Locomotives I Have Known*

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Introduction. My intention in this lecture is to review a number of the more noteworthy locomotives with which I have been concerned, and to draw attention to some details of their construction which are of interest to the designer, the operator, and the many upon whom the self-contained motive power unit exerts its attraction.

Some of the factors affecting the design of certain locomotives will be referred to, and the way in which the designer dealt with them will be examined. The limitations imposed by permanent-way restrictions on certain designs will be mentioned, with the means adopted to overcome them without avoidable loss of power.

The impact of modern developments on manufacturing methods, of the war time control of labour and materials, and of the insistent need for economy, on the design and construction of certain recent locomotives, will also be touched upon.

Ivatt's 0–8–0 Mineral Locomotives. In 1901 Mr. Ivatt, the locomotive engineer of the Great Northern Railway, put into service the first of his 0–8–0 tender mineral engines, No. 401, the first of 55 such engines. These engines were introduced to work the heavy mineral traffic between Doncaster, Peterborough, and London and were a great advance in power on any existing class. They were fitted with open-back balanced slide valves above the cylinders, and the exhaust was appreciably improved; the valves were operated by Stephenson valve gear through rocking shafts. In assessing the value of grate area and heating surface it is as well to remember that coal at that time, and on the Great Northern Railway especially, was good. The leading dimensions of these engines are given in Table 1.

As regards external outline, the engine incorporated all those features that were to determine the appearance of all Great Northern locomotives for many years. The engines represented a straightforward development of existing practice, the problems set the designer being those arising from their increased size and power.

A sister engine is illustrated in Fig. 1, Plate 1, which is of historical interest as it shows Mr. Ivatt and beside him Mr. Sturrock, the first locomotive engineer of the Great Northern Railway, who retired in 1866, and who was 85 when the photograph was taken in 1901.

Table 1. Leading Dimensions of Great Northern Railway 0–8–0 Engine (L.N.E.R. class Q1)‡

Grate area	24·5 sq. ft.
Firebox heating surface	136·7 sq. ft.
Total evaporative heating surface	1,438·84 sq. ft.
Total superheating surface	None
Boiler pressure	175 lb. per sq. in.
Weight of engine in working order	54 tons 12 cwt.
Weight of tender in working order	40 tons 18 cwt.
Weight of engine and tender in working order	95 tons 10 cwt.
Adhesive weight of engine in working order	54 tons 12 cwt.
No. of cylinders	2
Diameter and stroke	20×26 inches
Driving wheel diameter	4 ft. 8 in.
Tractive effort	27,620 lb.
Ratio $\frac{\text{Adhesive weight}}{\text{Tractive effort}}$	4·54
" $\frac{\text{Tractive effort}}{\text{Grate area}}$	1,128
" $\frac{\text{Firebox heating surface}}{\text{Grate area}}$	5·58
" $\frac{\text{Total evaporative heating surface}}{\text{Grate area}}$	58·7

Sturrock's and Ivatt's Eight-coupled Tank Engines. The especial interest of Fig. 1 lies in its link with Mr. Sturrock's own eight-coupled tank engines, Nos. 472–3 (Fig. 2), which were among the first eight-coupled engines in the country. They were built by the Avonside Engine Company, of Bristol, in 1866 and had two outside cylinders, 18½ inches diameter by 24-inch stroke; with their 4 ft. 6 in. wheels and boiler pressure of 150 lb. per sq. in. the tractive effort was 19,327 lb. The third pair of

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‡ The engine numbers and classification letters are those at present in use on the London and North Eastern Railway, not those to which the engines were built.

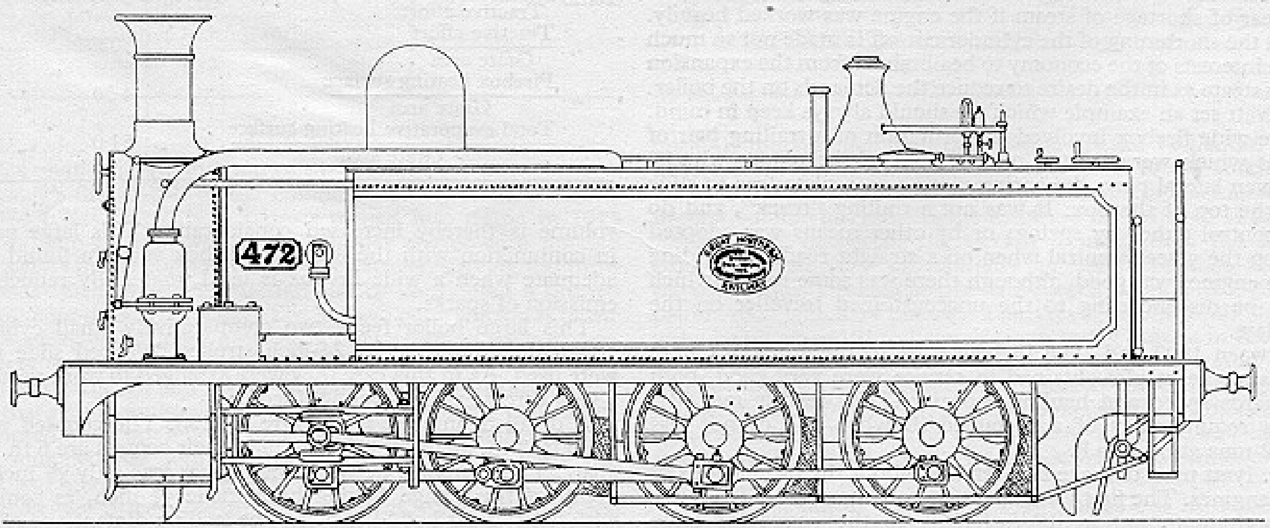


Fig. 2. Sturrock's 0–8–0 Tank Engine (1866)

TABLE 2. COMPARATIVE DIMENSIONS OF STURROCK'S AND IVATT'S EIGHT-COUPLED TANK ENGINES

	Sturrock 0–8–0 T	Ivatt 0–8–2 T	
	Nos. 472–3	No. 116, as built	No. 116, as rebuilt
Grate area, sq. ft.	17 (?)	24·5	17·8
Firebox heating surface, sq. ft.	100	136·7	107·7
Total evaporative heating surface, sq. ft.	1550·1	1438·84	1043·7
Boiler pressure, lb. per sq. in.	150	175	175
Weight of engine in working order, tons	56	79	70¼
Adhesive weight of engine in working order, tons	56	66	58¼
No. of cylinders	2	2	2
Diameter and stroke, inches	18¼ × 24	20 × 26	20 × 26
Driving wheel diameter	4 ft. 6 in.	4 ft. 8 in.	4 ft. 8 in.
Tractive effort, lb.	19,327	27,620	27,620
Ratio Adhesive weight / Tractive effort	6·48	5·35	4·72
" Tractive effort / Grate area	1,137*	1,128	1,552
" Firebox heating surface / Grate area	5·88*	5·58	6·04
" Total evaporative heating surface / Grate area	91·2*	58·7	58·6

* Based on 17 sq. ft. grate area.

wheels were the driving pair, so a long connecting rod was used. The leading and trailing pairs of wheels had ⅝ inch transverse play, which was controlled by check springs to Slaughter and Caillet's patent.

The boiler had a total heating surface of 1550·1 sq. ft., of which 100 sq. ft. was in the firebox. The total weight was 56 tons in working order. I have not been able to ascertain the grate area; it was probably about 17 sq. ft.

Table 2 gives the principal dimensions of Mr. Sturrock's engines, together with those of No. 116, a very large 0–8–2 tank locomotive built by Mr. Ivatt in 1903 for heavy suburban passenger traffic. Originally No. 116 was identical in design with the 0–8–0 No. 401, except for the addition of long side tanks, and a coal bunker supported by an additional pair of trailing wheels. No. 116 proved to be too heavy for the road, and was very soon given a much smaller boiler and shorter side tanks, to reduce the weight. Forty similar engines were built to this modified pattern during the next three or four years.

Ivatt's Large-boilered 4–4–2 "Atlantic" Express Engines. In 1902 Mr. Ivatt introduced his first large-boilered "Atlantic" type locomotive, No. 251 (Fig. 3, Plate 1). The boiler was the chief feature of interest, owing to its unusually large size and the use of a wide firebox extending above and beyond the frames.

The provision of a boiler of so large a capacity was a most valuable innovation in English locomotive design, as it removed any fear of shortage of steam if the engine was worked heavily. Often the shortening of the cylinder cut-off is made not so much in the interests of the economy to be obtained from the expansion of the steam as in the desire to reduce the demands on the boiler. Mr. Ivatt set an example which we should always keep in mind.

The wide firebox involved the provision of a trailing pair of wheels which were treated on the lines of the tender wheels, i.e. given lateral play, the spring resting on a plate free to slide over the top of the box. It was not a trailing "truck", and no side control either by springs or by other means was adopted to keep the wheels central when on a straight road. The riding of the engines was good, although there was some rolling which could be disconcerting to the unaccustomed traveller on the footplate.

Between 1902 and 1908 inclusive, 81 of these engines were built and the results obtained in service were very good, both as regards speed and hauling capacity. They readily met Mr. Ivatt's requirements of a sustained drawbar pull of not less than 2 tons at 60 m.p.h.

Mr. Ivatt used to make two remarks about the proportions of these engines. The first was: "It is no good having a large purse and nothing to put in it" (referring to the vogue for large cylinders and small boilers); the second, "The difficult thing is to get the steam out of the cylinders", related to the attention given to the exhaust passages.

The simple form of firebox is noteworthy, the inwardly inclined sides of which, it was claimed, allowed the bubbles of steam to pass through the water instead of creeping up the plate as in the narrow box. The rather flat brick arch—obtained by using large quarries in place of ordinary firebricks—will be noted. The external appearance of the smokebox is deceptive; the smokebox tubeplate is recessed into the barrel and the smokebox

TABLE 3. LEADING DIMENSIONS OF IVATT'S LARGE 4–4–2 *Atlantic* LOCOMOTIVES (L.N.E.R. CLASS C1), AS BUILT

Grate area	30·9 sq. ft.
Firebox heating surface	141 sq. ft.
Total evaporative heating surface	2,500 sq. ft.
Total superheating surface	None
Boiler pressure	175 lb. per sq. in.
Weight of engine in working order	68 tons 8 cwt.
Weight of tender in working order	40 tons 18 cwt.
Weight of engine and tender in working order	109 tons 6 cwt.
Adhesive weight of engine in working order	36 tons
No. of cylinders	2
Diameter and stroke of cylinders	18¾ × 24 inches
Driving wheel diameter	6 ft. 8 in.
Tractive effort	15,690 lb.
Ratio Adhesive weight / Tractive effort	5·14
" Tractive effort / Grate area	507
" Firebox heating surface / Grate area	4·56
" Total evaporative heating surface / Grate area	81·0

volume is thereby increased considerably. This large volume in conjunction with the lower smokebox vacuum found to be adequate when a wide firebox is used, materially reduced the emission of sparks.

This large boiler feeds two comparatively small cylinders, 18¾ inches diameter by 24-inch stroke. Balanced slide valves were used. As in this case they were arranged to work vertically, a very direct exhaust was attained.

A detail of interest is the tyre section. The coupled wheels are 6 ft. 8 in. diameter on tread, and their centres are 6 ft. 10 in. apart. The clearance between the flanges was only 3/16 inch, the depth of this flange having been made 29/32 inch, as compared with the standard of 1⅛ inches. The leading dimensions of these engines are given in Table 3.

The engines were subsequently brought up-to-date by fitting superheaters and 20-inch diameter cylinders with piston valves in place of the 18¾-inch cylinders with slide valves; and it was in their altered form that they did their finest work.

The following examples show the innate capabilities of these engines:—

(1) On Tuesday, 28th July 1936, No. 4404, the station pilot at Grantham, then 34 years old, was attached to the 1.20 p.m. ex-King's Cross at Grantham in place of the regular train engine. The train weighed 585 tons. A certain amount of difficulty was experienced starting from Grantham, but the 63·3 miles from Grantham to Brayton Junction, Selby, were run in 59 min. 24 sec. at an average speed of 64 m.p.h.

(2) On Friday, 4th September 1936, No. 4452 was attached to the up *Silver Jubilee* at Doncaster, and covered the 156½ miles thence to King's Cross in 139 minutes, at a start to stop speed of 67·3 m.p.h.

Mr. Ivatt retired in 1911, and will be remembered for his work in stressing the importance of a free exhaust, and above all for demonstrating beyond argument that the performance of a steam locomotive is determined by its boiler capacity.

Gresley's Early Designs. Mr., afterwards Sir Nigel, Gresley succeeded Mr. Ivatt in 1911. His first engines were the 2–6–0 tender engines known as the K1 class in the L.N.E.R. classification. These locomotives were intended for working express goods trains.

A feature of interest in these engines, and one used on all subsequent engines with two-wheeled leading trucks was the double swing-link truck, wherewith the level of the engine remains unaffected by the cant of the track.

Gresley's first 2–8–0 tender engine for heavy mineral traffic, No. 456 (class O1, L.N.E.R.) was turned into traffic in 1913 (Fig. 4, Plate 2). This was a two-cylinder engine with outside cylinders 21 inches diameter by 28-inch stroke, driving the third pair of coupled wheels; the design can be considered a normal development of G.N. practice. The leading pony truck was of the double swing-link design previously referred to. So far as performance was concerned, the engine showed itself to be very powerful (Table 4), and a very valuable addition to the stock.

At that period multicylindered engines were being considered or adopted on many lines. The remarkable performances of the Nord four-cylinder compound "Atlantics" between Paris and Calais had much to do with this.

