A MODERN LOCOMOTIVE HISTORY

TEN YEARS' DEVELOPMENT ON THE L.M.S.—1923-1932

Paper read before the Institution by E. S. COX, Member of Council, on January 2nd 1946 and repeated in Derby and Newcastle-on-Tyne.

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Introduction.

As a result of the amalgamation in 1923 of practically all the then existing Railway Companies into four main line groups, a period unparalleled in British Railway history occurred in which all the varying practices of the constituent companies were gradually welded together into a recognisable standard for each group. It was felt that some account of locomotive development during this period on the largest of the four groups might be of interest to the Institution, and that the many controversial features of design and performance touched upon might have a bearing on some present day problems and give rise to a measure of discussion.

As may be imagined this unifying process was not achieved without stress and strain. Eight Chief Mechanical Engineers had been in charge of locomotive design on the constituent companies of the L.M.S., and each had followed widely different policies and practice, having long years of local tradition in the background. Three men, successively, held the post of C.M.E. on the L.M.S. in the period under consideration, Hughes, Fowler and Lemon, and around them different personalities emerged to positions of power and exerted an influence inevitably coloured by their background and experience.

Under grouping, locomotives ran far afield from their parent system, and were tested one against the other, often with surprising results. Famous locomotive types of comparatively modern construction were broken up and others less well known were adopted as standard and built in large numbers. New designs were prepared, some of which were built, while others, sometimes of the greatest technical interest, were abandoned before construction.

Out of this ferment 14 standard types emerged, and a recognisable L.M.S. school of design arose which served as a stem to which Sir William Stanier in subsequent years grafted his G.W.R. experience in order to bring forth present-day L.M.S. locomotive practice.

This paper endeavours to show the "whyfore" behind the various decisions which were made, and to draw attention to the lessons learned from the types which failed as from those which succeeded and from new designs stillborn as from those now familiar to us to-day.

Only locomotive design and performance are touched on here with some reference to repair costs. The equally important developments in Works organisation and equipment are outside the scope of this paper.

Position at Grouping.

On January 1st, 1923, the L.M.S. came into being with 10,316 steam locomotives of 393 different types, most of which have been illustrated and described at one time or another in the Technical Press.

High degree superheating had been accepted for all important new construction since 1910 and numerous existing engines had been converted. In all 1,882 Superheated engines existed. In addition to forty-five 4-4-0 express engines on the Midland, compounding was represented by eleven 0-8-0 Freight engines on the L.Y.R. and ninety-eight Webb survivals on the L.N.W.R. of 4-4-0, 0-8-0 and 2-8-0 types. Stephenson's valve gear was the most widely used, but Joy's gear on the L.N.W. and L.Y.R. sections ran it a close second. Two hundred and twenty-three engines had Walschaert gear. Valve travel of 4in. to 4½in. and steam lap of about 1in. was all but universal. Only 33 engines had valve travel over 6in. and of these only 4 had as much as 1½in. lap.

Restrictions in weight per foot run were especially severe on the Midland, while the loading gauge, except on the Caledonian, allowed only a limited width at platform level, one reason for the small number of outside cylinder types. On the other hand any engine for general use north of the border, apart from the West Coast main line between Carlisle and Glasgow, had to be restricted to a height of 12ft. 11in., although 13ft. 5½in. was permissible on the L.Y.R. The L.N.W. and L.Y.R. main lines were equipped with water troughs roughly every 30 miles and thus required only small tenders. Midland troughs were spaced every 50 miles and Scotland had no troughs at all.

Each Company believed the engine types it had developed were especially suited to the natural features of its own lines and traffic conditions. Until the preliminary amalgamation of L.N.W.R. and L.Y.R. in 1922, hardly any exchange of locomotives between one Company and another had taken place within the lines forming the L.M.S. nor was there much interchange of design data.

In general the best performance in efficiency and reliability came from the smaller, older types which carried superheaters. With few exceptions the larger and later classes were less satisfactory. The newly-formed group lacked a first class modern express locomotive for the heavy Anglo-Scottish trains, a Mixed Traffic type of wide range, a large general purpose passenger tank, and a large main line freight engine.

Personalities and Policies.

In this country it is usual for the influence of the C.M.E. on locomotive design to be profound, and classic cases can be called to mind where an incoming C.M.E. has completely reversed the policy of his predecessor. More frequently, however, a succession of C.M.Es.

have followed a tradition, so that development has proceeded over many years within the framework of a school of design initiated by some famous predecessor. It so happened that the principal companies forming the L.M.S. had largely followed this latter course. Thus the influence of Webb (apart from his Compounding) and Whale, was strongly marked in the work of Bowen Cooke and Beames on the L.N.W. Kirtley, Johnson, Deeley and Fowler represented an unbroken line of development on the Midland, while Aspinall and MacIntosh greatly influenced the work of their successors on the L.Y.R. and Caledonian respectively. It was inevitable, therefore, that each former C.M.E. now called upon to serve the unified Company should retain a strong belief in his own policy and designs, and with him, in varying degree, Motive Power Superintendents and design staff as well.

Five men particularly influenced what was done in the first ten years—George Hughes, the first C.M.E., Sir Henry Fowler who succeeded him and J. E. Anderson, the first Superintendent of Motive Power, H. P. M. Beames, former C.M.E. of the L.N.W.R., and John Barr, in charge of Motive Power on the old Caledonian and subsequently on the Northern Division of the L.M.S.

The influence of these men was great, but the selection of engine types finally standardised and built, as well as those broken up, was not based on their personal opinions alone. From the beginning engines of one constituent Company were tried over the lines of the others whenever loading gauge and weight restrictions did not prohibit. Besides intensive Dynamometer car testing, a system of statistics was initiated some time after grouping known as " Individual Costing " which aggregated and related to mileage run every pound of coal used, and every penny spent on repairs for each individual engine on the system, subdivided to throw up the figures for the principal parts. This magnificent tool of management was eventually of the greatest value in enabling accurate long term comparisons to be made in such a period of rationalisation, between different engine types, and was very effective in separating the sheep from the goats with complete impartiality. No engine was permitted to enter the charmed circle of the standard types which did not make a good showing under all the foregoing headings.

Even more important than standardisation of types was standardisation of components, which was vigorously pursued. Thus amongst the 14 standard types of engine referred to, there were only 12 types of boiler, of which three took the same flanging blocks, while six out of 12 were also fitted to large groups of non-standard engines. Steam fittings, motion pins and bushes and consumable parts such as firebars and brakeblocks, etc., were standardised over a considerable number of different engine types, the overall result of this policy being the economic benefit of quantity production, coupled with reduced stocks.

One other matter of policy requires mentioning in order to understand the course of events. Before grouping the Midland had been unique in consistently pursuing a " small engine " policy. Passenger trains on that system were lighter and more frequent than on other lines, seldom averaging above 250 tons. At holiday times and other periods when heavy traffic was inevitable, double heading was freely resorted to. After grouping the Operating Department came under Midland influence and it was hoped to extend this policy to the L.M.S. as a whole, the intention being so to subdivide even the Western Division main line services that nothing larger than a Class 4* 4-4-0 passenger engine was required. This is not the place to discuss the merits or demerits of such policy, but the fact remains that, until it was proved impracticable by the natural development of traffic conditions, this objective was the source of considerable resistance to proposals for the introduction of new designs of large engines. Eventually the need for such engines became acute and they were constructed in 1927, and from that point onward the small engine policy was gradually abandoned.

New Construction 1923-1932.

Two thousand one hundred and sixty-five new locomotives were built for the L.M.S. in the period under review, 1,387 of them in the Company's own Shops. These are set out in Table I and the leading dimensions of the different classes are set out in Table II. The construction of these locomotives, among other factors, allowed of 4,123 existing engines of inferior performance and efficiency being broken up, so that with various subsidiary adjustments the stock fell to 8,450 by the end of 1932, a reduction of 18%. The number of different classes came down in the same time from 393 to 230.

No less than 2,002 of these new engines were to the 14 standard types, the development of which is described hereafter. Only 163 engines of non-standard type were built, and this insistence on keeping the number of types to be built down to a minimum from the start has been of the greatest subsequent value to the L.M.S in ensuring minimum repair costs.

Coal Consumption and Repair Costs, Yardsticks of Efficiency.

The yardsticks by means of which comparisons are drawn in the study of locomotive design which follows are the economic ones of fuel consumption and repair costs. Fuel consumptions taken on variable speed Dynamometer Car Tests are given, in all of which the coal used came from the same Yorkshire Colliery. Of these the coal per Drawbar Horsepower hour is the most reliable comparative figure provided the conditions of loading (e.g., full or empty wagons) speed or method of engine working does not vary too greatly over a given route. The same figure based on constant speed tests would have been more accurate, but no facilities for this kind of testing existed on the L.M.S.

*Note.—Power classification referred to throughout this paper is an L.M.S. system, segregating engines into one or other of eight classes based on tractive effort and boiler capacity at operating speeds. The higher figures refer to the higher powers, but due to different speed/power characteristics a Class 4 passenger engine, for example, is not directly comparable to a Class 4 freight engine.

in the period we are discussing. Projection of these test results into actual everyday service is given by the figures also quoted, for average coal consumption in lbs. per mile for the whole of the engines in a given class over long periods of time, 10 years in many cases. These latter figures are important commercially, since they measure the amount of coal the Company has to pay for including that supplied for lighting up, Shed duties, standing time, etc. While averaging out all the variations in weather, speed, load and quality of coal, such figures also include the effect of deterioration in efficiency between shoppings, and in addition the effect of occasional uneconomic use of the engines in the way of under or overloading made necessary by traffic conditions. They are thus really more accurate than test results in finally assessing the saving shown by one engine class over another on comparable work. Indeed, variable speed Dynamometer Car tests are only undertaken in order to telescope the long period in years necessary to obtain this overall average.

It is necessary that repair costs should be taken over a period of years, because it is only thus that the effect of major items such as tyre and cylinder renewals and heavy firebox repairs and renewals can be included and so bring repair costs up to a steady level truly representative of the performance of the class as a whole. Under "Individual Costing" repair costs were separately recorded for Engines and Boilers in the Shops and for such repair work as was carried out in the Sheds and the whole related to the annual mileage run to give a value in pence per mile. Many other things besides design enter into repair costs. Repair equipment and organisation, wage rates, piecework prices, cost of material and quality of repair to mention some. These are, however, liable on a given railway to have the same effect at any given time on the repairs costs of different engine classes, so that over a period of years, the difference between one class and another of comparable capacity, is principally that arising from difference in design or from the difference in repair mileage which design makes possible.

Because of the many variables, comparisons between repairs costs on one Railway against another would be invidious and for this reason the actual pence per mile values are not quoted in this paper. The L.M.S. Standard Class 2, 4-4-0 Passenger engine, especially cheap to repair, is rated at 100, and all other engine classes are rated pro rata, a class having the value 150 for example, having a 50% higher repair cost in pence per mile, averaged over the number of years stated in the table.

Hughes and Horwich.

George Hughes had been C.M.E. of the L.Y.R. since 1904, and a record of his work on that system is contained in his two papers before the Institution of Mechanical Engineers.* Familiar all his career with a railway of short runs and predominantly freight traffic, on his appointment in 1922 in charge of the locomotive department of the combined

*Proceedings of the Institution of Mechanical Engineers.
Locomotives designed and built at Horwich—1909, p. 561.
Compounding and Superheating on Horwich Locos.—1910, p. 399.

TABLE I.

NEW LOCOMOTIVES ADDED TO STOCK DURING TEN YEARS FOLLOWING AMALGAMATION.

