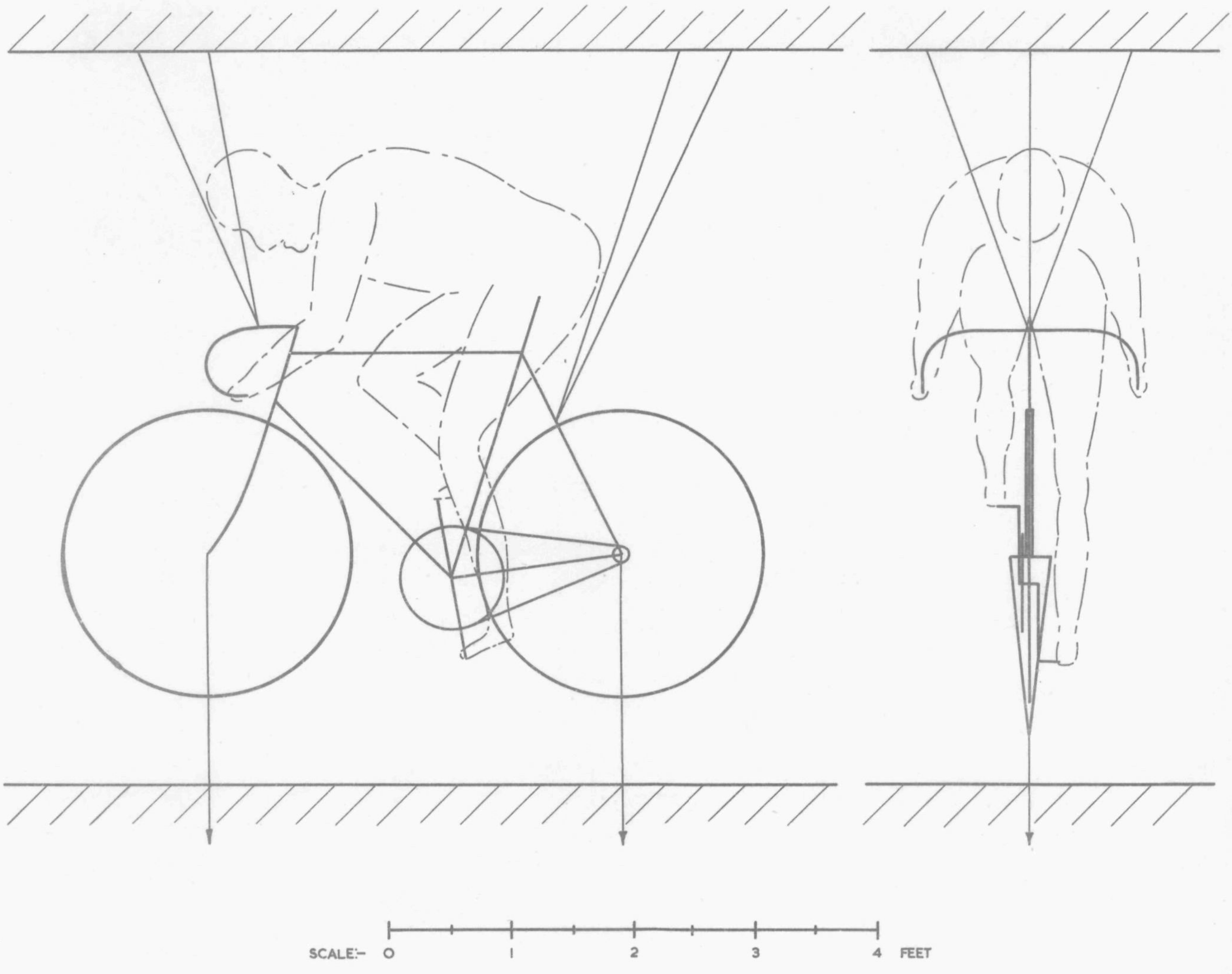
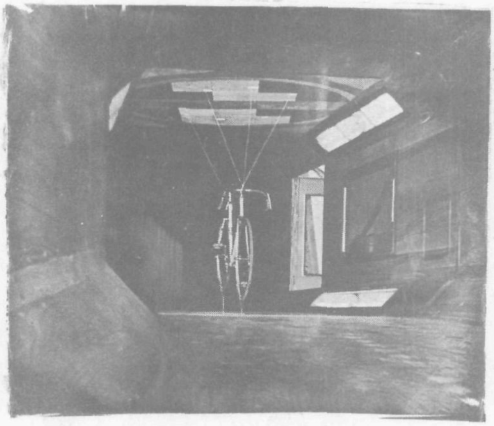


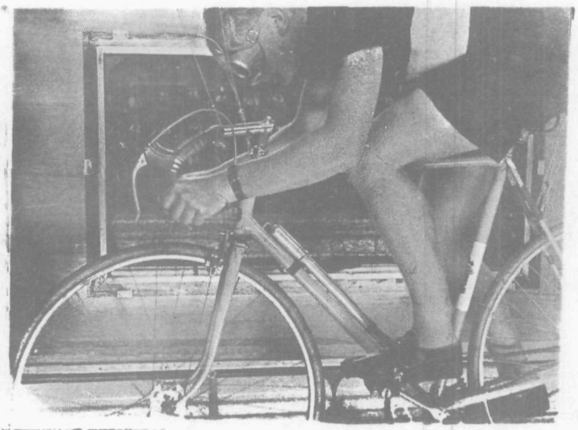
FIG. 1.