The Bridge Stress Committee set up in 1923 demonstrated the serious effects of hammer blow on bridges. The hammer blow is the result of balancing a proportion of the weight of the reciprocating parts, usually (at that time) about two-thirds. The Committee's report showed the benefits to be derived from three- and four-cylinder engines, and made it clear that with such engines higher axle loads would be less harmful to the track than lighter axle loads with two-cylinder engines balanced in the normal way. This Committee's recommendations led to increased attention being paid to the locomotive balancing.

Gresley's first three-cylinder 2–8–0 mineral engine, No. 461, was turned out in 1918. This engine was fitted with the original arrangement of derived valve gear, using a series of rockers, linked to the outside Walschaerts valve gear, to actuate the middle valve. The gear was complicated, but it led to the improved gear fitted to all subsequent Gresley three-cylinder engines.

The first batch of three-cylinder 2–8–0 engines with this improved gear were turned out in 1921, and the type continued to be built after the amalgamation (Fig. 5, Plate 2). This valve gear, which is now known as the Gresley gear consists of a "two-to-one" lever rocking about a fixed centre located between the frame plates, the end of the longer arm being coupled to an extension of the right-hand piston valve spindle. The end of the shorter arm carries a straight floating lever, the two arms of which are equal in length, one being coupled to an extension of the left-hand valve spindle, and the other to an extension of the middle valve spindle.

The leading dimensions and ratios of the O2 class are given in Table 5.

Gresley's 4–6–2 "Pacific" Locomotives. Sir Nigel Gresley completed his first Pacific type locomotive (L.N.E.R. class A1) in 1922. This engine is shown in Fig. 6, Plate 2. The boiler is not only much larger than those fitted to the "Atlantics", but differs from them in many respects. One of its interesting features is the combustion chamber which not only increases the firebox volume but reduces the length of the tubes to 19 feet.

The detail design of the motion is interesting, the weight being reduced very substantially by careful design and by the use of alloy steels. The piston is forged in one piece with the piston rod, which is hollow. The crank axle is built up, the webs being extended to balance the rotating masses in the same plane. The engine was fitted with the Gresley valve gear.

The trailing truck (Fig. 7) incorporates Cartazzi slides and is, therefore, self-centring, the axle boxes being set tangentially to a radius of 12 feet. The arrangement is simple and light in weight, and is fitted to all Gresley-designed locomotives with trailing trucks.

The balancing of the engine was carried out in accordance with Professor Dalby's method, Professor Dalby himself checking the calculations and diagrams; 60 per cent of the recipro-

TABLE 4. LEADING DIMENSIONS OF GRESLEY'S TWO-CYLINDER 2–8–0 ENGINE (L.N.E.R. CLASS O1)

Grate area	27·5 sq. ft.
Firebox heating surface	163·5 sq. ft.
Total evaporative heating surface	2,032 sq. ft.
Total superheating heating surface	430·5 sq. ft.
Boiler pressure	180 lb. per sq. in.
Weight of engine in working order	76 tons 4 cwt.
Weight of tender in working order	43 tons 2 cwt.
Weight of engine and tender in working order	119 tons 6 cwt.
Adhesive weight of engine in working order	67 tons 8 cwt.
No. of cylinders	2
Diameter and stroke	21 × 28 inches
Driving wheel diameter	4 ft. 8 in.
Tractive effort	33,736 lb.
Ratio Adhesive weight / Tractive effort	4·47
" Tractive effort / Grate area	1,227
" Firebox heating surface / Grate area	5·95
" Total evaporative heating surface / Grate area	73·8

TABLE 5. LEADING DIMENSIONS OF GRESLEY'S THREE-CYLINDER 2–8–0 ENGINE (L.N.E.R. CLASS O2)

Grate area	27·5 sq. ft.
Firebox heating surface	163·5 sq. ft.
Total evaporative heating surface	2,037 sq. ft.
Total superheating heating surface	430·5 sq. ft.
Boiler pressure	180 lb. per sq. in.
Weight of engine in working order	75 tons 16 cwt.
Weight of tender in working order	43 tons 2 cwt.
Weight of engine and tender in working order	118 tons 18 cwt.
Adhesive weight of engine in working order	67 tons 7 cwt.
No. of cylinders	3
Diameter and stroke	18½ × 26 inches
Driving wheel diameter	4 ft. 8 in.
Tractive effort	36,470 lb.
Ratio Adhesive weight / Tractive effort	4·14
" Tractive effort / Grate area	1·325
" Firebox heating surface / Grate area	5·94
" Total evaporative heating surface / Grate area	74·0

cating parts was balanced. One of the nickel-chromium connecting rods was tested at the City and Guilds of London College, and withstood, as a strut, a load of four times the piston steam load, without permanent deformation.

These class A1 engines were used in 1928 to run direct from King's Cross to Edinburgh, 393 miles without a stop. The problems involved in a working of such an unusual nature were many and difficult. The water required could be picked up from the troughs at Langley, Werrington, Muskham, Scrooby, Wiske Moor, and Lucker, the longest distance between which was 97 miles (between Wiske Moor and Lucker). The capacity of the tender is 5,000 gallons. The distance to be covered after

railcars, and a number of runs on these cars clearly showed the absence of disturbance along the sides.

Bugatti arrived at this form by building bodies of various shapes on to road chassis, and running them at high speed down the French main roads; the trials showed quite positively that the wedge front and back was the best shape.

Sir Nigel adopted the same form for the smokebox, without, however, altering the contour of the boiler. He followed this course in order not to interfere with the driver's look-out. He used the aerofoil shape for the running boards, so as to cause as little disturbance there as possible.

The boilers differed from those of the other Pacifics by

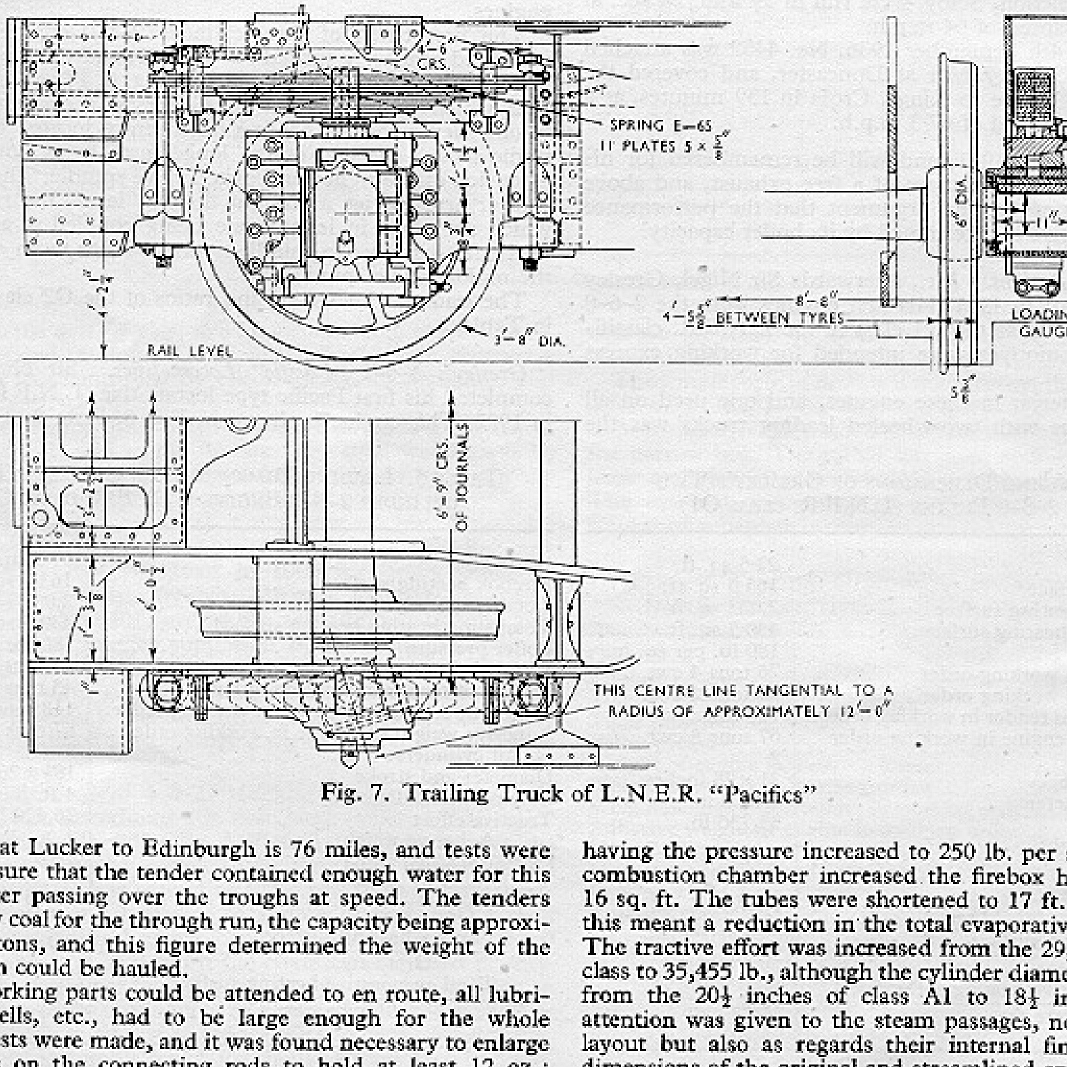


Fig. 7. Trailing Truck of L.N.E.R. "Pacifics"

picking up at Lucker to Edinburgh is 76 miles, and tests were made to ensure that the tender contained enough water for this distance after passing over the troughs at speed. The tenders had to carry coal for the through run, the capacity being approximately 10 tons, and this figure determined the weight of the trains which could be hauled.

As no working parts could be attended to en route, all lubrication oilwells, etc., had to be large enough for the whole journey. Tests were made, and it was found necessary to enlarge the oilwells on the connecting rods to hold at least 12 oz.; moreover, oils of the best quality were provided.

As one driver could not be expected to drive such a distance at such speeds, two sets of men had to be carried, one set on the footplate and one in the train. A changeover was made about half-way between London and Edinburgh, i.e. a few miles north of Alne. This necessitated the provision of a passage through the tender, and the result was the "corridor tender". The arrangement involved vestibule connexion between tender and train, a further improvement.

Streamlined Locomotives. The A4 class of Pacific's was designed for the *Silver Jubilee* train which in 1935 began to run between London and Newcastle; and later these engines were used to work the *Coronation* train between London and Edinburgh. Fig. 8, Plate 3, shows the streamlining.

Professor Dalby always argued that a wedge-shaped front was the best form for the leading end of a vehicle running on rails. Bugatti used a blunt wedge at both ends for his high-speed

having the pressure increased to 250 lb. per sq. in. The larger combustion chamber increased the firebox heating surface by 16 sq. ft. The tubes were shortened to 17 ft. 11¾ in., although this meant a reduction in the total evaporative heating surface. The tractive effort was increased from the 29,835 lb. of the A1 class to 35,455 lb., although the cylinder diameters were reduced from the 20¼ inches of class A1 to 18½ inches. Very close attention was given to the steam passages, not only as regards layout but also as regards their internal finish. Comparative dimensions of the original and streamlined engines are given in Table 6.

Fig. 9, Plate 3, shows one of these engines on its train. The valance below the carriage bodies to reduce air resistance will be noticed.

The work done by these locomotives is known to everybody; and to show their turn of speed, I cannot do better than give extracts from the run made by No. 4468, *Mallard*, with a 240-ton train on 3rd July, 1938 (Table 7). The regulator was full open throughout the test. The speeds in the speed column are the precise speeds on passing each of the points indicated. The changes in cut-off took place at the station or mile-post indicated on the same line.

Gresley's 2–8–2 Passenger Locomotives. In 1934 Sir Nigel built No. 2001 (Fig. 10, Plate 3), the first of his 2–8–2 three-cylinder passenger engines of the P2 class (*Cock o' the North*), in order to avoid double heading of heavy passenger trains north of

TABLE 6. LEADING DIMENSIONS OF GRESLEY'S ORIGINAL AND STREAMLINED 4–6–2 *Pacific* ENGINES

Type of engine (L.N.E.R. classification)	A1 (original)	A4 (streamlined)
Grate area	41·25 sq. ft.	41·25 sq. ft.
Firebox heating surface	215 sq. ft.	231·2 sq. ft.
Total evaporative heating surface	2,930 sq. ft.	2576·3 sq. ft.
Total superheating heating surface	525 sq. ft.	748·9 sq. ft.
Boiler pressure	180 lb. per sq. in.	250 lb. per sq. in.
Weight of engine in working order	92 tons 9 cwt.	102 tons 19 cwt.
Weight of tender in working order	56 tons 6 cwt.	64 tons 19 cwt.
Weight of engine and tender in working order	148 tons 15 cwt.	167 tons 18 cwt.
Adhesive weight of engine in working order	60 tons	66 tons
No. of cylinders	3	3
Diameter and stroke	20 × 26 inches	$18\frac{1}{2}$ × 26 inches
Driving wheel diameter	6 ft. 8 in.	6 ft. 8 in.
Tractive effort	29,835 lb.	35,455 lb.
Ratio $\frac{\text{Adhesive weight}}{\text{Tractive effort}}$	4·5	4·18
,, $\frac{\text{Tractive effort}}{\text{Grate area}}$	724	860
,, $\frac{\text{Firebox heating surface}}{\text{Grate area}}$	5·22	5·60
,, $\frac{\text{Total evaporative heating surface}}{\text{Grate area}}$	71·0	62·4

Edinburgh. The boiler follows the lines of the A4 "Pacifics", but has a grate area of 50 sq. ft. and 19-foot tubes. Table 8 gives other leading dimensions.

Cock o' the North was fitted originally, as an experiment, with poppet valve gear. The poppet valves were unusually large, so that the loads on the cams when lifting the valves against full pressure were also extremely high. As the original cams were continuously variable it will be appreciated that the contact surface was small and the heavy loading soon damaged the surface.