STANDARD DESIGNS	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	Totals
Class 6, 4-6-0 Pass. Tender (Royal Scot)					50			20			70
,, 5x, 4-6-0 ,, ,, (3-cylinder)								(2)*		15	15
,, 4, 4-4-0 ,, ,, (Compound)		40	95	5	50					5	195
,, 2, 4-4-0 ,, ,, ...						50	19	4	30	35	138
Class 4, 2-6-4 Pass. Tank					4	21	50			10	85
,, 3, 2-6-2 ,, ,, ...								21	39	10	70
,, 2, 0-4-4 ,, ,, ...										9	9
Class 7, 0-8-0 Freight Tender							100	3	32	40	175
,, 5, 2-6-0 ,, ,, ...				13	87	8	22	95	10	10	245
,, 4, 0-6-0 ,, ,, ...		11	161	132	137	89					530
2-6-6-2 Freight Tank (Garratt)					3			30			33
Class 3, 0-6-0 ,, ,, ...		42	8	128	36	157	36		15		422
,, 2, 0-6-0 ,, ,, (Dock)						7	3				10
,, 0, 0-4-0 ,, ,, (Saddle)										5	5
TOTAL STANDARD DESIGNS		93	264	278	367	332	230	103	126	139	2,002
EXISTING NON-STANDARD DESIGNS PERPETUATED											
Class 5, 4-6-0 Pass. Tender (4-cyl. L. and Y. Class 8) ...	21	16	4								41
,, 4, 4-6-0 ,, ,, (Prince of Wales)		1									1
,, 4, 4-6-0 ,, ,, (Caledonian 14630 Class) ...			2	18							20
Class 3, 4-4-2 Pass. Tank (L.T.S.)	10		5		10			10			35
,, 2, 0-4-4 ,, ,, (Caledonian)			10								10
Class 7, 2-8-0 Freight Tender (S. and D.)			5								5
Class 3, 0-6-2 Freight Tank (North Stafford)	4										4
TOTAL NON-STANDARD DESIGNS PERPETUATED ...	35	17	26	18	10			10			116
NON-STANDARD NEW DESIGNS											
Class 5, 4-6-4 Pass. Tank (4-cyl. Baltic) (Horwich design) ...		10									10
Class 7, 0-8-4 Freight Tank (Shunter) (Crewe design) ...	29	1									30
TOTAL NON-STANDARD NEW DESIGNS	29	11									40
"SENTINEL" LOCOMOTIVES							2	4		1	7
GRAND TOTAL	64	121	290	296	377	332	232	187	126	140	2,165
NUMBER OF NEW LOCOMOTIVES BUILT IN L.M.S. WORKSHOPS	64	78	162	135	166	175	194	153	126	134	1,387

***These two Engines were counted as rebuilds and are not represented, therefore, as additions to stock.**

TABLE

PRINCIPAL DIMENSIONS OF

	Cylinders No.	Dia. × stroke in. in.	Coupled wheel dia. ft. in.	Boiler Pressure lbs. per sq. in.
Standard Designs				
Class 6, 4-6-0 Pass. Tender (Royal Scot) ...	3	18 × 26	6 9	250
,, 5X, 4-6-0 ,, ,, (3 cylinder) ...	3	18 × 26	6 9	200
,, 4, 4-4-0 ,, ,, (Compound) ...	1 2	19 × 26 21 × 26	6 9	200
Class 2, 4-4-0 ,, ,, ...	2	19 × 26	6 9	180
Class 4, 2-6-4 Pass. Tank	2	19 × 26	5 9	200
,, 3, 2-6-2 ,, ,, ...	2	17½ × 26	5 3	200
,, 2, 0-4-4 ,, ,, ...	2	18 × 26	5 7	160
Class 7, 0-8-0 Freight Tender	2	19½ × 26	4 8½	200
,, 5, 2-6-0 ,, ,, ...	2	21 × 26	5 6	180
,, 4, 0-6-0 ,, ,, ...	2	20 × 26	5 3	175
2-6-6-2 Garratt.	4	18½ × 26	5 3	190
Class 3, 0-6-0 Freight Tank	2	18 × 26	4 7	160
,, 2, 0-6-0 ,, ,, (Dock)	2	17 × 22	3 11	160
,, 0, 0-4-0 ,, ,, (Saddle) ...	2	15½ × 20	3 10	160
Existing Non-Standard Designs Perpetuated.				
Class 5, 4-6-0 Pass. Tender (4-cyl. L. & Y. "Class 8")	4	16½ × 26	6 3	180
,, 4, 4-6-0 Pass. Tender (L. N. W. "Prince of Wales")	2	20½ × 26	6 3	180
,, 4, 4-6-0 Pass. Tender (Caledonian 14630 Class)	2	20½ × 26	6 1	180
Class 3, 4-4-2 Pass. Tank (L.T.S.) ...	2	19 × 26	6 6	170
,, 2t, 0-4-4 ,, ,, (Caledonian) ...	2	18¼ × 26	5 9	180
Class 7, 2-8-0 Freight Tender (S.&D.) ...	2	21 × 28	4 8½	190
Class 3, 0-6-2 Freight Tank (N.S.R.) ...	2	18½ × 26	5 0	175
Non-standard New Designs.				
Class 5, 4-6-4 Pass. Tank (4-cyl. Baltic) ...	4	16½ × 26	6 3	180
Class 7, 0-8-4 Freight Tank (Shunting) ...	2	20½ × 24	4 5½	185

II.

ENGINES SHOWN IN TABLE I.

Heating surfaces sq. ft. Tubes	Firebox	Total	Supr.	Grate Area sq. ft.	T.E. at 85% B.P. lbs.	Weight in working order Engine T	C	Q	Engine and Tender T	C	Q
1,892	189	2,081	399	31.2	33,150	84	18	0	127	12	0
1,450	183	1,633	365	30.5	26,520	80	15	0	123	9	0
1,170	147	1,317	272	28.4	22,649	61	14	0	104	8	0
1,034	124	1,158	246	21.1	17,729	54	1	0	95	5	0
953	137	1,090.5	266	25.0	23,125	86	5	0	—	—	—
693	103	796	173	17.5	21,486	70	10	0	—	—	—
967	104	1,071	—	17.5	17,099	58	1	0	—	—	—
1,402	150	1,552	342	23.6	29,747	60	15	0	101	19	0
1,345	160	1,505	307	27.5	26,580	66	0	0	108	4	0
1,034	124	1,158	246	21.1	24,555	48	15	0	89	19	0
1,954	183	2,137	466	44.5	45,620	155	10	0	—	—	—
967.5	97	1,064.5	—	16.0	20,830	49	10	0	—	—	—
923	85	1,008	—	14.5	18,400	43	12	0	—	—	—
603	57	660	—	11.75	14,200	33	0	0	—	—	—
1,730	180.5	1,910.5	394.9	27.0	28,879	79	1	0	119	1	0
1,376	136	1,512	304.4	25.0	22,290	66	5	0	105	10	0
1,529.5	146.5	1,676	258.25	25.5	22,900	74	15	0	116	5	0
1,052	128	1,180	—	19.8	17,388	71	10	0	—	—	—
994	98	1,092	—	17.0	19,201	59	12	0	—	—	—
1,321	148	1,469	373	28.4	35,296	64	15	0	109	16	3
807	118	925	152	19.0	22,061	64	19	0	—	—	—
1,817	180	1,997	394.9	29.6	28,879	99	19	0	—	—	—
1,538	149	1,687	358.6	23.6	29,814	88	0	0	—	—	—

L.N.W. and L.Y.R. Companies, and in 1923 to that of the whole L.M.S. group, he was faced with all the problems of a major trunk line entering the uncharted field of large scale amalgamation.

So far as locomotive design is concerned he had already in 1922 given consideration to provision of a main line passenger class, a large passenger tank and a heavy freight type for the L.N.W.R. system. The first of these was the super heater conversion of his earlier 4-cylinder 4-6-0 type, which unfortunately did not prove suitable for general use on the Anglo-Scottish service. A number of them were put into service on the Crewe-Carlisle Section, but although capable of good performance on occasion, their steaming, coal consumption and

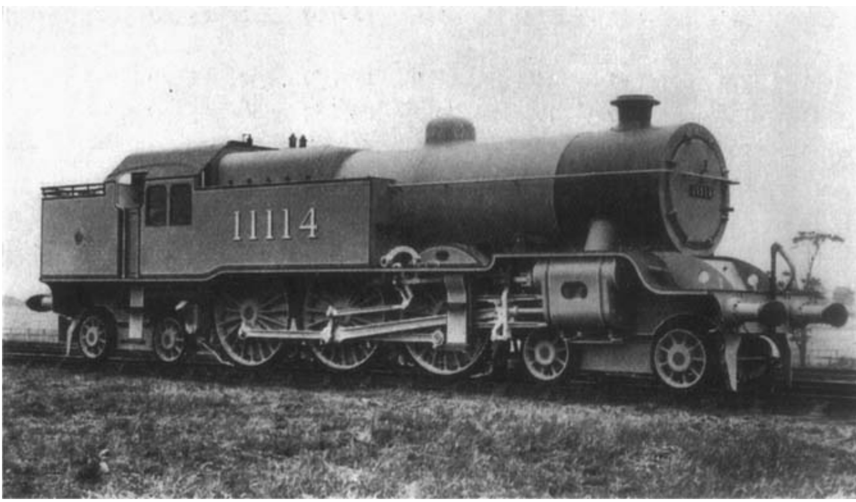


FIG. 1.

HORWICH 4-CYL. 4-6-4 TANK ENGINE.

reliability were not outstanding. Table III gives some particulars of their performance, which it is possible to realise now was affected by the type of piston valve used with integral ball compression release valves—Fig. 19. These caused serious internal steam leakage.

A tank version of this engine was put in hand and completed in 1924, in the form of the Baltic tank shown in Fig. 1. The original intention was to build 60, but in view of the great weight which limited general utility, only 10 were completed, frames and details which had been put in hand for the next 20 being used for further units of the tender engines. This class was not a success, being heavy on fuel and repair costs, as a comparison of Col. 3 Table III and Col. 3 Table X will indicate, and it was broken up between 1938 and 1942.

For freight work there existed a 2-10-0, 4-cylinder simple design, actually prepared in 1913, based on the Belgian engines of that wheel arrangement introduced by Flamme in 1910. Fig 2 depicts this interesting engine and gives leading dimensions. Intended to do the work of two 0-6-0 engines, it was to have a number of features conducive to efficiency such as wide firebox, 7in. valve travel, and direct steam-ports. This design was re-examined in 1922 and again in 1924 when the question arose of superseding double heading on the Nottinghamshire-London coal trains on the Midland Section. While this was the heaviest regular mineral traffic on the L.M.S., unfortunately the route was subject to severe width and weight limitations, and it was found impossible with the technique available at the time, to adapt a ten-coupled engine to that road. The future, which 20 years later has seen

TABLE III.

COMPARATIVE PERFORMANCE OF HORWICH DESIGNS.

Class of Engine	4-6-0 4-cyl.	4-6-4T 4-cyl.	2-6-0 Walschaert	2-6-0 Lentz
From Individual Costs Averaged over 10 years			(1)	(1)
Coal per mile - - lbs.	59.7	65.8	60.4	57.3
Repair Cost Index (4) ...	185	195	108 (both)	

Representative Dynamometer Car Tests	(2)	(2)	(3)		
Engine No.	10460 as built Ball anti compression valves	10464 later altn. to plain narrow ring valves	11112 as built Ball anti compression valves	13161 Walschaert	13129 Lentz
Route	Preston-Carlisle	Preston-Carlisle	S'thport-Mancr.	Mancr.-London	Mancr.-London
Av. Wt. of train tons ...	379	351	271	490	485
Av. Running speed m.p.h. ...	52.6	46.1	37.2	35.1	31.9
Coal consumption					
lbs. per mile	54.7	43.8	44.0	44.4	39.2
lbs. per ton mile (inc. engine)	.114	.094	.120	.076	.066
lbs. per DBHP/hr. ...	5.10	4.00	4.63	3.38	3.34
lbs. per sq. ft. grate per hour	96.5	68.1	55.1	56.8	45.4
Water consumption					
Gallons per mile	37.7	34.5	—	38.2	35.2
lbs. per DBHP/hr. ...	35.0	31.4	—	29.1	29.8
Evaporation lbs. water per lb. coal	6.87	7.88	—	8.61	8.00

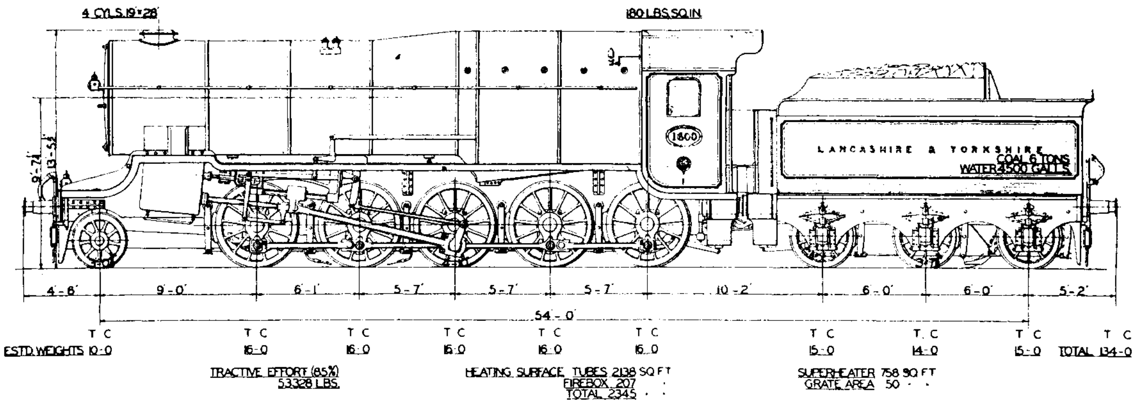
NOTES:—

(1) Six years' average.

