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International Railway Congress

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EXPRESS LOCOMOTIVES

By

J. A. F. ASPINALL C. E.

(18 Pages)

INTERNATIONAL RAILWAY CONGRESS
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Mr Gass from John A. F. Aspinall

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INTERNATIONAL RAILWAY CONGRESS

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QUESTION VI

EXPRESS LOCOMOTIVES

Type of engine most suitable for high speeds. The use of high pressure, and application of the compound principle. Improvements in distribution and balanced slide-valves. Engine-building regarded from the point of view of diminishing the strains on the permanent way. The effect from this latter point of view of the compound principle.

Contents :

REPORT, by Mr ASPINALL.

N. B. — Delegates are specially requested to bring with them to London all the reports which they will need for reference during the meeting, as the number printed is not sufficient to admit of extra copies being distributed.

Copy supplied to

Mr.

delegate of

REPORT

By John A. F. ASPINALL

CHIEF MECHANICAL ENGINEER LANCASHIRE AND YORKSHIRE RAILWAY

CONTENTS :

Type of engine most suitable for high speeds.

When originally asked to write a paper for the International Congress of 1895, the author was requested to take up the subject No. VI, on *Express locomotives,* the chief headings of which were to be the type of engines most suitable for high speeds; the use of high pressure and application of the compound principle; improvements in distribution and balance slide valves; engine building regarded from the point of view of diminishing the strain on the permanent way; the effect from this latter point of view, of the compound principle.

It has unfortunately, however, been quite impossible, owing to the very limited time given, to follow out this programme in its entirety, and practically, the following data represent the result of the replies which the author has been able to obtain from engineers on the continent, in Great Britain, the United States and the colonies, which deal almost entirely with the leading dimensions of the engines which they use for express traffic, and do not go beyond the mere facts as to the construction of such engines as they use today. The paper will not, therefore, deal with the subjects mentioned in the original programme, except where information has been given which can be included within it. The author considers that by presenting the diagrams and dimensions of the locomotives in use on the many railways which are mentioned in the paper, he at once gives in a practical form the opinions of the leading engineers as to the best practice, and the type of engine most suitable for high speeds which depends almost entirely upon the nature of the road over which it has to perform its duty. If the road is of an easy and level nature, and the loads of the trains to be hauled, comparatively light, engines with single driving wheels are found to be most successful, owing to the fact that the adhesive power is not so important a factor, and the absence of coupling rods enables the engine to run with greater freedom. On the other hand, when the road is heavy, and of a sinuous nature, engines with coupled wheels having plenty of adhesion, and tractive force, are found to give the best results. The most important part of a high speed locomotive is its boiler capacity, for as the speed increases, so will the demand for steam, the distance travelled in a given time being greater, and the train resistance augmented, consequently larger cylinders are required, and, therefore, steam must be more rapidly provided.

The engine which finds most favour in Great Britain and America, is the four wheels coupled type, the leading end being carried on a four wheeled bogie. The bogie not only enables the engine to pass round curves easily, but also, owing to the longer wheel base, distributes sufficient weight at the greatest distance from the driving wheel. This tends to solidify the road and it is then in the best position to support the heavier weight carried by the driving and trailing wheels. In this type, the first thing to be considered, is the rigid wheel base, which should be as short as possible, for if this is too long, accidents may arise through broken coupling rods, caused by the severe strains to which they are subjected.

The maximum capacity of the locomotive boiler is nearly reached. In America, and on the continent, engines with much larger boilers can be constructed, than in England, owing to the greater limits of the bridges and platforms in the respective countries. The rigid wheel base practically determines the size of the firebox, because, longitudinally, it has to be placed between the axles, and transversely, between the main frames, the latter being placed at present, as far apart as the wheels will permit. In America, fireboxes have been made much larger by placing them above the frames and pitching the boilers very high, a practice, which, in this country, cannot be accomplished on account of our bridges. This method has the additional advantage of enabling the wheel base to be shortened.

The question as to what may in future be done in the way of an increase of speed on railways, is one which has received a great deal of attention from many railway authorities, and though, perhaps, the fastest running that we have heard of as yet, has been made upon the New-York Central Railroad, in America, it is a question whether such high rates of speed can be maintained upon the more crowded railways of England, upon which the average speeds are already very much faster than are found on the continental railways. On this subject of the increase in speed, and the difficulties connected therewith, three papers appeared in the March number of the *Scribner's Magazine*, in 1892, by well-known American authorities, in one of which, Mr. M. N. Forney pointed out that fast running is largely a question of steam production, and that the limits placed on the weight and dimensions of a locomotive, were difficult to get over; while the generally accepted rules of resistance to trains on a level track were such as to put almost insuperable difficulties in the way of any great increase of speed.

