BULLETIN No. 16

THE BRITISH TRANSPORT COMMISSION

BRITISH RAILWAYS

Performance and Efficiency Tests
1 Co-Co 1 2000 HP MAIN LINE DIESEL-ELECTRIC LOCOMOTIVE No. 10203

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DIESEL - ELECTRIC LOCOMOTIVE No.10203

Photo. British Railways S.R.

WESTBOUND REVENUE EARNING TRAIN NEAR WILTON

Photo. British Railways S.R.

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1. INTRODUCTION

The tests which are the subject of this Bulletin were undertaken to produce the performance and fuel consumption characteristics of a representative 2000 h.p. diesel-electric locomotive of current design so that the capabilities of such a locomotive may be related to the practical power requirements of services on any route available to it and to the commercial cost of energy entailed in working the services; concurrently it was desired to produce information relative to operation and design.

The tests were carried out in two series.

The first comprised a small number of tests under controlled fuel rates with special trains for the purpose of establishing the principal relations of tractive effort, fuel consumption and speed in which are embodied the performance of the locomotive with any load and the efficiency with which mechanical energy is made available for traction.

The second was a series on normal revenue earning services, wholly observational in character. The commercial cost of energy - an important item in the cost of the net ton mile - is a function not only of the efficiency with which the mechanical energy required for the displacement of the load is supplied, the magnitude of the load and its speed of displacement but also of the economic use of mechanical energy. It became desirable therefore that deductions which may be made from the principal relations as established by the first series should be shown capable of reconciliation with results obtained under normal service conditions. This was the main purpose of the second series.

The programme was a development of that followed in the tests of the 1750 h.p. diesel-electric Locomotive No. 10202 reported in Bulletin 9.

The work was planned and carried out and the Bulletin was prepared by the Swindon Experimental and Locomotive Testing Station; the Western Region Dynamometer Car was used as the testing unit in the tests. The work was conducted under the auspices of the Locomotive Testing Joint Sub-Committee consisting of

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2. THE LOCOMOTIVE.

The 2000 H.P. 1Co - Co1 diesel electric locomotive No. 10203 was built at the Brighton works of the Southern Region of British Railways and is externally similar to the two earlier 1750 H.P. Southern Region locomotives No. 10201 and 10202. Diag. 1 is a dimensional diagram of the locomotive, and detailed particulars of general interest are given in Table 1.

Its weight is 132.8 tons, of which 109.5 tons are adhesive, with a maximum axle load of 18.6 tons. The leading dimensions are identical with the two 1750 H.P. locomotives, but the designed starting rail tractive effort is 50,000 lb. and the continuous rating 30,000 lb. at the rail at 19.5 m.p.h. The designed rail tractive effort-speed curve is shown in Graph 2. The maximum speed is 90 m.p.h. and the wheel diameters are :- driving, 3'7" and carrying 3'1", as for the 1750 H.P. locomotives. The six driving axles are each driven by a 6 pole nose-suspended motor through single-reduction straight-spur gearing with a ratio of 19 to 61. Supplies include 1180 gallons of fuel oil, 160 gallons of lubricating oil, 280 gallons of engine cooling water and 840 gallons of water for train heating. Braking equipment is Westinghouse straight air for the locomotive and vacuum for the train.

(a) Mechanical

The underframe consists of two heavy I section central longitudinals reinforced with plates to form a box girder and two outer channels, joined by suitable crossbracing to form a rigid structure. The body, of rivetted and welded construction with a driving cab at each end, is divided into compartments for radiators, engine, electrical equipment and boiler with through access. The two main fuel tanks are carried adjacent to the engine on either side of a central gangway, while water storage is provided in two side tanks alongside the electrical equipment compartment and one auxiliary tank formed in the centre portion of the underframe between the two main longitudinals.

The vacuum brake equipment consists of two Reavell rotary exhausters, motor driven and arranged for two-speed control. Separate brake valves for air and vacuum are provided, the driver's vacuum brake valve controlling the vacuum brakes and the air brakes through a proportional valve. The straight air brake valve gives an independent locomotive brake when required.

The power equipment controls are very simple, consisting of two handles. The main power handle automatically gives full control of the engine output matched with the electrical equipment and this and the master switch handle are interlocked. The master switch handle has four positions; "off", "forward", "engine only", and "reverse" and the main power handle gives infinitely variable (notchless) power output control.

(b) Engine

The diesel engine is the English Electric 16 cylinder V form four-stroke pressure-charged engine designated 16SVT/II. It is a recent version of the well known English Electric Company's 10" x 12" RK and VT series. The continuous traction rating is 2000 b.h.p. at 850 r.p.m. and the input to the main generator, after allowing for all auxiliaries, is calculated at 1880 b.h.p. The corresponding b.m.e.p. is 123 lb. per sq. in. and the piston speed 1700 ft. per min. In this application the engine weight is 46,510 lb. or 20.2 lb per b.h.p. The specific weight of the power unit complete with generators is 28 lb. per b.h.p.

The engine has four Napier type TS100/4 turbo-superchargers and the cylinder heads have two exhaust and two inlet valves. Push rods and rocker gear are of conventional pattern. The governor is of the variable speed hydraulic servo type and is driven through bevel gears from one cam shaft. It is arranged for remote setting from the master controller by compressed air. The load regulator is so designed as to give full torque control from 450 to 850 r.p.m. Idling speed is set at 450 r.p.m. A device is attached to the governor to avoid the torsional critical speeds which occur in the engine speed range by passing the engine rapidly through these critical speeds, which are 595 and 725 r.p.m. The mechanism is adjusted to give blank zones of approximately ± 25 r.p.m. at the above speeds. The four turbo-superchargers draw air from outside the locomotive body through air maze panel type intake filters. There are no silencers on intake or exhaust sides.

(c) Transmission

Electrical transmission and control gear is of the normal English Electric type and the ratings of the main generator and traction motors are discussed in Section 8.

The 10 pole self-ventilated main generator is directly coupled to the engine and the outer end of its shaft is supported on a self-aligning roller bearing. The shaft is extended to carry the armature of the auxiliary generator.

The auxiliary generator is overhung from the main generator. It is an 8 pole direct current machine rated at 48 k.W. 135 volts, 356 amps at 850 r.p.m. It supplies current to the auxiliary machines (except the radiator fan motor, which is supplied by the main generator) and to the control and battery charging circuits.

The six traction motors are of the 6 pole series wound forced-ventilated type, 3 motors being ventilated from each of the two motor driven blowers. Each motor drives a road wheel axle through single reduction gearing and is hung on the axle on one side and resiliently suspended from the bogie frame on the other.

Simplified power and auxiliary circuits are shown diagrammatically in Diag. 3 from which it will be seen that the motors are permanently connected in series-parallel, there being three groups of two in series; each group is fed from a separate motor contactor.

A fully automatic system of traction motor field diversion is incorporated to enable the available diesel engine output to be used through almost the full speed range of the locomotive. The diversion occurs in 3 stages and once it has been introduced is maintained until the control handle is returned to "off", or until the traction motor current approaches a limiting high value.

(d) Control Equipment

Power is the product of tractive effort and speed or, in an electrical transmission, the product of current and voltage. Therefore the ideal characteristic curve which fully utilises the available output of a prime mover is a rectangular hyperbola representing constant power as shown by A of Diag. 4. If a generator with this characteristic could readily be built no further apparatus would be required and the available output of the prime mover could be utilised at all train speeds. The design of generator with series, shunt and externally excited windings provides the best approach to the ideal characteristics but the form of the curve is similar to B and C of the figure.

Curve B utilises the full output at point x only and therefore at only one train speed. At all other speeds the power utilised is less than the maximum available but in no circumstance is the prime mover overloaded.

Curve C utilises the full output at points y and z only; outputs between these points overloading and outputs beyond them underloading the prime mover.

The functions of a torque regulator are to load the prime mover fully along the constant power line between the points y and z and to avoid overloading. It is not necessary to use the available output down to zero speed as this would give an infinitely high starting effort and beyond point z the natural characteristic of the generator is followed. Similarly the natural characteristic is followed at high train speeds beyond point y. This portion of the curve represents less power than the constant power hyperbola and arrangements are made to reduce fuel consumption beyond the "unloading point" which y represents.

It is, of course, necessary to provide for outputs below the maximum rating of the prime mover and the control system has to be arranged to select any one of an infinite number of curves within the band of output of the prime mover at the choice of the operator.

The control system of locomotive No. 10203 functions in two stages which cover consecutive portions of the power output range. The mechanism consists of pneumatic mechanical and hydraulic elements which are actuated by combinations of the controlled quantities.

(i) In the first stage the engine speed is maintained at the nominal idling figure of 450 r.p.m. over the first sector of movement of the driver's handle. The power output, however, is progressively increased by movement of the handle in the requisite direction. This initiates a sequence of events by way of a pneumatic-mechanical linkage which causes a motor driven resistor to increase the strength of the separately excited field winding of the main generator, whereby the loading on the engine is increased, tending to reduce its speed; this reacts on the centrifugal governor which moves the fuel racks by means of an oil operated servo-mechanism to increase the fuel injected per stroke until equilibrium of the servo-mechanism is restored.

The power output in this stage is very small, its use being confined to light engine working and yard movements and, therefore, it is not representative of normal passenger train duty.

(ii) In the second stage, the driver's handle operates over a section in which the engine r.p.m. is increased in such a manner that the maximum output at any given engine r.p.m. is obtained between the limits of 450 and 850 r.p.m. The boundary between the two sectors, representing the two stages, is maximum power output at minimum enginer.p.m. andcorresponds to the position where the operating linkage has just engaged the stop on the speed setting linkage of the governor, this member being inoperative in the first stage. Further movement of the handle causes the same sequence of events as in the first stage, but in addition the stop on the linkage rotates the governor member, which changes the position of a fulcrum, altering the governor setting and consequently the engine r.p.m.

If the track conditions are such that, even with the generator field excitation at its maximum, the engine is still not fully loaded the motor driven resistor arm continues to rotate in the "increase excitation" direction, closing contacts which connect the 1st stage diverting resistors across the traction motor fields. This causes the motors to take a higher current and lower voltage for a given train speed, enabling the torque regulator to further load the engine thereby increasing the train speed range over which the available engine power can be utilised. If the engine is still not fully loaded, the arm rotates further, closing contacts which in turn cause stages 2 and 3 of field diversion.

When the controller handle is moved to its maximum position the stop is engaged by the pneumatic portion of the linkage and the engine speed and torque (and therefore power) are all at their maxima.

Thus the control system permits the driver to select any required power output from the engine - generator unit. If, for instance, a rising gradient is encountered and the controller handle remains unchanged, the generator loading increases above the pre-set value, causing a tendency for the engine speed to fall and operate the governor, which in turn operates the motor driven resistor in such a direction as to weaken the separately excited field of the main generator. This decreases the load on the engine, the speed of which tends to rise until equilibrium is restored by the governor. While these changes are taking place the engine temporarily receives more fuel but at the end of the change the engine output has been restored to its original value so that the only permanent change is in the value of the excitation of the separately excited field, the engine-generator unit, of course, operating at a point lower down on the selected characteristic curve.

When the generator loading decreases, the sequence of events occurs in the opposite direction and the engine-generator unit moves to a higher point on the characteristic curve.

It is in the second stage that the representative passenger train duties are performed and the tests which are the subject of this bulletin covered the whole of this stage.

(e) Initial Setting of the Power Unit

The torque control equipment allows the power unit to function within the limits of ± 50 b.h.p. and the maximum output of the engine was set in the range 1950-2050 b.h.p. at the tests at the Maker's works. All power on these tests was absorbed by the main generator feeding into a suitable resistance, which enabled the b.h.p. input to be determined from the output and the known generator efficiency.

L.T. auxiliaries are all fed from the auxiliary generator and the radiator fan from the main generator; 120 h.p. was taken as their combined power absorption (though this varies somewhat under service conditions) leaving a mean of 1880 b.h.p. as being available for traction, to which corresponds an input to the traction motors of 1295 kW over the constant power range.

Due to the arrangement of the governor-operated switches it is the "loading" switch which takes control during acceleration and near-balancing speeds and therefore the power unit must nearly always operate on the lower limit of the power setting, which corresponds to just over 1260 kW input to the traction motors, except for brief periods following excitation changes.

3. OBJECTS OF THE TESTS

The object of the tests was to define the performance and efficiency characteristics of the locomotive, having regard to the condition of the power equipment, on the type of duty for which it was designed so that its capabilities may be related to the power requirements of services on any route available to it and to the commercial cost of energy entailed in working the services; concurrently to produce information relative to operation and design.

4. NATURE OF THE TESTS

It was considered that the objectives could best be attained by tests of an analytical nature arranged to explore not only the normal but also the unusual speed/load range. This factor and the necessity of controlling the fuel rates to a degree which is neither achieved nor warranted in normal services postulated the use of special trains. But obviously the objects are most completely attained when deductions from the data thus gathered can be reconciled with results obtained on normal revenue earning services.

(a) Tests with special trains - Controlled Road Tests.

From tractive effort related to train speed and fuel consumption and from resistance related to train speed, the performance of the locomotive with any weight of train on any route can be defined with the commercial cost of energy entailed. To produce these characteristics was regarded therefore as the minimum requirement. extending the analytical possibilities and the scope of the information produced by additional observations taken under the closely controlled conditions required for the main purpose. The nature of the special tests consequently hinged on the testing method employed for establishing tractive effort and resistance, this being the Swindon Controlled Road Testing System as adapted to diesel locomotives.

As illustrated in Diagram 5, the method is based on the ability of a dynamometer car, when the fuel rate is controlled, to define the tractive effort exerted on the trailing load and the latter's resistance. It is there shown that for the same fuel rate control, the tractive efforts exerted on loads of various denominations, at the same speeds vary directly as the trailing: gross weight ratios.

The properties of the locomotive may therefore be summarised on a comparative basis by two alternative series of curves each to a base of train speed

(i) Drawbar tractive effort at constant speed on the level (Equivalent D.B.T.E.) which is a function of actual D.B.T.E. exerted on the trailing load (Traction D.B.T.E.) and the resistance of the trailing load.

(ii) Traction D.B.T.E./trailing: gross weight ratio (Trac. D.B.T.E./k).

Both are resultants, i.e. are not actual efforts in the same way as the rail tractive effort and the traction drawbar tractive effort are actual efforts. (The rail tractive effort is not usually measurable by the dynamometer car though it is obtainable by deduction from certain other observations where there is electric transmission; on the other hand the traction drawbar tractive effort is measurable but is a function of the trailing load). But both (i) and (ii) contain the information required (additional to trailing load resistance) for train timing and the determination of the cost of energy of services. It should be noted that the equivalent drawbar tractive effort is equal to the rail tractive effort less the wind and track resistance of the locomotive, which concept is not of course qualified by gradient and acceleration as is the "drawbar" concept. The characteristic curves of traction D.B.T.E/**k** need no qualification as to gradient and acceleration.

Diagram 5 displays for a given trailing load the basic tractive effort relations which hold when the fuel rate remains constant over the speed range. When the total resistance of the trailing load on the level **R** is drawn on the diagram to the same scale as the effort the intersection of this curve with the equivalent drawbar tractive effort curve **P** marks the speed on the level at which there is no acceleration (the balancing speed on the level). The curve of traction drawbar tractive effort **p** (such as would be measured by a dynamometer car) is shown by the intermediate curve which passes through the intersection of the other two. It is so disposed that it divides the ordinate contained between the others in the ratio of the weights of locomotive and trailing load, changes in gradient and acceleration not affecting the curve. The equivalent drawbar tractive effort curve for the fuel rate control may therefore be constructed from the traction tractive effort curve established for any convenient load and the corresponding total resistance of the latter on the level.

The curve of traction drawbar tractive effort/trailing: gross weight ratio, **p/k** is simply curve **p** divided by the trailing: gross weight ratio appertaining to the test which produced **p** . For a particular fuel rate control, this characteristic curve, which may be used as an alternative to the equivalent drawbar tractive effort, may be established from the traction drawbar tractive effort produced on any convenient load, the observations not being affected by gradient and acceleration.

Though Diagram 5 illustrates a fuel control which effects a constant rate over the whole speed range, the relationships also hold when the fuel rate is a defined function of speed.

It is clear from the foregoing that a train made up of a dynamometer car and stock of the type required to a load which permits a wide speed range to be covered on a selected route with a given fuel rate control enables the required characteristics to be produced from the dynamometer car records. The resistance of the trailing load is that which, when used with the clearly definable traction drawbar tractive effort curve, can be shown to satisfy the speed-time and speed-distance curves of the test train that may be constructed from the automatically recorded data. This produces a most satisfactory solution for the mean trailing load resistance.

When the locomotive has electric power transmission observations may be extended with very great advantage to those of main and auxiliary generator output. A curve, which is virtually an effort equivalent of the main generator output (total input to the traction motor and the radiator fan) in respect to train speed, may them be produced from such observations if these have been co-ordinated with the other functions of force, time and distance on the dynamometer car recorders. Working one way from this curve the traction h.p. input to the main generator may be deduced from the known generator efficiency characteristics; by adding the h.p. input to the auxiliary generator from its observed output and efficiency characteristics the engine b.h.p. may be deduced. Working the other way, the rail tractive effort may be deduced by following the same procedure with the characteristics of traction motor efficiency through gears.

Since fuel may be measured with high accuracy by positive fuel meters registering small increments of consumption on the records of the dynamometer car, all effort and power curves are identifiable with fuel consumption.

Diagram 6 has been constructed to illustrate the nature of a Controlled Road test and to summarise the basic data it collects.

A series of tests may be programmed to cover as much of the power range as is desirable and practicable. When the various characteristic effort curves of each test of the series become available they must prove capable of being satisfactorily correlated on a basis of fuel consumption. It is no less important to obtain a satisfactory reconciliation as between the individual curves of specific trailing load resistance.

The stage is then reached when:

(i) the specific resistance of the trailing load may be presented.

(ii) the characteristics of equivalent drawbar tractive effort and of traction drawbar tractive effort/trailing: gross weight ratio may be produced, each covering as much of the working range as the tests and each fully related to fuel consumption.

In the case of a diesel-electric locomotive the following in addition :

(iii) the diesel engine performance and efficiency characteristics may be deduced and compared with such data relative to the original tests of the power equipment as may be available; this permits of the assessment of loss of performance and efficiency, if any, which may be due to fall off in condition.

(iv) the traction losses may be separated

(v) the wind and track resistance of the locomotive may be deduced

(vi) the full rail tractive effort characteristics related to fuel consumption may be deduced.

(b) Tests on Revenue Earning Services

The comprehensive comparison of results under service conditions with what may be estimated from the application of the principal relations discussed in the previous subsection calls for data in respect to the service trains in a most complete form. There are distinct advantages in employing for this purpose the Dynamometer Car exactly as in the Controlled Road Tests save only in the exercise of control in any form whatever. In following this course tests on the revenue earning trains become wholly observational by nature though the nature of the problem itself demands that services with nominally easy schedules for the locomotive should be included in the selection.

5. THE TESTS DESCRIBED.

All tests took place on the parent Region of the locomotive, where all its service up to this time had been spent. The locomotive then had a mileage of 106000 and 2865 engine hours to its credit during which its power equipment had received no more than the normal servicing. A gradient diagram of the test route is given in Diagram 7.

(a) Controlled Road Tests

It was decided that these should be carried out on the Salisbury - Exeter section of the Region in both directionsfor the sole reason of convenience to the Operating Department. Using the full power curve of the designed rail tractive effort characteristics Diagram 2, an estimate of wind and track resistance from previous tests of locomotive No.10202 and values of specific coaching stock resistance determined from past tests on the Controlled Road Testing system, it was calculated that a satisfactory speed range could be covered on the route with a trailing load of 400 tons. It was then calculated that the same schedule could very closely be observed with a load of 60 tons if the locomotive worked at maximum power for minimum engine r.p.m., the lower line on Diagram 2. These being the limits of the service working range, two intermediate rates were then interpolated, one at 700 engine r.p.m., about 80% of full power and the other at 560 engine r.p.m. 55% of full power. It was estimated that the same schedules as before could be kept if the corresponding loads were 290 tons and 130 tons respectively.

The point-to-point timings in both directions with the required loadings were submitted to and accepted by the Operating Department of the Southern Region which arranged the times to avoid interference with normal traffic.

Three intermediate stops of two minutes each were inserted in the Up run of 87.7 miles in order to correct, by extending or shortening the stopping times, any minor breaches of the schedule and to adjust for checks which could not be foreseen. A similar number of stops were scheduled in the Down trains for the same reasons. The stopping places were sited in positions which would be most likely to yield useful data on starting effort and subsequent acceleration.

The problem of the handling of the locomotive during the test periods reduced to first finding and then keeping a certain working position of the controller, this being different for each test r.p.m. For the full power tests the controller could be registered at its maximum position so that when test conditions had to be temporarily interrupted continuity with the previous test period could be ensured by replacing the controller in this register. In each of the other tests there could be no register. This was remedied by arranging for a tacho-generator to be driven from the engine crankshaft so that it indicated engine r.p.m. on two large-dial instruments, one in the driving cab and the other in the Dynamometer Car, arranging periodical checks on the instruments by a hand tachometer.

Functions of effort, time and distance were directly recorded on both distance-base and time-base records of the Dynamometer Car, as usual. To these direct recordings was added fuel in increments of 0.1 gallon, this being transmitted electrically from a positive fuel meter having an error less than 0.2% which was placed in the fuel line of the engine.

For the main generator current an ammeter was used in conjunction with a specially manufactured shunt. This ammeter, a main generator voltmeter and the engine r.p.m. indicator were arranged in instrument consoles in the Dynamometer Car, each under separate observation. Each observer could independently register any changes in condition at any moment simultaneously on the two records by electrically operated pen movements, coded in such a way that they could later be identified with the written observation. A similar procedure was followed with respect to observations of engine working made from the driving cab and in respect to observations of fuel oil metering temperature and auxiliary generator volts and amps made in the engine compartments. All recordings and observations were therefore co-ordinated by both time and distance.

Sampling of oil fuel was done at each re-fuel, the samples subsequently being examined at the laboratory by the methods of the Institute of Petroleum. The results are set out in Table 2, from which it will be seen that the gross calorific value and the specific gravity at elevated temperatures are included.

The cost of gas oil as delivered into the fuel tanks of the locomotive was 1.51 pence per pound at the time of the tests.

With the active co-operation of the Operating, Motive Power and Chief Mechanical and Electrical Engineer's Departments of the Southern Region the tests were carried out according to plan and without incident.

(b) Tests on Revenue Earning Trains

It was decided that these should take place over the whole of the Waterloo-Exeter route of the Southern Region because two distinctive characteristics as regards gradient profile are almost equally represented in this route. From Waterloo to Salisbury the line is of average undulating character whilst the western half has a "saw tooth" profile.

Examination of available services indicated that the 1.0 p.m. ex Waterloo train would possibly require extensive working in the high power range of the locomotive especially as far as Templecombe. For observations on normally easy schedules, which were also required, the 5.55 p.m. ex Exeter Central appeared suitable. This programme was agreed by the S.R. Operating Department and the tests took place on these services on four days of the week following the Controlled Road Tests.

These tests also were carried out as programmed and without incident.

6. DERIVATION OF THE PRINCIPAL RELATIONS

(a) Extraction of Data from the Controlled Road Tests.

In the two tests which were carried out at each of the four specified values of engine r.p.m. a mileage of 175 was covered, nearly all of which ranked as test conditions and as such had to be brought within the scope of examination. The illustrations of this process have had to be confined necessarily to short sections but these have been selected for the width of the speed range included in them. In inspecting each of these diagrams it should be noted that, although the plotted points of traction drawbar tractive effort shown on each of Graphs 9,12,15 and 18 appertain to the selected section, the full line which appears to represent the relation is that which is representative of the whole test mileage rather than the part; this also applies to the other relations shown by full lines viz., the effort equivalent of the generator output and the resistance of the trailing load.

Considering first the full power condition, Graph 8 shows the principal recordings and observations over a selected section (which may be readily identified on the gradient section of the route, Diagram 7) set out on a time base. Graph 9 then shows values of traction drawbar tractive effort (the actual effort recorded by the dynamometer) taken from Graph 8 and each plotted against its train speed without regard to gradient and acceleration; (values at changes of gradient have been excluded.) They may be compared with the full line marked C which has been drawn having regard also to all the other sections of the test. As C stands in respect to the recordings of tractive effort so A stands in respect to the observations of the effort equivalent of generator output.

The fuel rate in respect to train speed is seen in the inset diagram. The change from a constant rate to one which is a function of speed at the "unloading" point (see Section 2, sub-section (d)) should be noted.

If curve C is accepted as satisfactorily representing the tractive effort on the trailing load under the specified fuel conditions, it must follow that curve D must be accepted as representing to the same degree the resistance of the trailing load because these two in combination produce the speed-distance curve shown by the full line on Graph 10. It will be seen that this line shows near identity with the comparable relation actually recorded by the Dynamometer Car as indicated by the circles at every quarter of a mile, especially as the circles apply to the 14 mile section whilst the full line stems from relations which are representative of nearly 175 miles.

The equivalent drawbar tractive effort curve **B** was produced from the traction drawbar tractive effort curve **C** and the trailing load resistance curve **D** by the simple construction indicated by the basic relationship given in Diagram 5.

Curve **E** is curve **C** scaled up in the ratio of gross to trailing weight to produce the characteristic of traction tractive effort/trailing: gross weight ratio for the particular fuel rate control.

Similarly, graphs 11 to 13 are illustrative of the relationships from the tests at 704 engine r.p.m. Graphs 14 to 16 of those from tests at 560 engine r.p.m. and Graphs 17 to 19 of those from tests at 430 engine r.p.m.

(b) Virtual Tractive Efforts and Fuel Consumption at low train speeds.

Tractive efforts at low train speeds are absent from graphs 9, 12, 15 and 18. This is because the efforts in the initial part of an acceleration from rest are not steady, for handling is governed by maximum permissible current; engine speed and fuel consumption have yet to become stabilised.

It has been found possible however to fill the gap by Table 3. This table gives the mean equivalent drawbar tractive efforts with accompanying mean fuel rates for the 0-20 m.p.h. speed range. On all tests at the respective rates the speed of 20 m.p.h. was reached from rest at very closely the time and fuel consumption that may be calculated from these tabulated values having regard to the gradients and loads. Outside the immediate purpose of the tests the higher values only are of much practical importance. This is in respect to the estimation of maximum loads on steeply graded sections and in respect to the preparation of cost of energy and performance diagrams for train scheduling.

(c) Correlation of Data by the Fuel and Power Relations

When values at a given train speed were read from each equivalent drawbar tractive effort curve and converted to h.p. and when the same process was applied to the effort equivalent of generator output, two curves resulted when the two sets of h.p. values were plotted against the fuel rates. Graphs 20 to 23 show the curves resulting when the speed is successively 90 m.p.h. to 20 m.p.h. in 10 m.p.h. steps. The two curves referred to are marked "Eq.d.h.p." and "E.h.p." on these diagrams.

Values on the E.h.p.curves were taken and divided by the generator efficiency fraction appropriate to the conditions (e.g. as shown on Graphs 11, 14 and 17) which produced curves relating fuel rate with the h.p. input to the main generator, marked "M.G. h.p. I" on Graphs 20 to 23.

Values on the E.h.p. curves were again taken, reduced by the h.p. absorbed by the radiator fan and the results multiplied by the traction motor efficiency fraction (through gears) appropriate to the conditions. Curves relating rail h.p. to fuel rate could then be drawn as shown.

The h.p. absorbed by the auxiliary generator (observed output divided by the generator efficiency fraction) amounting to about 60 h.p. was then added to the traction b.h.p. which resulted in the curves relating diesel engine b.h.p. to fuel rate shown on the graphs.

Finally, at the given train speeds, test values of traction d.b.t.e/k were read from Graphs 9, 12, 15 and 18, converted to h.p. and plotted on Graphs 20 to 23 to produce the curves thereon, which are thus marked, so that these quantities also could be co-ordinated on a basis of fuel consumption.

(d) The Principal Relationships

The principal relationships could then be drawn up in the most convenient form, related to the diesel engine and fuel rate. These are:

Equivalent Draw Bar H.P.	Graph 24
Equivalent Draw Bar Tractive Effort	Graph 25
Traction Drawbar Tractive Effort/trailing: gross weight ratio	Graph 26
Tractive Effort at the Rail	Graph 26

No significant difference was found between the deduced tractive effort at the rail and the measured traction drawbar tractive effort/trailing: gross weight ratio, so these may be represented by the same diagram.

The mean values of effort and fuel rate given in Table 3 may be used to cover the lowest train speeds.

It became possible at this stage to deduce from the Fuel and Power relations the efficiency characteristics of the diesel engine, the efficiency of the transmission and the wind and track resistance of the locomotive. The curves relating engine b.h.p. with fuel rate on Graphs 20 to 23 are Willans' lines and the various losses are represented by the abscissae contained between the appropriate (full line) curves of these graphs.

(e) Diesel Engine Efficiency

The upper diagram in Graph 27 shows the deduced brake thermal efficiency of the diesel engine, in its condition at the time of the trials, on a basis of b.h.p. The lower diagram shows it constructed on a basis of engine r.p.m. Both are to type, the latter showing maximum brake thermal efficiency occurring at an engine r.p.m. which is about two-thirds of the maximum. Comparing the efficiency at the maximum engine r.p.m. of 850 given in Graph 27, with the test bed efficiency at the same r.p.m. given in Table 1, a 4% reduction is indicated. A 3% fall in power is also indicated when the maximum measured b.h.p. of 1888 is compared with the lower limit of the initial power setting, 1950 b.h.p; as stated in 2(e) it is this lower limit which is operable during the accelerations and near balancing speeds that provided the major part of the test data.

These reductions are taken as indicative of the order of the fall in efficiency and power at maximum output of the engine after completion of 106000 miles and a period of 2865 hours without more than the normal servicing.

(f) Transmission Efficiency

Generator output in E.h.p. remains a sensibly constant proportion of M.G. h.p. I. throughout the ranges covered by Graphs 20 to 23, this being 94%. The efficiency through gears of the traction motors shows only a 2% variation, and a mean of about 88%. Overall transmission efficiency is the product of these two and is therefore just short of 83%. This efficiency is not subject to deterioration.

(g) Rail Tractive Effort

Comparison of the full power rail tractive effort curve from Graph 26 with the corresponding curve in the designed rail tractive effort characteristics, Graph 2, shows substantial agreement. The designed rail tractive effort of 30000 lb at 19 m.p.h. was attained on test within 1400 lb. A rail tractive effort of 28600 lb. at 19 m.p.h. corresponds to a general current limitation of 1700 amps which obtained at this speed on all occasions which came under observation.

(h) Track and Wind Resistance

Differences in h.p. between the curves of equivalent drawbar and rail h.p. have been converted to resistance and plotted against train speed to produce the curve shown on Graph 28. These values can only be applied with caution to other locomotives having substantially different body contours and dimensions, wheel arrangements and weights.

(i) Resistance of Coaching Stock

The determination of the resistances of the trains of coaches, which were formed from available stock of Regional design, was an integral part of the testing procedure. When reduced to specific resistances, the values from the various tests were capable of being reconciled without difficulty having regard to the wind conditions, which varied a little during the Controlled Road Tests. As presented in Graph 29 they have been weighted towarded the 7½ m.p.h. wind condition; at 30 m.p.h. the resistance is 5½ lb/ton, rising to nearly 10 lb/ton at 60 m.p.h. and just over 16 lb/ton at 90 m.p.h. - values in close agreement with others which have been produced from time to time by Controlled Road tests in which typical coaching stock have been used.

(j) Traction Drawbar T.E./trailing : gross weight ratio

Diagram 5 indicates that where, as in this case, this characteristic is found to be substantially the same as the rail tractive effort, the specific wind and track resistance of the locomotive is substantially the same as the specific vehicle resistance of the trailing load.

7. RESULTS OF THE TESTS ON REVENUE EARNING TRAINS

The booked schedules of the trains are set out in Table 4. Tables 5, 5a and 6 summarise the results of each test in part and in the whole. In regard to the parts, Salisbury is the natural point of division, being roughly the half-way point in a route of which one half has an average undulating character and the other has a "saw-tooth" profile. An additional division of the down trains has been made at Templecombe because at this station the loads were reduced.

Assessment of results in respect to economic operation must take into account not only the efficiency of production of mechanical energy but also the economic use of mechanical energy. In a summary of this kind it is not difficult to provide an index to the first - as lines 34 of Tables 5, 5a and 6 - but it is practically impossible to provide an index to the second. These tables therefore should be regarded at this stage as containing facts for reconciliation with the results of the comprehensive examinations carried out in later sections of this bulletin.

8. ELECTRICAL RATINGS IN RELATION TO SERVICE OPERATION

The Generator has a specified output of 1313 k.W. as two continuous ratings - 1750 amps. at 750 volts and 1545 amps. at 850 volts.

The continuous rating of the traction motors is 202 h.p. at 300 volts, 565 amps (for 3 pairs 1695 amps) 393 r.p.m.

The one hour rating of the traction motors is 223 h.p. at 300 volts 630 amps (for 3 pairs 1890 amps) 370 r.p.m.

The main ammeter is calibrated to 2500 amps and the current is not allowed to exceed 1700 amps during normal running but can be allowed to exceed this for short periods during acceleration. Overload relays are set for 2550 amps.