(2) Both engines had 1¼ in. lap valves, but 10460 had been out of Shops 20,783 miles, by which time steam leakage past ball release valve heads would have set in. Engine 10464 had run 4 000 miles out of Shops and gained some advantage from lower booked speed with consequent lower rate of combustion.

(3) These engines had 1.3/16 in. lap, 6⅞ in. valve travel. Other tests over the harder Manchester-Colne line gave consumptions as high as 5.8 lbs. coal/DBHP/hr.

(4) Midland Class 2 4-4-0 engine taken as 100.



L & Y 2-10-0 GOODS ENG.

FIG. 2.

HORWICH PROPOSAL FOR 4-CYLINDER 2-10-0 FREIGHT ENGINE.

2-10-0's actually at work on the same route, was veiled to Hughes and his design staff, but in fairness it must be noted that the Ministry of Supply engines of to-day are much less powerful machines than were contemplated in 1924.

The unsuitability of the existing 4-6-0 engines and the fact that Gresley's Pacific had emerged on the L.N.E.R., urged Hughes to develop a 4-cylinder 4-6-2 design in 1924 which followed directly on the lines of the former engine but with 6ft. 9in. wheels, a wide firebox boiler having 42 sq. ft of grate area and with a starting tractive effort of 33,600 lbs. Development was slow because the Operating Department did not, at that time, favour the adoption of such a large engine and it did not proceed further than the scheming stage. Nine years were to elapse before the first Pacific appeared on L.M.S. metals.

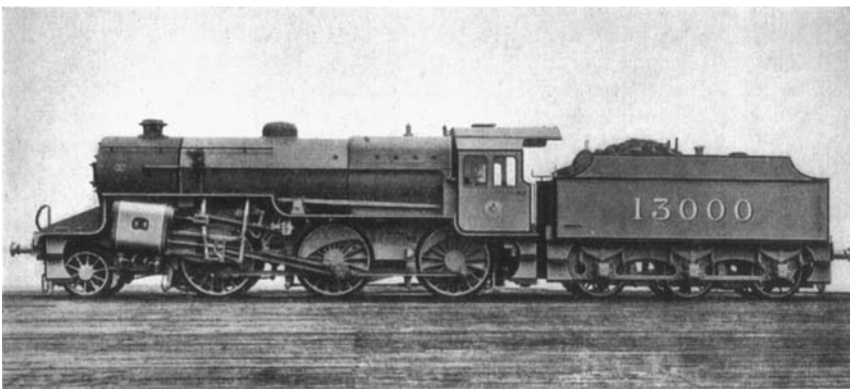


FIG. 3.
STANDARD 2-6-0 MIXED TRAFFIC ENGINE.

Parallel with the Pacific a corresponding 2-8-2 Freight type was worked out, but here again it would not pass the Civil Engineering restrictions, and later in the same year Hughes got in touch with outside firms specialising in articulated locomotives. Proposals were obtained for Kitson-Meyer, Modified Fairlie and Garratt type locomotives of the 2-6-2: 2-6-2 type. By his retirement in 1925 the larger freight engine question had progressed no further than the large passenger, but both formed a groundwork on which further progress was made by his successor.

It is pleasant to turn from these somewhat negative results to a positive success, one which moreover had an important influence for future L.M.S. design. The 2-6-0 engine shown in Fig. 3 re-introduced the specifically mixed traffic type which has since become such a feature of L.M.S. working and, more important, it introduced to the L.M.S. the long travel long lap valve gear, first adopted here by Churchward on the G.W.R., but otherwise little regarded by other C.M.Es. of the time. This was a completely new design of simple, straightforward character comprising a large boiler, modern valve events and adequate bearings. The first engine was not turned out until 1926, under the C.M.E.-ship of Fowler who added a number of standard Midland fittings but left the basic design unchanged. The restrictions of the Midland loading gauge were responsible for the unusual outside cylinder inclination, giving the engine a somewhat ungainly appearance, but no practical detriment has been found to result therefrom. In all 245 engines were built, and are at work all over the system, with a high degree of efficiency as is indicated in Col. 4 of Table III. Five of these engines were fitted in 1931 with Lentz Rotary Cam Poppet valve gear, and a separate column has been added to the table showing the comparative performance of the engines so fitted. These figures are discussed in the later section on valves and valve gears.

Hughes knew the value of the big engine, master of its job, and might have had the distinction of producing the first Pacific design on the L.M.S. It was his misfortune, however, to have to work with a newly formed Operating Department imbued with the small engine outlook so that his intentions in that respect did not come to fruition. He believed firmly in simplicity and was alive to modern trends, both of which factors were incorporated in his final design referred to above. This remains the best monument to his work, the only non-Derby inspired design to become a standard type in the period under consideration.

The Compounds.

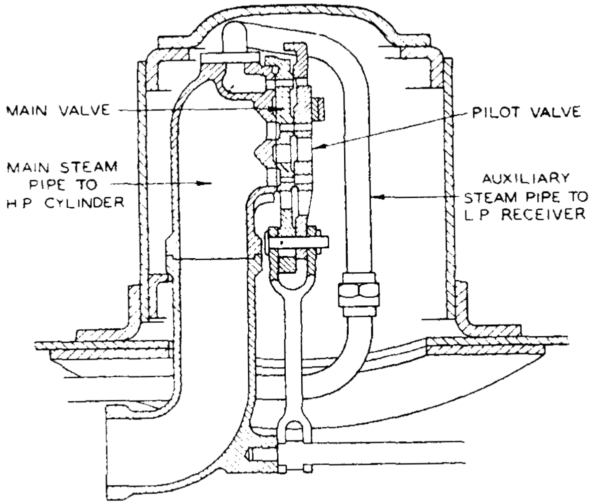
The L.M.S. is the only one of the four main line Companies which has designed and built compound locomotives since the Grouping and so has something to contribute to the, as yet, unresolved simple v. compound controversy.

The various stages in the quest for improved thermal efficiency in the superheated reciprocating steam engine in modern times may be listed as:—

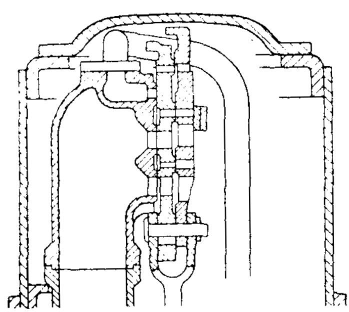
(1)	Moderate Steam Pressure. (160-190 lbs. sq. in.).	Simple expansion with short lap valves.
(2)	Higher Steam Pressure. (200-225 lbs. sq. in.).	Compound expansion with short lap valves.
(3)	Moderate Steam Pressure. (160-190 lbs. sq. in.).	Compound expansion with long lap valves.
(4)	Higher Steam Pressure. (200-250 lbs. sq. in.).	Simple expansion with long lap valves.
(5)	High Steam Pressure. (240 lbs. sq. in and over).	Compound expansion with long lap valves.

The results obtained on the L.M.S. on variable speed tests with passenger trains may be broadly epitomised as 5, 4, 3½ and 3¼ lbs. of coal per DBH P/hr. for stages 1, 2, 3 and 4 respectively. No engine has yet been built in stage 5.

In Stage 2 is the well known " Midland " 3-cylinder 4-4-0 Compound (Fig 4) of which 45 existed at the time of grouping and 195 were built subsequently. Except for the crank setting the only feature



PILOT VALVE ONLY OPENED; STEAM ADMITTED THROUGH SMALL PORTS TO MAIN AND AUXILIARY STEAM PIPES



REGULATOR FULLY OPENED, STEAM ADMITTED THROUGH LARGE PORTS TO MAIN STEAM PIPE ONLY

STANDARD COMPOUND REGULATOR

FIG. 5.

REGULATOR STARTING VALVE, MIDLAND COMPOUND.

which distinguishes these engines mechanically from a simple engine, is the addition of an extension to the regulator in the dome forming a starting valve, so that the initial movement of the handle admits HP steam to the LP steamchests (Fig. 5). This simplicity coupled with balanced proportions gave a degree of reliability and low maintenance

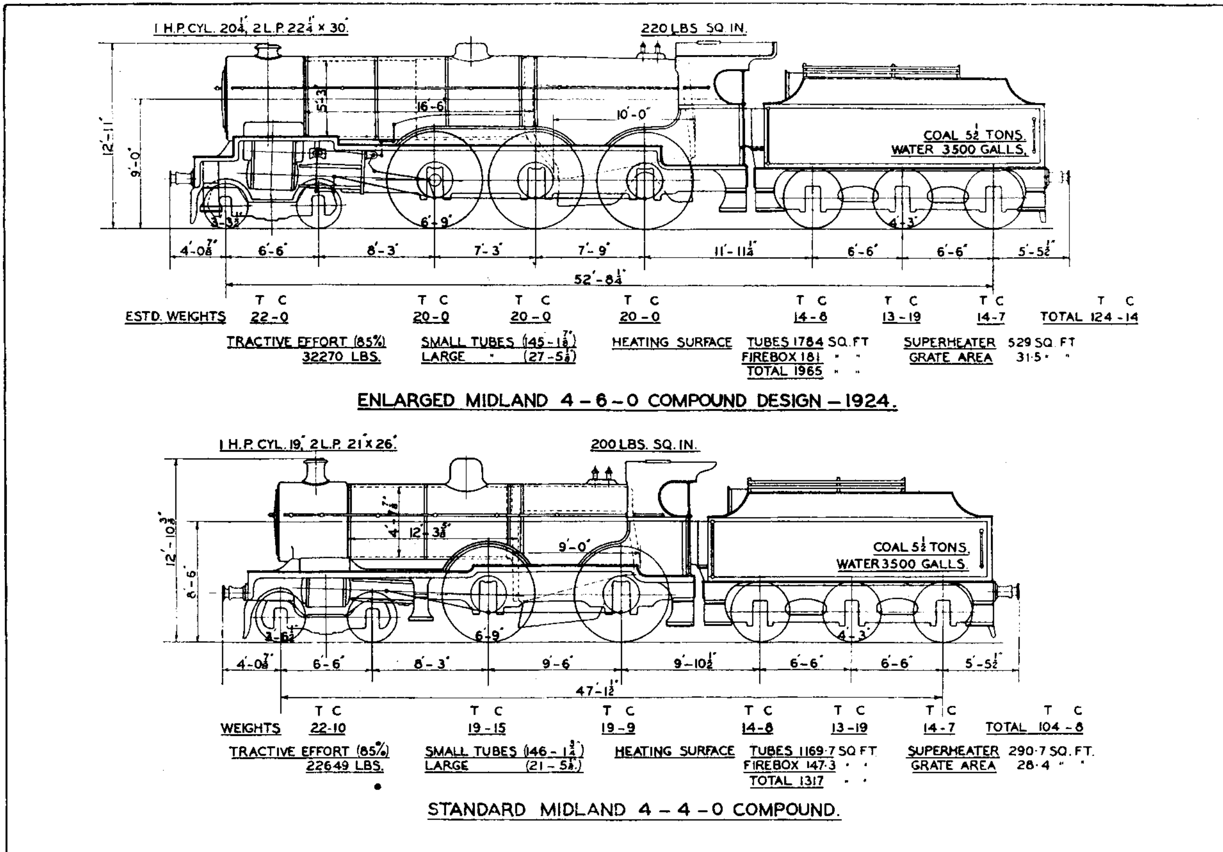


FIG. 6 (ABOVE) ENLARGED MIDLAND 4-6-0 COMPOUND DESIGN—1924.

costs in no way inferior to simple engines and a comparative indication of the latter may be seen in Table V. The choice of this engine as a standard type on its merits was inevitable and its use spread all over the L.M.S. system.