The freedom of the engine when coasting was quite remarkable owing to its being possible to lift all the exhaust valves off their seats. It was demonstrated with this engine that the machine resistance of a locomotive, in pounds per ton, differs little from that of the rest of the train.

This engine was sent to the French testing station at Vitry and was also tested with a counter-pressure locomotive and dynamometer car between Tours and Orléans. It demonstrated itself as a fast powerful machine and compared favourably with the French locomotives. In normal train service in Scotland the coal consumption was high; and as the cam wear was excessive, the cylinders were replaced by piston valve cylinders as used on the subsequent five sister engines illustrated by No. 2006 (Fig. 11, Plate 4).

TABLE 7. L.N.E.R. TEST RUN WITH *Coronation* TRAIN, JULY 1938

Engine: Streamlined 4–6–2 No. 4468, *Mallard*, class A4.
Driver, J. Duddington; fireman, T. H. Bray (Doncaster shed).
Load: 7 coaches, $236\frac{1}{2}$ tons tare, 240 tons gross.

Stations	Mile-posts	Times (p.m.) hr.	min.	sec.	Speeds, m.p.h.	Cut-off, per cent
Grantham	$105\frac{1}{2}$	4	24	19	24*	40
	Mile-post 105	4	25	13	32	,,
	,, 104	4	26	32	$52\frac{1}{4}$	,,
	,, 103	4	27	$36\frac{1}{2}$	$59\frac{1}{2}$	30
Gt. Ponton	102	4	28	$35\frac{1}{2}$	$63\frac{1}{2}$	,,
	Mile-post 101	4	29	30	69	40
Stoke Box						
	Mile-post 100	4	30	$20\frac{1}{2}$	$74\frac{1}{2}$	,,
	,, 99	4	31	05	$87\frac{1}{2}$	,,
	,, 98	4	31	$44\frac{1}{2}$	$96\frac{1}{2}$	,,
Corby						
	Mile-post 97	4	32	$20\frac{1}{2}$	104	,,
	,, 96	4	32	$54\frac{1}{2}$	107	,,
	,, 95	4	33	$27\frac{1}{2}$	$111\frac{1}{2}$	,,
	,, 94	4	33	$59\frac{1}{2}$	116	45
	,, 93	4	34	30	119	40
	,, $92\frac{3}{4}$	—	—	—	$119\frac{1}{2}$	,,
	,, $92\frac{1}{2}$	—	—	—	$120\frac{3}{4}$	,,
Little Bytham	$92\frac{1}{4}$	4	34	$52\frac{1}{2}$	$122\frac{1}{2}$	,,
	Mile-post 92	4	35	00	$122\frac{1}{2}$	,,
	,, $91\frac{3}{4}$	—	—	—	$122\frac{1}{2}$	,,
	,, $91\frac{1}{2}$	—	—	—	123	,,
	,, $91\frac{1}{4}$	—	—	—	$124\frac{1}{4}$	,,
	,, 91	4	35	29	$124\frac{1}{4}$	,,
	,, $90\frac{3}{4}$	—	—	—	$123\frac{1}{2}$	,,
	,, $90\frac{1}{2}$	—	—	—	124	,,
	,, $90\frac{1}{4}$	—	—	—	125	,,
	,, 90	4	35	$58\frac{1}{2}$	$124\frac{1}{4}$	,,

* Permanent way slack.

TABLE 8. LEADING DIMENSIONS OF GRESLEY'S THREE-CYLINDER 2-8-2 PASSENGER ENGINE (L.N.E.R. CLASS P2)

Grate area	50 sq. ft.
Firebox heating surface	237 sq. ft.
Total evaporative heating surface	2,714 sq. ft.
Total superheating heating surface	635·5 sq. ft.
Boiler pressure	220 lb. per sq. in.
Weight of engine in working order	110 tons 5 cwt.
Weight of tender in working order	55 tons 6 cwt.
Weight of engine and tender in working order	165 tons 11 cwt.
Adhesive weight of engine in working order	80 tons 12 cwt.
No. of cylinders	3
Diameter and stroke	21 × 26 inches
Driving wheel diameter	6 ft. 2 in.
Tractive effort	43,462 lb.
Ratio Adhesive weight / Tractive effort	4·15
" Tractive effort / Grate area	870
" Firebox heating surface / Grate area	4·74
" Total evaporative heating surface / Grate area	54·3

Sir Nigel's death must be deplored by all locomotive men: he ranks with our greatest locomotive engineers, and was equally at home in all other branches of mechanical engineering.

French Advances in Locomotive Design. Fig. 12, Plate 4, shows a Paris-Orléans 4-8-0 compound engine of 1935. These engines have given a very good account of themselves: they are the result of many years' development in conjunction with counter-pressure testing on the track under constant conditions of load and speed. They are not the result of research in a locomotive testing plant, the French station at Vitry not being in full use until after the design had been developed. It is an interesting speculation to think of the still further improvements that could be made if these locomotives were subjected to a full series of tests at Vitry. Fig. 13 shows the general arrangement of the engine.

The engines have very large and well-arranged steam passages, in consequence of which the work done in the cylinders is high. The power developed is great, as much as 4,000 i.h.p. being claimed. The engines have worked trains at 140 km.p.h. (87 m.p.h.), and in the French view confirm the value of compounding, especially in conjunction with high superheat.

The boiler has a narrow firebox with a grate 3·7 m. (12 ft. 1⅝ in.) long, the area being 3·77 sq.m. (40·45 sq. ft.). The boiler represents the limit of the hand-fired narrow firebox. The firebox is of steel and is fitted with a single Nicholson syphon, which not only improved the circulation but gave no trouble as regards maintenance. The smokebox is designed round the latest type "Kylchap" blast pipe arrangement, with double chimney (Fig. 14). The two nozzles, branching off a common exhaust box, are fitted with four V-shaped bars to spread the steam; between the nozzles and the chimney are two pairs of petticoats each giving three points of admission to the smokebox gases. The arrangement increases the surface of the exhaust steam in contact with the gases of combustion and gives a very even "draw" over the grate. William Adams led the way in this direction with his Vortex blast pipe, on the London and South Western Railway. By this device the combustion gases are drawn up inside an annular blast pipe so that there is contact and mixing of the gases with the exhaust steam inside the cone as well as outside it. The leading dimensions are given in Table 9.

As an example of the capabilities of these engines, on the 15th February 1935, a train of 640 tons behind the tender was

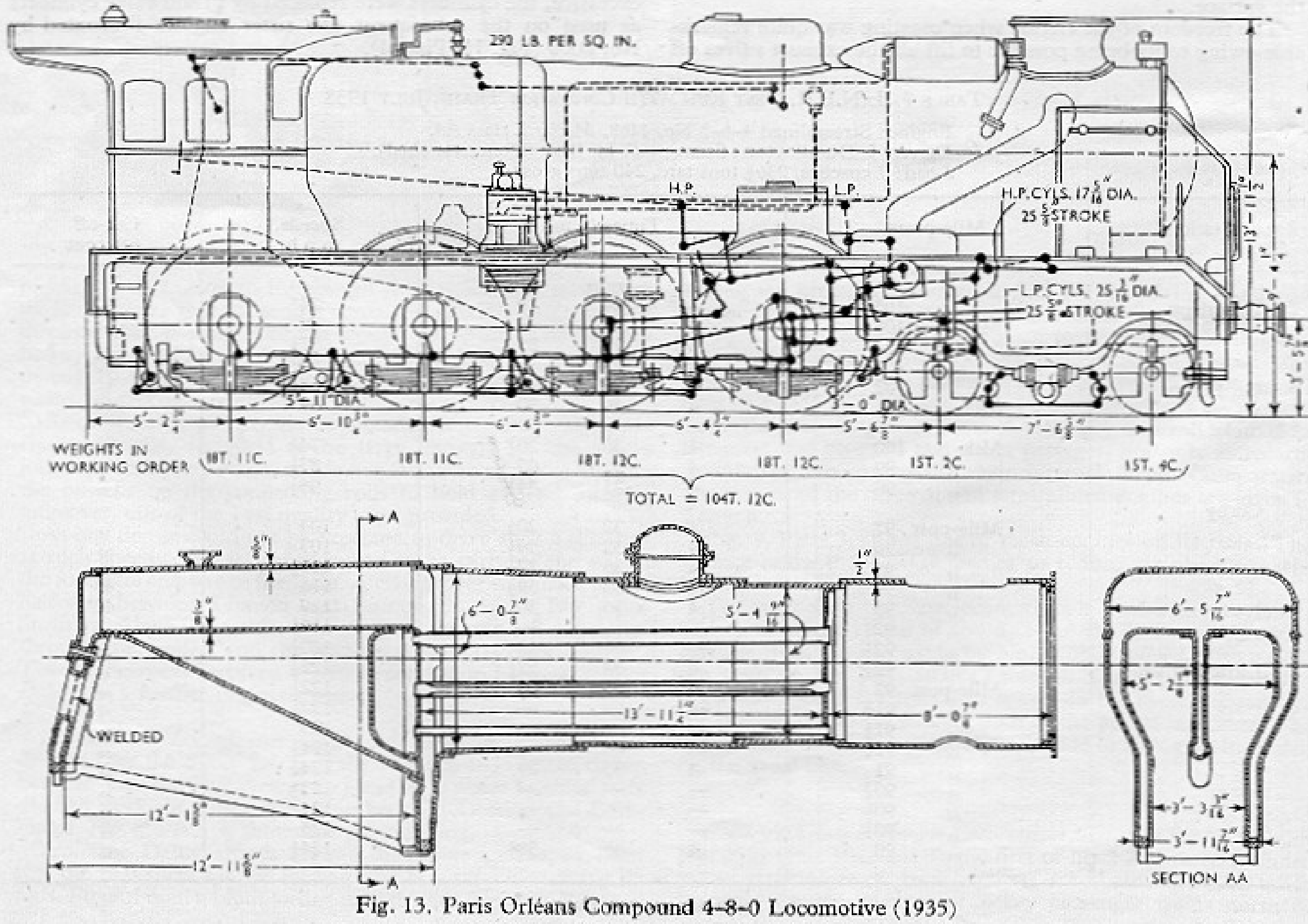


Fig. 13. Paris Orléans Compound 4-8-0 Locomotive (1935)

worked from Paris to Calais (183 miles) in 2 hr. 31 min. excluding the stop at Amiens, an average speed of 75·0 m.p.h.

The Paris–Orléans engineers made a most valuable contribution to locomotive design in the work they did in developing these engines, and above all in showing how much more work could be done in the cylinders by attention to the cross-sectional area and arrangement of the steam passages. In mid-Victorian days Crampton used a ratio of cylinder cross-section

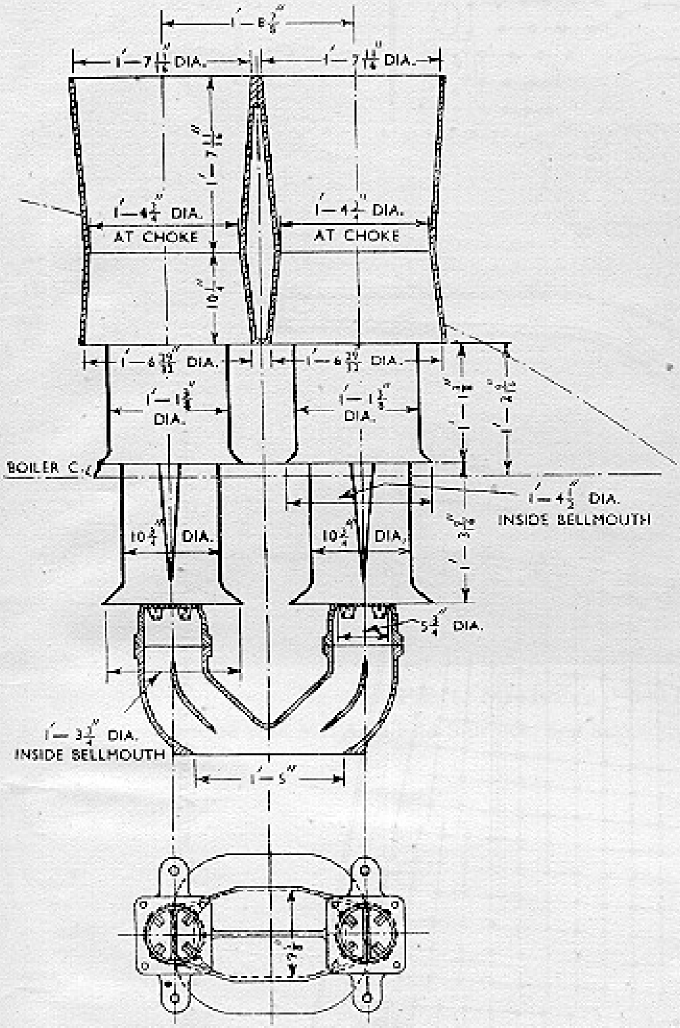


Fig. 14. Blast Pipe of Paris–Orléans Compound 4–8–0 Locomotive

to steam pipe cross-section of 5/1, and the Paris–Orléans Railway recommends a return to this ratio and even to 3·5/1 in the case of ultra high-speed locomotives. These locomotives also show the benefits of a large steam chest volume. They demonstrate the vital importance of getting the steam into the cylinders with the minimum drop of pressure during admission. They also show the greatly increased capacity of locomotives fitted with efficient blast pipes and chimneys.