Taking the traction motor continuous rating as a criterion, the figure of 3 x 565 = 1695 amps. agrees closely with the above limitation of 1700 amps. The one hour rating for the traction motors has minor significance as the total permissible current at this rating (1890 amps) is in excess of the normal 1700 amps; therefore the short time rating is only utilised (a) during the transients of field changing and (b) during initial acceleration, according to how the driver handles the locomotive.

Reverting to the generator and to its continuous rating of 1750 amps. 750 volts, it has been seen that the continuous safe current for the traction motors is 1700 amps. and therefore the supply of this current is within the capacity of the generator's 1750 amps. which it can produce for an unlimited period at 750 volts.

Regarding the generator and its second continuous rating of 1545 amps 850 volts, this rating gives the current which would be produced when operating at 850 volts for an unlimited period; therefore if 850 volts were maintained, the current output would be limited to 1545 amps. which is well below the continuous rating of the traction motors.

In practice, owing to varying track conditions, differing combinations of current and voltage are encountered as exemplified in Graph 8; the conditions never remain constant for more than a few minutes and consequently the two continuous ratings of the generator cover all the possibilities of service operation.

9. PERFORMANCE AND TRACTION EFFICIENCY

(a) Performance

Graph 26 shows characteristic curves of Traction d.b.t.e/trailing: gross weight ratio on a base of train speed. To produce curves of traction d.b.t.e. for a given load it is only necessary to multiply the values of Graph 26 by the trailing: gross weight ratio of the particular train. As the weight of the locomotive is 133 tons, for trailing loads of 200, 300, 400 and 500 tons the respective ratios are 200/333, 300/433, 400/533 and 500/633; by using them the effort curves of Graphs 30 to 33 have been produced, these being the efforts which would be recorded by a dynamometer car if formed as the first vehicle of the trains. When the total resistance of each trailing load on the level is calculated from the weight and the specific resistance values of Graph 29 and drawn on the appropriate graph and when these are shown raised and lowered (as the case may be) by the components of convenient gradients, the graphs become diagrams capable of presenting much useful information in ordinary terms which satisfies many practical requirements without further calculation.

They show when the pull on the trailing load (traction d.b.t.e.) is equal to its drag caused by resistance and gradient, indicating that the accelerating force has vanished and the speed is constant (a "balancing" speed). They show when the pull is greater than the drag, signifying an accelerating force acting on the trailing load and a rising speed. They show too when drag is greater than pull, indicating a deceleration.

Their use is exemplified by reference to Graph 32 which appertains to a load of 400 tons

Suppose a train is running on a long rising gradient of 1 in 200 under full power. The full power line crosses the line representing 1 in 200 rising at the point (a) which, being produced vertically downwards to the speed scale, indicates the speed of $53\frac{1}{2}$ m.p.h. which will be attained. Producing (a) horizontally to the effort scale shows that a pull of 8000 lb will then be exerted on the trailing load. Against the full power line is shown the engine b.h.p. of 1888 at 852 r.p.m. with a fuel rate of 752 lb/hr. Suppose the train then meets a long rising gradient of 1 in 120 still atfull power. At that moment there is a negative accelerating force (ab) and the speed will fall until this vanishes at (c), this being at the intersection of the full power and gradient lines; the speed corresponding to (c) is 42 m.p.h. and the effort 10200 lb; the power, r.p.m. and fuel rate of the engine remain as before.

At this point suppose the train runs on to a long level stretch. At that moment there is an accelerating force (cd) acting on the trailing load, and speed will eventually rise to 76 m.p.h. if the controller remains in the full register. This is when the accelerating force has fallen to zero, denoted by the intersection of the full power line with the line marked "level" at the point (e). It will be noted that this speed is higher than the "unloading" point at full power (70 m.p.h.) and that (e) lies on the extension of a lower power and fuel rate curve. From the data written against this lower curve, it will be seen that the engine b.h.p. will then be 1783 with a fuel rate of 700 lb/hr but the r.p.m. remains as before at 852 because the controller position has not been changed (see note on Graph 24). Drawbar pull will have fallen to 5200 lb.

The point (f) represents the train running at a constant speed of 55 m.p.h. on a rising gradient of 1 in 500. Through (f) runs the traction TE curve which gives the engine working conditions - b.h.p. 1355 at 646 r.p.m., fuel rate 500 lb/hr; effort, shown by producing (f) horizontally to the effort scale is 5300 lb. The controller is not, of course, at full register but if now it is increased to full power, there appears an accelerating force (fg) on the trailing load and speed will consequently rise eventually to $67\frac{1}{2}$ m.p.h. if the gradient is long enough as shown by (h) where the accelerating force vanishes; in this case the "unloading" point (70 m.p.h.) will not be reached so that the power and fuel rate remain at the maximum. The effort at $67\frac{1}{2}$ m.p.h. is seen to be 6300 lb.

(b) Traction Efficiency

Traction efficiency is concerned with the efficiency with which mechanical energy is transmitted to the trailing load to effect its displacement, this and the economic use of mechanical energy being important factors in the cost of the net ton mile. Thus traction efficiency is defined as the ratio of the energy transmitted to the trailing load to the energy in the fuel used. Diagram 5 shows that the trailing: gross weight ratio k is a factor which is present in traction efficiency as well as in traction d.b.t.e. and traction d.b.h.p. By eliminating this factor, traction efficiency $/k$ is an index of the overall efficiency with which mechanical energy is made available.

It has already been noted that the characteristics of traction d.b.t.e./**k** are substantially identical with those of rail te, so that traction efficiency/**k** is substantially the same as the efficiency at the rail - this being, in the absence of auxiliaries, the product of the thermal efficiency of the diesel engine and the efficiency of the transmission.

Instead of using a single line on the inset diagram on Graph 26 to indicate the maximum value of traction efficiency/**k** at various speeds and on the large diagram to indicate the corresponding efforts, bands are employed, these conforming to a tolerance of 2% on the apparent maximum efficiency factor in the inset diagram and to cover the conditions on the large diagram for which the efficiency factor is within 2% of its maximum value. This is because variations in some of the conditions and the experimental error do not warrant the assumption of a greater accuracy. In each diagram any point lying within the band is assumed to have the same efficiency factor as any other point at the same speed which also lies within the band.

But it must be noted that the band covers a very wide proportion of the normal service range. This is because the curves of traction d.b.h.p/**k** on Graphs 20 to 23 are shallow (as are also the other curves). They do not diverge greatly from straight lines which may be drawn through the origins. This also implies that no point in the working range which lies outside the band has an efficiency factor which is very much less than any other point at the same speed which lies within the band. It means that the efficiency at the rail and traction efficiency/**k** which are concerned only with the efficiency of production of mechanical energy, vary very little over the whole working range.

Variation in traction efficiency is therefore almost wholly due to variation in the trailing: gross weight ratio. As Graphs 30 to 33 are merely reproductions of the large diagram on Graph 26 scaled down in the trailing: gross weight ratios to which they refer, so the corresponding traction efficiencies on Graph 34 are merely reproductions of the inset diagram of Graph 26 with the efficiency values similarly scaled down. But as these latter are confined to the band of efficiency, the bands are relatively to each other, in respect to efficiency, exactly as their trailing: gross weight ratios.

When the results of tests on service trains are examined for locomotive efficiency, i.e. the efficiency with which mechanical energy is made available, traction efficiency must be divided by the trailing: gross weight ratio to supress the influence of the load; traction efficiency must obviously be calculated on fuel used only when a force is being transmitted to the trailing load if it is to be comparable with values produced from the characteristic relations.

The Controlled Road Tests concerned trains in which the fuel rates were controlled but they were otherwise normal trains. As such the average results set out in Table 7 are of very considerable interest since the speed effect was controlled as a factor by all schedules in the same direction being the same; loads showed the unusually large variation of 60 to 400 tons which should tend to emphasise the influence of the trailing: gross weight ratio on traction efficiency; the working rates appropriate to the loads varied between full and minimum power, two being within the band of maximum traction efficiency, one outside the band and above it and one outside and below, but as these rates were strictly controlled and almost continuous the relative effect of working within the band should be reflected in the results. Col. 7 of Table 7 shows traction efficiency varying roughly between 8½% and 19%; eliminating the load factor by dividing each by its trailing: gross weight ratio produces the almost uniform set of values expected and shown in col. 8; lines 3 to 6 of this column, which correspond to fuel rates within the band, show to a small advantage over the others, but as a whole they are in agreement with the inset diagram of Graph 26. Hence variation in traction efficiency in col.7 is almost wholly due to the variation in the load factor. The results are presented graphically in Graph 35. The measured averages are denoted by horizontal lines and these are shown against a background of curves of maximum traction efficiency which are reproductions of the inset diagram of Graph 26 to the scale of the appropriate trailing: gross weight ratio. Horizontals would be expected to lie just above the lowest part of their corresponding curves where rates of working have been within the band of maximum traction efficiency and significantly disposed above where the rates have not been. This may be observed in all cases in Graph 35, thus illustrating the small influence on traction efficiency of this factor relative to that of the other factors.

Passing to the results of the tests on the revenue earning trains which are summarised in Tables 5, 5a and 6, it is noticeable that the values of traction efficiency given in lines 33 show the expected uniformity when divided by the appropriate trailing: gross weight ratios in lines 34 in spite of the very wide variation in conditions under which the service train operates. Hence the traction efficiences themselves may be reconciled when the effect of the load is taken into account. A graphical presentation of each result is given in Graphs 36 to 41 on the same lines as those of the Controlled Road tests presented in Graph 35. The significant point about Graphs 36 to 41 is that the inset diagram of Graph 26 may be used to predict with certainty the efficiency with which mechanical efficiency will be made available on whatever duties the locomotive may be employed and, using the trailing: gross weight ratio, the traction efficiency which will result and which may be measured by a dynamometer car. It reflects satisfactorily on the validity of both the tractive effort characteristics related to fuel consumption and the resistance characteristics that are given in this bulletin. Nevertheless the efficiency with which mechanical energy is made available and the influence of the trailing: gross weight ratio are by no means the only factors in the commercial cost of energy.

(10) THE TIME SCHEDULE AND COMMERCIAL COST OF ENERGY

The previous section has shown that the locomotive is capable of making mechanical energy available at a substantially constant efficiency no matter where in the service range the locomotive may be worked and is capable of transmitting mechanical energy to the trailing load for its displacement at an efficiency proportional to the trailing: gross weight ratio. The commercial cost of energy is affected not only by these factors but also by the economy with which mechanical energy is used; it is also a function of the average speed of displacement as well as of the load displaced.

The use of the locomotive on duties commensurate with its power is bounded on the one hand by capacity, which can be precisely defined, on the other hand by the small return on the annual capital cost of the locomotive hour. Between the two limits lies the operatingrange within which the duties may be freely chosen having regard to allowances which, from local experience, must be made for correcting minor breaches of the timetable and delays due to permanent way repairs.

The problem is how to translate all the performance and efficiency relations which have been extracted from the results of the Controlled Road Tests, and all the observations which have been made on revenue earning trains in respect to the conservation of mechanical energy, into the ordinary non-technical terms required for the construction of the timetable in respect to the minimum commercial cost of energy; how to display clearly and simply the range of duties offered to the operating and commercial departments in a way which presents the implications of the choice without restricting it. But whilst the availability of mechanical energy and the efficiency with which it can be supplied can be presented in a few simple relations there is no such short cut for dealing with the cost of energy. The fly wheel effect of the mass of the train, the track features of the route, the restoration of kinetic energy following destruction by braking so affect the cost of energy that each route must be treated individually.

The problem has been resolved in this bulletin by the simplified cost of energy and performance diagram. After discussing the diagram with illustrations and examples, it is shown applied to the sections of the Southern Region, over which the tests on the revenue earning trains were carried out. This enables the examination of the results of these tests to be completed. Application of the system to other routes and faster services are then discussed and illustrated.

(a) The Cost of Energy and Performance Diagram

Diagrams such as this should be arranged to cover sections roughly 100 miles in length, as convenient.

They may be explained by reference to Graph 42. The base of the diagram is load in tons and the vertical scale, marked off on the right hand border, is total running time. A non-linear scale on the left enables total running time to be related to average running speed by horizontal projection. This is useful in showing the influence of speed on fuel consumption.

Suppose it is desired to run a service at an overall running time of 84 mins. with a load of 343 tons. A line drawn vertically upwards from 343 tons on the base to meet a horizontal from 84 mins on the time scale locates the point A . This point is seen to lie below the diagonal marked "maximum power" which signifies that such a service is beyond the capabilities of the locomotive.

Increasing the time to 88 mins with the same load locates the point **B** on the maximum power line. This means that if there are no temporary speed restrictions and no other checks this service could be worked by the locomotive by using full power wherever possible and practicable strictly observing all permanent speed restrictions. The schedule corresponding to the maximum conservation of mechanical energy is that set out alongside the total running time of 88 mins. (All point-to-point times have been rounded off to the half-minute, as this is the minimum practical time period). The fuel consumption indicated by **B** is seen to be .027 lb/ton mile. Total running fuel consumption is therefore, not likely to be less than .027 x 343 x 87.7 = 813 lb or 96.3 gallons. But it is extremely likely that the timekeeping reputation of this service would prove unsatisfactory as there is no margin for countering minor breaches of the timetable and repairs to the permament way.

Examine now the proposal to increase the overall running time to 92 mins, the load remaining as before. This is indicated by the point **C** . The schedule of the train which corresponds to the maximum conservation of mechanical energy is that written against the new time. It is clear that the locomotive now has a nominal time margin of 4 mins. with the given load. The fuel consumption shown by **C** is .0262 lb/ton mile with no delays, but may be as high as given by **B** at the intersection of the load line with the maximum power line in adverse circumstances. Hence total running fuel consumption is not likely to be less than .0262 x 343 x 87.7 = 788 lb or 93.5 gallons nor more than the 96.3 gallons indicated by **B** .

Another proposal which illustrates points of great practical importance is that of increasing the overall running time to 100 mins for the same load. This is denoted by point **D** . Since **D** lies above the upper diagonal of the diagram, its fuel consumption for the schedule given, in good operating conditions, is read at the intersection of the horizontal through the point with the upper diagonal, which is at .0227 lb/ton mile. If intermediate stops are infrequent and the recommended point-to-point timings are accepted, **D** represents a generous margin of 12 mins. It is unlikely that the whole of this margin would then be required, and the maximum probable fuel consumption may well be taken at the more practical margin indicated by **C** .0262 lb/ton mile. Hence total running fuel consumption is unlikely to be less than .0227 x 343 x 87.7 = 663 lb (78.7 galls) nor more than 788 lb (93.5 galls). In these circumstances the booked (recommended) schedule is an easy schedule; it is so far removed from the full power schedule for the load that the point-to-point times are capable of some modification within the overall time, but any such modification is done at the expense of increasing the mechanical energy required and consequently fuel consumption.

Even so, the economical running of an easy schedule depends ultimately on the handling of the locomotive. The tests clearly demonstrated that when drivers avoided light fuel rates and worked the locomotive in these circumstances by alternating periods of high power and drifting, taking every advantage offered by the gradient profile, total fuel consumptionswere significantly less than those resulting from more regularly applied light fuel rates, which agrees with theoretical findings. This produces a discontinuity in the curves of fuel per ton mile, roughly indicated by the upper diagonal.

On easy schedules in which mechanical energy is conserved by the proper planning of the point-to-point times and skilled handling of the locomotive, small return is rendered on the capital cost of the locomotive hour, which means that such duties are generally more advantageously worked by locomotives of lower power classification. Nominally easy schedules are, of course, often a matter of convenience and are sometimes resorted to to guarantee good timekeeping.

But if the point **D** refers to a schedule in which stops are frequent and if the sectional times do not agree with those recommended the margin indicated may not be real. Where the depart to arrival times are shorter, the locomotive has to work harder and for a larger proportion of the section; much more energy is destroyed by braking and easy sections do not compensate for the tighter sections in respect to fuel consumption When pegged by public times, drivers are limited in what they can do by way of conserving mechanical energy. Relative to the consumption given by **D** , the consumption in these circumstances may more likely be nearer that indicated by **B** at the maximum power line, which is 20% higher.

(b) Southern Region services between Waterloo and Exeter

Taking the Waterloo - Salisbury section of the services run on 5 and 7 July, it will be noted from Table 5a that the booked running time was 95 mins (Cols. 2 & 5, line 7) and the loads were 425 and 464 tons (Cols. 2 & 5 line 1). On Graph 43 they are denoted by points **E** and **F** which, by horizontal projection to the upper diagonal, indicate that fuel consumption may be .0213 lb/ton mile in the best operating conditions and with economical use of mechanical energy. By projection of **E** and **F** vertically downwards to the maximum power line it is estimated that the fuel consumption may rise to .0249 and .0237 lb/ton mile respectively in adverse circumstances. Actual consumptions (Cols. 2 & 5 line 31) were .0249 and .0222 lb/ton mile respectively; actual running time, having been a little less than the booked, accounts for a little of the increase on the estimated minimum. The margins indicated by the vertical heights (in minutes) of **E** and **F** above the maximum power line were the smallest of any of the services. The nearest schedule to **E** and **F** , that against 96 mins, may be compared with the booked schedule given in Table 4.

To examine the Salisbury - Exeter services in respect of Graph 44, an adjustment to the total fuel and ton miles is made necessary by the reduction of the load at Templecombe. Total fuel (difference of lines 19 & 22, Cols. 3 & 6 Table 5a), has to be reduced by the product of the fuel/ton mile between Salisbury and Templecombe and the load reduction; ton miles to the product of the reduced load and overall mileage. The adjusted consumptions of .0226 and .0220 lb/ton mile are then obtained; these would probably have resulted had the reduced load only been taken throughout. The booked running time (Cols. 3 & 6 line 7) was 108 mins. and the reduced loads were 329 and 367 tons on the respective days (Cols 3 & 6 line 2). These are denoted by points **G** and **H** which obviously show a most generous margin and a very easy schedule. Projection of **G** and **H** horizontally to the upper diagonal indicates that a consumption of .0205 lb/ton mile should have been obtained if the booked running time was kept and if mechanical energy was economically used by the driver in the presence of good operating conditions.

But running times were 7 mins less than the booked (cols 3 & 6 line 9) as indicated by **J** and **K** which projected horizontally to the upper diagonal brings the minimum up to .0223 lb/ton mile under the most favourable operating and handling conditions. Close agreement with the (adjusted) actual consumptions of .0226 and .0220 lb/ton mile implies that such conditions were in fact obtained.

Graph 45 refers to the Exeter - Salisbury section which contains frequent stops. Booked running time was 116 mins for the services tested on 4 and 6 July (Table 6 cols 2 & 5 line 7) with loads of 362.5 and 407.5 tons (cols 2 & 5 line 1) on the respective days. These conditions are denoted by **L** and **M** which show that the margin was large on the recommended point-to-point timings. But the following table shows that both booked and actual point-to-point times involved a deployment of mechanical energy much less economic than is recommended in the graph for the same overall time. In respect to the actual, lateness in starting and temporary speed restrictions account for some of this. In view of the circumstances it would be expected that the consumptions would lie very much nearer points **N** and **O** on the maximum power line than at **L** and **M** These are .0288 and .0268 lb/ton mile respectively. Actual consumptions were .0296 (col 2 line 31) and .0262 (col 5 line 31) lb/ton mile respectively.

		Miles	Point to point timings mins.			
			Recommended, Graph 45	Booked	Actual	
					4 July	6 July
Exeter	dep	12.1	17½	18	15	15
Sidmouth Jct.	arr dep	11.5	17½	16	15.4	15.8
Seaton Jct.	arr dep	3.3	5½	5	4.8	4.8
Axminster	arr dep	21.9	27	28	26.5	29.1 ⌿
Yeovil Jct.	arr dep	10.6	16	16	13.8	15.4
Templecombe	arr dep	28.3	32½	33	31.9 ⌿	30.8
Salisbury	arr				8.6 +	4.7 +
TOTAL		87.7	116	116	116.0	116.0

\+ net time made up by locomotive
⌿ temporary restriction of speed observed

Graph 46 refers to the Salisbury - Waterloo section and points **P** and **Q** represent the booked running time plotted against the loads of the test trains - 362.5 and 407.5 tons respectively (Table 6 cols 3 & 6 line 7). Points **R** and **S** denote the actual running times on the very easy schedules which were 108.7 and 110.1 mins respectively (cols 3 &6 line 9) for which minimum fuel consumptions of .0184 and .0180 lb/ton mile are respectively indicated by the horizontal projections of **R** and **S** to the upper diagonal. Actual consumption on the second day was .0184 lb/ton mile (col 6 line 31) which indicates that the good operating conditions and conservation of mechanical energy that qualify the estimate of the minimum were achieved. The actual consumption on the first day was .0209 lb/ton mile (col. 3 line 31) somewhat higher than the estimated minimum of .0184 lb/ton mile under the best conditions but this difference can be explained by the handling of the locomotive. It may be noted from Table 6 cols 3 & 6 lines 9 & 11 that on the second day 68 mins of a total running time of 110.1 mins were under power conditions whilst on the first day the proportion was 88.1 mins under power in a total 108.7 mins. this indicates that mechanical energy was more economically used on the second day than on the first thus accounting for the somewhat higher fuel consumption on the first day.

Though mechanical energy can be made available by the locomotive at a substantially constant efficiency right down to low power demands, it is the economic use of mechanical energy which predominates on the easy schedule; this is then achieved by working wherever possible in the higher powers interspersed with periods of drifting, taking every advantage offered by the gradient profile. In general it was found that drivers had a highly developed sense of conservation of mechanical energy but their efforts were restricted on occasions by sectional timings which were unrelated to the economic use of mechanical energy; fuel consumption was then higher than need be in consequence. But where they were free to exercise their skill the speed-distance curves produced conformed almost exactly with those which form the basis of the recommended schedules in the diagrams.

(c) Extension to other Routes

Graphs 47 and 48 illustrate how the principal relations given in this bulletin enables the cost of energy and performance diagrams to be prepared for another type of duty on an entirely different route from the same basic calculation as were used in the preparation of the diagrams for the Southern Region.

11. CONCLUSIONS

(1) The diesel engine had fallen 4% in efficiency and 3% in power at full load after completion of 106,000 miles and 2,865 hours without more than the normal servicing.

The fall in power is based on the comparison of the maximum measured b.h.p. of 1888 with the lower limit of the initial power setting, 1950 b.h.p., since it is the lower limit which is operable during acceleration and near balancing speeds that provided the major part of the test data.

(2) Losses in the auxiliary generator and provision for all auxiliaries, including the radiator fan, under average running conditions account for some 105 engine b.h.p.

(3) Between 20 m.p.h. and 90 m.p.h. the inclusive efficiency of the electric transmission is nearly 83% throughout the service range of 38% to 100% of full output.

(4) The thermal efficiency of the diesel engine at the maximum power measured (1888 b.h.p.) was found to be 32.4%, which falls to 30.6% when referred to the power remaining when absorption by the auxiliaries is deducted; multiplying this last figure by the efficiency of the electric transmission gives a representative average efficiency at the rail of 25½%, a figure also reached under passenger service conditions. It was demonstrated that this value does not fall at part load ratings down to 38% of full output; in fact the value rises to 27% at intermediate part load ratings under service conditions.

(5) A tractive effort at the rail of 28600 lb was produced at 19 m.p.h. at the continuous rating of the electrical equipment. This compares with the designed effort of 29000 lb. obtainable with the current limitation of 1700 amps. At higher speeds the rail tractive effort characteristics at full power substantially agree with the designed characteristics. During accelerations between 0 and 20 m.p.h. a mean effort at the rail of 32800 lb. may be assumed under the general current limitations; to this corresponds a mean fuel rate of 450 lb/hr.

(6) The two specified continuous ratings for the generator have been shown to provide for all the possibilities of service operation and to cover the traction motors.

(7) From the test data it has been found possible to extract the characteristics of Equivalent Drawbar Tractive Effort (Drawbar T.E. on level at constant speed) and of Traction Drawbar Tractive Effort/trailing: gross weight ratio, both related to fuel consumption for all speeds up to the maximum (90 m.p.h.) and for the whole of the practical service range of working. The latter in this locomotive is identical with the Rail Tractive Effort Characteristics.

(8) In average wind conditions the specific wind and track resistance of the locomotive is 5.29 lb/ton weight of the locomotive at 30 m.p.h., 9.78 lb/ton at 60 m.p.h. rising to 16.3 lb/ton at 90 m.p.h. The wind and track resistance therefore, accounts for about ½ h.p. per ton at 30 m.p.h., just under 1¾ h.p. per ton at 60 m.p.h. and 4 h.p. per ton at 90 m.p.h.

(9) Resistance of the coaching stock was determined as an integral part of the tests. It amounts to 5.29 lb/ton at 30 m.p.h., 9.78 lb/ton at 60 m.p.h., rising to 16.30 lb/ton at 90 m.p.h. in conditions comparable with those applicable to the locomotive track and wind resistance.

(10) The speed-distance and speed-time relations and fuel consumption in normal service were found to be in very close agreement with those which may be calculated from the specific resistance of the coaching stock and either the Rail T.E. and track and wind resistance of the locomotive, or the Equivalent D.B.T.E. or the traction D.B.T.E/k characteristic all as given in this bulletin. Similarly, the drifting characteristics in normal service may be represented by those which may be calculated from the specific resistance of the coaching stock and track and wind resistance of the locomotive.

(11) Traction Efficiency (the efficiency with which energy in the fuel is converted into mechanical energy supplied to the trailing load) is a function of two independent variables - the "built-in" efficiency of the locomotive and the trailing: gross weight ratio. Over the whole range of working rates the former varies but little at any given train speed. This receives extensive confirmation from test results of service trains operating in a wide variety of conditions; when the traction efficiencies (based on work done and fuel consumed only when effort is being exerted on the trailing load) are divided by the appropriate trailing: gross weight ratios, the results, which are values of "built-in" efficiency, show substantial uniformity. The "built-in" efficiency is substantially the same as the efficiency at the rail for which representative values have been given in (4).

(12) Though the efficiency with which thermal energy is converted into mechanical energy is substanially uniform over the range of working rates, trains are displaced at the minimum cost of energy only if mechanical energy is conserved to the maximum extent. This is initiated in the planning of the schedule and implemented by the driver. The sense of conservation of mechanical energy is highly developed in drivers generally, but their efforts are restricted when pegged down to sectional timings which are not related to economic deployment of mechanical energy. For a service with frequent stops, the difference in fuel consumption as between schedules which are and which are not based on the principle of the maximum conservation of mechanical energy may be nearly 20% of the minimum even if the same overall times apply to both and all point-to-point times are within the capacity of the locomotive.

(13) It has been shown how the test data contained in this bulletin can be applied to the construction of simplified Cost of Energy and Performance diagrams for any service over any route. In the ordinary non-technical terms required for the construction of timetables and for the determination of fuel consumption, these diagrams, at a glance :

(a) show the power limitation of the locomotive

(b) indicate the duties from which small return can be expected on the annual capital cost of the locomotive hour

(c) indicate the range of duties which are available, their schedules based on the maximum conservation of mechanical energy, the fuel consumptions and the nominal margins on the locomotive's maximum performance.

TABLE 1

LEADING PARTICULARS, DESIGNED PERFORMANCE AND EFFICIENCY AND PRINCIPAL DETAILS AND RATIOS OF THE LOCOMOTIVE

Wheel arrangement	1Co - Co1
Length over buffers	63'9"
Weight in working order	132T. 16C.
Maximum Tractive Effort at rail	50,000lb. up to 10.5 m.p.h.
Continuous Tractive Effort at rail.	30,000lb. at 19 m.p.h.

DIESEL ENGINE

Maker	English Electric Co.
Type	16SVT/II Vee-form, Turbo-pressure charged.
Rated Output	2000 b.h.p. at 850 r.p.m. (1880 traction)
B.M.E.P. at rated output	123 lb/sq. in.
Designed brake thermal efficiency	34.8% (test figure 33.9%)
Corresponding fuel consumption	.369 lb/bhp/hr. (test figure .379 lb/bhp/hr.)
Cycle	Four-stroke
Cylinders, number	16
bore	10"
stroke	12"
Valves, per cylinder	2 inlet, 3 7/16" diam. 2 exhaust, 3 7/16" diam.
Combustion chamber	Open type
Pistons	Aluminium Alloy.
" gas rings	4, top ring chrome-plated.
" scraper rings	2, S.O.C. type.
" Speed at full load	1,700 feet/min.
Maximum Cylinder pressure	900 lb/sq.in.
Cylinder liners	Wet type, cast iron.
Exhaust temperature, from cylinder.	900°F. full load.
Exhaust temperature, inlet to turbine.	1080°F.
Superchargers, number.	4
" maker and type	Napier T.S.100/4
" revs. at full load	18,700
" Boost pressure at full load.	6 lb/sq.in.
Main and big-end bearings	Copper-lead lined steel shells.
Bearing oil pressure	60-75 lb/sq.in. gauge
Fuel injection equipment	C.A.V. direct-injection
Nozzle blow-off pressure	2,500 lb/sq.in.
Weight of engine-generator set, complete.	56,000 lb.

MAIN GENERATOR

Maker	English Electric Co.
Type	EE. 822/1B
Continuous Ratings at 850 rpm.	1313 kW. 1750 amps 750V 1313 kW. 1545 amps 850V
Maximum Current	2600 amps
Number of Poles	10

Machine has one bearing only at the Commutator end.

TABLE 1 (Cont.)

AUXILIARY GENERATOR

Maker	English Electric Co.
Type	EE. 911A
Continuous Rating 450/850 r.p.m.	43/48 kW. 318/356A 135V
Number of Poles	8

This machine is overhung on an extension of the main generator shaft and has no bearings

TRACTION MOTORS

Maker	English Electric Co.
Type	EE. 526A (Series wound)
Number	6
Continuous Rating	202 HP 565 amps 300 volts 393 r.p.m.
1 Hour Rating	223 HP 630 amps 300 volts 370 r.p.m.
Gear Ratio	3.21 : 1 (61/19)
Maximum Revs.	2330 r.p.m.
No. of Poles	6
Connections	3 groups of traction motors in parallel across main - generator each group consisting of two motors in series
Field Shunting 1st stage	55% of full field
" " 2nd "	37% of full field
" " 3rd "	25% of full field
" " Method	Non-inductive shunt
Ventilation - Method	Forced
- Quantity of air	2000 cu. ft/min.

TABLE 2

RESULTS OF EXAMINATION OF SAMPLES OF FUEL OIL

	Controlled Road Tests			Service Tests			
Sample No.	1	2	3	4	5	6	7
Specific Gravity at 60°F/ 60°F	0.844	0.844	0.844	0.844	0.846	0.846	0.847
80°F/ 60°F	0.837	0.837	0.837	0.837	0.839	0.839	0.840
100°F/ 60°F	0.830	0.830	0.830	0.830	0.832	0.832	0.833
120°F/ 60°F	0.823	0.823	0.823	0.823	0.825	0.825	0.826
Gross Calorific Value B Th U/lb	19420	19280	19440	19420	19340	19400	19400
Viscosity, centistokes at 100°F	3.6						
Distillate recovered at 350°F by volume %	96						
Flash point (closed) °F	212						
Pour point °F	Below 15						
Water content by volume %	Nil						
Diesel index	60						
Ash %	less than 0.01						
Carbon residue (Conradson Method) %	0.01						
Sulphur %	0.8						
Sediment %	trace						
Inorganic acidity (mg KOH/1g oil)	nil						
Corrosion test, copper strip at 212°F	negative						
Colour	straw						
Clearness	clear						

The methods of test are those of the Institute of Petroleum. Sample No. 1 was subjected to the full tests of BS 209: 1947, Fuels for Oil Engines, Class A and complies with the requirements of this specification; the other samples No. 2 - 7 were similar in general characteristics to sample No. 1.

TABLE 3.

VIRTUAL STARTING EFFORTS AND FUEL RATES DURING ACCELERATIONS FROM REST TO 20 M.P.H.

General limitation: Current not exceeding 1700 amps except momentarily. Engine r.p.m. not exceeding the r.p.m. eventually stabilised.

Stabilised Conditions at or after 20 mph		Means 0 - 20 m.p.h.	
% Full Power	Engine r.p.m.	Equivalent D B T E lb.	Fuel Rate lb/hr
100	850	32,250 +	450
81	704	27,800	390
56	560	21,200	300
38	430	16,500	240

+ 32,800 lb at Rail and as Trac D.B.T.E./k value

On all Controlled Road Tests on the respective routes the speed of 20 m.p.h. was reached from rest at very closely the time and with very closely the fuel consumption as may be calculated from the appropriate mean efforts and mean fuel rates tabulated above, having regard to the gradients and loads.

TABLE 4.

BOOKED SCHEDULES OF SERVICE TESTS

Station		Booked time		Point-to-Point mins
	arr.		dep.	
		p.m.		
Down Trains				
Waterloo			1.00	
Clapham Jct.		1.07		7
Hampton Court Jct.		1.18		11
Woking	1.29		1.31	11
Worting Jct.		2.00		29
Andover Jct.	2.16		2.18	16
Tunnel Jct.		2.36½		18½
Salisbury	2.39		2.45	2½
Templecombe	3.19		3.23	34
Sherborne	3.34		3.35	11
Yeovil Jct.	3.43		3.46	8
Exmouth Jct.		4.38		52
Exeter Central	4.41			3
UP TRAINS				
Exeter Central			5.55	
Sidmouth Jct.	6.13		6.15	18
Seaton Jct.	6.31		6.32	16
Axminster	6.37		6.39	5
Yeovil Jct.	7.07		7.11	28
Templecombe	7.27		7.30	16
Salisbury	8.03		8.09	33
Andover Jct.	8.33		8.35	24
Worting Jct.		8.56		21
Basingstoke	9.00		9.02	4
Woking	9.31		9.34	29
Surbiton	9.49		9.50	15
Clapham Jct.		10.01		11
Waterloo	10.08			7

TABLE 5

SUMMARISED RESULTS OF TESTS ON REVENUE EARNING TRAINS

DOWN TRAINS

1.00 p.m. ex WATERLOO TO EXETER CENTRAL
STOPPING AT WOKING, ANDOVER JCN.,
SALISBURY, TEMPLECOMBE, SHERBORNE AND
YEOVIL JCN.

