THE BRITISH TRANSPORT COMMISSION

Performance and Efficiency Tests

BRITISH RAILWAYS STANDARD CLASS 8 3 CYL 4-6-2 EXPRESS PASSENGER STEAM LOCOMOTIVE No. 71000

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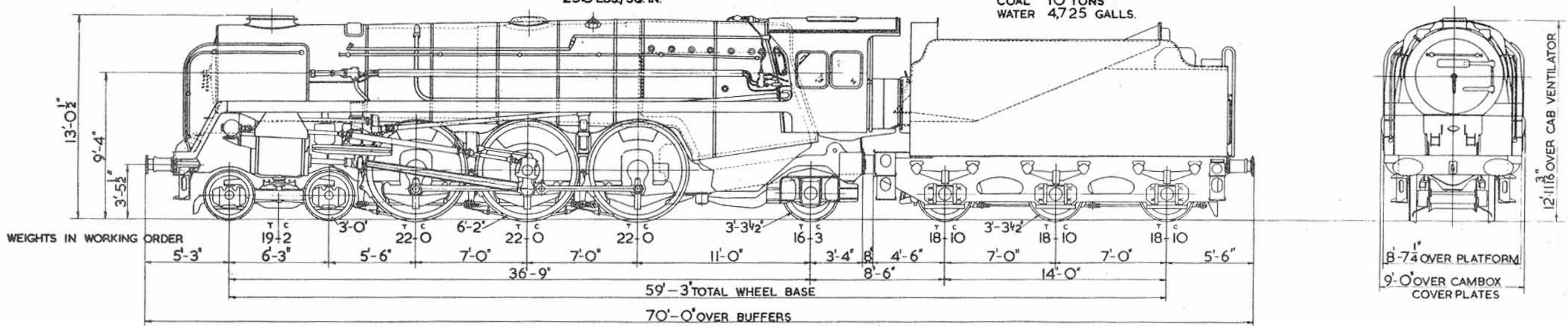
British Railways
Standard Class 8,
3 *cylinder,* 4-6-2
Express Passenger
Locomotive No. 71000
"Duke of Gloucester."

Photo B.R. (W.R.)

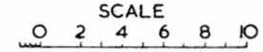


MINIMUM RADIUS CURVE WITHOUT GAUGE WIDENING 6 CHAINS (4½ CHAINS DEAD SLOW).

BOILER BARREL DIAMETER (OUTSIDE)	5'-9" INCREASING TO 6'-5½"
FIREBOX (OUTSIDE)	8'-0⅛" LONG x 7'-9" TO 7'-4" WIDE
TUBES	40 LARGE 5¼" O.D. x 7 S.W.G.
	136 SMALL 2⅛" O.D. x 11 S.W.G.
SUPERHEATER ELEMENTS	1⅜" O.D. x 9 S.W.G.
LENGTH BETWEEN TUBEPLATES	17'-0"
HEATING SURFACES: TUBES	2264 SQ. FT.
FIREBOX	226 SQ. FT.
TOTAL EVAPORATIVE	2490 SQ. FT.
SUPERHEATER	691 SQ. FT.
FREE FLUE AREA	6·8 SQ. FT.
GRATE AREA	48·6 SQ. FT.

CYLINDERS (THREE)	18" x 28"
TRACTIVE EFFORT	39,080 LBS.
ADHESION FACTOR	3·78
BRAKE % ENGINE & TENDER	51·17
BOILER TYPE	B.R. 13
TENDER TYPE	B.R. 1E.

WEIGHTS	FULL	EMPTY
	T. C.	T. C.
ENGINE	101-5	92-0
TENDER	55-10	24-8
TOTAL	156-15	116-8



STANDARD CLASS 8. 4-6-2 ENGINE.

BRITISH-CAPROTTI VALVE GEAR

BULLETIN No. 15

THE BRITISH TRANSPORT COMMISSION

Performance and Efficiency Tests

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1957

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1. INTRODUCTION

The subject of this Bulletin is the British Railways Standard Class 8 Express Passenger Locomotive No. 71000. Besides having several features not previously incorporated in British Railways Standard locomotives - of which the most noteworthy is steam distribution by poppet valve gear - it represents the ultimate stage of development of the steam locomotive in this country.

Special interest may therefore be attracted to this Bulletin which in common with others has, as its object, the placing on record the results of tests which have been undertaken to establish the principal relations involved in the conversion of heat into useful mechanical energy and the inter-relations which are their factors.

These, which are of importance in design, have to be supplemented by associated relations before the scope of the locomotive in operating services may be defined and the relative cost of energy of operating services within these boundaries may be indicated.

This is one of the aims of the Bulletin and involves factors in the sphere of railway mechanics besides that of the built-in thermal efficiency of the locomotive.

The testing work and the preparation of this Bulletin was done by the Swindon Experimental and Locomotive Testing Station under the auspices of the Locomotive Testing Joint Sub-Committee consisting of :

Mr. E.S. Cox (Chairman)	-	Mechanical Engineer (Development) Chief Mechanical Engineer's Dept., British Transport Commission, British Railways Central Staff.
Dr. H.I. Andrews	-	General Assistant, Electrical Engineering, New Works & Development Section, B.T.C., B.R. Central Staff.
Mr. T. Baldwin	-	Superintendent, Engineering Division, Research Department, British Transport Commission, British Railways Central Staff.
Mr. D.R. Carling	-	Superintending Engineer, Locomotive Testing Station, Rugby, B.T.C. B.R. Division.
Mr. C.S. Cocks	-	Chief Techncial Assistant, C.M.& E.E. Department. L.M. Region.
Mr. S.O. Ell	-	Assistant to C.M.& E.E. (Locomotive Testing) Western Region, Swindon Experimental & Locomotive Testing Station.

Mr. R. Thompson	-	Motive Power Officer, B.T.C., British Railways Central Staff.
Mr. T.M. Herbert	-	Director of Research, B.T.C. British Railways Central Staff.
Mr. A.G. Hopking	-	Assistant for Rolling Stock, Electrical Engineering, New Works & Development Section, B.T.C., British Railways Central Staff.
Mr. R.G. Jarvis	-	Chief Technical Assistant (Locomotives), C.M.& E.E. Department, Southern Region.
Mr. B. Spencer	-	Chief Technical Assistant (Loco.), C.M.& E.E. Department, E.& N.E. Regions.

2. THE LOCOMOTIVE

The locomotive was built at Crewe Works in 1954 and incorporates several features not previously applied to British Railways standard steam locomotives. Intended for operating heavy express passenger services, it is provided with three cylinders having steam distribution by British-Caprotti Valve Gear.

A photograph and diagram are reproduced as frontispieces to this Bulletin. A full list of the dimensional details and ratios are given in Table I. The 18" x 28" cylinders provide a rated tractive effort of 39080 lb. with coupled wheels of 6' 2" diameter and boiler pressure of 250 lb. per sq. in.

Boiler. The boiler is outlined in Diagram I. It is of normal design and is the same as that of the B.R. Class 7 locomotives except that the firebox is one foot longer, which increases the grate area by 6.6 sq. ft. to 48.6 sq. ft. The performance and efficiency of the Class 7 prototype is given in Bulletin No. 5.

Evaporative heating surface is 2490 sq. ft. and superheater heating surface 691 sq. ft., these being in the ratio of 3.6 to 1.

The boiler is provided with a rocking grate with 14 rocking sections, seven on each side of the centre line. Each rocking section carries 14 renewable finger-type firebar units giving a 43% free air space. The ashpan has three self-emptying hoppers with damper doors in each hopper at the front and one in the centre hopper at the back.

Smokebox and Draughting Arrangements. As shown in Diagram 2, the smokebox is of the self-cleaning type, having plates and a wire mesh grid arranged to prevent accumulation of ash in the smokebox.

The twin blast pipe has plain circular converging nozzles of 4 ins. minimum diameter. With it is associated a double chimney of plain circular converging-diverging shape; the choke diameter is 12" and the inclination of the diverging portion is 1 in 14.

Steam Distribution. The separate inlet and exhaust poppet valves at each end of the cylinder are actuated by rotary cams. Machined from solid steel forgings, the valves, Fig. 3, are housed in cages to form complete units. The cages expand under influence of temperature at the same rate as the valves, thus avoiding differential expansion and promoting maximum steam tightness; this is further safeguarded by the position and design of the valve seats, the bottom being flat and the top having an angle which is a function of the distance between them, as may be seen in Diagram 5. The valves are designed to give good port openings, free steam flow, and adequate strength with minimum weight.

The main engine regulator incorporates a special valve which automatically admits saturated steam through an actuation pipe to the bottom of the valve spindles before the main steam supply is admitted to the cylinders. The actuation steam lifts the valves into the working position and provides the closing force during running, although the major force on the inlet valves is the steam chest pressure acting on the section of the spindle above the valve. The valves are therefore springless, and work without lubrication.

The camshaft assembly is illustrated by Diagram 6. The cam profiles are designed for low opening and closing velocities, with smooth acceleration in order to avoid roller bounce. Two inlet cams are mounted on a bush at one end of the camshaft and an exhaust cam assembly at the other, these assemblies being shown in Diagrams 7 and 8. Between the assemblies, two scrolls are fitted to the square threaded portion of the camshaft. Each scroll is connected to an inlet cam by two cam-rods in a manner which allows relative angular movement to be imparted to the inner and outer cams. The scrolls are housed in collars which are connected to the reversing crankshaft.

The exhaust cams are directly coupled to cam-rods, the system being identical in principle to that of the inlet cams.

A view of the cambox with cover removed is produced as Fig. 4.

As may be seen in the photograph which forms the frontispiece, the drive for the camboxes on the outside cylinders is taken from the intermediate coupled wheels by means of worm gears mounted on return cranks. Tubular shafts transmit the drive. The drive for the inside cambox is taken from an extension on the worm shaft on the left hand cambox through a right-angle bevel gear box.

From each of the three reversing gearboxes, a transmission tube connects with a cambox, enabling the reversing of the engine to be done by advancing or retarding the angular position of the cams relative to the camshafts. Any cut-off desired is obtained by the angular adjustment of the inlet cams relative to each other.

The designed valve events are shown in Diagram 9.

The valve gear was designed and manufactured by the Associated Locomotive Equipment Company Ltd. of London and Worcester.

3. COAL

Coals used in the tests were of two grades of Yorkshire hard steam coal, viz.

Grade 1A, South Kirkby, for which a representative analysis is given in Table 2. Results for this coal have been referred to a calorific value of 13550 BThU/lb. The price of the coal, as loaded on the tender at the time of the tests, was £3.16s.6d. per ton.

Grade 2B, Blidworth, for which a representative analysis is given in Table 3. Results for the coal have been referred to a calorific value of 12850 BThU/lb. Price, as loaded on the tender at the time of the tests, was £3.11s.6d. per ton.

4. PRESENTATION OF RESULTS

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4. PRESENTATION OF RESULTS

The results are presented in two parts.

Part I consists of the principal relations occurring in the conversion of heat into mechanical energy and their factors. Associated relations are also given, including locomotive and train resistance. This part summarises the testing work done on the stationary plant and on the track under controlled conditions.

Part 2 treats of the service performance of the locomotive and the commercial economy of operation with respect to fuel consumption, and of the factors of these. For this purpose the data given in Part I has been applied to a comprehensive range of main line services which are typical of the locomotive's normal duties. The results are summarised in the form of a series of Cost of Energy and Performance Diagrams.

A note is appended on the relative place of the cost of energy of movement in the factors of the criterion of operating costs.

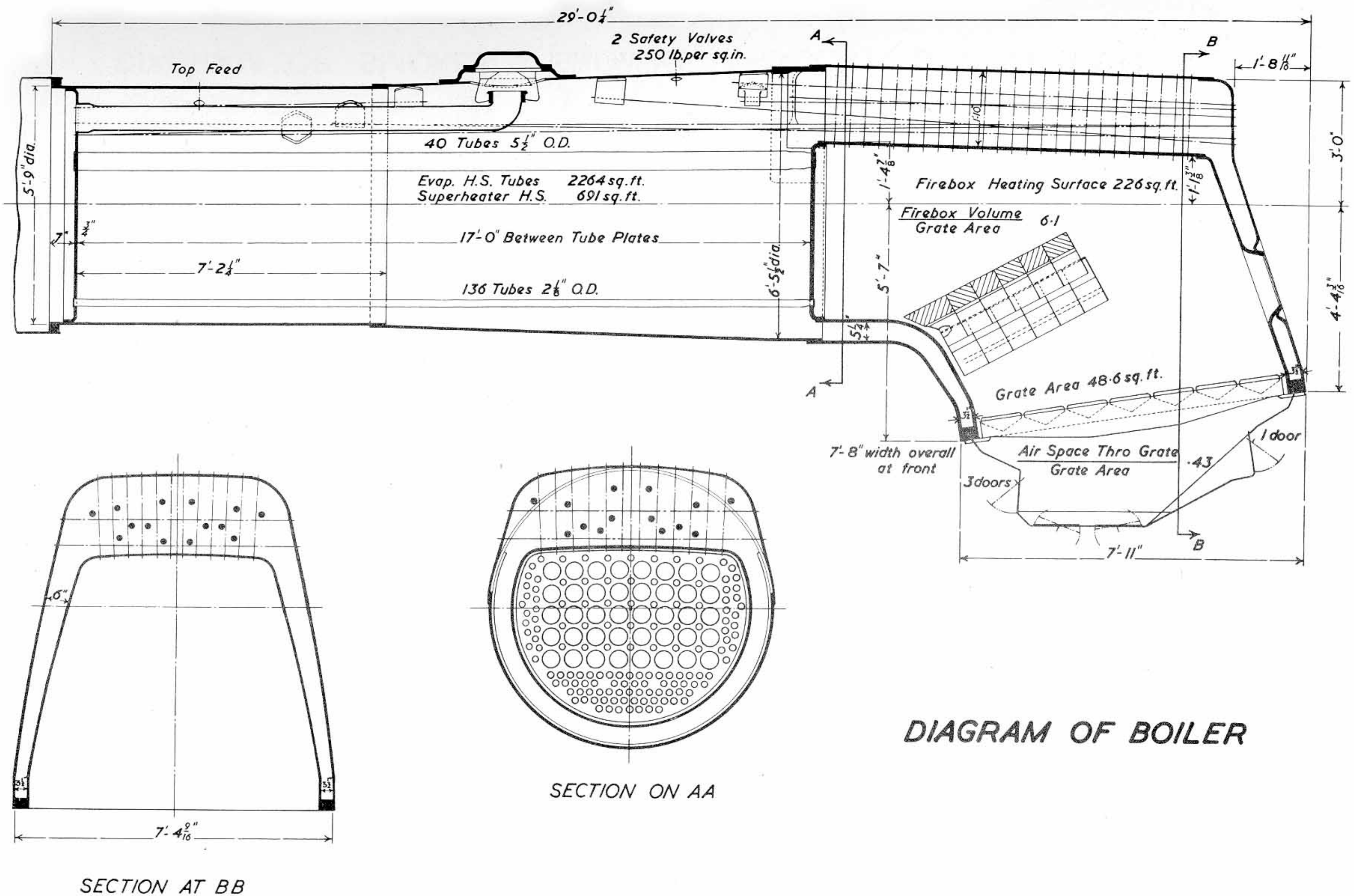
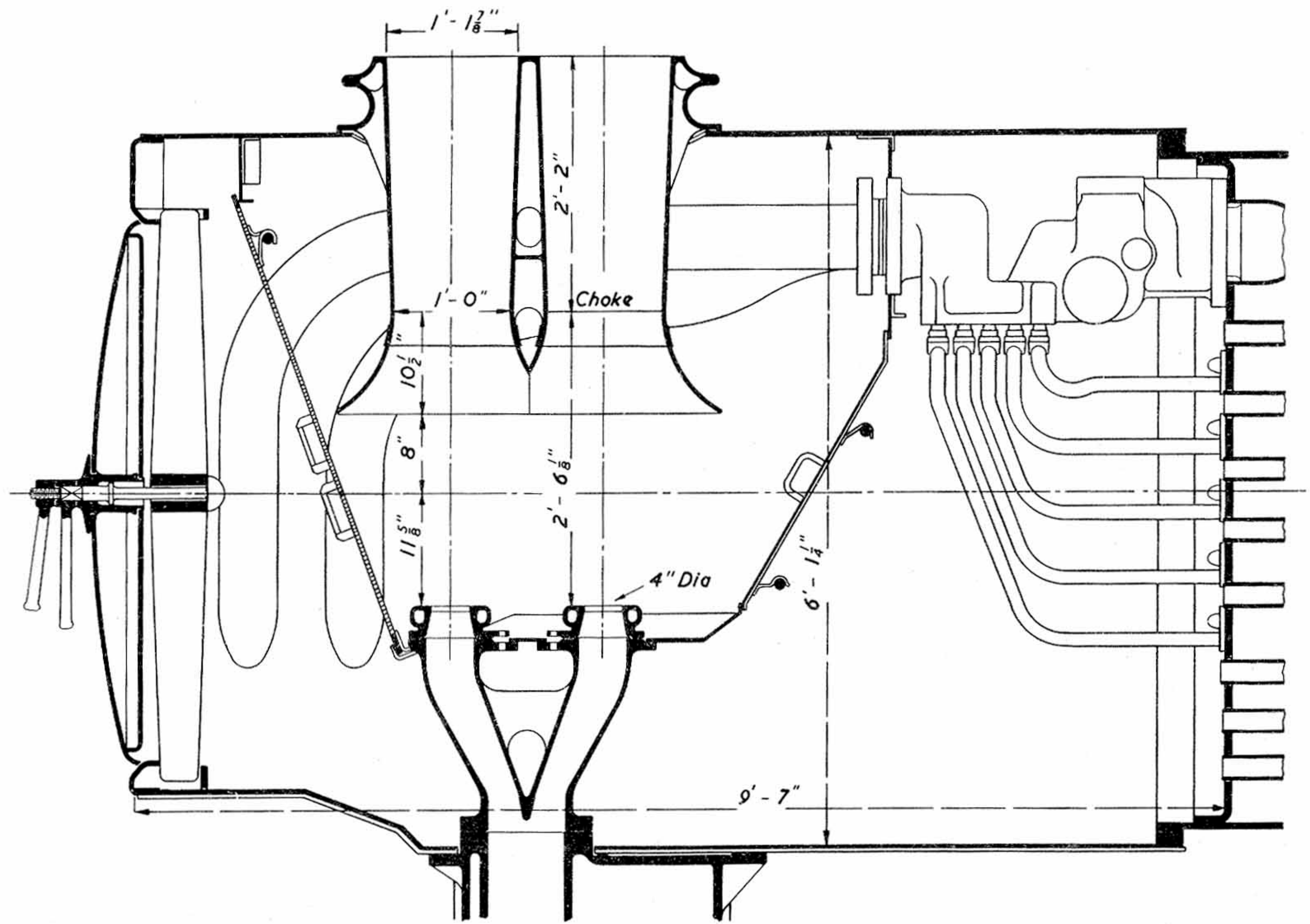


DIAGRAM OF BOILER

1



2

DIAGRAM OF SMOKEBOX SHOWING DRAUGHTING ARRANGEMENTS

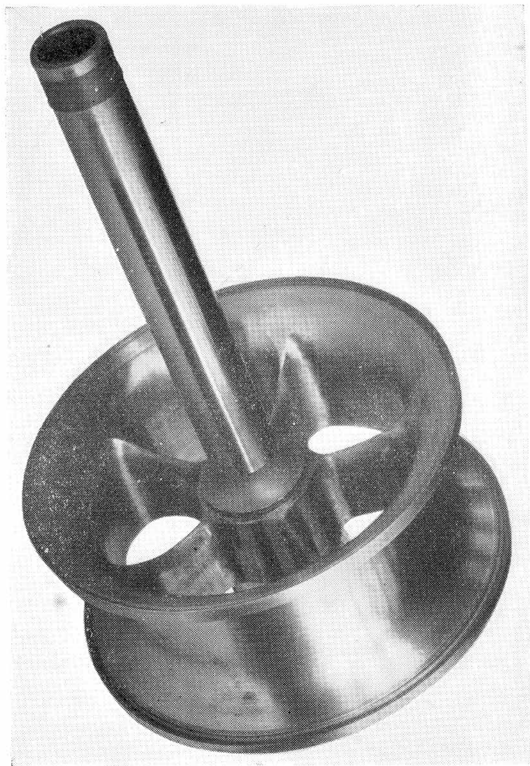


Fig. 3. Poppet Valve and Spindle

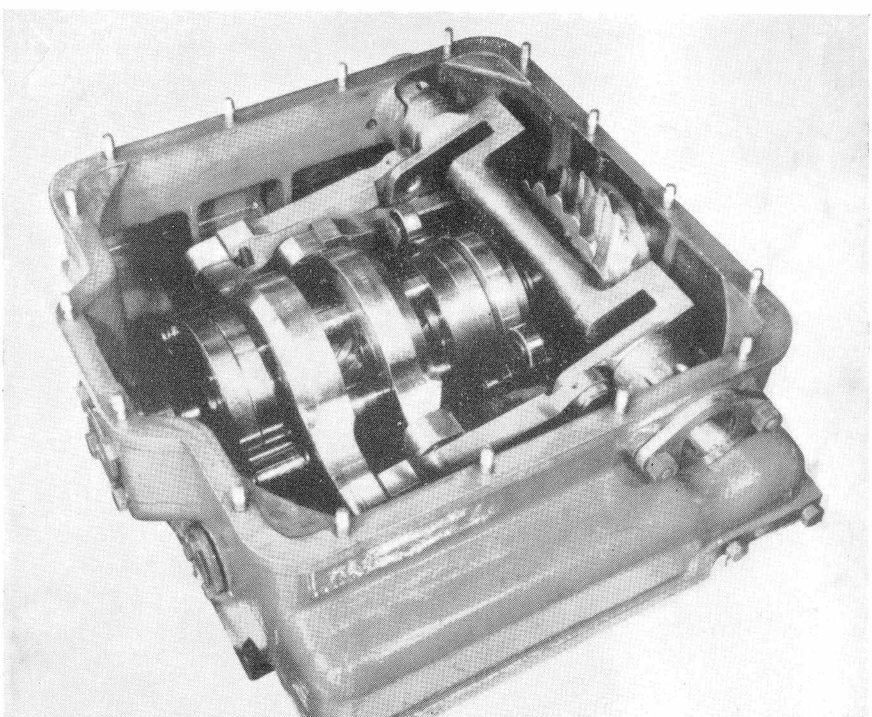
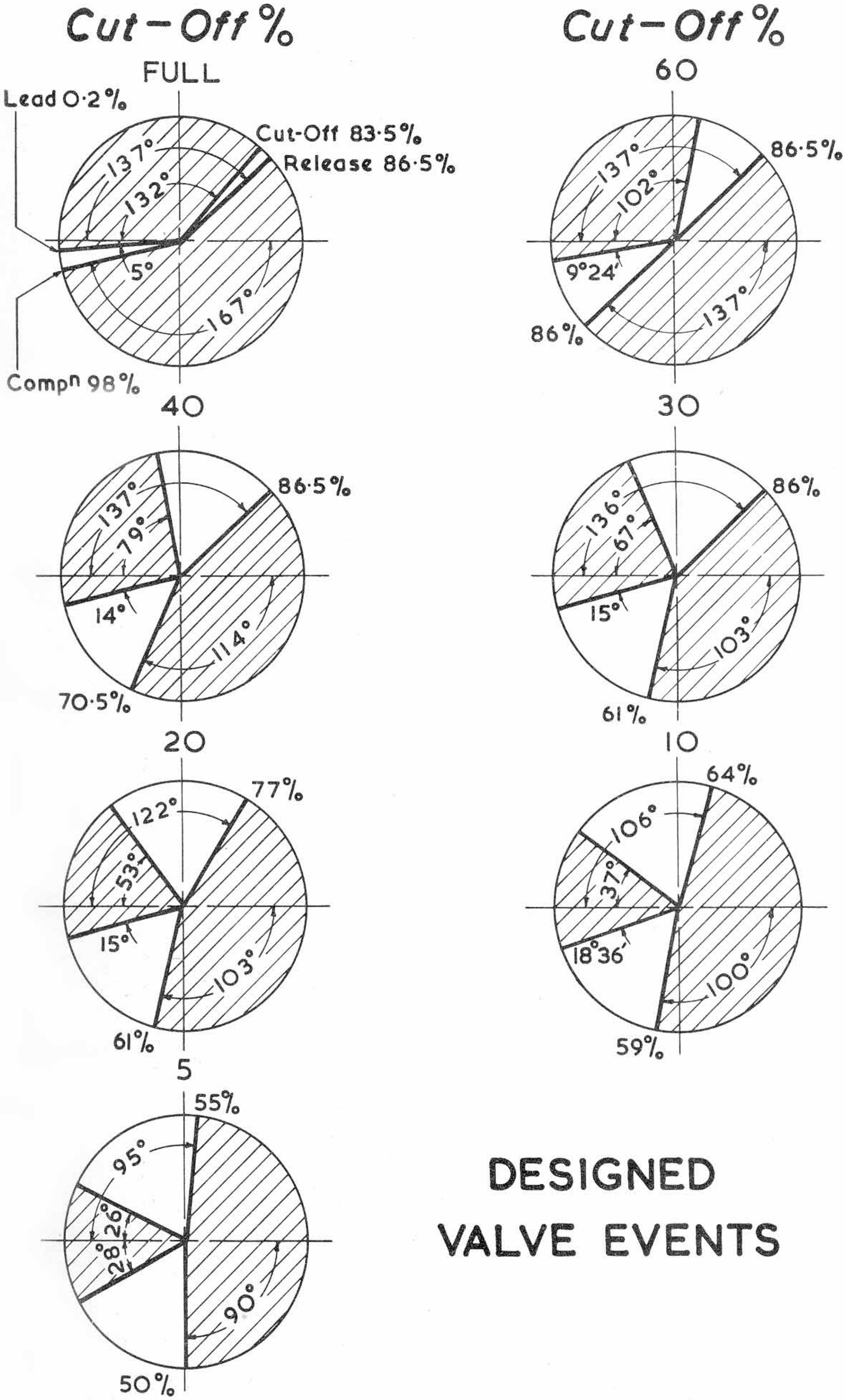
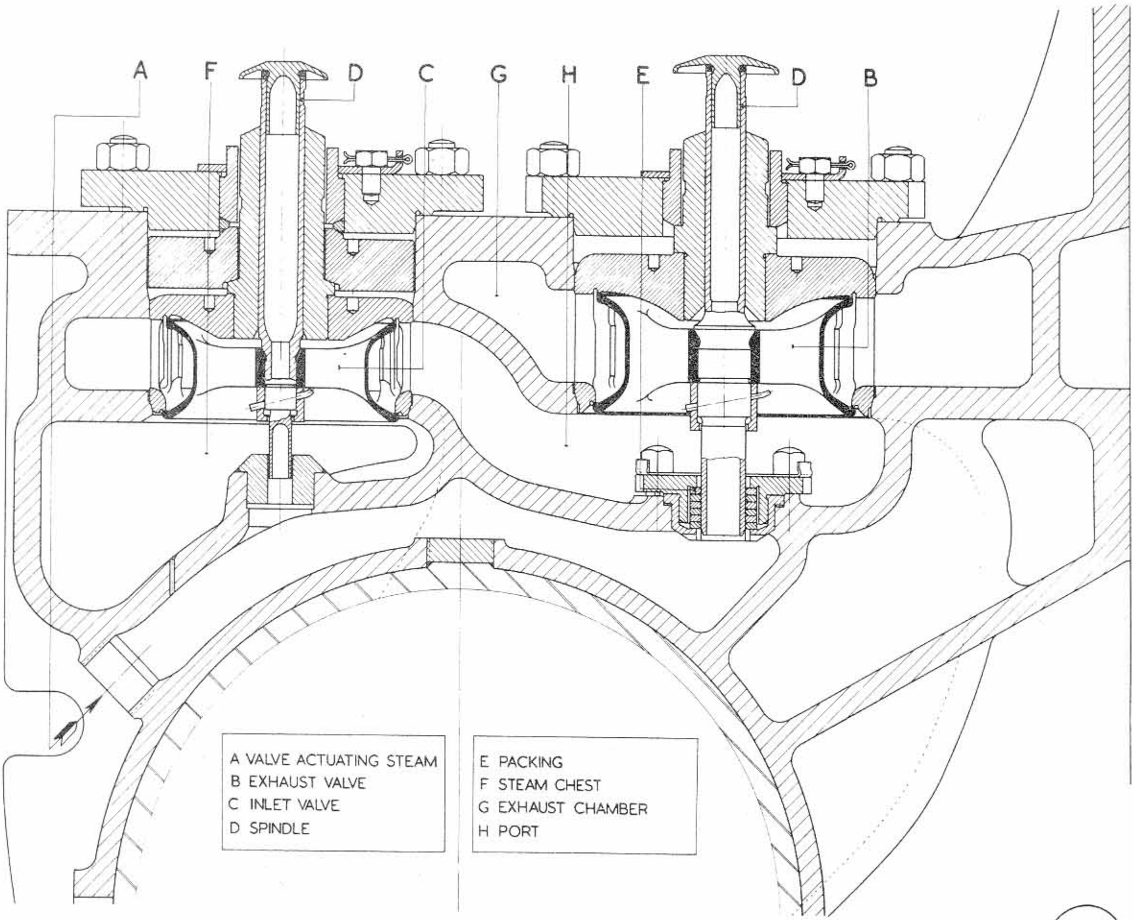


Fig. 4. Cambox with cover removed

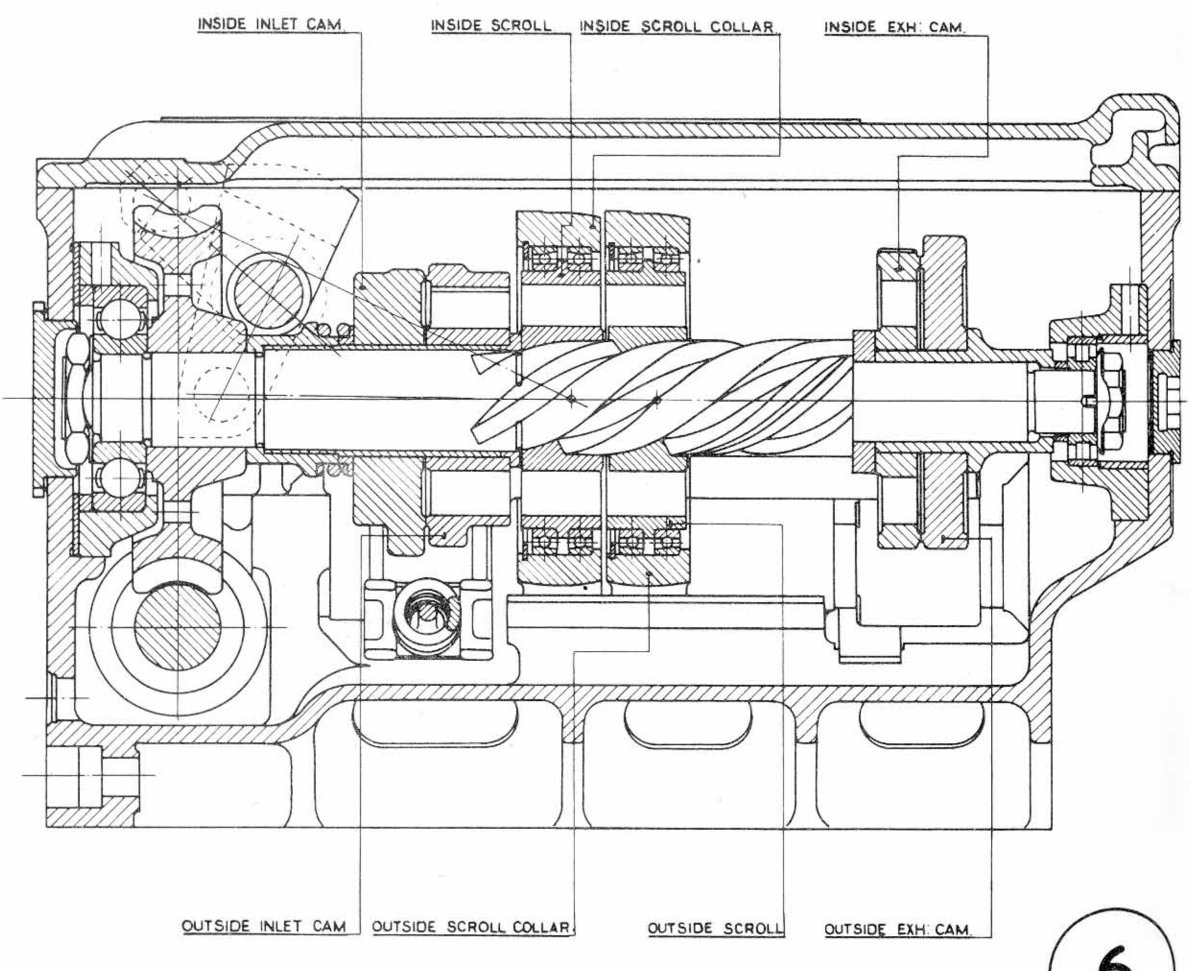


DESIGNED VALVE EVENTS



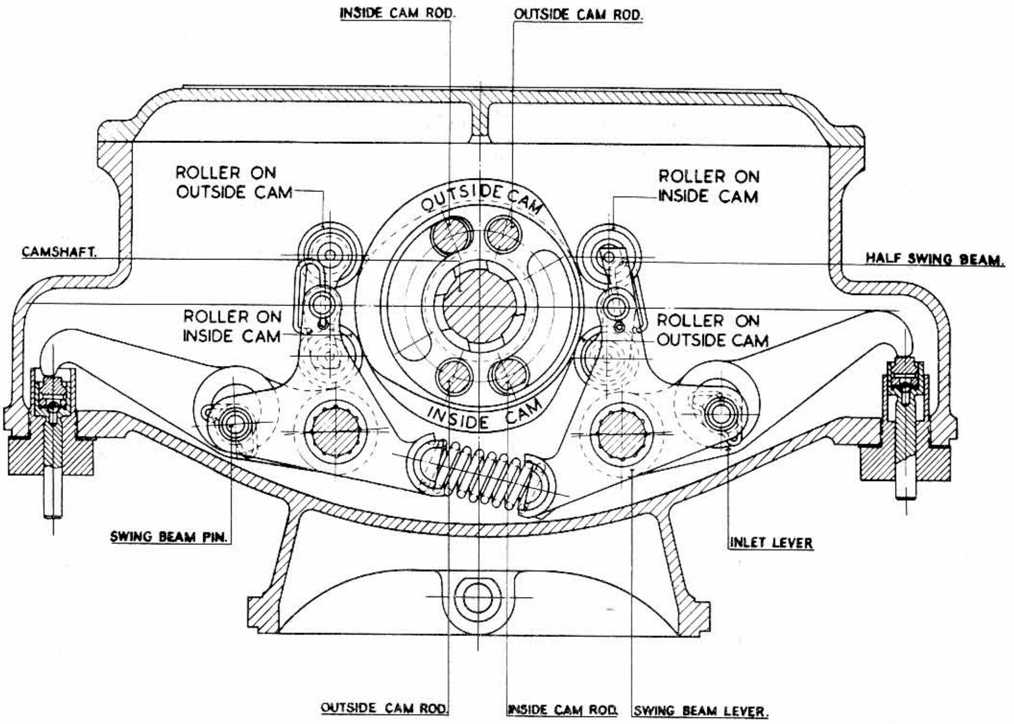
A
F
D
C
G
H
E
D
B
A VALVE ACTUATING STEAM
B EXHAUST VALVE
C INLET VALVE
D SPINDLE
E PACKING
F STEAM CHEST
G EXHAUST CHAMBER
H PORT

5

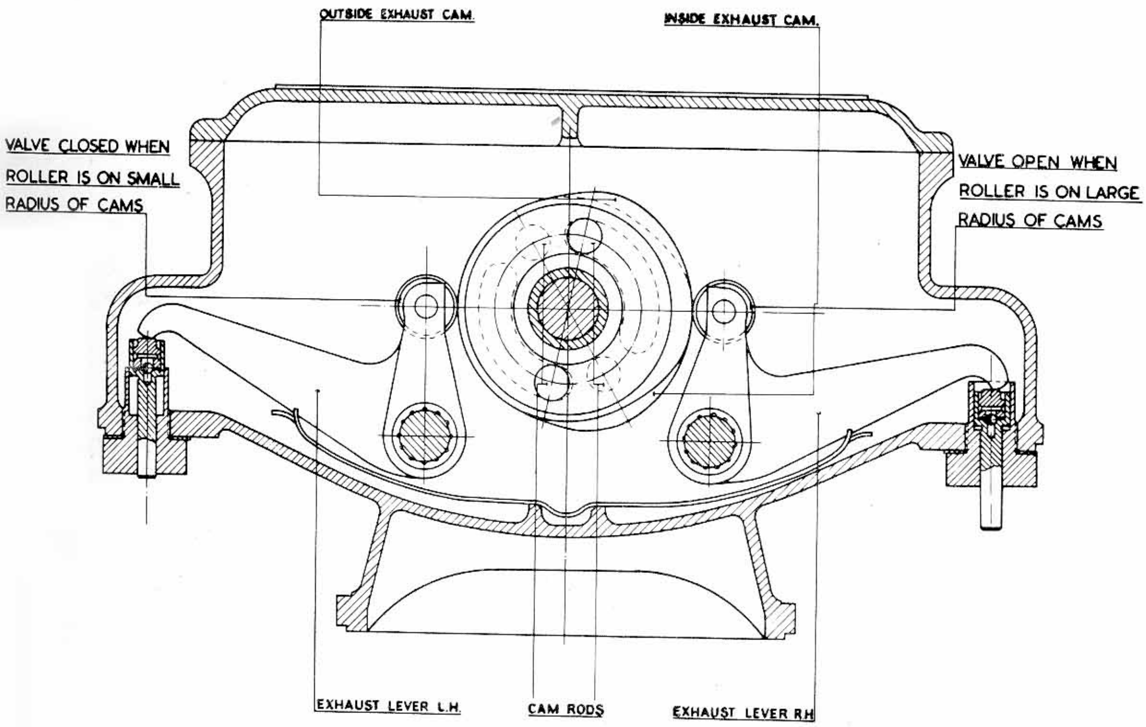


INSIDE INLET CAM
INSIDE SCROLL
INSIDE SCROLL COLLAR
INSIDE EXH: CAM
OUTSIDE INLET CAM
OUTSIDE SCROLL COLLAR
OUTSIDE SCROLL
OUTSIDE EXH: CAM

6


INSIDE CAM ROD.
OUTSIDE CAM ROD.
ROLLER ON
OUTSIDE CAM
OUTSIDE CAM
ROLLER ON
INSIDE CAM
CAMSHAFT.
HALF SWING BEAM.
ROLLER ON
INSIDE CAM
ROLLER ON
OUTSIDE CAM
INSIDE CAM
SWING BEAM PIN.
INLET LEVER
OUTSIDE CAM ROD.
INSIDE CAM ROD.
SWING BEAM LEVER.