Maunsell's Four-cylinder 4–6–0 (Lord Nelson), Southern Railway. In 1926 Mr. Maunsell, my predecessor on the Southern Railway, introduced his four-cylinder 4–6–0 tender engine, the *Lord Nelson*. The general appearance of the engine as originally built is shown in Fig. 15, Plate 4. The boiler has almost the largest narrow firebox that can be used within the limitations of the Southern Railway loading gauge, consistent with ample view from the cab. Monel metal stays, because of their resistance to corrosion and to electrolytic action are used to fasten the inner and outer fireboxes together, this being the first application of the material, as standard practice, to locomotive fireboxes in

TABLE 9. LEADING DIMENSIONS OF PARIS–ORLÉANS FOUR-CYLINDER COMPOUND 4–8–0 ENGINES

Grate area	40·45 sq. ft.	
Firebox heating surface	268 sq. ft.	
Total evaporative heating surface	2,323 sq. ft.	
Total superheating heating surface	652 sq. ft.	
Boiler pressure	290 lb. per sq. in.	
Weight of engine in working order	104 tons 12 cwt.	
Weight of tender in working order	—	
Weight of engine and tender in working order	—	
Adhesive weight of engine in working order	74 tons 5 cwt.	
No. of cylinders	4	
Diameter and stroke	High-pressure: $17\frac{5}{16} \times 25\frac{5}{8}$ inches; Low-pressure: $25\frac{3}{16} \times 25\frac{5}{8}$ inches	
Driving wheel diameter	5 ft. 11 in.	
	Simple	Compound
Tractive effort	57,470 lb.	45,930 lb.
Ratio $\frac{\text{Adhesive weight}}{\text{Tractive effort}}$	2·9	3·62
,, $\frac{\text{Tractive effort}}{\text{Grate area}}$	1,420	1,137
,, $\frac{\text{Firebox heating surface}}{\text{Grate area}}$	6·62	
,, $\frac{\text{Total evaporative heating surface}}{\text{Grate area}}$	57·4	

this country. Leading dimensions of this locomotive are given in Table 10.

The drive from the four cylinders is divided, the two outside cylinders driving the middle pair of coupled wheels and the two inside cylinders the leading pair. The most interesting feature is the setting of the cranks at 135 deg., as apart from experimental engines, this arrangement had not previously been used on main line express locomotives. The arrangement

TABLE 10. LEADING DIMENSIONS OF MAUNSELL'S 4–6–0 *Lord Nelson* LOCOMOTIVES, SOUTHERN RAILWAY

Grate area	33 sq. ft.
Firebox heating surface	194 sq. ft.
Total evaporative heating surface	1,989 sq. ft.
Total superheating heating surface	376 sq. ft.
Boiler pressure	220 lb. per sq. in.
Weight of engine in working order	83 tons 10 cwt.
Weight of tender in working order	56 tons 14 cwt.
Weight of engine and tender in working order	140 tons 4 cwt.
Adhesive weight of engine in working order	61 tons 19 cwt.
No. of cylinders	4
Diameter and stroke	$16\frac{1}{2} \times 26$ inches
Driving wheel diameter	6 ft. 7 in.
Tractive effort	33,500 lb.
Ratio $\frac{\text{Adhesive weight}}{\text{Tractive effort}}$	4·15
,, $\frac{\text{Tractive effort}}{\text{Grate area}}$	1,014
,, $\frac{\text{Firebox heating surface}}{\text{Grate area}}$	5·88
,, $\frac{\text{Total evaporative heating surface}}{\text{Grate area}}$	60·3

gives eight exhausts per revolution. This setting is ideal for counterbalancing a four-cylinder engine, and gives a regular turning moment.

In 1938 it became necessary to renew the cylinders of these engines. It had been demonstrated since the engines were built that a greatly increased performance could be obtained by increasing the size of the steam passages and improving their layout (as already mentioned in the section dealing with the Paris–Orléans locomotives), so advantage was taken of the

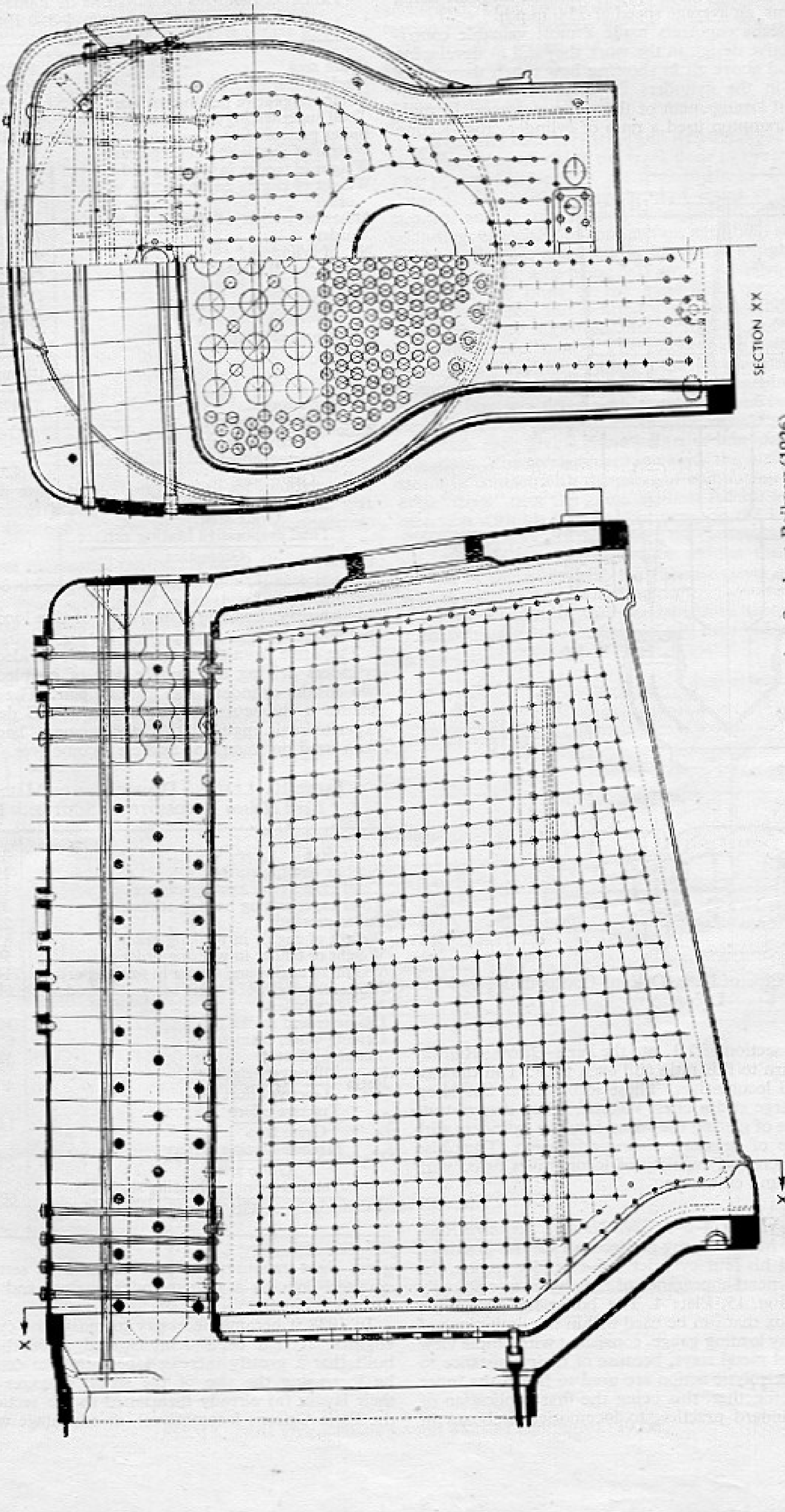


Fig. 16. Firebox of *Lord Nelson* Locomotive, Southern Railway (1926)

opportunity to incorporate such changes in the new cylinders required.

In order to increase the production of steam without raising the back pressure, the engines were fitted at the same time with large chimneys and five-nozzle blast pipes based on the Lemaître arrangement introduced on the Nord-Belge Railway and applied to the French Nord engines subsequently. The arrangement is much simpler than the Kylchap, although the designer of the Kylchap argues that the absence of the mixing petticoats renders it less efficient. The effectiveness of the large chimney with the multiple-nozzle blast pipe top has been demonstrated quite clearly.

Having reviewed these few locomotives in rather a superficial manner we now come to the latest locomotives of the Southern Railway.

The First "Austerity" Locomotives. We had in service a limited number of six-coupled tender locomotives known as class Q, but in 1941 the shortage of this type of locomotive made itself felt. Orders were given to build forty 0–6–0 engines during 1942, and with the need for standardization in mind, the duplication of the existing type seemed to be justified. Investigations showed, however, that increased boiler capacity would be advantageous. It was evident that the largest possible boiler should be provided, but the design of the Q class engine would have had to be modified in many respects to enable such a boiler to be fitted. Furthermore, the new engines would be required to work over the whole of the railway system except for unimportant branches aggregating no more than 7 per cent of the system; and this meant that the total engine weight must be under 54 tons. There was insufficient time for the normal processes of design, so short cuts had to be taken.

I propose to describe the design in some detail, in order to illustrate how the designer dealt with his problem under war time conditions.

We will take the boiler first. The *Lord Nelson* firebox in cross-section, i.e. over the Belpaire plate, is the largest that can be used over certain sections, owing to the restricted loading gauge dimensions. As the press blocks for these plates were in existence it was natural, in order to save much time and material to endeavour to use them again, and used they were. This determined the cross-sectional shape of the firebox which, in fact, is a shortened version of the *Lord Nelson* firebox, giving 27 sq. ft. of grate area (Fig. 16). It was decided to retain the wheelbase of the Q class, and this determined the length of barrel. The boiler is shown in Fig. 17, whilst in Fig. 18 it is superimposed on the boiler of the original Q class. Calculation showed that a boiler designed on these lines would alone weigh

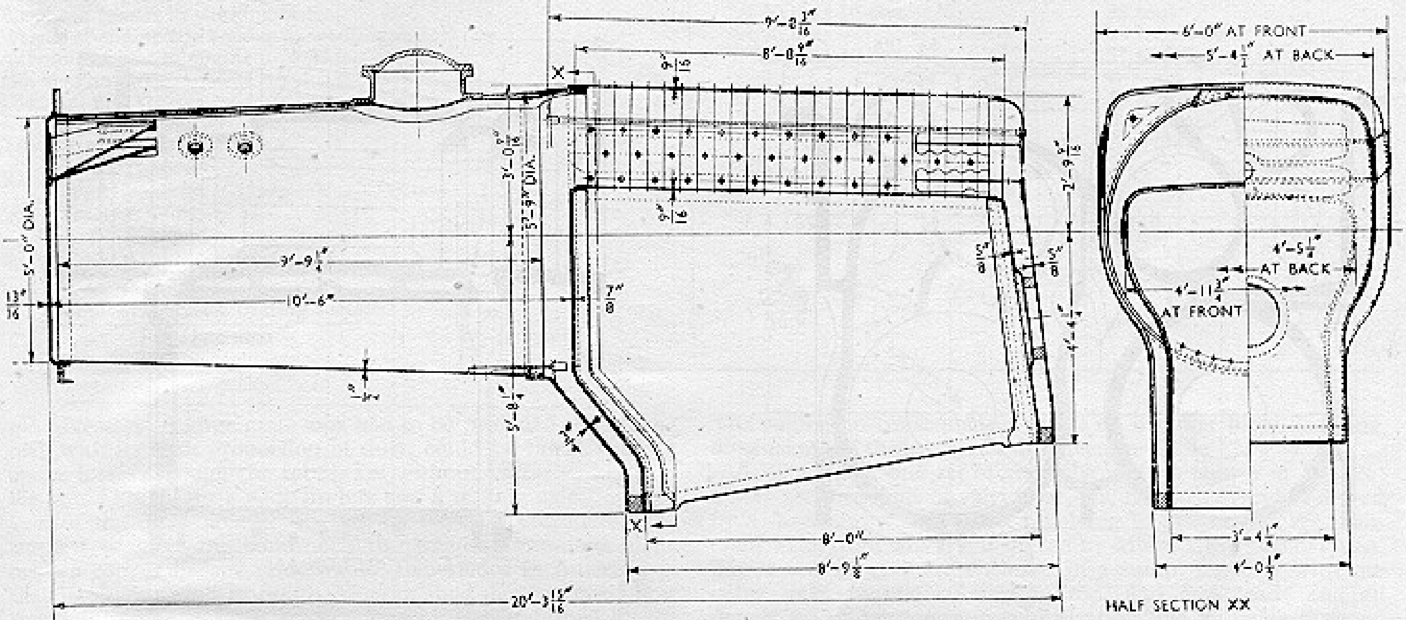


Fig. 17. Boiler of "Austerity" 0–6–0 Locomotive, Southern Railway (1941)