Mr. Theo. N. Ely, of the Pennsylvania Railroad, followed with a short paper, in which he, also, pointed out that the « measure of the speed and the capacity of a locomotive rests in the firebox » and then went on to say, with regard to the possibility of attaining an average speed of 100 miles an hour, that « first of all we must know how soon after receiving warning of danger, a train, running a mile in 36 seconds, can be stopped. It is estimated that, if running at 60 miles per hour, with the full braking weight of the train utilised, and the rails in the most favourable condition, this train could be brought to a full stop in 900 feet; at 80 miles per hour, in 1,600 feet; at 90 miles per hour, in 2,025 feet; and, finally, at 100 miles per hour, in 2,500 feet. These figures at once establish the fact, that under the best possible conditions, the track must be kept clear of all obstruction for at least 2,500 feet in advance of a train running at the highest limit; but we must estimate the clearance for the worst conditions such as slippery rails, foggy weather, and unfavourable grades. The personal equation of the engineman must also be considered in a train covering 145 feet each second. Would it, therefore, be too much to ask that the engineman receive his warning at least three quarters of a mile before he must halt? It is fair, therefore, we think, to rest the burden upon the transportation shoulders, and predict that with it, and it alone, lies the practical limit of the speed of railway trains drawn by steam locomotives. »

Mr. Ely has, undoubtedly, hit upon the most serious difficulty, when he thus points out that a very clear track is needed for such great increase of speeds; but, Mr. H. Walter Webb, in the third paper, follows on and tells us, that having acquired a clear track for a certain train they actually ran, from New York to East Buffalo, a distance of 436·3 miles in 439·5 minutes, and, dealing only with the higher speeds attained, he states that 151 miles were run at a rate varying from 65 to 70 miles per hour; and 37 miles were run at a rate varying from 70 to 78 miles per hour. It was for this road that the celebrated No. 999 engine, designed by Mr. William Buchanan, was built, and speeds much in excess of the maximum named have been actually attained in practice with this engine. A Statement supplied to the author by Mr. Buchanan mentions a run with this engine from New York to Buffalo, May 9th. 1893. The train consisted of 4 cars weighing with load 361,950 lbs , the engine and tender weighing 204,000 lbs., total 565,950 lbs. The *Engineer*, London, for March 7th. 1890, records a speed of 90 miles per hour, which was attained on the level with a compound engine built by the North Eastern Railway Company, hauling a train of 18 carriages, the gross weight of which was 310 tons.

Another American writer, however, Mr. David L. Barnes, in the June number of the *Engineering Magazine* 1894, speaking of very fast running, says that « High maximum speed is spectacular, but not practical, while a high average speed is a real necessity, and can be obtained. He states in a similar manner, to the authors previously mentioned, the absolute necessity for larger boiler capacity than we at present possess, and, further, that « High average speed on heavy grades is impossible within the limits of steam locomotive construction, » by the fact that a grade of 1 per cent demands about 1,500 additional horse power at 100 miles per hour, and 900 at 60 miles per hour. This shews how a light grade may increase considerably the demand on the locomotive boiler at high speed.

M. Du Bousquet, the President of the French Society of Civil Engineers, pointed out, in March 1894, that speeds of 75 miles per hour are attained daily on down grades by express trains in their ordinary running, thus shewing that high speeds are not dangerous. The reason why such speeds are not maintained on the level, is, he states, because the engines are not sufficiently powerful.

« The drawbar pull which would give a speed of 75 miles per hour on a down grade of 1 in 200, would only give a speed of 57 $^{1}/_{2}$ miles per hour on the level,

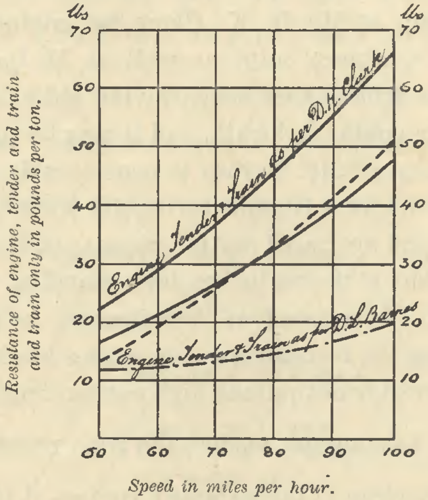


Fig. 1.

━━━━ Shews resistance of engine, tender and train as per Mr. D. K. Clark's formulae.

──── — of train only as per Mr. D. K. Clark's formulae.

– – – – – — — — M. Du Bousquet's experiments.

- - - - - - — of engine, tender and train as given by Mr D. L. Barnes.

and 31 $^{1}/_{4}$ miles per hour on an up grade of 1 in 200. To increase the average speed by a small amount, the power of the engine must be greater in proportion; thus, if 322 H. P. is sufficient to haul a train at 50 miles per hour up an incline of 1 in 200, 2,960 H. P. will be required to draw the same train up the grade at a speed of 125 miles per hour. In dealing with such high speeds, the weight of the engine per horse power generated, is of importance, as there is always a limit of speed beyond which the engine cannot draw itself, let alone a train as well. At present, French express locomotives weigh about 158 lbs. per indicated horse power when exerting their maximum effort. By an application of these figures, we find that to draw a train of 100 tons at a speed of 75 miles per hour, up an incline of 1 in 200, an engine would have to weigh 130 tons and generate 1,810 horse power. If the speed was increased to 87 miles per hour, on a similar incline, the engine would have to weigh 468 tons, and generate 6,532 horse power. »