A WATERLOO - EXETER OVERALL
B WATERLOO - TEMPLECOMBE SECTION
C TEMPLECOMBE - EXETER SECTION

LINE		COL. NO.	5th JULY, 1955			7th JULY, 1955		
			A	B	C	A	B	C
			1	2	3	4	5	6
1	Load & No. of Vehicles Waterloo to Templecombe	Tons Tare	425 (13)	425 (13)		464 (14)	464 (14)	
2	Templecombe to Exeter	" "	329 (10)		329 (10)	367 (11)		367 (11)
3	Distance : Actual	Miles	171.4	112	59.4	171.4	112	59.4
4	Under Power	"	139.9	99.4	40.5	137.75	95.35	42.4
5	TON MILES: (tare weight of trailing load)		67140	47600	19540	73800	52000	21800
6	TIME: Booked overall	Mins.	221	≠ 139	≠ 79	221	≠ 139	≠ 79
7	running	"	203	129	74	203	129	74
8	Actual overall	"	217.3	≠ 139.5	≠ 75.3	217.9	≠ 138.6	≠ 73.5
9	running	"	194.9	126.3	68.6	195.0	127.0	68.0
10	standing at stations	"	22.4	≠ 13.2	≠ 6.7	22.9	≠ 11.6	≠ 5.5
11	under power	"	157.3	108.8	48.5	156.8	106.1	50.7
12	drifting and braking	"	37.6	17.5	20.1	38.2	20.9	17.3
13	AVERAGE SPEED: On running time	m.p.h.	52.8	53.1	51.9	52.8	53.0	52.4
14	Under power	"	53.4	54.8	50.1	52.7	53.9	50.2
15	WORK DONE: Traction D.B.H.P. Hours		2433	1807.5	625.5	2481	1800	681
16	AVERAGE TRACTION D.B.H.P.		928	996	758	950	1020	806
17	AVERAGE TRACTION D.B.T.E.	Tons	2.91	3.04	2.59	3.02	3.17	2.69
18	OIL: Gross Calorific Value	B.Th.U/lb	19340	19340	19340	19400	19400	19400
19	TOTAL used	lb.	1618	+ 1180	+ 436	1645	+ 1167	+ 474
20	used under power	lb.	1574	1157	417	1601	1143	458
21	av. rate under power	lb/hr.	601	639	516	614	647	542
22	used while standing at stations	lb.	16	+ 9	+ 5	16	+ 8	+ 4
23	av. rate while standing at stations	lb/hr.	42.9	40.9	44.8	41.9	41.4	43.6
24	used while drifting and braking	lb.	28	14	14	28	16	12
25	av. rate while drifting and braking	lb/hr.	44.7	48.0	41.8	44.0	45.9	41.6
26	lb/Traction D.B.H.P. Hour on total fuel used		0.665	0.653	0.698	0.663	0.648	0.696
27	lb/Traction D.B.H.P. Hour under power		0.648	0.640	0.667	0.645	0.635	0.673
28	lb/mile on total fuel used		9.44	10.53	7.35	9.60	10.41	7.99
29	lb/mile under power		11.25	11.63	10.30	11.63	12.00	10.81
30	lb/ton mile on total fuel used		0.0241	0.0248	0.0223	0.0223	0.0224	0.0217
31	lb/ton mile on fuel used while running		0.0239	0.0246	0.0220	0.0221	0.0223	0.0216
32	Energy transmitted to trailing load x 100 Energy in total fuel	%	19.8	20.1	18.9	19.8	20.3	18.9
33	Energy transmitted to trailing load x 100 - Traction Efficiency Energy in fuel used under power	%	20.3	20.6	19.8	20.3	20.7	19.5
34	Traction Efficiency k	%	-	27.0	27.8	-	26.6	26.55

The term "Under Power" refers to periods when power generated by the power unit is being transmitted to the trailing load

The terms "Traction D.B.H.P.Hr." and "Traction D.B.T.E." refer to power and tractive effort transmitted to the trailing load as measured by the Dynamometer Car.

\+ Excludes fuel used while standing at Templecombe station

≠ Excludes time standing at Templecombe station

$$k = \frac{\text{Weight of Trailing Load}}{\text{Total Weight}}$$

TABLE 5a

SUMMARISED RESULTS OF TESTS ON REVENUE EARNING TRAINS

A WATERLOO - EXETER OVERALL
B WATERLOO - SALISBURY SECTION
C SALISBURY - EXETER SECTION

DOWN TRAINS

1.00 p.m. ex WATERLOO TO EXETER CENTRAL
STOPPING AT - WOKING, ANDOVER JCN., SALISBURY, TEMPLECOMBE, SHERBORNE AND YEOVIL JCN.

LINE			5th JULY, 1955			7th JULY, 1955		
			A	B	C	A	B	C
		COL. NO.	1	2	3	4	5	6
1	Load & No. of Vehicles: Waterloo to Salisbury	Tons Tare	425 (13)	425 (13)		464 (14)	464 (14)	
2	Salisbury to Exeter	" "	425 (13)		425 (13)	464 (14)		464 (14)
			ø329 (10)		ø 329 (10)	ø 367 (11)		ø 367 (11)
3	Distance : Actual	Miles	171.4	83.7	87.7	171.4	83.7	87.7
4	Under Power	"	139.9	74.4	65.5	137.75	75.69	62.06
5	TON MILES: (tare weight of trailing load)		67140	35570		73800	38850	
	Salisbury - Templecombe				12030			13150
	Templecombe - Exeter				19540			21800
6	TIME: Booked overall	Mins.	221	≠ 99	≠ 116	221	≠ 99	≠ 116
7	running	"	203	95	108	203	95	108
8	Actual overall	"	217.3	≠ 98.4	≠ 110.4	217.9	≠100.0	≠ 112.48
9	running	"	194.9	93.7	101.2	195.0	93.86	101.14
10	standing at stations	"	22.4	≠ 4.7	≠ 9.2	22.9	≠ 6.14	≠ 11.34
11	under power	"	157.3	79.7	77.6	156.8	81.04	75.80
12	drifting and braking	"	37.6	14.0	23.6	38.2	12.82	25.34
13	AVERAGE SPEED: On running time	m.p.h.	52.8	53.6	52.0	52.8	53.5	52.0
14	Under power	"	53.4	56.0	50.6	52.7	56.1	49.2
15	WORK DONE: Traction D.B.H.P. Hours		2433	1359	1074	2481	1342.6	1138.6
16	AVERAGE TRACTION D.B.H.P.		928	1023	830	950	995	900
17	AVERAGE TRACTION D.B.T.E.	Tons	2.91	3.06	2.75	3.02	2.98	3.06
18	OIL: Gross Calorific Value	B.Th.U/lb	19340	19340	19340	19400	19400	19400
19	TOTAL used	lb.	1618	+ 890	+ 722.7	1645	+ 865	+ 775.0
20	used under power	lb.	1574	876	698.5	1601	850.7	749.4
21	av. rate under power	lb/hr.	601	659	540.0	614	630	594.0
22	used while standing at stations	lb.	16	+ 2.9	+ 7.1	16	+ 4.16	+ 7.7
23	av. rate while standing at stations	lb/hr.	42.9	37.0	46.4	41.9	40.6	40.7
24	used while drifting and braking	lb.	28	11.27	17.1	28	10.16	17.9
25	av. rate while drifting and braking	lb/hr.	44.7	48.1	43.4	44.0	47.50	42.5
26	lb/Traction D.B.H.P. Hour on total fuel used		0.665	0.666	0.674	0.663	0.645	0.682
27	lb/Traction D.B.H.P. Hour under power		0.648	0.645	0.650	0.645	0.635	0.659
28	lb/mile on total used		9.44	10.66	8.24	9.60	10.35	8.83
29	lb/mile under power		11.25	11.80	10.69	11.63	11.35	12.1
30	lb/ton mile on total fuel used		0.0241	0.025	0.0229	0.0223	0.0223	0.0222
31	lb/ton mile on fuel used while running		0.0239	0.0249	0.0227	0.0221	0.0222	0.0220
32	$\frac{\text{Energy transmitted to trailing load x 100}}{\text{Energy in total fuel}}$	%	19.8	20.1	19.6	19.8	20.4	19.3
33	$\frac{\text{Energy transmitted to trailing load x 100}}{\text{Energy in fuel used under power}}$ - Traction Efficiency	%	20.3	20.4	20.2	20.3	20.7	20.0
34	$\frac{\text{Traction Efficiency}}{k}$	%	-	26.75	-	-	26.7	-

The term "Under Power" refers to periods when power generated by the power unit is being transmitted to the trailing load

The terms "Traction D.B.H.P.Hr." and "Traction D.B.T.E." refer to power and tractive effort transmitted to the trailing load as measured by the Dynamometer Car

\+ Excludes fuel used while standing at Salisbury station
≠ Excludes time standing at Salisbury station
ø Load reduced at Templecombe
k = $\frac{\text{Weight of Trailing Load}}{\text{Total Weight}}$

TABLE 6

SUMMARISED RESULTS OF TESTS ON REVENUE EARNING TRAINS

UP TRAINS

5.55 p.m. ex EXETER CENTRAL TO WATERLOO
STOPPING AT - SIDMOUTH JCN. SEATON JCN., AXMINSTER,
YEOVIL JCN., TEMPLECOMBE, SALISBURY, ANDOVER JCN.,
BASINGSTOKE, WOKING AND SURBITON

A EXETER - WATERLOO OVERALL
B EXETER - SALISBURY SECTION
C SALISBURY - WATERLOO SECTION

			4th JULY, 1955			6th JULY, 1955		
			A	B	C	A	B	C
LINE		COL. NO.	1	2	3	4	5	6
1	LOAD & NO. OF VEHICLES: Exeter to Salisbury	Tons Tare	362.5 (11)	362.5 (11)		407.5 (13)	407.5 (13)	
2	Salisbury to Waterloo	Tons Tare	362.5 (11)		362.5 (11)	407.5 (13)		407.5 (13)
3	DISTANCE: Actual	Miles	171.4	87.7	83.7	171.4	87.7	83.7
4	Under power	"	138.0	66.4	71.6	121.5	64.7	56.8
5	TON MILES: (tare weight of trailing load)		62100	31800	30300	69900	35800	34100
6	TIME: Booked overall	Mins.	253	⌿ 128	⌿ 119	253	⌿ 128	⌿ 119
7	running	"	227	116	111	227	116	111
8	Actual overall	"	251.1	⌿ 124.5	⌿ 119.8	251.9	⌿ 123.8	⌿ 120.9
9	running	"	216.1	107.4	108.7	221.4	111.3	110.1
10	standing at stations	"	35.0	⌿ 17.1	⌿ 11.1	30.5	⌿ 12.5	⌿ 10.8
11	under power	"	169.4	81.3	88.1	150.3	82.3	68.0
12	drifting and braking	"	46.7	26.1	20.6	71.1	29.0	42.1
13	AVERAGE SPEED: On running time	m.p.h.	47.6	49.0	46.2	46.5	47.3	45.5
14	Under power	"	48.8	48.9	48.7	48.5	47.2	50.1
15	WORK DONE: Traction D.B.H.P. Hours		2288	1370	918	2262	1379	883
16	AVERAGE TRACTION D.B.H.P.		811	1011	626	903	1006	779
17	AVERAGE TRACTION D.B.T.E.	Tons	2.78	3.46	2.15	3.12	3.57	2.60
18	OIL: Gross Calorific Value	B.Th.U/lb.	19420	19420	19420	19400	19400	19400
19	TOTAL used	lb.	1604	+ 957	+ 642	1585	+ 945	+ 636
20	used under power	lb.	1540	923	617	1481	913	568
21	av. rate under power	lb/hr.	545	681	420	591	666	501
22	used while standing at stations	lb.	28	+ 14	+ 9	21	+ 9	+ 8
23	av. rate while standing at stations	lb/hr.	48.0	49.1	48.7	41.3	43.2	44.5
24	used while drifting and braking	lb.	36	20	16	83	23	60
25	av. rate while drifting and braking	lb/hr.	46.2	46.0	46.6	70.1	47.6	85.6
26	lb/Traction D.B.H.P. Hour, on total fuel used		0.702	0.699	0.700	0.701	0.686	0.721
27	lb/Traction D.B.H.P. Hour, under power		0.673	0.674	0.673	0.655	0.663	0.643
28	lb/mile on total fuel used		9.37	10.91	7.69	9.25	10.76	7.62
29	lb/mile under power		11.16	13.90	8.62	12.20	14.10	10.00
30	lb/ton mile on total fuel used		0.0258	0.0301	0.0212	0.0227	0.0264	0.0186
31	lb/ton mile on fuel used while running		0.0254	0.0296	0.0209	0.0224	0.0262	0.0184
32	$\frac{\text{Energy transmitted to trailing load x 100}}{\text{Energy in total fuel}}$	%	18.7	18.75	18.7	18.8	19.2	18.2
33	$\frac{\text{Energy transmitted to trailing load x 100}}{\text{Energy in fuel used under power}}$ Traction Efficiency	%	19.5	19.45	19.5	20.1	19.8	20.4
34	$\frac{\text{Traction Efficiency}}{k}$	%	-	26.55	26.61	-	26.4	27.2

The term "Under Power" refers to periods when power generated by the power unit is being transmitted to the trailing load

The terms "Traction D.B.H.P." and "Traction D.B.T.E." refer to power and tractive effort transmitted to the trailing load as measured by the Dynamometer Car.

\+ Excludes fuel used while standing at Salisbury station

⌿ Excludes time standing at Salisbury station

k = $\frac{\text{Weight of Trailing Load}}{\text{Total Weight}}$

TABLE 6

SUMMARISED RESULTS OF TESTS ON REVENUE EARNING TRAINS

UP TRAINS

5.55 p.m. ex EXETER CENTRAL TO WATERLOO
STOPPING AT - SIDMOUTH JCN. SEATON JCN., AXMINSTER,
YEOVIL JCN., TEMPLECOMBE, SALISBURY, ANDOVER JCN.,
BASINGSTOKE, WOKING AND SURBITON

A EXETER - WATERLOO OVERALL
B EXETER - SALISBURY SECTION
C SALISBURY WATERLOO SECTION

LINE		COL. NO.	4th JULY, 1955			6th JULY, 1955		
			A	B	C	A	B	C
			1	2	3	4	5	6
1	**LOAD & NO. OF VEHICLES** Exeter to Salisbury	Tons Tare	362.5 (11)	362.5 (11)		407.5 (13)	407.5 (13)	
2	Salisbury to Waterloo	Tons Tare	362.5 (11)		362.5 (11)	407 5 (13)		407.5 (13)
3	DISTANCE: Actual	Miles	171.4	87.7	83.7	171.4	87.7	83.7
4	Under power	"	138.0	66.4	71.6	121.5	64.7	56.8
5	TON MILES: (tare weight of trailing load)		62100	31800	30300	69900	35800	34100
6	TIME: Booked overall	Mins.	253	≠ 128	≠ 119	253	≠ 128	≠ 119
7	running	"	227	116	111	227	116	111
8	Actual overall	"	251.1	≠ 124.5	≠ 119.8	251.9	≠ 123.8	≠ 120.9
9	running	"	216.1	107.4	108.7	221.4	111.3	110.1
10	standing at stations	"	35.0	≠ 17.1	≠ 11.1	30.5	≠ 12 5	≠ 10.8
11	under power	"	169.4	81.3	88.1	150.3	82.3	68.0
12	drifting and braking	"	46.7	26.1	20.6	71.1	29.0	42.1
13	AVERAGE SPEED: On running time	m.p.h.	47.6	49.0	46.2	46.5	47.3	45.5
14	Under power	"	48.8	48.9	48.7	48.5	47.2	50.1
15	WORK DONE: Traction D.B.H.P. Hours		2288	1370	918	2262	1379	883
16	AVERAGE TRACTION D.B.H.P.		811	1011	626	903	1006	779
17	AVERAGE TRACTION D.B.T.E.	Tons	2.78	3.46	2.15	3.12	3.57	2 60
18	OIL: Gross Calorific Value	B.Th.U/lb	19420	19420	19420	19400	19400	19400
19	TOTAL used	lb.	1604	+ 957	+ 642	1585	+ 945	+ 636
20	used under power	lb.	1540	923	617	1481	913	568
21	av. rate under power	lb/hr.	545	681	420	591	666	501
22	used while standing at stations	lb.	28	+ 14	+ 9	21	+ 9	+ 8
23	av. rate while standing at stations	lb/hr.	48.0	49.1	48.7	41.3	43.2	44.5
24	used while drifting and braking	lb.	36	20	16	83	23	60
25	av. rate while drifting and braking	lb/hr.	46.2	46.0	46.6	70.1	47.6	85.6
26	lb/Traction D.B.H.P. Hour, on total fuel used		0.702	0.699	0.700	0.701	0.686	0.721
27	lb/Traction D.B.H.P. Hour, under power		0.673	0.674	0.673	0.655	0.663	0.643
28	lb/mile on total fuel used		9.37	10.91	7.69	9 25	10.76	7.62
29	lb/mile under power		11.16	13.90	8 62	12.20	14.10	10.00
30	lb/ton mile on total fuel used		0.0258	0.0301	0.0212	0.0227	0.0264	0.0186
31	lb/ton mile on fuel used while running		0.0254	0.0296	0.0209	0.0224	0.0262	0.0184
32	Energy transmitted to trailing load x 100 / Energy in total fuel	%	18.7	18.75	18.7	18.8	19.2	18.2
33	Energy transmitted to trailing load x 100 / Energy in fuel used under power	Traction Efficiency %	19.5	19.45	19.5	20.1	19.8	20.4
34	Traction Efficiency / k	%	-	26.55	26.61	-	26.4	27.2

The term "Under Power" refers to periods when power generated by the power unit is being transmitted to the trailing load

The terms "Traction D.B.H.P." and "Traction D.B.T.E." refer to power and tractive effort transmitted to the trailing load as measured by the Dynamometer Car.

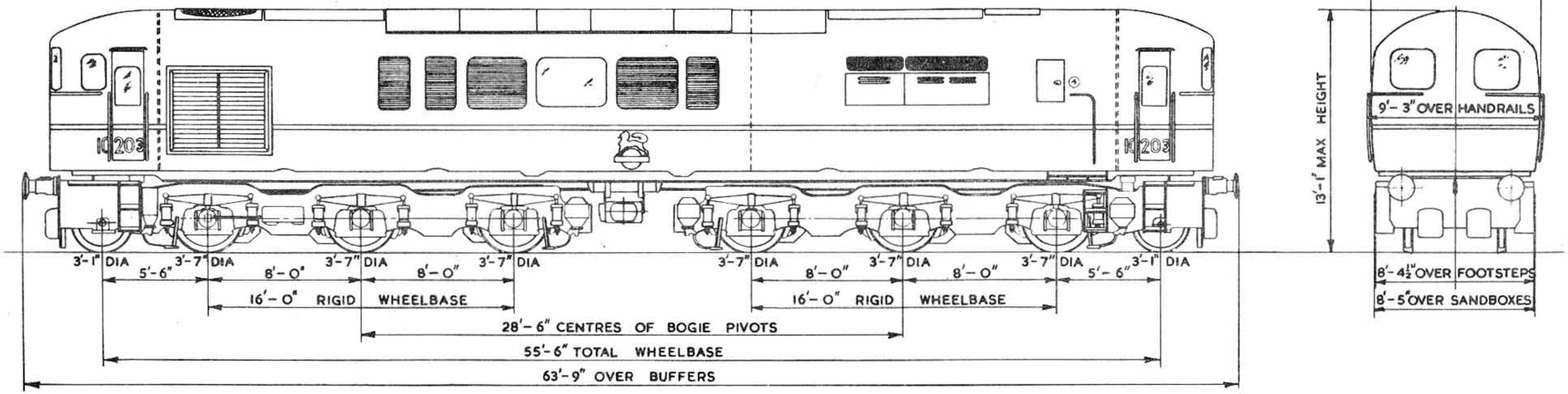
\+ Excludes fuel used while standing at Salisbury station

≠ Excludes time standing at Salisbury station

$$k = \frac{\text{Weight of Trailing Load}}{\text{Total Weight}}$$

BRITISH RAILWAYS
SOUTHERN REGION
2000 BHP OIL-ELECTRIC LOCOMOTIVE (TYPE 1 C_o-C_o 1)

No 10203



WEIGHT									TOTAL
	T C	T C	T C	T C	T C	T C	T C	T C	T C
IN WORKING ORDER	11 - 5	18 - 6	18 - 12	18 - 10	18 - 3	17 - 19	18 - 0	12 - 1	132 - 16
UNSPRUNG	1 - 18½	3 - 10	3 - 10	3 - 10	3 - 10	3 - 10	3 - 10	1 - 18½	24 - 17

①

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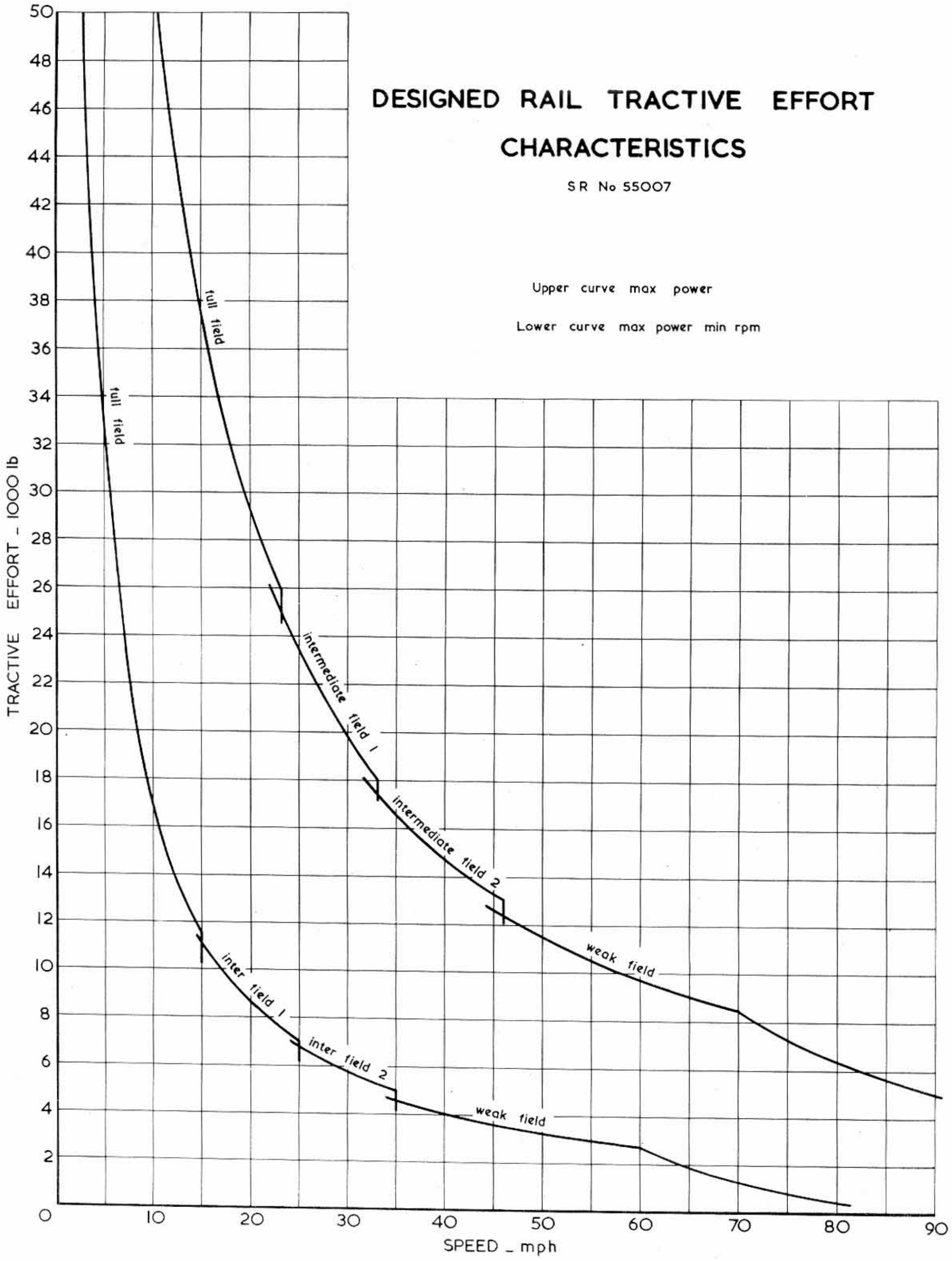

DESIGNED RAIL TRACTIVE EFFORT CHARACTERISTICS

S R No 55007

Upper curve max power

Lower curve max power min rpm

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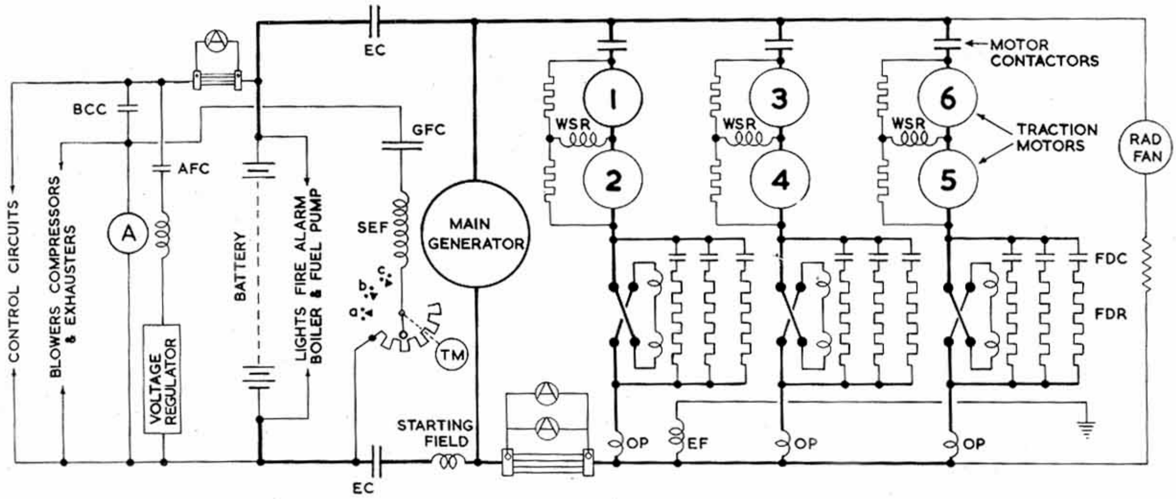
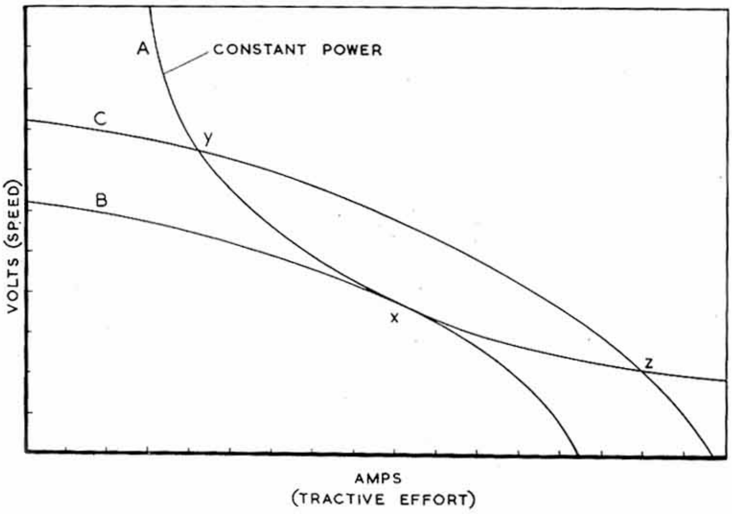
②



A	Auxiliary Generator	FDR	Field Diverting Resistor
AFC	Auxiliary Generator Field Contactor	GFC	Main Gen Field Contactor
BCC	Battery Charging Contactor	OP	Overload Protection Relay
EC	Engine Starting Contactor	SEF	Separately Excited Field
EF	Earth Fault Relay	TM	Torque Control Motor
FDC	Field Diverting Contactor	WSR	Wheel Slip Relay
a,b,c Field Diverting Contacts on Torque Regulator			

SIMPLIFIED POWER & AUXILIARY CIRCUITS

3



TYPICAL GENERATOR CHARACTERISTICS

4

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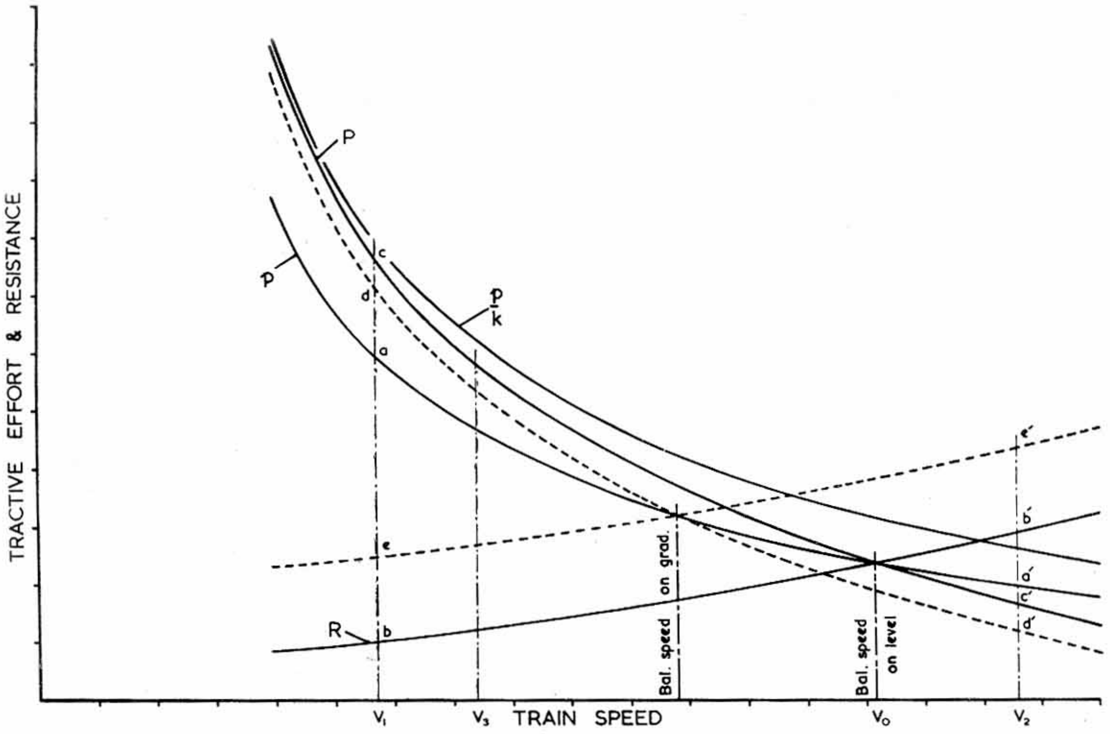


W_e = weight of locomotive W_c = weight of trailing load $n = \frac{W_c}{W_e}$ $k = \frac{W_c}{W_e + W_c}$ = trailing : gross weight ratio

F = fuel rate $V_0 . V_1 . V_2 . V_3$. etc. = train speed

r_c = specific resistance of trailing load on the level r_e = specific wind and track resistance of locomotive on the level

$R = r_c \times W_c$ = total resistance of trailing load on the level

$C = r_c \times W_e$

P = equivalent drawbar tractive effort or drawbar tractive effort on the level at constant speed = rail tractive effort $- r_e W_e$

p = tractive effort on trailing load or traction drawbar tractive effort (trac. d.b.t.e.)

Residual Forces bc b′c′ etc.

On Level:–

ab a′b′ etc. accel. force on trailing load

ac a′c′ etc. accel. force on locomotive

Locomotive and trailing load have same accel^n.

$$\therefore \frac{ab}{ac} = \frac{a'b'}{a'c'} = \frac{W_c}{W_e} = n$$

On Gradient:–

cd c′d′ grad. component of locomotive

eb e′b′ grad. component of trailing load

$$\therefore \frac{cd}{eb} = \frac{c'd'}{e'b'} = \frac{W_e}{W_c} = \frac{1}{n}$$

ad a′d′ accel. force on locomotive

ae a′e′ accel. force on trailing load

Locomotive and trailing load have same accel^n.

$$\therefore \frac{ae}{ad} = \frac{a'e'}{a'd'} = \frac{W_c}{W_e} = n$$

Thus p is not qualified by gradient and accel^n.