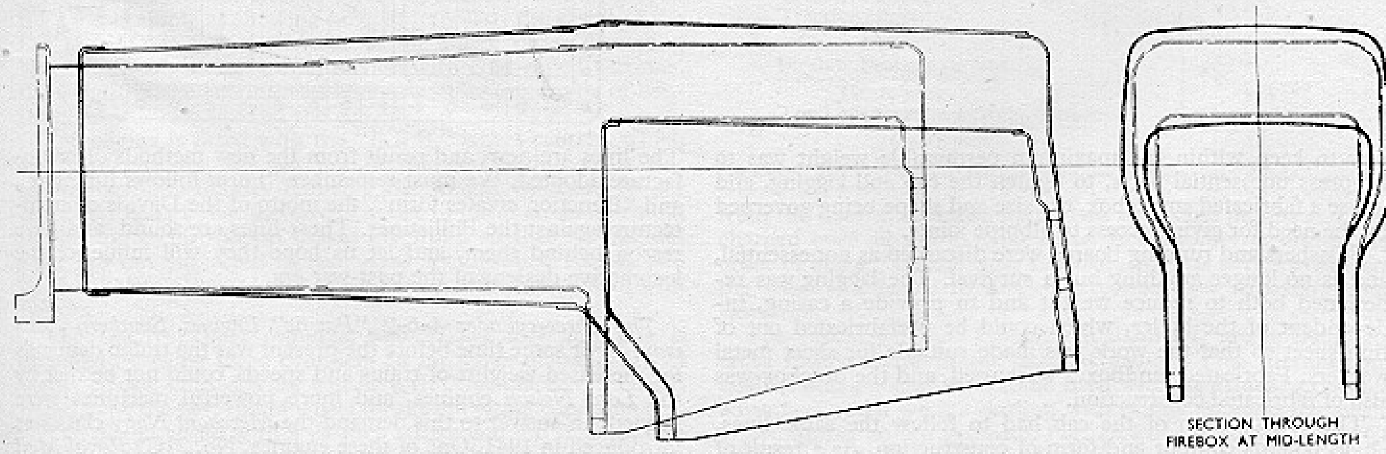
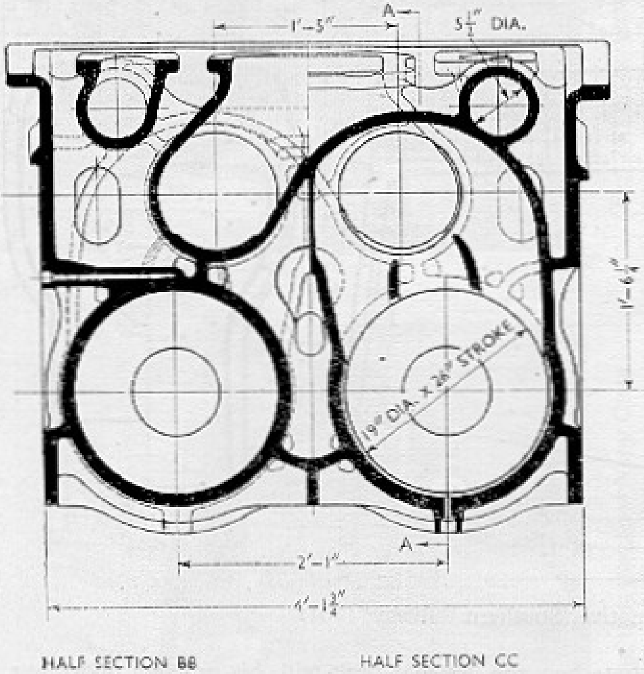


Fig. 18. Comparison between Boilers of Original Q Class 0–6–0 Locomotive and Enlarged Q1 ("Austerity") Class, Southern Railway (1941)

– – – – Q Class. ——— Q1 Class.

about 22 tons, leaving some 30 tons for the rest of the engine, not a very liberal amount. The tractive effort was fixed at 30,000 lb. The motion adopted that of the Q's, with some detail modifications which it was found would improve the valve events. The cylinders were completely redesigned to improve the steam passages and to simplify the attachment to the smokebox. Fig. 19 shows the cylinders. The lighter "B.F.B." wheel centres referred to later were adopted.

A check of the probable weight showed that the designer was very near the maximum limit of the 32 tons allowable. The only



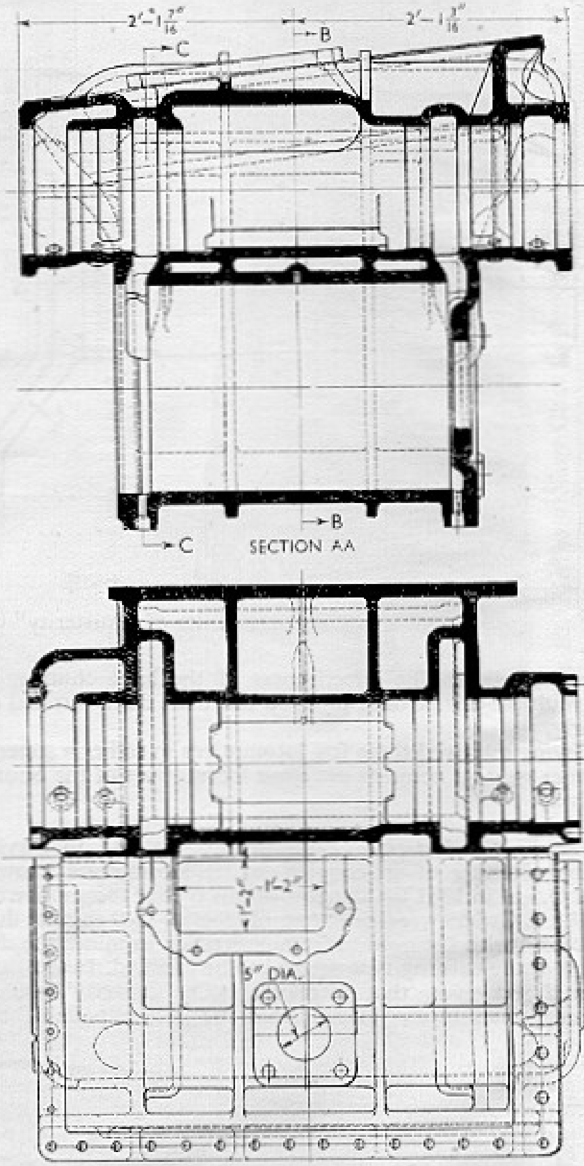


Fig. 19. Cylinders of Q1 Class ("Austerity") Locomotives, Southern Railway (1941)

way to keep within the maximum permissible weight was to suppress unessential parts, to lighten the cab and lagging, and to use a fabricated smokebox, the size and shape being governed by the need for giving access to all pipe joints.

Splashers and running boards were discarded as not essential, and as no longer anything but a survival. The lagging was redesigned both to reduce weight and to provide a casing, independent of the boiler, which could be prefabricated out of thin sheet so that the work was made suitable for sheet metal workers. Fabricated sandboxes were used, and the dragbox was also of fabricated construction.

The construction of the cab had to follow the same lines, i.e. as regards contour and form of construction. As a result of the care taken, the weight of the engine in working order is only 51¼ tons, whilst that of the engine and tender is 89¼ tons.

This 0–6–0 tender engine (Figs. 20–22, Plate 5) was nicknamed "Austerity" by the *Daily Express*. It is the most powerful engine of the type in the country, and is hauling the heaviest goods train on the Southern Railway; it is also used to work ordinary passenger trains. Consequently this locomotive provides an interesting study for the designer, as it combines the maximum boiler and cylinder power that can be provided within such a restricted weight as 52 tons. Table 11 gives the leading dimensions; those of the original class Q engines are also included for comparison.

The looks of the engine have given rise to much discussion. The lines are new, and result from the new methods of manufacture adopted. We must remember "Form follows function", and "Function creates form", the motto of the Davids of architecture against the Philistines. These lines are sound, and have reason behind them, and let us hope they will influence the locomotive designs of the post-war era.

The Three-cylinder 4–6–2 "Pacific" Engines, Southern Railway. For some time before the present war the traffic demands for increased weights of trains and speeds could not be met by the *Lord Nelson* engines, and more powerful machines were needed; in answer to this demand the *Merchant Navy* class was introduced in 1941. One of these engines, No. 21C3 *Royal Mail* is shown in Fig. 23, Plate 6. A front-end view of No. 21C12 is shown in Fig. 24, Plate 6.

The design problem was difficult, as a very powerful boiler

TABLE 11. LEADING DIMENSIONS OF 0–6–0 ENGINES, CLASSES Q AND Q1, SOUTHERN RAILWAY

Class	Q	Q1
Grate area	21·9 sq. ft.	27 sq. ft.
Firebox heating surface	122 sq. ft.	170 sq. ft.
Total evaporative heating surface	1,247 sq. ft.	1,472 sq. ft.
Total superheating heating surface	185 sq. ft.	218 sq. ft.
Boiler pressure	200 lb. per sq. in.	230 lb. per sq. in.
Weight of engine in working order	49 tons 10 cwt.	51 tons 5 cwt.
Weight of tender in working order	40 tons 10 cwt.	38 tons
Weight of engine and tender in working order	90 tons	89 tons 5 cwt.
Adhesive weight of engine in working order	49 tons 10 cwt.	51 tons 5 cwt.
No. of cylinders	2	2
Diameter and stroke	19 × 26 inches	19 × 26 inches
Driving wheel diameter	5 ft. 1 in.	5 ft. 1 in.
Tractive effort	26,157 lb.	30,000 lb.
Ratio $\frac{\text{Adhesive weight}}{\text{Tractive effort}}$	4·23	3·82
" $\frac{\text{Tractive effort}}{\text{Grate area}}$	1,195	1,110
" $\frac{\text{Firebox heating surface}}{\text{Grate area}}$	5·57	6·3
" $\frac{\text{Total evaporative heating surface}}{\text{Grate area}}$	56·9	54·5

was necessary. A large grate area had to be provided so that the coal, with its high proportion of dust, could be burnt without undue losses through the tubes, i.e. without excessive blast on the fire. This meant a wide firebox and a trailing axle.

With the grate area of 48½ sq. ft. which I considered the smallest to meet the conditions the weight limitations alone made a copper firebox undesirable. Experience in America, in the Dominions, and in South America, had demonstrated how successful the steel firebox was, and this was confirmed by the results on the Paris–Orléans Railway, with which I was familiar. The main reason imposing the use of a steel firebox was, however, the high boiler pressure—280 lb. per sq. in.—which had been decided upon. This pressure exceeds the recommended limit of pressure for copper boxes. Having decided to use steel fireboxes, the next step was to decide to weld the various plates; and this was done, both the inner and outer fireboxes being welded throughout. The resulting firebox is most attractive; there is no double thickness of plate anywhere. Two Nicholson syphons were fitted in order to improve the circulation. Drop type fusible plugs, which have a brass plug held in position by fusible metal, were fitted as an additional precaution against damage through low water. In order to protect the steel box and syphons as much as possible against cold air, Ajax automatic firedoors were provided. A general arrangement of the cab, including this firedoor, is shown in Fig. 25, Plate 6.

Fabrication was introduced wherever feasible. The smokebox is a good example as showing how, at long last, the shape of the box is made to suit the layout of the steam pipes. By using No. 22 S.W.G. sheet, in conjunction with cold-rolled sections, the weight of the lagging was kept low. The same type of construction was also used in the cab.

The engine is fitted with the "B.F.B." wheel centres, which are neither of the Boxpok nor of the double-disk types but something new. Besides reducing the weight by some 10 per cent, they ensure that the tyre is under uniform stress all round the circumference. Clasp brakes are fitted so that wheels and axles are not subjected to the usual longitudinal thrust, and by this means a larger brake block area is placed in contact with the tyre.

The tractive effort required was 37,500 lb.; and this is obtained by using three cylinders 18 inches in diameter by 24 inches stroke, with driving wheels 6 ft. 2 in. diameter. This is found to be the best size of wheel for the operating conditions.

The piston speed with a 24-inch stroke and a 6 ft. 2 in. diameter wheel, is the same as with a 26-inch stroke and a 6 ft. 8 in. wheel at any speed (expressed in miles per hour). Three cylinders driving the same shaft give practically perfect balance, and render the counterbalancing of reciprocating parts unnecessary. The engine, in consequence, exerts no hammer blow. Leading dimensions of these engines are given in Table 12.

A diagram of one set of the valve gear is shown in Fig. 26. There are three sets of valve gear, one for each cylinder, driven by a three-throw crankshaft revolving in phase with the main crank axle, from which it is driven by Morse silent rocker chain. These sets of gear are enclosed in a sump, together with the crank axle, middle connecting rod, and crosshead; and all details are under continuous lubrication, the oil being pumped from the bottom of the sump by two reversible pumps and discharged over all the moving parts. Accessibility is needed, in order to make good the wear and tear, but it is better to obviate the wear and hence to render accessibility a secondary consideration.

TABLE 12. LEADING DIMENSIONS OF THREE-CYLINDER 4–6–2 *Merchant Navy* LOCOMOTIVE, SOUTHERN RAILWAY

Grate area	48·5 sq. ft.
Firebox heating surface	275 sq. ft.
Total evaporative heating surface	2,450·9 sq. ft.
Total superheating heating surface	822 sq. ft.
Boiler pressure	280 lb. per sq. in.
Weight of engine in working order	94 tons 15 cwt.
Weight of tender in working order	47 tons 16 cwt.
Weight of engine and tender in working order	142 tons 11 cwt.
Adhesive weight of engine in working order	63 tons 0 cwt.
No. of cylinders	3
Diameter and stroke	18 × 24 inches
Driving wheel diameter	6 ft. 2 in.
Tractive effort	37,500 lb.
Ratio $\frac{\text{Adhesive weight}}{\text{Tractive effort}}$	3·76
" $\frac{\text{Tractive effort}}{\text{Grate area}}$	773
" $\frac{\text{Firebox heating surface}}{\text{Grate area}}$	5·67
" $\frac{\text{Total evaporative heating surface}}{\text{Grate area}}$	50·5

The piston valves, 11 inches in diameter, are operated by cross rocker-shafts in the exhaust cavity. This arrangement enables outside admission to be used without glands, a decided advantage when we are dealing with highly superheated steam at 280 lb. per sq. in. pressure. Fig. 27, Plate 6, shows No. 21C8 working the 10.50 a.m. train from Waterloo.

It may be interesting, before I conclude this address, to compare the Great Northern Railway "Atlantic" engine of 1902 with the Southern Railway "Pacific" engine of 1942 (Table 13).