7


OUTSIDE EXHAUST CAM.
INSIDE EXHAUST CAM.
VALVE CLOSED WHEN
ROLLER IS ON SMALL
RADIUS OF CAMS
VALVE OPEN WHEN
ROLLER IS ON LARGE
RADIUS OF CAMS
EXHAUST LEVER L.H.
CAM RODS
EXHAUST LEVER R.H.

8

TABLE I

DIMENSIONAL DETAILS & RATIOS

Boiler

Barrel Diameter, Outside - Minimum	5' 9"
- Maximum	6' 5½"
Small Tubes - Number	136
- Outside Diameter	2⅛"
- Thickness	11 S.W.G.
Large Tubes - Number	40
- Outside Diameter	5½"
- Thickness	7 S.W.G.
Superheater Elements (Double Return Loop)	
- Outside Diameter	1⅜"
- Thickness	9 S.W.G.
Length between Tube Plates	17' 0"
Heating Surfaces) Grate Area) See Engine Diagram	
Water Surface at ½ Glass	127.5 sq. ft.
Volume of Steam above water at ½ Glass (Gross)	113.0 cu. ft.
Total Piston Swept Volume, as percentage of Steam Volume	10.95
Firebox Volume/Grate Area	6.1
Firebox Volume/Firebox Heating Surface	1.31
A/S Large Tubes	1/420
A/S Small Tubes	1/435

Steam Circuit

Regulator - Area through Pilot Valve	2.46 sq. in.
- Area through, all valves open	52.88 sq. in.
Main Steam Pipe through Boiler, - Diameter	7.0 in.
Cross Sectional Area	38.48 sq. in.
Superheater Elements -	
- Area through spherical ends	34.9 sq. in.
- Area through tubes	37.2 sq. in.
Steam Pipes to Cylinders	
- Cross Sectional Area	28.27 sq. in.
Exhaust Passage at point of convergence of passages below blast pipe	98.0 sq. in.

Gas Circuit

Max. Area through Ashpan Dampers - Front	3.62 sq. ft.
- Rear	1.74 sq. ft.
Air Space through grate as percentage Grate Area	43.2
Free Area through tubes - Large	4.13 sq. ft.
- Small	2.66 sq. ft.
- Total	6.79 sq. ft.
Total free tube area as percentage of grate area	14
Area through large tubes as percentage of total free area	60.8

Draughting Arrangements

Blast pipe Orifice - Diameter (2)	4"
- Area	12.56 sq. in.
Chimney - Diameter at Choke (2)	1' 0"
- Area at Choke	.7854 sq. ft.
- Diameter at Top	1' 1⅞"
Blast Pipe Orifice below Smokebox Centre Line	11⅝"

Chimney Choke above Blast Pipe Orifice	2' $6\frac{1}{8}$"
Height of Chimney, Choke to Top	2' 2"
Chimney Sides, Taper	1 in 13.85

$\frac{\text{Chimney Choke Diameter}}{\text{Blast Pipe Orifice Diameter}}$ = 3

$\frac{\text{Height of Choke above Orifice}}{\text{Diameter of Choke}}$ = 2.51

Cylinder and Steam Chests

Piston Swept Volume	7126 cu. in.
Clearance Volumes as percentage of Piston Swept Volume :-	
Outside Front	13.08
Outside Back	12.88
Inside Front	12.02
Inside Back	11.83
Steam Chest Volumes as percentage of Piston Swept Volume :-	
Outside	41.44
Inside	26.25

Valves

Inlet $6\frac{1}{4}$" diameter Working Travel $\frac{51}{64}$"

Exhaust 7" diameter " " $1\frac{5}{64}$"

Steam Circuit

Steam Chest, Cross Sectional Area at entry to Cylinder	30.55 sq. in.
Exhaust Passage adjacent to Steam Chest :-	
Outside (Min)	36.0 sq. in.
Inside (Min)	22.0 sq. in.
Through the Valves	47.4 sq. in.

TABLE 2

Description of Coal :	Barnsley Hards
Colliery :	South Kirkby
Suppliers :	N.C.B. (N.E.Division, Area No.4)
When Sampled :	22nd November, 1954
Truck No. :	116092, containing 11 ton 3 cwt.

Visual Inspection of Sample

Appearance : Generally fairly bright and very hard; laminated structure, some of the lamina having a dull-grey, slate-like appearance.

Size : Size varied from 3 ft to 6 ins. in greatest dimension, with a small proportion of coal below 2 ins.

		As received	Dry	Air Dried
Calorific Value (Gross)				
British Thermal Units per lb.		13,550	13,910	13,770
Proximate Analysis				
Moisture	%	2.6	-	1.1
Volatile Matter, less moisture	%	30.1	30.9	30.6
Fixed Carbon	%	61.2	62.8	62.1
Ash	%	6.1	6.3	6.2
Total Sulphur	%	1.59	1.63	1.61
Iron in Ash	%	-	18.1	-

Remarks

The coal was sampled and tested in accordance with British Standard procedure.

TABLE 3

Description of Coal :	Blidworth Small Cobbles
Colliery :	Blidworth
Suppliers :	N.C.B. (East Midland No.3 Area)
When Sampled :	10th December, 1954
Truck No :	187220, containing 9 ton 17 cwt.

Visual Inspection of Sample

Appearance : Small, hard cobbles having a lamellar structure. Generally rather dull in appearance with some bright pieces.

Size : Size varied from 6" to 2" with an average of 3 ins. and a very small proportion of dust.

		As received	Dry	Air Dried
Calorific Value (Gross)				
British Thermal Units per lb		12,850	13,980	13,070
Proximate Analysis				
Moisture	%	8.1	-	6.6
Volatile Matter, less moisture	%	33.7	36.6	34.2
Fixed Carbon	%	54.0	58.8	54.9
Ash	%	4.2	4.6	4.3
Total Sulphur	%	0.86	0.93	0.87
Iron in Ash	%	-	6.5	-

Remarks

The coal was sampled and tested in accordance with British Standard procedure.

PART I.

The Principal Relations occurring in the conversion of Heat into Mechanical Energy, the Efficiencies at various points in the process, and their factors. Associated Relations. Nature of the Tests. Mechanical Condition.

1. THE PRINCIPAL RELATIONS

(a) Characteristics of Equivalent Drawbar TE and HP, at constant speed on the level, are respectively given in Graphs 10 and 11. These, up to a cylinder steam rate of 31000 lb/hr, were established directly by Controlled Road Tests. This rate was the maximum permitted by the tender coal capacity in relation to an acceptable period of test. Values given for other steam rates have been obtained by combining the indicated characteristics established on the Testing Plant for higher rates with resistances established on the road tests at lower rates.

(b) Characteristics of Indicated TE and HP are shown in Graphs 12 and 13. The normal reconciliation of road and test plant results was rendered most difficult because of the effect of high frequency vibrations set up by pressure waves in the steam pipes at high speeds. On the testing plant the indicators, attached directly to the cylinder castings, were unaffected, but these positions could not be retained for the road trials. A further reference to the pressure waves is made at a later stage.

(c) Rate of Evaporation - Coal Rate Relation. This for South Kirkby coal is given in Graph 14 and that for Blidworth in Graph 15. The relation was established in the first instance, and in the interests of accuracy, with water fed by the live steam injector. Subsequent comparative tests with the exhaust steam injector provided the modification to the rates produced when this injector is used. The steam, water and coal relations given in Graphs 10 to 13 and 39 to 43 against the curves of tractive effort and power are those of Graphs 14 and 15 as the case may be.

2. THE PRINCIPAL EFFICIENCIES

(a) Boiler, Transmission and Grate Efficiencies with South Kirkby coal are shown separately in Graph 16. The first is, of course, the product of the others after allowing for external radiation. External radiation has been taken as .8% of the heat released from the grate, a figure which has been obtained from the basic expression for the transference of heat by conduction through a series of conductors for which the thermal conductivities and dimensions are known or can be assumed. The results of all tests are plotted, those of each type of trial being readily distinguished. Early tests at the testing plant were responsible for the unusual degree of scatter in parts of the testing plant series. This was due to bounce of the rear end of the locomotive which had a disturbing influence on the management of the fire. Except for this effect the oscillation was of no consequence and was readily checked by applying outside vertical damping to the rear end. The oscillation came from the slide bar reactions which set up a resonance with the helical springs of the trailing truck; it was not noticeable on the road trials. The boiler efficiency with the Blidworth coal is shown in Graph 17.

(b) Specific Steam Consumption per IHP hr. is shown in Graph 18, from which it may be noted that, in a limited range, consumption falls to a minimum of under $12\frac{1}{4}$ lb. per IHP hr.

(c) Specific Coal Consumption per IHP hr. is shown by Graph 19 for South Kirkby coal and Graph 20 for Blidworth.

(d) Cylinder Thermal Efficiency, with the mean feed water temperature as a datum, is illustrated by Graph 21 and this efficiency relative to that of an ideal engine working on the Rankine cycle is shown by Graph 22.

(e) The combined cylinder and boiler efficiencies are given as contours on Graph 12. The overall efficiencies on the basis of work done at the drawbar at constant speed on the level are shown by contours on Graph 10.

3. THE FACTORS OF THE PRINCIPAL RELATIONS AND EFFICIENCIES.

(a) Admission and Exhaust Steam Temperatures with respect to Steam Rate are shown in Graph 23. At maximum rates the steam is superheated 350°F (temperature 750°F). Mean exhaust steam temperatures at discharge rise by 90°F to 350°F at maximum rates.

(b) Combustion Gas Temperatures at Rejection with respect to Gas Flow are given in Graph 24. These follow the steam temperatures at a little lower level.

(c) Firebox Gas Temperatures with respect to Gas Flow, as measured just before entry to the tube system, are shown in Graph 25.

They rise to 2000°F at maximum rates of working but the maximum gas temperatures, occurring elsewhere in the firebox, are most likely to be about 50°F higher at the lower end and 300°F higher at the higher end of the range.

(d) The character of all relations (a) to (c) is such that a linear relation appears to exist between their logarithms, Graph 26.

(e) The Gas - Steam Relation of the draughting arrangements appears to be linear, Graph 27, the mean value of the ratio being 1.63 : 1.

(f) Draught losses through the boiler in respect to Gas Flow are shown in Graph 28, which has been constructed from Graph 29, in which the logarithms of observed values have been plotted.

(g) The Weight of mixed gas per pound of coal fully burned is given in Graph 30; this shows a slight decline with increase in rate of combustion.

(h) Rate of Combustion with respect to Rate of Firing is given in Graph 31, the former being defined as the rate at which coal is fully burned.

(i) The Boiler Heat Balance is given in Graph 32 on two bases, one on dry coal fired and one on coal fully burned.

These show clearly that loss of unburnt coal is the greatest factor in the decline of boiler efficiency with firing rate.

(j) The Steam - Air - Combustion Cycle is illustrated by Graph 33, which is in 4 quadrants. The top right is Graph 27, the lower right Graph 14, the lower left Graph 31. The upper left shows the gas ejected per pound of coal fully burned as the top curve. The lowest curve in this quadrant is the minimum air theoretically required to support combustion. The intermediate curve shows the air supplied as deduced from the gas ejected. The excess air shows the adequacy of the air supply and the general effectiveness of the draughting arrangements up to the maximum rate of combustion. The following example illustrates the use of the diagram :-

For the production of 20,000 lb. of steam per hour, 33,000 lb. of gas per hour are produced and ejected, top right quadrant. Projecting the steam rate vertically downwards to the curve of the lower right quadrant and then horizontally to the vertical scale on the left indicates that 2,600 lb. of coal per hour are required. Projecting this horizontally to the curve of the left hand quadrant and then vertically to the horizontal scale shows that 2,300 lb. are fully burned in the process. Continuing the projection vertically into the top left quadrant, it may be seen that air 30% in excess of theoretical requirements is supplied, which ensures efficient combustion.

(k) The Nozzle Differential Pressure relative to Steam Rate is given in Graph 34. This was used as a control on the Controlled Road Tests and when indicating on the testing plant. The relation is connected with nozzle conditions which are of importance in the study of draughting efficiency.

(l) The Isentropic Heat Drop of the Exhaust Steam in discharging to atmosphere, shown in Graph 35, is also important in the same connection.

(m) The Steam - Gas - Draught - Differential Nozzle Pressure Relation is given in the 4 - quadrant diagram of Graph 36. The upper right has been constructed from Graph 34; the upper left is Graph 27, the lower left is the final smokebox draught relation from Graph 28. The curve of the lower right quadrant has been generated from the curves of the upper right and lower left quadrants. From this it may be seen, as an example, that, when 25,000 lb. of steam are being exhausted per hour, the gas flow is 42,000 lb/hr., (top left), for the ejection of which a draught of 4.6 inches of water is required (bottom left). The nozzle differential pressure is then 2.4 lb. per sq. in.) bottom right.

4. ASSOCIATED RELATIONS

(a) The Total Resistance of the Locomotive on the level, relative to train speed is given by Graph 37. It is the difference between Indicated and Equivalent Drawbar Tractive Efforts, Graphs 12 and 10 respectively.

(b) The Specific Resistance of Coaching Stock on the level, relative to train speed, is shown in Graph 38. It refers to average conditions and was produced as an integral part of the Controlled Road Tests.

(c) Traction Performance and Efficiency

Whereas the Equivalent Drawbar Characteristics at constant speed on the level suppress the effect of gradient, acceleration and mass in order to form a basis for the comparison of the locomotive with others similarly treated, these effects have to be taken into account in performance and cost of energy applications for the individual locomotive.

The combination of the Equivalent Characteristics and Train Resistance shown in Graphs 39 and 40 is not only more convenient for such purposes but provides a ready reference for performance and efficiency with a variety of passenger train loads.

The graphs refer to the actual or traction dbhp and dbte that is exerted on the trailing load, as may be measured by a dynamometer. These are independent of gradient and acceleration whilst the steam rate can be assumed to remain constant. Variation in loading however introduces an important and independent variable - the trailing: gross mass ratio, k - which accounts for the difference between tractive effort and horsepower transmitted to different loads in otherwise similar circumstances, as explained in Diagram 5 of Bulletin 16.

Graphs 39 and 40 show respectively how the traction te/k and traction hp/k vary with train speed.

To make them applicable to any given load, values of te/k, hp/k and efficiency /k read from them have only to be multiplied by the k value for the given load. (k. Coal per dbhphr has to be divided by k). Contours of efficiency/k (which of course refer to the work done on the trailing load) are shown on Graph 39.

Thus, for a trailing load of 314 tons, k is 2/3 and the tractive effort at 60 mph with a steam rate of 26,000 lb/hr. is 10750 x 2/3 = 7167 lb., where the first figure is obtained from Graph 39. The efficiency is 9.5 x 2/3 = 6.3% where the first figure is also read from Graph 39.

If any ordinate of speed on Graph 39 be considered with respect to the efficiency/k contours which cross it, it may be noted that efficiency /k reaches its maximum in the middle range of steam rates, though the rate of change of efficiency in this vicinity is relatively small. For all practical purposes, the portion of the ordinate cut by the hatched band on the graph is of equal and maximum efficiency. The same applies to all other ordinates of speed, though the maximum value of efficiency /k varies from one to the other. The hatched band actually covers all values on any ordinate which lie within 2% of the maximum for the ordinate.

In the smaller inset diagram these maximum values of efficiency /k, also given as minimum values of k. coal per dbhphr, are shown as a curve. For values outside the hatched band the efficiency /k contours may be used, or they may be calculated from the tractive effort, speed and fuel rate.

The substantial influence of the trailing: gross mass ratio on traction efficiency has been demonstrated by tests with a diesel-electric locomotive on a variety of loads and described in Bulletin 16.

It is most informative to redraw Graph 39 for a number of trailing loads as shown in Graphs 41 for 300 tons, 42 for 400 tons and 43 for 500 tons. This is done by multiplying all tractive effort /k values in Graph 39 by the individual values of k for the loads, which are .678, .737 and .778 respectively. Performances may then be read directly. Referring to Graph 41 (300 tons), consider the train running at 35 mph with the locomotive steaming at 26,000 lb/hr. as represented by the point A. If then it meets a rising gradient of 1 in 100, the ordinate AB, where B lies on the 1 in 100 R line, represents a positive accelerating force, since the tractive effort is the greater magnitude. The train would accelerate until this force vanishes at X, which is seen to be at 45 mph. The remainder of the gradient is then worked at this speed. Next consider the train running at 60 mph with the locomotive steaming again at 26,000 lb/hr. as represented by D. If the train meets another rising gradient of 1 in 100, the ordinate DC, where C lies on the 1 in 100 R line, represents a negative accelerating force, because the tractive effort is the smaller magnitude. The train would decelerate until a speed of 45 mph is reached when the difference vanishes (point X again). Actual drawbar efforts in all cases may be read by projecting points horizontally to the vertical scale. Thus tractive efforts are 9700 lb. at X, 12,000 lb. at A and 7350 lb. at D. Converting to hp. and dividing into the coal rates shown against the steam rates gives the coal per dbhphr.

All intersections such as X have the same significance and there are obviously numerous conditions which may be treated as in theexample.

5. THE NATURE OF THE TESTS

(a) Tests on the Testing Plant.

(i) Determination of the coal and water rates

Rates of evaporation and firing can be reliably determined only by direct measurement over a substantial period of time, with a minimum of variation in the rates during this period. It amounts to the virtual suppression of the storage capacity contained in the steam space and firebed. With constant speed and uniform boiler pressure, the steam demand is kept constant, and this is required to be balanced continuously by a uniform rate of firing. It is, perhaps, the most difficult part of steam locomotive testing because it requires high standards of firing and control. It is then only reliably realised when the air for combustion is in adequate supply so that the fuel requirements can be unmistakably indicated by the tendency of the boiler pressure to rise or fall.

In all tests in this series, the actions of the fireman were guided but not instructed. The fuel was taken from a relatively small scuttle, which was replenished when it became empty with another weighed quantity or 'increment'. On these occasions, time and water consumption were observed. Variation in the increment rates from the mean of the preceding rates could therefore be kept under observation. The degree of these variations was indicated to the fireman for his guidance by individual simple 3 - light signal systems giving 5 aspects per signal. The quality of combustion from the smokebox gas analysis was transmitted to him in the same way and for the same purpose. The validity of the mean rates for the whole period was decided by the uniformity of the rates during the period of test.

Two representative tests are graphically illustrated in Diagrams 44 and 45. These combined firing and Summations of Increments diagrams are essentially coal and water consumptions plotted against elapsed time at intervals corresponding to the consumption of 2 cwt. of coal (the increment) in Graph 44 and 1 cwt. of coal in Graph 45. The quality of combustion at various points in the tests is indicated by the results of the smokebox gas analyses set out against the times of sampling. On the test reprepresented by Graph 44, the mean coal rate for the whole test is given as 3220 lb/hr., but the uniformity of conditions was such that this rate could probably have been determined within 3% from the time taken to fire only four increments in any period during the test, and within 1% from a series of such observations. The mean water rate for the test is shown as 23700 lb/hr. Again this could probably have been determined within 3% from the water injected whilst four increments of coal were being fired in any period during the test, and within 1% from a series of such observations.

The mean rates on the test represented by Graph 45 are lighter, the coal rate being 1990 lb/hr. and the water rate 16800 lb/hr. The value of the coal increment chosen for this was 1 cwt. Over any 5 of such increments, taken successively at random during the test, the rate would probably lie within 4% of the mean for the whole and within 1% from a number of such observations.

Between the plots of coal and time on both Graphs the coal lines are shown as a series of steps, each step representing the firing of a shovelful of coal. These lines graphically describe the response of the fireman to the demands of the boiler. They illustrate clearly the firing technique, which is traditional. Though the mean rates differ the pattern is the same, - a few shovelfuls fired in succession as the boiler pressure tends to drop, followed by a pause to note the effect.

At the start of the test the content and condition of the firebed is of very great importance, the content depending on the rate of evaporation which is being demanded. A firebed, which, during the test, proves sensitive and responsive in the manner described, remains constant in content.

At the highest firing rates, considerable disintegration of the fuel into small pieces, the size of large smokebox ash, occurred. This is characteristic of conditions near the grate limit. When large accumulations of these pieces occur, air supply is so seriously impaired that the period of constant conditions is limited. Tests where this limitation applied have been excluded from the results.

(ii) Indicated Horsepower

The indicating of the engine was done only on tests which ranked also for inclusion in boiler efficiency determinations, for clearly it is of prime importance to relate IHP directly with the steam and coal rates as well as with speed, cut off and pressure of admission steam. Some variations in steam rate and pressure occurs however close may be the control. Such variations are reflected in the differential orifice pressure, which enables the indicating periods to be selected to coincide with the mean value of the differential orifice pressure and thus with the mean steam rate.

Examples of Indicator Diagrams are given in Diagrams 46a, b, c and d. Co-ordination was made on Willans' lines, Graph 48. These, it may be seen, are to type. Minimum specific steam consumption occurs in the vicinity of the points of tangency of straight lines which spring from the origin as, for example, the line shown chain-dotted on the graph. The zone of maximum efficiency in the steam rate range is invariably predicted by the maximum mean temperature drop across the cylinders as shown in Graph 23.

Although admission steam temperatures increase with the steam rate, the exhaust steam temperatures ultimately increase at a greater rate, as seen in this Graph, due to reduction in the expansion ratio. This accounts for the position of the optimum rate for maximum efficiency and for the typical shape of the Willans' lines in the higher steam rate range.

Nevertheless, at 75 mph 28,000 lb. of steam per hour can be passed through the cylinders with a cut-off of just over 15%, producing 2250 IHP, and 32,000 lb. per hour with a cut-off of just over 20%, producing 2500 IHP.

Minimum specific steam consumptions do not occur in the very early cut-off range, which corresponds with low steam rates. This accords with the conventional pattern of the steam engine and gives to the Willans' lines their typical form in the low steam rate range. At the extreme end of this range, however, the specific steam consumptions produced by the tests are the least reliable because of the erratic behaviour of the cylinder relief valves which were fitted. Specific steam consumptions with the design of British-Caprotti gear provided are generally lower than obtainable with the normal piston-valve gear and maximum economy is sustained over a wider range of working.

In general, there is very good agreement between the steam consumption by heat drop and by indicator diagram especially at the higher speeds when IHP is substantial. But this agreement was not well established at low power when the behaviour of the relief valves was erratic.

Throughout the series of tests there was never any evidence of the inlet and exhaust valves leaking.

The steam-chest pressure remains very steady below 70-75 mph, Diagram 47a, but above this a severe pulsation develops, Diagram 47b. Though maximum pressure rises well above boiler pressure the minimum occurs during admission i.e. there is a "depressed" admission. There is no substantial evidence however that cylinder thermal efficiency is affected, probably because no heat loss is involved. The periodicity of the pulsation is governed by crank phasing and speed, but length and volume of steam passages are contributory factors in the production of the pulsation. The most troublesome effect is the vibration set up in all parts that are in association with the main steam pipes. Whilst indicators were directly attached to the cylinder casting as could be done at the Testing Plant the effect on indicating was not evident in any way.

(b) Controlled Road Tests

The road tests were conducted with normal loads under controlled conditions on the Controlled Road Testing System. In this the demand on the boiler is kept constant by the driver adjusting his cut-off to maintain the differential orifice pressure at a constant amount, this being shown by a special gauge conveniently situated for the purpose. Train speed of course varies and the test is planned so that gradients cause speed variation under constant steam rate conditions between 20 mph and 85-90 mph for express passenger locomotives. Measurements of coal and water rates follow precisely the same pattern as described in connection with the constant speed testing plant tests and all the aids to control then provided, were provided also on the road tests.

The diagrams here produced to illustrate two examples of this type of test include the Summations of Increments Diagrams 50 and 53; with the exception of the omission of the firing steps, these are comparable in all respects to Diagrams 44 and 45.

The coal increments were weighed previous to the tests and put up in bags, which were carried in the coal space of the tender. A temporary scuttle was formed, into which each increment was tipped and from which the coal was fired. The principle of the summations of increments method, as previously described, permits of a fairly close prediction of the final rate from early observations, which gets more accurate as the test progresses. By commencing observations during the preliminary "warming-up" period, the water rate is known with considerable accuracy at the start of the test proper. By keeping the rate of injection under close observation from the dynamometer car at one minute intervals, it is relatively easy to keep a constant rate of injection which matches the constant demand of the cylinders. This makes the determination of the water rate independent of the effects on water level of gradient, acceleration, and other disturbances.

In the interests of accuracy the exhaust steam injector was made to operate on live steam only and the overflow of both injectors was returned automatically to the tender, the return being visible to the fireman.

As energy is fed into the cylinders at a constant rate, it is only to be expected that the dbhp exerted on the trailing load should remain very constant over a wide speed range. This may be seen from the character of the curves of Graph 40, which are only scaled-up actual dbhp characteristics.

Advantage is taken of this in setting the control conditions on each test run. The schedule of the train is planned to cover the speed range required on the test route on the basis of a certain dbhp per ton of trailing load. Although the differential orifice pressure indicator is set to the rate estimated to be required by the load on the particular test run, using the relation of Graph 34, final adjustment is left to the later stages of the preliminary warming-up period when the HP shown by the dynamometer is made the required multiple of the tonnage of the particular load. Varying the load from one test to another varies the steam rate and enables the whole practical range of steam rates to be covered during the series.

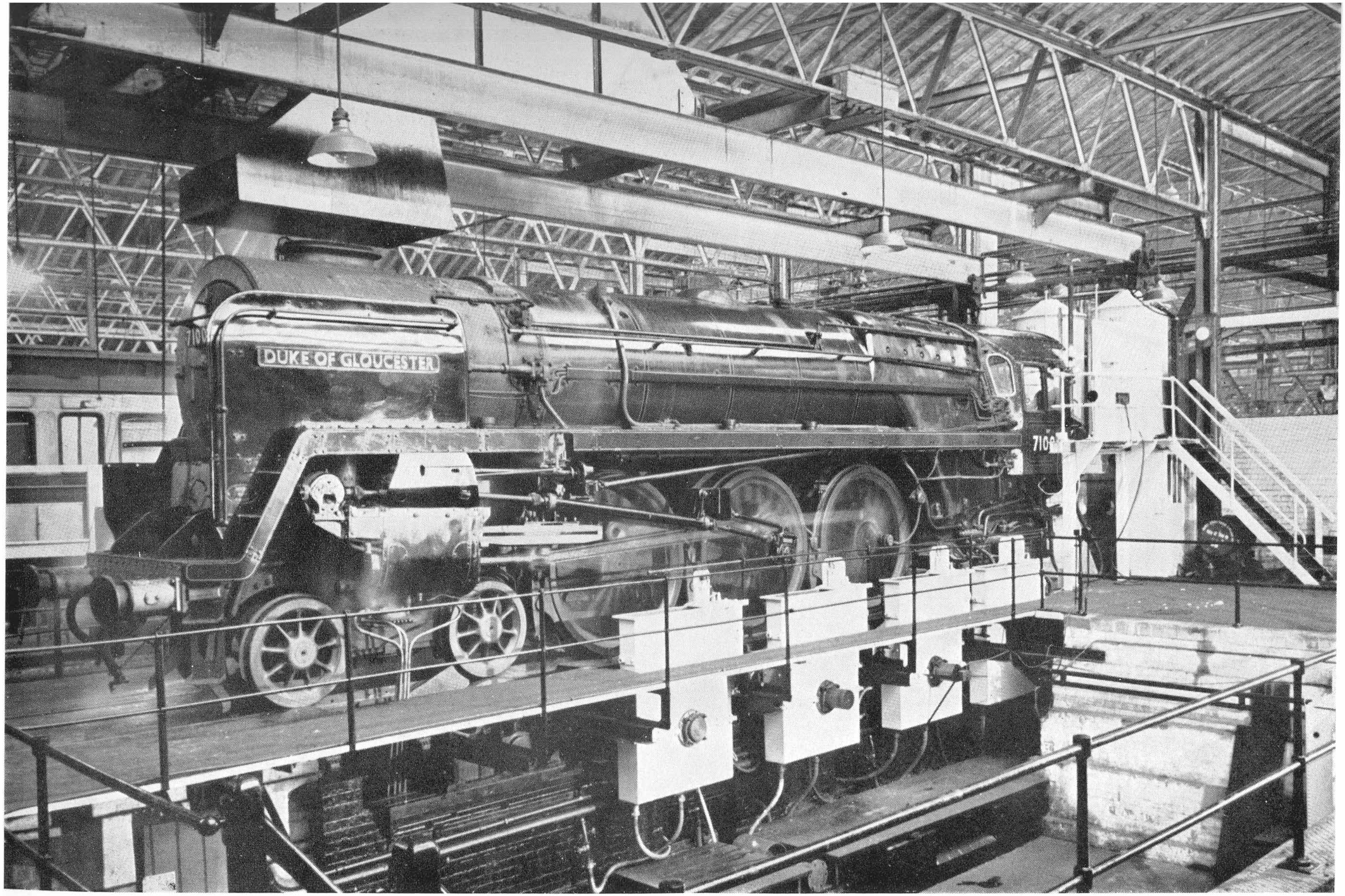


Photo B.R.(W.R.)

No. 71000 undergoing tests on the British Railways, Western Region Plant at Swindon.

No. 71000 *passing Didcot, Western Region, with a load of* 586 *tons at* 80 *m.p.h. on the Controlled Road Test illustrated by Graphs* 51 *and* 54.
*Actual Drawbar HP.*1478
IHP 2400.
Cylinder Steam Rate 30,000 *lb./hr.*
Coal Rate 4850 *lb./hr.*

The usual test route being subjected at the time to low speed restrictions because of bridgework, a route taking a hairpin course was chosen, Diagram 49, this being the Up Bristol to Paddington main line from Swindon to Reading West Junction, through the loop line to Oxford Road Junction, and then proceeding on the Berks and Hants main line to Westbury. The return was made over the same route. It was a little unfortunate that a severe temporary permanent way restriction in force at the time at Patney, reduced the headway of the express train in front, so that the tests were frequently shortened by signal checks in the neighbourhood of Savernake and Pewsey. Nevertheless none of the tests were rendered invalid. Speed had to be reduced on occasions to observe speed restrictions, this being done by maintaining the steam rate against the brakes. Only the force measurements during these periods were therefore invalid.

Diagram 52 graphically describes a test when the trailing load was 459 tons (trailing: gross mass ratio k = .745) the steam rate 22910 lb/hr. and the coal rate 3139 lb/hr., both after deduction for the requirements of the ejector. The values of actual dbte when plotted against the corresponding speeds lay on or about the curve D of Graph 51. This is qualified by the particular value of k for this test.

As with similar curves from other tests, each with their individual values of k, curve D was reduced to a common standard by dividing by its particular k value, .745, this producing the curve B.

The small circles on the speed curve of Graph 52 were the actual speeds attained as given by the Dynamometer Car records. Curve E of Graph 51 is the mathematical complement of the tractive effort curve D and is such that the two produce, by calculation, the speed curve which best fits the recorded values as shown by the full line speed curve.

The actual or traction dbte curve D of Graph 51 is such that it divides any ordinate between curves C and E in the ratios of the masses of the locomotive and trailing load. Curve C is the equivalent dbte at constant speed on the level.

Diagram 55 graphically describes a test at a high rate of working when the trailing load was 568 tons (trailing: gross mass ratio .789). The steam rate was 30,000 lb. per hour, and the coal rate was 4850 lb. per hour, both after adjustment for ejector requirements. Graph 54 shows the curves corresponding to those of Graph 50. Curves D and E of Graph 54 are shown verified in Graph 55 in the same manner as in Graph 52.

All results of road tests were co-ordinated on Willans' lines of steam rate against traction dbte/trailing: gross mass ratio. This co-ordination is shown on Graph 56, from which Graphs 39 and 40 were constructed.

Similarly Graphs 10 and 11 were produced from a co-ordinated set of Equivalent dbte curves (as curves C of Graphs 51 and 54).

The total resistance curves of each test were divided by the tonnage of their particular loads to produce the common specific train resistance curve, Graph 38.

A wind station was established at Reading for the duration of the test and from the recordings of the station adjustments for wind condition were made, but these were small as the winds were on no occasion strong.

(c) Reconciliation of Testing Plant and Road Tests

Results from the road tests were in good agreement with those of the testing plant tests. Where results of individual tests are plotted in the various graphs, those from each type of test may be distinguished. It may be noted that, where differences may be considered significant, draught and gas flow rather than heat transfer are concerned and these imply freer air and gas flow under road conditions without noticeable effect on efficiency.

6. MECHANICAL CONDITION

The engine had had only a small mileage in service before testing commenced. Test mileage was 7450.

Heavy wear of piston rings occurred, rings having to be renewed after about 2400 miles. No reduction in rate of wear followed an appreciable increase in oil feed. After the completion of the tests, the parent design office modified the position of the oil feeds and the wear rate is now satisfactory.

The poppet valves failed to rise when steam was turned on during the latter part of the testing plant series. An examination revealed a hard film of baked oil on the spindles which was undoubtedly due to the overlubrication described above.

The knuckle-joint pins and bushes of both coupling rods became very badly worn and wasted by fretting. These were renewed, with bronze bushes substituted for the original steel bushes.

The inside connecting rod big-end bearing failed on a Controlled Road Test and a coupling rod bearing had to be remetalled. Both failures were due to over-restriction of the oil feeds. On remedying this, no further trouble was experienced.

PART II

Performance and Cost of Energy of Movement.

PERFORMANCE AND COST OF ENERGY OF MOVEMENT

(1) The Coal per ton mile and its factors

The criterion of fuel economy is the fuel per ton mile. In locomotive-hauled passenger trains the useful load is always a small and somewhat variable fraction of the trailing tare load, which is consequently a predominating factor in performance. It is therefore convenient to assume that the total trailing load is proportional to the tare load for the purpose of calculation and to refer the coal per ton mile to the tare trailing load. This may be expressed, when desired, in terms of the net ton mile by division by the assumed useful load fraction and then carrying out any adjustment for the load fraction that statistics may show to be necessary; it is also, of course, readily expressed in terms of the gross ton mile. Generally, however, relative economy can be assessed on the present terms. In the present application the useful load has been taken as 10% of the trailing tare load.

The factors of the coal per ton mile are shown by the statement on the top of Graph 57. It may be seen from this that coal per ton mile

is proportional to the coal per dbhphr
is proportional to the dbhp per ton hauled
is inversely proportional to the train speed.

It is important to note

(1) That the first factor is a function of the 'built-in' thermal efficiency of the locomotive and that the second and third factors are functions of the duties required of the locomotive.

(2) That for a given duty, the running that makes the coal per ton mile a minimum in the formula is the most economic in fuel consumption.

(3) That the factors of the coal per ton mile are interdependent variables.

The practical solution to the problem postulated in (2) is such that makes the horse power per ton hauled approximately constant for the greater proportion of the speed range and in the neighbourhood of the average speed. It may be noted from Graph 40 that a constant traction horse power corresponds to a constant steam rate over a large part of this range, when a constant horse power per ton may be expressed as a constant steam rate or a constant fuel rate.

At low speeds the nominal horse power can be maintained only by increasing the nominal steam rate.

The factors of coal per ton mile are not critical in the neighbourhood of the average speed.

Discontinuities have to be assumed on steep falling gradients, on which speeds can rise to the reasonable maximum where this can be done without power; low steam rates with speeds much in excess of the average are uneconomic.

Discontinuities are also introduced by the necessary observance of speed restrictions. These and the booked stops are assumed to be approached by a period of drifting before the brake application, in order to conserve energy and to conform to practice.