The advantage the engine had in coal consumption over simple engines of the old, conventional type was very real. The advent of simple engines in Stage 4, however, immediately showed nearly as much advantage over this particular form of compound, as the latter had shown over the previous simple engines and construction was discontinued after 1932. E. L. Diamond* has analysed the inadequacy of the short travel valve events on this engine and pointed out the various losses in the steam cycle which resulted. Several proposals were made at different times to give these engines a better steam distribution, but after they were taken off top link working, it was not felt the considerable expenditure could be justified.

Table IV sets out representative test results confirming the foregoing remarks.

When it came to be realised in 1925 that a larger engine was required, Fowler naturally thought along the lines of a 4-6-0 version of the Standard Compound, and a scheme was prepared for such an engine as shown in Fig. 6. The cylinders and driving mechanism

TABLE IV.

MIDLAND COMPOUND PERFORMANCE IN COMPARISON WITH THAT OF OTHER CLASSES.

Group No.	1	1	2	4
Class of Engine	LNW 2-cyl. 4-6-0 Prince of Wales	Caledonian 2-cyl. 4-6-0 14630 Class	Standard 3-cyl. 4-4-0 Compound	Standard 3-cyl. 4-6-0 Royal Scot
Route	Preston-Carlisle	Preston-Carlisle	Crewe-Carlisle	Euston-Carlisle
Av. wt. of trains Tons	323	351	298	440
Av. running speed m.p.h.	50.7	48.4	50.0	52.1
Coal consumption—				
lbs. per mile	44.1	51.6	34.1	37.1
lbs. per ton mile (inc. engine)	.105	.112	.087	.066
lbs. per DBHP/hr.	5.07	5.19	4.06	3.25
lbs. per sq. ft. grate/hr.	89.6	97.7	60.1	62.4

*Proceedings of the Institution of Mechanical Engineers. Investigation into the Cylinder Losses in a Compound Locomotive—1927 p. 465.

TABLE V.

3-YEARS' AVERAGE COAL CONSUMPTION AND REPAIR COSTS FOR SELECTED ENGINE CLASSES, 1928-1930, INCL.

(All Superheater engines.)

Class	Coal lbs. per mile	*Comparative Repair Cost Index
Passenger Class 4, 4-4-0 Midland Comp.	46.5	136
4-6-0 L.N.W. Prince of Wales	51.1	157
4-6-0 Cal. 60 Class	66.3	117
4-6-0 G. & S.W.R.	59.0	190
Class 3, 4-4-0 L.N.W. George V.	56.4	149
4-4-0 Caledonian	59.1	110
4-4-0 G. & S.W. Drummond	63.4	147
Class 2, 4-4-0 Midland	45.9	100
Freight Class 4, 0-6-0 Midland	66.1	105
Class 3, 0-6-0 L.Y.R.	56.9	135
0-6-0 Caledonian	68.7	120

*Taking the Midland Class 2, 4-4-0 Engine as 100.

were to be on the same lines as the smaller engine except for piston valves and outside valve gear for the LP cylinders. The boiler foreshadowed that designed later for the Royal Scot Class. Impressed, however, by the work of the Compound Pacifics in France, Sir Henry decided at the end of the same year to enter Stage 5 by the construction of some 4-6-2 engine with 4 compound cylinders, long lap valve gear and 240 lbs. sq. in. pressure. The Hughes simple Pacific design of 1924 provided the gound work for the engine shown in Fig. 7. The drive was divided and two sets of outside Walschaert gear drove the four valves. Separate HP and LP gears were ruled out because it was felt that both by training and temperament, it was unlikely that British drivers would make full use of independent cut-offs. A notable feature in the boiler was the length of the combustion chamber extending 4ft. forward into the barrel. In view of the statement sometimes made that large Compounds cannot be arranged within the British loading gauge (Fig. 9) made up from the actual detail drawings shows how the problem was solved in this case.

Simultaneously a corresponding 2-8-2 Freight Compound was developed using the same boiler and details except that here all cylinders were to drive on to the same axle (Fig. 8). These two large designs proceeded a long way towards completion and some cylinders were actually cast. Work was discontinued in 1927 under circumstances to be described in connection with the inception of the Royal Scot. One feature only of their design survives in the most modern "Coronation" type Pacifics of the present day, namely the 4-ply frame construction at the back end over the trailing truck.

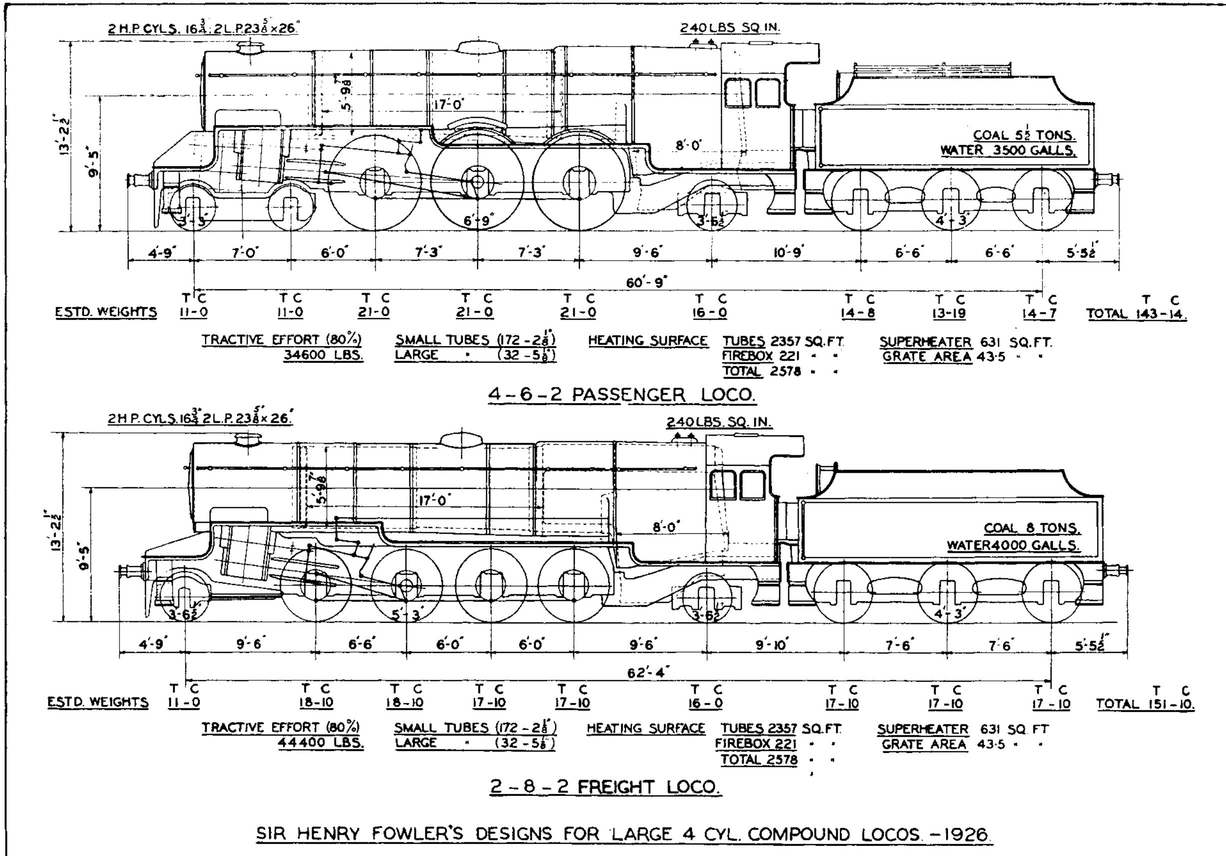
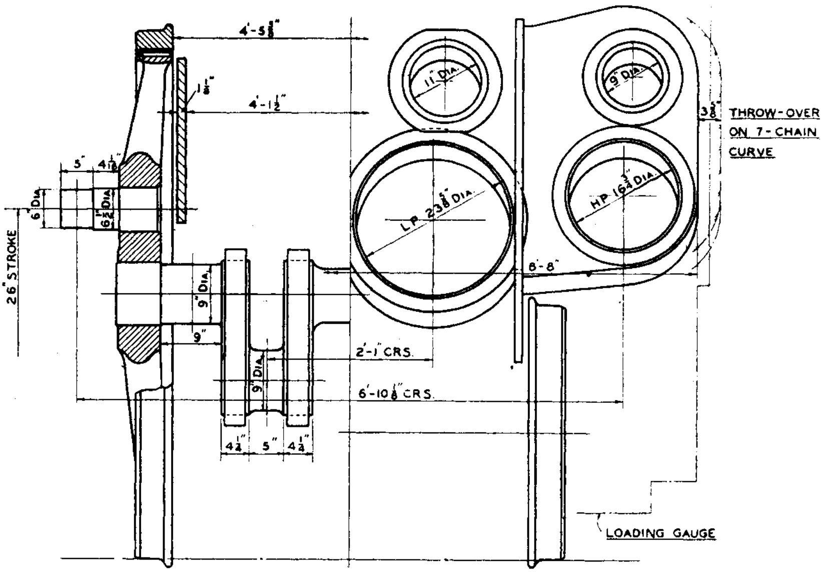


FIG. 7 (ABOVE) FOWLER'S DESIGN FOR 4-CYLINDER COMPOUND 4-6-2.
FIG. 8 (BELOW) FOWLER'S DESIGN FOR 4-CYLINDER COMPOUND 2-8-2.

While the above work was proceeding, the practical step was taken of altering in advance one of the Hughes' 4-cylinder 4-6-0 engines to Compound expansion, so as to obtain some preliminary data. Engine 10456 (Fig. 10) was turned out of Horwich in July, 1926, with new inside cylinders 22in. diameter, and its existing outside cylinders linered up to 15½in. diameter. Boiler pressure remained at 180 lbs. sq. in. and 9in. diameter piston valves were fitted throughout. The outside valve gear drove the inside L.P. valves through unequal armed rocking shafts giving a travel of 5⅝in. L.P., 6⅜in.



COMPOSITE DIAGRAM SHOWING CYLINDER & BEARING CENTRES
FOWLER COMPOUND PACIFIC

FIG. 9.

H.P., the respective valves having laps of 1in. and 1⅜in. The starting valve was of extreme simplicity, the same in principle as used by Hughes in the LYR 0-8-0 Compounds in 1907*, but involving the use of a small piston valve. Fig. 11 illustrates this valve, which was connected directly to a short arm on the reversing shaft, so proportioned that when the cut-off was within about 5% of full gear, forwards or backwards, the port was uncovered admitting HP steam to the LP cylinders.

*Proceedings of the Institution of Mechanical Engineers.
Compounding and Superheating on Horwich Locomotives—1910, p. 399.

No. 10456 spent its life on the Crewe-Carlisle section, was very free running and was well liked by the drivers. On test with 350 ton trains it burned 3.67lbs. of coal per DBHP/hr. as compared with 4.0lbs. which the simple engine was capable of achieving when in first class condition, a saving of 9%. Both engines were run with full open regulators under the following conditions.

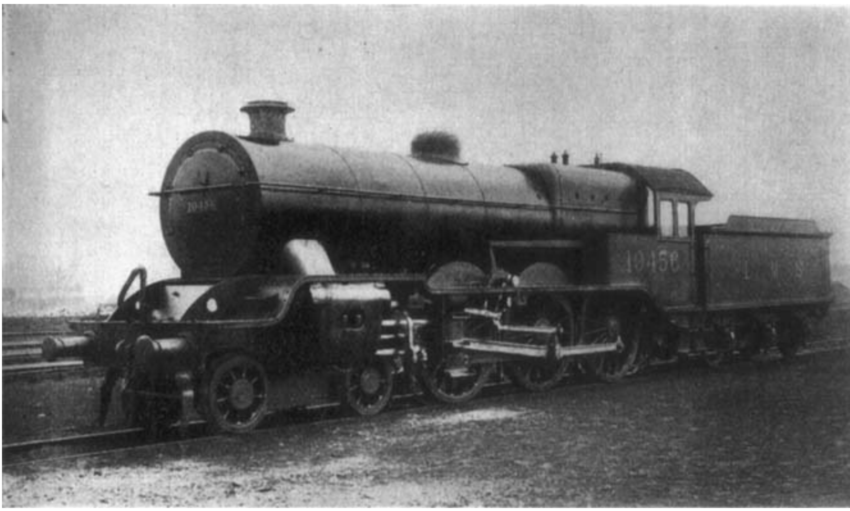


FIG. 10.