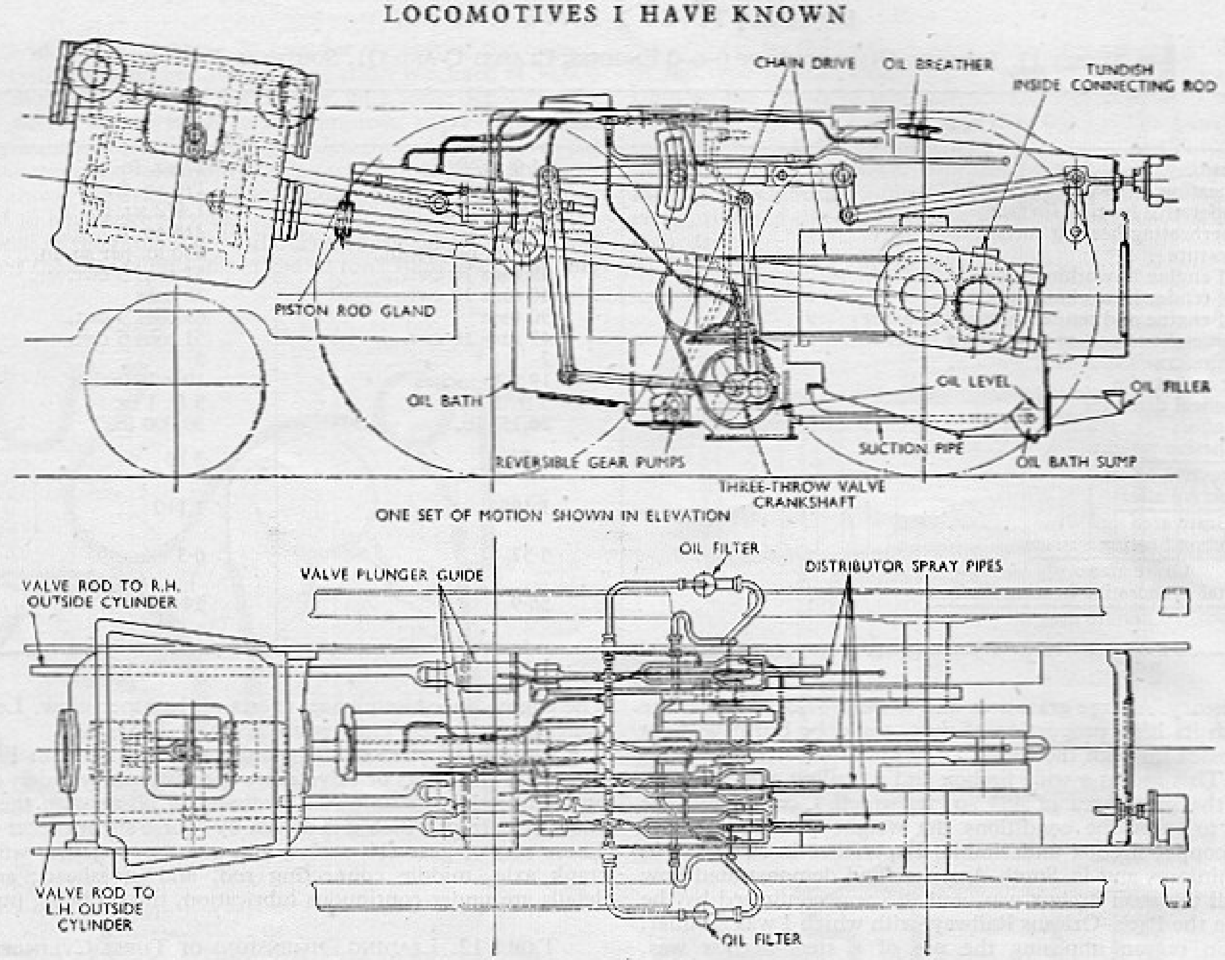


Fig. 26. Valve Gear of 4–6–2 Three-Cylinder Locomotive, Southern Railway

Conclusion. The steam locomotive has continued to make steady progress in efficiency and in capacity. The major disadvantages militating against the development of the locomotive are incidental to the use of coal as mined, and raw water with its dissolved salts and gases. Apart from the smoke nuisance, the handling of coal and the disposal of the ashes are serious drawbacks to its use.

Table 13. Comparison of Leading Dimensions of G.N.R. *Atlantic* Engine (1902) with S.R. *Pacific* Engine (1942)

	G.N.R. *Atlantic*	S.R. *Pacific*	Percentage increase
Grate area, sq. ft.	30·9	48·5	57
Firebox heating surface, sq. ft.	141·0	275·0	95
Total combined heating surface, sq. ft.	2500·0	3272·9	30·9
Boiler pressure, lb. per sq. in.	175	280	60·0
Weight of engine in working order, tons.	68·4	94·75	38·5
Adhesive weight, tons	36	63	75·0
No. of cylinders	2	3	—
Diameter and stroke of cylinders, inches	$18\frac{3}{4} \times 24$	18×24	—
Driving wheel diameter	6 ft. 8 in.	6 ft. 2 in.	—
Tractive effort, lb.	15,690	37,500	139

Experiments with pulverized coal and a mixture of pulverized coal and oil have been unsuccessful so far. We must hope that home-produced liquid fuel, either natural or synthetic, will become available for use in locomotives, just as imported liquid fuel is now provided for other forms of transport. The restriction on availability resulting from the limited weight of coal carried, the need to replenish it, and the need for the disposal of ashpan and smokebox ashes will then disappear.

The water problem, so far as ordinary water is concerned, we may now consider in sight of solution, in view of recent progress in water treatment. Crude water can now be treated, especially when allied with all-steel boilers, in such a way as to obviate corrosion and priming trouble. The loss of working days required for boiler washing out and for boiler attention will then be a thing of the past. We must not be satisfied, however, until we have recovered most, if not all, of the water lost in the exhaust steam. We must not forget the latent heat in the exhaust steam waiting to be returned to duty.

As regards the mechanical side of the locomotive, we now have engines with fully enclosed motions under continuous lubrication, and this development, we may hope, will overcome lubrication troubles. The high-pressure all-steel welded boiler, by enabling repairs to be carried out quickly and readily (thanks to the development of welding) should reduce the mechanical care required to the boilers. We have seen too that it is possible to balance a locomotive so that no hammer blow is exerted on the track. We have also seen that the achievement of a high power/weight ratio has been assisted by adopting designs only realizable by the latest process of fabrication.

As regards the efficiency of the engine, higher pressures, in conjunction with higher superheats, have reduced the quantity of steam used; and the improvements in valve events and cylinder design have allowed more work to be extracted from the steam in the cylinders. We must remind ourselves that it is the efficiency of the machine as regards the power developed at the rail that matters, and in this the steam locomotive has little to fear.

The progress already made, and to be expected, in all the above directions, by increasing the reliability and availability of the steam locomotive and its economical efficiency, will ensure its continued and extended use. There is no reason to think finality has been reached.

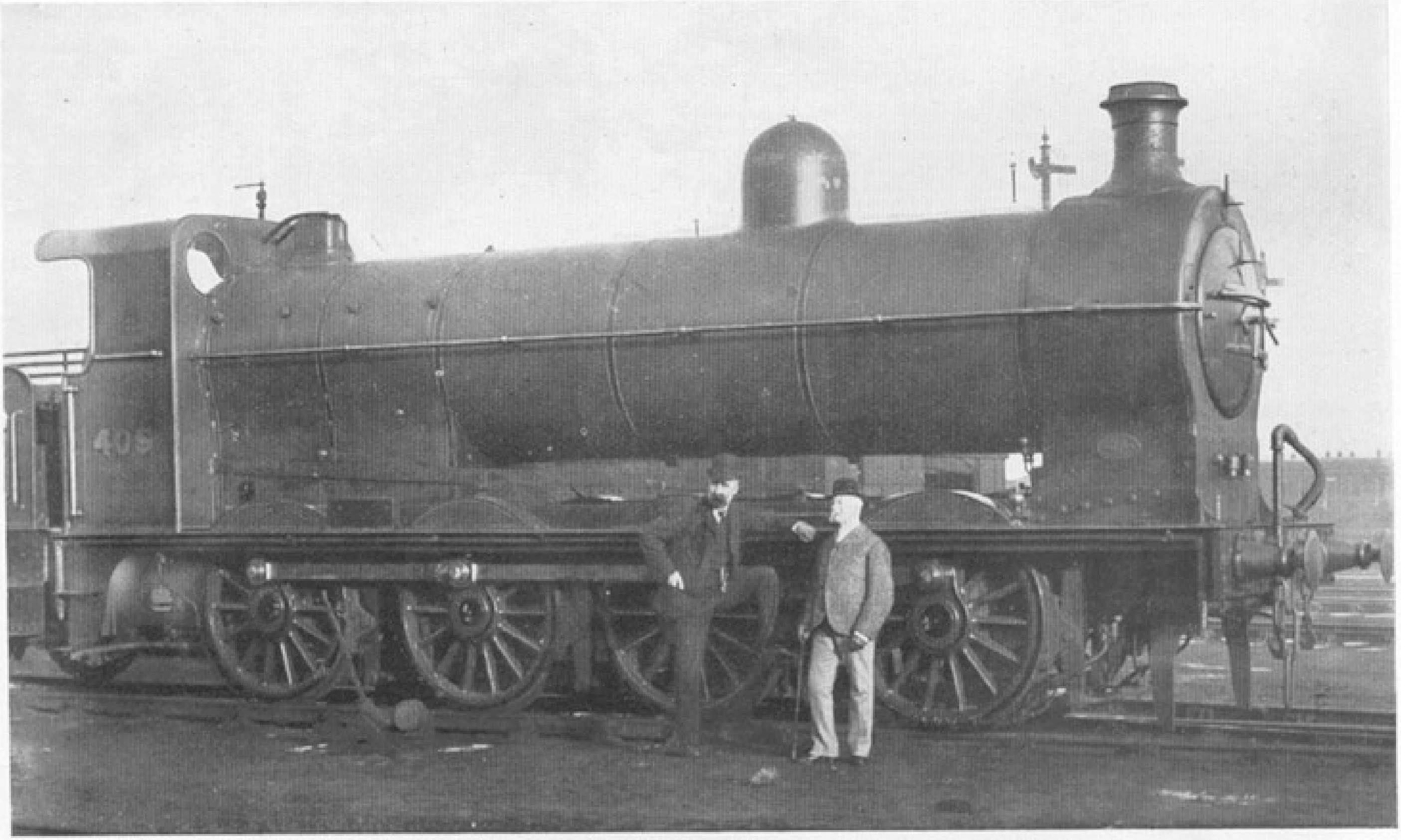


Fig. 1. Mr. Ivatt's 0–8–0 Mineral Locomotive (1901)

Mr. Ivatt (left) is seen with Mr. Archibald Sturrock, first locomotive superintendent of the G.N.R., who held office from 1850 to 1866.

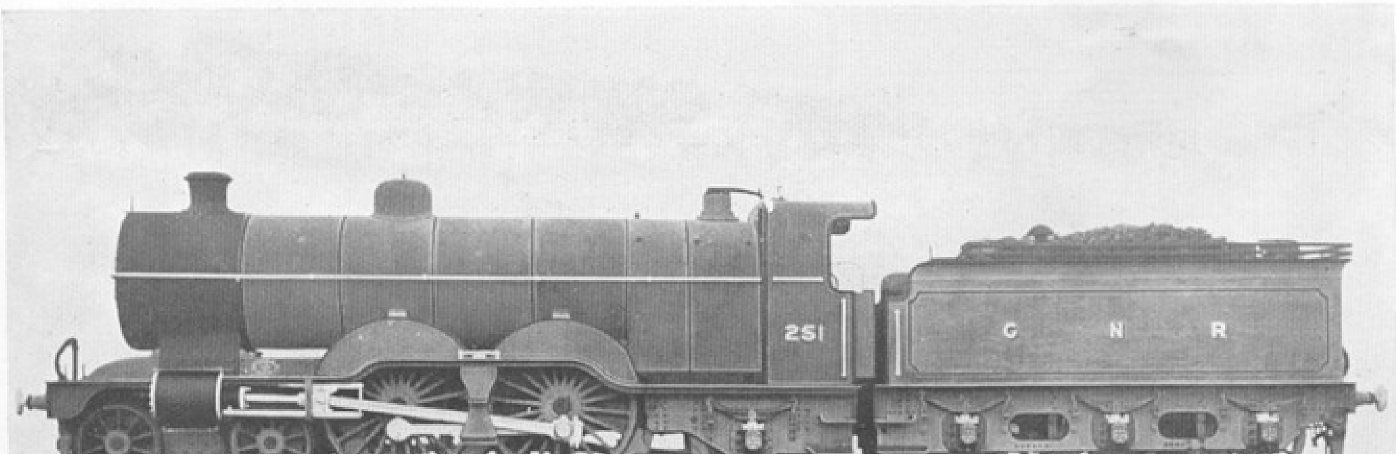


Fig. 3. Mr. Ivatt's first Large-Boilered 4–4–2 ("Atlantic") Locomotive (1902)

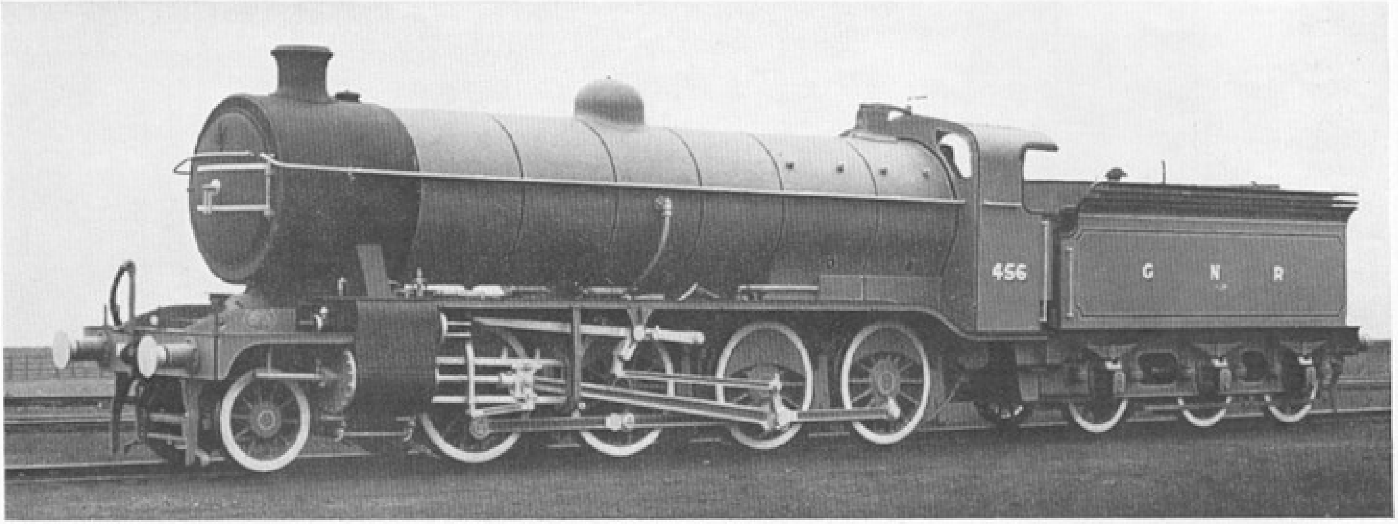


Fig. 4. Sir Nigel Gresley's first 2–8–0 Heavy Mineral Locomotive (1913)