On nearly all routes the proportion of the running which can be assumed to be at a constant horse power, or a constant steam rate, is a high proportion of the total running time under power so that these may be conveniently used to identify a particular duty with the rate of working. In this Bulletin this rate is referred to as the Ruling Rate and is generally expressed as steam rate but it may also be expressed as fuel rate or as traction horse power.

These principles have been used to examine the performance and fuel economy of the locomotive over a comprehensive range of main line services which are typical of the locomotive's normal duties. It is appropriate to choose for this purpose the Euston - Carlisle route of its owning Region, especially as it contains three sections of average undulating line, of which two are relatively free from and the other considerably subject to restriction, and a fourth section in which gradients are severe.

2. Cost of Energy and Performance Diagrams for a comprehensive range of main line services which are typical of the locomotive's normal duties.

The locomotive data and train resistance from Part I have been used in this examination. Grade 1A coal and working with the exhaust steam injector have been assumed. The resultant coal consumption is that for traction purposes only: consumption covering the ejector, live steam injector, various losses and steam raising is to be considered additional. All current permanent speed restrictions are observed and ideal operating conditions are initially assumed.

For reference purposes the definition of a maximum rate is desirable but difficult to state for a steam locomotive. For the present purpose a rate of 30,000 lb. of steam per hour has been assumed. On the one hand it is a rate which, by demonstration, can be more than maintained continuously with Grade 1A coal and barely maintained with Grade 2B coal. On the other hand it is wished to avoid higher but possibly transitory performances of which the locomotive is undoubtedly capable, because of the desirability of indicating reliable day-to-day working, rather than maximum performances.

The results of the examination are presented in the four Cost of Energy and Performance Diagrams, Graphs 58a, b, c and d. They may be described with reference to Graph 58a which is for the undulating Euston - Rugby section with few restrictions. The diagram is one in which tare load on the horizontal scale is plotted against overall time on the right hand vertical scale. Horizontal projection across the diagram to the left hand vertical scale indicates the average train speed. Thus an 80 minute timing corresponds to an average speed of 62 mph and the schedule which give minimum coal per ton mile for the timing is set out on its right. In practice the point-to-point times would be rounded off to the nearest half-minute as this is the minimum practical time period. The vertical ordinates of all loads from 200 tons to over 600 tons cut the 80 minute line within the boundaries of the diagram and above the "Assumed Limit" line. This range of loadings therefore falls within the capabilities of the locomotive for the 80 minute timing but for practical purposes the range must be limited at its higher end. The vertical ordinate for 320 tons cuts the assumed limit line at a timing 12 minutes less than 80 minutes. This is the nominal margin in the locomotive with 320 tons. It means that if the train left Euston 12 minutes late it could reach Rugby on time, if the road be clear, by working at its assumed maximum rate wherever possible; or leaving Euston on time, and whilst running to time, meets a 6 minute delay half-way in the journey. But for 600 tons the nominal margin is only 3 minutes on the whole distance which is insufficient to preserve the time-table under practical operating conditions, besides making a high physical demand on the fireman. The practical nominal margin would not be less than 6 to 8 minutes, which would limit the load to 460 - 500 tons for the 80 minutes timing.

Similarly, to provide for a load of 600 tons a timing of not less than 86 minutes is apparently required, as this gives a margin of some 8 minutes or more for the load. The best point-to-point timings can be interpolated between those for 88 and 84 minutes and rounded off.

It is useful to know the physical demand made on the fireman in firing the locomotive. As a point of reference, Ruling Rates which lie about the lines XX demand just over 3000 lb. of coal per hour with Grade 1A coal and about 3700 lb. per hour with Grade 2B coal.

For the cost in fuel consumption, the intersection of overall time and load is referred to the grid of constant coal per ton mile. Thus, the intersection of a 380 ton load with an 80 minute timing falls on the curve marked .13 lb. per ton mile. Total fuel consumption for traction is therefore .13 x 380 x 82.54 = 4075 lb, where 82.54 is the mileage. This is at the rate of 49.4 lb. per mile.

Conditions appertaining to maximum built-in efficiency (minimum coal per dbhphr) lie within the hatched band, which covers Ruling Rates that correspond to Steam Rates falling within the hatched band of maximum efficiency shown on Graph 39. It is important to note, however, that the band on the Cost of Energy and Performance Diagram must be read with respect to the vertical lines of constant load, for which k, the independent variable in efficiency, is constant, and not in respect to the horizontal lines of constant overall time, for which k varies because the trailing load varies.

Analyses of points on the Diagram may be readily made with the help of the formula on Diagram 57. Since the Ruling Rate is the predominating rate of working for any given condition, an approximation can be made by assuming this, with its corresponding coal rate and tractive effort at the average speed, to apply to the whole journey. Diagram 39 can be used for this purpose with the appropriate value of k. The dbhp per ton and coal per dbhphr required by the formula are then known, thus permitting the coal per ton mile to be evaluated approximately. This figure will of course be less than that given by Diagram 58a. Analyses are given here for two sets of points on this Diagram. The first set applies to points on a line of constant load (varying speed) as shown by D, E and F on the (vertical) 576 tons line. The second set applies to points on a line of constant overall time (varying load) as indicated by A, B and C on the (horizontal) 80 minutes line.

The steps in the respective analyses are shown in Tables 4 and 5. The estimated factors for the first case have been plotted separately on Diagram 57a, together with their product - the estimated coal per ton mile. The coal per ton mile from the Cost of Energy Diagram is also given and the two are seen to be proportionate.

Starting from the F line in Graph 57a it may be noted that the hp per ton increases as the speed rises because of the extra energy required. The coal per dbhphr between the F and E lines remains sensibly constant and a minimum because these span the hatched band of maximum traction efficiency. These two in combination more than offset the effect of speed so that an increase in the average speed with a given load (and therefore with a common k) increases the coal per ton mile. In these circumstances, the coal per mile reflects the coal per ton mile, lines 8 and 7 Table 4.

The estimated factors in the second series (constant average speed, varying load), points A, B and C, are plotted in Diagram 57b. In this series, because the load varies, coal per dbhphr is influenced by the independent factor k. To show this, k. coal per dbhphr, and 1/k have been plotted separately. The first is shown to be relatively constant between the A and B lines, because these span the hatched band of maximum traction efficiency; thereafter it rises as the C line is approached. But 1/k falls as the load increases and this has the pronounced effect of displacing the efficiency band so that its minimum now lies between B and C, as shown by the curve of their product, the coal per dbhphr. The speed is constant so that its effect is common to each case. The factor k is therefore mainly responsible for the tendency for the coal per ton mile to be lowest with the heaviest load when the overall time remains the same. In these circumstances the coal per ton mile criterion conflicts with the coal per mile criterion, (lines 6 and 7 Table 5), which is so often used.

The influence of lower grade coal is shown by the dotted line for .15 lb. of Grade 2B coal per ton mile drawn on Graph 58a. At the left hand side of the diagram it coincides with the line for .13 lb. of Grade 1A coal per ton mile, but has commenced to diverge rapidly from that line before the middle of the diagram is reached. The divergence is due to the difference in boiler efficiency at equal rates of evaporation, which is very considerable at maximum rates. Even for the Grade 1A coal, the influence of the decline in boiler efficiency with rate of evaporation is pronounced. For instance the line for .13 lb. per ton mile would have fallen vertically down the 400 ton ordinate if the mean slope of the steam rate - coal rate relation between 16,000 and 24,000 lb. of steam per hour had been maintained up to 30,000 lb. steam per hour.

The line XX on Graphs 58a, b, c and d is the maximum power line of the 2000 hp. D E Locomotive No. 10203 from the data given in Bulletin 16. Overall running times for various loads, read from this line must, of course, have sufficient allowances added for the practical margin against contingencies, as discussed in Bulletin 16. For the same overall times the point-to-point times are the same for the two types of motive power because the constant horse power principle applies to both. The relative power classification of the two locomotives may therefore be assessed from the diagrams.

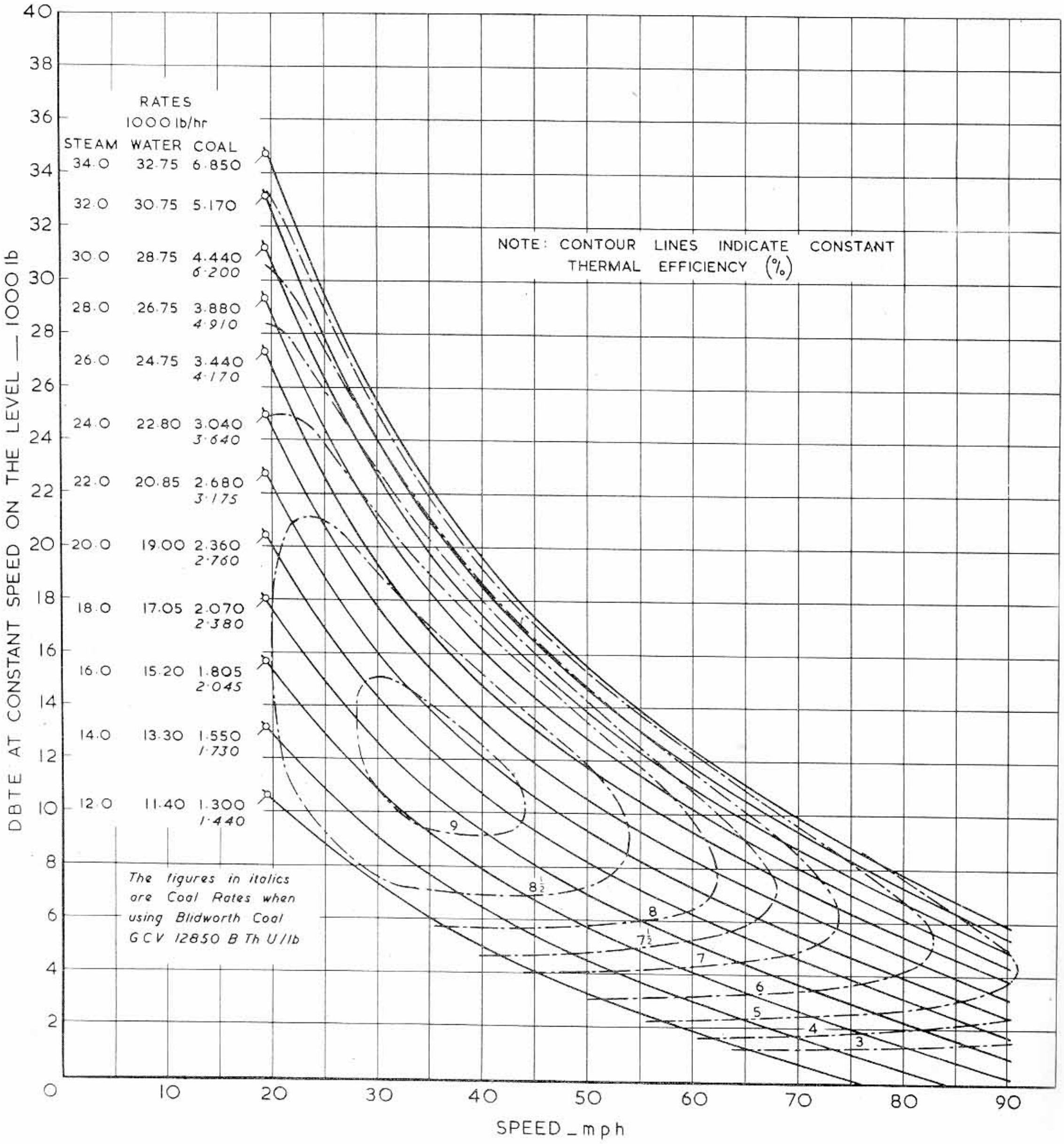
The pattern of Graph 58a is repeated in Graphs 58b, c and d. In the heavily graded section to which Graph 58d corresponds, it may be noted that the fuel economy is not adversely affected by heavily working the locomotive on the rising gradients when speed is low. In fact with the heavier loads there is some advantage to be gained. As a point of interest a train of

600 tons trailing load can be worked over Shap Summit at 24 mph without exceeding the Assumed Limit of continuous steaming (30,000 lb. steam per hour). This rate is the same as that of the Controlled Road Test with approximately the same load described and illustrated with reference to Graph 55.

As previously stated, the fuel consumptions given on the diagrams assume ideal operating conditions, which, of course, cannot be regarded as the general case. The permanent way, for instance, has to be repaired. Temporary speed restrictions for this purpose, and other minor disturbances to the timetable are expected to be met by adjustment in the running. Recovery, by the locomotive, of time lost in meeting these contingencies results in increased fuel consumption because of the additional energy required, irrespective of whether or not the thermal efficiency is significantly decreased by the heavier working rate entailed in the recovery. Referring again to Graph 58a it may be seen that the coal consumption for a 400 ton train timed at 84 minutes, Euston to Rugby non-stop is .12 lb/ton mile in the ideal conditions assumed. If 6 minutes are lost and recovered during the journey, thus making the equivalent running time 78 minutes, the fuel consumption is seen to rise to .13 lb/ton mile, an increase of 8%.

3. <u>The Criterion of Operating Costs</u>.

The criterion of operating costs is not dependent on any one factor but is the cost of the Net Ton Mile which is dependent upon a large number of factors both economic and technical, all of which must be considered. G.V. Lomonosoff has established an expression for the cost of the Net Ton Mile and this has been specially arranged for the Bulletin, Diagram 59, to illustrate the relative position of the cost of energy of movement (the last term in the expression) in the factors of the criterion of operating costs.