HORWICH 4-CYLINDER 4-6-0 CONVERTED TO COMPOUND.

		Simple		Compound	
Cut off.	Level Sections ...	17-20%	...	HP	35-40%
				LP	49-53%
	On Shap Incline...	37%	...	HP	65-68%
				LP	74-76%

Receiver Pressure:

Level Sections	...	...	40-50lbs./sq.in.
On Shap Incline	...	...	85lbs./sq.in.

With the suspension of the Pacific design and the subsequent success of the Royal Scot, interest in this engine subsided, and it was broken up in 1936, the most modern, but least known compound engine to run in this country.

Attention must finally be drawn to a feature of Compound engines which seems to place them at a disadvantage compared with simple expansion, at any rate so far as L.M.S. experience is concerned. A glance at Fig. 12 will show how the efficiency of the former deteriorates once they are taken off the top link jobs, and out of the hands of the most experienced drivers. The simple engine is able to survive this treatment without serious disturbance to its average

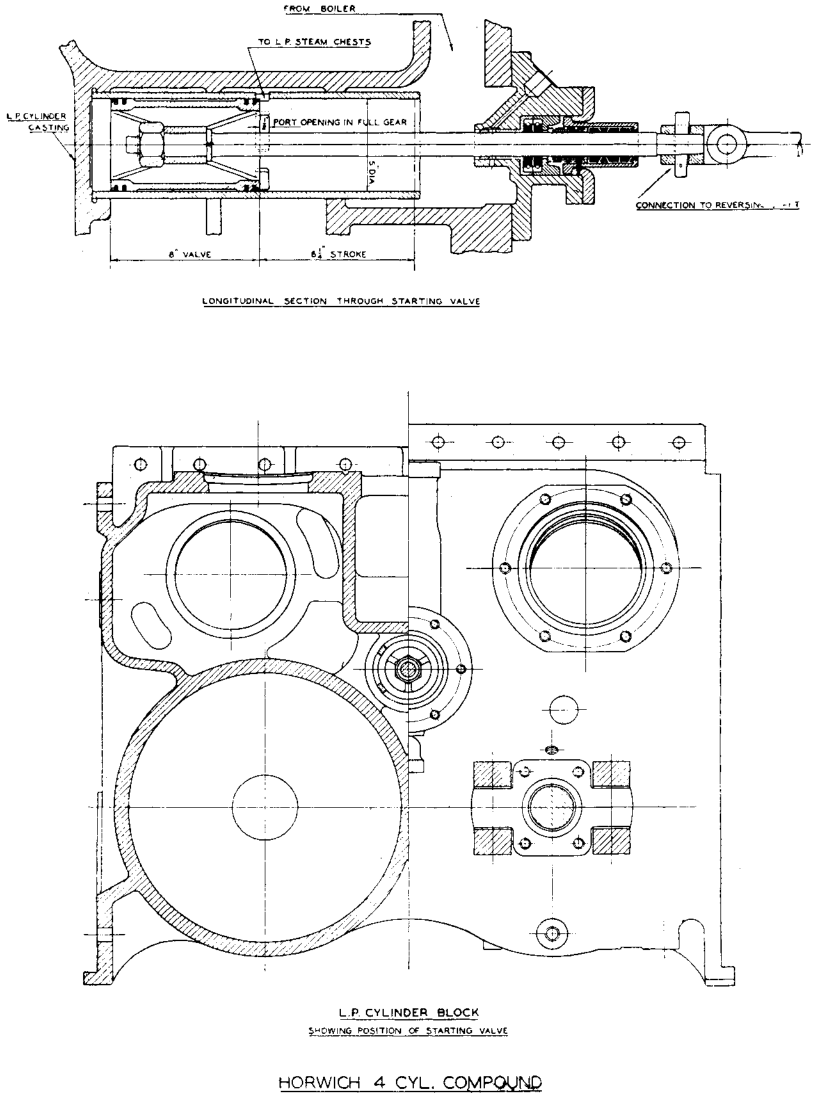


FIG. 11.

STARTING VALVE, HORWICH COMPOUND.

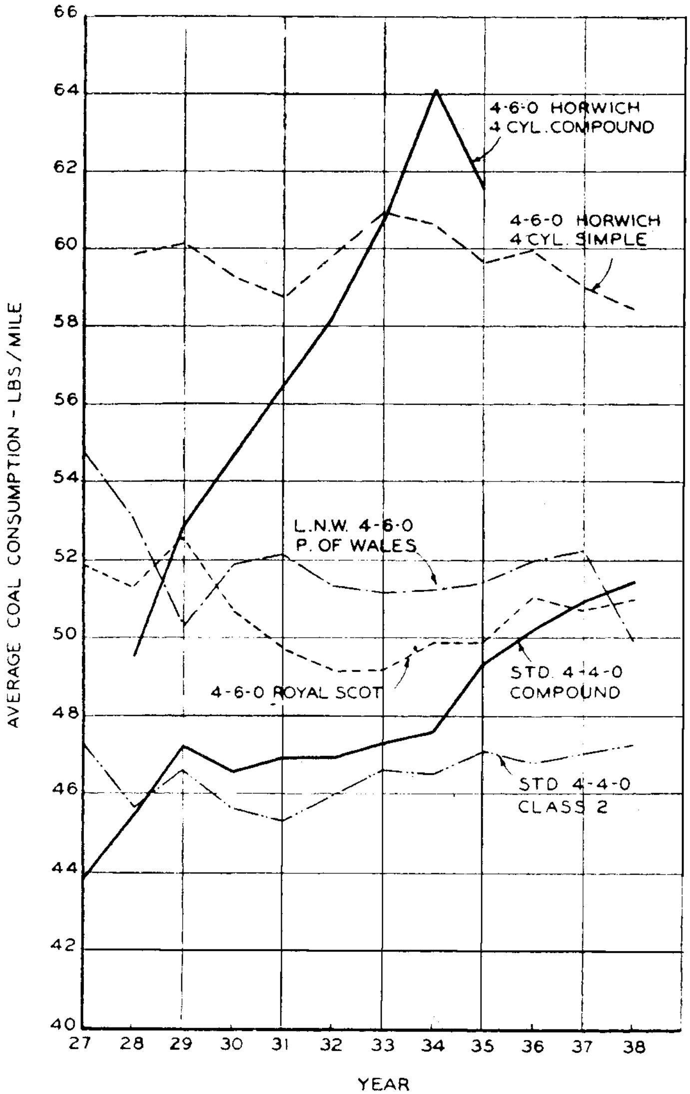


FIG. 12.

GRAPH OF ANNUAL COAL CONSUMPTIONS, SIMPLE AND COMPOUND LOCOMOTIVES.

coal consumption, but not so the Compound, and to refer to one example, the eventual crossing of the coal consumption lines for Prince of Wales and Midland Compound, once so far apart, is certainly striking. It seems clear that for the time in which they cannot be working under ideal conditions, Compound locomotives must actually be relatively inefficient, and a policy based only on the performance of such engines when new and on first class work might go far astray.

Midlandisation.

This word has been coined to cover the extension of Midland Railway outlook and practice to the newly-formed group as a whole which took place under Sir Henry Fowler, at any rate so far as rolling stock design was concerned, and it is a fact that Midlandisation is the centrepiece of the locomotive pattern we are endeavouring to trace. It may be summarised as:—

- (a) The selection of previously existing Midland types for perpetuation as L.M.S. standard classes.
- (b) The application of Midland detail design to all new designs it might be necessary to introduce.
- (c) To leave non-standard, non-Midland types for the most part unchanged until broken up.

There was some justification for this course apart from the natural predilections of the men in charge after 1925. First of all Midland design practice was demonstrably productive of the lowest repair costs, special attention having been paid to good lubrication, and good and robust design of detail fittings, while bearing performance was, on the whole, better than on the other constituent Companies, while bearing loads remained low.

Secondly, coal consumption was in general lower for comparable power, since, where all clung at that time to the old fashioned short travel valve events, the Midland used ruggedly designed valve gear giving accurate timing, while its boilers were well endowed with grate area, giving reasonable rates of combustion.

These two features of low repair and fuel costs are illustrated in Table V covering a three years' average of coal consumption and repair costs for different groups of engines.

Thirdly, the decision to standardise on the design of one of the constituent Companies rather than branch out into a completely new standard range, produced overnight a block of 3,019* engines having standard parts, giving a much more immediate effect in keeping down stocks in Shops and Sheds than would have been the case had the alternative policy been pursued.

Apart from the 4-4-0 Compounds already described, three other Midland classes were standardised with only minor alterations, namely the 4-4-0 Class 2 Passenger engine, the 0-6-0 Class 4 Freight and the

* This includes 94 engines to former London Tilbury and Southend design which had already been equipped with a variety of Midland details.

0-6-0 Class 3 Freight tank, of which 394 units in all existed before grouping and 1,083 were built in the next ten years. The first of these suffered from poor cylinder design, resulting in a rather undistinguished performance. Before a final decision on standardisation was taken a good deal of work was done on the alternative design in Fig. 13 having two outside cylinders with inside Stephenson valve gear, but this idea was finally given up, probably due to loading gauge restrictions. The cylinders of the existing class were then completely redesigned to give better steam passages, and the size was reduced from 20½in. to 19in. diameter, and the pressure raised from 160 to 180 lbs./sq. in.—the valves remaining in the same position

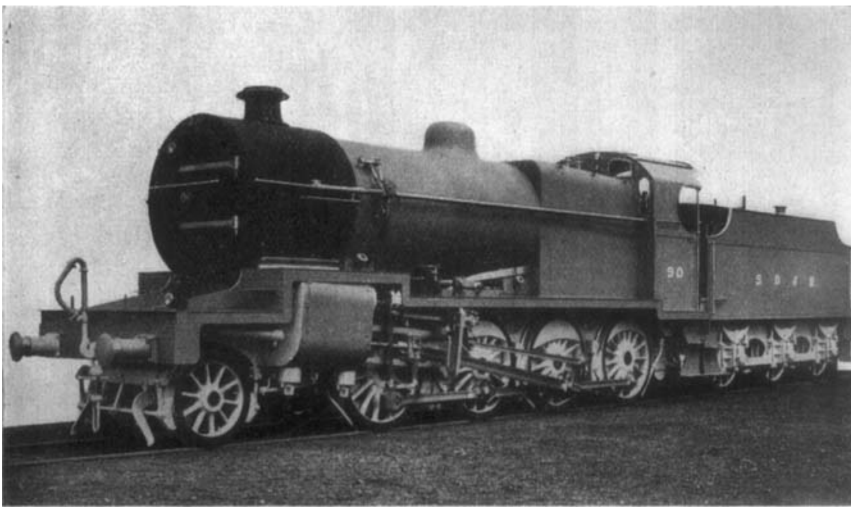


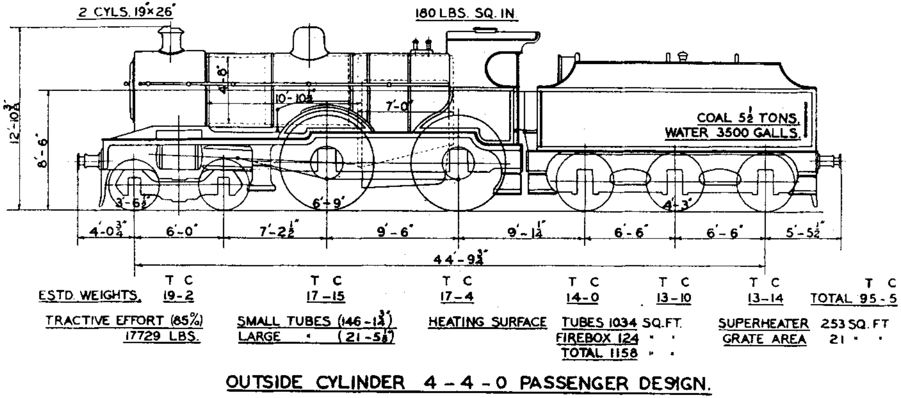
FIG. 14.