RIGGING OF BICYCLE IN TUNNEL SHOWING MAIN DIMENSIONS AND POSITION OF SUBJECT "B" WHEN MOUNTED.



a. Bicycle when rigged

b. Bicycle mounted by Subject "B"



c. View through tunnel window during test, illustrating a modified racing position of Subject "B"

FIG. 2. BICYCLE RIG

a. Racing Position

b. Touring Position

FIG. 3. RIDING POSITIONS

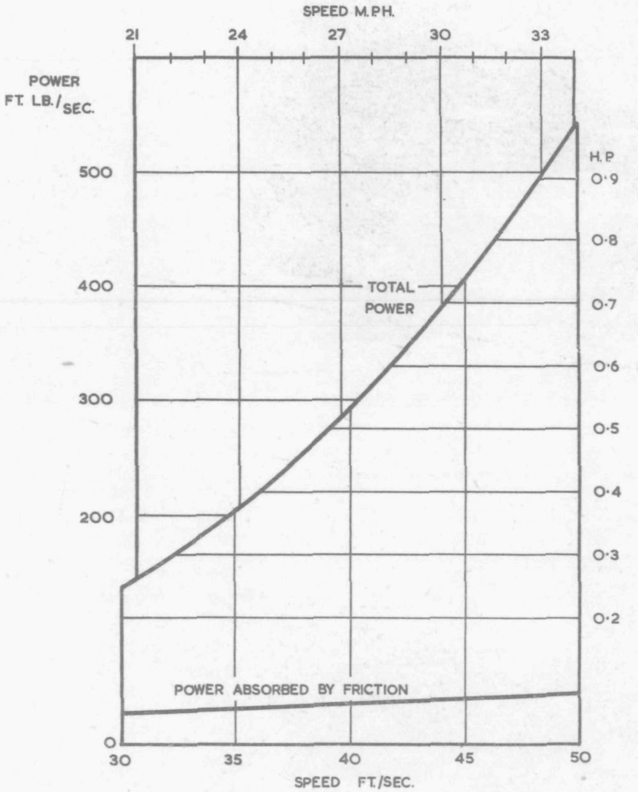


FIG. 4.

POWER NEEDED BY CYCLIST "B" TO MAINTAIN SPEED IN STILL AIR AND ON LEVEL SURFACE.

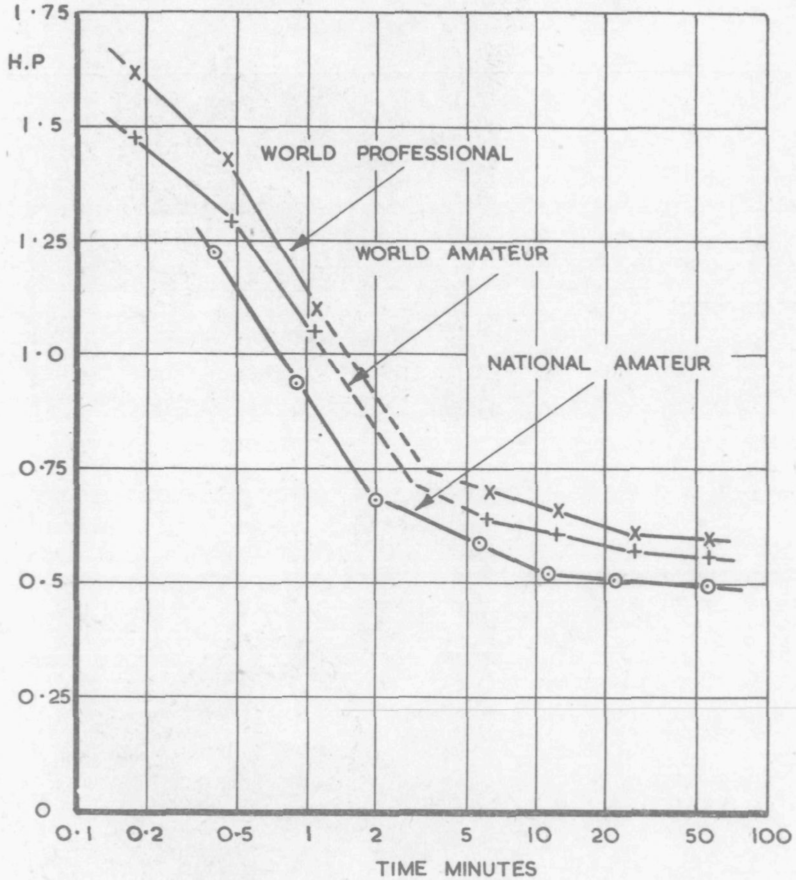


FIG. 5. POWER TO BE GENERATED BY AN AVERAGE CYCLIST IN EQUALLING UNPACED RECORDS ON CLOSED CIRCUIT