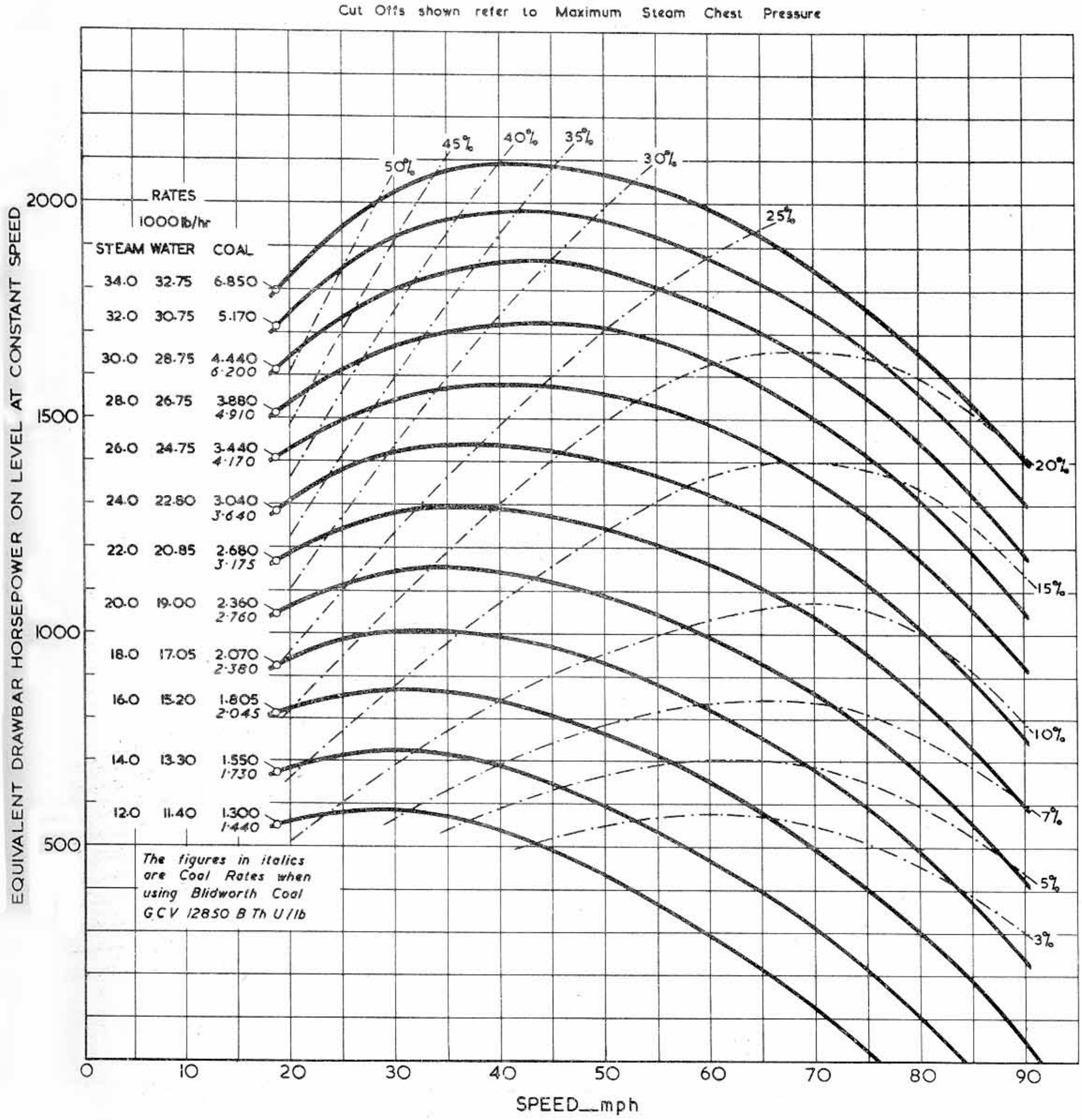


SOUTH KIRKBY COAL — 13550 BThU/lb

EXHAUST STEAM INJECTOR

EQUIVALENT DBTE CHARACTERISTICS

BR 8/71000/55



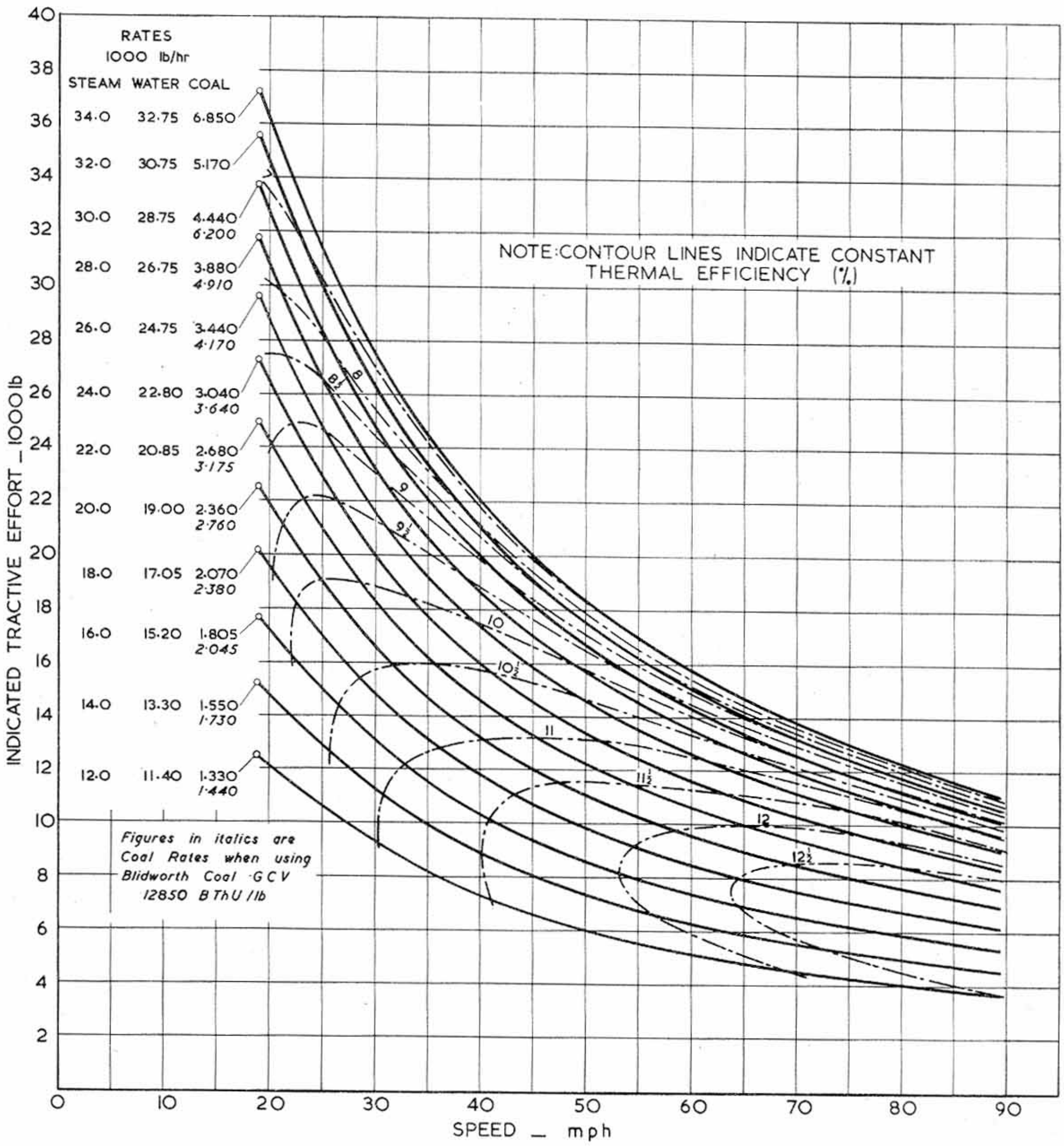
SOUTH KIRKBY COAL—13550 BThU/lb

EXHAUST STEAM INJECTOR

DRAWBAR HORSEPOWER CHARACTERISTICS

BR 8/71000/55

11

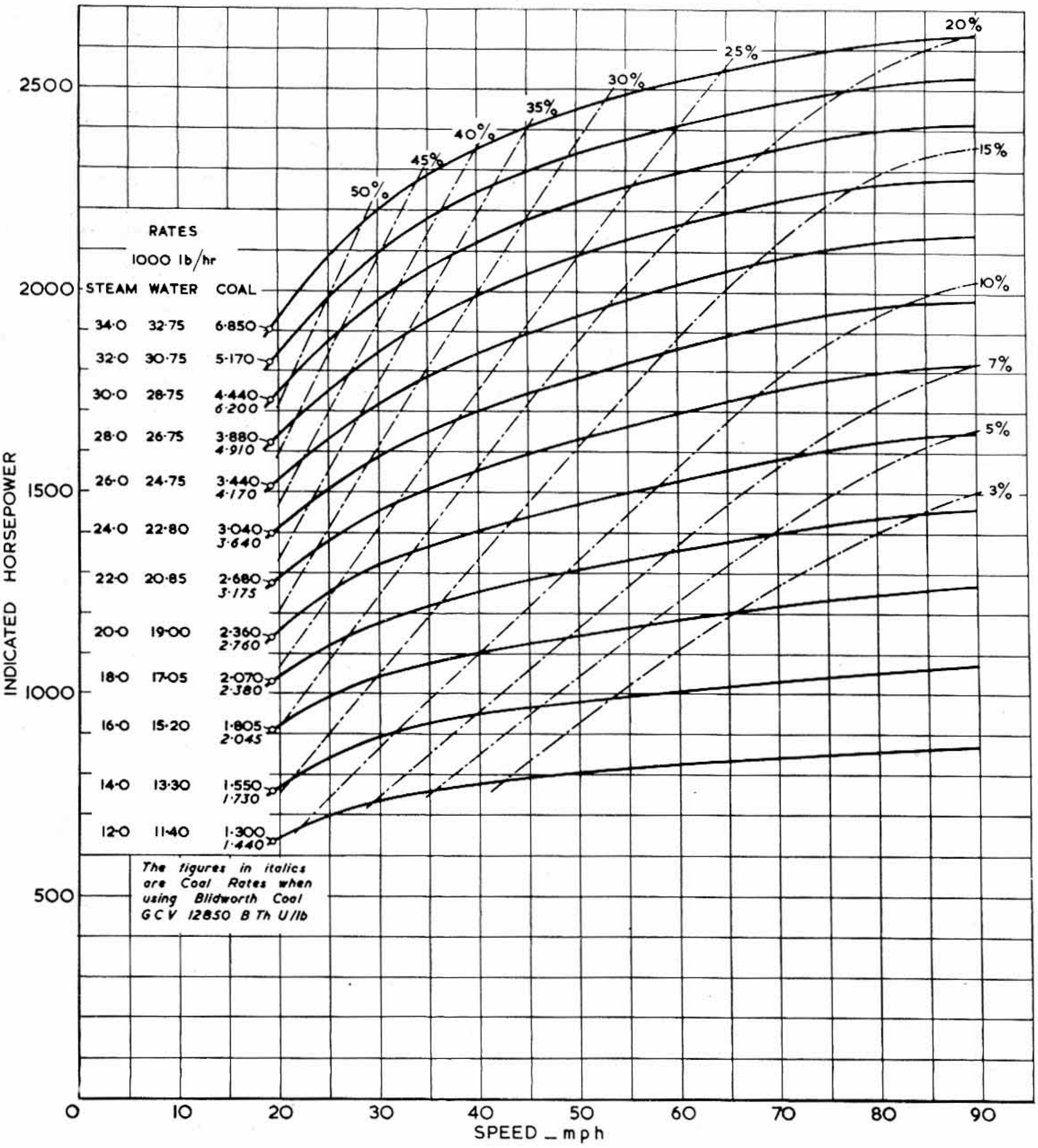


INDICATED TRACTIVE EFFORT CHARACTERISTICS & OVERALL EFFICIENCY REFERRED TO CYLINDERS

12

BR8/71000/55

Cut Offs shown refer to Maximum Steam Chest Pressure



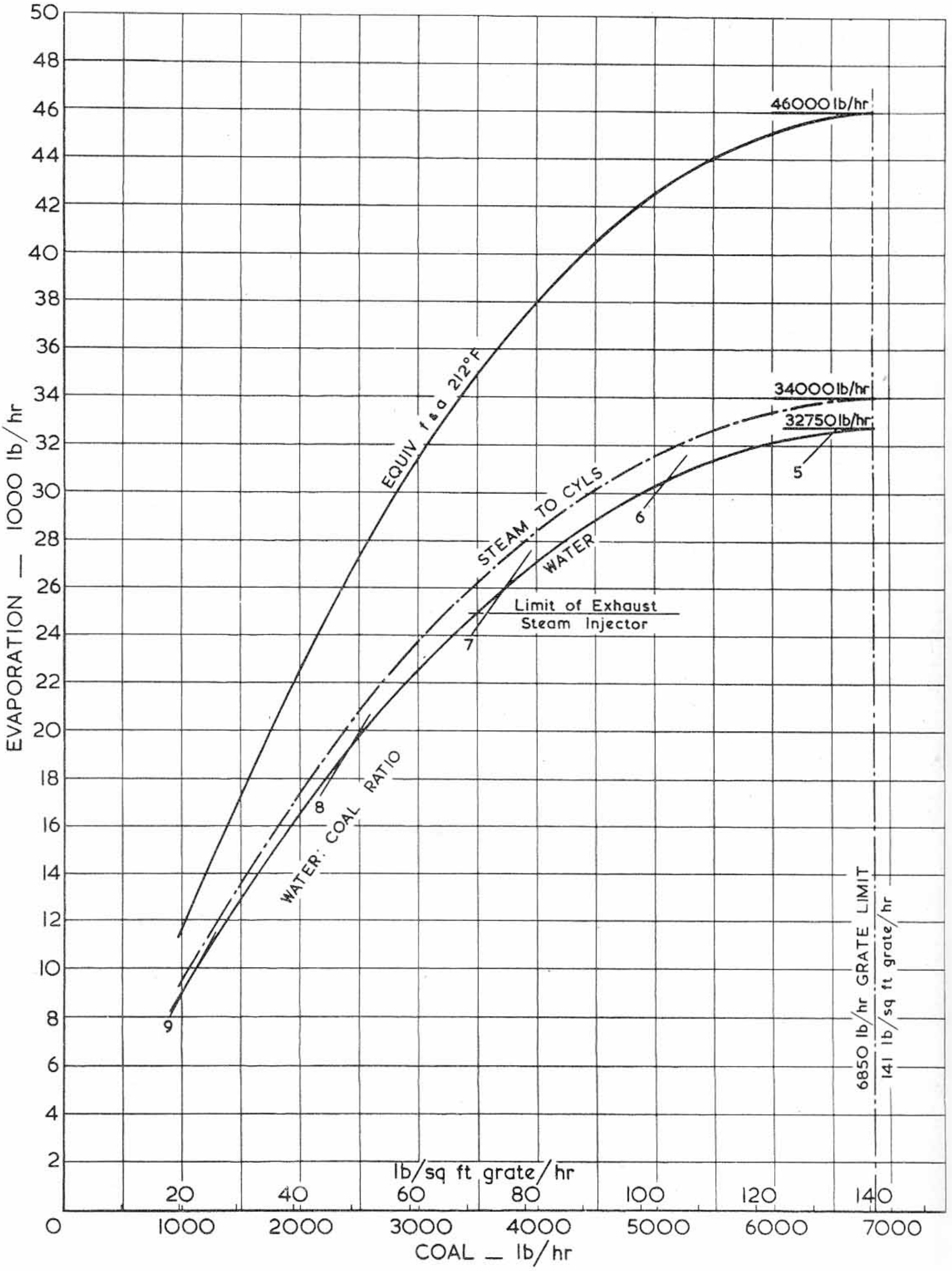
SOUTH KIRKBY COAL _ 13550 B Th U/lb

EXHAUST STEAM INJECTOR

INDICATED HORSEPOWER CHARACTERISTICS

13

BR8/71000/55

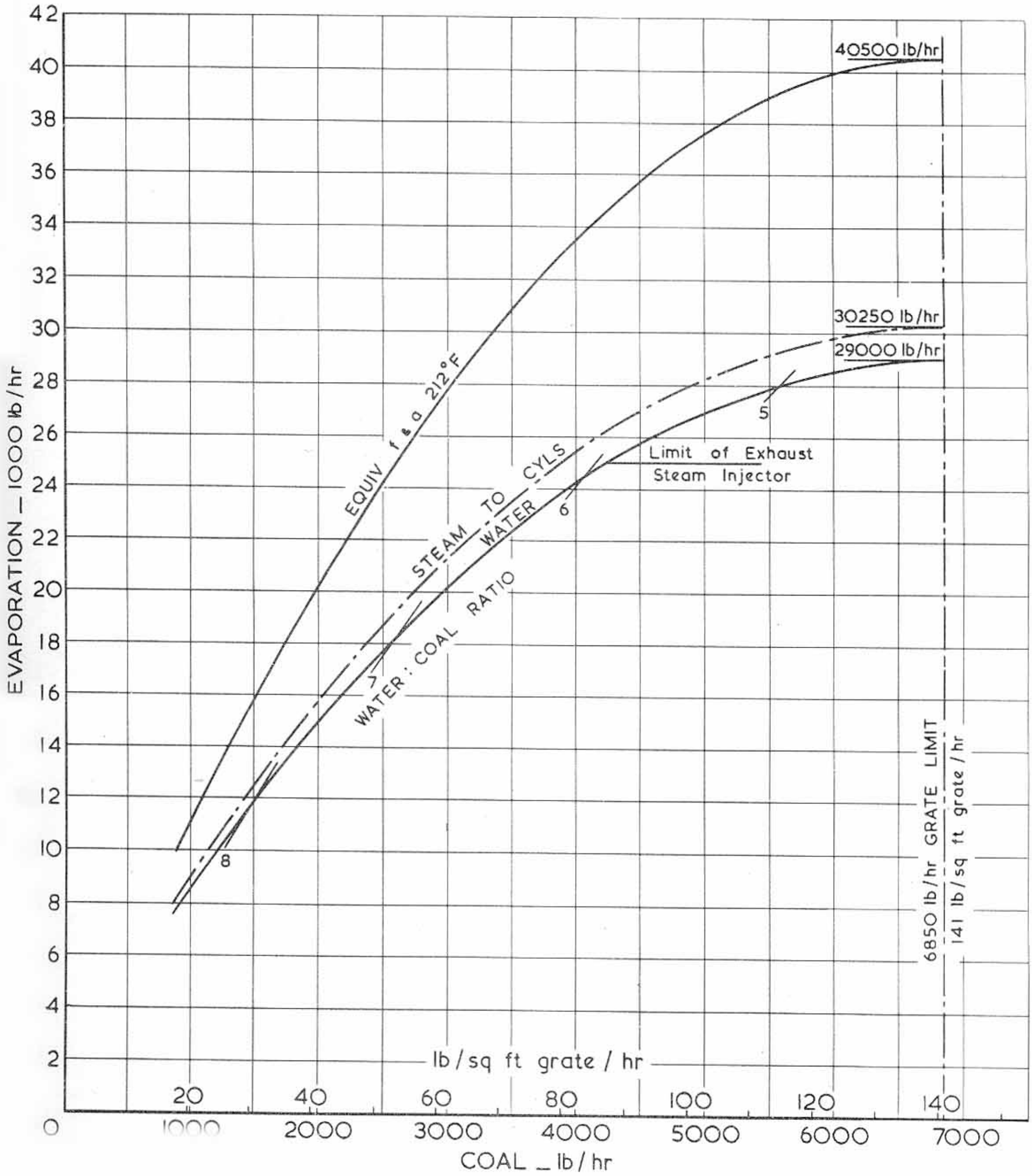


SOUTH KIRKBY COAL 13550 B Th U/lb

EXHAUST STEAM INJECTOR

EVAPORATION

BR8/71000/55



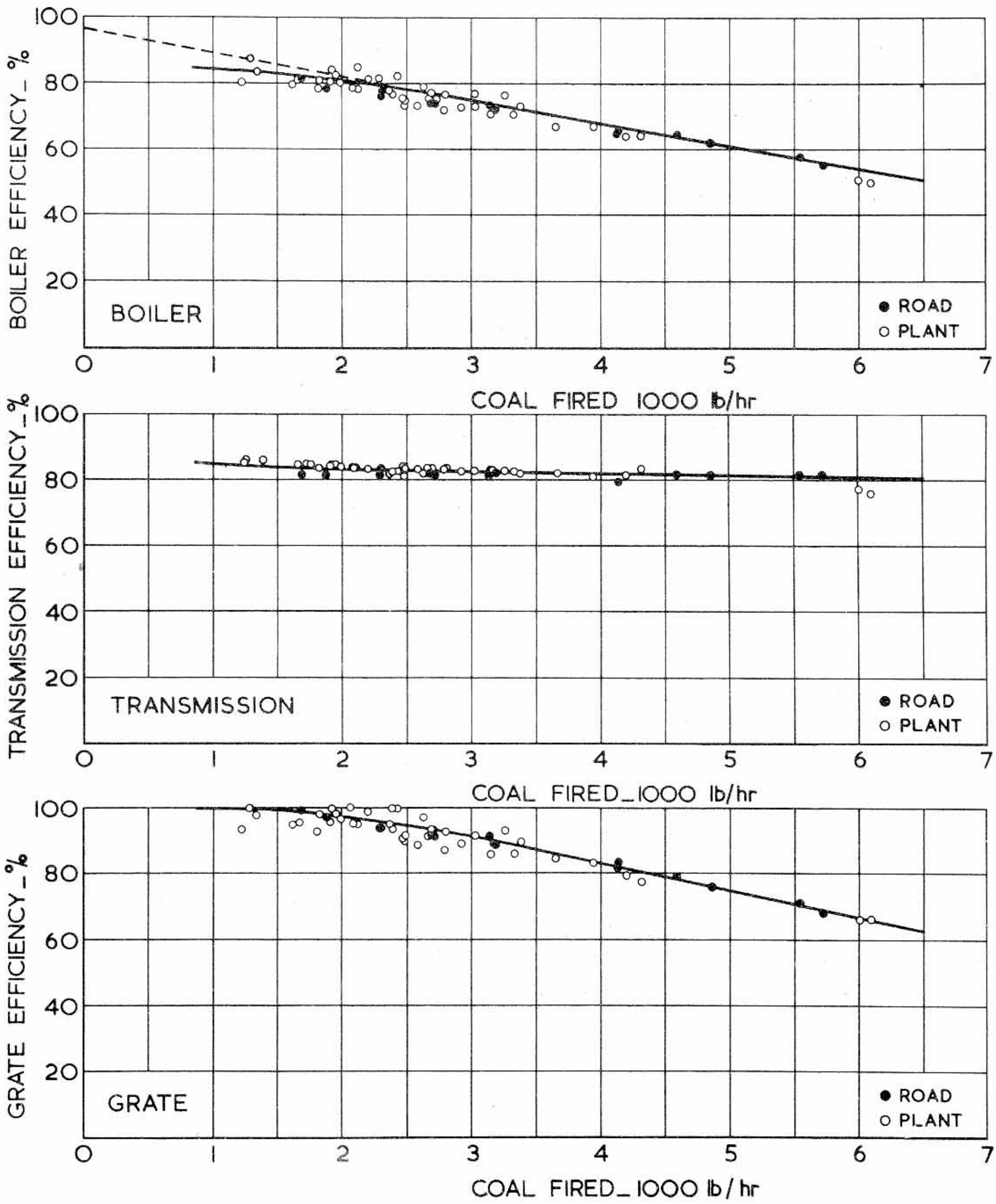
BLIDWORTH COAL _ 12850 B Th U/lb

EXHAUST STEAM INJECTOR

EVAPORATION

15

BR8/71000/55

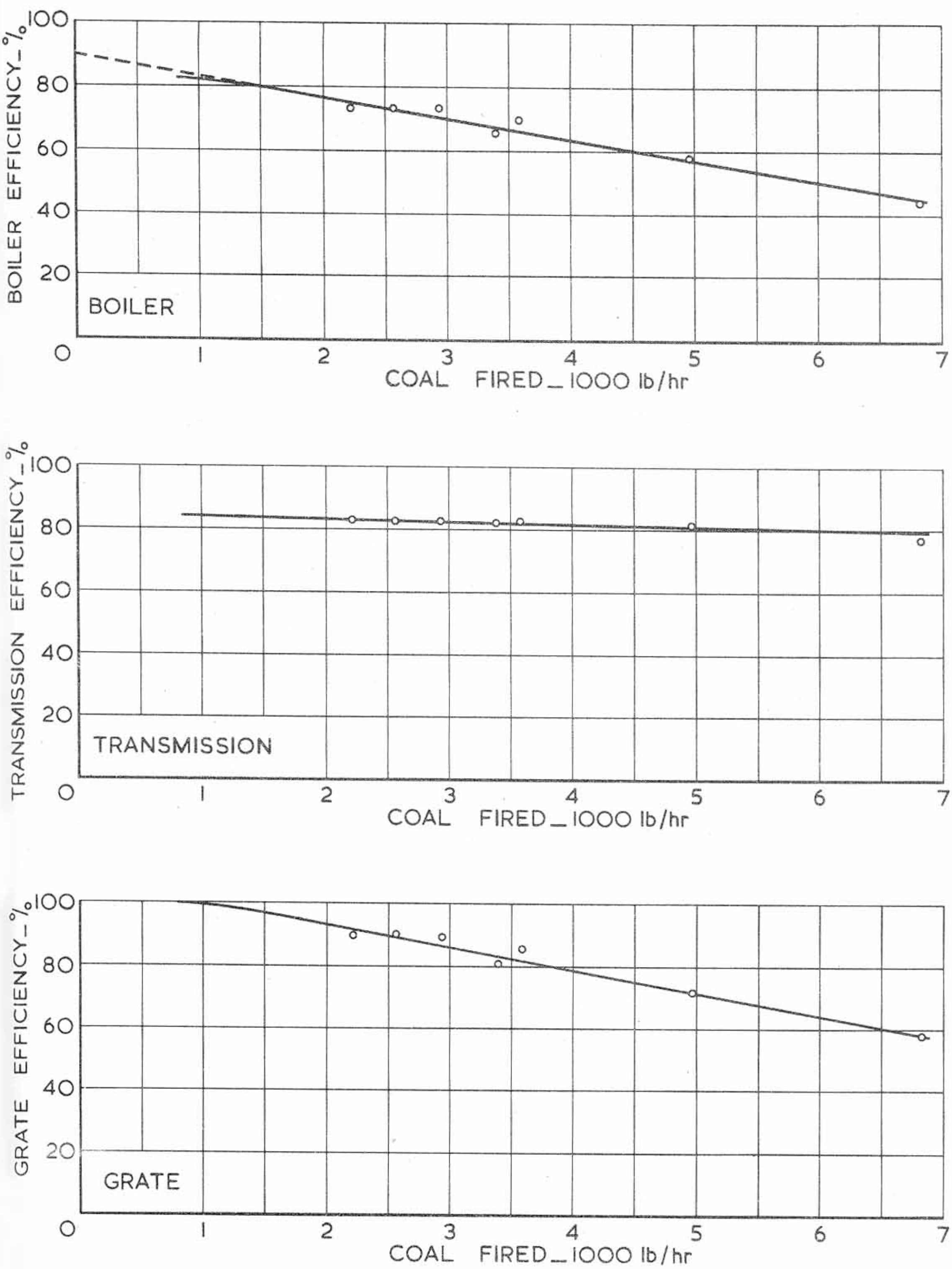


SOUTH KIRKBY COAL _ 13550 BThU/lb

EFFICIENCIES

16

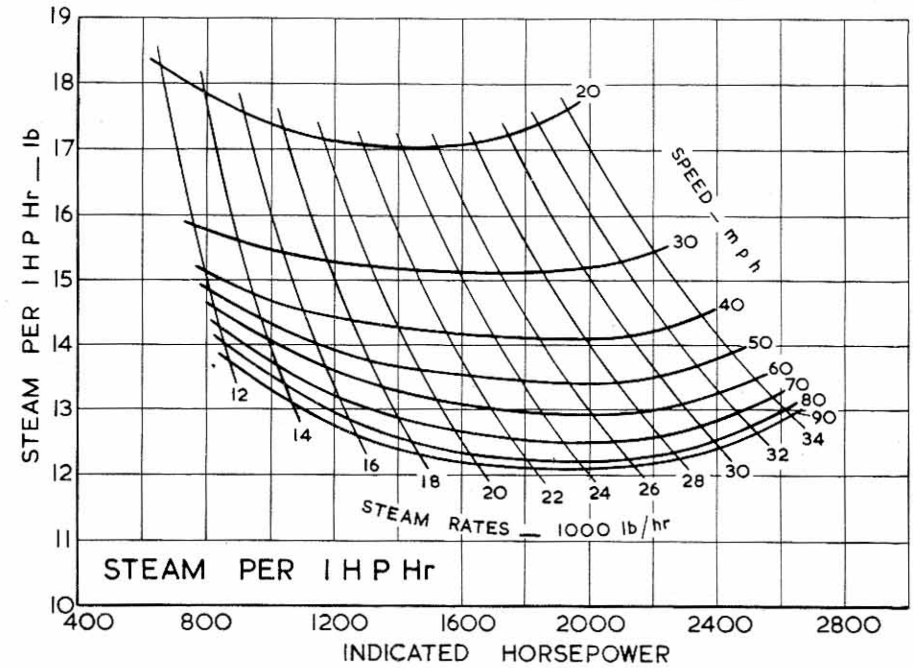
BR8/71000/55



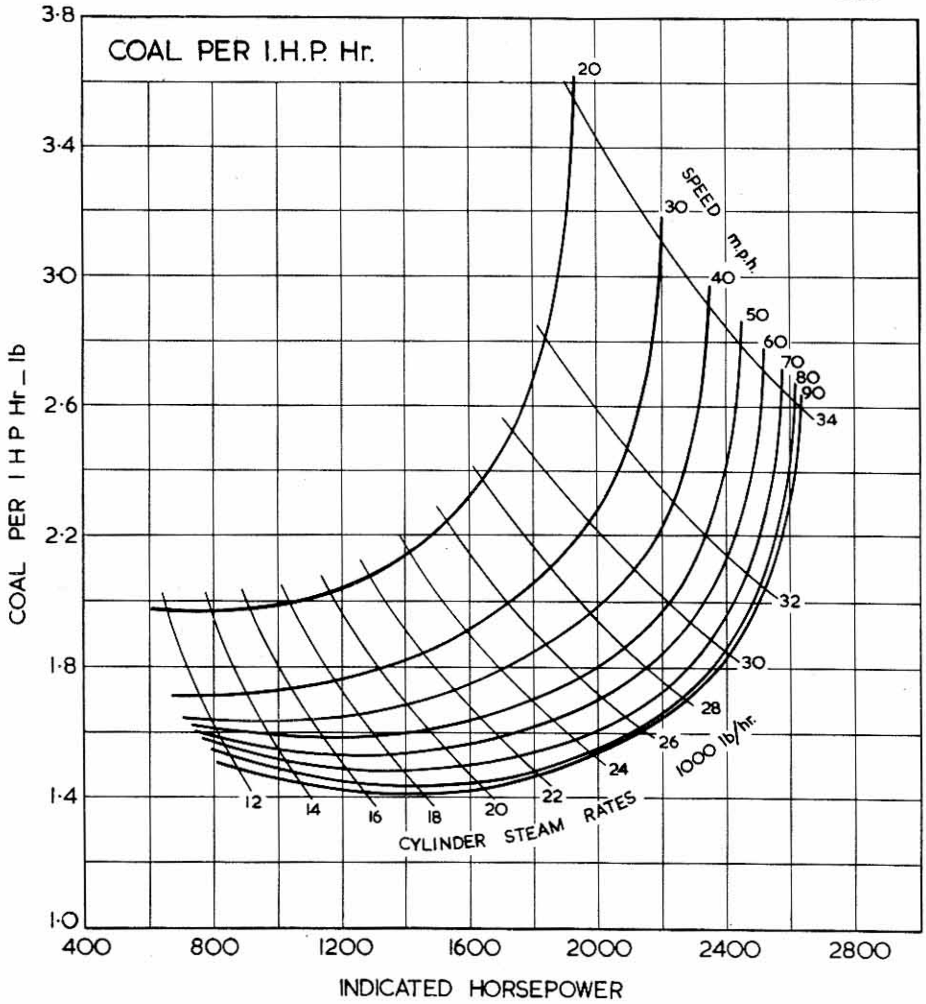
BLIDWORTH COAL _ 12850 B Th U/lb

EFFICIENCIES

17



18

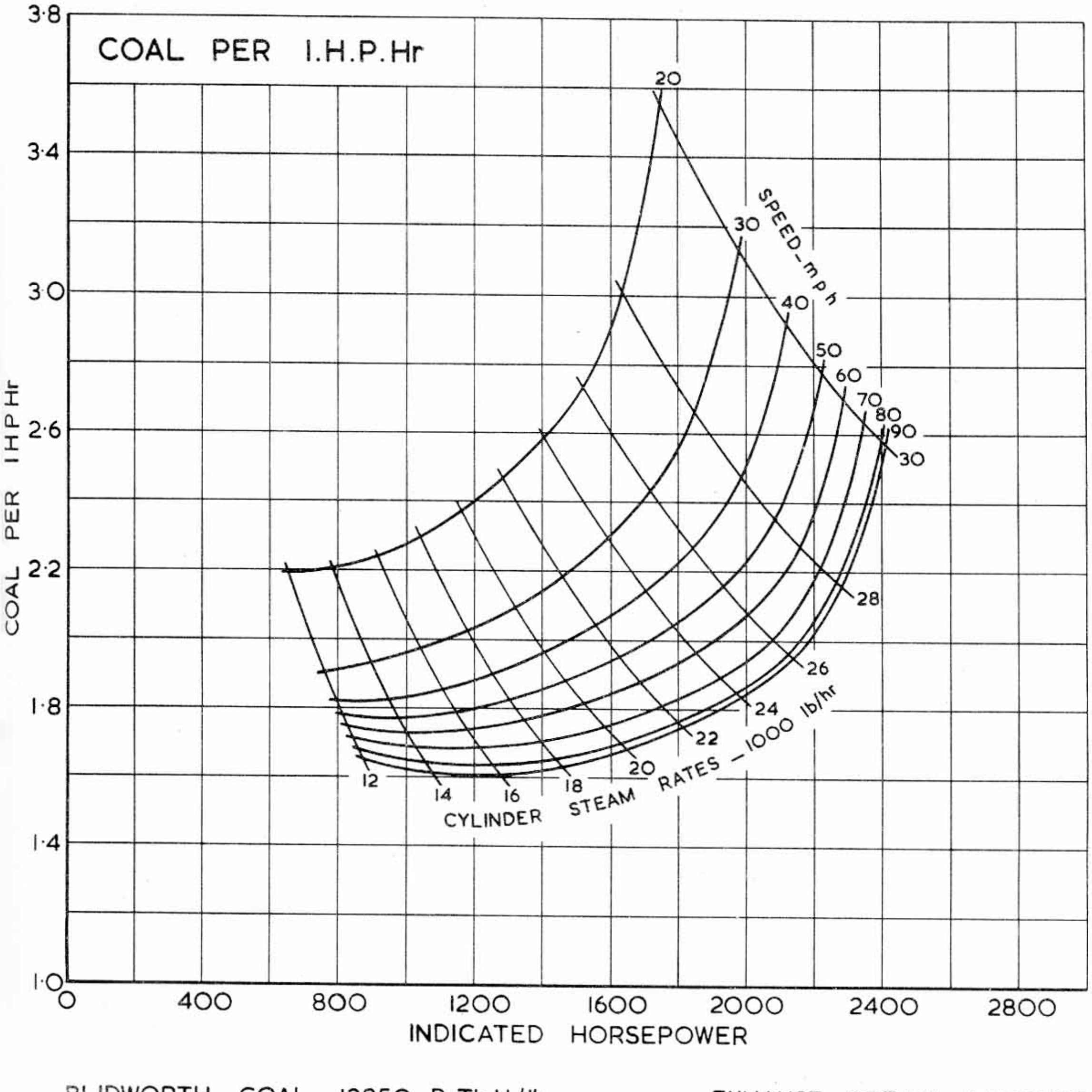


SOUTH KIRKBY COAL _ 13550 BThU/lb EXHAUST STEAM INJECTOR

STEAM & COAL PER I H P Hr

19

BR 8/71000/55



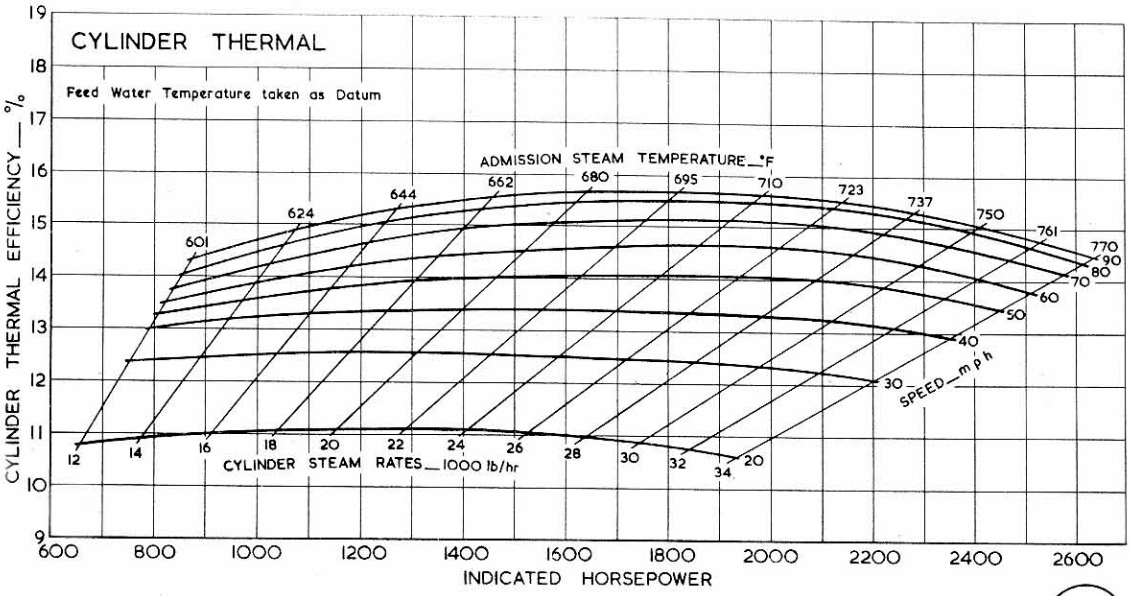
BLIDWORTH COAL – 12850 B Th U/lb

EXHAUST STEAM INJECTOR

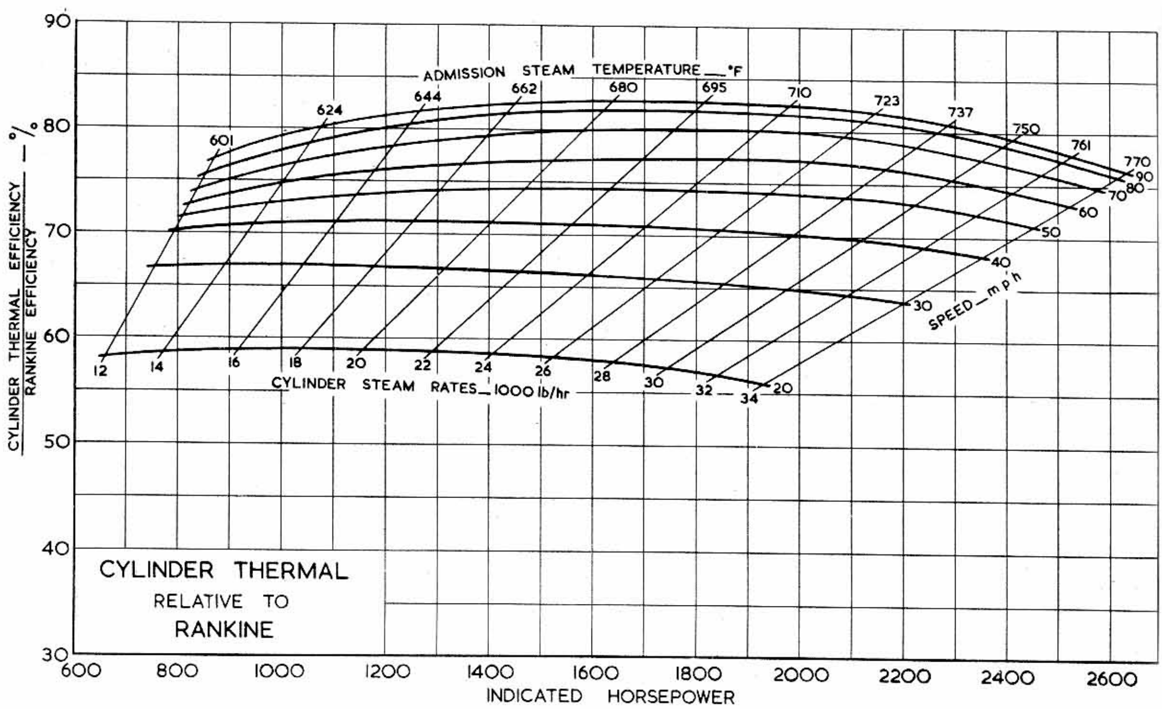
COAL PER I H P Hr

20

BR8/71000/55



21



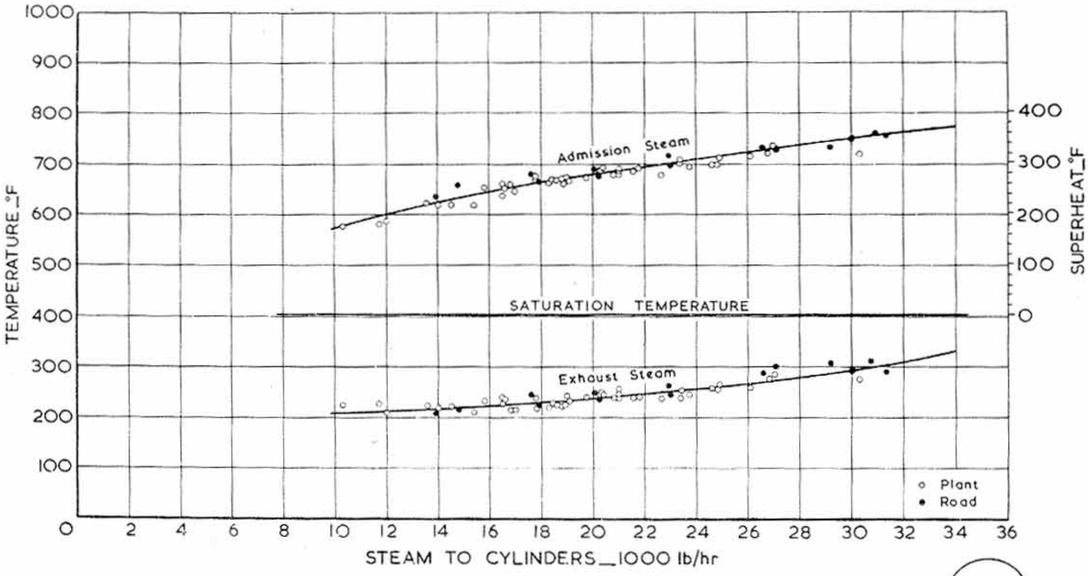
The Rankine Efficiency is based on an Admission Steam Pressure of 255 lb/sq in abs and Exhaust Pressures as shown in Graph 36

SOUTH KIRKBY COAL — 13550 B Th U/lb

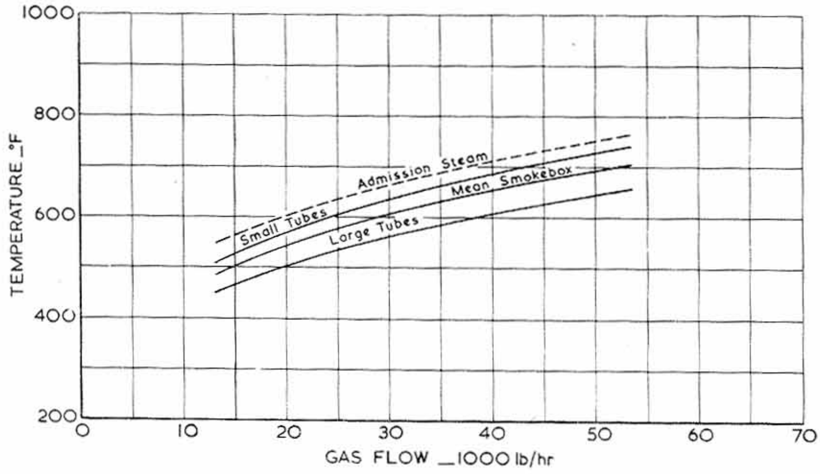
EXHAUST STEAM INJECTOR

EFFICIENCIES

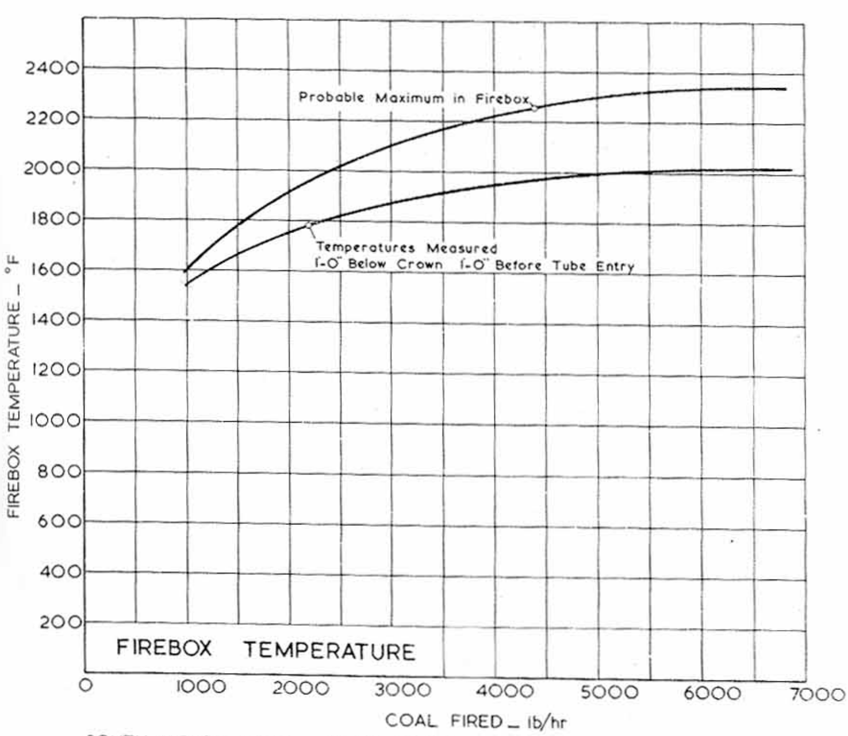
22



23



24

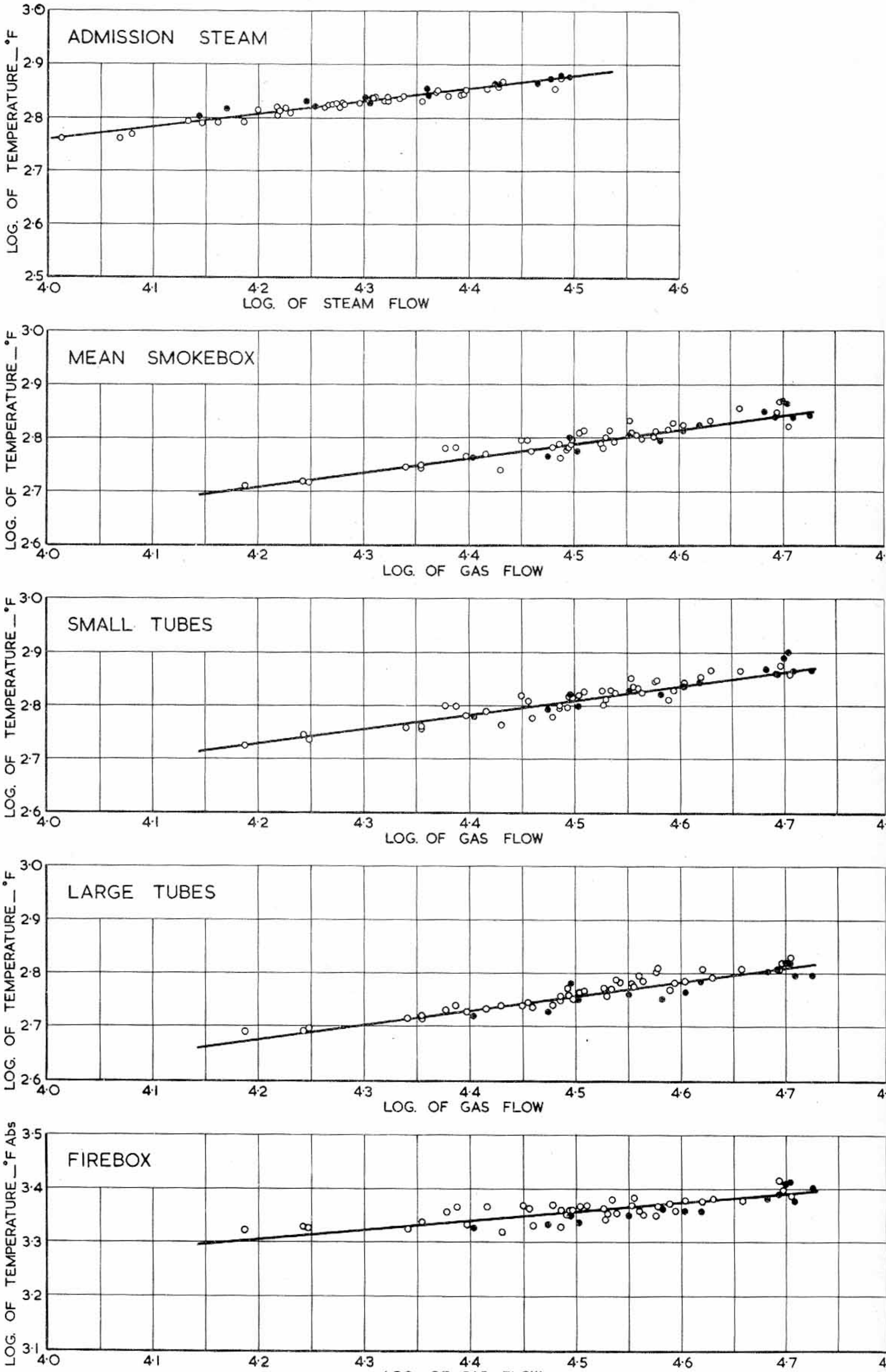


SOUTH KIRKBY COAL _ 13550 BThU/lb

TEMPERATURES

25

BR 8/71000/55



Rates of Steam and Gas Flows are in lb/hr

● Road
○ Plant

SOUTH KIRKBY COAL — 13550 B Th U/lb

GAS FLOW — TEMPERATURE RELATION

26

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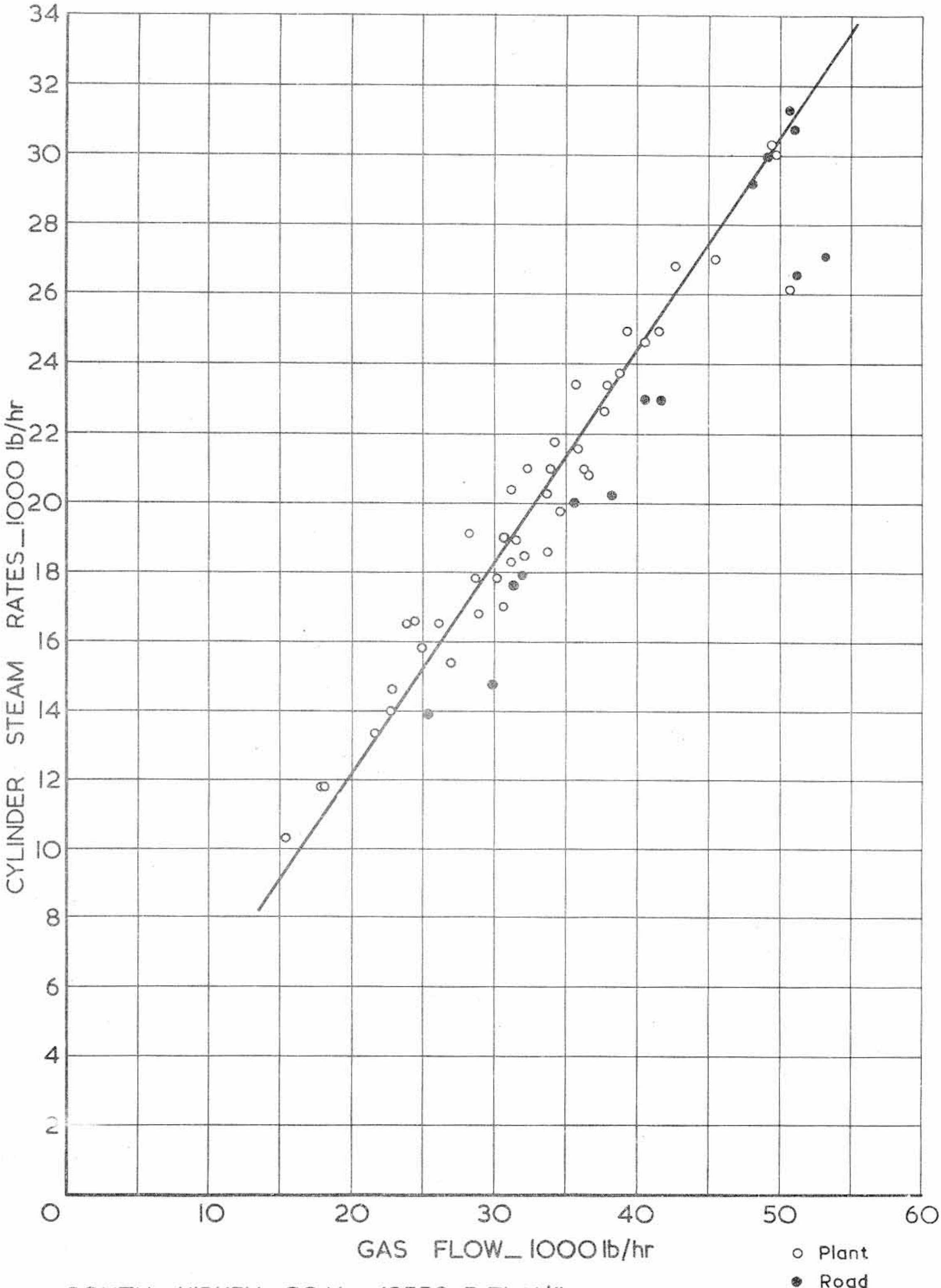
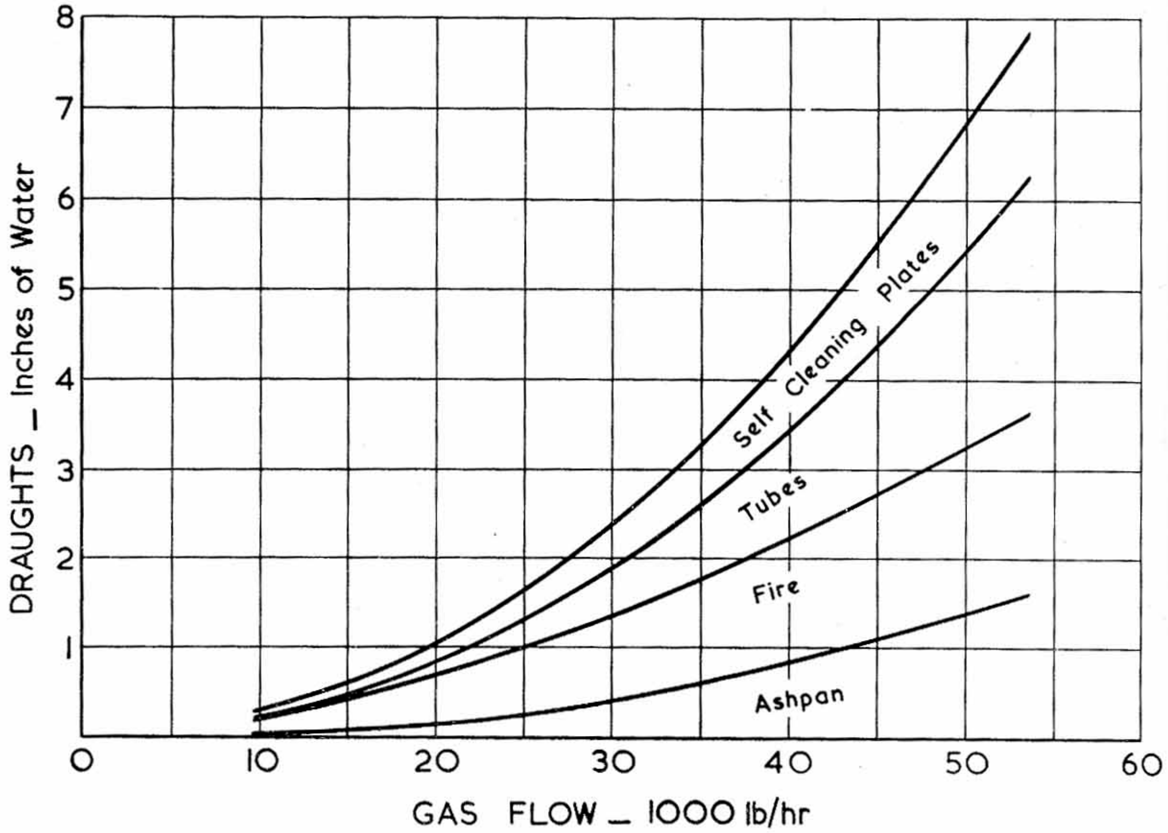