Consider a given fuel rate F and speed V_3

as $W_c = n W_e$, $R = nC$ and $k = \frac{n}{n+1}$

$$p = P - (P - nC)\frac{W_e}{W_e + W_c}$$
$$= P - P\frac{W_e}{W_e + W_c} + nC\frac{W_e}{W_e + W_c}$$
$$= P\left[1 - \frac{W_e}{W_e + W_c}\right] + nC\frac{W_e}{W_e + W_c}$$

But $1 - \frac{W_e}{W_e + W_c} = k$ and $W_c = n W_e$

$$\therefore p = Pk + Ck$$
$$\therefore p = k\,(P + C) \text{ ———————— } ①$$

Note

(i) This result is independent of n and therefore holds for all values of n

(ii) Thus for a given fuel rate and speed, P and C are constant, $p \propto k$ from ①

$$\therefore \frac{p_1}{k_1} = \frac{p_2}{k_2} = \frac{p_3}{k_3} = \ldots\ldots\ldots\ldots\ldots$$

(iii) This may be extended to traction d.b.hp. and fuel / traction d.b.hp.hr. as follows:–

traction d.b.hp. $\propto p \propto k$

fuel / traction d.b.hp.hr. $\propto \frac{1}{p} \propto \frac{1}{k}$

(iv) When $r_e = r_c$ $C = W_e r_c = W_e r_e$

$$p = k\,(P + C) = k\,(P + W_e r_e)$$
$$= k \times \text{rail t.e.}$$

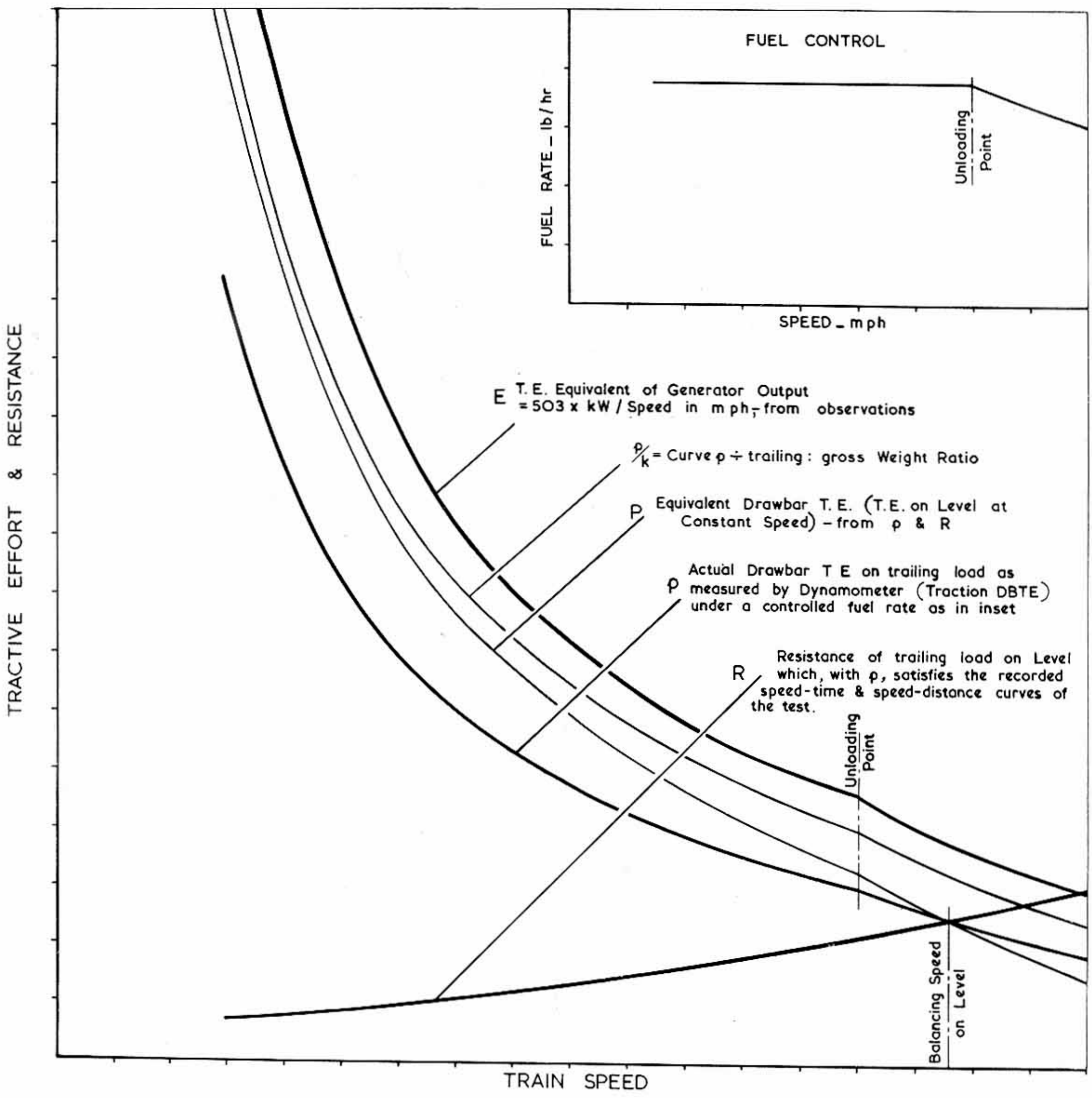
When $r_e > r_c$

$$p = k\left[\text{rail t.e.} - W_e\,(r_e - r_c)\right]$$

BASIC TRACTIVE EFFORT RELATIONS

(Basis of Controlled Road Testing System)

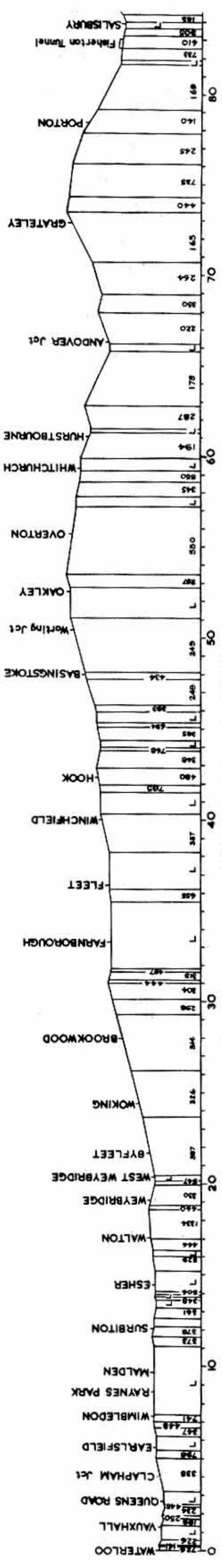
DE 2000/10203/55



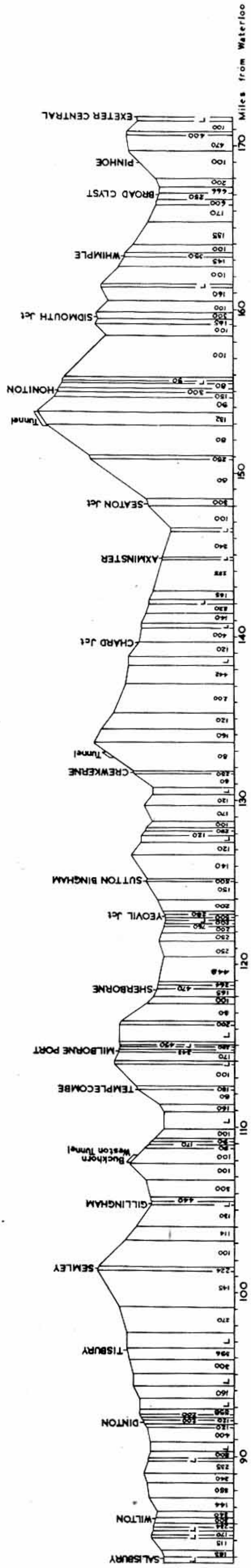
SHOWING HOW THE BASIC DATA FOR ESTABLISHING THE PRINCIPAL RELATIONS IS COLLECTED BY CONTROLLED ROAD TESTS

DE 2000/10203/55

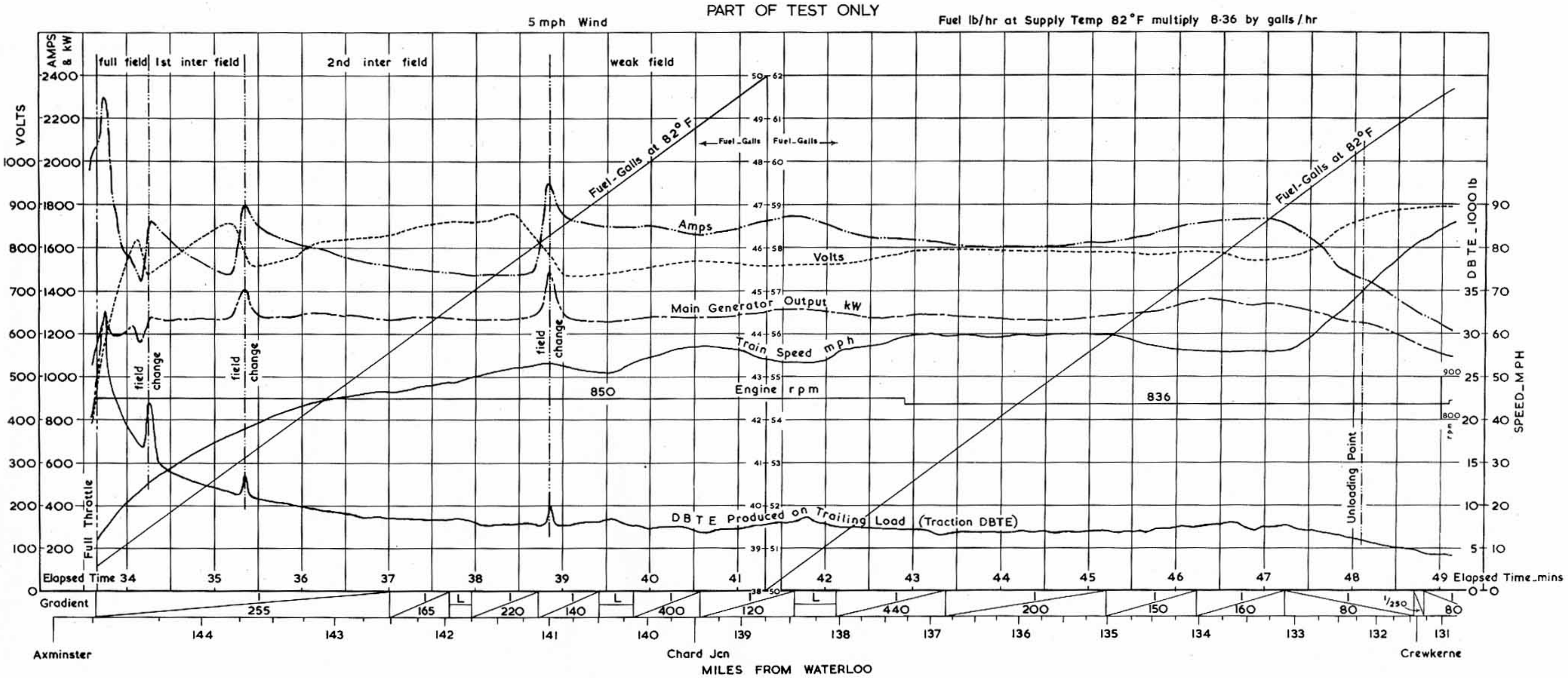
6



WATERLOO _ SALISBURY



SALISBURY _ EXETER



EXAMPLE OF OBSERVATIONS MADE ON A CONTROLLED ROAD TEST

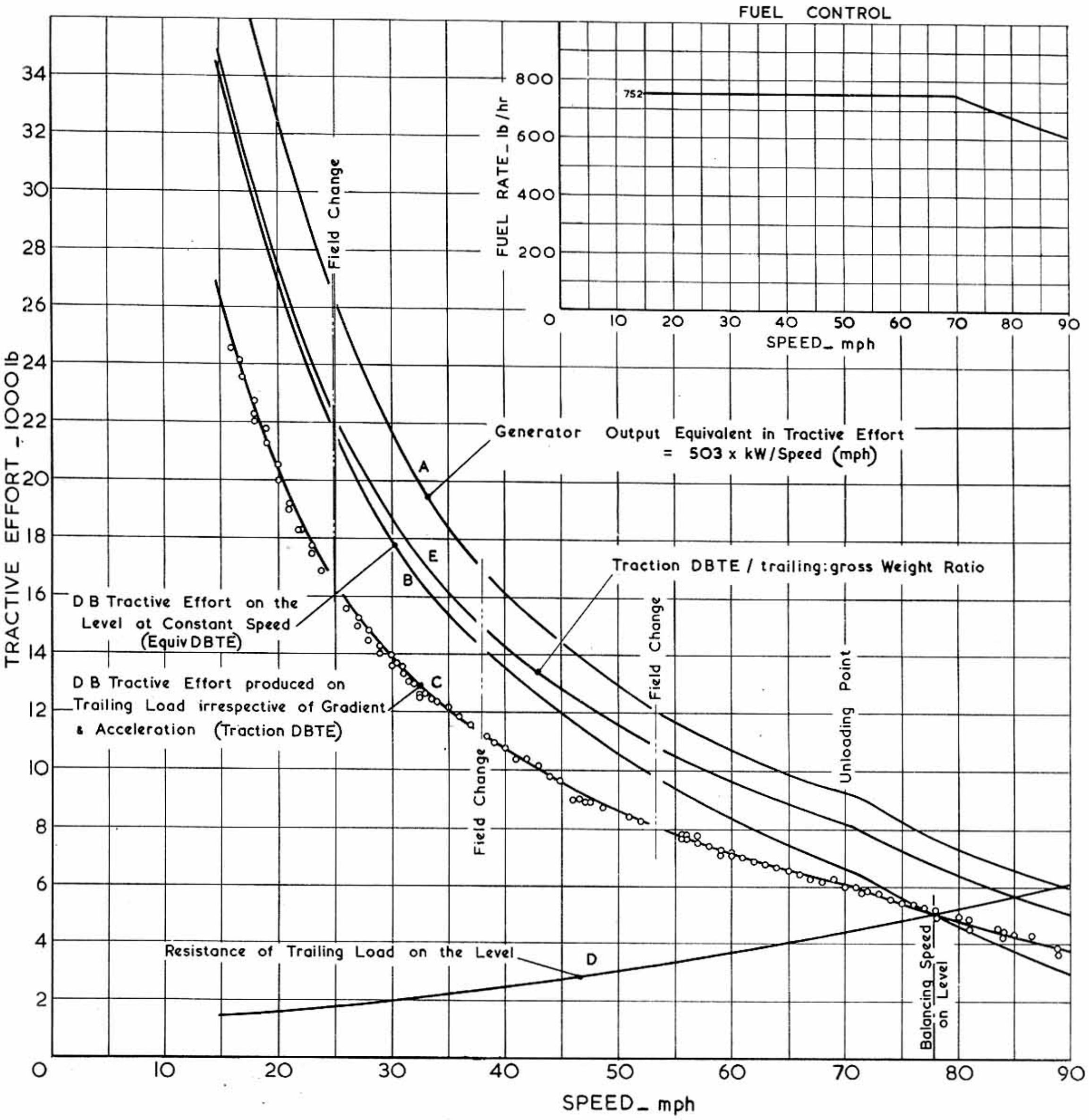
FULL POWER LOAD 392 TONS FOR 12 VEHICLES

GCV OF FUEL 19420 BThU/lb

FOR ANALYSIS OF TEST SEE GRAPH 9

8

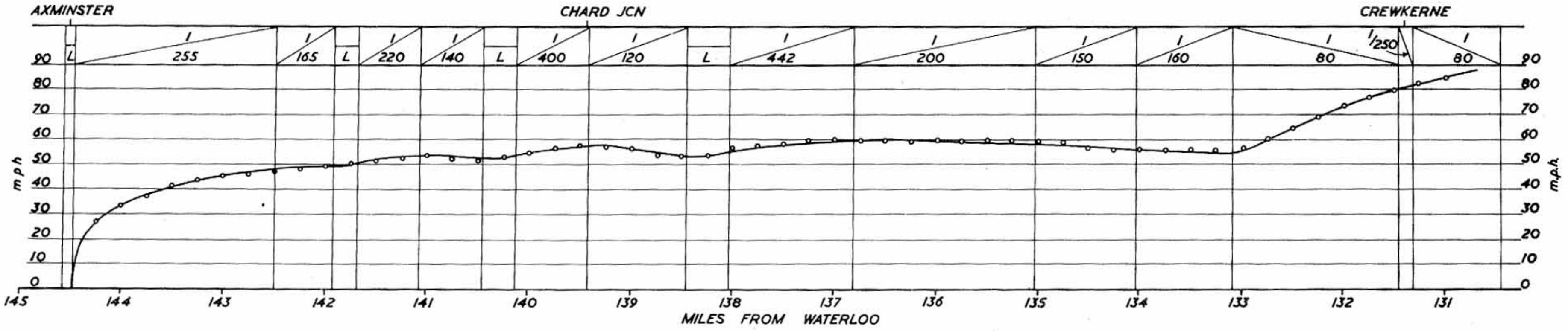
DE 2000/10203/55



EXAMPLE OF AN ANALYSIS OF A CONTROLLED ROAD TEST

FULL POWER LOAD 392 TONS for 12 VEHICLES

PART ONLY



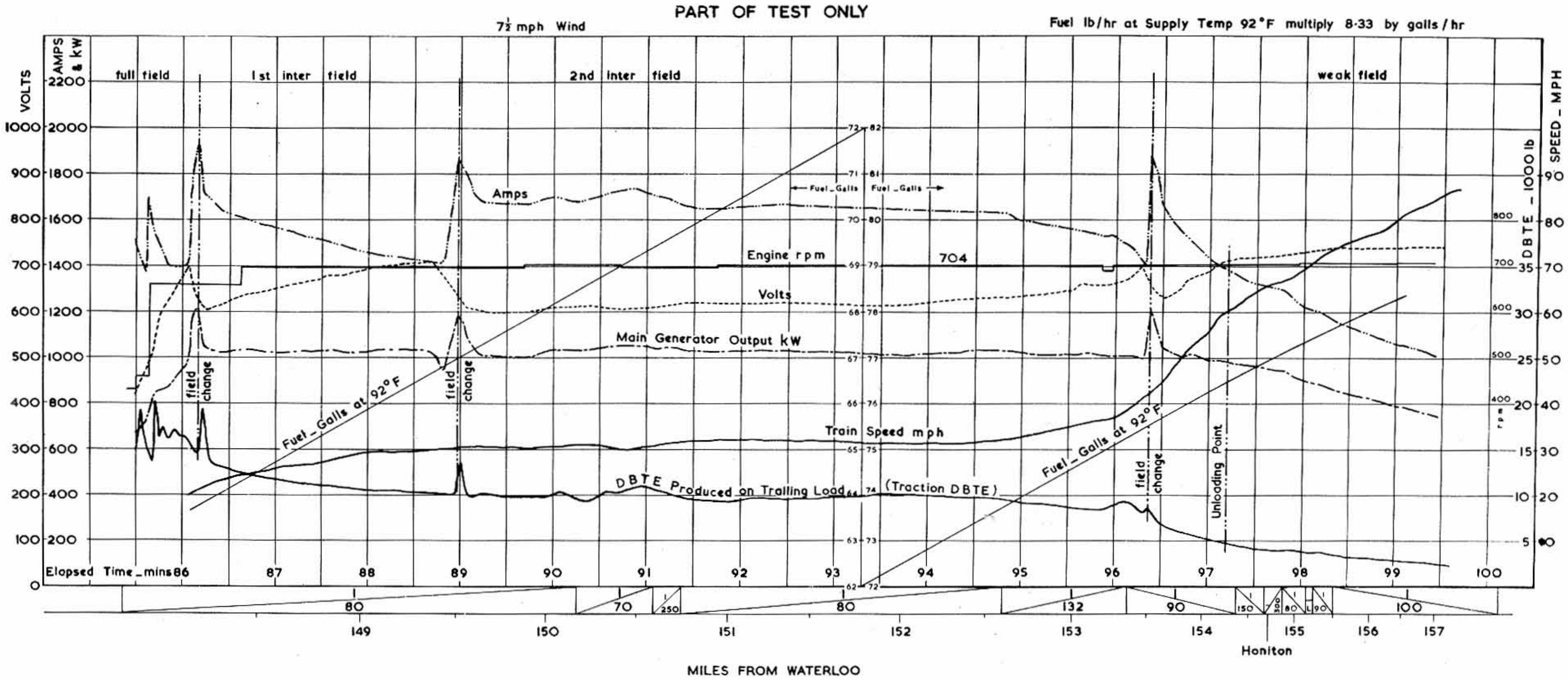
EXAMPLE OF PROVING THE DRAWBAR AND RESISTANCE CHARACTERISTICS OF A CONTROLLED ROAD TEST

FULL POWER LOAD 392 TONS FOR 12 VEHICLES

The above shows the speed-distance curve calculated from Curves C and D Graph 9 compared with the actual speed (shown thus-o) attained on the test as given in Graph 8

D.E. 2000/10203/55

11



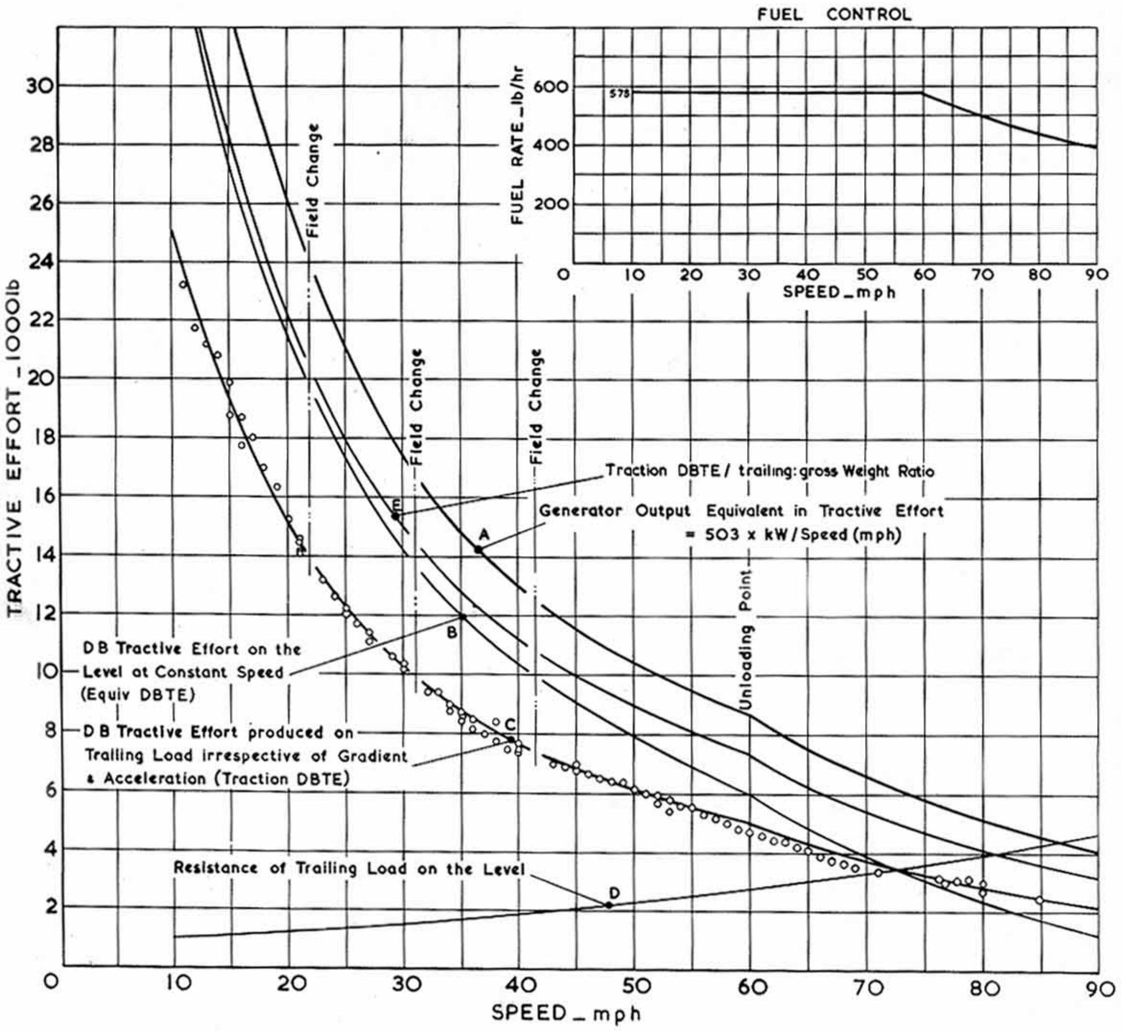
EXAMPLE OF OBSERVATIONS MADE ON A CONTROLLED ROAD TEST

81% maximum bhp LOAD 286 TONS FOR 9 VEHICLES

GCV OF FUEL 19420 BThU/lb

FOR ANALYSIS OF TEST SEE GRAPH 12

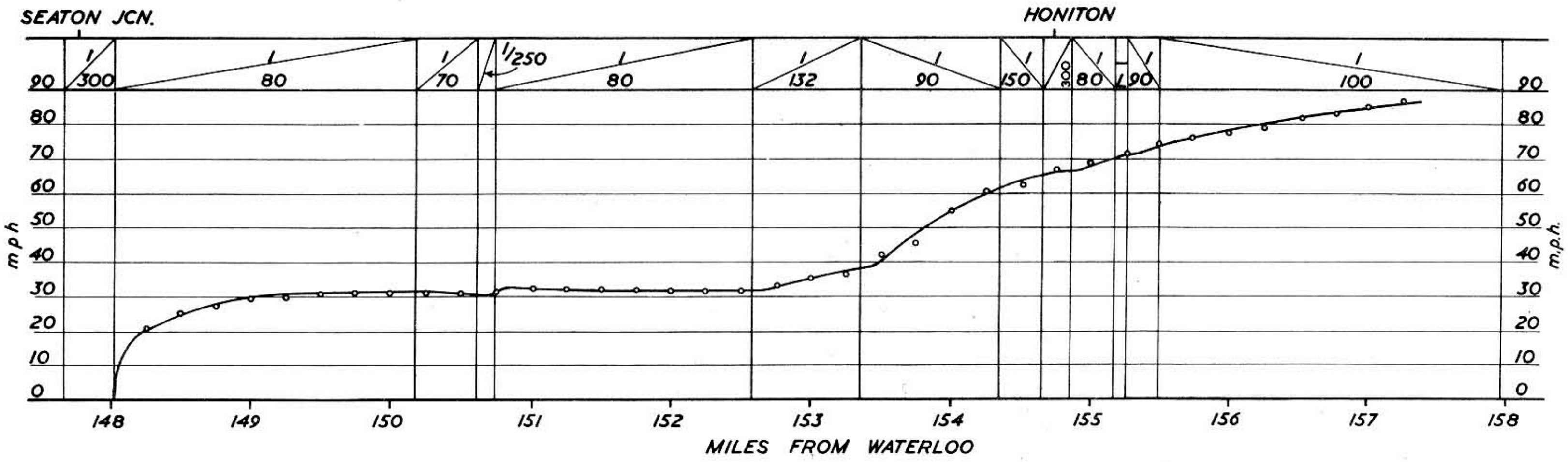
DE 2000/10203/55



EXAMPLE OF AN ANALYSIS OF A CONTROLLED ROAD TEST

81% max bhp LOAD 286 TONS for 9 VEHICLES

PART ONLY



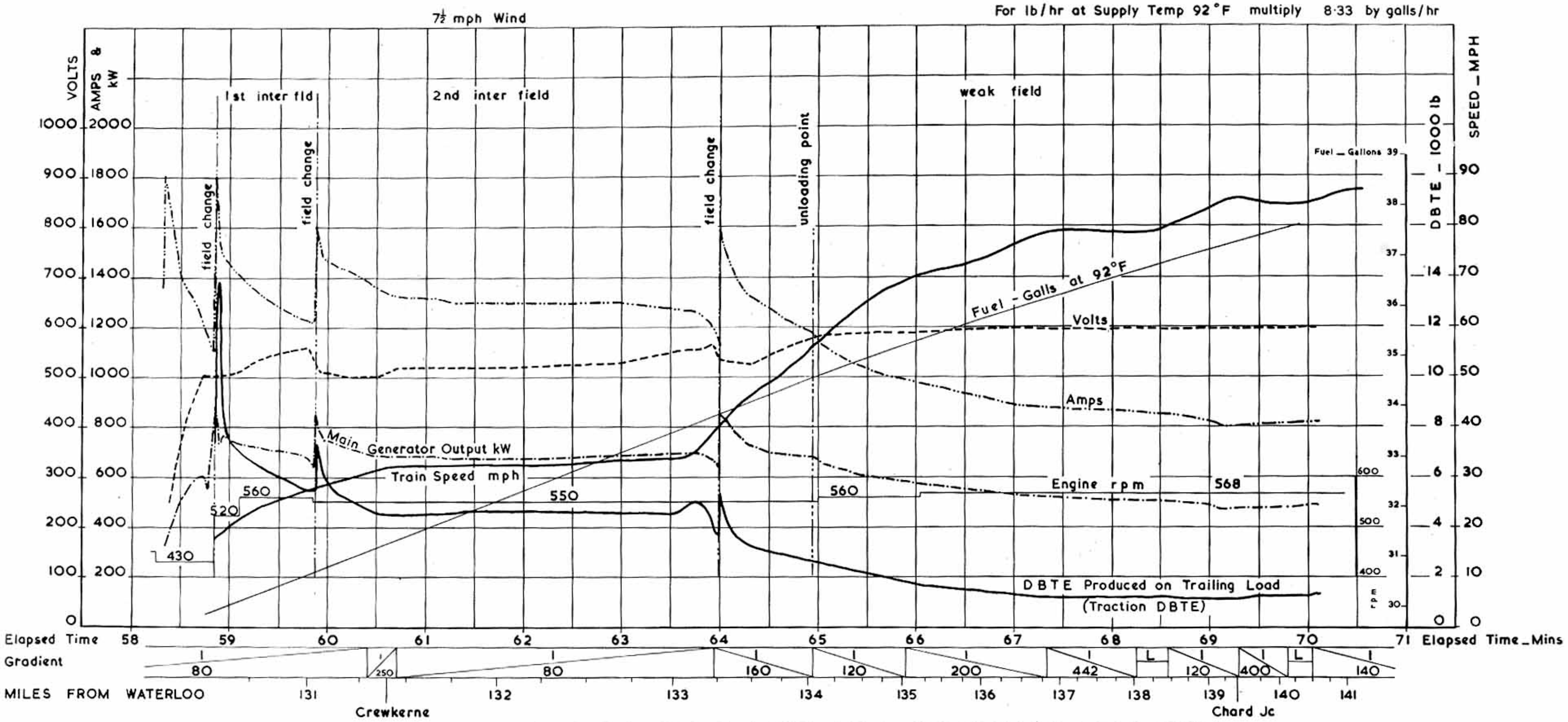
EXAMPLE OF PROVING THE DRAWBAR AND RESISTANCE CHARACTERISTICS OF A CONTROLLED ROAD TEST

81% maximum bhp LOAD 286 TONS FOR 9 VEHICLES

The above shows the speed distance curve calculated from Curves C and D Graph 12 compared with the actual speed (shown thus - o) attained on the test as given in Graph 11