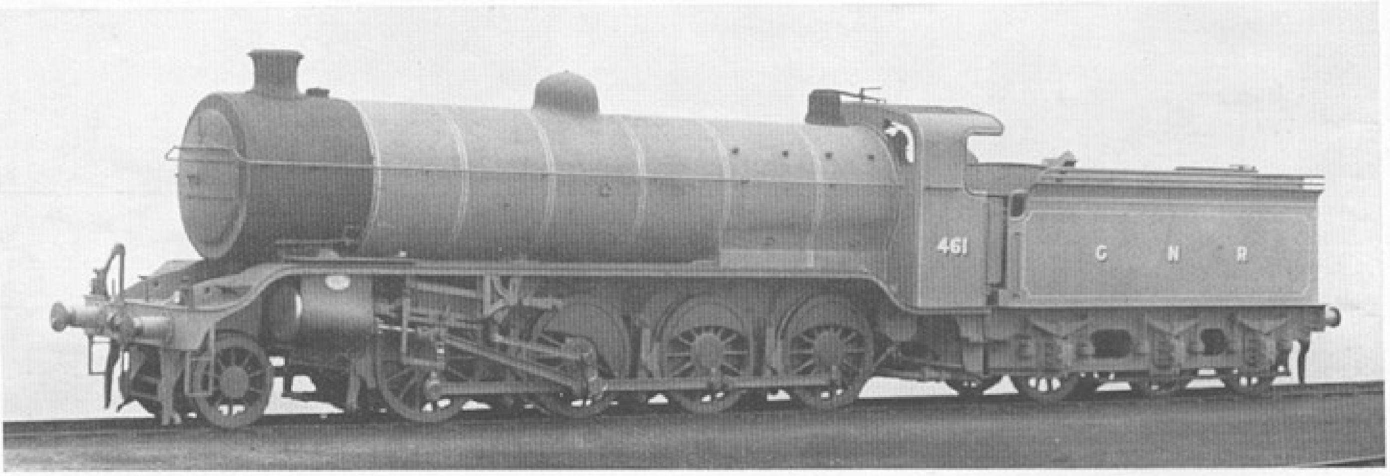


Fig. 5. Sir Nigel Gresley's first Three-Cylinder Locomotive (1918)

Fig. 6. Sir Nigel Gresley's first 4–6–2 ("Pacific") Locomotive (1922)

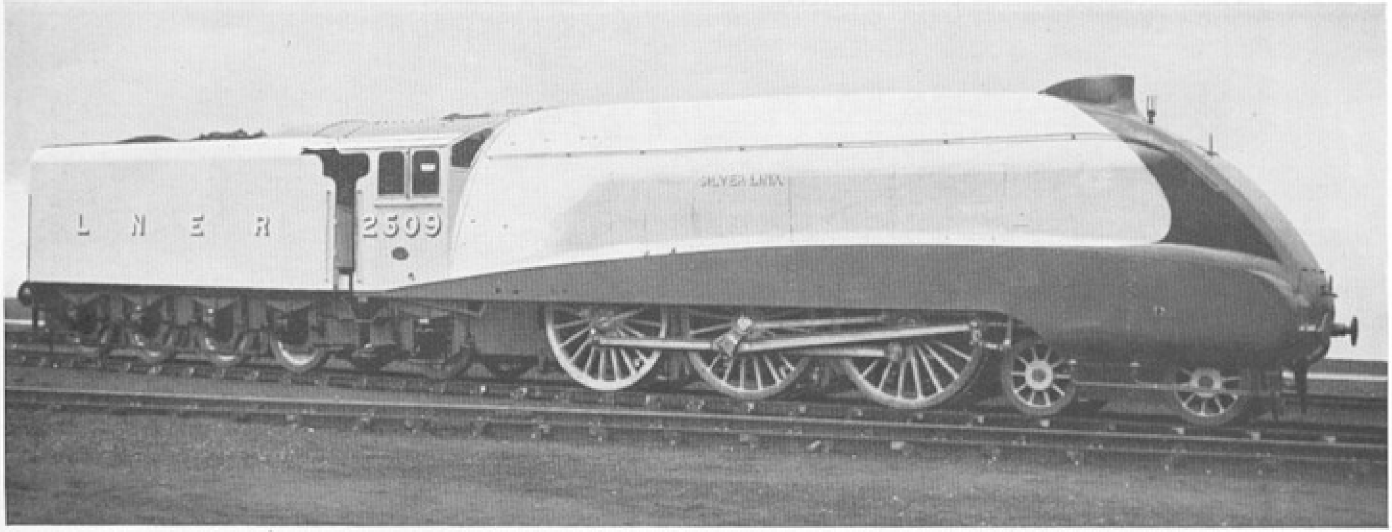


Fig. 8. Streamlined "Pacific" Locomotive (1935)

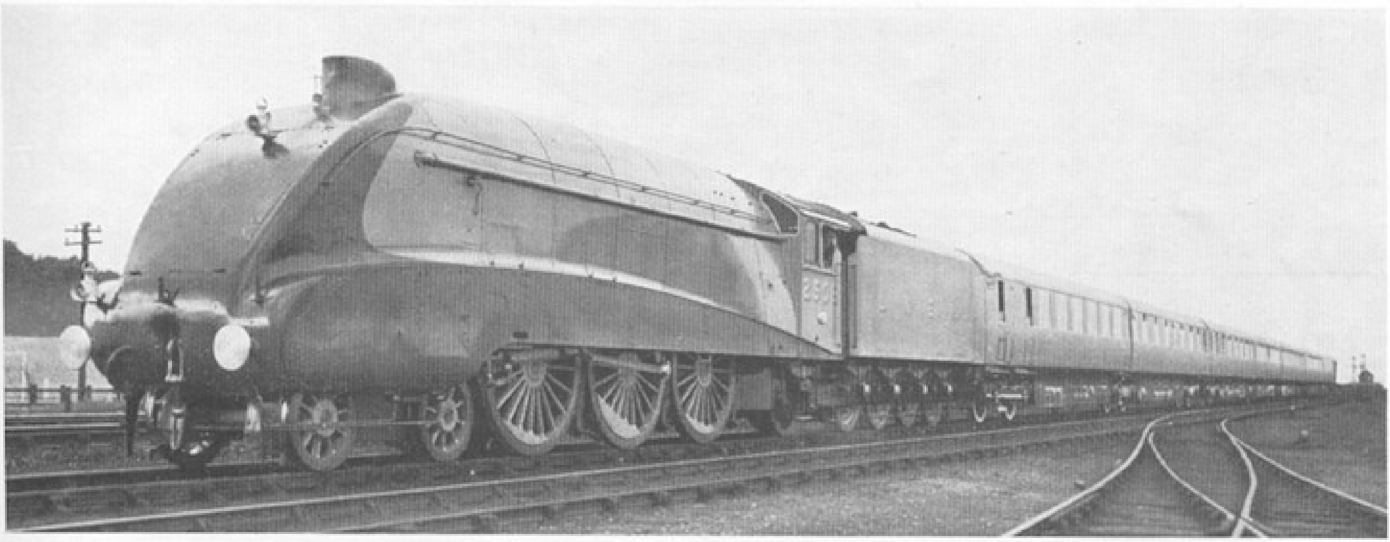


Fig. 9. Streamlined "Pacific" Locomotive No. 2509, *Silver Link*, and the *Silver Jubilee* Train (1935)

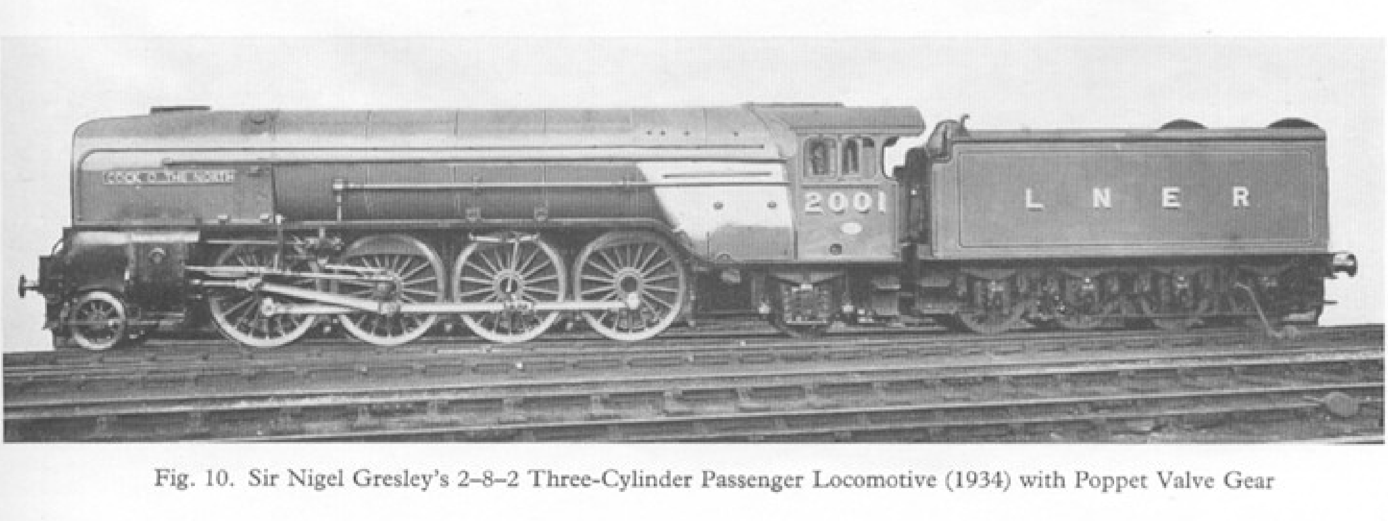


Fig. 10. Sir Nigel Gresley's 2–8–2 Three-Cylinder Passenger Locomotive (1934) with Poppet Valve Gear

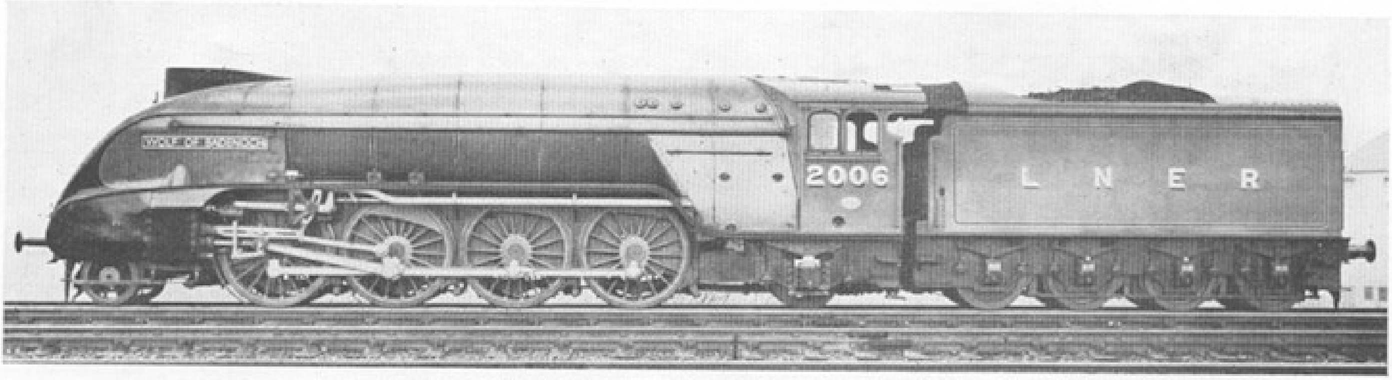


Fig. 11. Sir Nigel Gresley's 2–8–2 Passenger Locomotive with Walschaerts Gear and Modified Shape of Smokebox

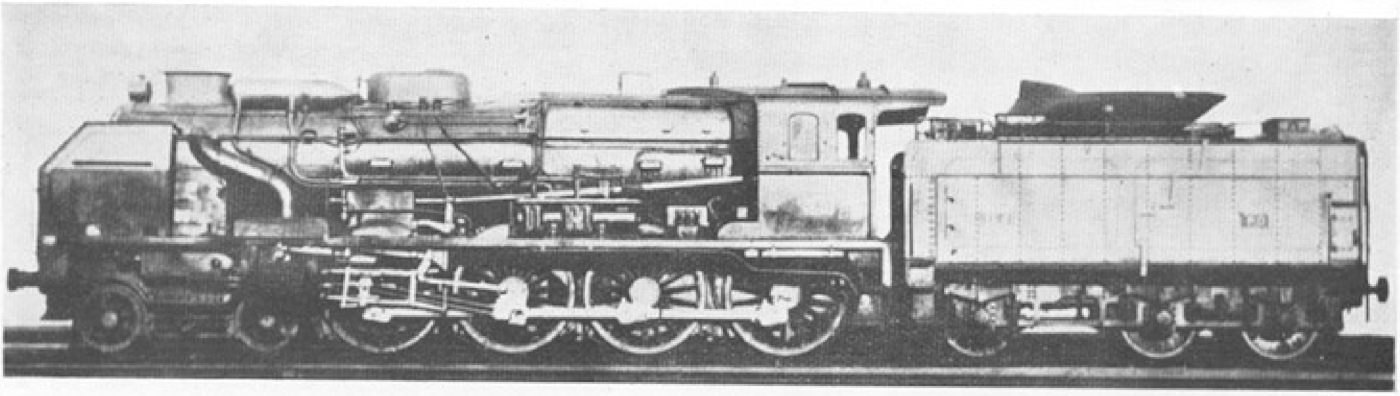


Fig. 12. Paris–Orléans Railway 4–8–0 Four-Cylinder Compound Locomotive (1935)