SOUTH KIRKBY COAL_13550 B Th U/lb

GAS : STEAM RATIO

27

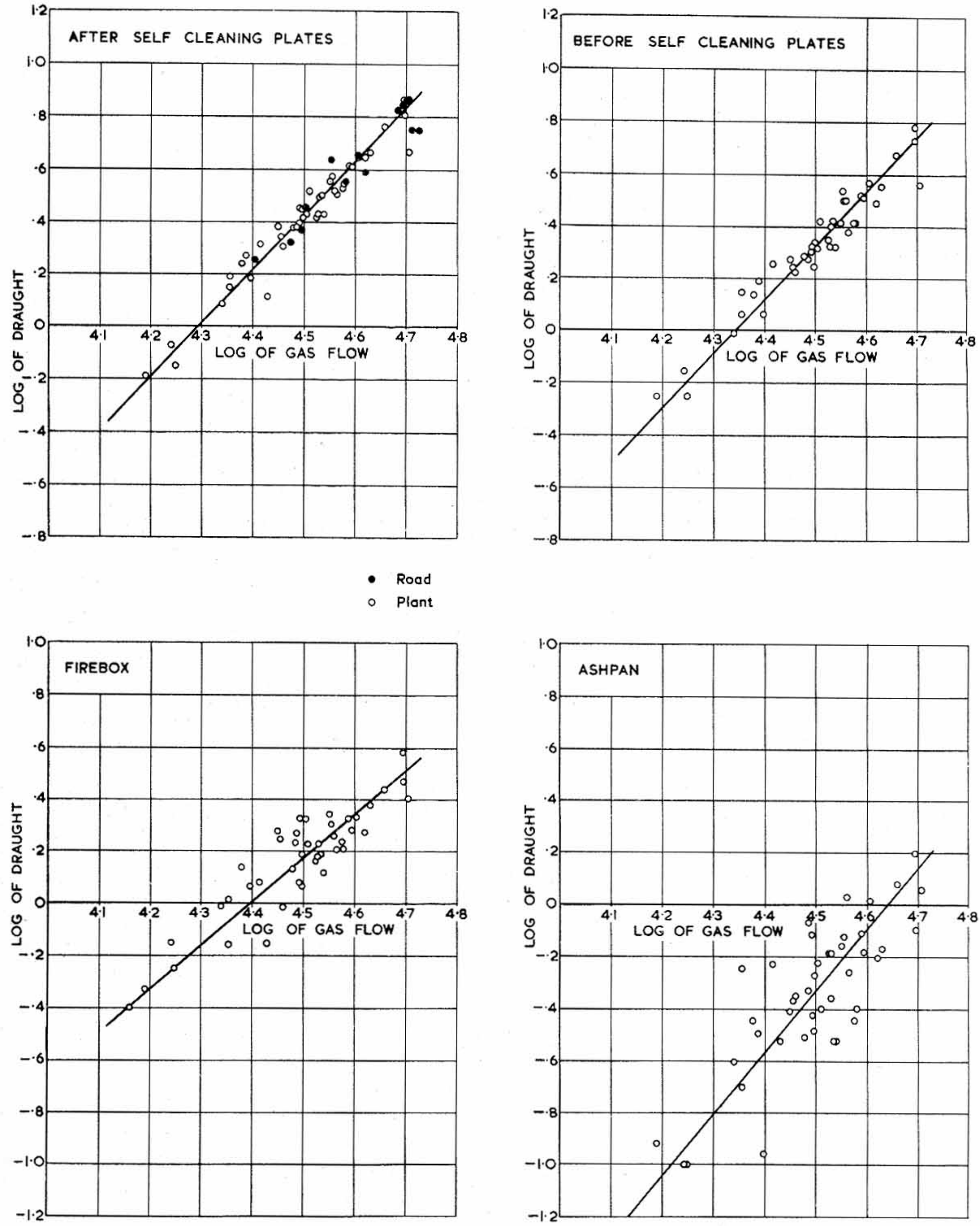
BR8/71000/55



SOUTH KIRKBY COAL _ 13550 BThU/lb

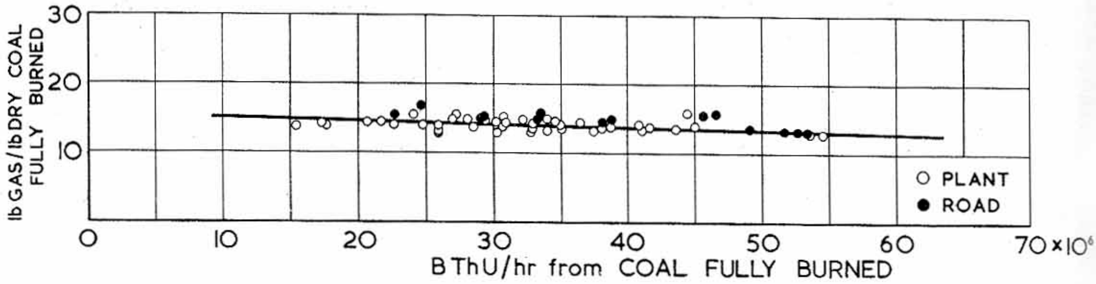
DRAUGHTS

BR8/71000/55



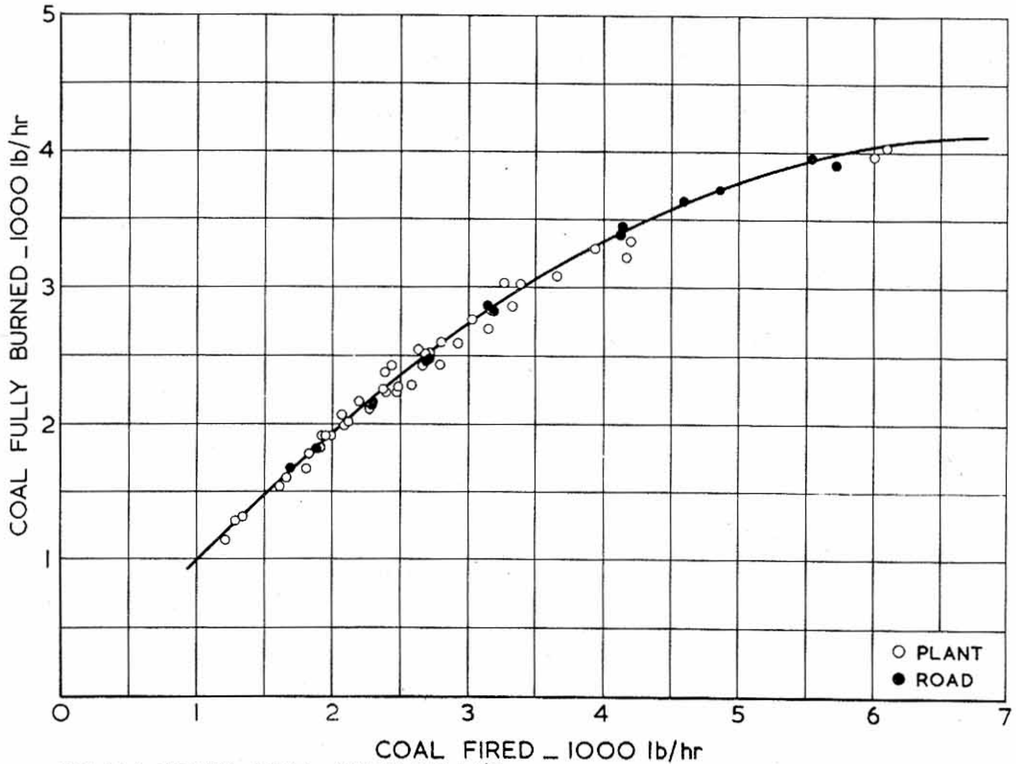
SOUTH KIRKBY COAL 13550 B Th U/lb

GAS FLOW — DRAUGHT RELATION



SOUTH KIRKBY COAL _ 13550 BThU/lb

30

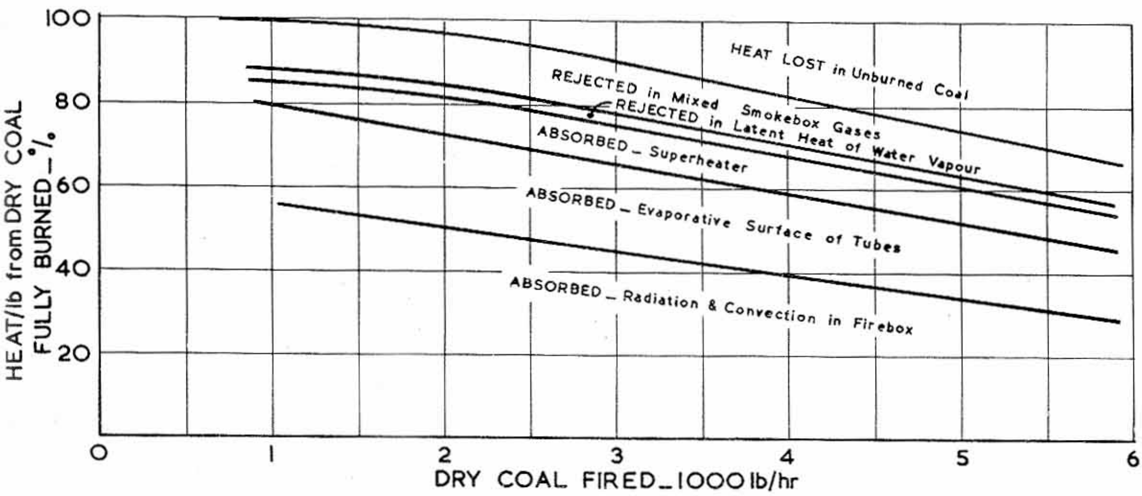


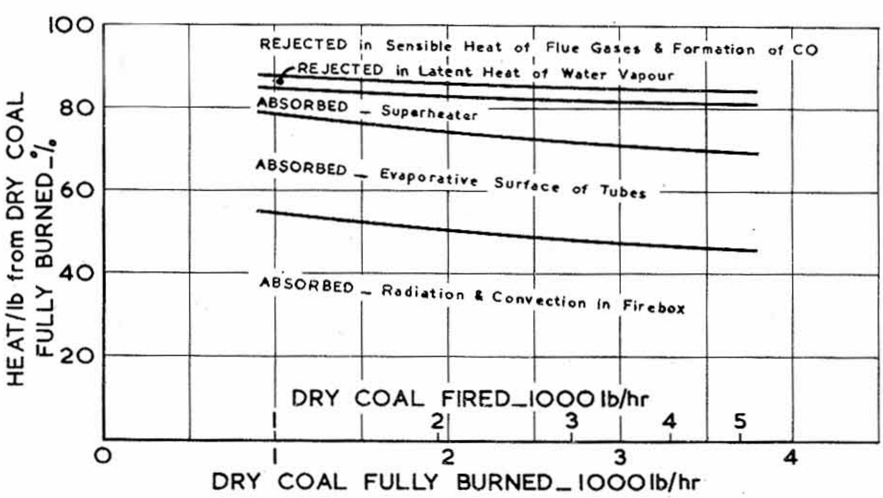
SOUTH KIRKBY COAL _ 13550 BThU/lb

31

BR8/71000/55

COMBUSTION RELATIONS

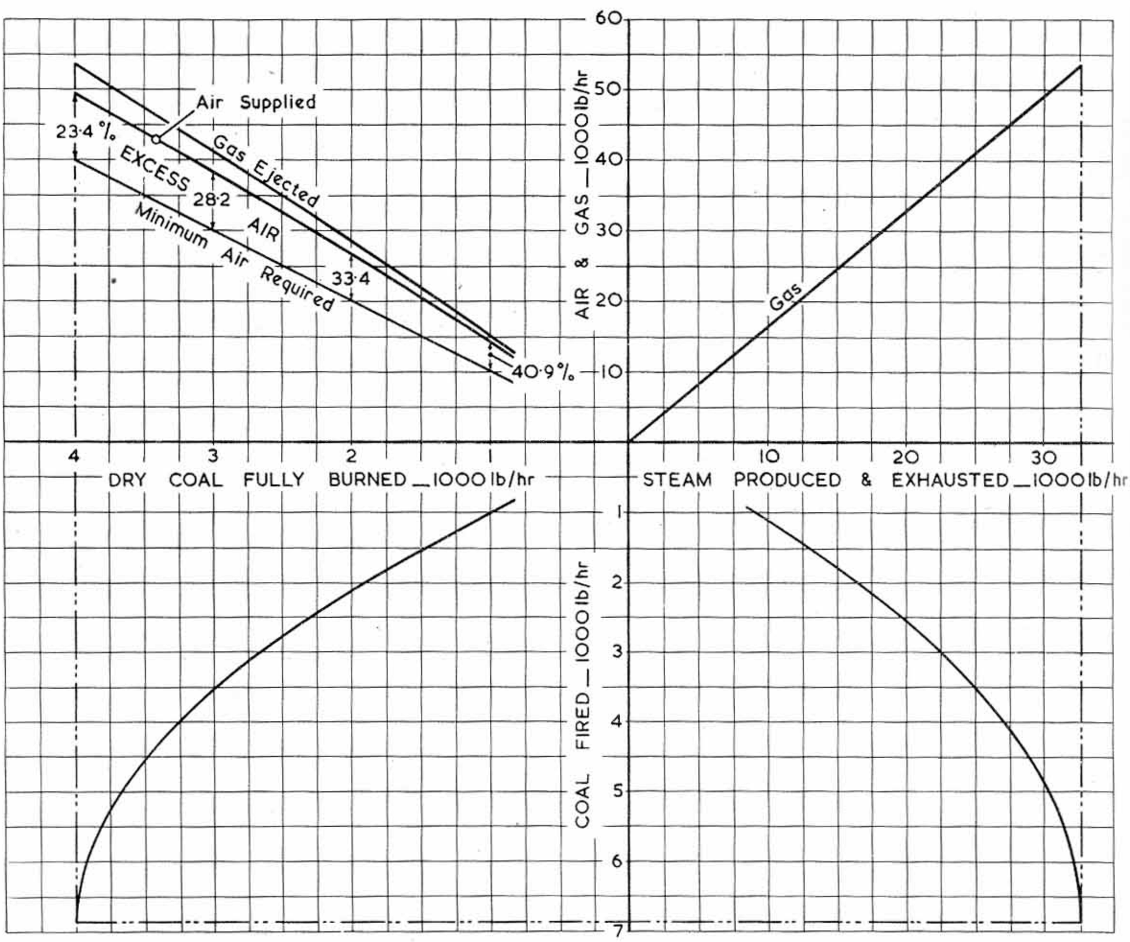




SOUTH KIRKBY COAL _ 13550 BThU/lb

BOILER HEAT BALANCE

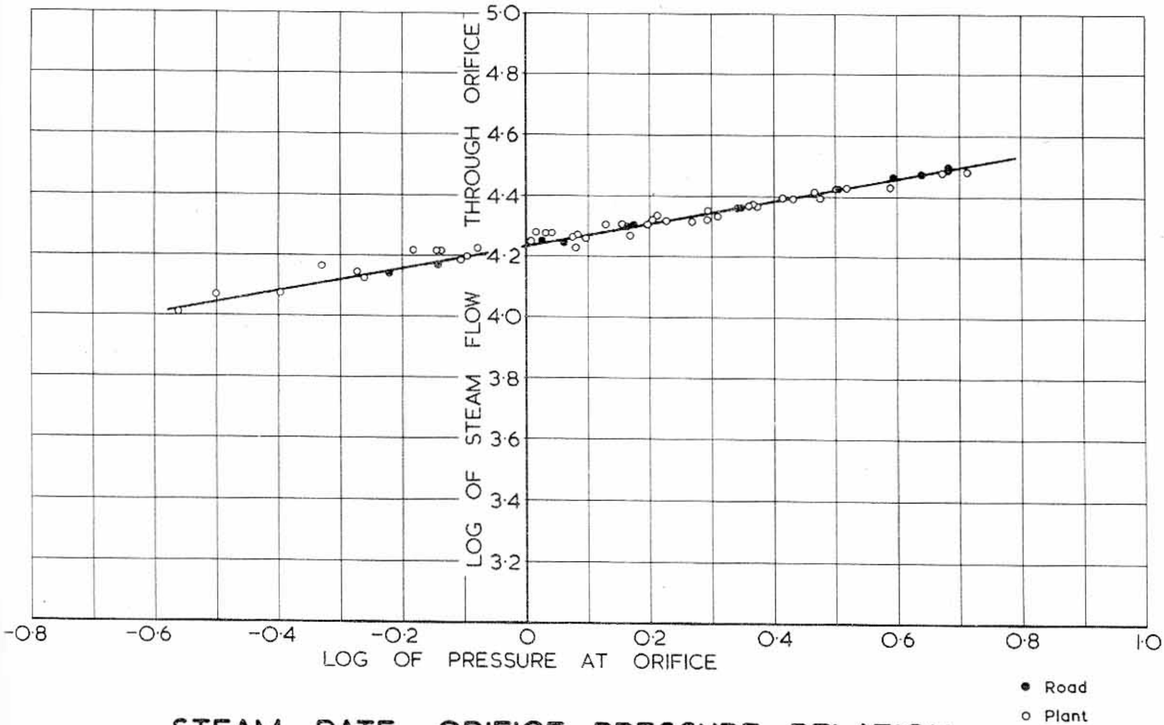
BR8/71000/55



STEAM—AIR—COMBUSTION

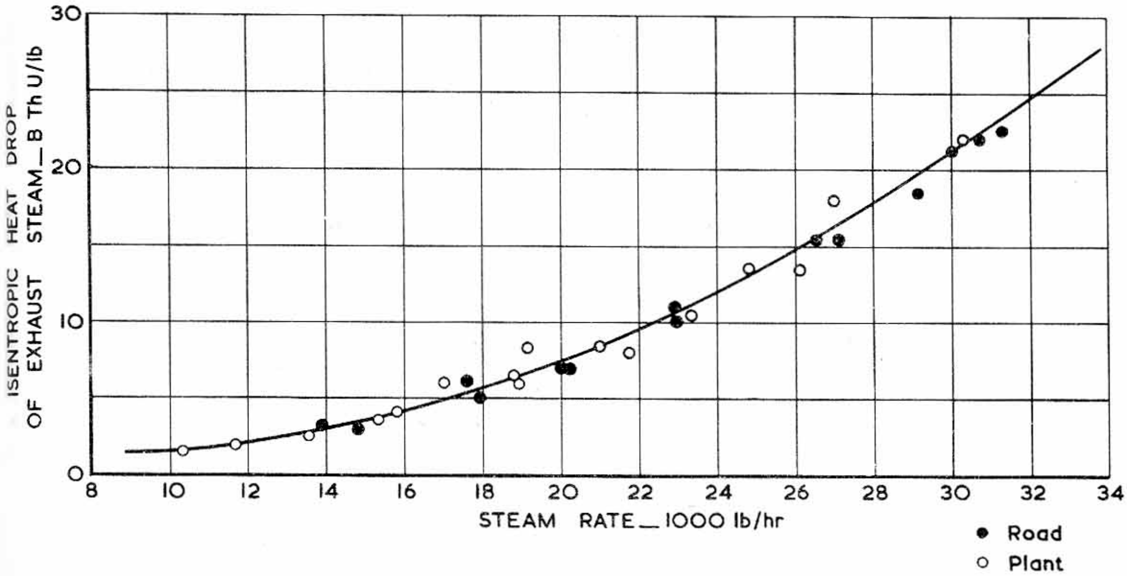
SOUTH KIRKBY COAL _ 13550 B Th U/lb

BR8/71000/55



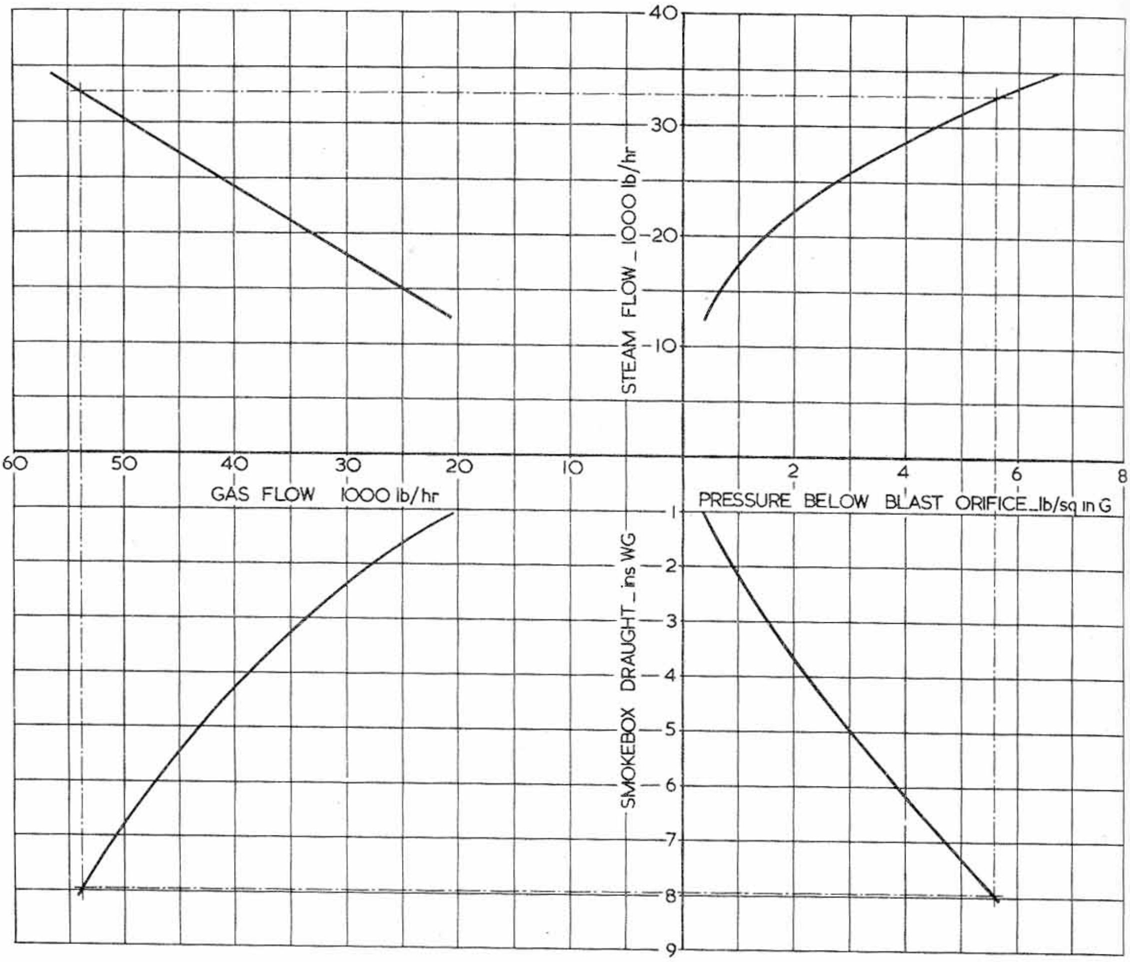
STEAM RATE — ORIFICE PRESSURE RELATION

34



ISENTROPIC HEAT DROP OF EXHAUST STEAM

35

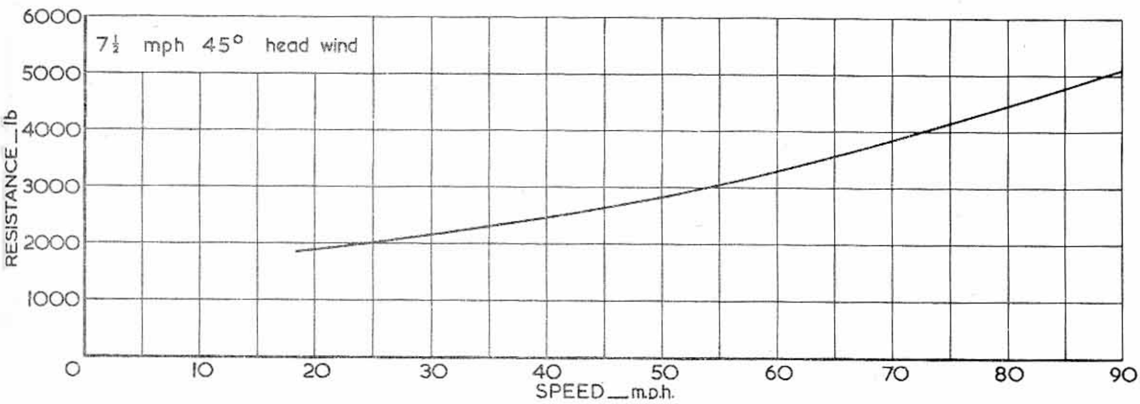


Smokebox draught measured after self cleaning plates

STEAM _ GAS _ DRAUGHT & ORIFICE PRESSURE

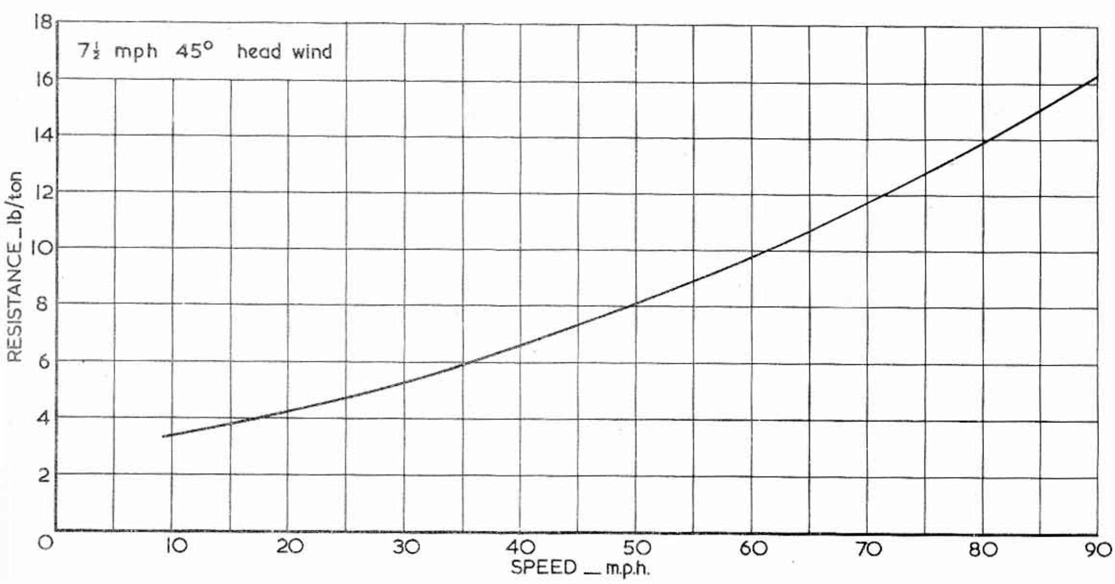
SOUTH KIRKBY COAL __ 13550 BThU/lb

BR 8/71000/55



TOTAL RESISTANCE OF LOCOMOTIVE

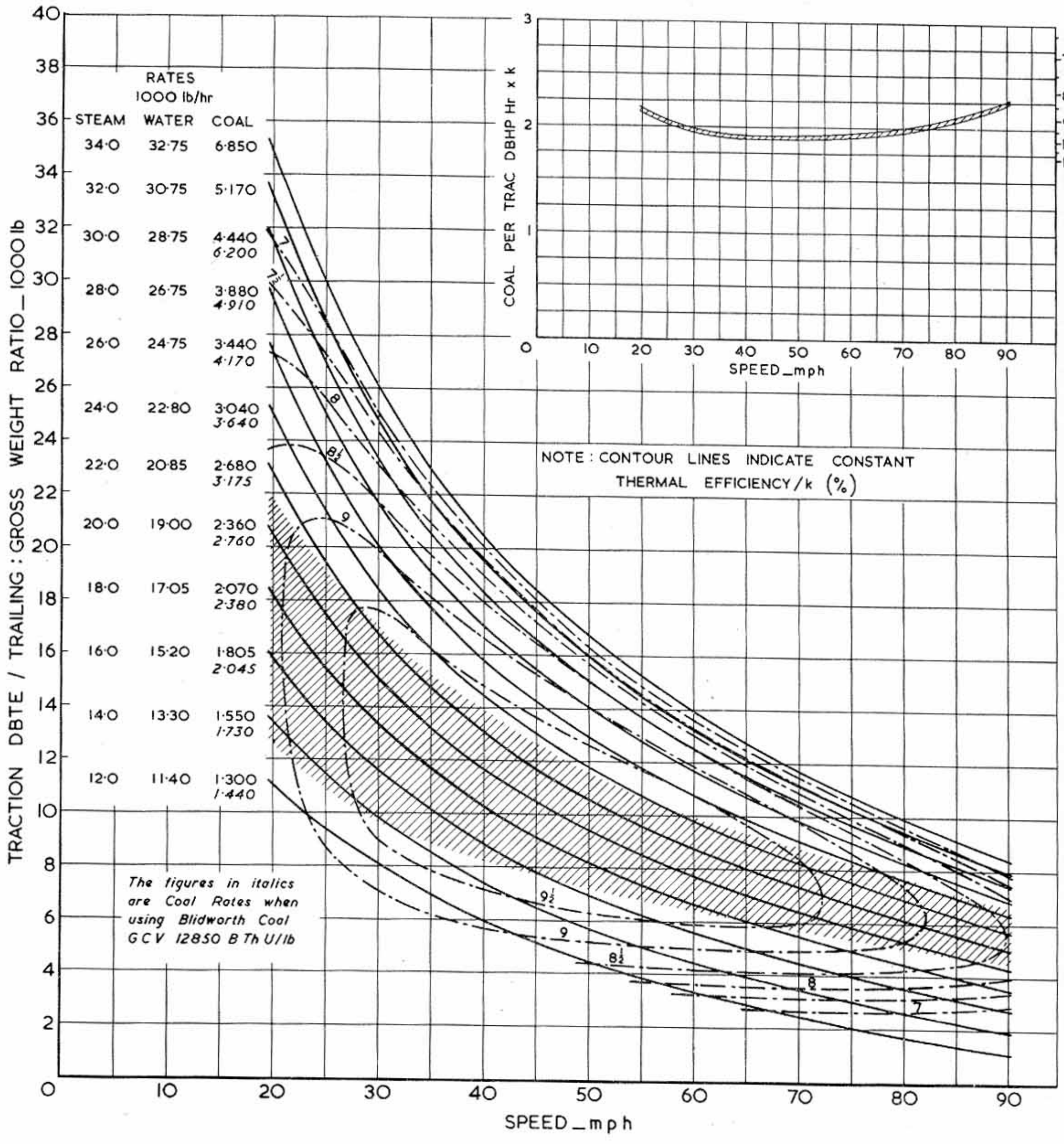
37



SPECIFIC RESISTANCE OF COACHING STOCK

BR8/71000/55

38



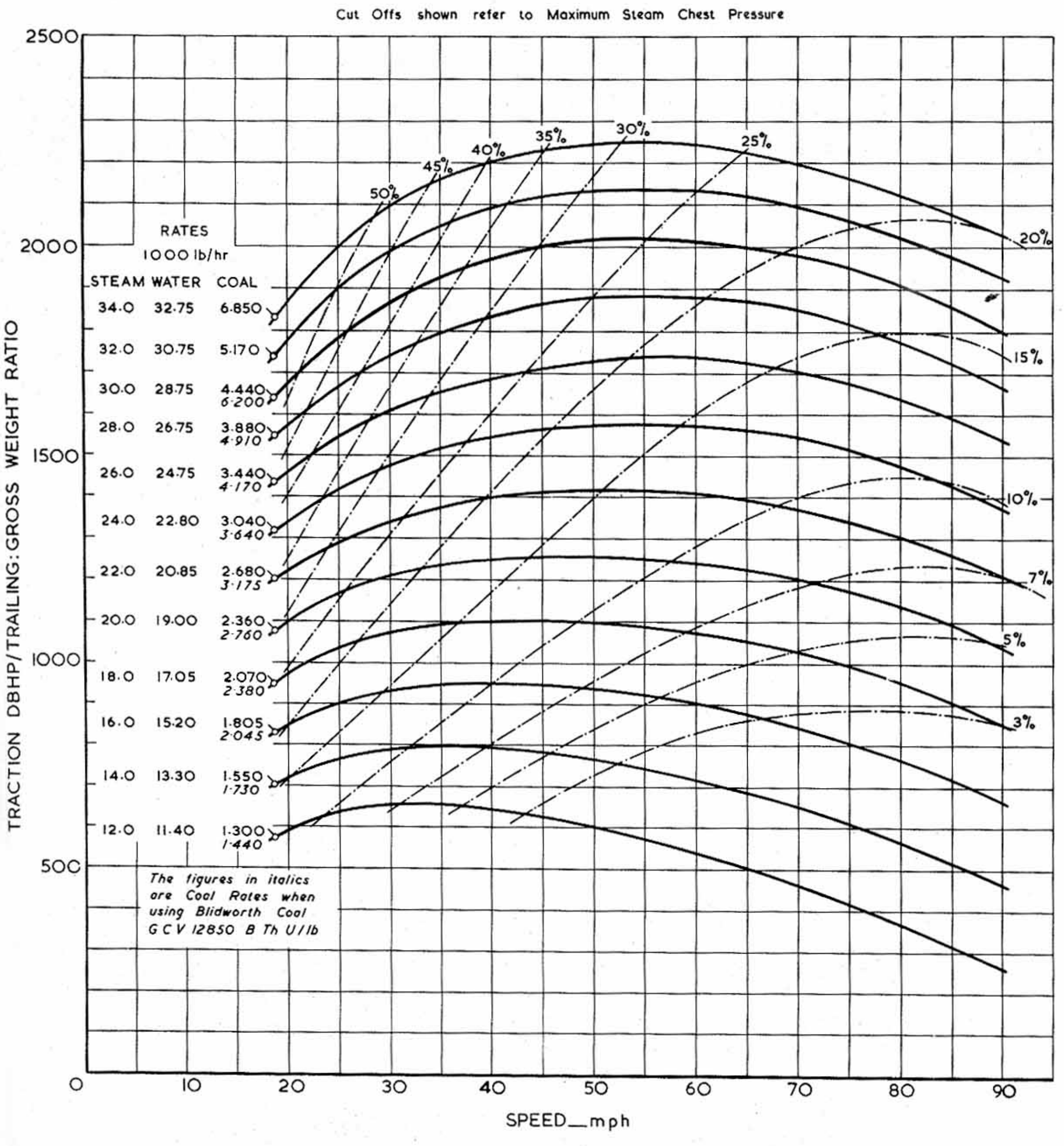
The hatched band covers all rates of working for which traction efficiency / trailing : gross weight ratio is within 2 % of the maximum as shown in inset diagram