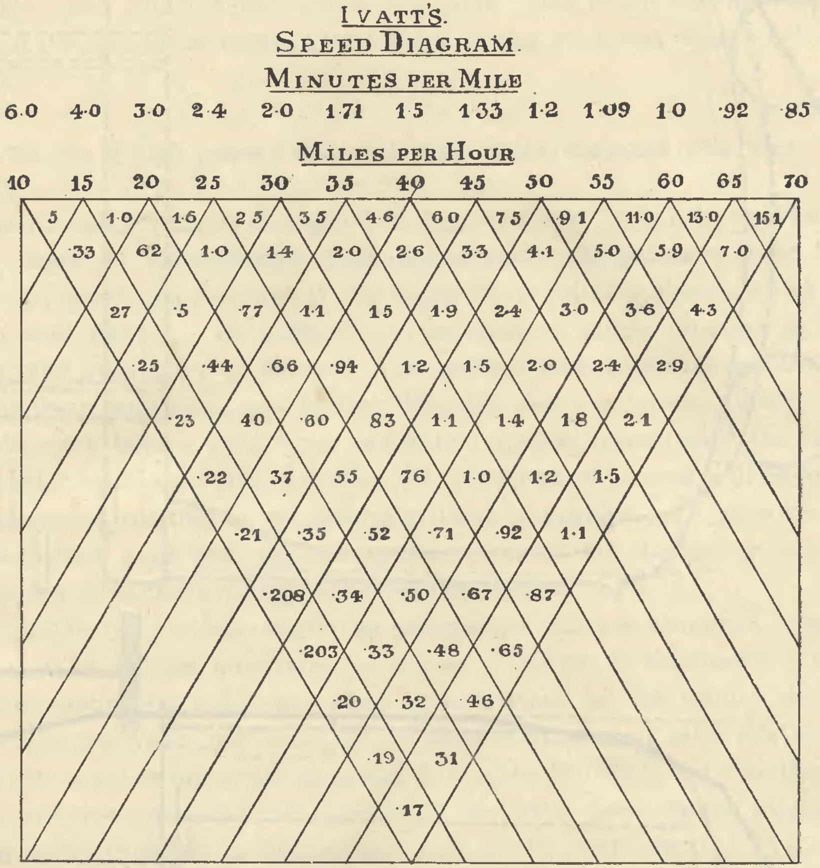
This consideration of high speeds reminds the author that Mr. D. L. Barnes, in his paper, already referred to, shewed the engine and train resistance to be much lower than generally supposed. The former diagram (fig. 1) illustrates the well-known formula of Mr. D. K. Clark for engine, tender, and train resistance, also train resistance only; as well as M. Du Bousquet's figures, which were taken from actual experiments by the aid of a dynamometer fixed on the coupling between engine and train, and it may be noted how very closely they agree, whereas that of Mr. Barnes is considerably lower for the total resistance. The latter diagram is plotted from the few tests that were made up to 90 miles per hour, and are based on the assumption that the bearings were warmed by running, but if the train has been standing for a long time, the resistance from starting to a speed of 30 miles per hour, would be greatly increased. In each case the resistance due to grades has been neglected.

The co-efficient is probably not quite so high as represented by Mr. D. K. Clark in his formulae $\frac{V^2}{171} + 8$ for engine, tender, and train resistance. If this formulae is applied to the American « Empire State Express » at 100 miles per hour, the total resistance becomes 66·5 × 283 tons = 18,800 lbs., but as the tractive force of the engine, No. 20, is only 13,399 lbs., and as probably it does not develope more than 1,200 to 1,400 horse power at its maximum effort, it points to the fact that Clark's and du Bousquet's figures are too high, but, at the same time, the author is of opinion that those of Barnes are too low.

The difficulty of making up any time lost by a train, which is booked to run high speeds, is very great indeed, and is, perhaps, better shewn by Ivatt's Speed Table (fig. 2) than in any other way.

As an example. If a train running at 65 miles per hour has lost a minute, it has to run 15 miles at 70 miles per hour in order to make up that minute, shewing prominently, what a great length of line must be run over in order to make up even so small an amount of time as one minute.

Having thus far considered the limitations fixed by speed, and upon the supposition that these difficulties have been surmounted, the most serious one of all



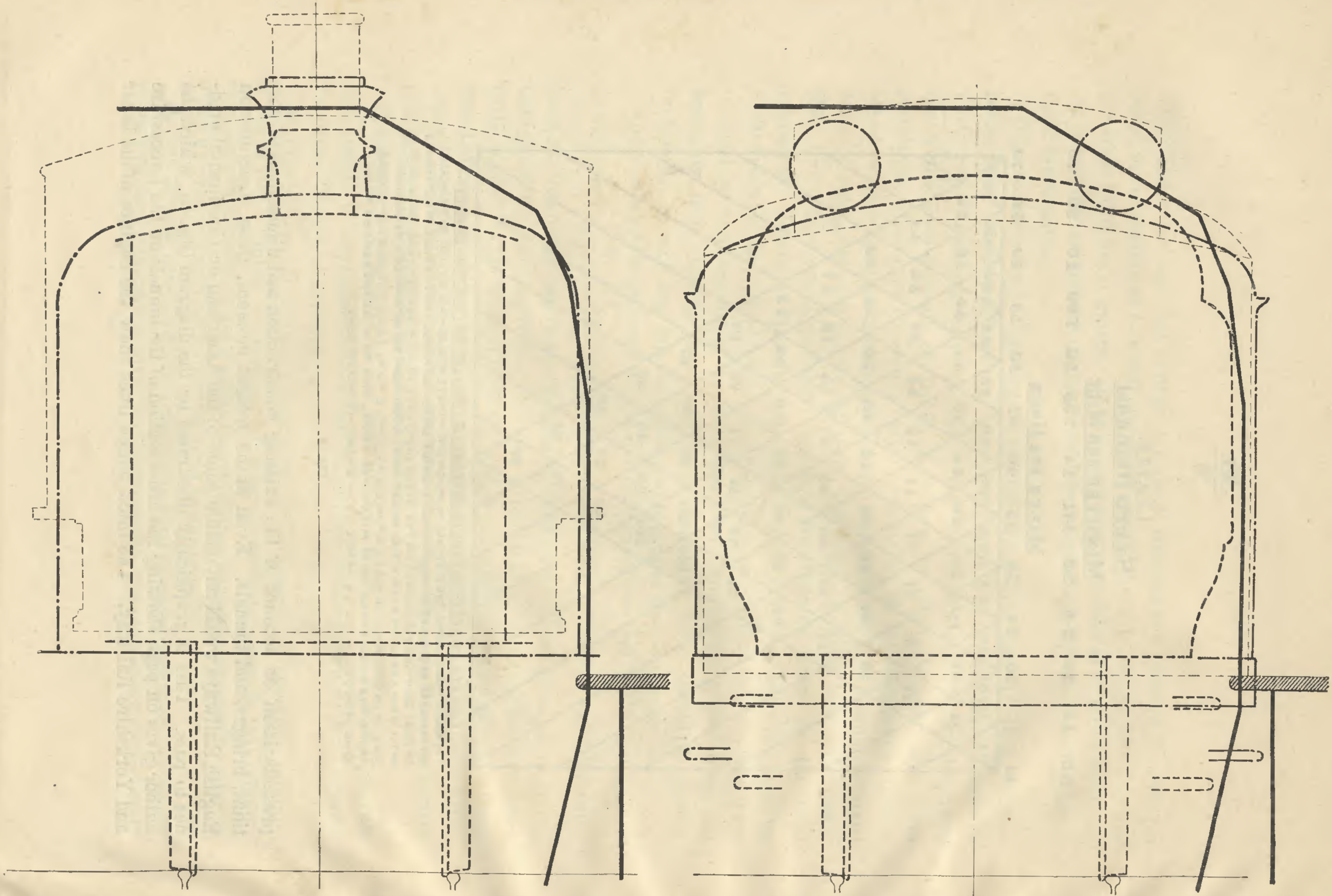
FIGURES IN SPACES DENOTE DISTANCES IN MILES OR FRACTION OF A MILE.