D.E. 2000/10203/55

PART OF TEST ONLY

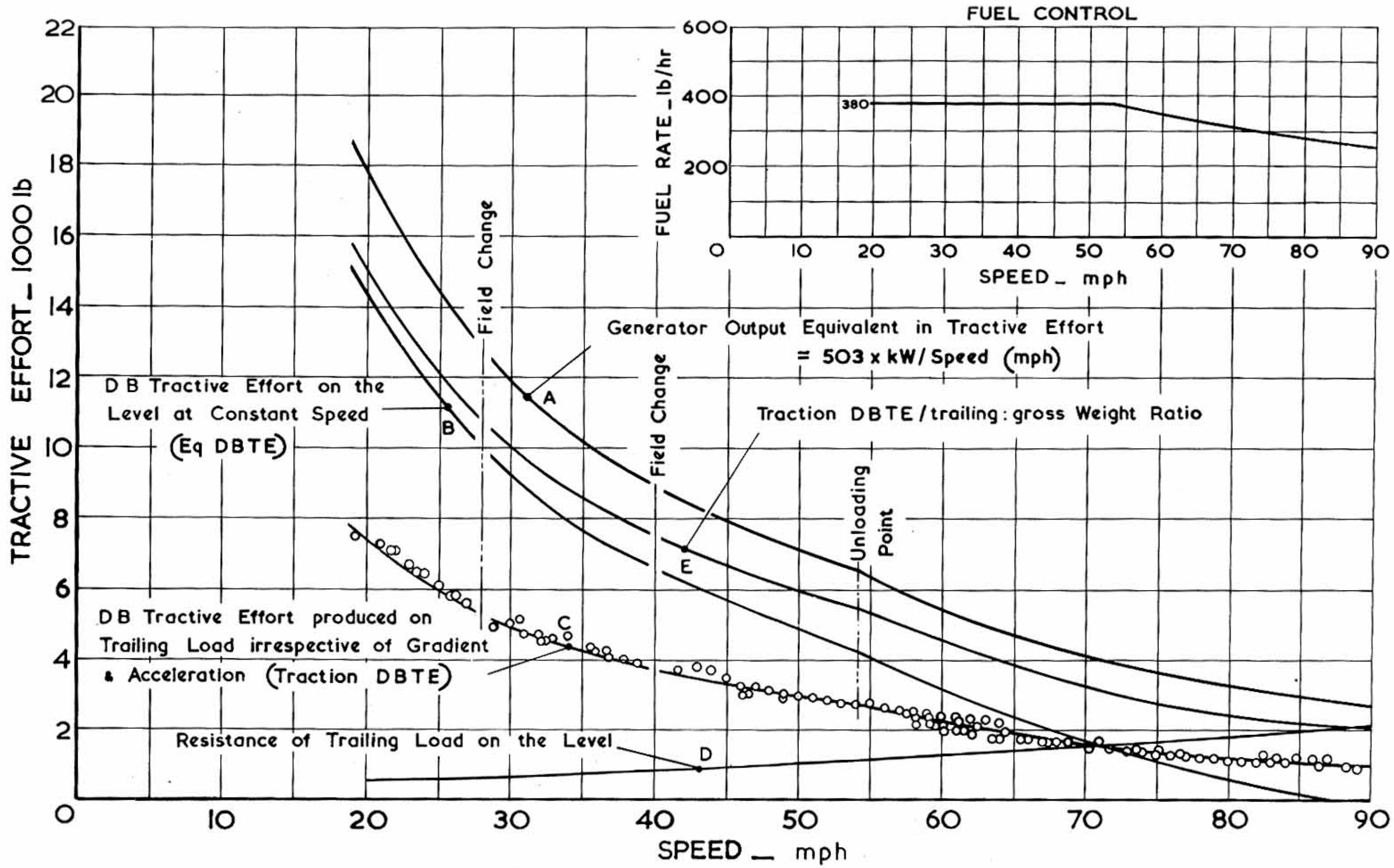


EXAMPLE OF OBSERVATIONS MADE ON A CONTROLLED ROAD TEST

56% maximum bhp 130 TONS FOR 4 VEHICLES

GCV OF FUEL 19420 BThU/lb

FOR ANALYSIS OF TEST SEE GRAPH 15



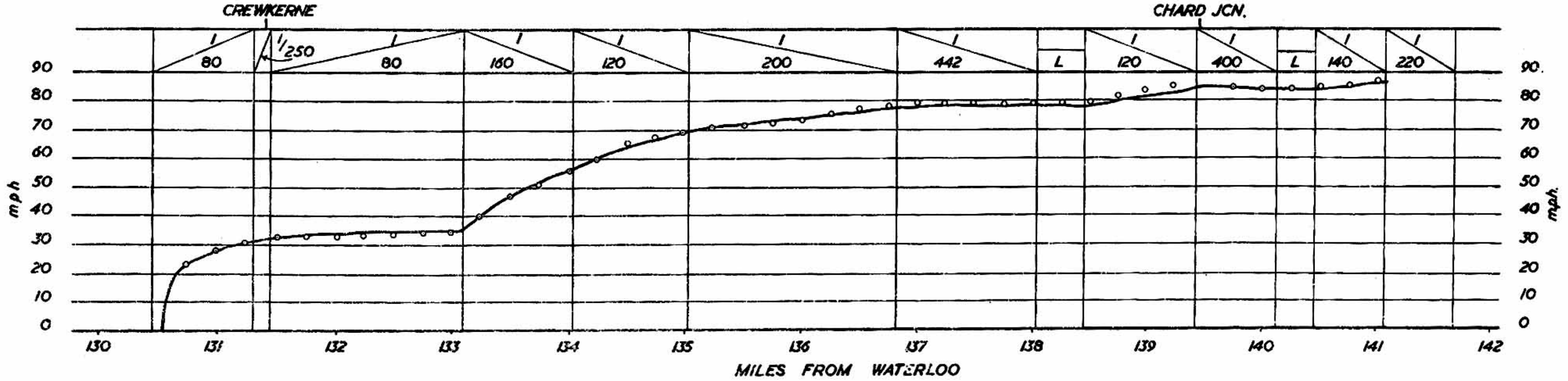
EXAMPLE OF AN ANALYSIS OF A CONTROLLED ROAD TEST

56% max bhp LOAD 130 TONS for 4 VEHICLES

15

DE 2000/10203/55

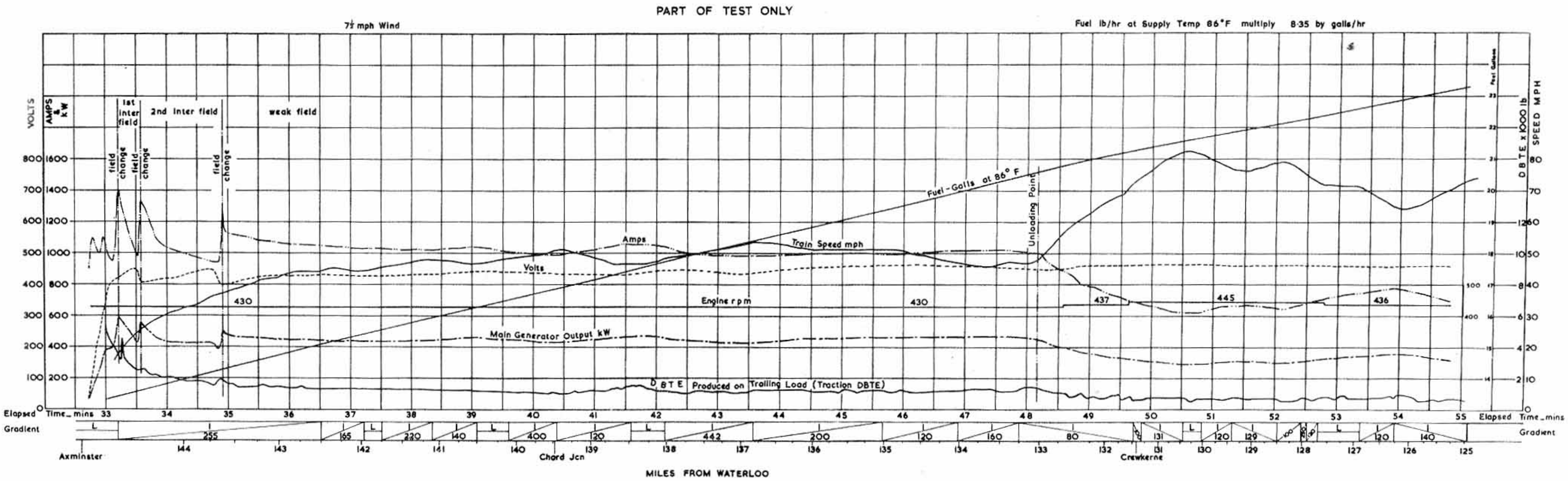
PART ONLY



EXAMPLE OF PROVING THE DRAWBAR AND RESISTANCE CHARACTERISTICS OF A CONTROLLED ROAD TEST

56% maximum bhp LOAD 130 TONS FOR 4 VEHICLES

The above shows the speed-distance curve calculated from Curves C and D Graph 15 compared with the actual speed (shown thus –o) attained on the test as given in Graph 14



⑰

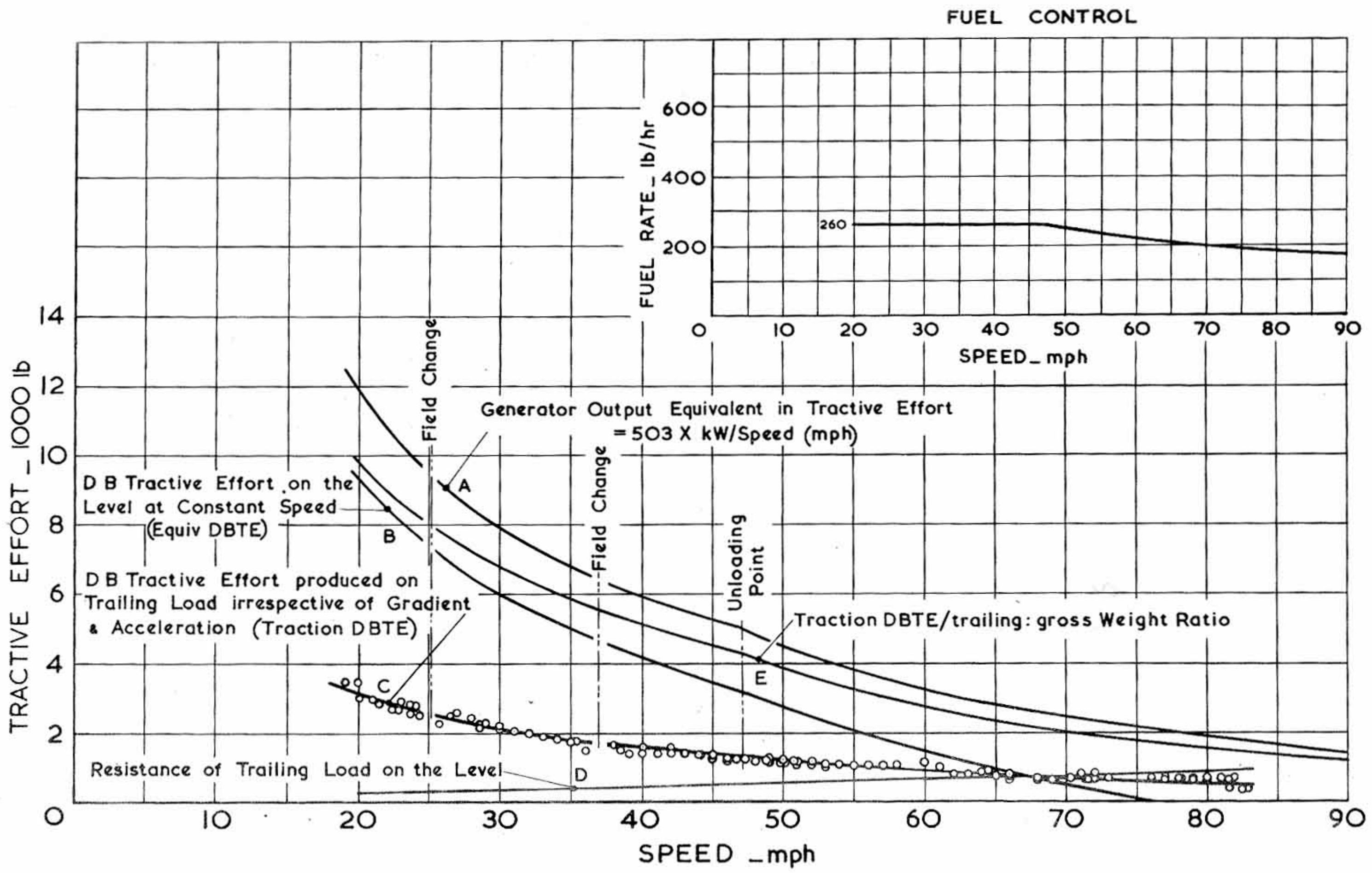
EXAMPLE OF OBSERVATIONS MADE ON A CONTROLLED ROAD TEST

38% max bhp (max power, min rpm) LOAD 63 TONS FOR 2 VEHICLES

GCV OF FUEL 19420 BThU/lb

FOR ANALYSIS OF TEST SEE GRAPH 18

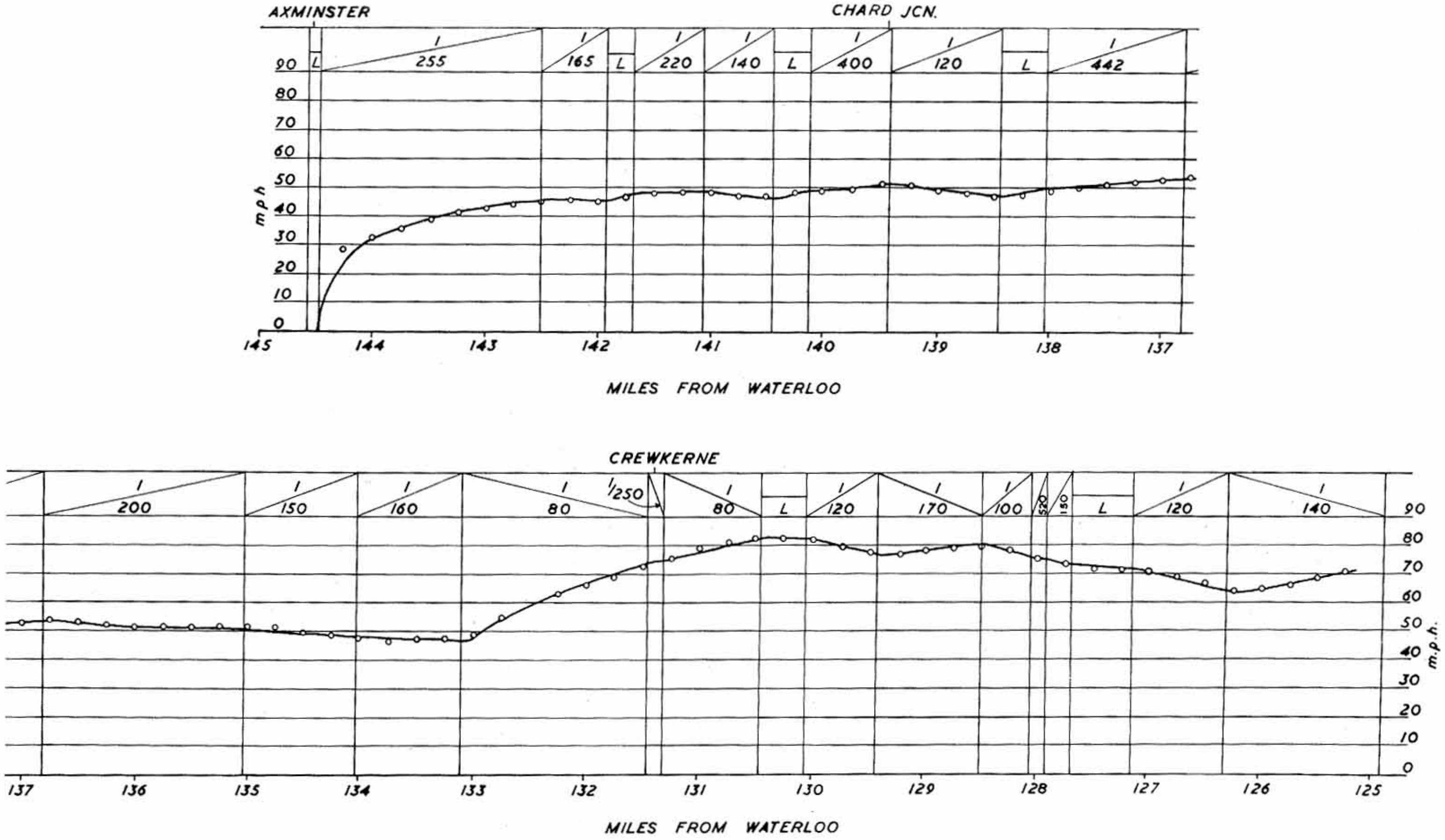
DE 2000/10203/55



EXAMPLE OF AN ANALYSIS OF A CONTROLLED ROAD TEST

38% max bhp (max power min r p m)   LOAD 63 TONS for 2 VEHICLES

PART ONLY



EXAMPLE OF PROVING THE DRAWBAR AND RESISTANCE CHARACTERISTICS OF A CONTROLLED ROAD TEST

38% max bhp (max power, min rpm) LOAD 63 TONS FOR 2 VEHICLES

The above shows the speed-distance curve calculated from Curves C and D Graph 18 compared with the actual speed (shown thus—o) attained on the test as given in Graph 17

19

D.E. 2000/10203/55

MG hp I = Main Generator Input in hp

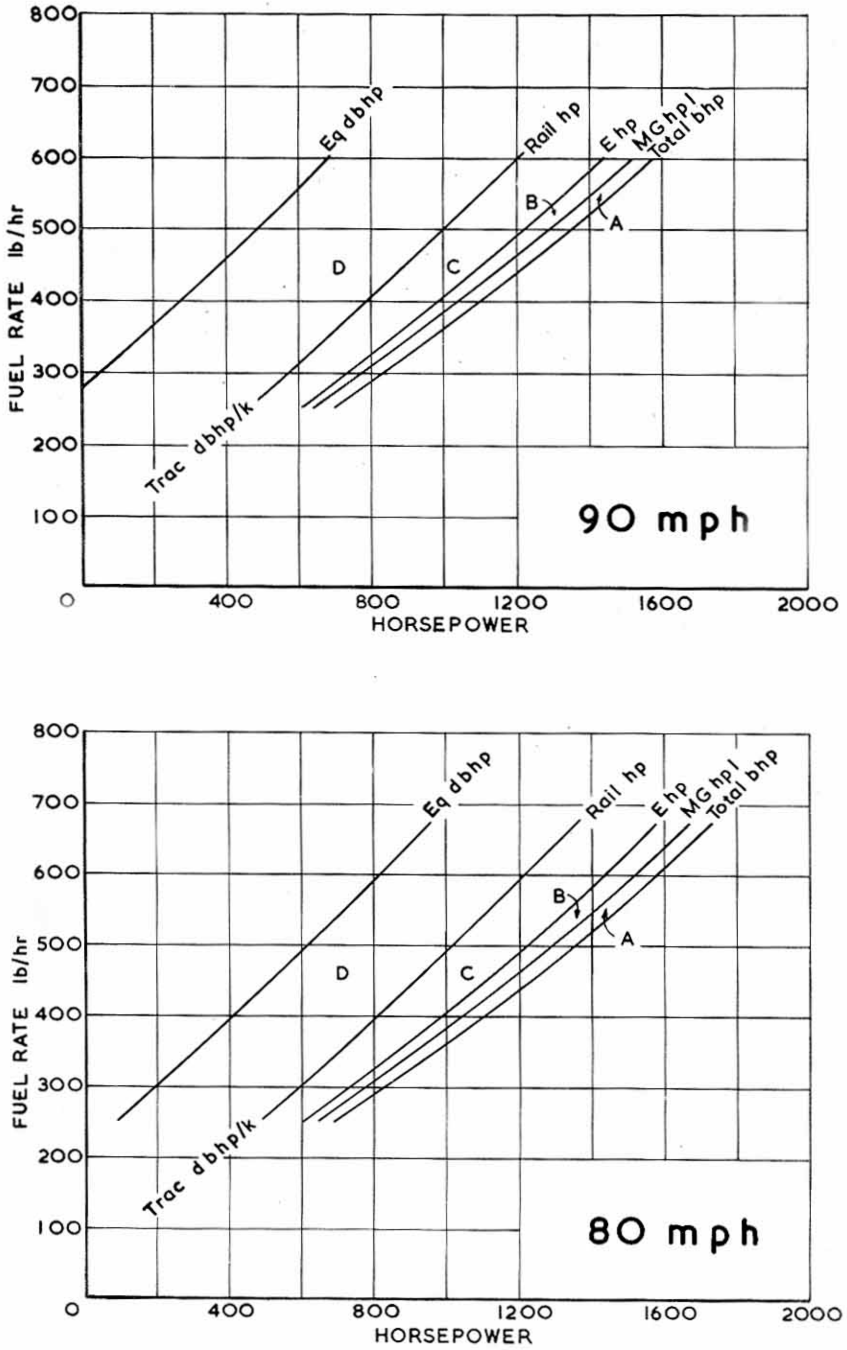
Ehp = Main Generator Output in hp = kWx1000/746 = Input to Traction Motors and radiator fan.

Eq dbhp = Equivalent Drawbar hp = Drawbar hp on level at constant speed

Trac dbhp/k = Traction Drawbar hp ÷ trailing : gross Weight Ratio

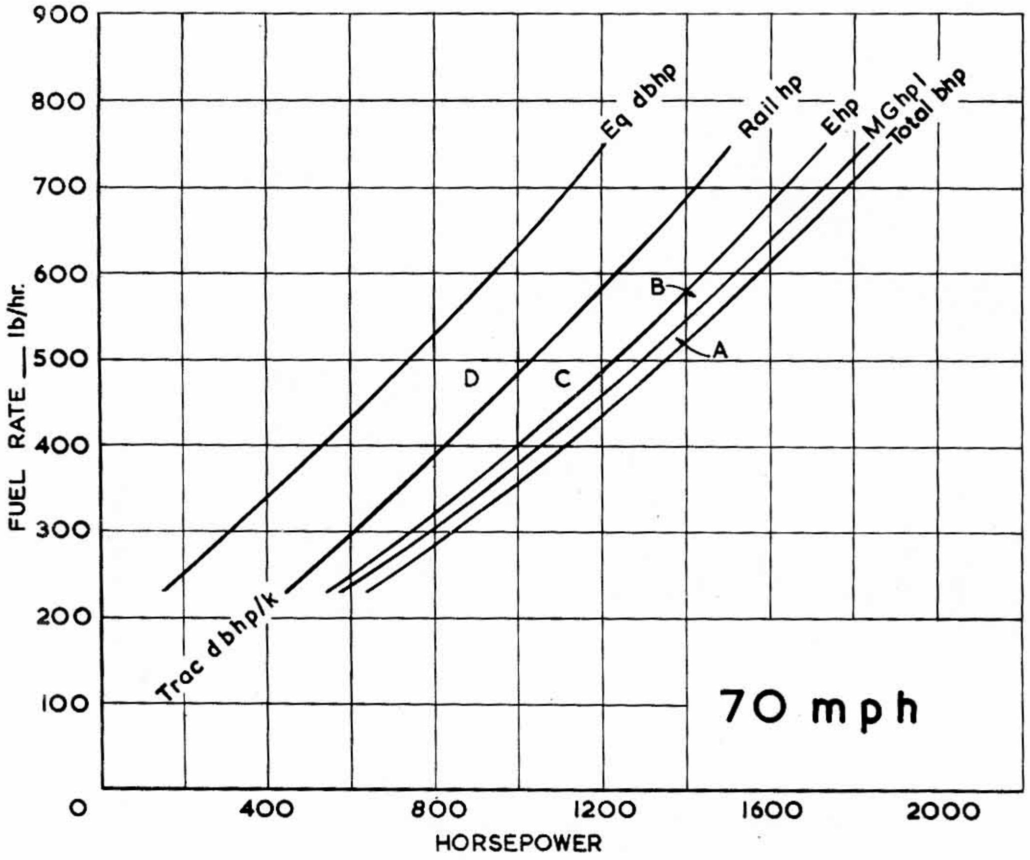
Traction Losses (hp) are denoted thus:

A — To Auxiliaries and in Auxiliary Generator
B — In Main Generator
C — In Traction Motors and Gears and radiator fan
D — By Track and Wind