SOUTH KIRKBY COAL _ 13550 B Th U / lb

EXHAUST STEAM INJECTOR

CHARACTERISTICS OF TRACTION DBTE / TRAILING : GROSS WEIGHT RATIO

BR8 / 71000 / 55

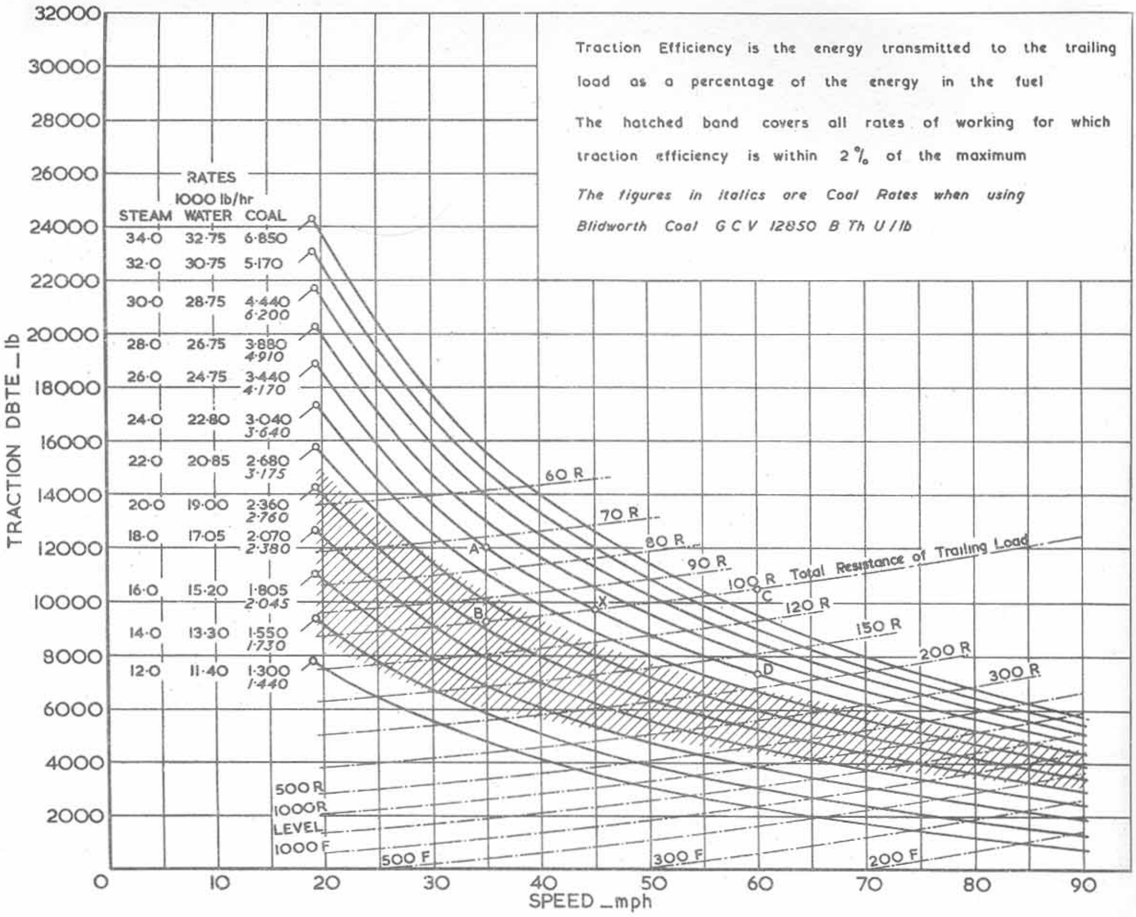


SOUTH KIRKBY COAL _ 13550 B Th U / lb

EXHAUST STEAM INJECTOR

CHARACTERISTICS OF TRACTION DBHP / TRAILING : GROSS WEIGHT RATIO

BR8/71000/55



SOUTH KIRKBY COAL _ 13550 B Th U / lb

EXHAUST STEAM INJECTOR

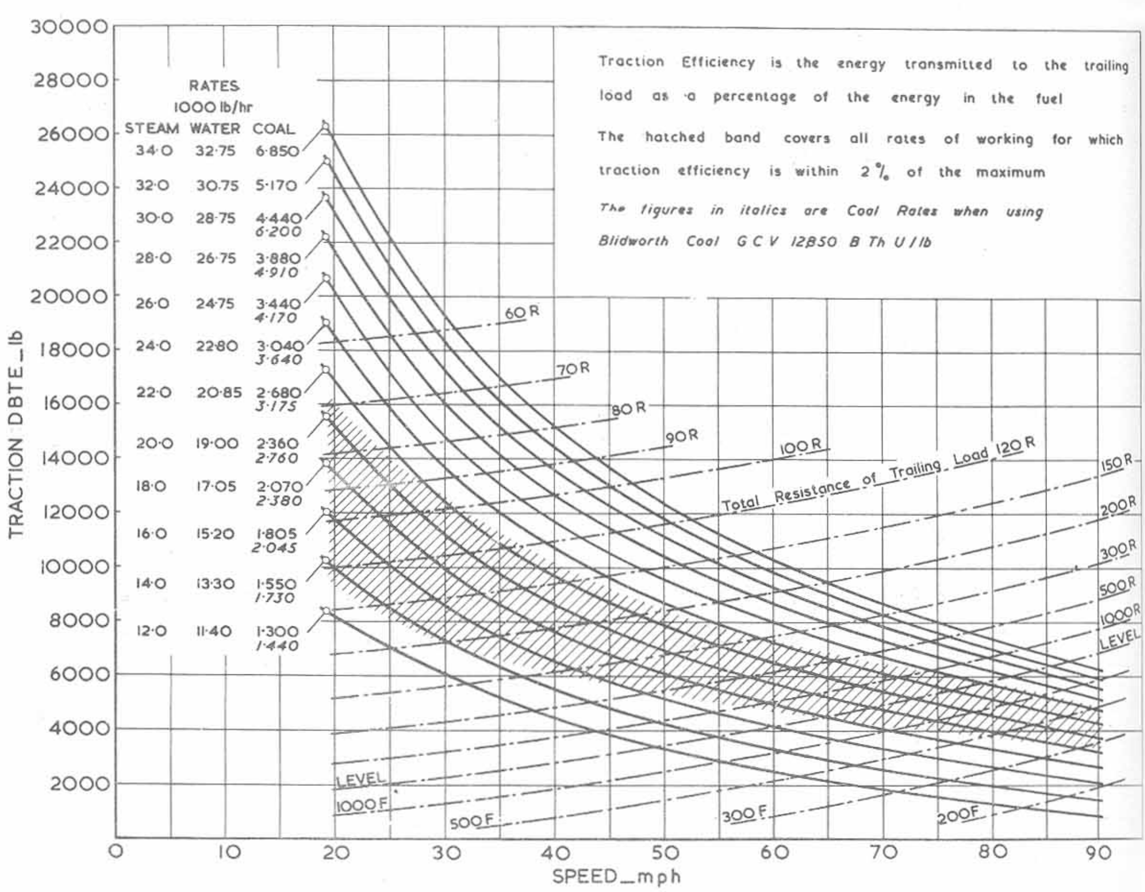
PERFORMANCE & TRACTION EFFICIENCY

300 TONS PASSENGER TRAIN

k = 0·678

BR8/71000/55

41



SOUTH KIRKBY COAL _ 13550 B Th U / lb

EXHAUST STEAM INJECTOR

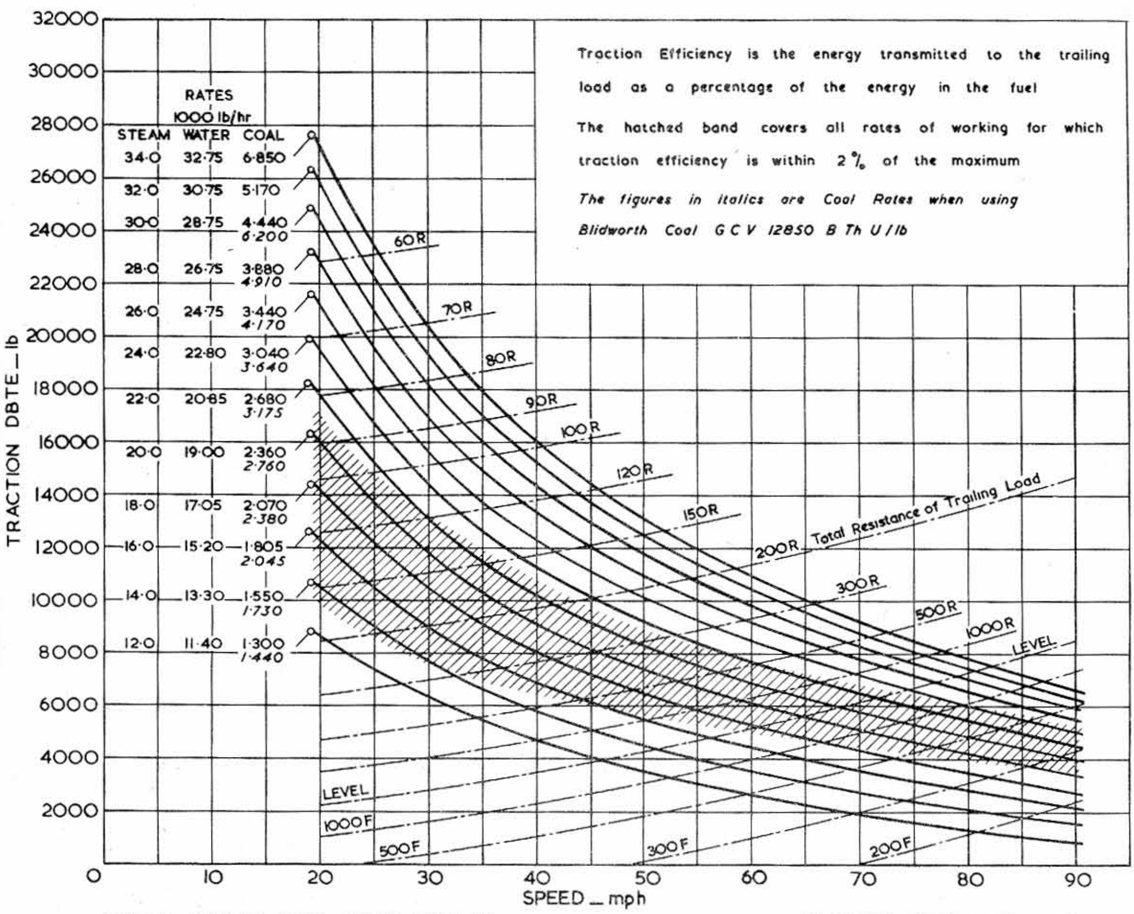
PERFORMANCE & TRACTION EFFICIENCY

400 TONS PASSENGER TRAIN

k = 0·737

BR8/71000/55

42



SOUTH KIRKBY COAL 13550 BThU/lb

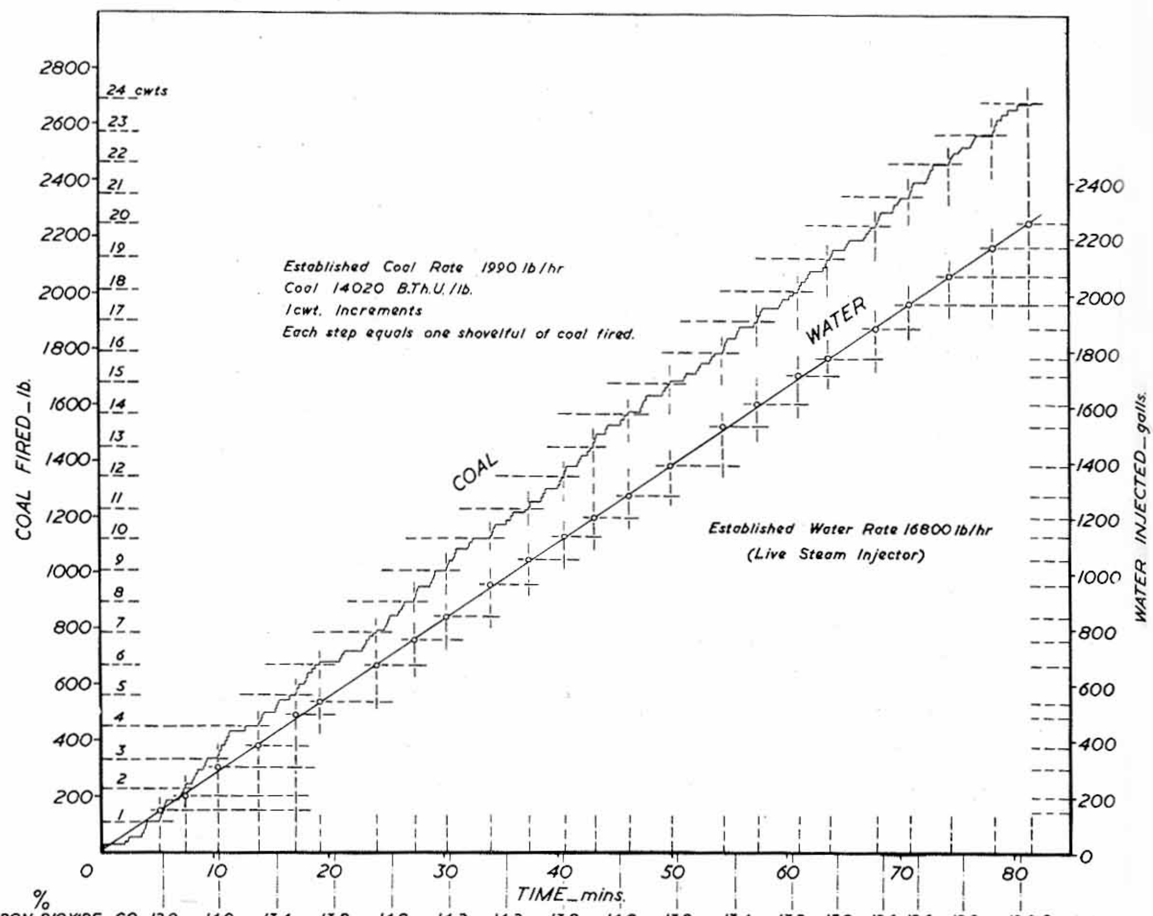
EXHAUST STEAM INJECTOR

PERFORMANCE & TRACTION EFFICIENCY

500 TONS PASSENGER TRAIN

k=0·778

BR8 / 71000/55

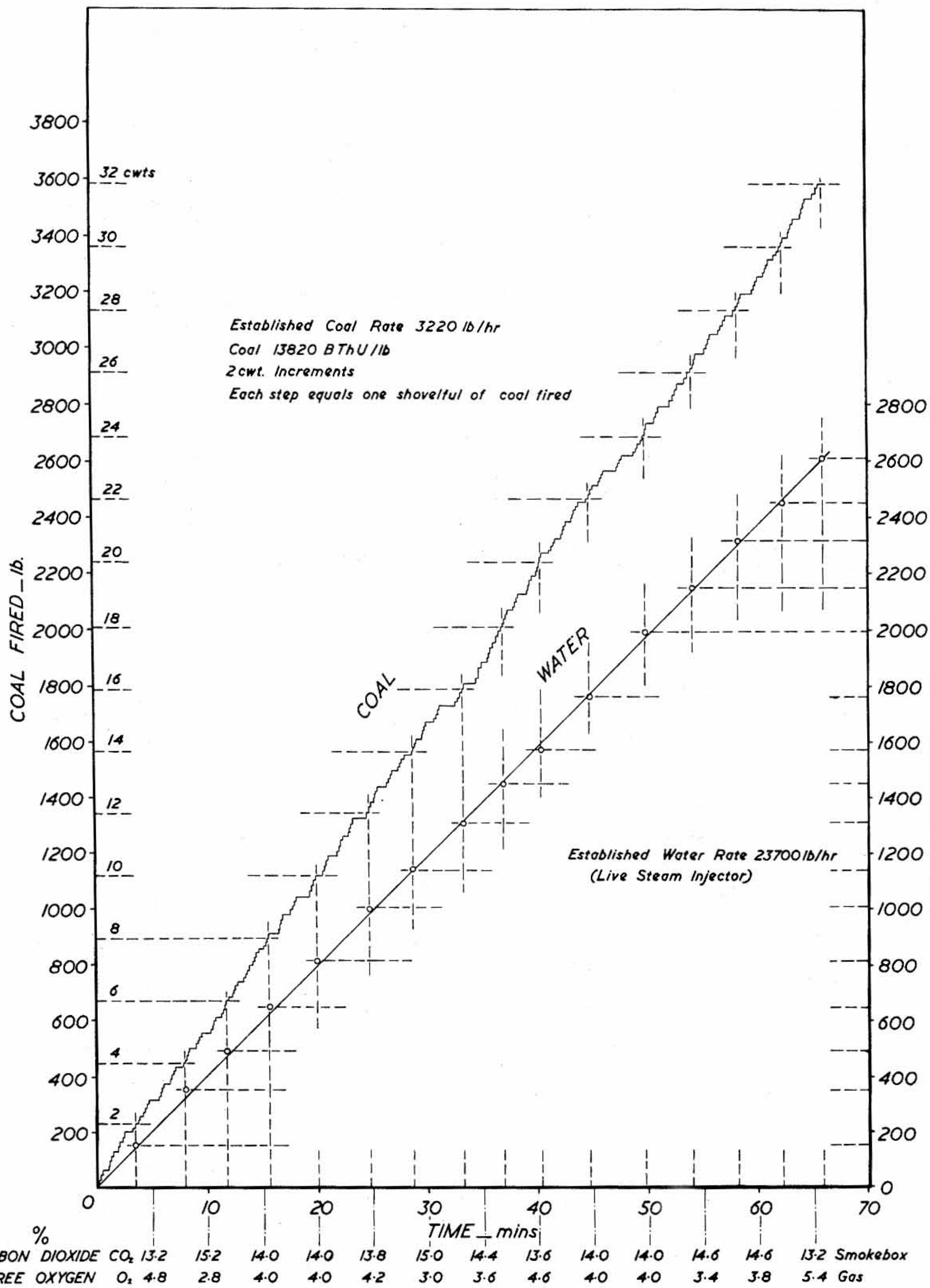


%																		
CARBON DIOXIDE _ CO_2	12·0	14·0	13·4	13·8	14·0	14·2	14·2	13·8	14·0	13·8	13·4	13·2	13·0	12·6	12·6	12·8	12·8	Smokebox
FREE OXYGEN _ O_2	6·2	4·0	4·8	4·4	4·2	4·2	4·0	4·4	4·6	4·4	4·8	5·0	5·0	5·4	5·4	5·2	5·2	Gas
CARBON MONOXIDE _ CO	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Analysis

COMBINED FIRING AND SUMMATIONS OF INCREMENTS DIAGRAM

SHOWING TRADITIONAL FIRING TECHNIQUE

BR 8/71000/55



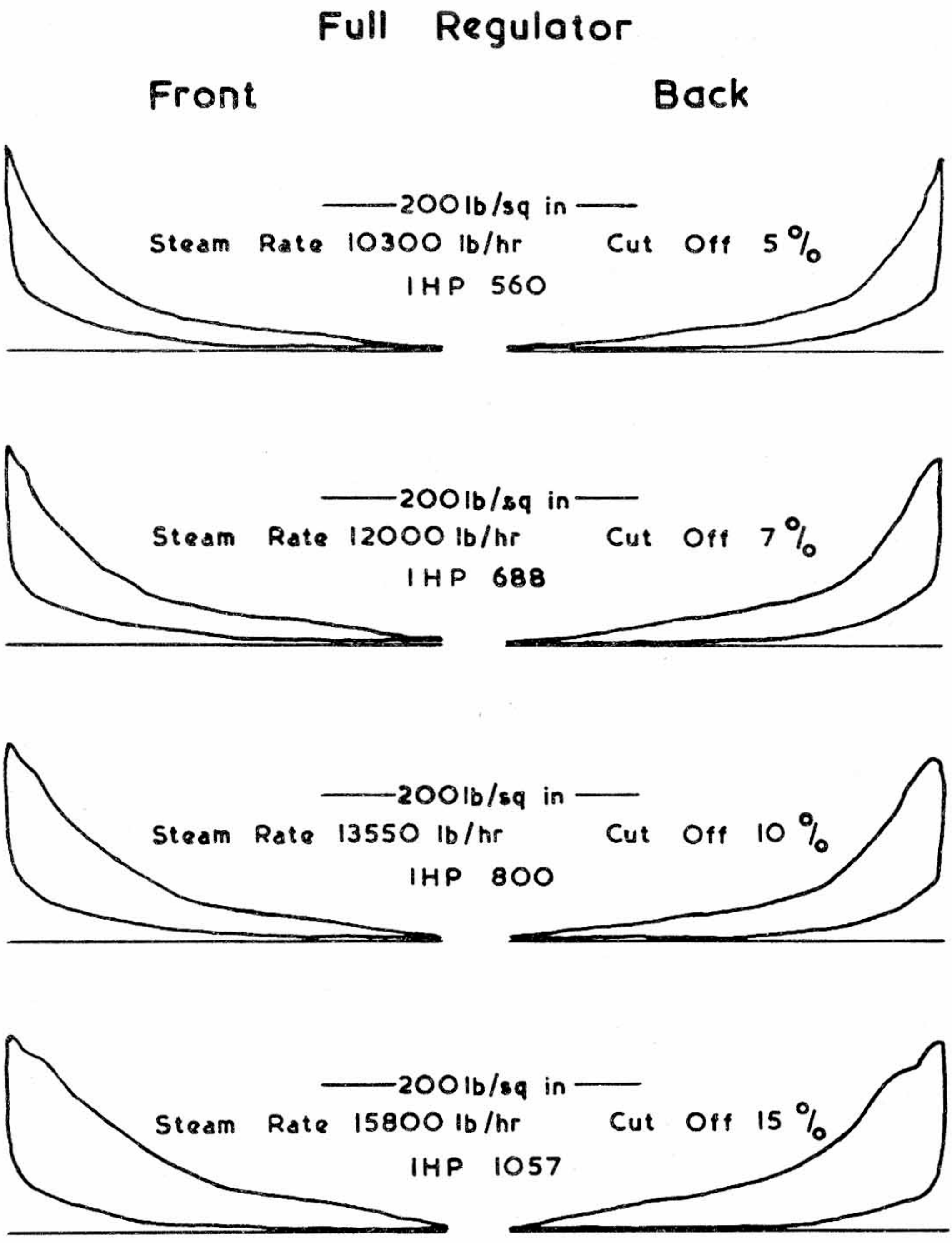
%														
CARBON DIOXIDE	CO_2	13·2	15·2	14·0	14·0	13·8	15·0	14·4	13·6	14·0	14·0	14·6	14·6	13·2 Smokebox
FREE OXYGEN	O_2	4·8	2·8	4·0	4·0	4·2	3·0	3·6	4·6	4·0	4·0	3·4	3·8	5·4 Gas
CARBON MONOXIDE	CO	-	-	-	-	-	-	-	-	-	-	-	-	- Analysis

COMBINED FIRING AND SUMMATIONS OF INCREMENTS DIAGRAM

SHOWING TRADITIONAL FIRING TECHNIQUE

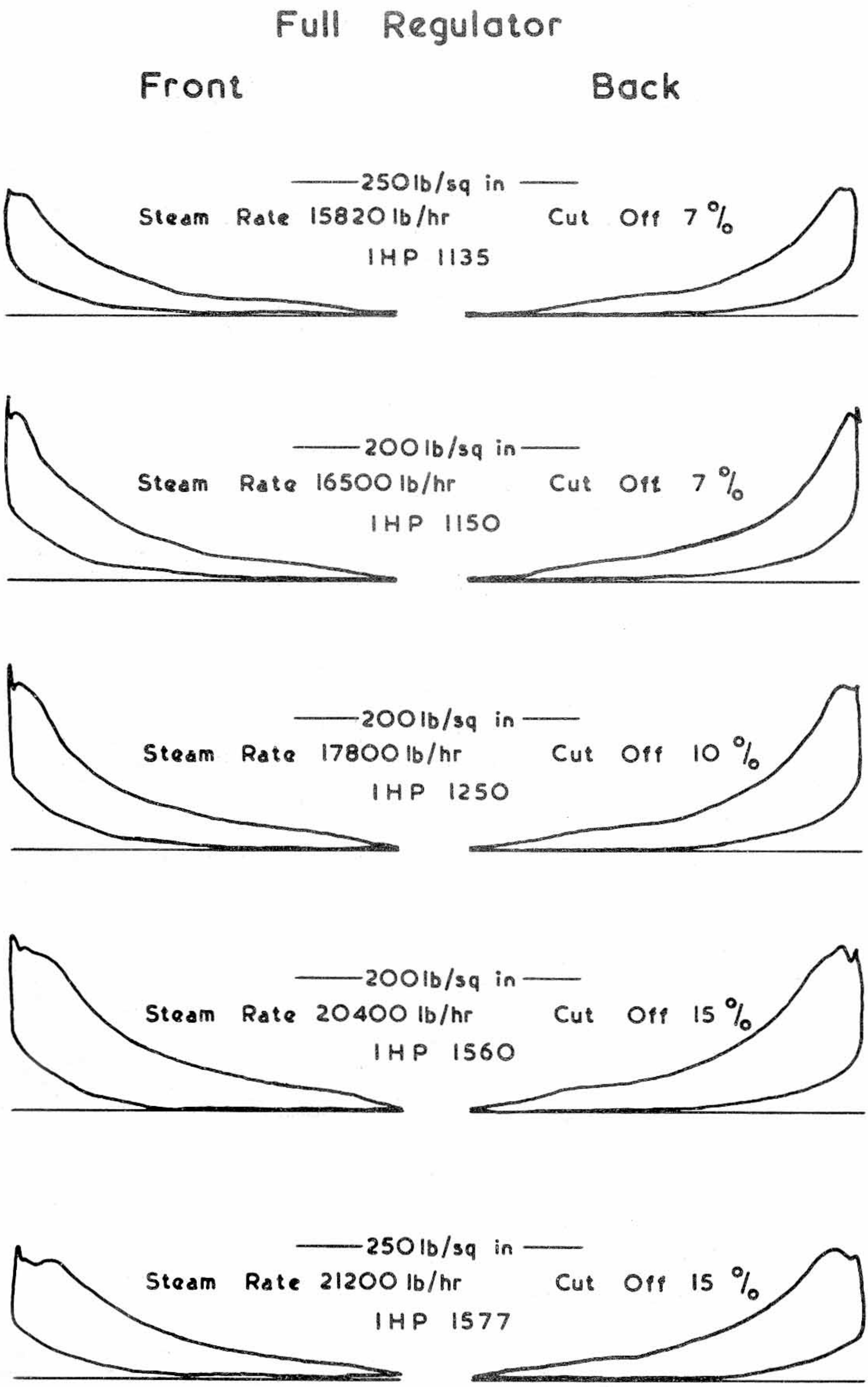
BR8/71000/55

45



EXAMPLES OF INDICATOR CARDS
AT 30 mph

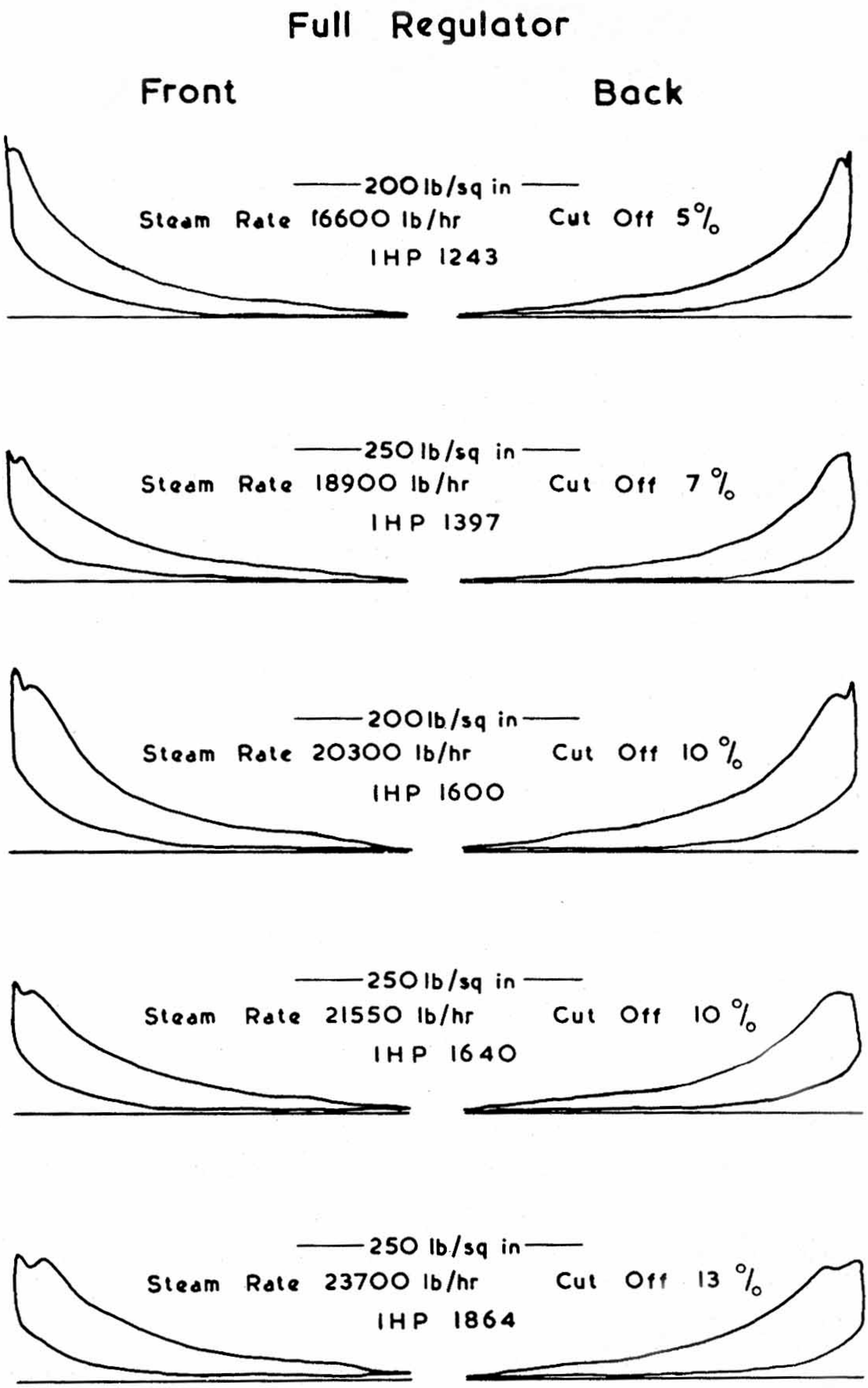
BR8/71000/55



EXAMPLES OF INDICATOR CARDS AT 45 mph

46b

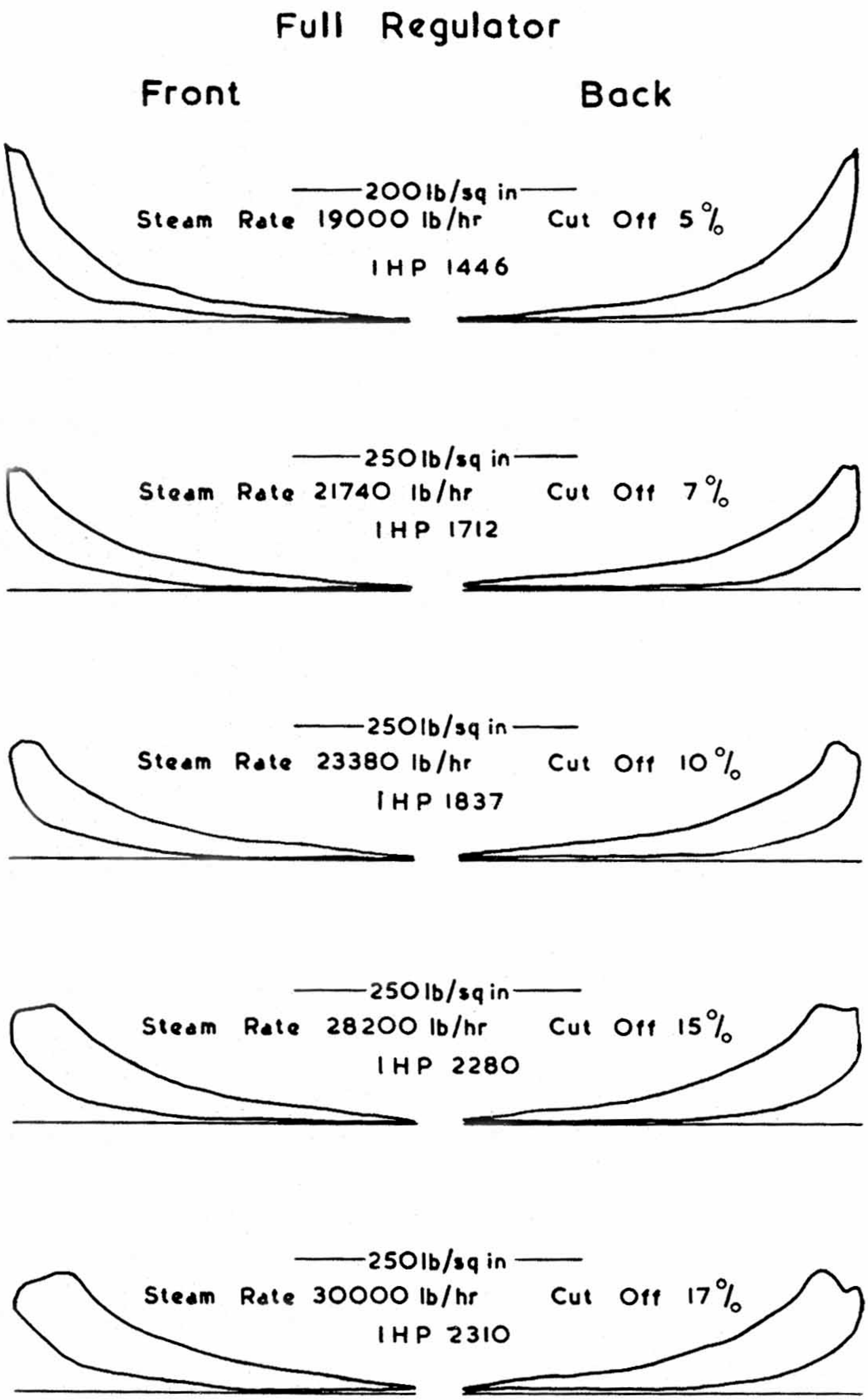
BR8/71000/55



EXAMPLES OF INDICATOR CARDS
AT 60 mph

46c

BR8/71000/55

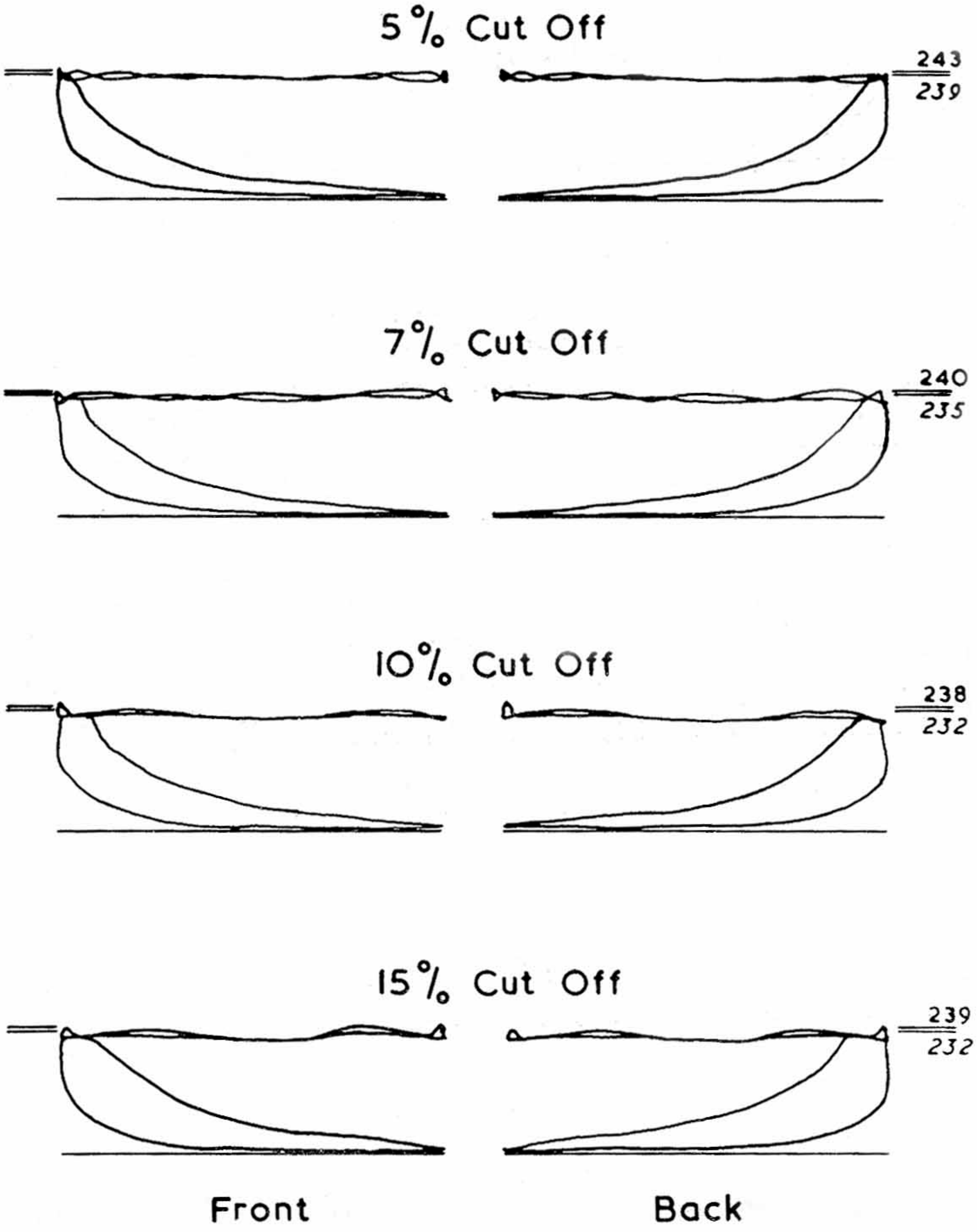


EXAMPLES OF INDICATOR CARDS AT 75 mph

46d

BR8/71000/55

FULL REG _ 60 mph

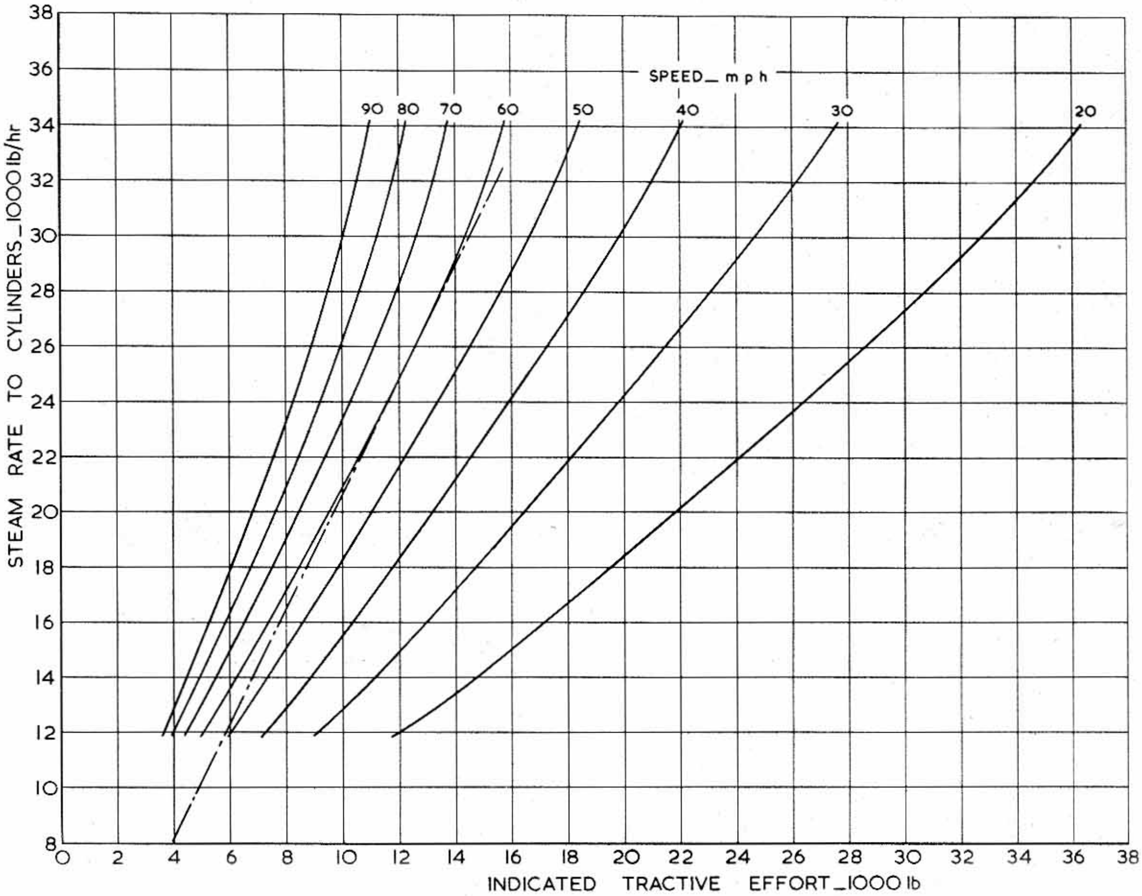


Figures thus 243 denote Boiler Pressure _ lb/sq in g
Figures thus 232 denote Steam Chest Pressure _ lb/sq in g