THE ABOVE TABLE SHOWS THE DISTANCE IN WHICH ONE MINUTE WILL BE MADE OR LOST BY AN INCREASE OR DECREASE OF 5 MILES PER HOUR IN THE AVERAGE SPEED. SUPPOSE THE AVERAGE SPEED REQUIRED IS TO BE 20 MILES PER HOUR, AND THE SPEED INCREASED TO 25 MILES PER HOUR, ONE MINUTE WILL BE MADE UP IN EVERY 1·6 MILES RUN; AND FROM 20 TO 30 MILES PER HOUR, ONE MINUTE WILL BE MADE UP IN EVERY 1 MILE RUN. TAKE THE EXTREME CASE, IF THE AVERAGE SPEED IS 10 MILES PER HOUR, AND THIS BE INCREASED TO 70, ONE MINUTE WILL BE MADE UP IN EVERY ·17 MILES RUN.

Fig. 2.

presents itself on account of the existing construction and dimensions of stations, bridges, and tunnels. Even at the present moment, these structures on English Railways would not enable some of the American or Continental engines to pass. This is graphically illustrated by the diagram (fig. 3), which the author gives on page shewing the cross section of the tunnels on the Lancashire and Yorkshire Railway. The thick dotted lines shew the engines of the latter

Diagram of minimum structure compared with English, Continental and American stock. (Fig. 3.



- - - - - - Denotes English locomotive stock. — — — — Denotes American locomotive stock.
-·—·—·— — Continental — ▬▬▬ — outline English minimum structure.

- - - - - - Denotes English carriage stock. — — — — Denotes American carriage stock.
—·—·—·— — Continental — ▬▬▬ — outline English minimum structure.

Company, round which there is ample margin of space, but, it will be observed that both the American engines, and those of the continent would not pass through.

The use of high pressure and application of the compound principle.

The compound principle, as applied to the locomotive, may now be taken as having passed the experimental stage, consequently, the author will not presume to lay before the members of this Congress its primary objects, which are now so well known. Its application has received much attention in this country, and even more so abroad. The systems now generally adopted are know by their exponents, viz : Mallet, Worsdell and von Borries, Webb, and Vauclain, each having two, three and four cylinders respectively, the latter being mostly used in the United States, and a description of each will be found in the statement relating to the various railway companies. A system known as the « Lindner » has been applied on the continent, but the author has not received any particulars of engines of this description.

The cylinder proportions should be so arranged that the combined effort is as continous as possible, otherwise the engine would not be balanced in a very important particular, and heavy shop repairs would be the result. As the cylinders in the Webb and Vauclain systems are equal upon each side of the engine, this is not so important as in the Mallet, the Worsdell and von Borries systems and the accumulated experience of the latter points to the volume of the low pressure being at least double that of the high pressure cylinder. A difficulty arises in the two cylinder system, from the fact that the least objectionable position for them is between the frames, and even this necessitates cutting the frame on the low pressure side. Another important matter, is the steam port area of the low pressure cylinder. In an ordinary locomotive, this is about ·10 of the piston area, and, if this proportion is carried out for a large cylinder, the result would be an unwieldy and heavy slide valve, consequently, these figures cannot be applied, and the ports are smaller, but the difficulty of steam admission is overcome by the use of the Allen or double ported valve, which gives approximately twice the amount of steam for a similar travel of an ordinary valve.