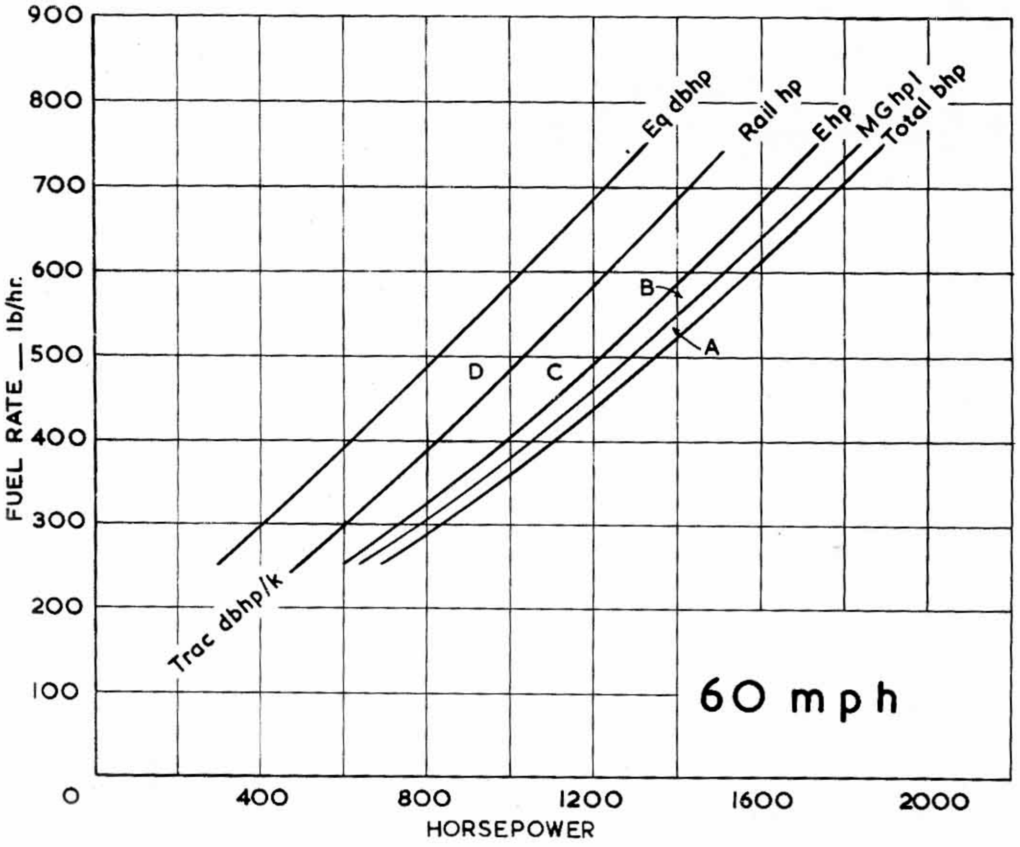


FUEL & POWER RELATIONS

DE 2000/10203/55



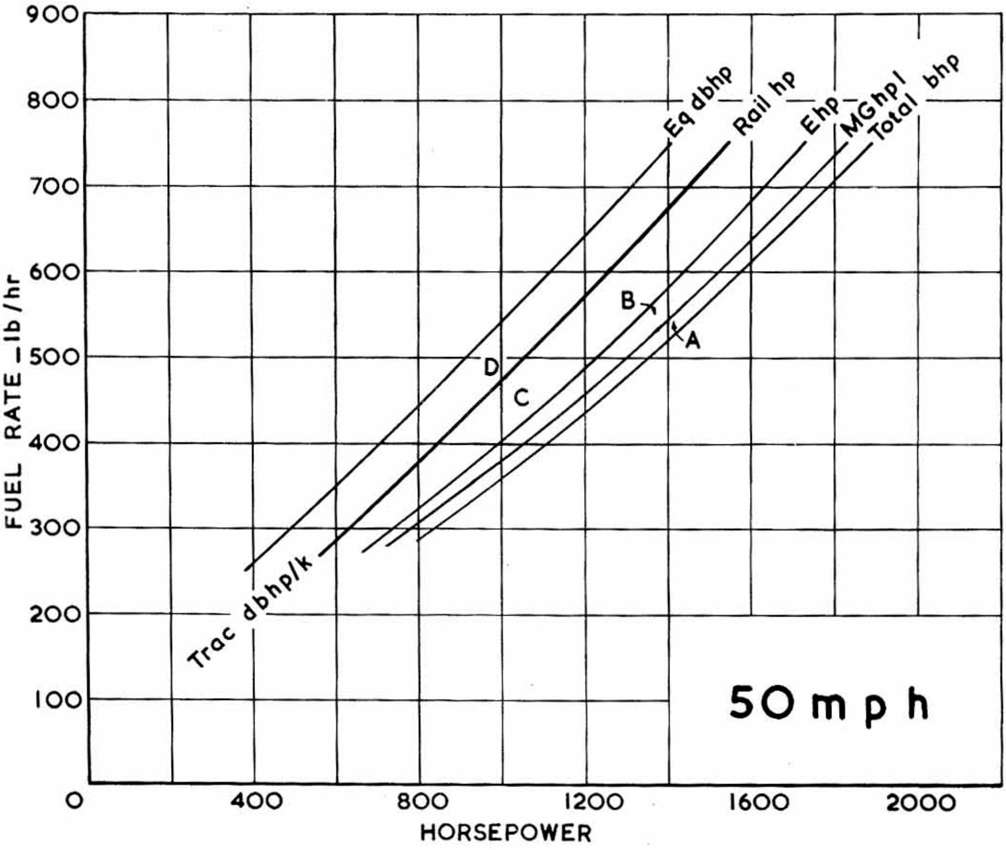
See notes on Graph 20



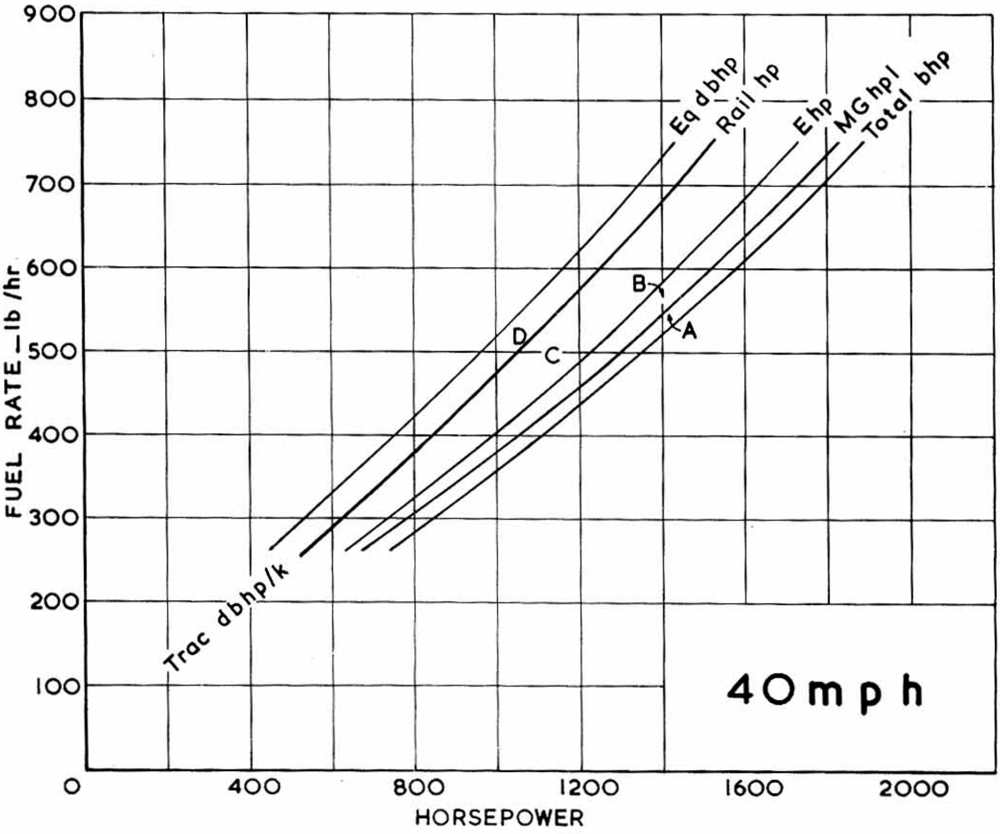
FUEL & POWER RELATIONS

DE 2000/10203/55

①21

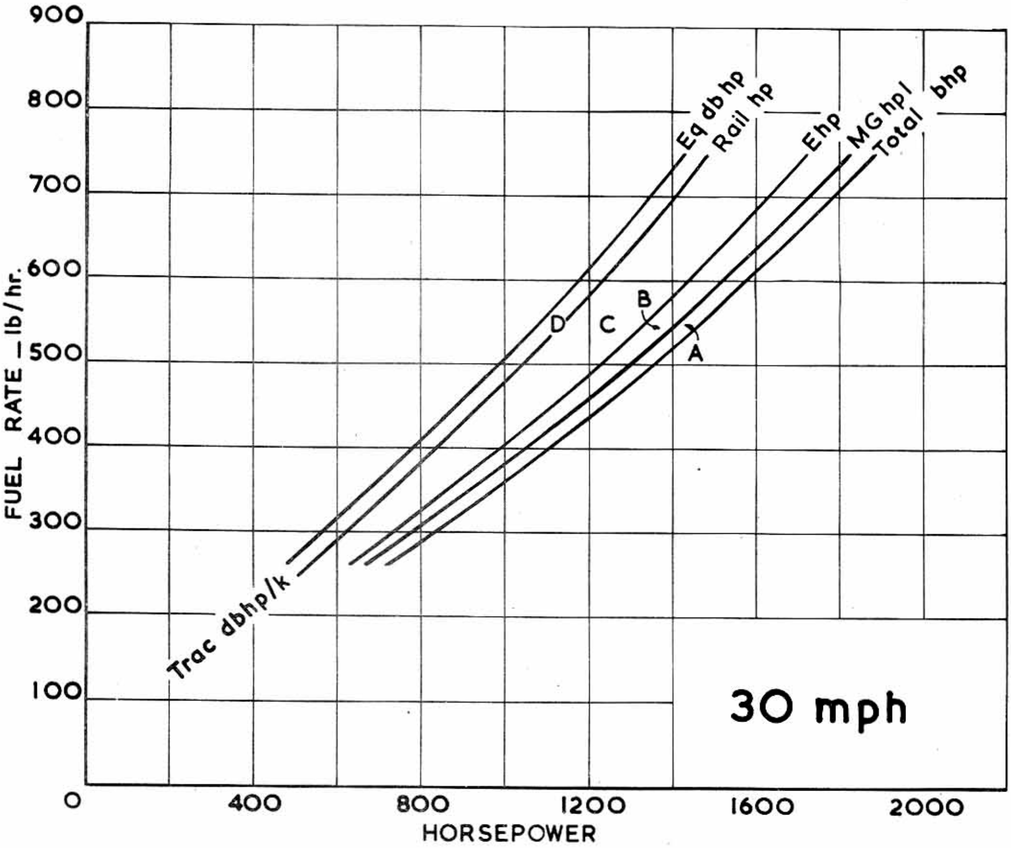


See notes on Graph 20

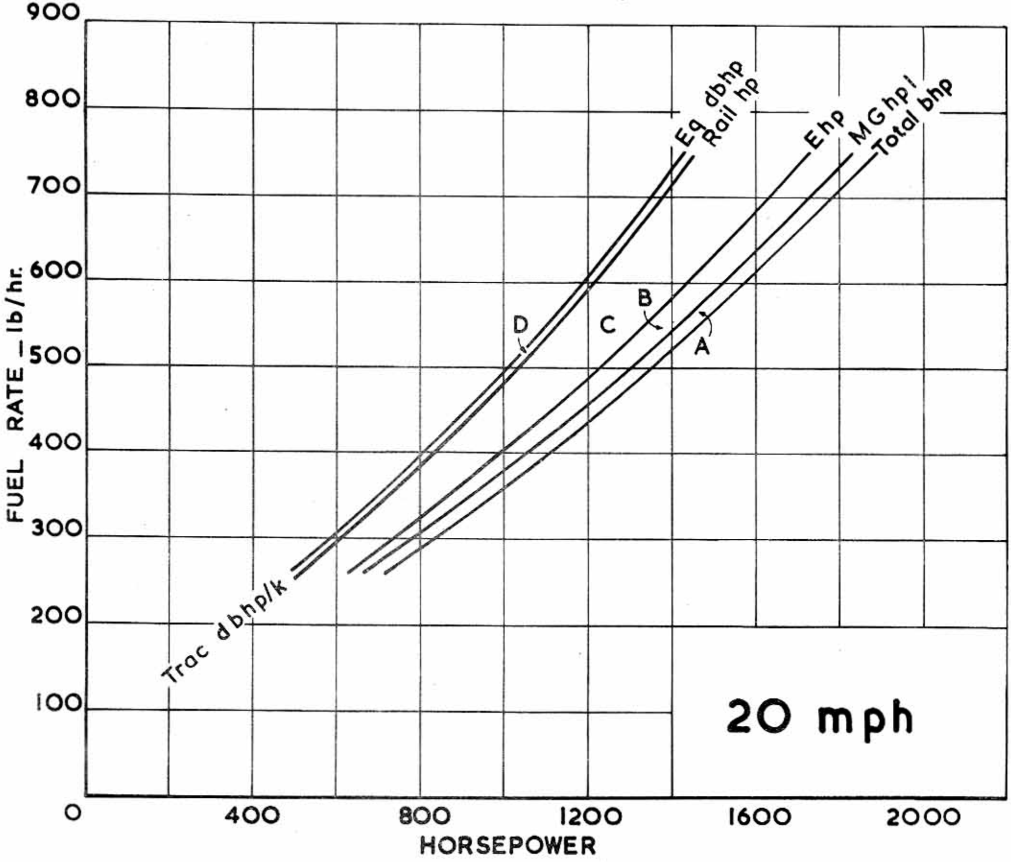


FUEL & POWER RELATIONS

DE 2000/10203/55



See notes on Graph 20



FUEL & POWER RELATIONS

NOTES

1 Condition after 106000 miles
2865 engine hours

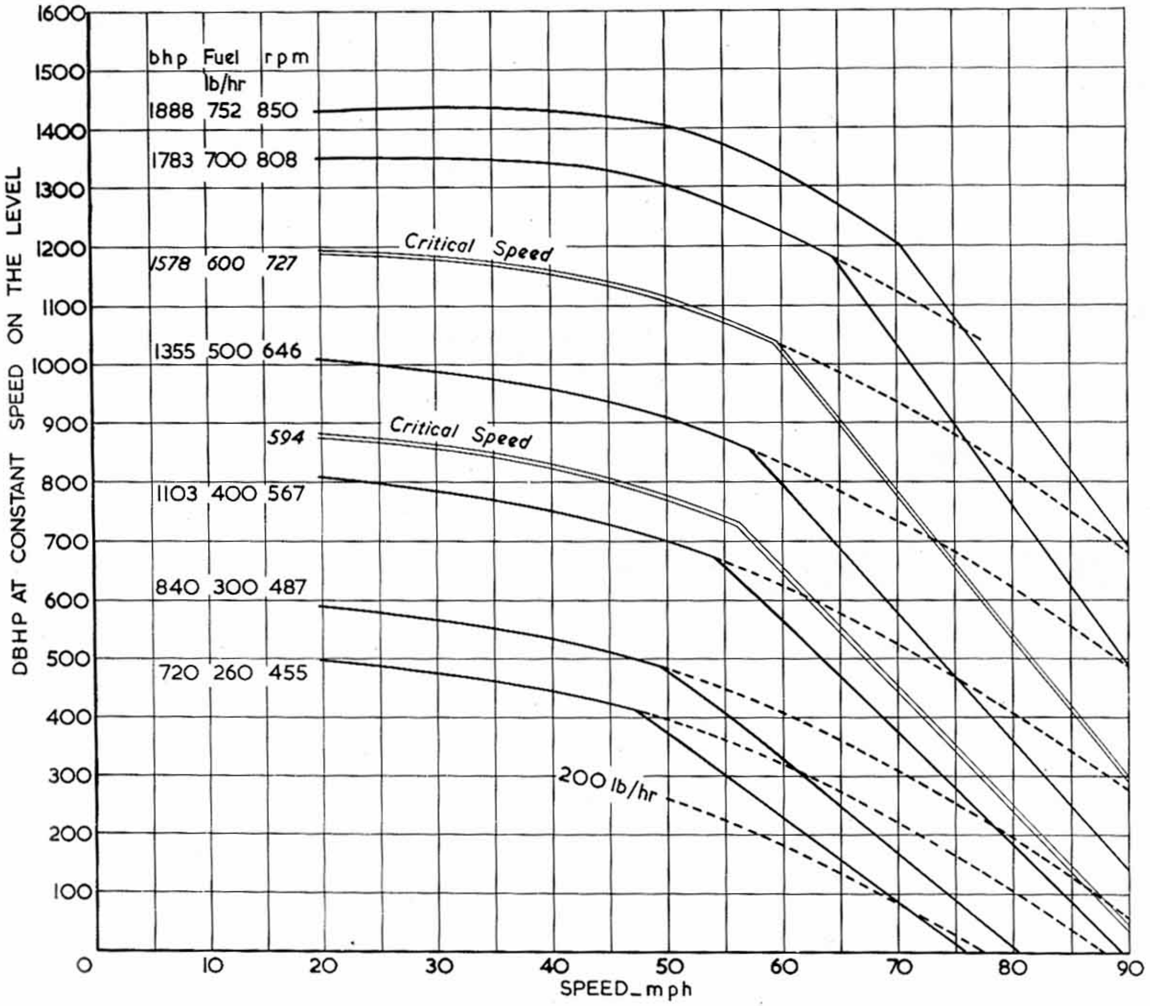
2 Top full line – max power max eng r p m
Bottom full line – max power min eng r p m
For lighter duties, power is available, at min eng r p m, below that shown by bottom full line

3 Powers between top and bottom full lines are infinitely variable by movement of controller, but the engine is automatically prevented from working at the two critical speeds shown

4 Temporary fluctuations of power at the field changes have been disregarded in this diagram

5 Full lines are lines of constant controller position, fuel rate, b h p and r p m up to the unloading point
From this point the lower branch represents the same r p m with reducing fuel rate and power, controller position unchanged; the upper branch (dotted) represents the continuation of the constant power and fuel rate which may be obtained by changing the controller position to increase r p m

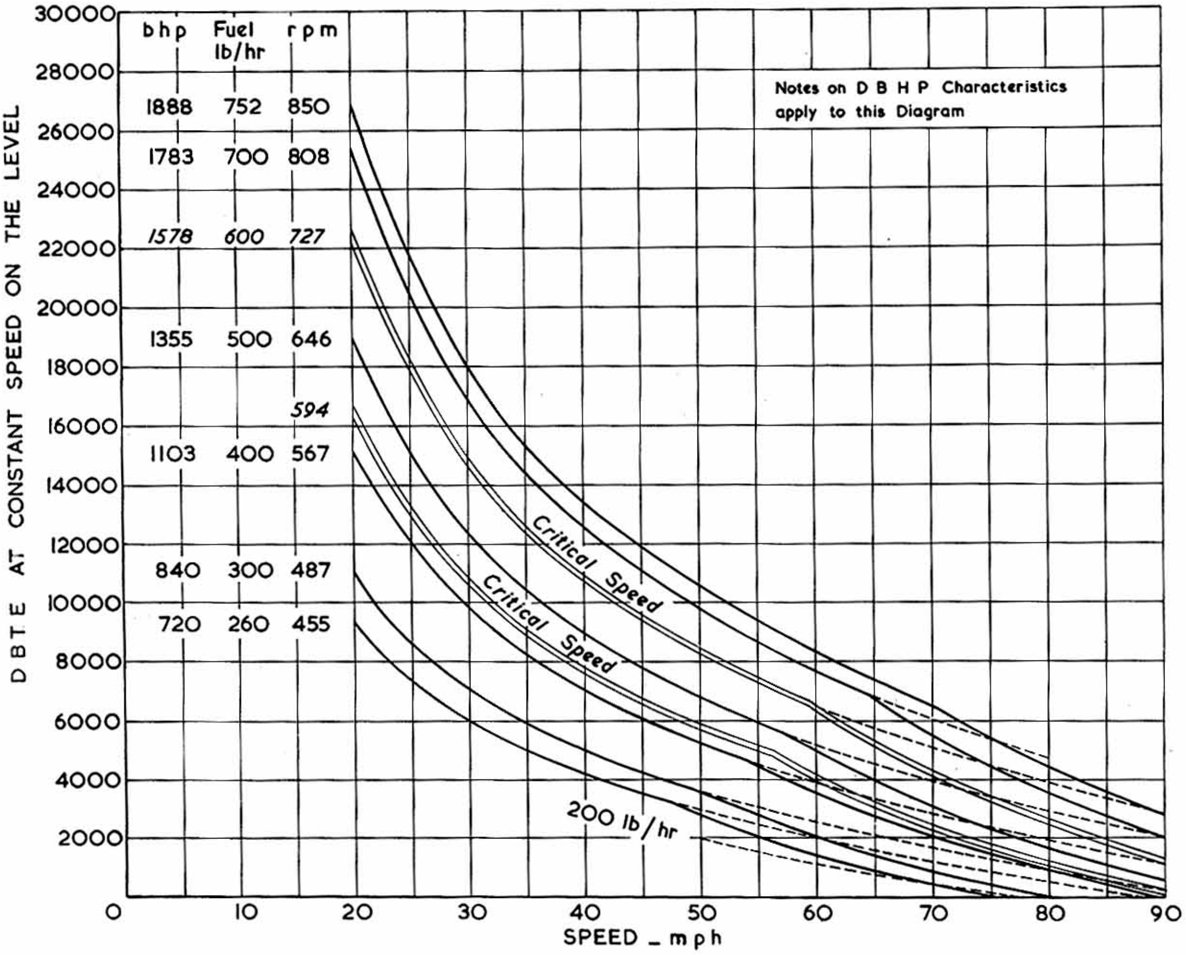
6 Bhp and fuel rate are inclusive of all auxiliaries except train heating



EQUIVALENT DBHP CHARACTERISTICS

(Drawbar H P at constant speed on the level)

DE 2000/10203/55

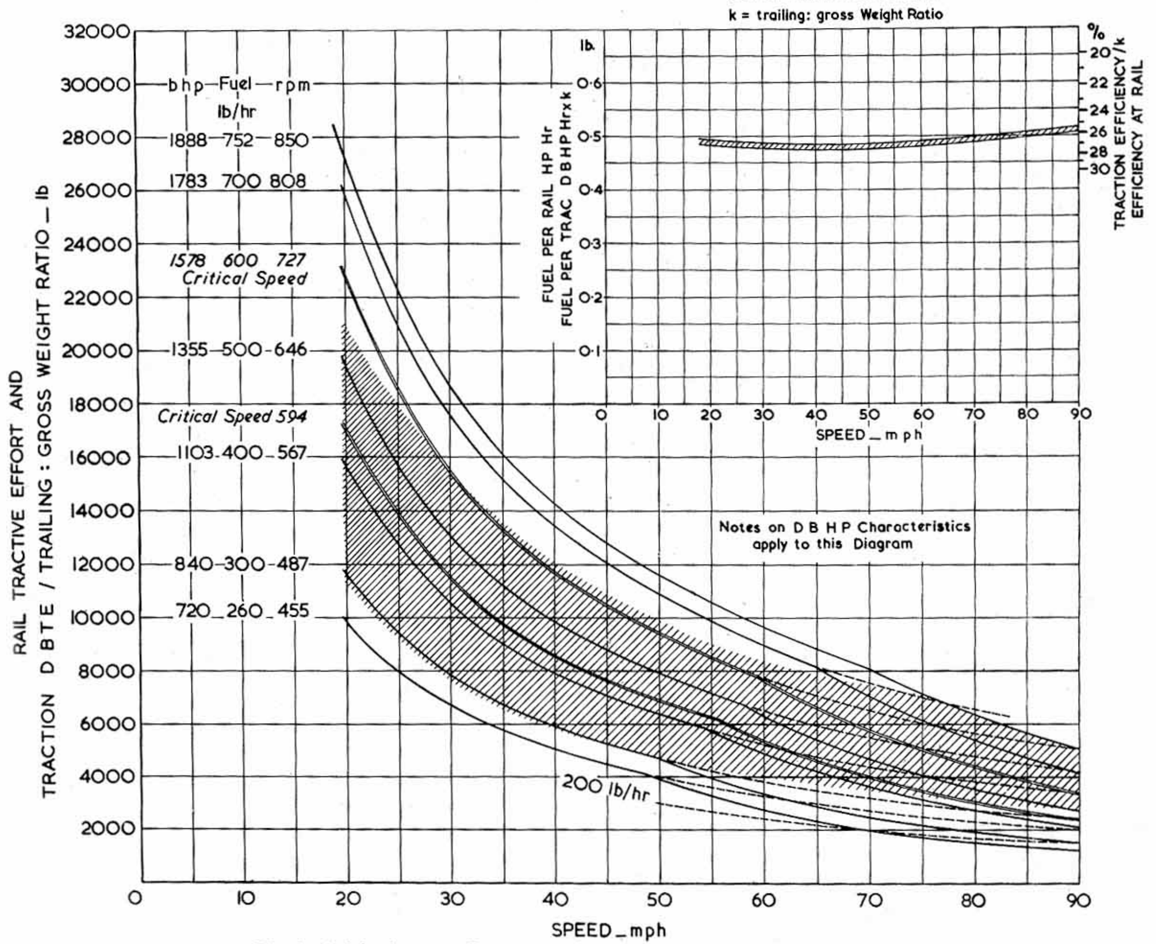


EQUIVALENT D B T E CHARACTERISTICS

(Drawbar T E at constant speed on the level)

DE 2000 / 10203 / 55

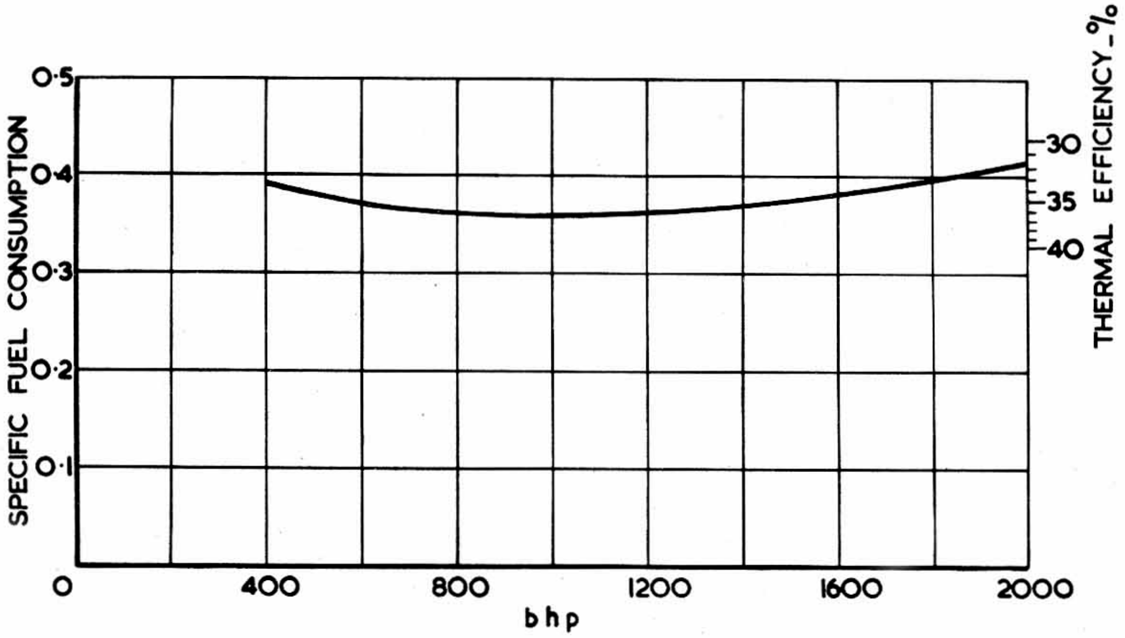
As identity (assumed limited to Loco. No. 10203) was found in Rail Tractive Effort and Traction Tractive Effort / Trailing: gross weight ratio, the characteristics of both may be represented by the one diagram, as below

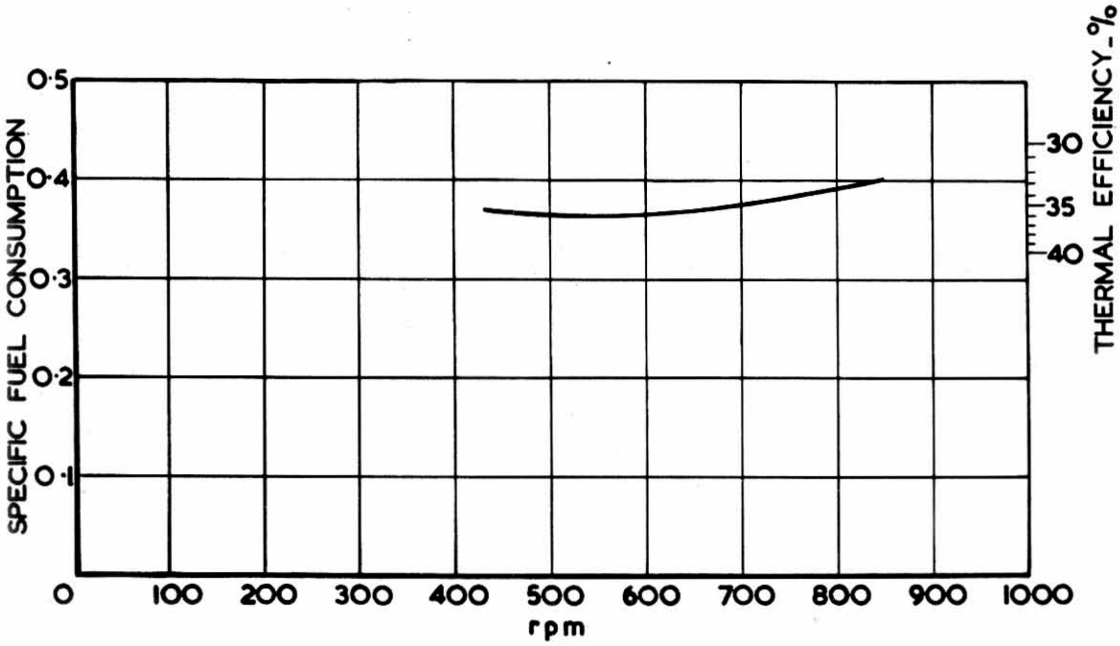


The hatched band covers all rates of working for which traction efficiency / trailing : gross weight ratio and efficiency at the rail is within 2% of the maximum as shown in inset diagram

CHARACTERISTICS OF TRACTION D B T E / TRAILING : GROSS WEIGHT RATIO AND OF RAIL TRACTIVE EFFORT

D E 2000/10203/55

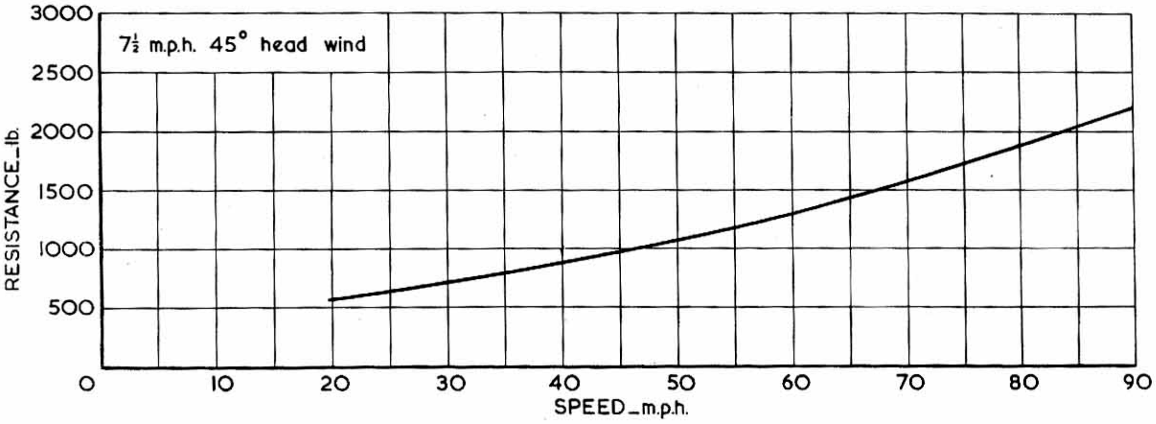




DIESEL ENGINE CHARACTERISTICS

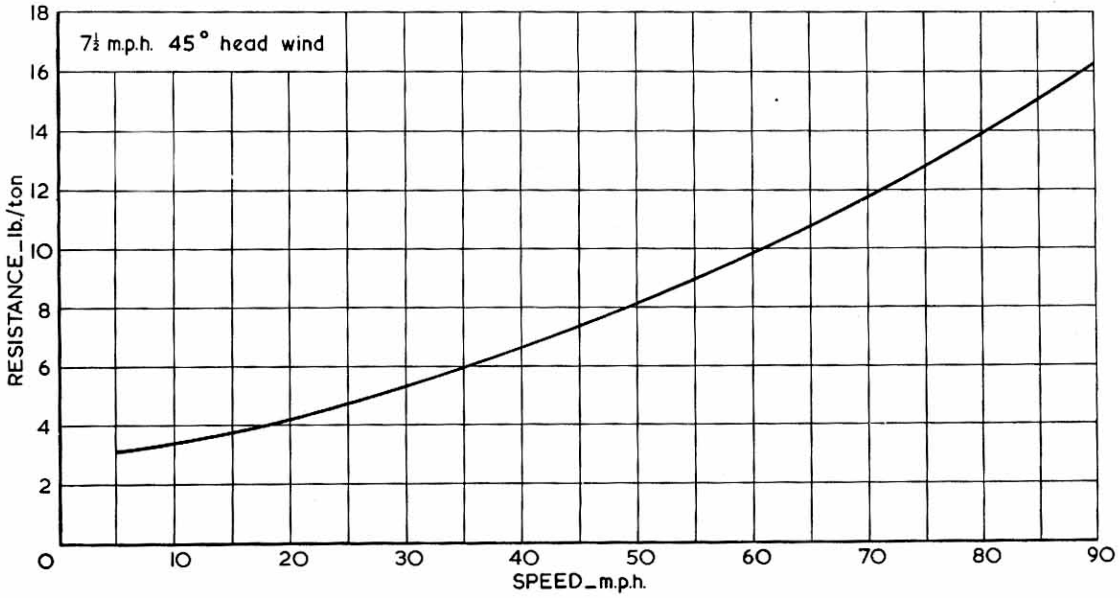
After 106000 miles 2865 hours

D E 2000/10203/55



TOTAL WIND & TRACK RESISTANCE OF LOCOMOTIVE

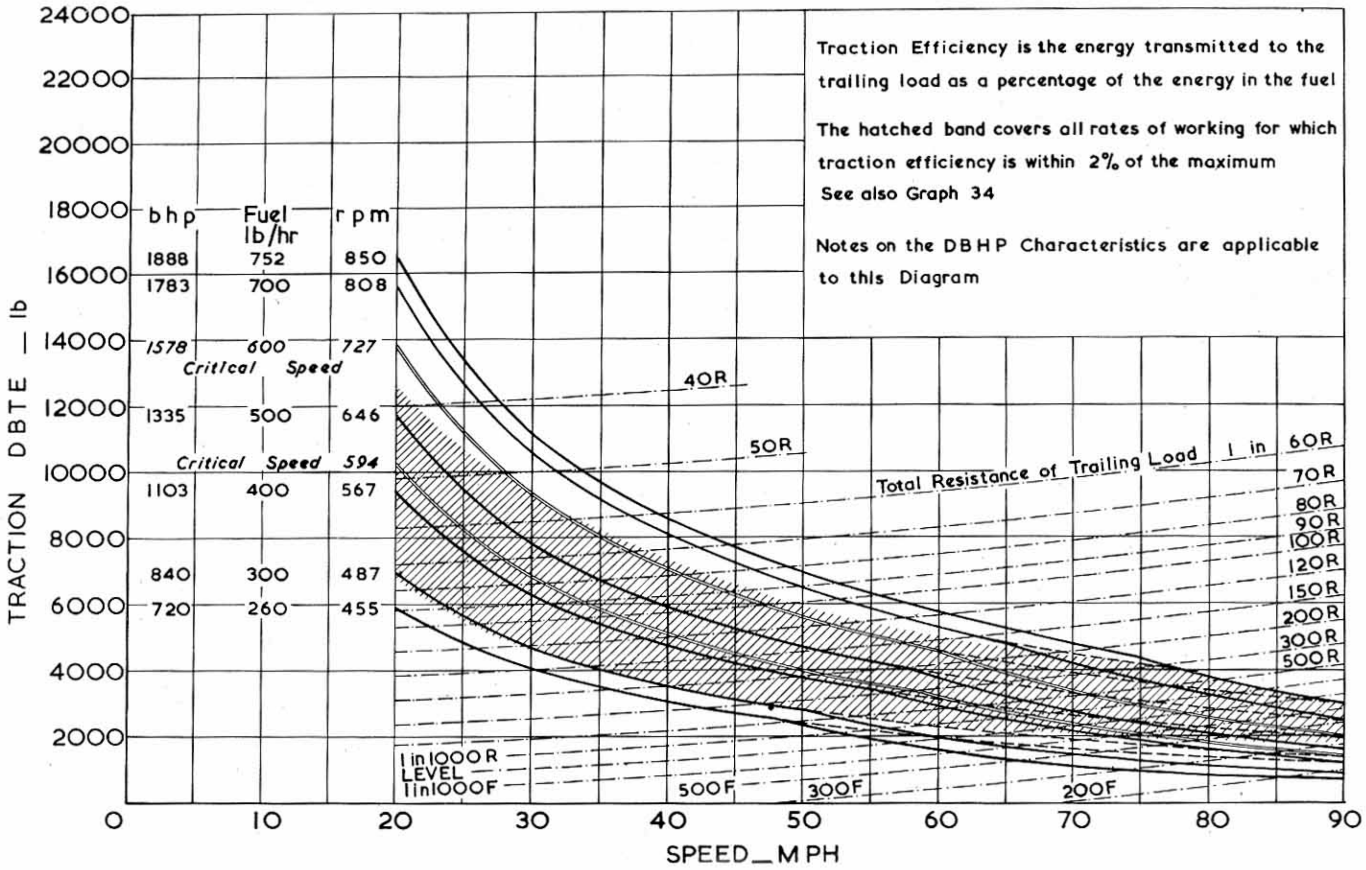
28



SPECIFIC RESISTANCE OF COACHING STOCK

D.E. 2000/10203/55.

29



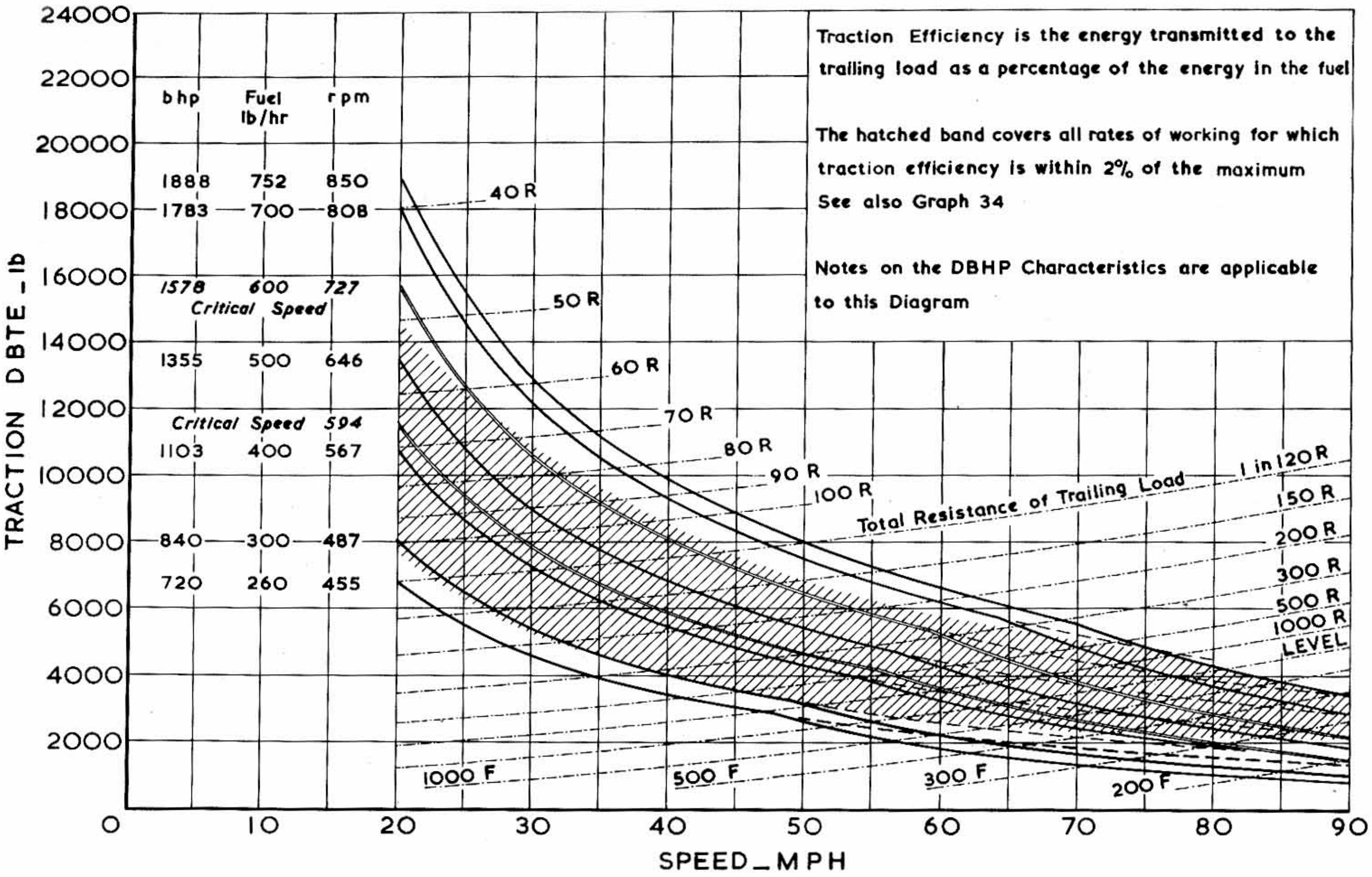
Traction Efficiency is the energy transmitted to the trailing load as a percentage of the energy in the fuel

The hatched band covers all rates of working for which traction efficiency is within 2% of the maximum
See also Graph 34

Notes on the DBHP Characteristics are applicable to this Diagram

PERFORMANCE & TRACTION EFFICIENCY
200 TONS PASSENGER TRAIN

DE 2000/10203/55



Traction Efficiency is the energy transmitted to the trailing load as a percentage of the energy in the fuel