STEAM CHEST PRESSURE
SHOWING DEGREE OF SURGE

47a

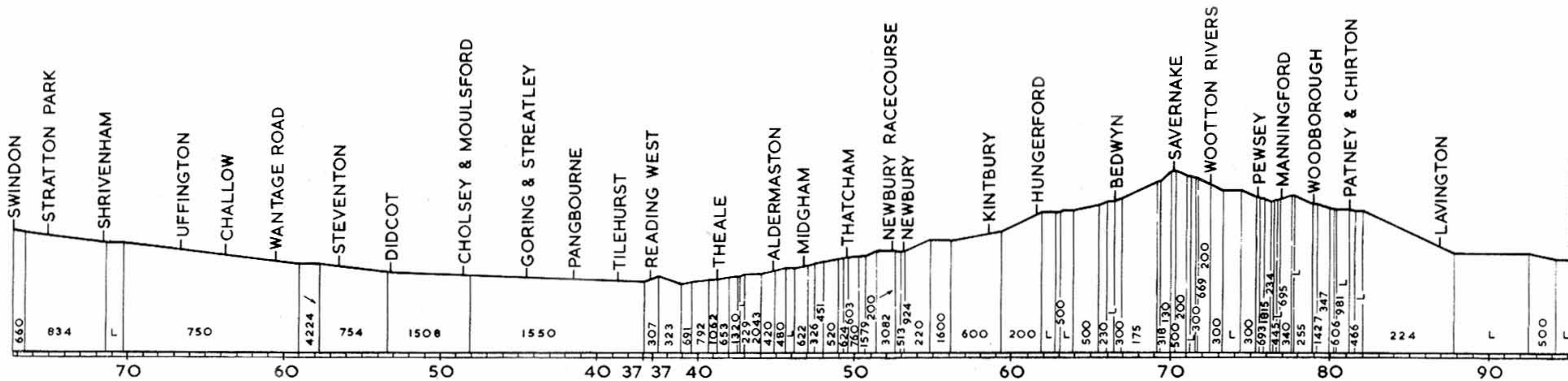
BR8/71000/55



CO·ORDINATION OF TEST RESULTS BY WILLANS LINES

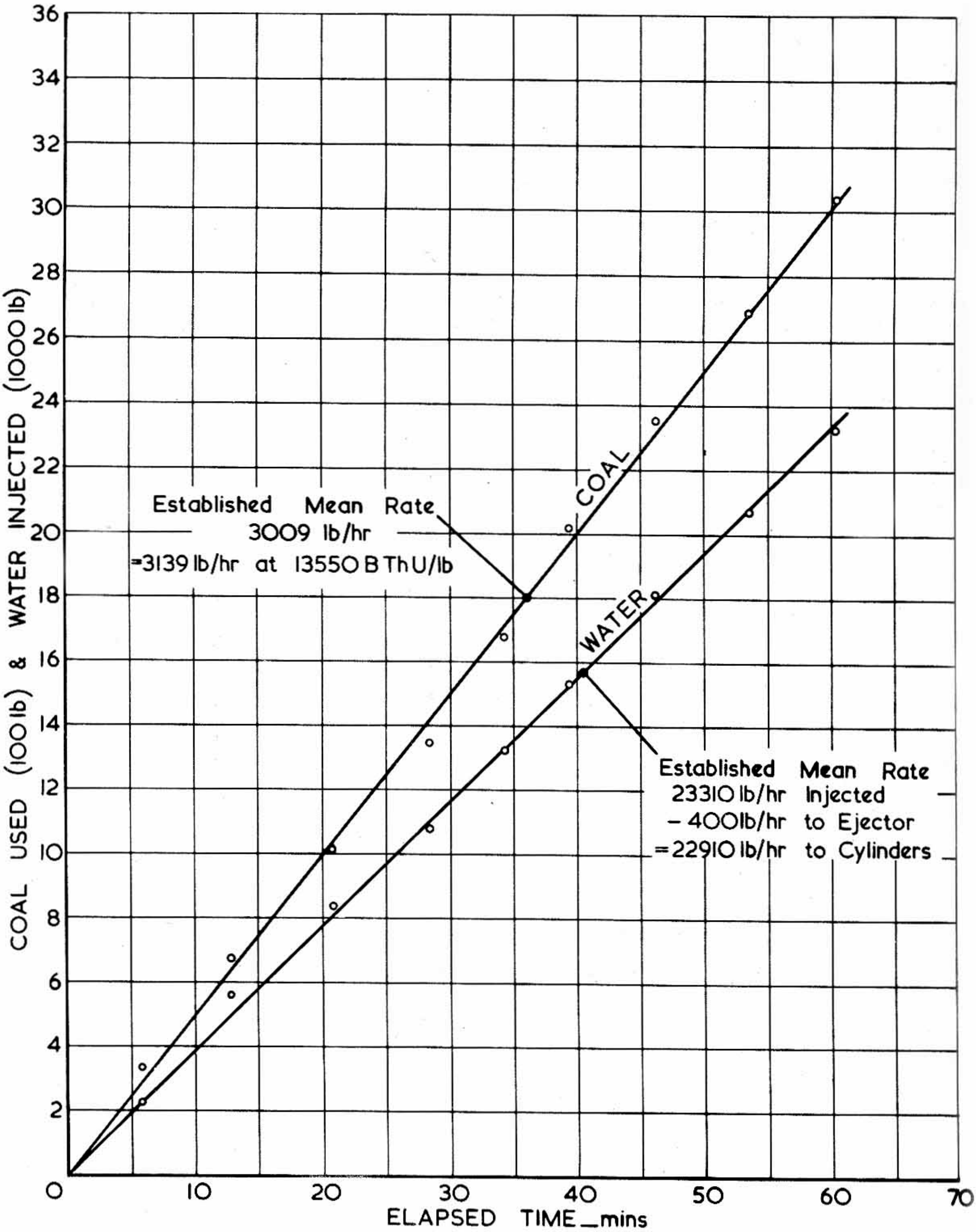
48

BR8/71000/55



SWINDON–WESTBURY

GRADIENT DIAGRAM OF TEST ROUTE



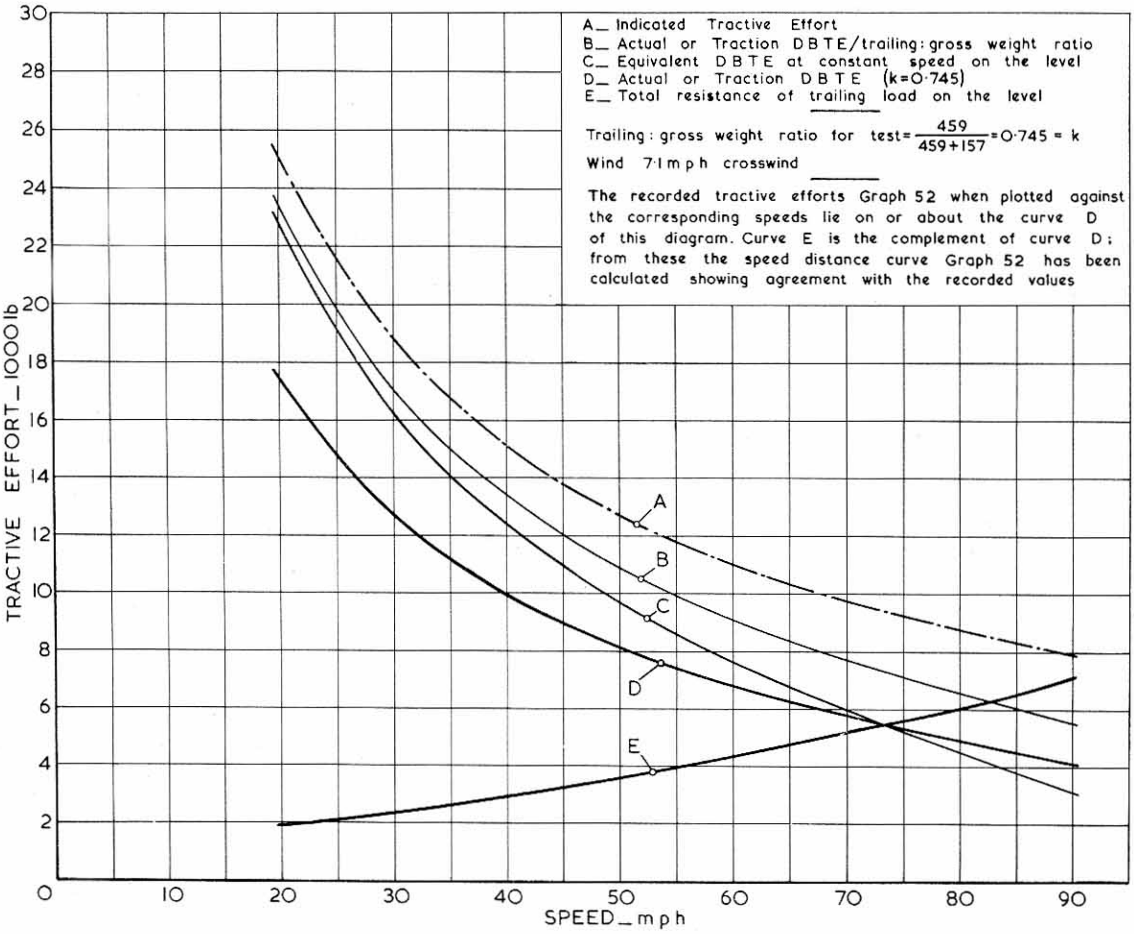
SUMMATIONS OF INCREMENTS

CONROLLED ROAD TEST No 6 R

SOUTH KIRKBY COAL _ 13970 B Th U/lb

See also graphs 51 & 52

BR8/71000/55

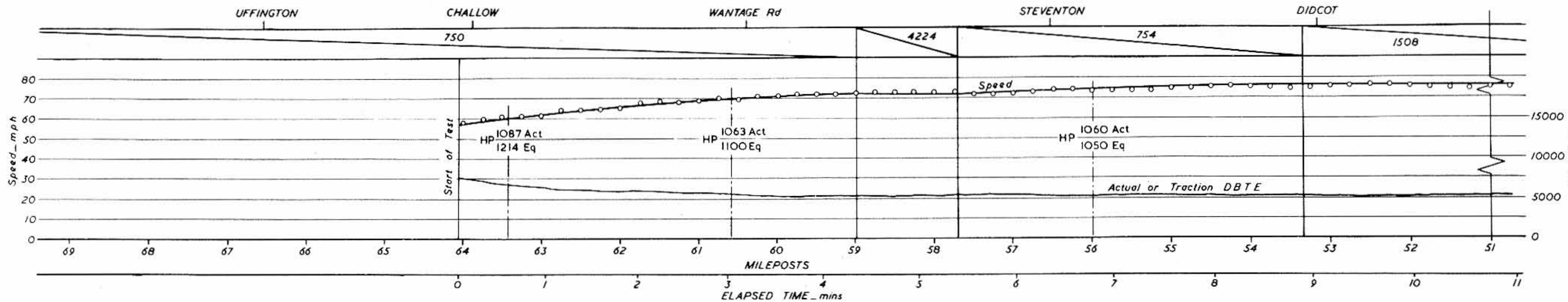


CHARACTERISTICS PRODUCED BY CONTROLLED ROAD TEST No 6 R

Steam Rate 22910 lb/hr Coal Rate 3139 lb/hr

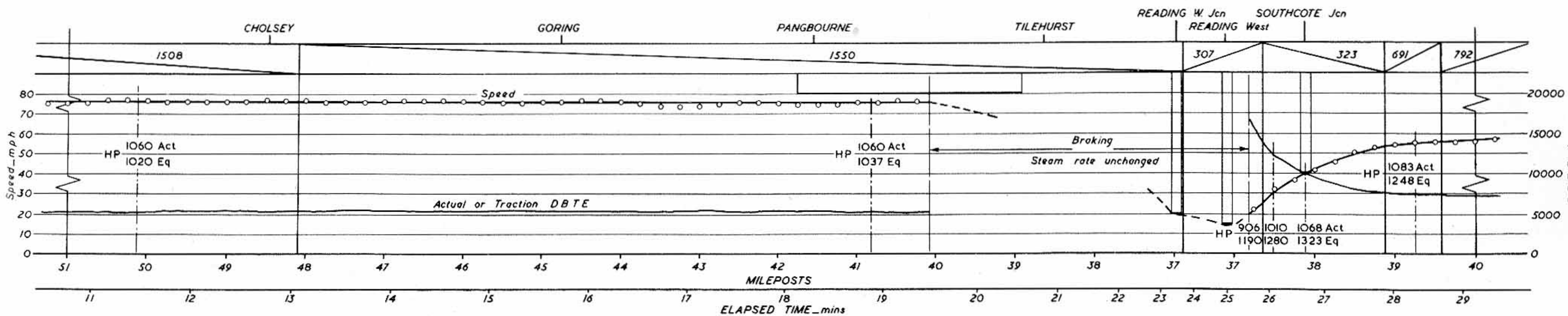
SOUTH KIRKBY COAL 13550 B Th U/lb

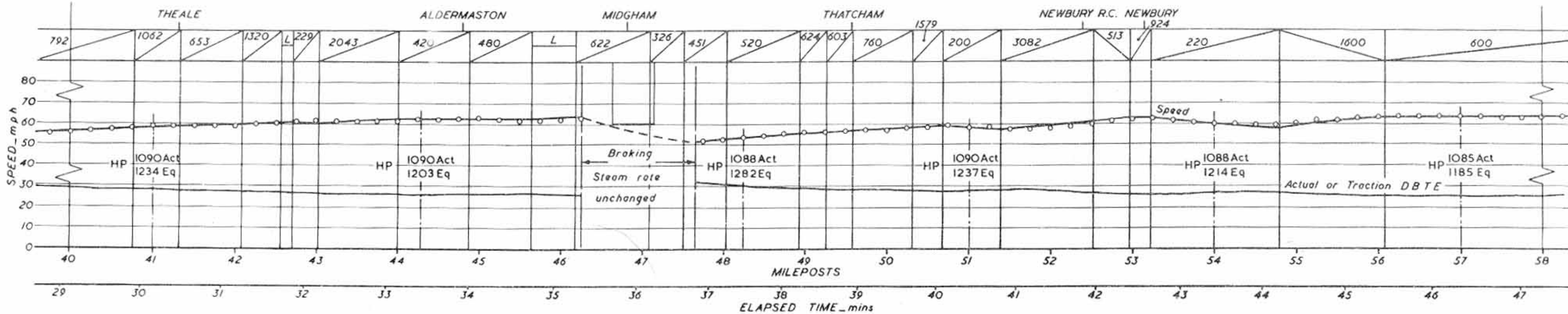
BR8/71000/55



Boiler Efficiency 73·8%   Average Steam Temperature 717°F   7·1 mph Crosswind

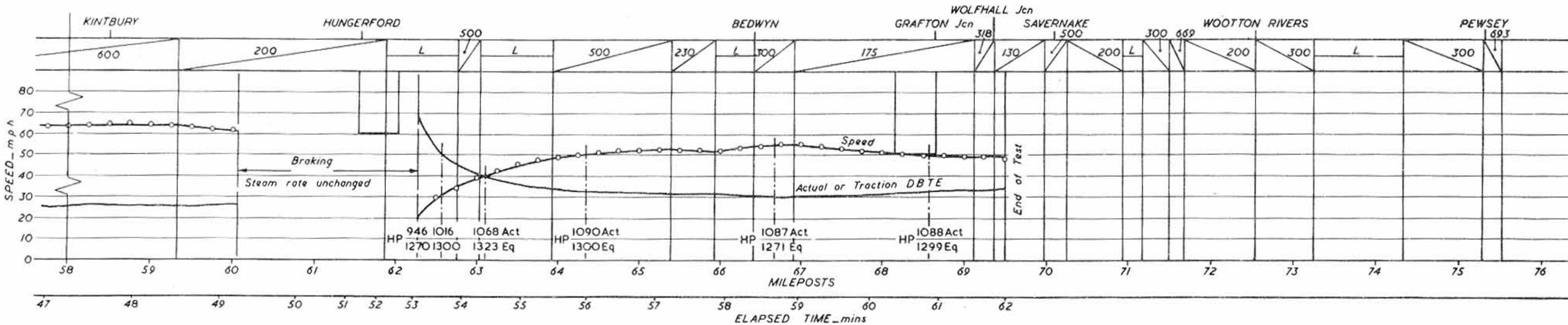
For Summations of Increments of Coal & Water see Graph 50





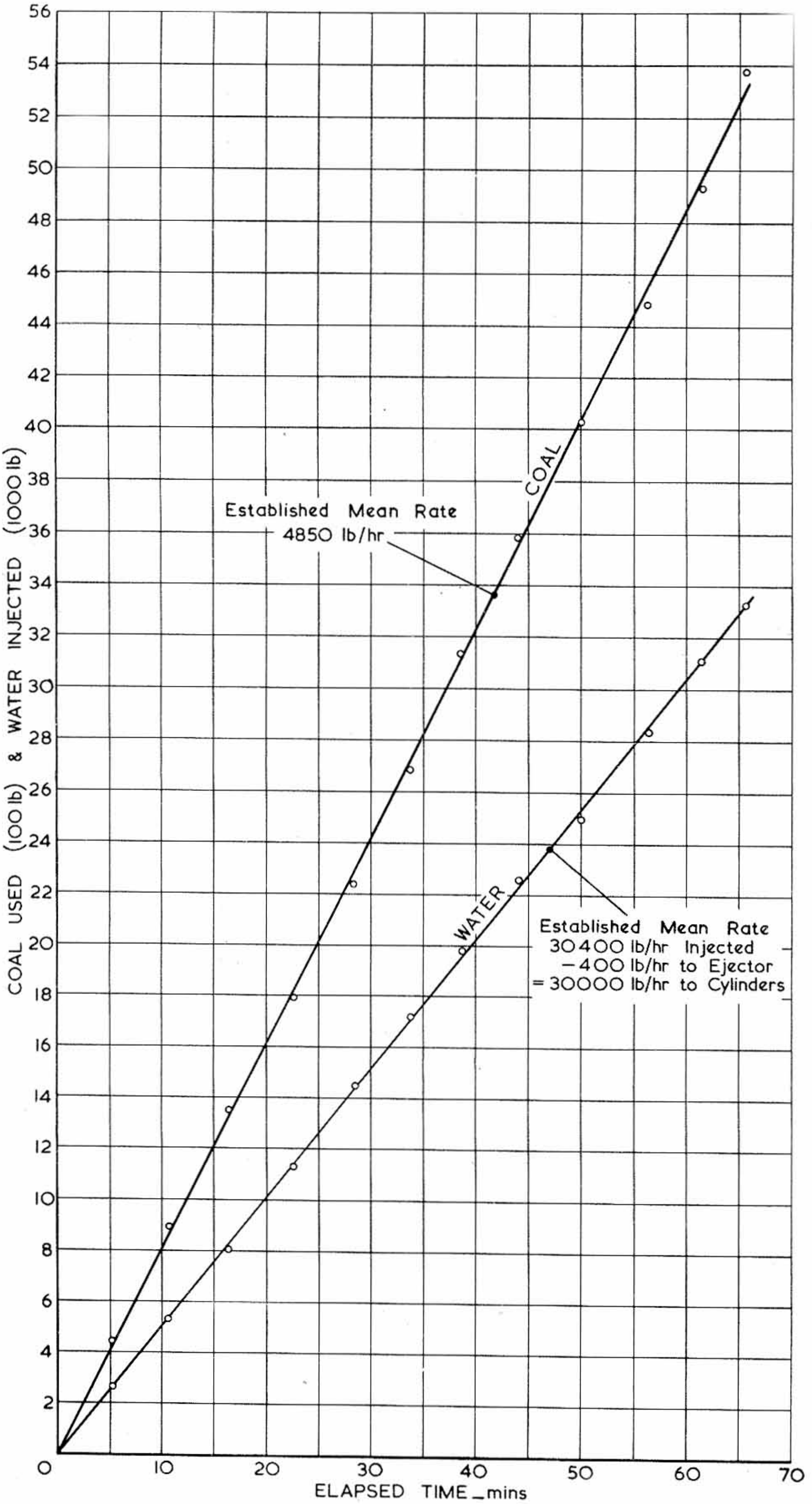
To verify the mean resistance curve, the full line speed curve has been calculated from this and the tractive effort curve D for comparison with the recorded speeds shown thus ○

The tractive efforts shown on this diagram when plotted against the corresponding speeds lie on or about curve D of graph 51



CONTROLLED ROAD TEST No 6 R at a Constant Rate of Steam Production and Utilisation of 22910 lb/hr Coal Rate 3139 lb/hr Load 459 tons passenger stock

BR8/71000/55



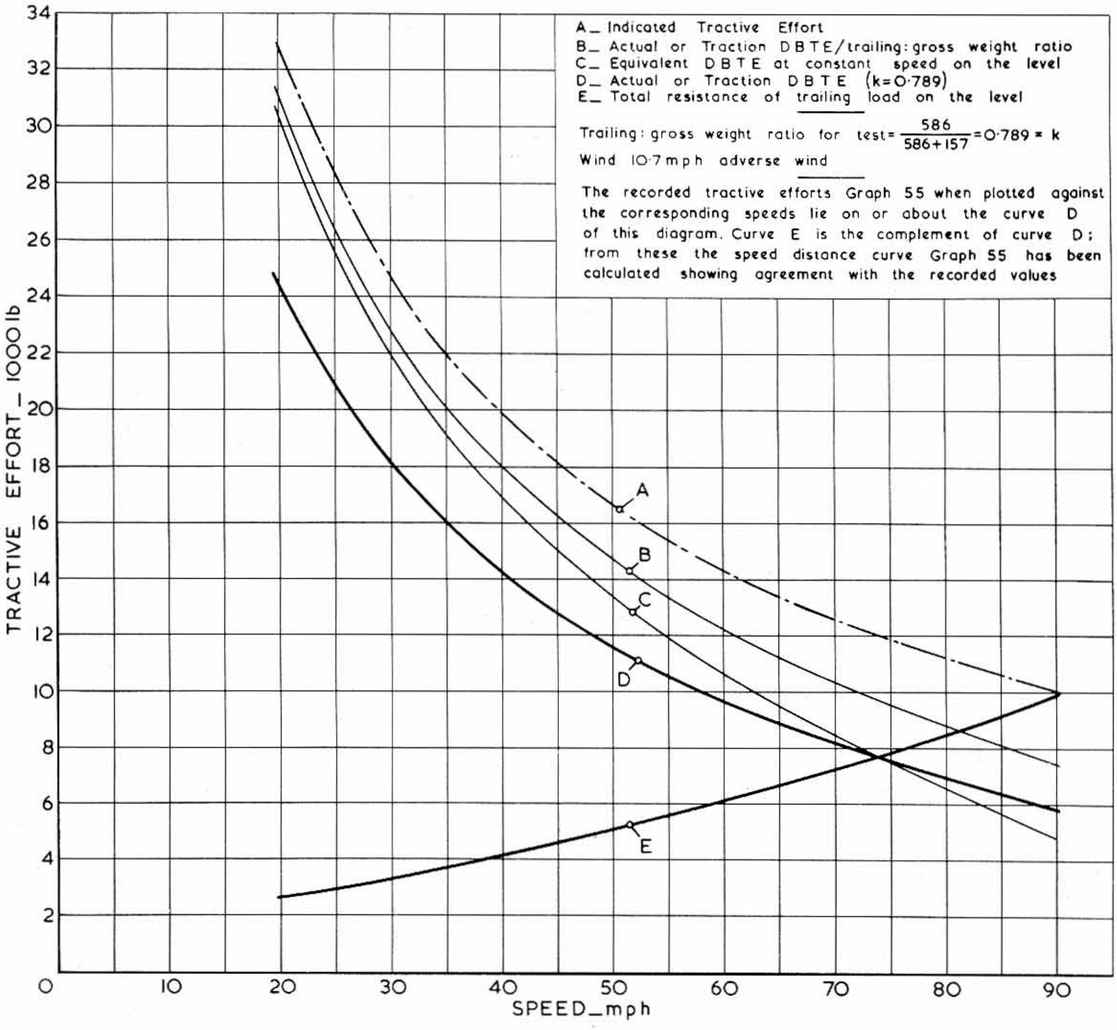
SUMMATIONS OF INCREMENTS

CONTROLLED ROAD TEST No 10 R

SOUTH KIRKBY COAL _ 13550 B Th U/lb

See also graphs 54 & 55

BR8/71000/55

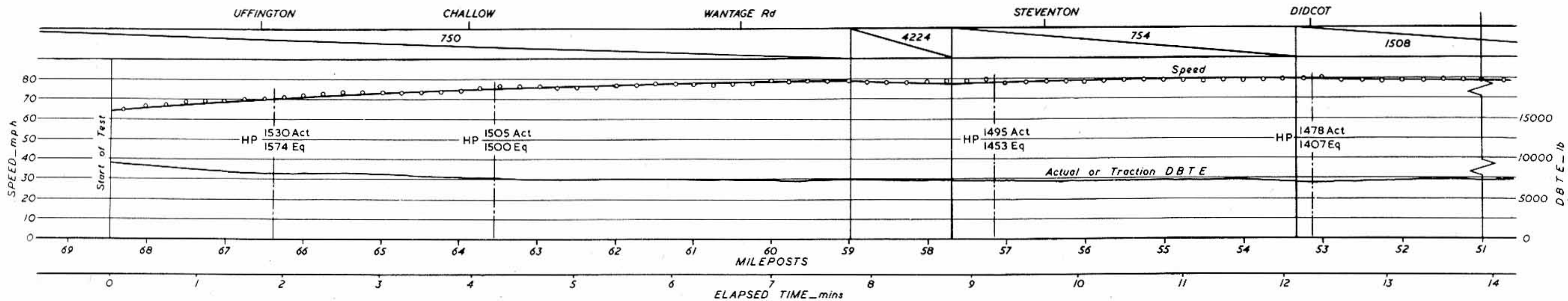


CHARACTERISTICS PRODUCED BY CONTROLLED ROAD TEST No 10R

Steam Rate 30000 lb/hr Coal Rate 4850 lb/hr

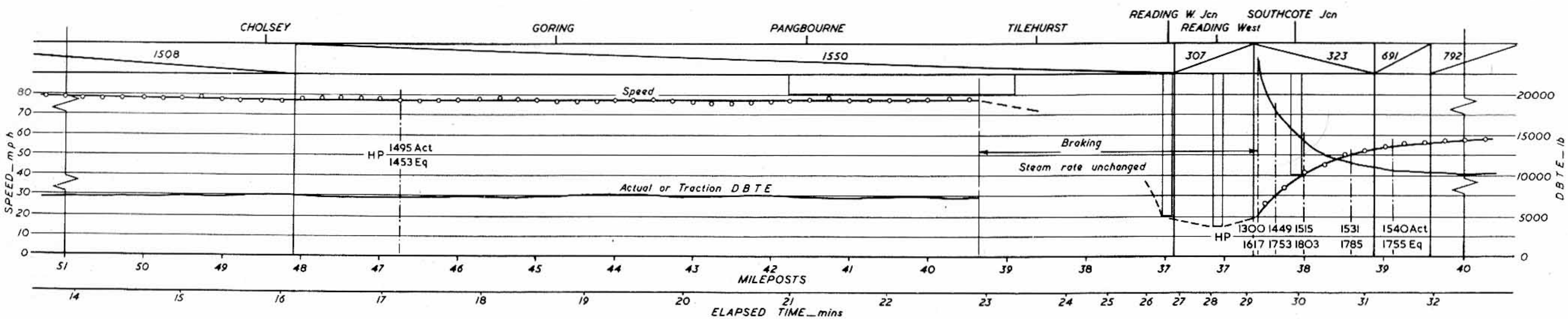
SOUTH KIRKBY COAL 13550 B Th U/lb

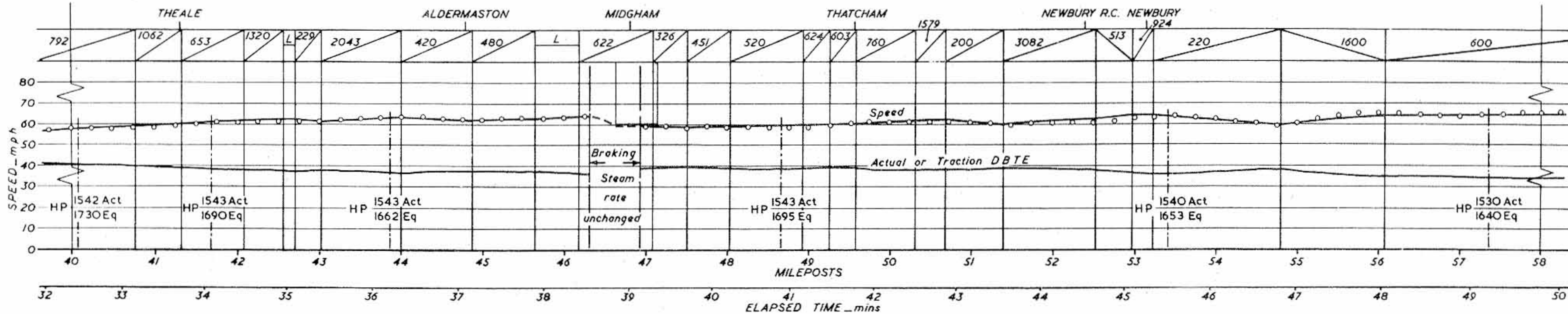
BR8/71000/55



Boiler Efficiency 62 %   Average Steam Temperature 750° F   10·7 m p h Adverse Wind

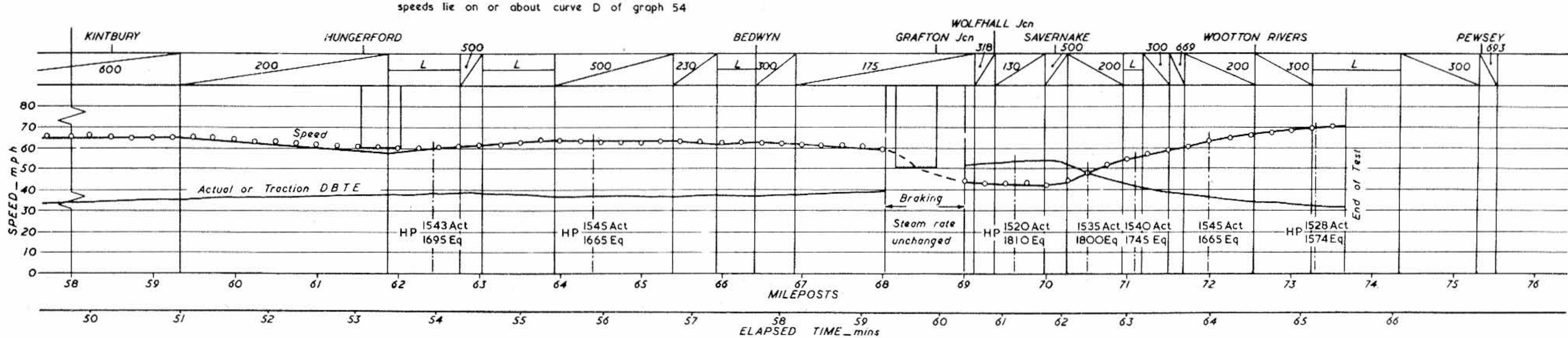
For Summations of Increments of Coal & Water see Graph 53





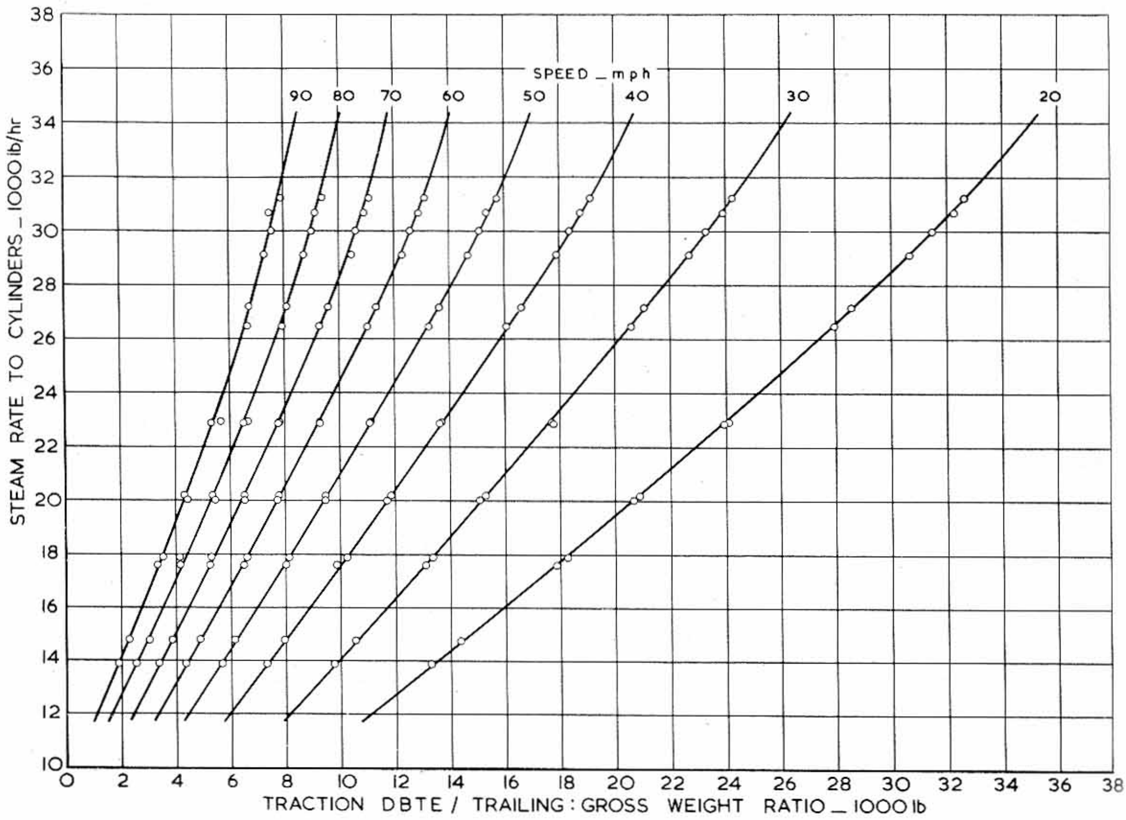
To verify the mean resistance curve, the full line speed curve has been calculated from this and the tractive effort curve D for comparison with the recorded speeds shown thus o

The tractive efforts shown on this diagram when plotted against the corresponding speeds lie on or about curve D of graph 54



CONTROLLED ROAD TEST No 10R at a Constant Rate of Steam Production and Utilisation of 30000 lb/hr   Coal Rate 4850 lb/hr   Load 586 tons passenger stock

BR8/71000/55



CO·ORDINATION OF TEST RESULTS BY WILLANS LINES

56

BR8/71000/55

TABLE 4

FACTORS OF THE COAL/TON MILE

(a) Constant Load, Varying Average Speed

Three Examples from the timings for a tare load of 576 tons on the Euston - Rugby route, Graph 58a.

Line			Identification on Graph D	E	F
1	Trailing Load (Tare + 10%)	tons	634	634	634
2	Gross Weight	tons	791	791	791
3	Trailing:Gross Mass Ratio	k	.801	.801	.801
4	1/k		1.25	1.25	1.25
5	Average Speed	mph	65.2	53.1	45.6
6	Running Time	mins	76	93	109
7	Coal/ton mile, Graph 58a	lb.	.11	.098	.069
8	Coal/mile (7)x 82.5/tare load	lb.	63.3	56.4	39.8
9	Ruling Steam Rate	lb/hr.	30,000	24,000	16,000
10	Firing Rate, Graph 39	lb/hr.	4,440	3,040	1,805
11	Trac. DTE/k, Speed (5) Graph 39	lb.	11,450	11,100	7,700
12	Trac.DHP/k, Speed (5) (11)x(5)/375		1,990	1,572	935
13	Trac.DHP/(12)x(3)		1,595	1,255	749
14	Trac.DHP/ton hauled (13)/(1)		2.52	1.98	1.18
15	k.coal/dbhphr, (10)(12)	lb.	2.24	1.93	1.93
16	Coal/dbhphr, (15)(13)	lb.	2.80	2.42	2.41
17	Coal/ton mile by Approx'n (16)x(14)/(5)	lb.	.108	.090	.063
18	Ratio, (7):(17)		1.02	1.09	1.09
19	Probable coal/dbhphr (16)x(18)	lb.	2.85	2.64	2.63

Values in Lines 16, 5, 15, 7 and 17 are shewn plotted in Graph 57a.

TABLE 5

FACTORS OF THE COAL/TON MILE

(b) Constant Average Speed, Varying Load

Three Examples from the 80 minute timing on the Euston - Rugby route, Graph 58a. Average Speed 62 m.p.h.