The greatest tractive force of a locomotive is generally required at starting, consequently, a special valve is provided to enable boiler steam to be admitted into the low pressure steam chest. This steam is reduced in pressure by wire drawing it through a small pipe, and relief valves are placed in connection with the cylinder and the steam chest to insure no excessive pressure. Many engineers consider that the action of this valve should be made quite independent of the driver lest he should be tempted to use it too often and endanger the economy of the engine. On the other hand rapidity at starting is gained if the driver can control the valve by hand. Another, and most important auxiliary, is what may be termed the intercepting valve, which should be so arranged, that the exhaust from each cylinder is independent, a point worthy of emphasis, as then, in case of failure to either cylinder, the engine can work itself home.

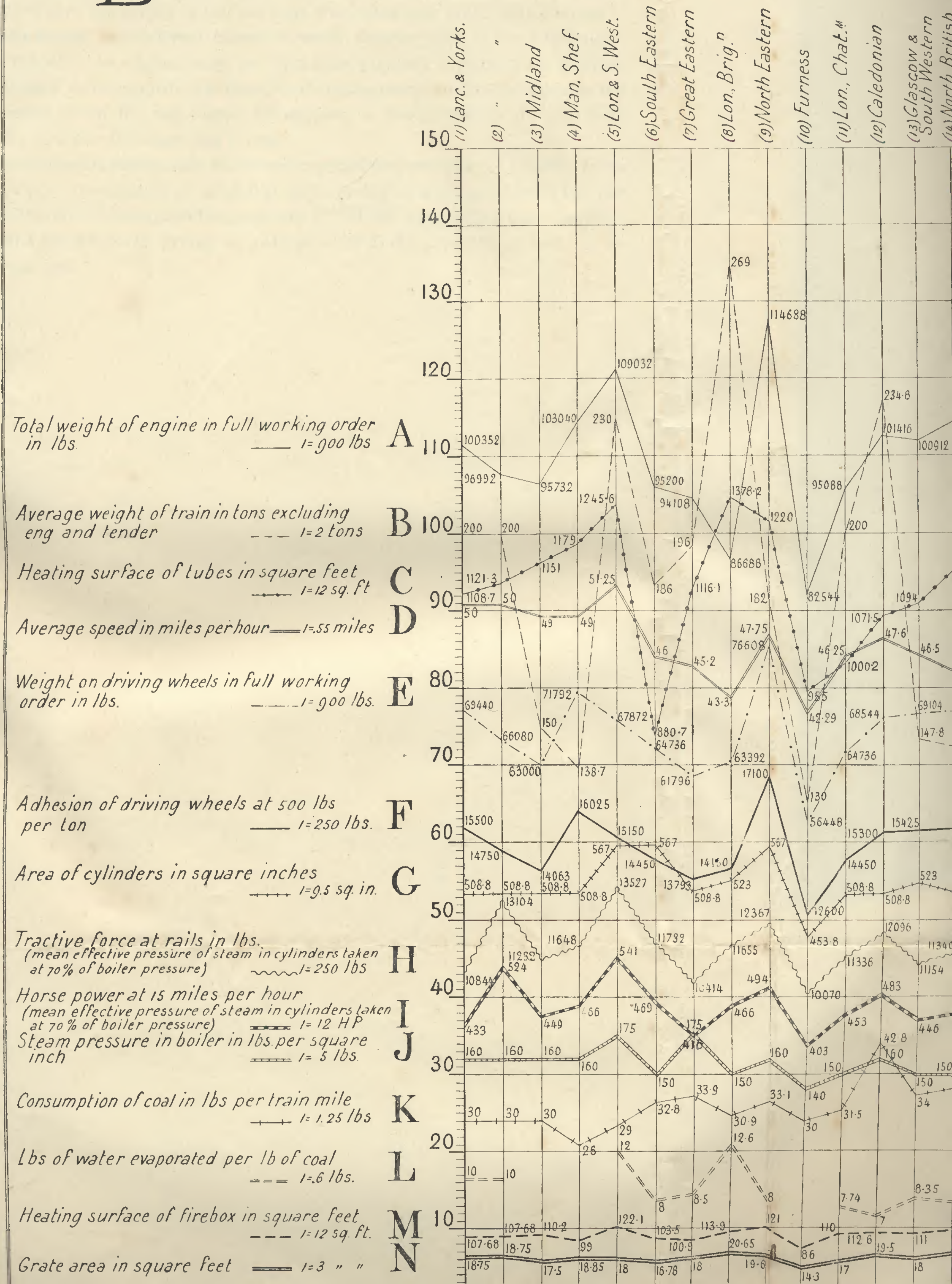
To insure a constant supply of steam at a uniform pressure to the large cylinder, the receiver capacity of the two-cylinder compound, with its cranks at right angles, should be at least equal to the volume of the high pressure cylinder. The receiver should be well protected, and when placed in the smoke box it derives great benefit from the hot gases superheating or reviving the steam.

The information which has hitherto been published in England with regard to compound engines is not of an extensive character, but one of the most complete sets of figures which has as yet come under the notice of the author, is that which Mr. Wilson Worsdell, the locomotive superintendent of the North Eastern Railway, has been good enough to supply with regard to the working of compounds made to the design of his brother, Mr. T. W. Worsdell, of that railway at a period when he was the locomotive superintendent. This voluminous contribution embodies in all, about 17 different statements shewing the working of the compounds in relation to engines of an ordinary type. It would be impossible to publish these figures in their entirety, owing to their being so extensive, and the author has, therefore, extracted from them a statement as to detailed results. This shews the consumption of coal, as given upon the chief statement, and deals with periods extending over 2 $^1/_2$ and 3 years, so that the figures are of much greater value than for short trials extending only over a few weeks. The saving in coal effected in each lot of engines is shewn in a column to the right.