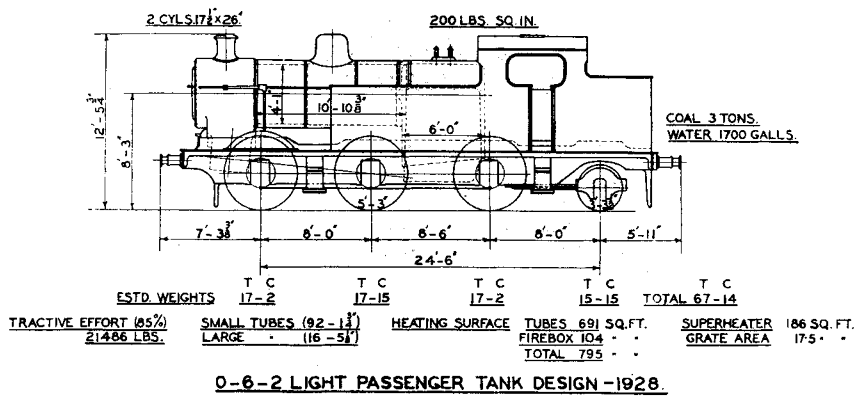
2-8-0 ENGINE FOR SOMERSET AND DORSET RAILWAY, DESIGNED AT DERBY.

below the cylinders. Short valve travel was retained, but later engines were fitted with double exhaust valves, Fig. 19d.

The 2-8-0 engine illustrated in Fig. 14 built for the Somerset and Dorset section is an example of pure Midland design in a more modern application. With enlarged Midland Compound boiler, outside admission short travel piston valves, Class 4 freight axle boxes, and complete range of Midland standard details, it represents most fully what might be termed the Fowler-Anderson school of thought. Although not suitable on account of weight for the Midland main line, this design had an influence on that of the Garratt engines next to be referred to.

The stopping of work on the Compound Freight engine already referred to, left unsolved the provision of a large engine for the Toton-Brent coal trains. The 0-10-0 Banking engine No. 2290 from the Lickey Incline was tried out over part of this section, but proved





FIGS. 13 AND 15.

(ABOVE) OUTSIDE CYLINDER 4-4-0 PASSENGER DESIGN.
(BELOW) 0-6-2 LIGHT PASSENGER TANK DESIGN—1928.

quite unsuitable for main line work, so the Garratt project, initiated by Hughes, was resurrected, and in 1927 Beyer Peacocks delivered three 2-6-0 : 0-6-2 engines to the dimensions shown in Table II. Although the boiler and frame design was Beyer's, all the detail work was to Derby requirements based on the S. and D. design referred to above. It is difficult to understand at this distance of time how all the modern efficient features of the Royal Scot, 2-6-0 and 2-6-4 Tank classes of contemporary design were omitted from these Garratts, except to say that the old Midland influence was dominant in this case. Thus short travel gear was conjoined with undersized coupled boxes, interchangeable for the sake of standardisation with those of the Class 4, 0-6-0 engines, and guiding wheels at the inner ends of the units were omitted. Thirty more of these engines were delivered in 1930, double exhaust valves giving a slight improvement in efficiency.

This class was successful in being able to do single handed the work of two 0-6-0 engines, but with no great advantage in efficiency, and Table VI shows clearly how cling'ng to the short travel valve

TABLE VI.

COMPARATIVE PERFORMANCE OF MIDLAND DESIGNS FOR FREIGHT SERVICE.

	MIDLAND DESIGNS.				OTHER TYPES FOR COMPARISON.	
		2-6-6-2 Garratt				
Engine Class	0-6-0 Cl. 4.	Original	Later with double exh. valves.	2-8-0 S. & D.	0-8-0 LNW G2 Class	0-8-0 Standard Class 7.
From Individual Costs averaged over 10 years.					(2)	(2)
Coal per mile lbs. ...	64.9	116.6		*	74.6	69.9
Repair Cost Index (1)...	111	202		*	156	124
Representative Dynamometer Car Tests over Toton-Brent route.						
Av. Train Load tons ..	742	1423	1452	927	940	900
Av. Running Speed m.p.h.	17.1	16.0	16.0	17.5	17.6	17.3
Coal Consumption						
lbs. per mile	59.4	128.7	112.6	80.6	79.0	53.9
lbs. per ton mile (inc. engine)	.072	.082	.071	.078	.076	.055
lbs. per DBHP/hr. ...	4.13	4.09	3.61	4.37	4.02	2.80
lbs. per sq. ft. grate per hour	48.3	46.7	40.6	49.5	59.0	39.4
Water Consumption						
Galls. per mile ...	46.4	88.3	84.6	60.8	50.0	46.1
lbs. per DBHP/hr. ...	32.4	29.5	27.1	32.9	25.4	24.0
Evaporation lbs. water per lb. coal	7.82	6.87	7.51	7.54	6.32	8.57

*No figures given. Apart from special tests these engines are confined to S. & D. Section where abnormal working conditions prevail.

(1) Midland Class 2, 4-4-0 engine taken as 100.

(2) In comparing with Class 4. 0-6-0, it is necessary to take into account the higher average loading represented by Power Classification No. 7

gear penalised all engines designed according to the old Midland school of thought, as compared with, as an example, the standard 0-8-0 having long travel gear. In addition, the undersized boxes have always caused the Garratts to require Shop repairs at lower than average mileages. Authentic records from overseas railways using these engines, but of up to date design, indicate that the L.M.S. is not in a good position to judge the full capabilities of this type.

Another extension of Midland design tradition into post grouping construction is the Standard Class 3, 2-6-2 Tank engines. Originally conceived as a 0-6-2 type with inside cylinders, Fig. 15, certain criticism raised against the existing Midland 0-6-4T type as a vehicle on the track, led to the adoption of guiding wheels fore and aft and the use of outside cylinders. Short travel valves were fitted and this, in conjunction with the undersized boiler fitted, rendered this type the least distinguished in performance of all the standard types.

It will be seen, therefore, that under Fowler, two influences were in conflict, one struggling to survive and the other to be born. One was the mechanically sound, but thermally inefficient, Midland tradition outlined above, and the other stemmed from the work of Hughes reinforced by the broad tendencies of the outer locomotive world in the direction of high pressures, better steam distribution and freedom from subservience to any particular school. Before describing this emergence of a recognisable modern L.M.S. policy, however, two further influences require examination, those of Crewe and St. Rollox.

Crewe Influence.

Throughout the whole ten years under review, the influence of Crewe was continuous in spite of the overwhelming predominance of Derby. One reason was the continuation in an influential position of H.P.M. Beames to whom Crewe and its traditions were the breath of life. Another was the not inconsiderable block of 3,360 ex L.N.W. engines which passed over to the newly formed group.

As Table I shows, only 31 engines of L.N.W. design were built after grouping, but a sustained attempt was at first made to develop something worth while out of the 4-cylinder 4-6-0 Claughton Class, 130 strong, built from 1913 onwards, and in firm possession of the Western Division main lines. Although capable of sustained fast running, the performance of this class was curiously uneven, and its coal consumption left a good deal to be desired.

The first step was the fitting of No. 5908 at Crewe with Caprotti poppet valve gear. At a single stroke an indifferent steam distribution was improved out of recognition and an engine whose normal mode of progression on the level was 30 per cent. cut-off with a partially opened regulator, now ran at 10 per cent. cut-off with full regulator. At the same time in conjunction with Derby, the boiler design was examined, and another engine, No. 5923, had its existing boiler re-tubed to give increased diameter and spacing of the small tubes, and increased air spaces through ashpan and grate. At the same time the trick ports were eliminated from the valves. The first three columns of Table VII show the average results of the Dynamometer Car tests which followed.

TABLE VII.

COMPARATIVE PERFORMANCE OF DIFFERENT MODIFICATIONS TO THE L.N.W. "CLAUGHTON" CLASS.

	(1) Original Boiler Engine as built.			(2) Large Boiler Caprotti	Walschaert
From Individual Costs averaged over 7 years					
Coal per mile lbs.	54.3			48.3	51.6
Repair Cost Index	200			175	
Representative Dynamometer Car Tests.					
Engine No.	5980 Caprotti	5923 Altered boiler ratios and piston valves.	5917 As built	5908 Caprotti	Walschaert Gear. Narrow ring valves
Route	Crewe-Carlisle			Euston-Manchester	
Av. Wt. of Train tons ...	316	327	316	418	417
Av. Running Speed m.p.h. ...	50.7	50.0	49.5	52.9	52.7
Coal consumption					
lbs. per mile	33.3	40.0	44.5	39.9	38.2
lbs. per ton mile (inc. engine)	.078	.091	.104	.078	.075
lbs. per DBHP/hr. ...	4.10	4.34	5.22	3.53	3.25
lbs. per sq. ft. grate per hour	53.3	65.5	73.7	69.1	65.8

(1) 175 lbs. per sq. in. (2) 200 lbs. per sq. in.

A significant fact emerged. The Caprotti engine showed a coal saving of 27 per cent. over the standard but the modified engine, No. 5923, itself gave 17 per cent., thus showing that other things than steam distribution alone were decisive.

Based on the performance of the latter engine a new, larger diameter boiler was designed having 200 lbs./sq. in. pressure instead of 175 lbs. This was fitted to 20 Claughtons during 1928, one of which was the Caprotti engine 5908, and nine others were also fitted with this gear. The remaining ten engines retained their Walschaert gear but with plain valves. Five engines in the Caprotti group had cranks set at 135° giving eight exhaust beats per revolution, but it can be said at once that no vestige of advantage was ever found from this arrangement. Fig. 16 shows one of the Caprotti engines, and the final columns in Table VII summarise the test performance. Once again the outstanding feature was the improvement it was possible to make on the standard engine which had subsequently been fitted with narrow ring valves. Further observations on the performance of the poppet valve engines are made in the next section, but in the last resort, none of the modifications made sufficed to save the class, because availability, fuel and repair costs were in all cases inferior to those of the 3-cylinder, 5X class, 4-6-0 to be described later. Accordingly the 4-cylinder engines were gradually broken up and replaced by the latter, only one now remaining at work.

The Prince of Wales 2-cylinder, 4-6-0 was actually the mainstay of the L.N.W. passenger service before grouping. These engines were capable of the most astonishing performances for their size, fitted as they were with a kind of supercharger in the form of the trick ported valves and generous exhaust clearance. There seemed no limit to the amount of overloading they would take, but at the expense of high coal consumption, broken frames and hot driving boxes. Because at one time a good deal of trouble was experienced with the connecting rods, pierced in mid length by the pin which drove the Joy's valve gear, Beames rebuilt three engines with outside Walschaert gear whilst retaining inside cylinders, and another engine was purchased from Beardmores in 1924 (shown in Fig. 17). The idea was not extended and

FIG. 16.
REBUILT "CLAUGHTON" ENGINE WITH LARGE BOILER AND CAPROTTI VALVE GEAR.

these engines remained as the only British examples of a practice not uncommon in Central Europe.

Most generally satisfactory of all Crewe designs were the G1 and G2 Class 0-8-0 engines of Bowen Cooke's design. Unlike the passenger engines these did not show themselves inferior to the current Midland designs, as shown in Table VI, so an improved version was developed as an L.M.S. standard design known as the Class 7, 0-8-0. The boiler remained, although increased to 200 lbs./sq. in. pressure, but the chassis was re-designed with new cylinders and inside long travel Walschaert gear. The effect of the improved steam distribution was very marked indeed, a reduction in coal consumption per H.P. hour of 30% being achieved, as shown in the last column of Table VI. Unfortunately, this class has been handicapped by high piston loads on undersized axleboxes, so that like the Garratts, it gives lower mileages between repairs than are generally attained by the standard types.

The swan song of Crewe practice came in 1931 when Fowler was succeeded by Lemon as Chief Mechanical Engineer. Beames, as Deputy Chief Mechanical Engineer, now had a more direct hand in influencing design, and a general purpose mixed traffic engine of better speed capacity than the Horwich 2-6-0 being proposed, a new design was worked out based on the " Prince of Wales " class, as shown in Fig. 18.