Line			Identification on Graph		
			A	B	C
1	Tare Load	tons	210	357	556
2	Trailing Load (Tare + 10%)	tons	231	393	612
3	Gross Weight	tons	388	550	769
4	Trailing:Gross Mass Ratio	k	.596	.715	.798
5	1/k		1.68	1.40	1.257
6	Coal/ton mile, Graph 58a	lb.	.13	.133	.11
7	Coal/mile (6)x 82.5/(1)	lb.	27.3	47.4	61.1
8	Ruling Steam Rate	lb/hr.	16,000	24,000	28,300
9	Firing Rate, Graph 39	lb/hr.	1,805	3,040	4,000
10	Trac.DTE/k at 62 mph Graph 39	lb.	5,400	9,500	11,400
11	Trac.DHP/k at 62 mph (10)x 62/375		893	1,575	1,885
12	Trac.DHP at 62 mph (11)x(4)		532	1,125	1,500
13	Trac. DHP/ton hauled (12)/(2)		2.30	2.87	2.46
14	k.coal/dbhphr (9)/(11)	lb.	2.02	1.94	2.12
15	Coal/dbhphr (14)/(4)	lb.	3.39	2.72	2.66
16	Coal/ton mile by approx'n (15)x(13)/(62)	lb.	.126	.126	.105
17	Ratio (6):(16)		1.03	1.05	1.05
18	Probable coal/dbhphr (15)x(17)	lb..	3.5	2.86	2.79

Values in Lines 5, 6, 13, 14, 15 and 16 are shown plotted in Graph 57b.

$$\text{Coal/ton mile} = \frac{\text{coal/hr}}{\text{mph}} \times \frac{1}{\text{tons hauled}}$$

But $\text{Coal/hr} = \text{Coal/dbhphr} \times \text{dbhp}$

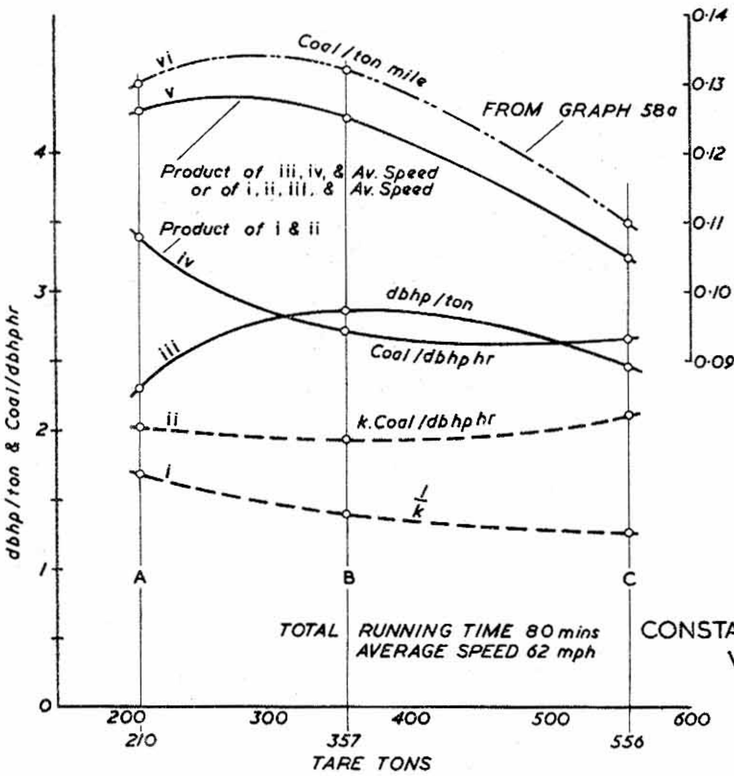
Substituting :-

$$\text{Coal/ton mile} = \frac{\text{coal/dbhphr}}{\text{mph}} \times \text{dbhp/ton hauled}$$

$$\text{Coal/ton mile} = k.\text{coal/dbhphr} \times \frac{1}{k} \times \frac{\text{dbhp/ton hauled}}{\text{mph}}$$

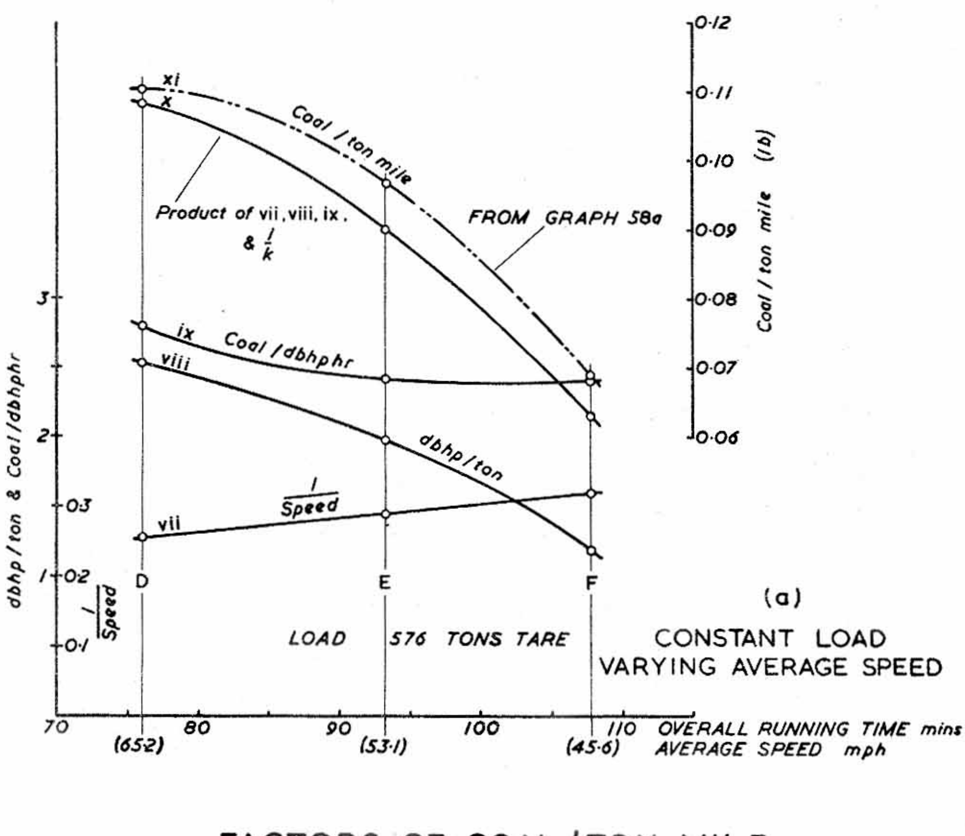
Where k = trailing : gross weight ratio

k.coal/dbhphr can be obtained from Graph 39



(b)

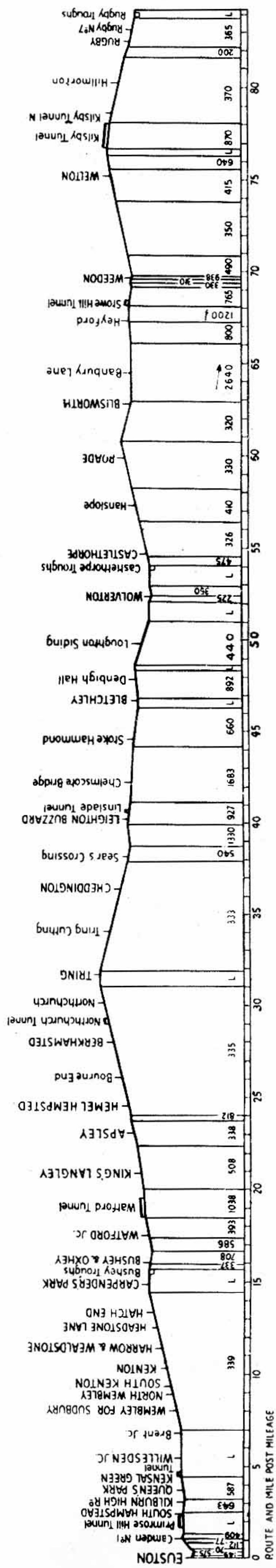
CONSTANT AVERAGE SPEED
VARYING LOAD



(a)

CONSTANT LOAD
VARYING AVERAGE SPEED

FACTORS OF COAL / TON MILE

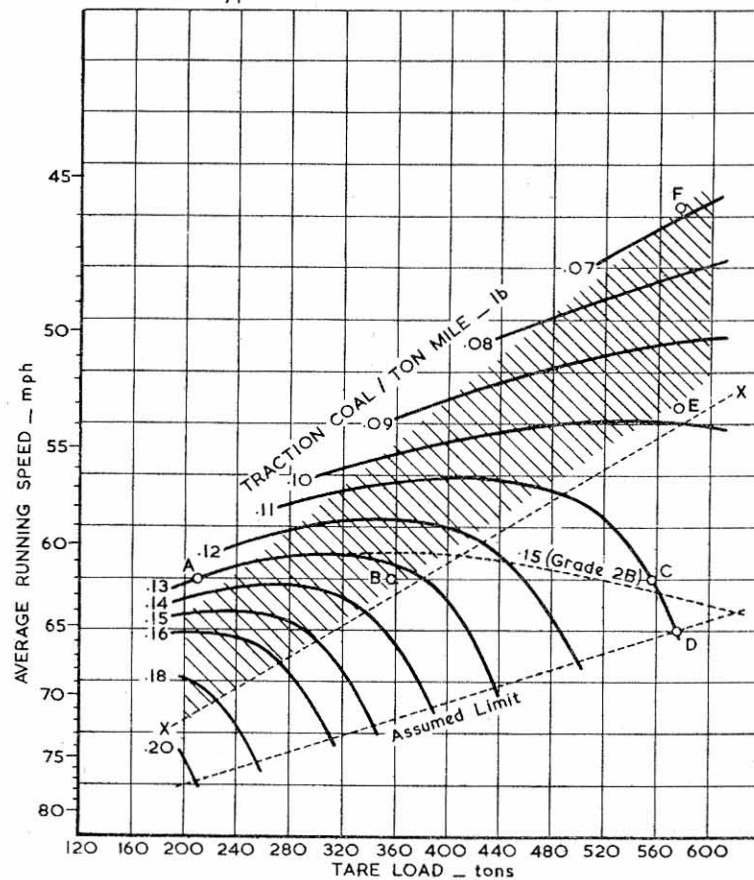

EUSTON
Camden No1
Primrose Hill Tunnel
SOUTH HAMPSTEAD
KILBURN HIGH Rd
QUEEN'S PARK
KENSAL GREEN Tunnel
WILLESDEN JC
Brent Jc.
WEMBLEY FOR SUDBURY
NORTH WEMBLEY
SOUTH KENTON
KENTON
HARROW & WEALDSTONE
HEADSTONE LANE
HATCH END
CARPENDER'S PARK
Bushey Troughs
BUSHEY & OXHEY
WATFORD Jc.
Watford Tunnel
KING'S LANGLEY
APSLEY
HEMEL HEMPSTED
Bourne End
BERKHAMSTED
Northchurch Tunnel
Northchurch
TRING
Tring Cutting
CHEDDINGTON
Sear's Crossing
LEIGHTON BUZZARD
Linslade Tunnel
Chelmscote Bridge
Stoke Hammond
BLETCHLEY
Denbigh Hall
Loughton Siding
WOLVERTON
Castlethorpe Troughs
CASTLETHORPE
Hanslope
ROADE
BLISWORTH
Banbury Lane
Heyford
Stowe Hill Tunnel
WEEDON
WELTON
Kilsby Tunnel
Kilsby Tunnel N
Hillmorton
RUGBY
Rugby No7
Rugby Troughs
ROUTE AND MILE POST MILEAGE

EUSTON - CARLISLE PASSENGER SERVICES Stopping at Rugby and Crewe

Euston _ Rugby

Loco Type · BR Class 8 4-6-2

Mileage 82·54



TOTAL RUNNING TIME _ mins	SCHEDULES POINT-TO-POINT TIMES _ mins								
	Euston	*Willesden Jcn*	*Watford Jcn*	*Tring*	*Bletchley*	*Roade*	*Blisworth*	*Weedon*	*Rugby*
108	10·2	17·7	21·6	15·4	15·0	3·9	7·7	16·5	
104	9·9	17·0	20·8	14·9	14·4	3·8	7·4	15·8	
100	9·7	16·3	19·8	14·4	13·8	3·6	7·1	15·3	
96	9·4	15·5	18·8	14·0	13·3	3·4	6·9	14·7	
92	9·2	14·8	17·9	13·4	12·8	3·3	6·6	14·0	
88	9·0	14·0	16·9	13·0	12·2	3·1	6·3	13·5	
84	8·8	13·2	15·9	12·5	11·7	2·9	6·1	12·9	
80	8·6	12·4	14·9	12·0	11·2	2·8	5·8	12·3	
76	8·5	11·5	13·8	11·5	10·7	2·6	5·6	11·8	
72	8·3	10·7	12·7	11·0	10·2	2·4	5·3	11·4	
68	8·1	9·8	11·6	10·5	9·8	2·3	5·0	10·9	
64	8·0	8·9	10·3	10·1	9·3	2·1	4·8	10·5	

XX _ Maximum Power 2000 hp DE No 10203 _ Bulletin 16

The Diagram assumes Grade 1A coal, 13600 BThU/lb approx. For typical Grade 2B coal, 12900 BThU/lb approx, increase the coal/ton mile by 13% and 20% at the lower and higher boundaries of the hatched areas respectively and by 40% at the assumed limit.

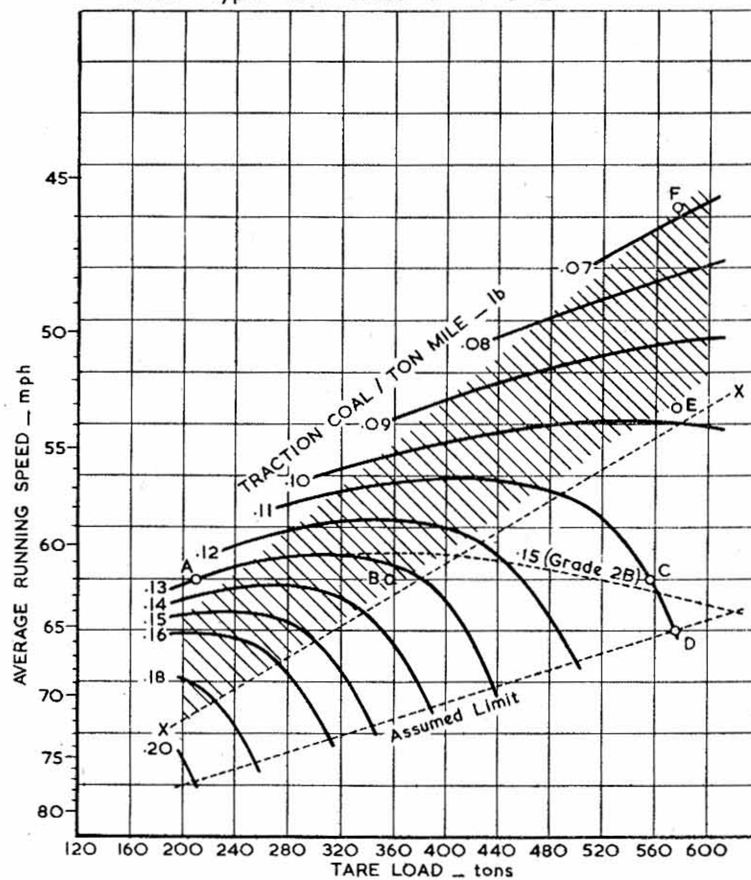
COST OF ENERGY AND PERFORMANCE

BR8/71000/55

EUSTON - CARLISLE PASSENGER SERVICES Stopping at Rugby and Crewe

Euston – Rugby

Loco Type · BR Class 8 4-6-2 Mileage 82·54



TOTAL RUNNING TIME – mins	Euston – Willesden Jcn	Willesden Jcn – Watford Jcn	Watford Jcn – Tring	Tring – Bletchley	Bletchley – Roade	Roade – Blisworth	Blisworth – Weedon	Weedon – Rugby
108	10·2	17·7	21·6	15·4	15·0	3·9	7·7	16·5
104	9·9	17·0	20·8	14·9	14·4	3·8	7·4	15·8
100	9·7	16·3	19·8	14·4	13·8	3·6	7·1	15·3
96	9·4	15·5	18·8	14·0	13·3	3·4	6·9	14·7
92	9·2	14·8	17·9	13·4	12·8	3·3	6·6	14·0
88	9·0	14·0	16·9	13·0	12·2	3·1	6·3	13·5
84	8·8	13·2	15·9	12·5	11·7	2·9	6·1	12·9
80	8·8	12·4	14·9	12·0	11·2	2·8	5·8	12·3
76	8·5	11·5	13·8	11·5	10·7	2·6	5·6	11·8
72	8·3	10·7	12·7	11·0	10·2	2·4	5·3	11·4
68	8·1	9·8	11·6	10·5	9·8	2·3	5·0	10·9
64	8·0	8·9	10·3	10·1	9·3	2·1	4·8	10·5

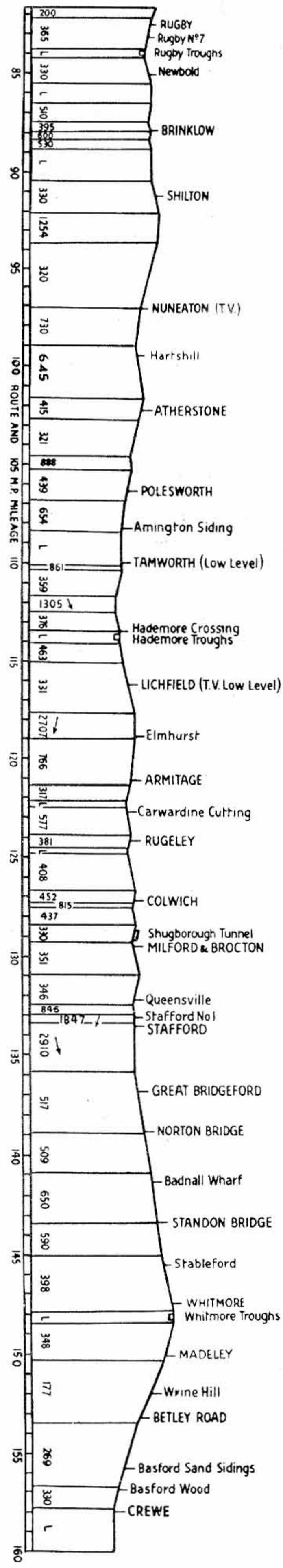
SCHEDULES POINT-TO-POINT TIMES – mins

XX – Maximum Power 2000 hp DE No 10203 – Bulletin 16

The Diagram assumes Grade 1A coal, 13600 BThU/lb approx. For typical Grade 2B coal, 12900 BThU/lb approx, increase the coal/ton mile by 13% and 20% at the lower and higher boundaries of the hatched areas respectively and by 40% at the assumed limit.

COST OF ENERGY AND PERFORMANCE

BR8/71000/55

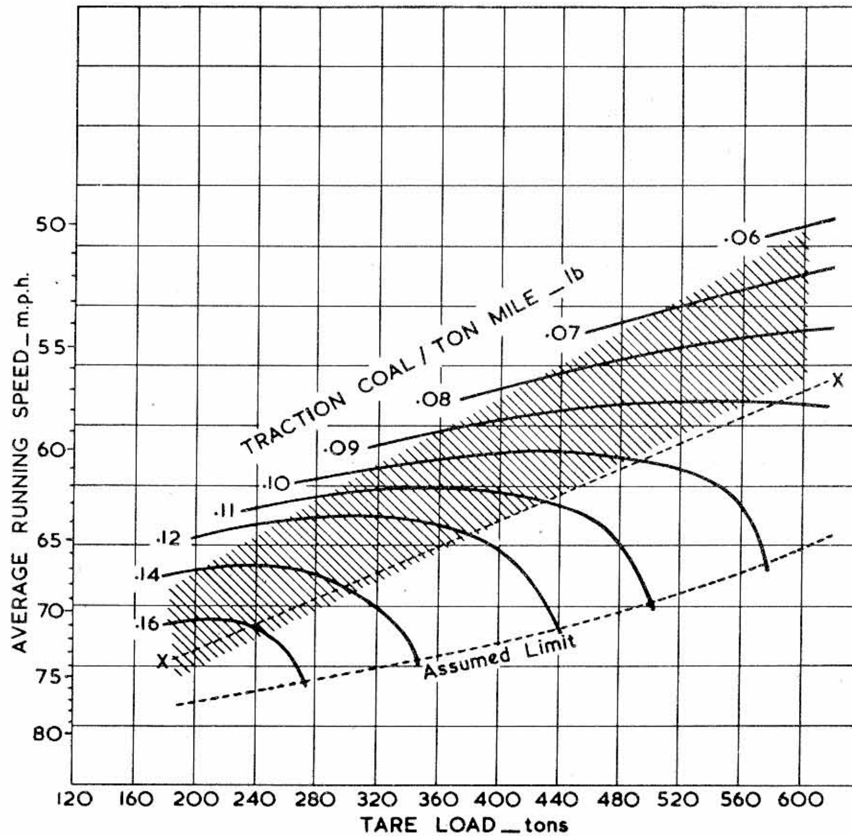

RUGBY
Rugby No7
Rugby Troughs
Newbold
BRINKLOW
SHILTON
NUNEATON (T.V.)
Hartshill
ATHERSTONE
POLESWORTH
Amington Siding
TAMWORTH (Low Level)
Hademore Crossing
Hademore Troughs
LICHFIELD (T.V. Low Level)
Elmhurst
ARMITAGE
Carwardine Cutting
RUGELEY
COLWICH
Shugborough Tunnel
MILFORD & BROCTON
Queensville
Stafford No1
STAFFORD
GREAT BRIDGEFORD
NORTON BRIDGE
Badnall Wharf
STANDON BRIDGE
Stableford
WHITMORE
Whitmore Troughs
MADELEY
Wrine Hill
BETLEY ROAD
Basford Sand Sidings
Basford Wood
CREWE
ROUTE AND M.P. MILEAGE
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
200
365
L
330
L
510
395
600
530
L
330
1254
320
730
645
415
321
888
439
654
L
861
359
1305
376
L
463
331
2707
766
317
L
577
381
L
408
452
815
437
330
351
346
846
1847
2910
517
509
650
590
398
L
348
177
269
330
L

EUSTON – CARLISLE PASSENGER SERVICES Stopping at Rugby and Crewe

Rugby - Crewe

Loco Type _ BR Class 8 4-6-2

Mileage 75·48



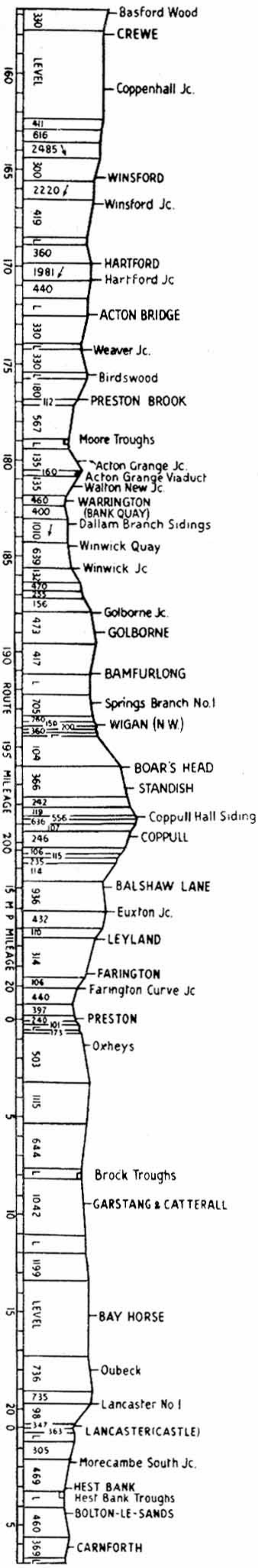
TOTAL RUNNING TIME _ mins	SCHEDULES POINT-TO-POINT TIMES _ mins									
	Rugby – *Nuneaton*	*Nuneaton* – *Tamworth*	*Tamworth* – *Lichfield*	*Lichfield* – *Rugeley*	*Rugeley* – *Milford*	*Milford* – *Stafford*	*Stafford* – *Norton Bridge*	*Norton Bridge* – *Whitmore*	*Whitmore* – *Crewe*	
89	20·9	12·9	6·5	9·5	6·0	4·5	5·8	11·8	11·1	
85	19·9	12·2	6·2	9·0	5·7	4·3	5·7	11·2	10·8	
81	18·8	11·6	5·9	8·5	5·5	4·2	5·6	10·5	10·4	
77	17·8	11·0	5·6	8·0	5·3	4·0	5·4	9·8	10·1	
73	16·8	10·5	5·3	7·5	5·0	3·9	5·2	9·1	9·7	
69	15·7	10·1	5·0	7·0	4·8	3·8	4·9	8·4	9·3	
65	14·5	9·7	4·7	6·4	4·6	3·6	4·7	7·8	9·0	
61	13·2	9·5	4·5	5·9	4·4	3·5	4·4	7·1	8·5	

XX _ Maximum Power 2000 hp DE No 10203 _ Bulletin 16

The Diagram assumes Grade 1A coal, 13600 B Th U/lb approx. For typical Grade 2B coal, 12900 B Th U/lb approx, increase the coal/ton mile by 13% and 20% at the lower and higher boundaries of the hatched areas respectively and by 40% at the assumed limit

COST OF ENERGY AND PERFORMANCE

BR8/71000/55

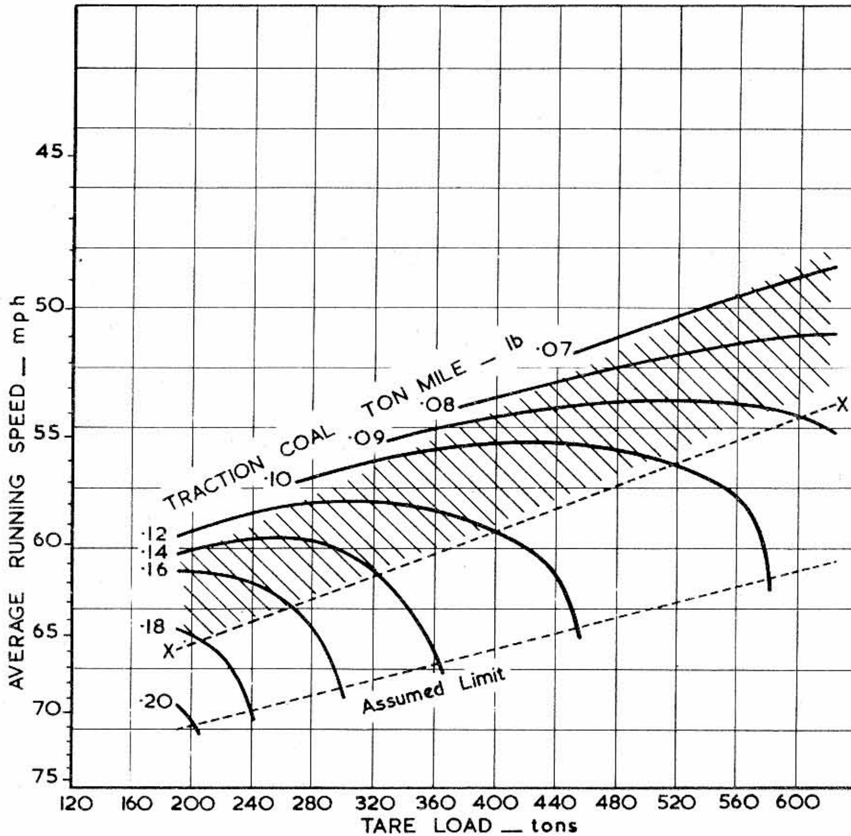

Basford Wood
CREWE
Coppenhall Jc.
WINSFORD
Winsford Jc.
HARTFORD
Hartford Jc
ACTON BRIDGE
Weaver Jc.
Birdswood
PRESTON BROOK
Moore Troughs
Acton Grange Jc.
Acton Grange Viaduct
Walton New Jc.
WARRINGTON
(BANK QUAY)
Dallam Branch Sidings
Winwick Quay
Winwick Jc
Golborne Jc.
GOLBORNE
BAMFURLONG
Springs Branch No.1
WIGAN (N.W.)
BOAR'S HEAD
STANDISH
Coppull Hall Siding
COPPULL
BALSHAW LANE
Euxton Jc.
LEYLAND
FARINGTON
Farington Curve Jc
PRESTON
Oxheys
Brock Troughs
GARSTANG & CATTERALL
BAY HORSE
Oubeck
Lancaster No 1
LANCASTER(CASTLE)
Morecambe South Jc.
HEST BANK
Hest Bank Troughs
BOLTON-LE-SANDS
CARNFORTH
ROUTE MILEAGE
M P MILEAGE

EUSTON CARLISLE PASSENGER SERVICES Stopping at Rugby and Crewe

Crewe _ Carnforth

Loco Type BR Class 8 4-6-2

Mileage 78·23



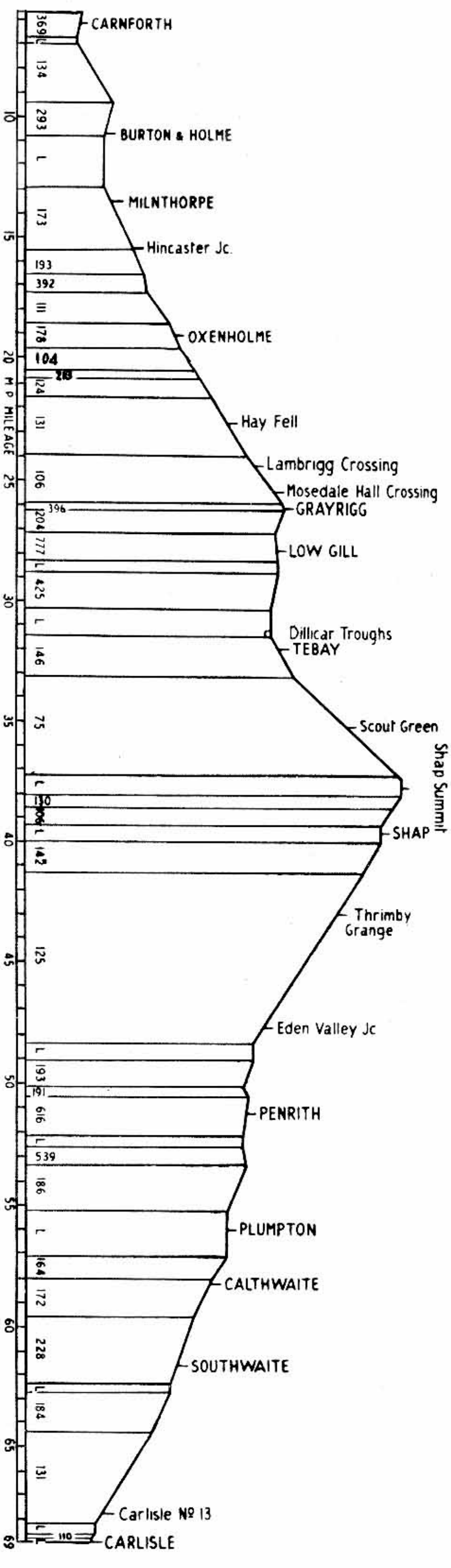
TOTAL RUNNING TIMES _ mins	Crewe – Coppenhall Jcn.	Coppenhall Jcn. – Winsford Jcn.	Winsford Jcn. – Weaver Jcn.	Weaver Jcn. – Acton Grange Jcn.	Acton Grange Jcn. – Warrington	Warrington – Winwick Jcn.	Winwick Jcn. – Springs Branch	Springs Branch – Wigan	Wigan – Standish Jcn.	Standish Jcn. – Euxton Jcn.	Euxton Jcn. – Preston	Preston – Oxheys	Oxheys – Garstang	Garstang – Lancaster	Lancaster – Carnforth
98	5·9	7·0	7·7	5·9	2·2	3·6	9·7	1·7	6·1	8·5	5·2	3·4	10·9	13·9	6·3
94	5·8	6·8	7·4	5·8	2·1	3·5	9·1	1·6	5·7	8·1	5·1	3·3	10·5	13·0	6·2
90	5·7	6·5	7·0	5·7	2·0	3·5	8·6	1·6	5·3	7·6	5·0	3·2	10·0	12·2	6·1
86	5·5	6·2	6·7	5·6	1·9	3·4	8·1	1·5	5·0	7·2	4·9	3·1	9·5	11·5	5·9
82	5·3	5·9	6·3	5·4	1·8	3·4	7·6	1·4	4·7	6·7	4·8	3·1	9·0	10·9	5·7
78	5·0	5·5	6·0	5·2	1·8	3·4	7·2	1·4	4·4	6·2	4·8	3·0	8·4	10·2	5·5
74	4·8	5·1	5·7	5·0	1·7	3·4	6·9	1·3	4·1	5·7	4·7	2·9	7·7	9·7	5·3
70	4·5	4·7	5·4	4·7	1·6	3·4	6·6	1·3	3·9	5·2	4·7	2·8	7·1	9·0	5·1
66	4·2	4·3	5·1	4·5	1·6	3·3	6·3	1·3	3·7	4·6	4·6	2·7	6·5	8·5	4·8

XX _ Maximum Power 2000 hp DE No 10203 _ Bulletin 16

The Diagram assumes Grade 1A coal, 13600 B Th U/lb approx. For typical Grade 2B coal, 12900 B Th U/lb approx, increase the coal/ton mile by 13% and 20% at the lower and higher boundaries of the hatched areas respectively and by 40% at the assumed limit.

COST OF ENERGY AND PERFORMANCE

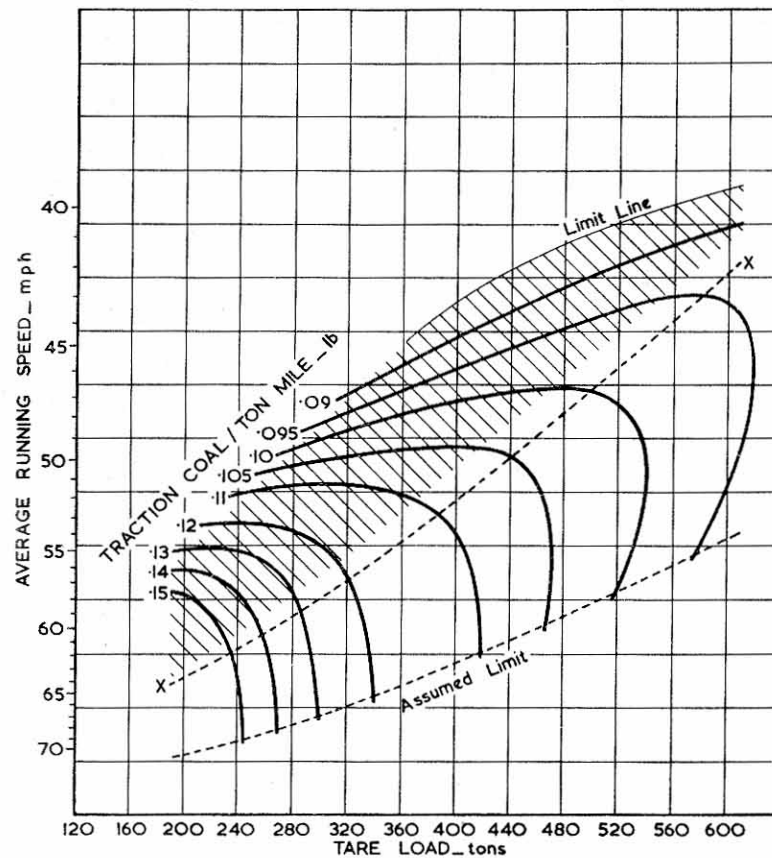
BR8/71000/55


CARNFORTH
BURTON & HOLME
MILNTHORPE
Hincaster Jc.
OXENHOLME
Hay Fell
Lambrigg Crossing
Mosedale Hall Crossing
GRAYRIGG
LOW GILL
Dillicar Troughs
TEBAY
Scout Green
Shap Summit
SHAP
Thrimby Grange
Eden Valley Jc
PENRITH
PLUMPTON
CALTHWAITE
SOUTHWAITE
Carlisle Nº 13
CARLISLE
M P MILEAGE

EUSTON – CARLISLE PASSENGER SERVICES Stopping at Rugby and Crewe

Carnforth – Carlisle

Loco Type BR Class 8 4-6-2 Mileage 62·86



TOTAL RUNNING TIMES – mins	Carnforth–Oxenholme	Oxenholme–Tebay	Tebay–Shap Summit	Shap Summit–Penrith	Penrith–Plumpton	Plumpton–Carlisle
93	19·8	25·4	17·0	14·0	4·7	12·1
89	18·6	24·2	15·7	13·8	4·6	12·1
85	17·4	23·0	14·3	13·7	4·6	12·0
81	16·3	21·7	13·1	13·5	4·5	11·9
77	15·2	20·3	11·8	13·4	4·5	11·8
73	14·2	19·0	10·5	13·2	4·4	11·7
69	13·2	17·6	9·3	12·9	4·3	11·7
65	12·2	16·1	8·2	12·6	4·2	11·7
61	11·2	14·5	7·0	12·4	4·2	11·7
57	10·3	12·9	6·0	12·1	4·1	11·6
53	9·3	11·4	5·0	11·8	3·9	11·6

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The Diagram assumes Grade 1A coal, 13600 B Th U/lb approx. For typical Grade 2B coal, 12900 B Th U/lb approx, increase the coal/ton mile by 13% and 20% at the lower and higher boundaries of the hatched areas respectively and by 40% at the assumed limit.

COST OF ENERGY AND PERFORMANCE

BR 8/71000/55

working expenditure proportional to net ton miles

working expenditure proportional to length of track

annual cost per mile of track

average tare weight of train / mean useful tonnage

working expenditure proportional to train mileage

working expenditure proportional to train hours

capital cost of 1 locomotive hour = price paid for each locomotive per year / mean annual working time

working expenditure proportional to vehicle mileage

working expenditure proportional to vehicle hours

mean price paid for each vehicle per year / mean annual working time

expenditure per gross ton mile

cost of unit of energy

energy per gross ton mile

Reduction in these
Reduces cost of
the net ton mile

$$\text{Cost of the NET TON MILE} = b_p + \frac{a_b + \gamma_s c_s}{I} + (1+\lambda)\left[\frac{b_k}{Q} + \frac{h_2 + h'_k}{QV_k} + \frac{b_m}{q'} + \frac{h_s + h'_m}{q'V_m} + b_q + c_e e_k\right]$$

mean daily mileage of vehicle / mean daily working time

gross weight of train / mean number of vehicles per train

mean daily mileage of locomotive / mean daily working time, shed to shed

mean gross weight of train

intensity of traffic on division = net ton miles / train miles

Increase in these
Reduces cost of
the net ton mile

The Lomonossoff Formula for the Cost of the Net Ton Mile

"Introduction to Railway Mechanics" Equation 126 Page 164

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