It has been thought desirable to deal with the coal question alone; as that is, after all, the matter of importance in connection with compound engines. The full statements above referred to, shew that there has been an economy in the maintenance of these engines as compared with ordinary engines, but, on the other hand, the consumption of oil has increased. The author thinks that neither of these items are consequent upon, or in any way connected with the compound principle, and therefore, omits them from the condensed statement. It will be observed that the saving in lbs. per mile fluctuates very much with engines of various design, and different classes of work, shewing that, in some instances, it is probable the engines may not have been perfectly adapted to the work to which they were applied, this remark of course being applicable either to the compound or to the non-compound engines, as the statements do not shew exactly how the difference has arisen.

The statement shews that 447 non-compound engines ran 14,807,261 miles with a coal consumption of 4,829,040 cwts. giving an average of 36·52 lbs. per mile; and that 395 compound engines ran 13,799,482 miles with a coal consumption of 4,122,239 cwts. giving an average of 33·45 lbs. per mile, or a saving of 8·40 per cent.

B


(1) Lanc. & Yorks.
(2) "
(3) Midland
(4) Man. Shef.
(5) Lon. & S. West.
(6) South Eastern
(7) Great Eastern
(8) Lon., Brig.n
(9) North Eastern
(10) Furness
(11) Lon., Chat.M
(12) Caledonian
(13) Glasgow & South Western
(14) North British
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
Total weight of engine in full working order in lbs. 1 = 900 lbs A
Average weight of train in tons excluding eng and tender 1 = 2 tons B
Heating surface of tubes in square feet 1 = 12 sq. ft C
Average speed in miles per hour 1 = .55 miles D
Weight on driving wheels in full working order in lbs. 1 = 900 lbs. E
Adhesion of driving wheels at 500 lbs per ton 1 = 250 lbs. F
Area of cylinders in square inches 1 = 9.5 sq. in. G
Tractive force at rails in lbs. (mean effective pressure of steam in cylinders taken at 70% of boiler pressure) 1 = 250 lbs H
Horse power at 15 miles per hour (mean effective pressure of steam in cylinders taken at 70% of boiler pressure) 1 = 12 HP I
Steam pressure in boiler in lbs. per square inch 1 = 5 lbs. J
Consumption of coal in lbs per train mile 1 = 1.25 lbs K
Lbs of water evaporated per lb of coal 1 = .6 lbs. L
Heating surface of firebox in square feet 1 = 12 sq. ft. M
Grate area in square feet 1 = 3 " " N
269
114688
109032
234·6
103040
230
100352
101416
100912
96992
95732
95200
95088
94108
1245·6
1378·2
1220
200
200
200
1179
196
1151
86688
1121·3
1108·7
50
50
49
49
51·25
186
1116·1
182
82544
1094
1071·5
47·75
76608
47·6
46·5
46
45·2
46·25
10002
71792
69440
69104
67872
150
880·7
64736
66080
43·3
955
42·29
68544
147·8
63000
138·7
61796
63392
17100
64736
130
56448
16025
15500
15150
15425
15300
14750
567
567
567
14450
14150
14063
14450
508·8
508·8
508·8
13527
13793
523
523
13104
508·8
508·8
508·8
508·8
12367
12600
12096
11648
11792
11232
524
11655
453·8
11336
11340
10844
541
10414
494
10070
11154
433
449
466
469
466
483
453
446
175
175
416
403
160
160
160
160
160
42·8
160
150
150
150
140
150
150
34
30
30
30
32·8
33·9
30·9
33·1
30
31·5
26
29
12
12·6
10
10
8
8·5
8
7·74
7
8·35
122·1
107·68
110·2
103·5
113·9
121
110
112·6
107·68
18·75
99
100·9
20·65
86
19·5
111
18·75
17·5
18·85
18
16·78
18
19·6
14·3
17
18

NORTH EASTERN RAILWAY.

Comparison of coal consumption by compound and non-compound

NON-COMPOUND ENGINES.

DURATION OF EXPERIMENT.	PASSENGER, GOODS OR MINERAL.	N° of engines employed.	CYLINDERS.		WHEELS.		MILES RUN.	COAL.	
			Diameter.	Stroke.	Diameter.	Number coupled.		Total.	Per mile.
			Ins.	Ins.	Ft. Ins.			Cwts.	Lbs.
Year 1888.	Express passengers.	50	Particulars not given.				1,350,156	371,845	30.84
— 1889.	—	50		—	—		1,666,616	472,514	31.75
— 1890.	—	50		—	—		1,672,712	490,868	32.87
2 years to June 1887	—	6	18	24	7.0	Four.	601,371	171,227	31.37
— — 1889	—	6	18	24	7.0	Four.	439,297	123,211	31.41
Year 1888.	Goods tank.	50	Particulars not given.				1,355,340	454,987	37.59
— 1889.	—	50		—	—		1,217,503	402,530	37.02
— 1890.	—	50		—	—		1,195,093	399,285	37.42
— 1888.	—	11		—	—		232,920	76,221	36.65
— 1889	—	11		—	—		192,351	66,170	38.52
— 1890.	—	11		—	—		221,501	77,186	39.02
— 1889.	Mineral.	29		—	—		559,743	239,802	47.98
— 1890.	—	14		—	—		92,241	40,250	48.87
2½ years to December 1889. . .	Goods and mineral.	6	17	24 (4) 26 (2)	5.0	Six	1,001,589	367,493	41.1
— to August 1891. . . .	—	6	17	26 (4) 28 (2)	5.0	—	640,236	278,515	48.7
2½ years or latest period in same link.	Goods.	5	18	24	5.0	—	119,324	43,764	41.09
	—	5	17	24	5.0	—	200,571	64,345	35.93
	—	6	17	24	5.0	—	335,920	101,180	33.74
	—	5	18 (1) 17 (4)	24	5.0	—	197,675	61,892	35.06
	—	5	17 (4) 17½ (1)	24	5.0	—	236,635	79,404	37.58
	—	6	17	24 (2) 26 (4)	5.8 (1) 5.0 (5)	—	426,060	150,576	39.58
	—	5	17	24 (4) 26 (1)	5.0	—	284,079	97,037	38.26
	—	5	17	24 (4) 26 (1)	5.0	—	278,332	100,784	40.56
	—	5	17	24	5.0	—	289,996	97,954	37.83