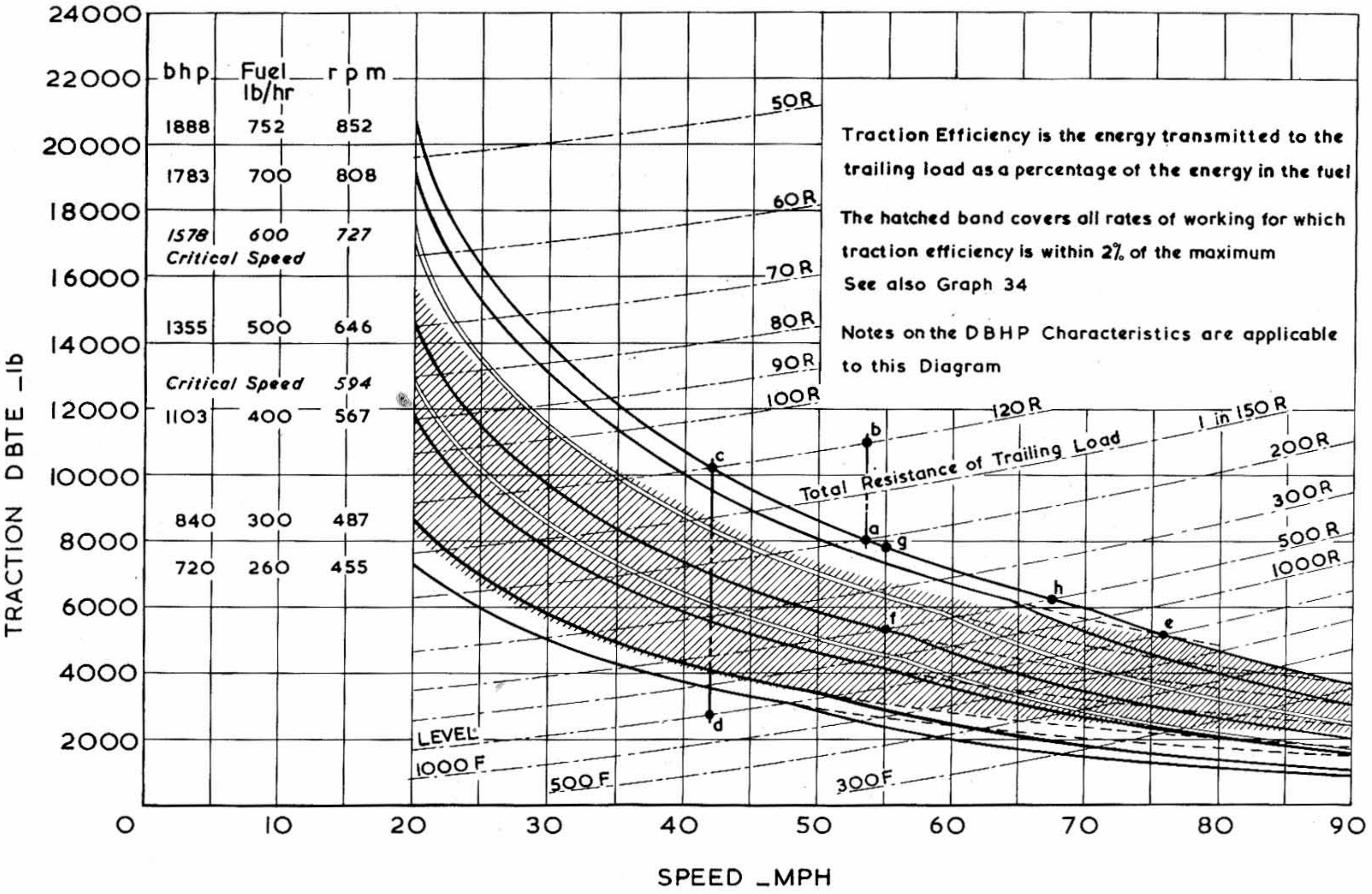
The hatched band covers all rates of working for which traction efficiency is within 2% of the maximum
See also Graph 34

Notes on the DBHP Characteristics are applicable to this Diagram

PERFORMANCE & TRACTION EFFICIENCY
300 TONS PASSENGER TRAIN

31

DE 2000/10203/55



Traction Efficiency is the energy transmitted to the trailing load as a percentage of the energy in the fuel

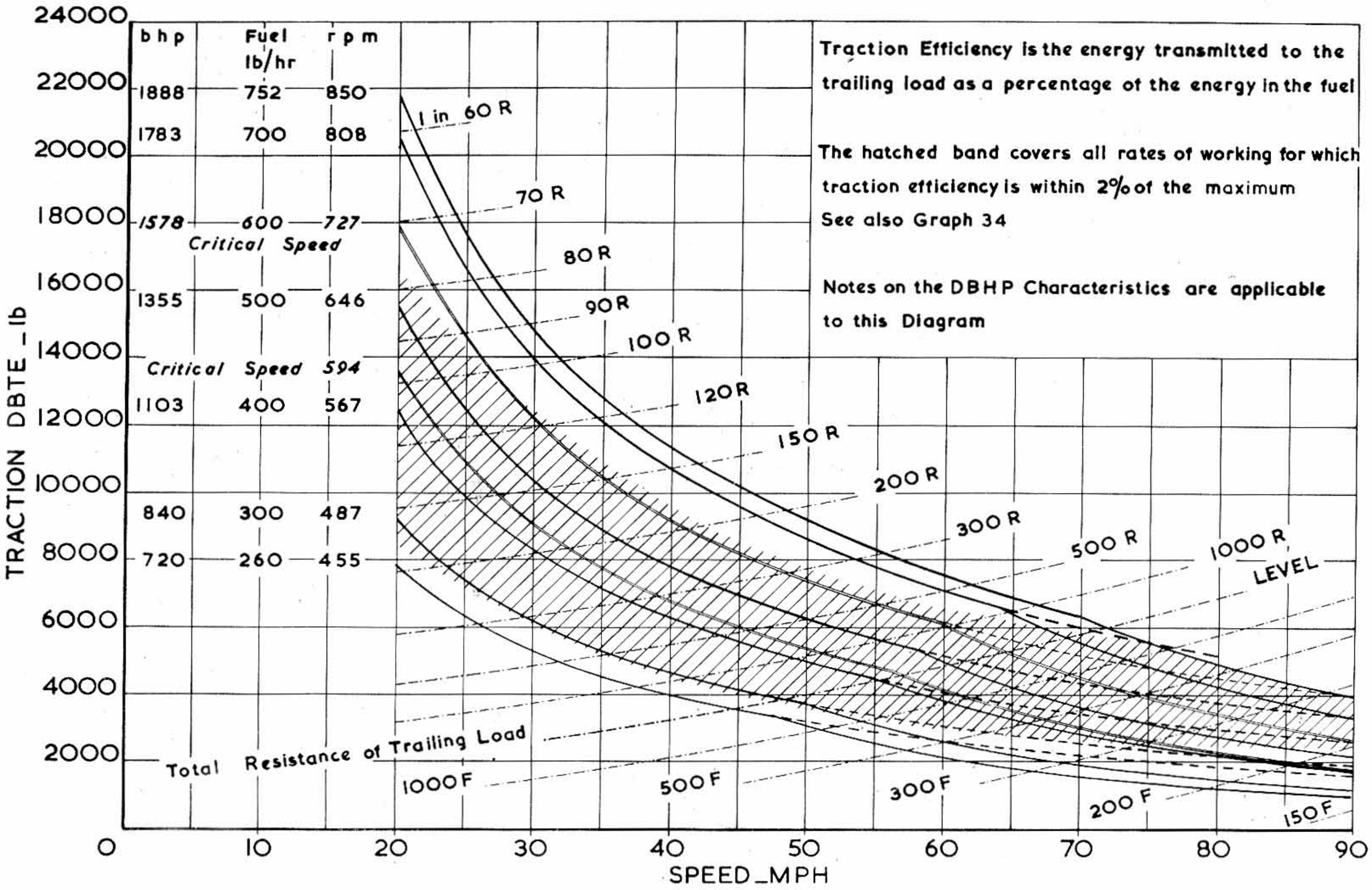
The hatched band covers all rates of working for which traction efficiency is within 2% of the maximum
See also Graph 34

Notes on the DBHP Characteristics are applicable to this Diagram

32

PERFORMANCE & TRACTION EFFICIENCY
400 TONS PASSENGER TRAIN

D E 2000/10203/55



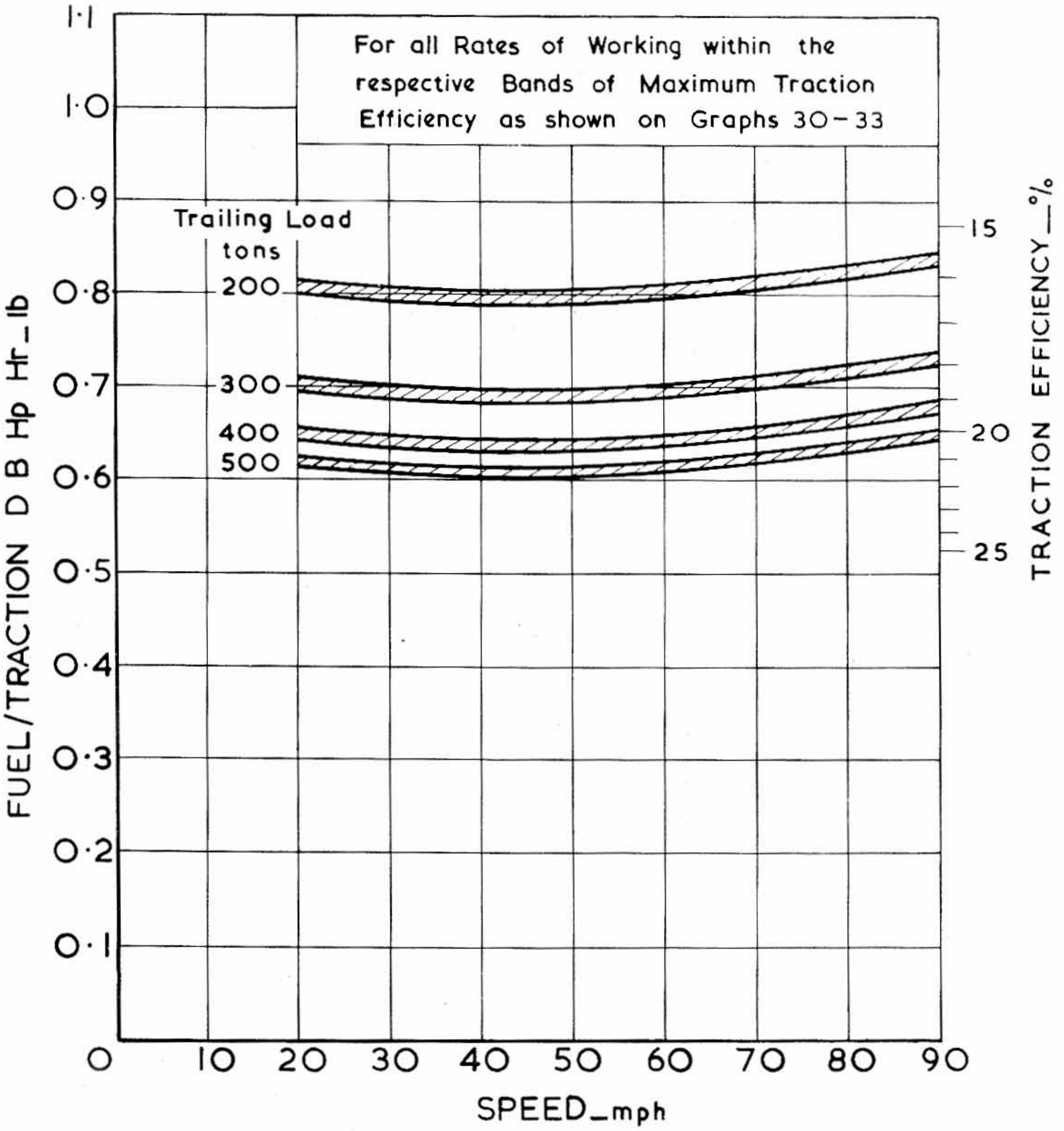
Traction Efficiency is the energy transmitted to the trailing load as a percentage of the energy in the fuel

The hatched band covers all rates of working for which traction efficiency is within 2% of the maximum
See also Graph 34

Notes on the DBHP Characteristics are applicable to this Diagram

PERFORMANCE & TRACTION EFFICIENCY
500 TONS PASSENGER TRAIN

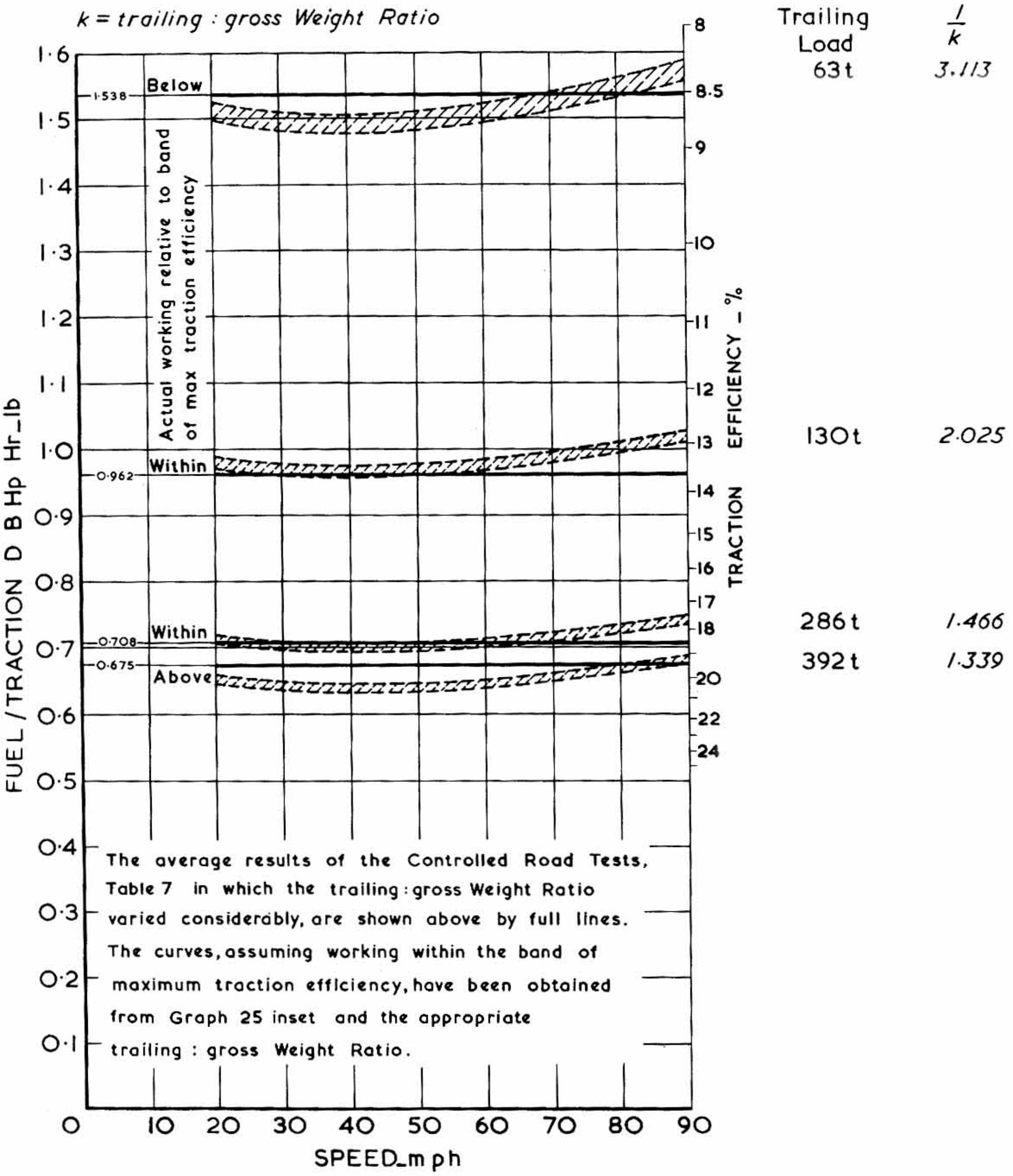
DE 2000/10203/55



Fuel Rates inclusive of Auxiliaries

MAXIMUM TRACTION EFFICIENCY
FOR VARIOUS LOADS

D E 2000/10203/55



The average results of the Controlled Road Tests, Table 7 in which the trailing : gross Weight Ratio varied considerably, are shown above by full lines. The curves, assuming working within the band of maximum traction efficiency, have been obtained from Graph 25 inset and the appropriate trailing : gross Weight Ratio.

SHOWING THE PREDOMINATING INFLUENCE OF THE TRAILING : GROSS WEIGHT RATIO ON TRACTION EFFICIENCY

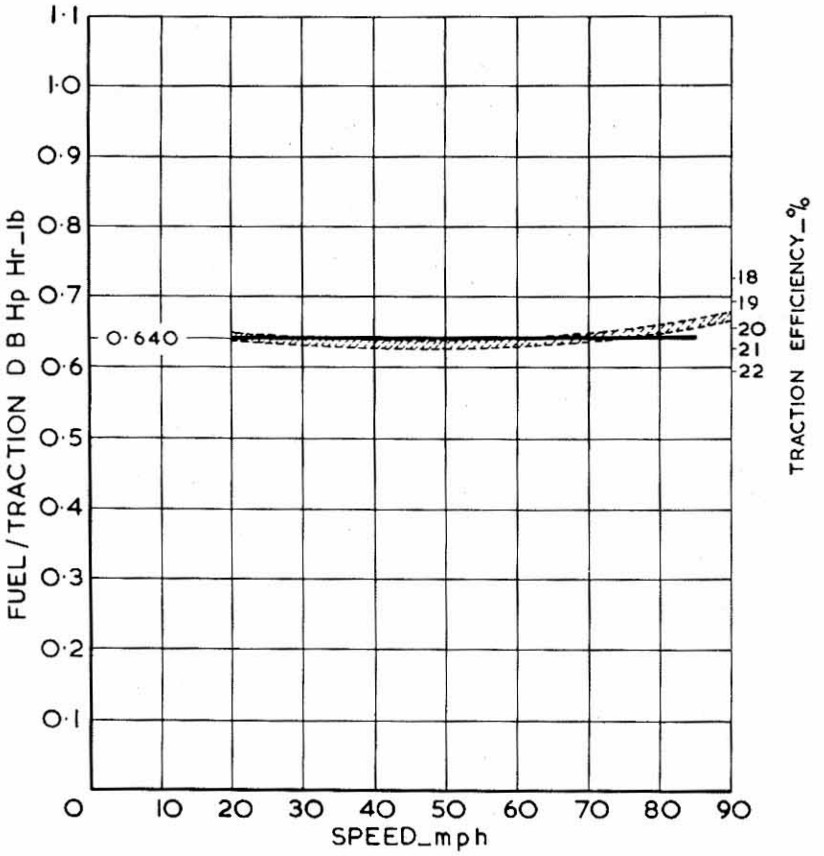
DE 2000/10203/55

35

DOWN TRAIN, 5-7-55, WATERLOO – TEMPLECOMBE SECTION

LOAD 425 TONS

The horizontal full line on this diagram, representing the test results, is positioned by the information in Table 5 . Column 2 . Line 27. The curve is a reproduction of Graph 25 inset in which efficiency is scaled down in the ratio of 425 : 558 ; it assumes all working to be within the band of maximum traction efficiency.



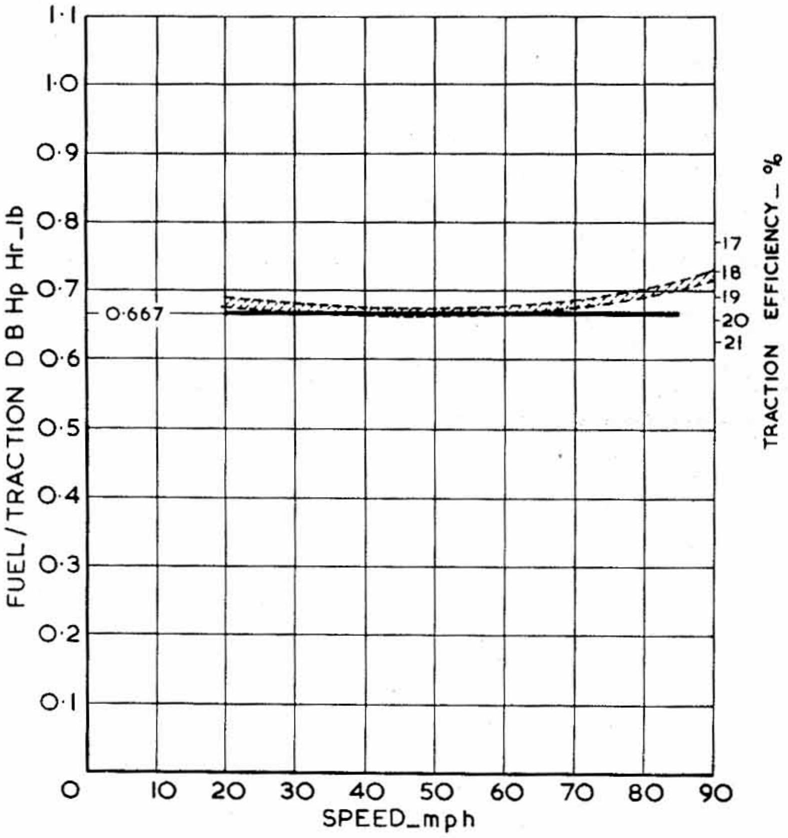
RESULTS OF A TEST ON A REVENUE EARNING TRAIN REFERRED TO THE TRACTION EFFICIENCY CHARACTERISTICS DERIVED FROM THE CONTROLLED ROAD TESTS, GRAPH 25

D.E. 2000/10203/55

DOWN TRAIN, 5-7-55, TEMPLECOMBE— EXETER SECTION

LOAD 329 TONS

The horizontal full line on this diagram, representing the test results, is positioned by the information in Table 5 . Column 3 . Line 27. The curve is a reproduction of Graph 25 inset in which efficiency is scaled down in the ratio of 329 : 462 ; it assumes all working to be within the band of maximum traction efficiency.



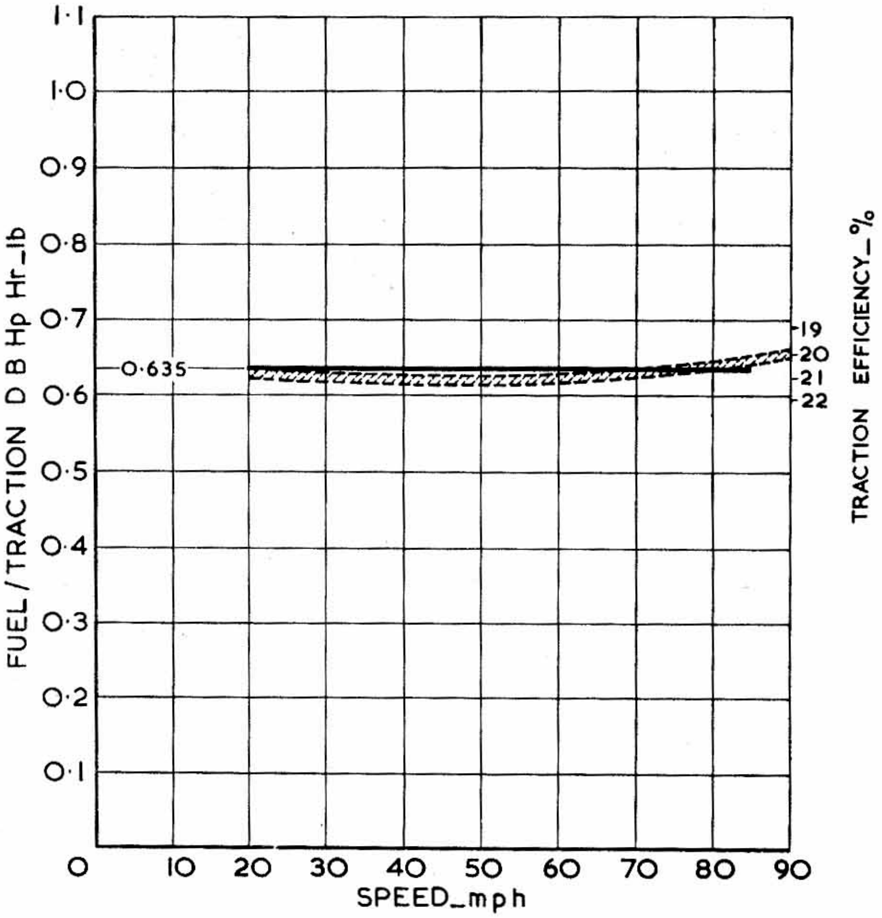
RESULTS OF A TEST ON A REVENUE EARNING TRAIN REFERRED TO THE TRACTION EFFICIENCY CHARACTERISTICS DERIVED FROM THE CONTROLLED ROAD TESTS, GRAPH 25

D.E. 2000/10203/55

DOWN TRAIN, 7-7-55, WATERLOO — TEMPLECOMBE SECTION

LOAD 464 TONS

The horizontal full line on this diagram, representing the test results, is positioned by the information in Table 5 . Column 5 . Line 27. The curve is a reproduction of Graph 25 inset in which efficiency is scaled down in the ratio of 464 : 597 ; it assumes all working to be within the band of maximum traction efficiency.

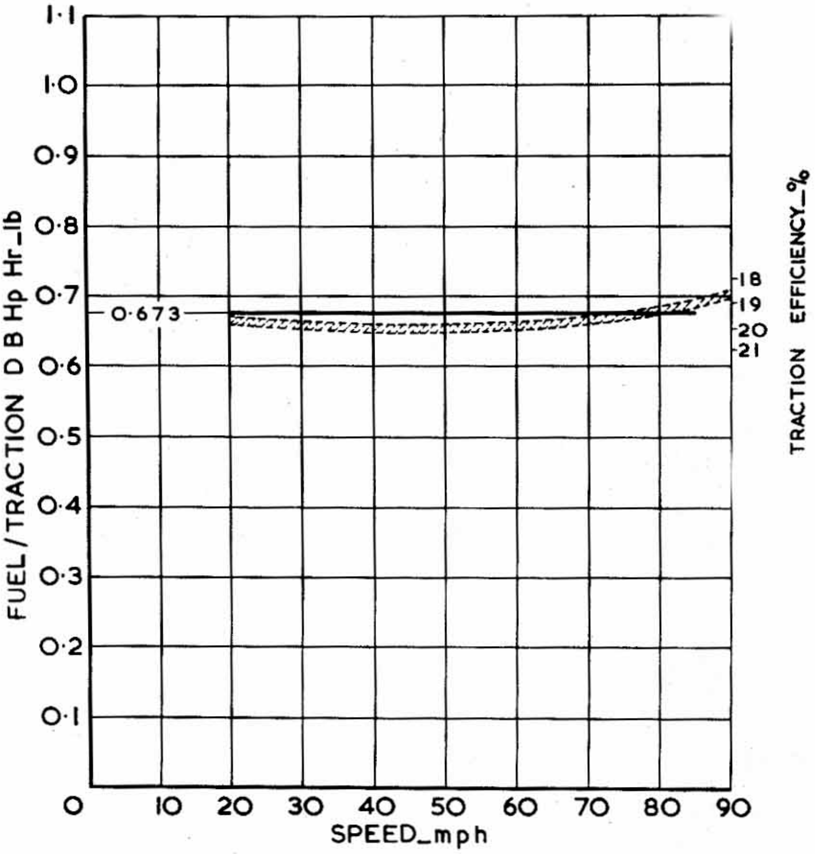


RESULTS OF A TEST ON A REVENUE EARNING TRAIN REFERRED TO THE TRACTION EFFICIENCY CHARACTERISTICS DERIVED FROM THE CONTROLLED ROAD TESTS, GRAPH 25

D.E. 2000/10203/55

DOWN TRAIN, 7-7-55, TEMPLECOMBE – EXETER SECTION
LOAD 367 TONS

The horizontal full line on this diagram, representing the test results, is positioned by the information in Table 5 Column 6 . Line 27. The curve is a reproduction of Graph 25 inset in which efficiency is scaled down in the ratio of 367 : 500 ; it assumes all working to be within the band of maximum traction efficiency.



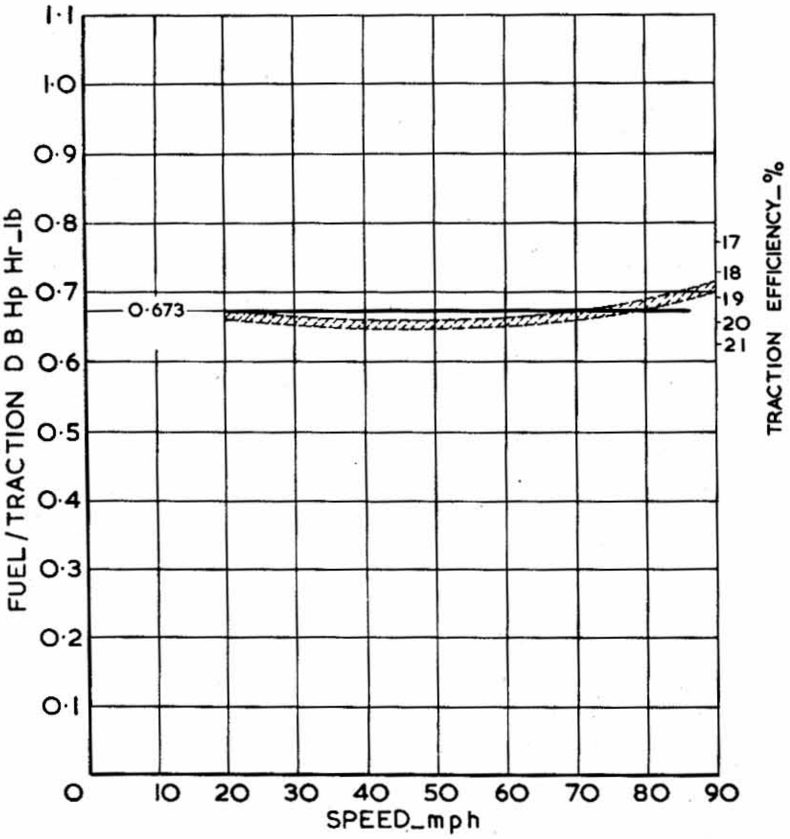
RESULTS OF A TEST ON A REVENUE EARNING TRAIN REFERRED TO THE TRACTION EFFICIENCY CHARACTERISTICS DERIVED FROM THE CONTROLLED ROAD TESTS, GRAPH 25

D.E. 2000/10203/55

UP TRAIN, 4-7-55. EXETER — WATERLOO

LOAD 362·5 TONS

The horizontal full line on this diagram, representing the test results, is positioned by the information in Table 6 . Column I . Line 27. The curve is a reproduction of Graph 25 inset in which efficiency is scaled down in the ratio of 362·5 : 495·5 ; it assumes all working to be within the band of maximum traction efficiency.



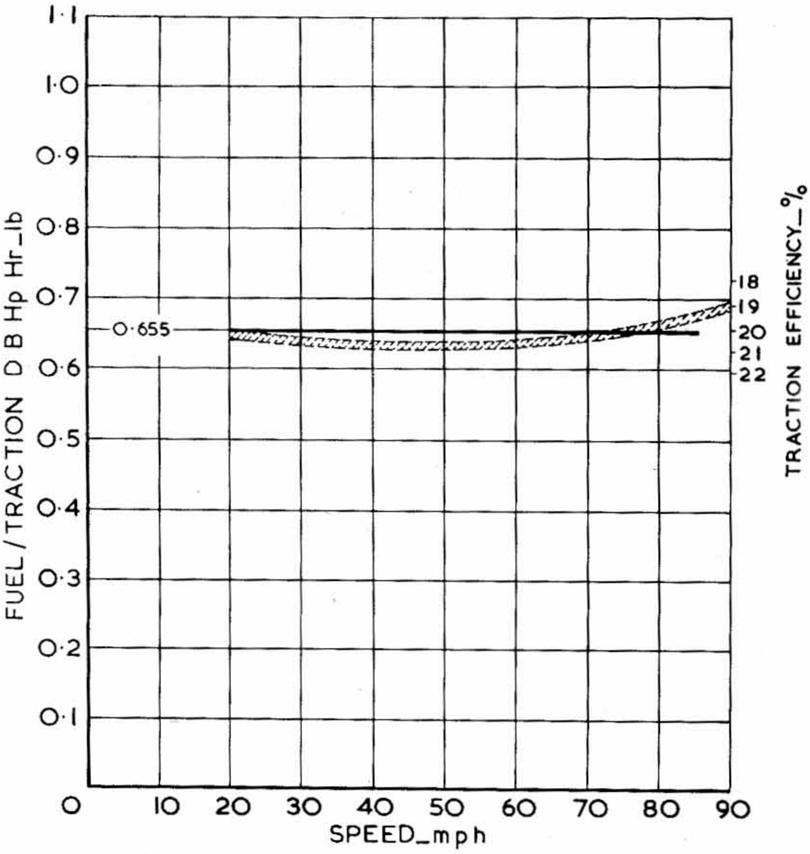
RESULTS OF A TEST ON A REVENUE EARNING TRAIN REFERRED TO THE TRACTION EFFICIENCY CHARACTERISTICS DERIVED FROM THE CONTROLLED ROAD TESTS, GRAPH 25

D.E. 2000/10203/55

UP TRAIN, 6-7-55, EXETER — WATERLOO

LOAD 407·5 TONS

The horizontal full line on this diagram, representing the test results, is positioned by the information in Table 6. Column 4. Line 27. The curve is a reproduction of Graph 25 inset in which efficiency is scaled down in the ratio of 407·5 : 540·5 ; it assumes all working to be within the band of maximum traction efficiency.