This remarkable looking machine ante-dated the recent vogue for " Austerity " engines by a good 10 years, with its stovepipe chimney, absence of splashers, and generally severe aspect. Inside cylinders

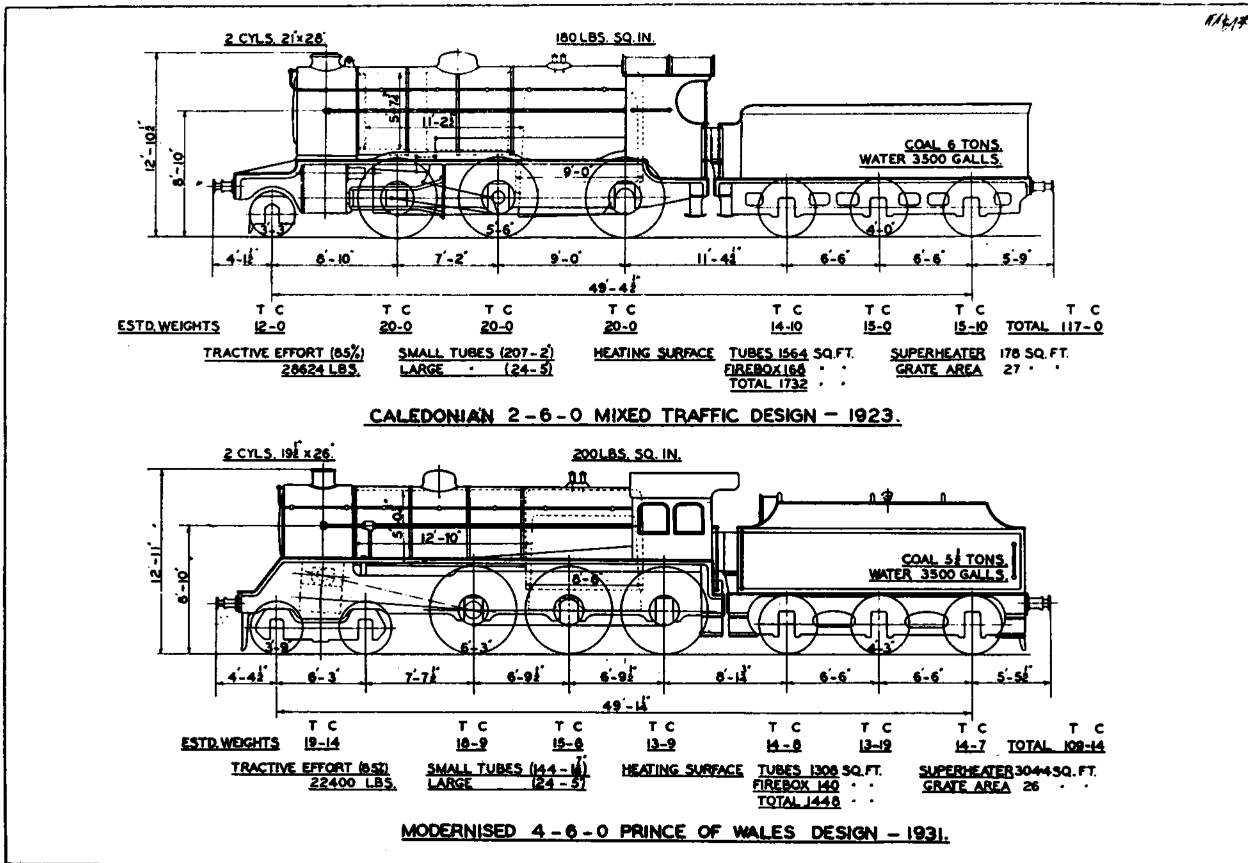
FIG. 17.

4-6-0 PRINCE OF WALES ENGINE WITH OUTSIDE VALVE GEAR.

were retained but Caprotti poppet gear was to provide efficient distribution. This is the engine which undoubtedly would have become the standard L.M.S. fast mixed traffic type had Lemon not passed on to a Vice-Presidency in charge of Traffic and Operation and Stanier come over from the G.W.R. in 1932.

Another proposal at this time was to introduce the 4-8-0 type, hitherto unknown in this country, for freight working. The engine was to have the large Claughton boiler, and outside cylinders, but this development also was put on one side when Stanier came.

Thus terminated a locomotive tradition reaching down from the days of Ramsbottom, whose clearly marked features contained virtues and vices in full measure. Crewe engines were in general vigorous and noisy, cheap in first cost, effective traffic machines for the schedules then in force, but relatively expensive to run and maintain.



FIGS. 20 AND 18.

DESIGN—1923.

Valves and Valve Gear.

Poppet valve gear, trick ports, narrow rings and double exhaust valves having been mentioned in the preceding sections, it is convenient to turn aside at this point to discuss valves and valve gear.

(a) **Valve events.** The effect of adding ½in. to the steam lap and 2in. to the valve travel has probably given the biggest return for the smallest expenditure of any modern locomotive innovation. It is now freely accepted by all Railways in this country, and the figures given in this paper give a measure of the improvement which has been effected. The practicability of extending this modification to existing older designs is a matter for discussion.

The next step of separating inlet and exhaust events by means of some form of rotary valve gear is still indecisive. L.M.S. experience has covered the two best known types, Lentz and Caprotti, and has been able to compare those with efficient examples of the normal Walschaert gear. Table VIII summarises the results. It will be seen from this that in the very broadest sense, separated events have not so far shown themselves superior to the normal arrangement in conjunction with present day speeds, temperatures and pressures. The difference between the test and service results is probably ascribable to the better average steam-tightness of the poppet valve between shoppings, which has, of course, nothing to do with the actual distribution. It is clear, therefore, that the limitations of the interconnected events given by the piston valve have not been generally reached yet, but when pressures exceed 250 lbs./sq. in. and steam temperatures 750° in conjunction with high power and speed requirements, then separated valve events may come into their own.

TABLE VIII.

RESULTS WITH POPPET VALVE GEARS.

Type of Valve	Caprotti	Lentz
Class of Engine	Crewe 4-6-0 Claughton	Standard L.M.S. 2-6-0
No. of Engines fitted	10	5
On Test.		
Av. coal consumption lbs./DBHP/hr. compared with identical engine having Walschaert gear.	Excess of 0.28 lbs. =8%	Saving of 0.04 lbs. =1%
In Service.		
Six years' av. coal per mile compared with Walschaert engines on similar duties.	Saving of 3.3 lbs. =6½%	Saving of 3.1 lbs. =5%

(b) **Mechanical Performance.** Stephenson and Walschaert gears have proved themselves very reliable and are low in maintenance cost, but their lubrication consumes a good deal of oil and man hours. Rotary cam gears of both types have given no particular mechanical trouble, but in the early examples we are dealing with, the drive and gear boxes have not proved sufficiently oil tight. The freedom from wear and ease in servicing which a well designed, fully oil-sealed rotary drive should be able to offer is an objective still worth striving after. From the drivers' point of view the "infinitely variable" Caprotti type is preferred to the Lentz stepped cam which gives only a very limited range of working cut-offs.

(c) **Alternative forms of valve.** The trick port (Fig. 19a) in general use on the former L.N.W. Railway had the effect of increasing the quantity of steam admitted for a given cut-off, which assisted the admission side, but did nothing to assist in getting rid of the steam at exhaust. Considerable exhaust clearance was necessary for this purpose which was both wasteful and noisy. The idea of double admission was neatly turned into one of double exhaust in the valve, shown in Fig. 19d, the purpose of which was to give a free exhaust while retaining a short valve travel. This valve has been described already* and has been used on about 200 new L.M.S. engines of Derby design. The results obtained were much inferior to those given by normal long travel gear, and there was sometimes difficulty in withdrawing these valves from the liners if carbon was present. Pressure relief valves were incorporated in the valve heads of Hughes' 4-6-0 and 4-6-4 designs as shown in Fig. 19b. When steam was shut off the balls dropped from their seats giving an effective bye-pass. As already stated serious steam leakage occurred as the balls became worn.

With the introduction of higher pressure, attention became drawn to the serious effect of steam leakage past the valves when running, which was a feature of the single Schmidt wide ring (Fig. 19d), generally fitted since the introduction of superheating, and it was possible for coal consumption to rise by as much as 80% between shoppings. The six ring head (Fig. 19E) which was standardised after 1929 has shown itself able to keep this deterioration to within 8%.

Although no direct tests have been made it seems probable that poppet valves may maintain a higher standard of steam-tightness than the piston valve. Certainly operating conditions are very easy for them in the steam loco as compared with the internal combustion engine although the relatively greater weight might be expected to present a problem at high speeds due to inertia. No especial difficulties of pitting or distortion have been prevalent in the actual applications. The small or negative savings shown in

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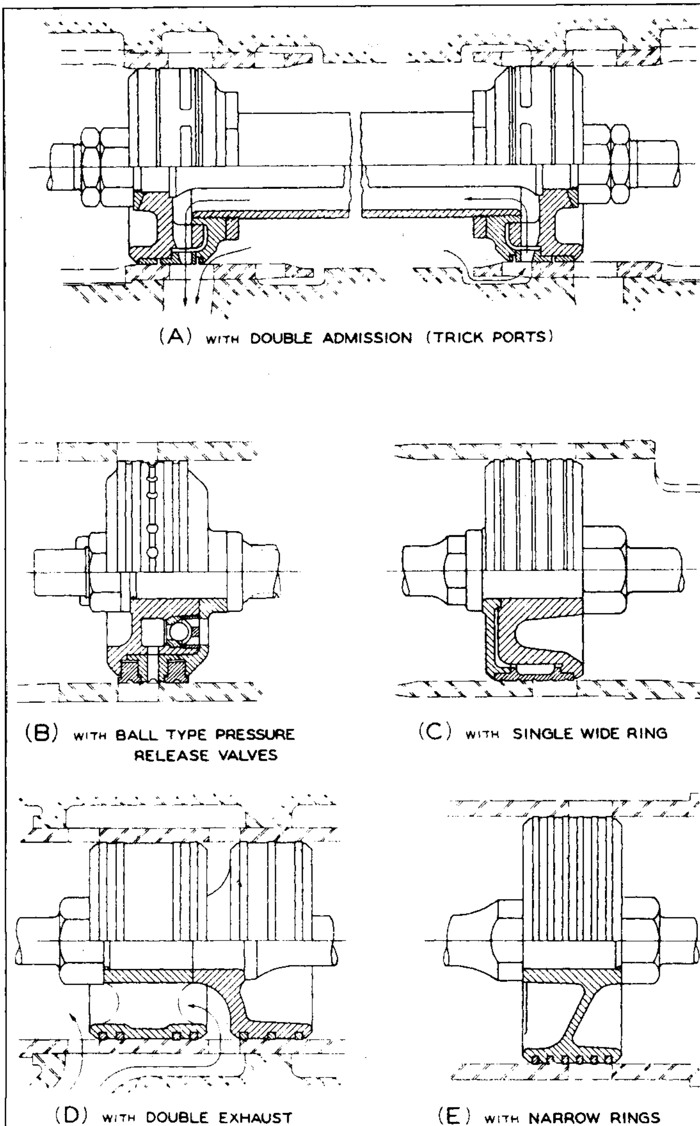
* Institution of Locomotive Engineers, Proceeding 5.
Development of the Piston Valve to Improve Steam Distribution. D. W. Sanford, Journal No. 100, 1931.



TYPES OF PISTON VALVE HEADS

FIG. 19.

(*a*) TRICK PORT.
(*b*) HUGHES BALL TYPE RELIEF AND BYE-PASS VALVE.
(*c*) SCHMIDT WIDE RING.
(*d*) DOUBLE EXHAUST.
(*e*) NARROW RING.

Table VIII when all is new, in comparison with the greater savings apparent over a period of years certainly seems to point to a better average steam-tightness. Mechanically the easily accessible horizontal Lentz valves are preferred to the vertical Caprotti valves which are not so easy to remove.

The Scottish Contribution.

One thousand seven hundred and seventy-one engines came into the new group from the Scottish Companies and only 30 engines to Scottish designs were built subsequently. The whole of these engines were divided into a remarkably high number of different varieties. In the early days three of the best of these were tried out in England, namely the McIntosh/Pickersgill Class 3, 4-4-0, the Pickersgill Class 4, 4-6-0 of the 14630 Class, and the McIntosh 0-4-4 Tank, all Caledonian types. The first and last of these failed to keep time with English schedules, but the 4-6-0 class ran trials between Carlisle and Preston satisfactorily with average results which are indicated in Table IV. All the more recent types of Caledonian engine gave a high fuel consumption because the effect of the short travel valve gear was enhanced by insufficient grate area giving low boiler efficiency. The influence of Caledonian design in the wider field of the L.M.S. thus turned out to be small.