*These figures are not given on the original documents, but have been deduced from the full Statements.

DURATION OF EXPERIME
Year 1888 . . . . .
— 1889 . . . . .
— 1890 . . . . .
2½ years to June 1893 .
2 years to June 1889 . .
Year 1888 . . . . .
— 1889 . . . . .
— 1890 . . . . .
— 1888 . . . . .
— 1889 . . . . .
— 1890 . . . . .
— 1889 . . . . .
— 1890 . . . . .
2½ years to March 1891
— to May 1889
2½ years or latest pe same link . . .

H EASTERN RAILWAY.

tion by compound and non-compound locomotives.

LES UN.	COAL. Total.	COAL. Per mile.	DURATION OF EXPERIMENT.	PASSENGER, GOODS OR MINERAL.	COMPOUND ENGINES. Nº of engines employed.	CYLINDERS. Diameter inches.	CYLINDERS. Stroke inches.	WHEELS. Diameter.	WHEELS. Number coupled.	MILES RUN.	COAL. Total.	COAL. Per mile.	SAVING EFFECTED BY COMPOUND ENGINES. Per mile.	SAVING EFFECTED BY COMPOUND ENGINES. Per cent of ordinary engines.
	Cwts.	Lbs.						Ft. Ins.			Cwts.	Lbs.	Lbs.	
0,156	371,845	30.84	Year 1888	Express passengers.	12	Particulars not given.				595,130	153,255	28.84	2.00	6.4
6,616	472,514	31.75	— 1889	—	20		—	—		539,921	146,33)	30.35	1.40	4.4
2,712	490,868	32.87	— 1890	—	27		—	—		730,429	200,408	30.73	2.14	6.5
1,371	171,227	31.37	2 ½ years to June 1893 . . .	—	6	$\frac{20}{28}$	24	7.6	Nil.	539,491	141,485	29.37	2.00*	6.3*
9,297	123,211	31.41	2 years to June 1889	—	6	$\frac{18}{26}$	24	6.6	Four.	468,710	128,755	30.76	0.65*	2.0*
5,340	454,987	37.59	Year 1888	Goods tank.	20	Particulars not given.				588,932	178,685	33.98	3.61	9.6
7,503	402,530	37.02	— 1889	—	54		—	—		1,430,020	426,600	33.64	3.38	9.1
5,093	399,285	37.42	— 1890	—	91		—	—		2,546,099	786,247	34.58	2.84	7.6
2,920	76,221	36.65	— 1888	—	11		—	—		76,335	22,906	33.60	3.05	8.3
2,351	66,170	38.52	— 1889	—	24		—	—		537,615	153,986	32.08	6.44	16.7
1,501	77,186	39.02	— 1890	—	26		—	—		667,747	183,210	30.73	8.29	21 2
9,743	239,802	47.98	— 1889	Mineral.	13		—	—		147,349	51,219	38.93	9.05	18.8
2,241	40,250	48.87	— 1890	—	25		—	—		616,912	205,010	37.22	11.65	23.8
01,589	367,493	41.1	2 ½ years to March 1891. . .	Goods and mineral.	6	$\frac{18}{26}$	24	5.0	Six.	358,924	117,910	36.7	4.4 *	10.7*
40,236	278,515	48.7	— to May 1889 . . .	—	6	$\frac{18}{26}$	24	5.0	—	566,816	191,557	37.8	10.9 *	22.4*
19,324	43,764	41.09	2 ½ years or latest period in same link	Goods.	5	$\frac{18}{26}$	24	5.0	—	413,000	129,535	35.13	5.96*	14.5*
00,571	64,345	35.93		—	6	$\frac{18}{26}$	24	5.0	—	417,147	125.323	33.65	2.28*	6 3*
35,920	101,180	33.74		—	6	$\frac{18}{26}$	24	5.0	—	468,352	127,025	30.37	3.37*	10.0*
97,675	61,892	35.06		—	5	$\frac{18}{26}$	24	5 0	—	253,159	67,522	29.88	5.18*	14.7*
36,635	79,404	37.58		—	5	$\frac{18}{26}$	24	5.0	—	277,828	75,900	30 60	6 98*	18.5*
26,060	150,576	39.58		—	6	$\frac{18}{26}$	24	5.0	—	442,319	149,938	37 97	1.61*	4.0*
84,079	97,037	38.26		—	5	$\frac{18}{26}$	24	5.0	—	435,545	140,193	36 05	2.21*	5 7*
78,332	100,784	40.56		—	5	$\frac{18}{26}$	24	5.0	—	374,943	135,759	40.56	0.00*	0.0*
89,996	97,954	37.83		—	5	$\frac{18}{26}$	24	5.0	—	306,749	83,481	30.48	7.35*	19.4*

While discussing the subject of coal consumption, it is natural to revert to an investigation of grate areas, and, by consulting the lists of dimension « A » and the diagram « B », it will be found that this detail varies from 14·25 to 50·6 square feet in the four wheels coupled engines; 16·6 to 27 square feet in the six wheels coupled engines; 17·75 to 20·8 in the single wheel engines, and 19·6 to 76 square feet in the compounds, omitting in the latter case, the small engine, No 65, of the Norwegian State Railway, which has only 13·98 square feet. It will be noticed that in each case the range is wide, and the author concludes that this is in a great measure due to the variation of quality in the class of coal which can be used in the various districts in which the engines run. The small diagram (fig. 4), illustrates graphically the point in question.