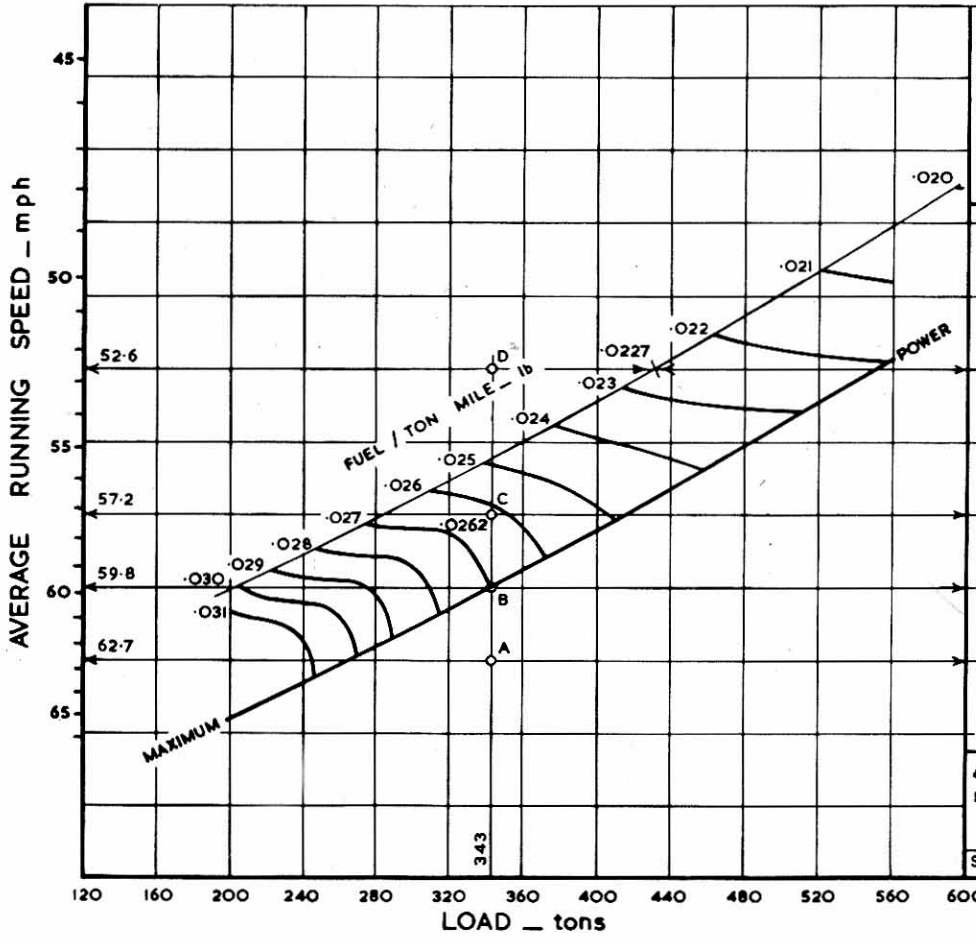
RESULTS OF A TEST ON A REVENUE EARNING TRAIN REFERRED TO THE TRACTION EFFICIENCY CHARACTERISTICS DERIVED FROM THE CONTROLLED ROAD TESTS, GRAPH 25

D.E. 2000/10203/55

BR-SR SALISBURY - EXETER PASSENGER SERVICES calling at Templecombe Sherborne & Yeovil Jcn

LOCO TYPE: 2000 hp DE

MILEAGE 87·7



TOTAL RUNNING TIMES _ MINS	SCHEDULES POINT TO POINT TIMES _ MINS				
	SALISBURY d TEMPLECOMBE a	TEMPLECOMBE d SHERBORNE a	SHERBORNE d YEOVIL JCN a	YEOVIL JCN d EXMOUTH JCN p	EXMOUTH JCN p EXETER a
108	33½	12	8	52½	2
104	32½	11	7½	51	2
100	31½	11	7	48½	2
96	30½	10	6½	47	2
92	29	9½	6½	45	2
88	27½	9	6½	43	2
84	26½	8½	6	41	2
80	25½	8	6	38½	2

a = Arrive d = Depart p = Pass

PERMANENT SPEED RESTRICTIONS
AS AT JULY 1955

SW. SYS: CAL. SW: AUTHY. BULL. 16

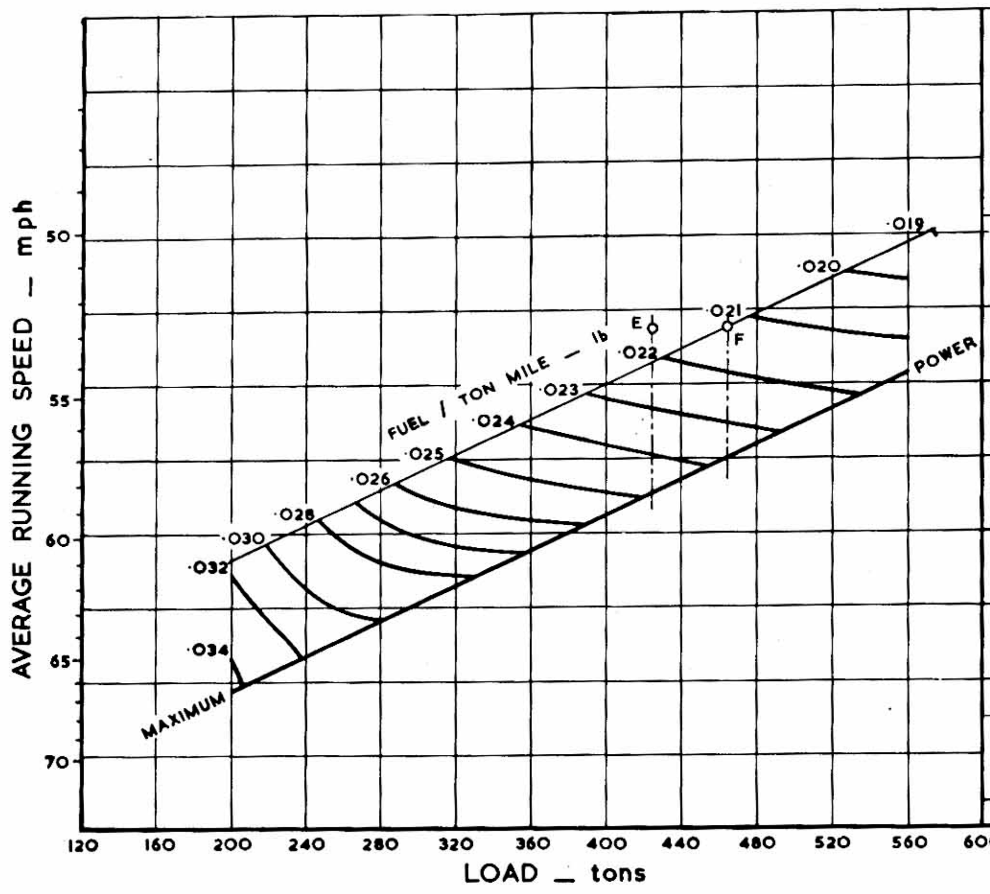
TO CONVERT LB. OIL TO GALLS
AT 60° F DIVIDE BY 8·44

COST OF ENERGY AND PERFORMANCE

DE 2000/10203/55

BR-SR WATERLOO-SALISBURY PASSENGER SERVICES calling at Woking & Andover Jct

LOCO TYPE: 2000 hp D-E MILEAGE 83·7



TOTAL RUNNING TIMES — MIN	SCHEDULES POINT TO POINT TIMES — MIN						
	WATERLOO d CLAPHAM JCN p	CLAPHAM JCN p HAMPTON CT J p	HAMPTON CT J p WOKING a	WOKING d WORTING JCN p	WORTING JCN p ANDOVER JCN a	ANDOVER JCN d TUNNEL JCN p	TUNNEL JCN p SALISBURY a
100	7	11	11	31	16	21½	2½
96	7	10½	10½	29½	15½	20½	2½
92	6½	10½	10	28	14½	20	2½
88	6½	10	10	26½	14	18½	2½
84	6	9½	10	25	13½	17½	2½
80	6	9½	9½	23½	13	16	2½
76	5½	9½	9	21½	13	15	2½

a = Arrive d = Depart p = Pass

PERMANENT SPEED RESTRICTIONS
AS AT JULY 1955

SW. SYS: CAL. SW: AUTHY. BULL. 16

TO CONVERT LB OIL TO GALLS
AT 60°F DIVIDE BY 8·44

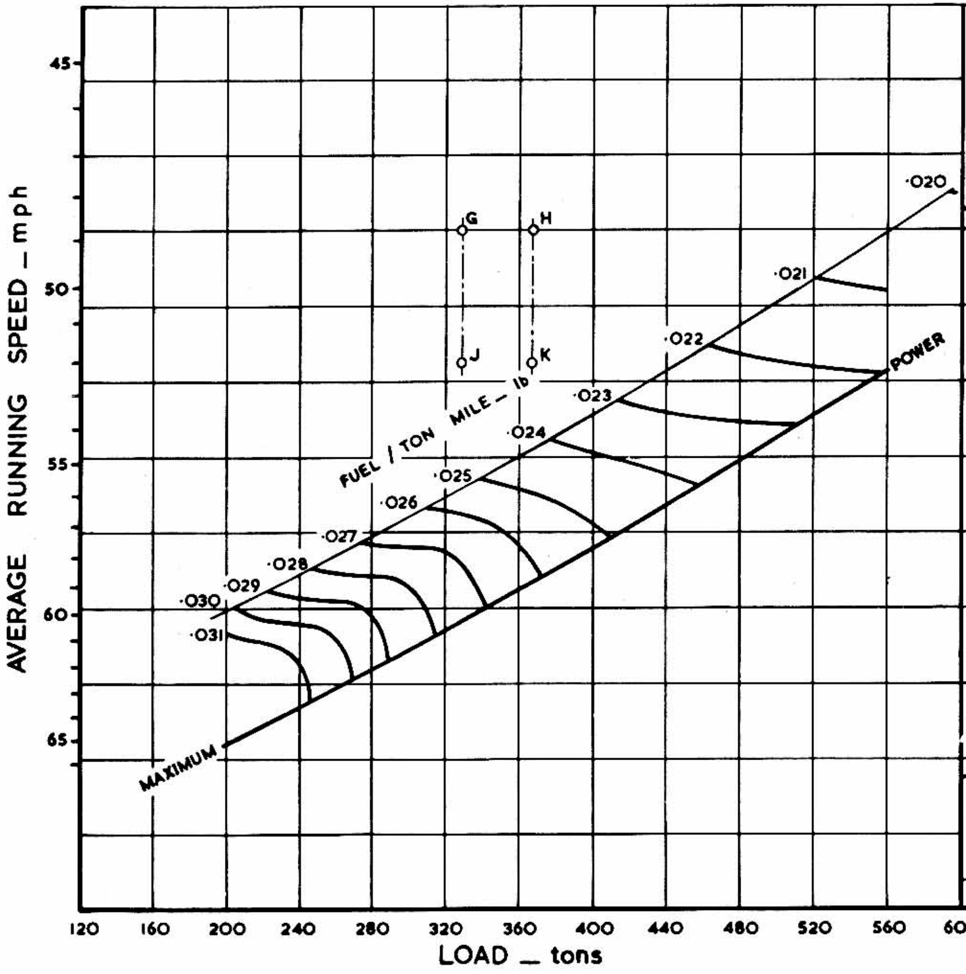
COST OF ENERGY AND PERFORMANCE

DE 2000/10203/55

BR-SR SALISBURY - EXETER PASSENGER SERVICES calling at Templecombe Sherborne & Yeovil Jcn

LOCO TYPE: 2000 hp DE

MILEAGE 87·7



TOTAL RUNNING TIMES _ MINS	SALISBURY d TEMPLECOMBE a	TEMPLECOMBE d SHERBORNE a	SHERBORNE d YEOVIL JCN a	YEOVIL JCN d EXMOUTH JCN p	EXMOUTH JCN p EXETER a
	SCHEDULES POINT TO POINT TIMES _ MINS				
108	33½	12	8	52½	2
104	32½	11	7½	51	2
100	31½	11	7	48½	2
96	30½	10	6½	47	2
92	29	9½	6½	45	2
88	27½	9	6½	43	2
84	26½	8½	6	41	2
80	25½	8	6	38½	2

a = Arrive d = Depart p = Pass

PERMANENT SPEED RESTRICTIONS AS AT JULY 1955

SW. SYS: CAL. SW: AUTHY. BULL. 16

TO CONVERT LB. OIL TO GALLS AT 60° F DIVIDE BY 8·44

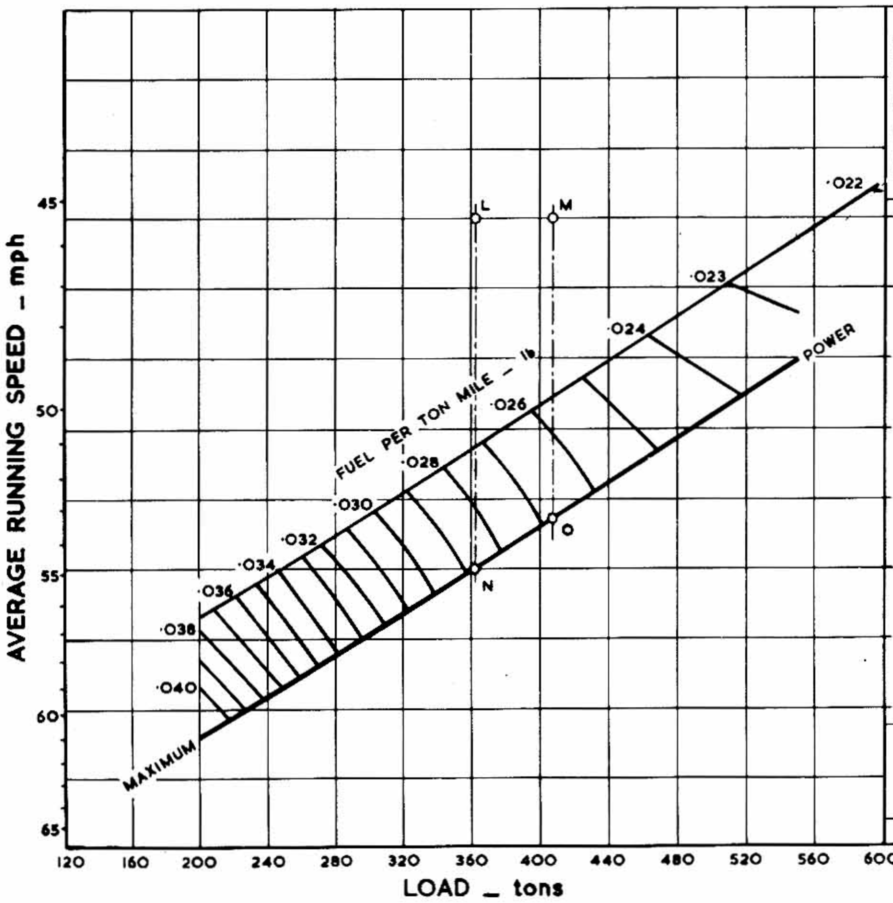
COST OF ENERGY AND PERFORMANCE

DE 2000/10203/55

BR – SR EXETER – SALISBURY PASSENGER SERVICES

calling at Sidmouth Jcn Seaton Jcn Axminster Yeovil & Templecombe

LOCO TYPE: 2000hp D-E MILEAGE 87·7



TOTAL RUNNING TIMES _ MIN	SCHEDULES POINT TO POINT TIMES _ MIN					
	EXETER d SIDMOUTH JCN a	SIDMOUTH JCN d SEATON JCN a	SEATON JCN d AXMINSTER a	AXMINSTER d YEOVIL JCN a	YEOVIL JCN d TEMPLECOMBE a	TEMPLECOMBE d SALISBURY a
116	17½	17½	5½	27	16	32½
112	16½	16½	5½	26½	15½	31½
108	16	16	5½	25½	14½	30½
104	15½	15½	5	24½	14	29½
100	14½	15	5	23½	13½	28½
96	14	14	5	22½	13	27½
92	13½	13½	4½	21½	12	27
88	12½	13	4½	20½	11½	26

a = Arrive d = Depart

PERMANENT SPEED RESTRICTIONS
AS AT JULY 1955

SW. SYS: CAL. SW: AUTHY. BULL. 16

TO CONVERT LB OIL TO GALLS
AT 60°F DIVIDE BY 8·44

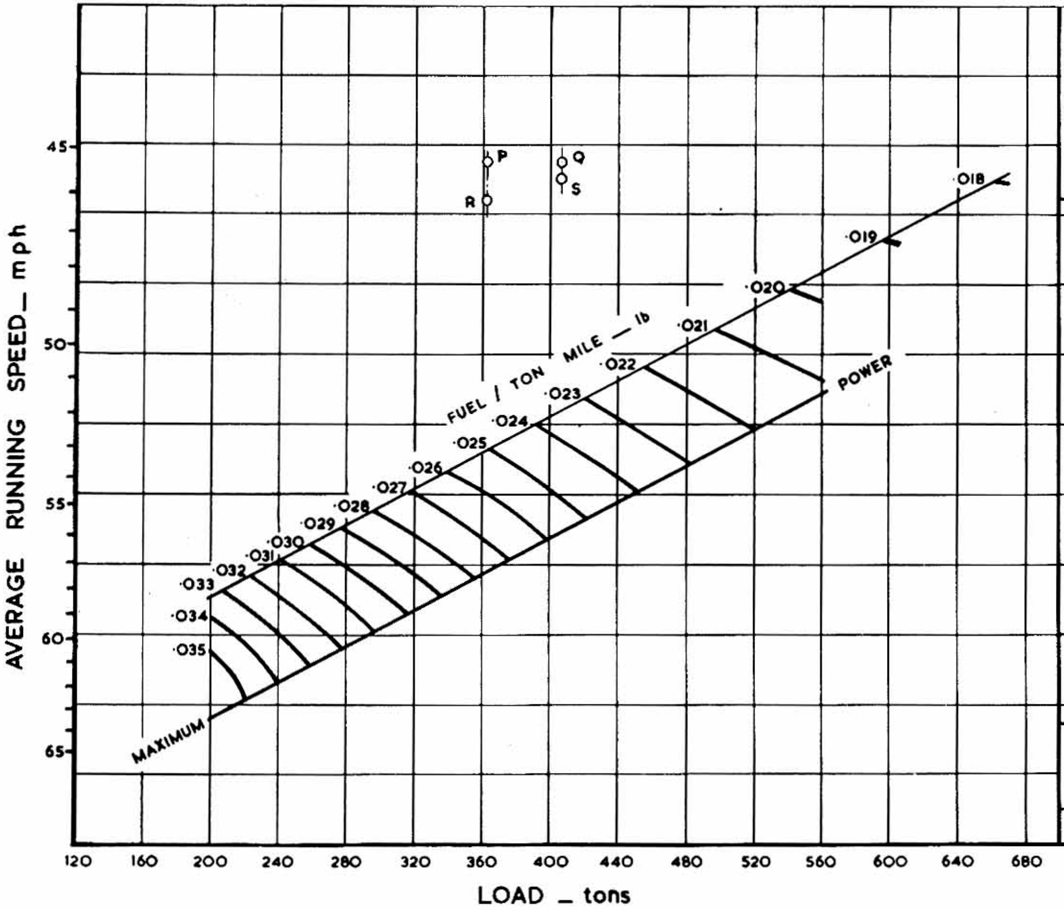
COST OF ENERGY AND PERFORMANCE

DE 2000/10203/55

BR-SR SALISBURY - WATERLOO PASSENGER SERVICES calling at Andover Basingstoke Woking & Surbiton

LOCO TYPE: 2000 hp DE

MILEAGE 83·7



TOTAL RUNNING TIMES _ MINS	SCHEDULES POINT TO POINT TIMES _ MINS						
	SALISBURY d ANDOVER JCN a	ANDOVER JCN d WORTING JCN p	WORTING JCN p BASINGSTOKE a	BASINGSTOKE d WOKING a	WOKING d SURBITON a	SURBITON d CLAPHAM JCN p	CLAPHAM JCN p WATERLOO a
108	26	21½	3½	25½	15	11½	5
104	24½	21	3	24½	14½	11½	5
100	23	20	3	23½	14	11½	5
96	22	19	3	22½	13½	11	5
92	21	17½	3	21½	13	11	5
88	19½	16½	2½	21	12½	11	5
84	18½	15½	2½	20	12	10½	5
80	17½	14	2½	19½	11½	10	5

a = Arrive d = Depart p = Pass

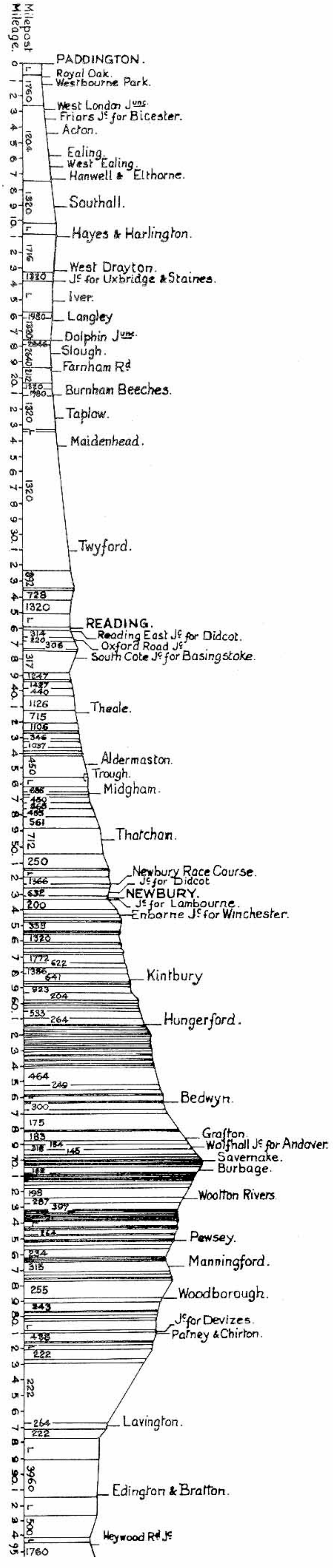
PERMANENT SPEED RESTRICTIONS
AS AT JULY 1955

SW. SYS. : CAL. SW. : AUTHY. BULL. 16.

TO CONVERT LB OIL TO GALLS
AT 60°F DIVIDE BY 8·44

COST OF ENERGY AND PERFORMANCE

DE 2000/10203/55



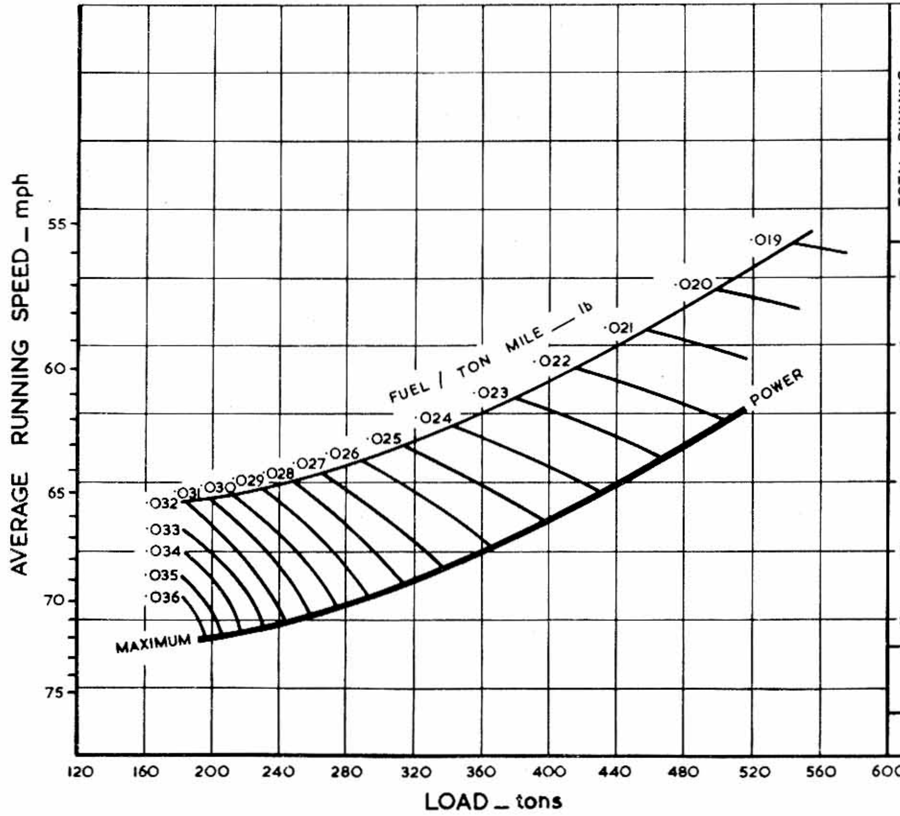
Milepost Mileage.
PADDINGTON.
Royal Oak.
Westbourne Park.
West London Jns.
Friars Jc for Bicester.
Acton.
Ealing.
West Ealing.
Hanwell & Elthorne.
Southall.
Hayes & Harlington.
West Drayton.
Jc for Uxbridge & Staines.
Iver.
Langley
Dolphin Jns.
Slough.
Farnham Rd.
Burnham Beeches.
Taplow.
Maidenhead.
Twyford.
READING.
Reading East Jc for Didcot.
Oxford Road Jc.
South Cote Jc for Basingstoke.
Theale.
Aldermaston.
Trough.
Midgham.
Thatcham.
Newbury Race Course.
Jc for Didcot
NEWBURY.
Jc for Lambourne.
Enborne Jc for Winchester.
Kintbury
Hungerford.
Bedwyn.
Grafton.
Wolfhall Jc for Andover.
Savernake.
Burbage.
Wootton Rivers.
Pewsey.
Manningford.
Woodborough.
Jc for Devizes.
Patney & Chirton.
Lavington.
Edington & Bratton.
Heywood Rd Jc.
L
1760
1804
1320
1716
1980
2640
2112
728
314
820
306
317
1247
440
1126
715
1106
346
1037
450
561
712
250
1366
632
200
1772
622
1386
641
923
204
533
264
464
249
300
175
183
318
184
145
198
287
397
315
255
343
438
222
3960
500

BR_WESTERN REGION – PADDINGTON – NEWTON ABBOT NON-STOP PASSENGER SERVICES

PADDINGTON – HEYWOOD ROAD SECTION

LOCO TYPE : 2000 hp DE

MILEAGE 94·6



SCHEDULES

POINT TO POINT TIMES _ MINS

TOTAL RUNNING TIMES _ MINS	PADDINGTON d WESTBOURNE PK. p	WESTBOURNE PK. p SOUTHALL p	SOUTHALL p SLOUGH p	SLOUGH p MAIDENHEAD p	MAIDENHEAD p TWYFORD p	TWYFORD p READING p	READING p NEWBURY p	NEWBURY p BEDWYN p	BEDWYN p SAVERNAKE p	SAVERNAKE p PATNEY p	PATNEY p HEYWOOD Rd. Jcn. p
100	5	9½	9	5½	6½	5	19	15	4½	10½	10½
96	4½	9	8½	5½	6½	5	18½	14	4½	10	10
92	4½	8½	8	5	6	5	18	13	4½	9½	10
88	4½	8	7½	5	5½	4½	17½	12½	4	9	10
84	4½	7½	7	4½	5½	4	17	12	4	8½	9½
80	4	7	6½	4	5	4	16½	11½	4	8	9½

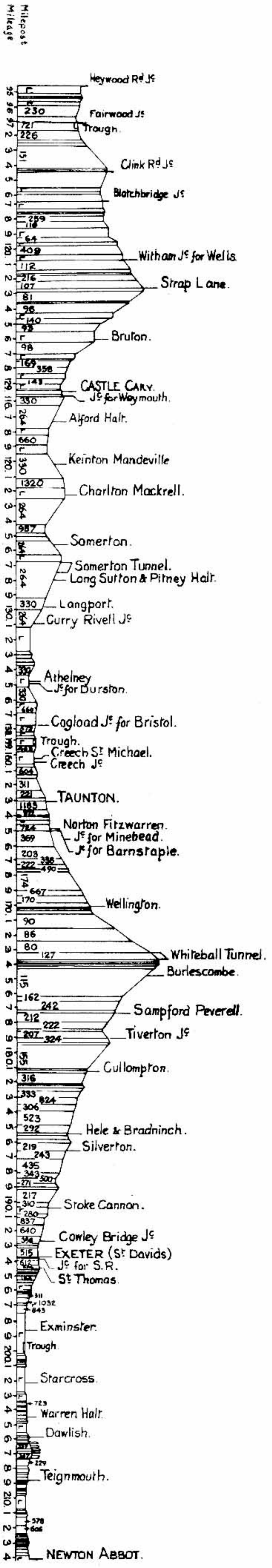
d = Depart p = Pass

PERMANENT SPEED RESTRICTIONS AS AT JULY 1955

SW. SYS. : CAL. SW. : AUTHY. BULL. 16.

TO CONVERT LB OIL TO GALLS AT 60°F DIVIDE BY 8·44

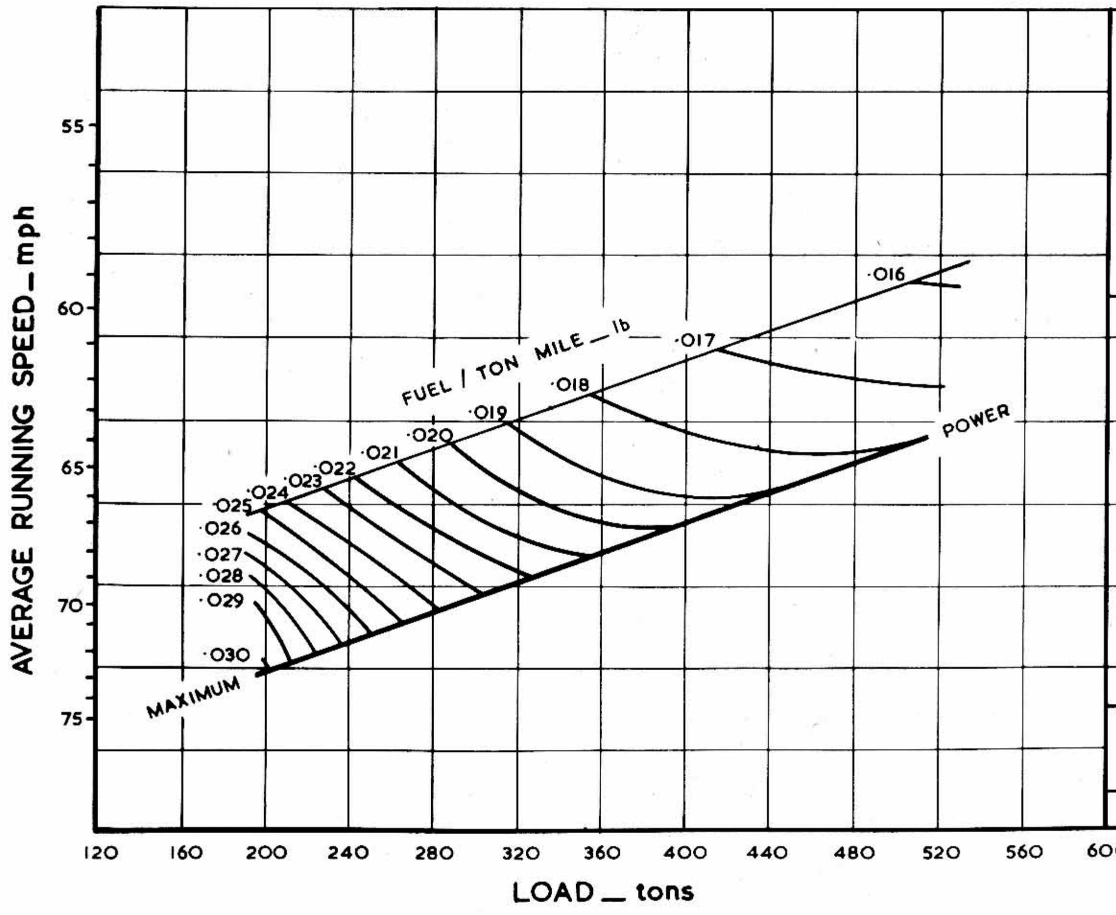
COST OF ENERGY AND PERFORMANCE


Milepost
Mileage
Heywood Rd Jc
Fairwood Jc
Trough.
Clink Rd Jc
Blatchbridge Jc
Witham Jc for Wells.
Strap Lane.
Bruton.
CASTLE CARY.
Jc for Weymouth.
Alford Halt.
Keinton Mandeville
Charlton Mackrell.
Somerton.
Somerton Tunnel.
Long Sutton & Pitney Halt.
Langport.
Curry Rivell Jc
Athelney
Jc for Durston.
Cogload Jc for Bristol.
Trough.
Creech St Michael.
Creech Jc
TAUNTON.
Norton Fitzwarren.
Jc for Minehead.
Jc for Barnstaple.
Wellington.
Whiteball Tunnel.
Burlescombe.
Sampford Peverell.
Tiverton Jc
Cullompton.
Hele & Bradninch.
Silverton.
Stoke Cannon.
Cowley Bridge Jc
EXETER (St Davids)
Jc for S.R.
St Thomas.
Exminster.
Trough.
Starcross.
Warren Halt.
Dawlish.
Teignmouth.
NEWTON ABBOT.

BR_WESTERN REGION_ PADDINGTON_ NEWTON ABBOT NON-STOP PASSENGER SERVICES
HEYWOOD ROAD JCN _ NEWTON ABBOT SECTION

LOCO TYPE : 2000 hp DE

MILEAGE 99·3



TOTAL RUNNING TIMES_MINS.	SCHEDULES POINT TO POINT TIMES_MINS							
	HEYWOOD Rd. Jcn. p BLATCHBRIDGE Jcn. p	BLATCHBRIDGE Jcn. p CASTLE CARY p	CASTLE CARY p CREECH Jcn p	CREECH Jcn. p TAUNTON p	TAUNTON p WHITEBALL p	WHITEBALL p COWLEY BRIDGE Jcn. p	COWLEY BRIDGE Jcn. p EXETER p	EXETER p NEWTON ABBOT p
98	7	12½	21½	2½	13½	16½	1½	23
94	6½	12	21	2	12	16	1½	23
90	6	11½	20	2	10½	15½	1½	23
86	6	11	18½	2	9½	14½	1½	23
82	5½	10	18	1½	8½	14	1½	23

p = Pass

PERMANENT SPEED RESTRICTIONS
AS AT JULY 1955

SW. SYS : CAL SW. : AUTHY BULL 16

TO CONVERT LB OIL TO GALLS AT 60°F
DIVIDE BY 8·44

COST OF ENERGY AND PERFORMANCE

DE 2000/10203/55

Process Work, Printing & Binding
by
British Railways, Western Region,
Swindon.