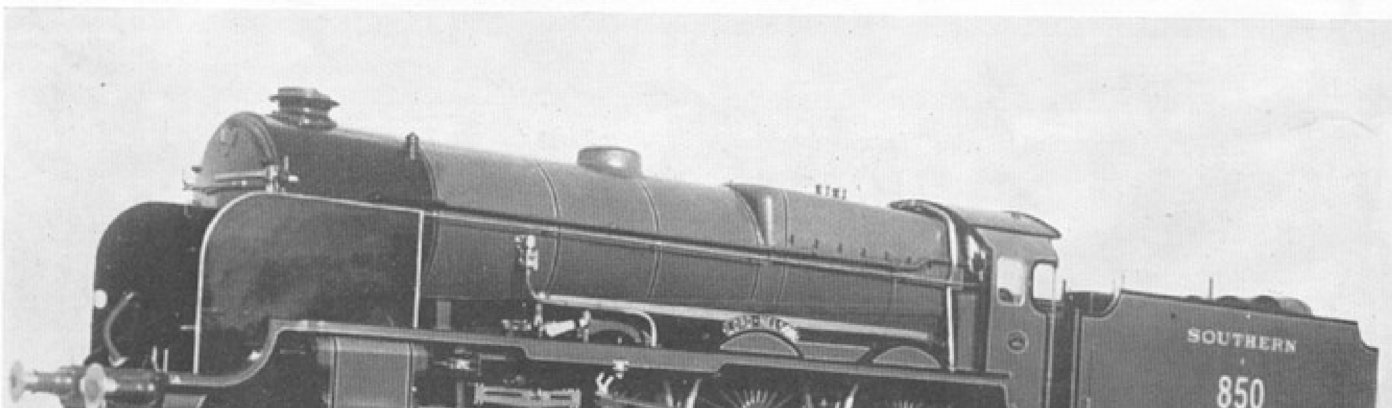


Fig. 15. Mr. Maunsell's Four-Cylinder 4–6–0 Locomotive *Lord Nelson* (1926)

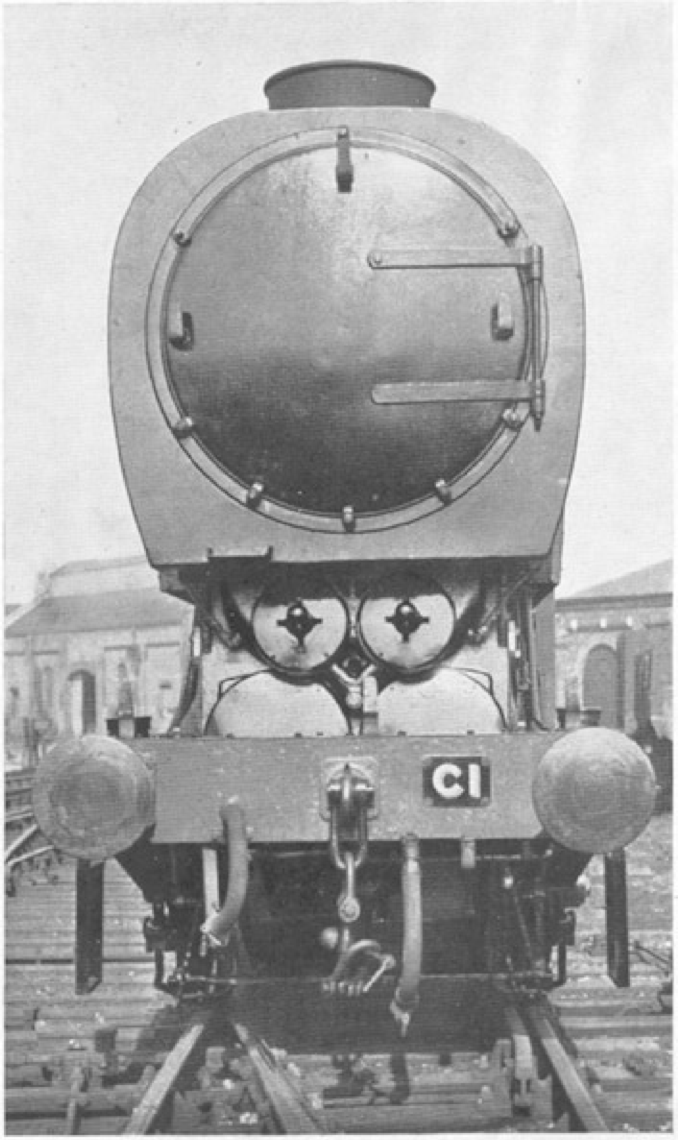


Fig. 20. Front View of Southern Railway 0–6–0 "Austerity" Locomotive (1942)

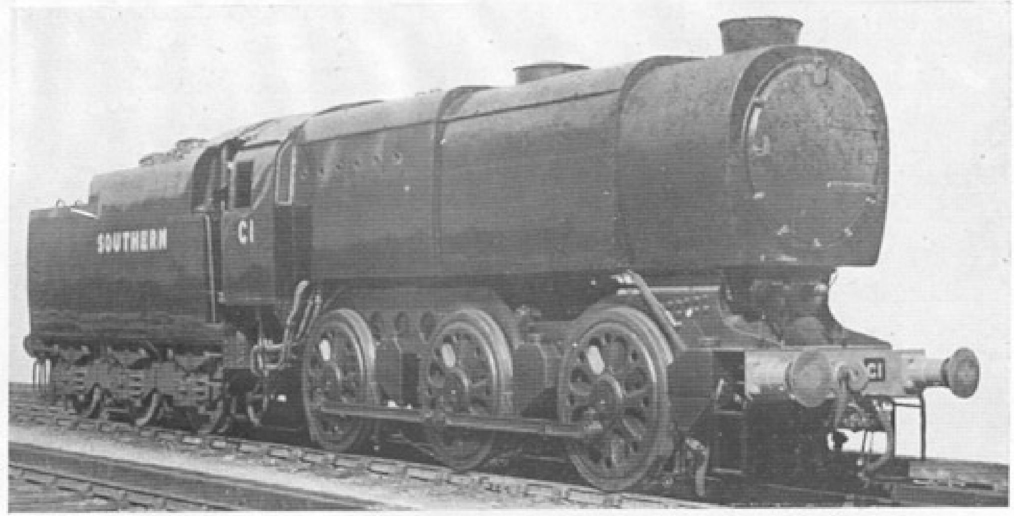


Fig. 21. Southern Railway 0–6–0 "Austerity" Locomotive (1942)

Fig. 22. Southern Railway 0–6–0 "Austerity" Locomotive hauling a Passenger Train

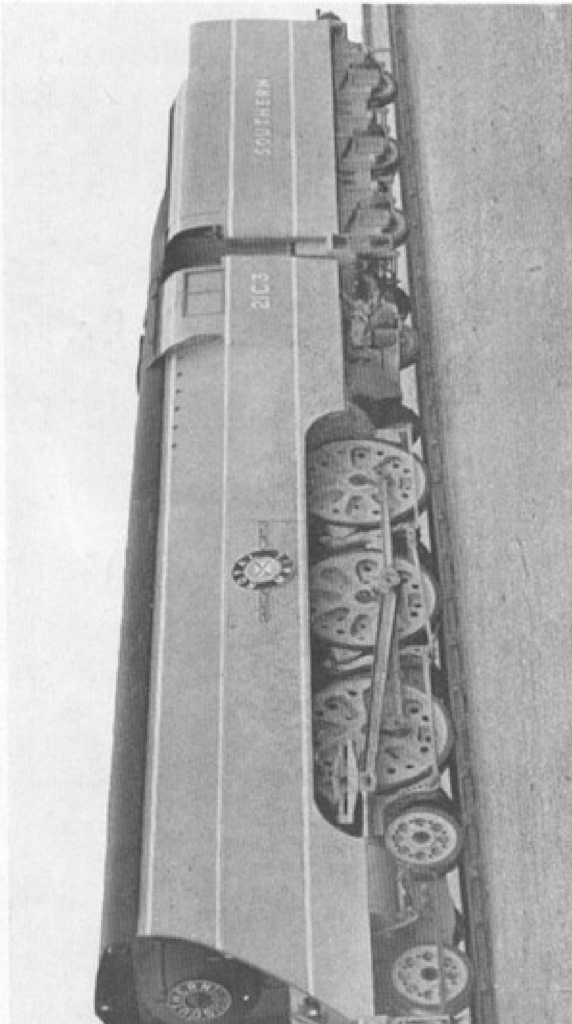


Fig. 23. Southern Railway Three-Cylinder 4-6-2 ("Pacific") Locomotive, of the *Merchant Navy* Class

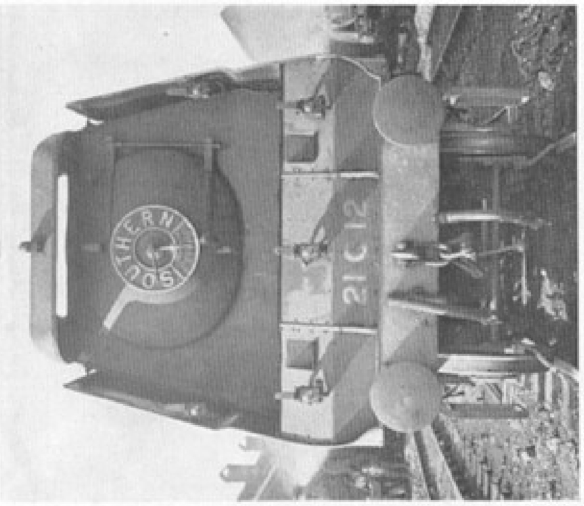


Fig. 24. Front View of *Merchant Navy* Class Locomotive

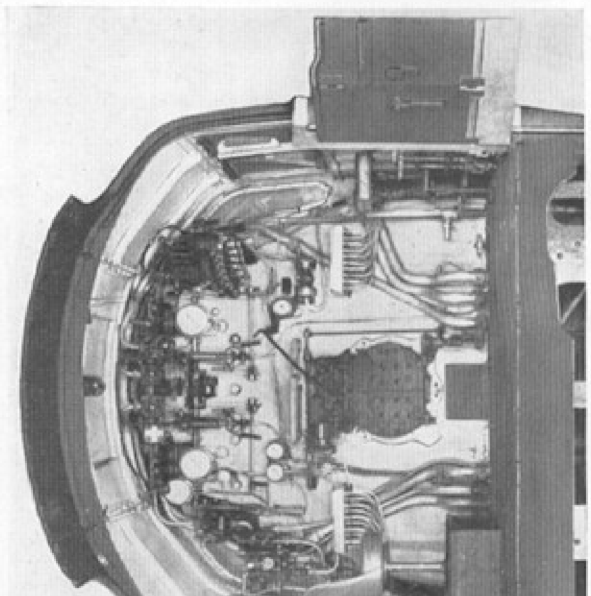


Fig. 25. Cab of *Merchant Navy* Class Locomotive

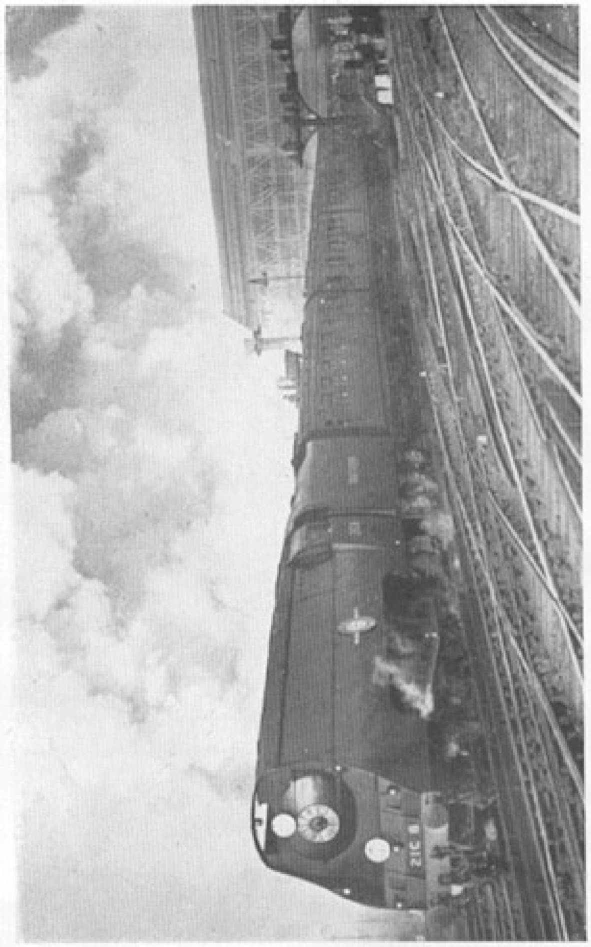


Fig. 27. *Merchant Navy* Class Locomotive working the 10.50 a.m. Train from Waterloo