It represents the different percentages of carbon, volatile matter, and ash, in the coals which have been used by the Lancashire and Yorkshire Railway Company. Unfortunately, the author has no analysis of the briquette fuel used on the Belgian State Railways, which necessitates the large grate area of 50·6 square feet in the engine No 31, nor that of the anthracite egg and « buckwheat or pea » coal, used by the Philadelphia and Reading Railway Company's compound engine No 57, which has a grate area of 76 square feet.

Mr. Webb, the chief mechanical engineer of the London and North Western Railway, has given the author particulars of one week's running between London and Carlisle by the 7 ft. Compound Express Passenger Engine « Greater Britain » No 54, from the 17th. April to the 22nd April 1893, during which period the mileage run was 3,588, in 76 hours and 7 minutes, actual running time, and in 82 hours and 12 minutes including stops. The leading particulars of these runs will be found in the following statement :

Weight of engine and tender in working order	77 tons, 2 cwts.
Average weight of train, including passengers, luggage and mails, (and excluding engine and tender)	160 — 8
Average weight of train, including passengers, luggage and mails (and including engine and tender).	237 —10
Time table time, deducting stops.	76 hours 7 mins.
Deduct also, for time made up by locomotive	50 —
Actual running time	75 hours 17 —
Total distance travelled	3,588 miles.

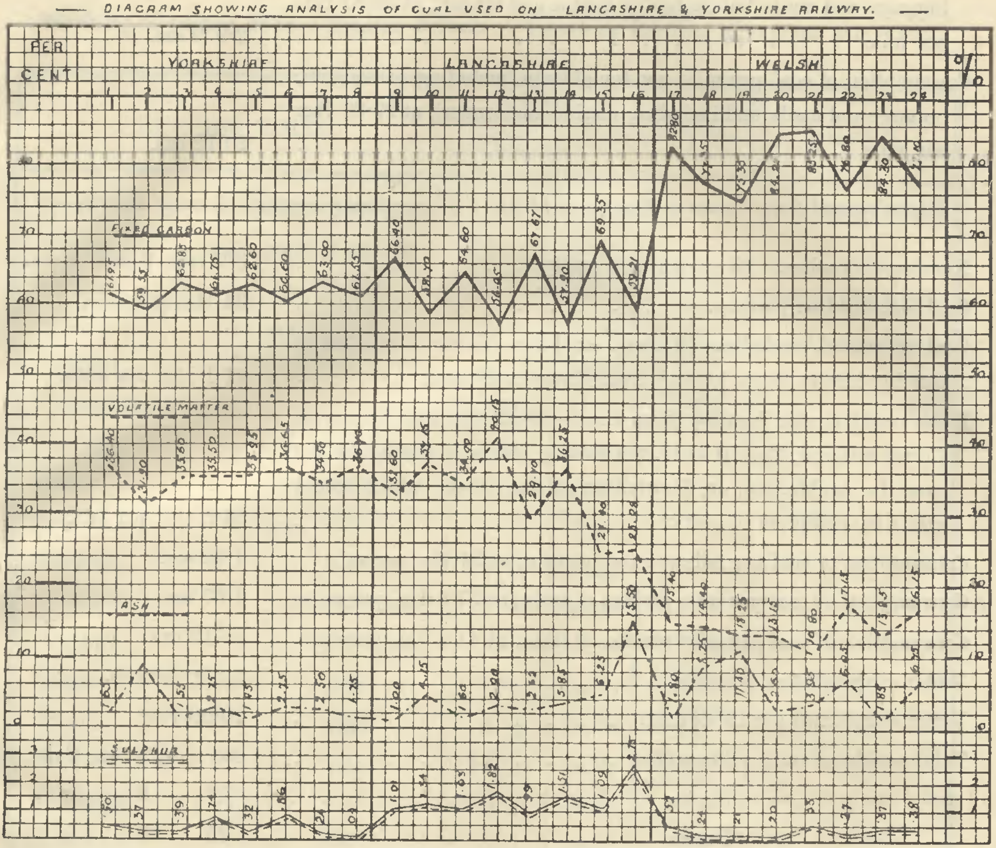


Fig. 4.

Average speed $= \dfrac{3{,}588 \text{ miles.}}{75 \text{ hours } 17 \text{ minutes}}$	47·66 miles per hour.
Total weight of coal consumed (excluding lighting up)	47 tons, 17 cwts.
Actual consumption of coal per mile (excluding lighting up) . . .	29·87 lbs.
Consumption of coal per mile (including 1·2 lbs. for lighting up). .	31·07 lbs.
Total number of ton miles, including passengers, luggage and mails, but excluding engine and tender.	575,557
Total number of ton miles, including passengers, luggage and mails and including engine and tender	852,224