It is not generally known, however, that the present L.M.S. standard 2-6-0 had a Scottish origin. At grouping the Caledonian Railway had ready for production a 2-6-0 Mixed Traffic engine, the leading particulars of which are shown in Fig. 20. Examination of the design soon showed that it could not be used on any English Division because the large horizontal cylinders fouled the loading gauge. Accepting the same power characteristics Hughes started afresh and designed the Horwich version already referred to.

Mechanically Caledonian engines were very robustly constructed and frame fractures were almost unheard of, but hot bearings were a frequent trouble. Repair costs were relatively light, although the excellent quality of water north of the border also contributed to this. A stout fight was made north of the border for the retention of Caledonian types, which were claimed to be specially suited to Scottish conditions. Accordingly less of these engines pro rata were broken up than was the case with any other constituent Company, as is shown in Table IX.

In contrast to the above the locomotives of the G. and S.W. Railway soon found their way to the scrap heap, none of them measuring up to L.M.S. standards of effectiveness and efficiency.

The Highland Railway engines were probably, on the whole, the best Scottish types of all, particularly the three most recent outside cylinder superheater classes of Cummings design, and these engines continued throughout these ten years to work the difficult Highland section supplemented only by a few of the Horwich 2-6-0 engines.

Only one legacy from Scottish practice now remains, the deep melodious whistle. Soon after grouping, when standardisation of

TABLE IX.

REDUCTION IN LOCOMOTIVE STOCK OF FORMER OWNING COMPANIES 1923-1932.

Former Owning Company	Locomotive stock at grouping 31st Dec., 1922	Locomotive stock at 31st Dec., 1932	Reduction in stock during 10 years	% Reduction
L. & N.W.	3,360	2,021	1,339	39.8
North London†	109	24	85	78.0
North Staffordshire	192	88	104	54.5
Leek, Manifold	2	—	2	100
Wirral	17	1	16	94.0
Midland	2,925	1,752	1,173	40.5
L.T. & S.§	94	101	—	—
S. & M.J.	13	—	13	100
S. & D.	80	51	29	36.2
L. & Y.	1,654	1,224	430	26.0
Furness	136	31	105	80.1
Maryport & Carlisle	33	2	31	95.1
Cleator & Workington	6	—	6	100
Knott End	4	—	4	100
Caledonian	1,077	940	137	12.7
G.S.W.	528	109	419	79.4
Highland	173	110	63	36.4

†Had been absorbed in L.N.W. before 1923 Grouping.
§Had been absorbed in M.R. before 1923 Grouping.

details were being examined by Hughes, a whistle from each constituent Company was mounted on a long steam pipe and a performance given before all the ex-Chief Mechanical Engineers. The musical tones of the Caledonian hooter easily won the day, and one was fitted to an L.Y.R. "Atlantic" preparatory to general adoption. Unfortunately it was heard one day in Manchester Victoria Station by still higher authority from the south, and such an affront to an Englishman's idea of what a locomotive whistle ought to sound like was instantly removed, only to reappear long afterwards in an era of greater courage as the sign audible of the Taper boiler.

Emergence of the L.M.S.

A definitely L.M.S. trend of design can be said to have emerged with the introduction of the 4-6-0 Royal Scot and 2-6-4 Tank classes laid down in 1927. Having roots reaching back into purely Midland design, they embodied much experience gained with other types, introducing for the first time in combination, higher working pressure, high degree superheat, long travel valve gear and generously proportioned bearings. With various modifications dictated by progress these basic features have been projected forward to the present time, and the converted Scots and Taper Boiler tank engines being turned out of the L.M.S. Shops to-day, although they owe so much to Stanier, are none the less the direct lineal descendants of these 1927 designs.

The introduction of the Royal Scot engine was somewhat dramatic. Reference has been made to the active preparations under way in 1926 for launching a Compound Pacific design. In the meantime, however, the Operating Department, whose task it was to run the engines when built, was profoundly sceptical. They had a rooted objection to the Pacific type, and saw no virtue in four cylinders if three could be made to do the work. The means by which the management was persuaded are veiled in the past, but in September, 1926, there suddenly appeared in daily working on the L.M.S., G.W.R. "Castle" class engine No. 5000, first of all between Euston and Crewe, and then on the Carlisle road. It was intended to show the directors and management by actual demonstration what kind of engine would satisfactorily do the work.

The need was becoming very urgent indeed in view of the intention to introduce in 1927 the Royal Scot train as the show-piece of the Anglo-Scottish services, a train which it was beyond the capacity of any existing L.M.S. engine to run to time single handed.

The G.W.R. engine performed with quiet mastery all the work on

TABLE X.

COMPARATIVE PERFORMANCE OF L.M.S. DESIGNS.

Engine Class	4-6-0 Royal Scot	4-6-0 3-cyl. 5x	2-6-4.T
From individual costs averaged over 10 years.			
Coal per mile, lbs.	50.6	47.7*	51.9
Repair cost index	177	118*	123
Representative Dynamometer Car Tests.			
Route	Euston-Carlisle	Euston-Manchester	Southport-Manchester
Av. Train Load Tons	440	409	297
Av. Running Speed m.p.h.	52.1	52.7	37.5
Coal consumption—			
lbs. per mile	37.1	35.2	39.1
lbs. per ton mile incl. Eng.	.066	.070	.103
lbs. per DBHP/hr.	3.25	3.12	3.15
lbs. per sq. ft. grate per hour	62.4	60.9	58.5
Water consumption—			
Gallons per mile	30.3	29.5	28.9
lbs. per DBHP/hr.	26.5	26.1	23.3
Evaporation—			
lbs. water per lb. coal	8.15	8.39	7.45

* 8 years.

which the Claughtons lost time, dropped their steam pressure, and made the welkin ring with their reverberating exhaust. It displayed the full measure of the extent to which Bowen Cooke had failed to absorb the true lesson of the earlier G.W.-L.N.W. locomotive exchange in 1910 which was the forerunner of the Claughton design.

Dynamometer car tests on the Carlisle road showed a very substantial coal saving, and so far in advance was the performance over anything yet seen on the L.M.S. metals, that a profound impression was made. Work on the Pacific was stopped, and a decision was made that the new engine should conform to Operating Department requirements. Thus was the Royal Scot engine born, owing its inception to

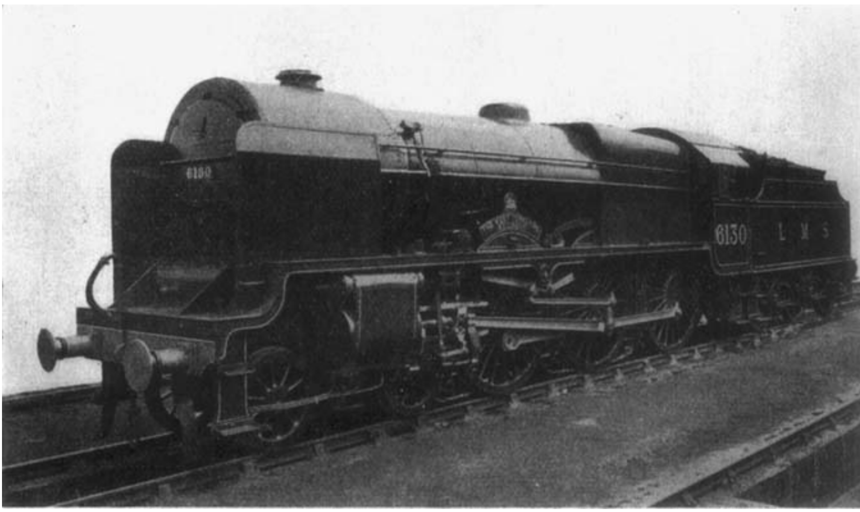


FIG. 21.
ROYAL SCOT ENGINE.

a measure of G.W.R. experience, foreshadowing the much more extensive G.W. influence which came with Stanier five years later.

So urgent was the need that fifty were ordered at once from the North British Locomotive Company who carried out the work at their Hyde Park and Queens Park Works simultaneously. The actual drawings were made by the firm under the close supervision of Herbert Chambers, the Derby Chief Draughtsman, and many features from the 2-6-4 tank engine currently being designed at Derby were introduced. Ordered at the turn of the year, the first engine was turned out in August, 1927, and the whole fifty were on the road by the end of December. Twenty more were built at Derby in 1930. Details of this class are too well known to need repeating, apart from the principal dimensions in Table II. Fig. 21 shows one of these engines; from the first they were eminently successful both in performance and efficiency and representative results are given in Table X.

Stepping outside the ten year period of this study, a glance at the subsequent career of these engines over 18 years of continuous heavy main line work is of interest as indicating certain features of the original design which proved capable of improvement.

In the first place cylinder bye-pass valves, bogie brakes and cross-head driven vacuum pumps have all been shed as more trouble than they were worth. Atomisers have been added to the cylinder mechanical lubricators, and the bogie side check springs have been strengthened. Steel axleboxes with pressed in brasses have taken the place of the original manganese bronze type and the bearing spring gear has been re-designed and side bolsters now transfer the weight on to

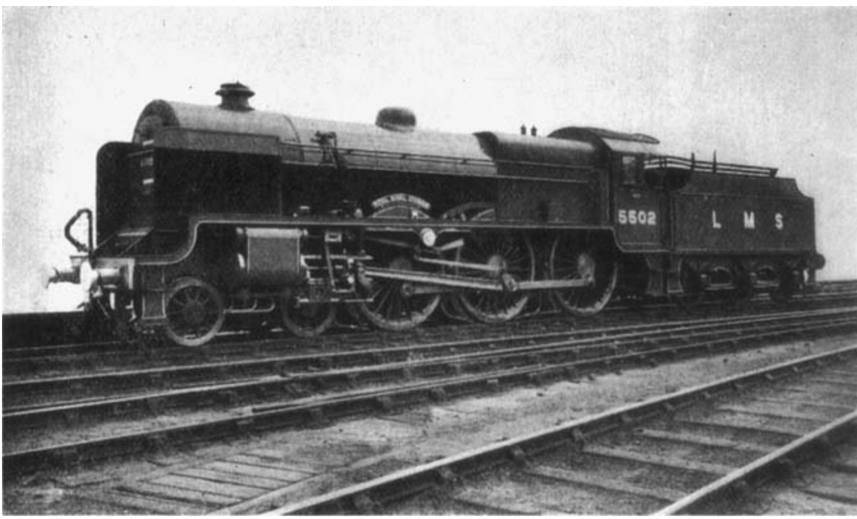


FIG. 22.

STANDARD 3-CYLINDER 5X CLASS 4-6-0 ENGINE.

the bogie. Narrow rings have been fitted to the piston valves and finally side deflector plates were found necessary for lifting the exhaust steam from the cab windows. As the engines grew older, trouble arose with the " built-up " type of smokebox drawing air, a defect which it has only been found possible to correct with the circular smokebox and saddle arrangement of the recent conversion to taper boiler.

The success of the Royal Scot had its repercussion on the quest to improve the Claughtons already referred to, and while Crewe were turning out a number of rebuilds retaining the four cylinder chassis, Derby applied the new large Claughton boiler to what was practically a Royal Scot chassis to form the three cylinder 5X class, Fig. 22, of which two trial engines were built in 1930. Reference to Table X shows that a higher efficiency was obtained by this rebuilding than in the case of any previous alteration including the Caprotti conversion.

This was coupled with much improved reliability so that it was not difficult to decide upon a policy of replacement along these lines. Like the Scots, these engines, of which fifty-two were ultimately built, have continued to give first class service up to the present time and are the basis of the subsequent taper boiler 5X class.

Finally the 2-6-4 Tank already mentioned, Fig. 23, was the forerunner of no less than 331 engines having similar basic features built up to the present day. Although Hughes had at one time considered a 2-6-4T version of his 2-6-0, Fowler's adoption of a higher pressure and certain clearance relaxations over the English Divisions made it unnecessary to follow the large, steeply inclined cylinder arrangement

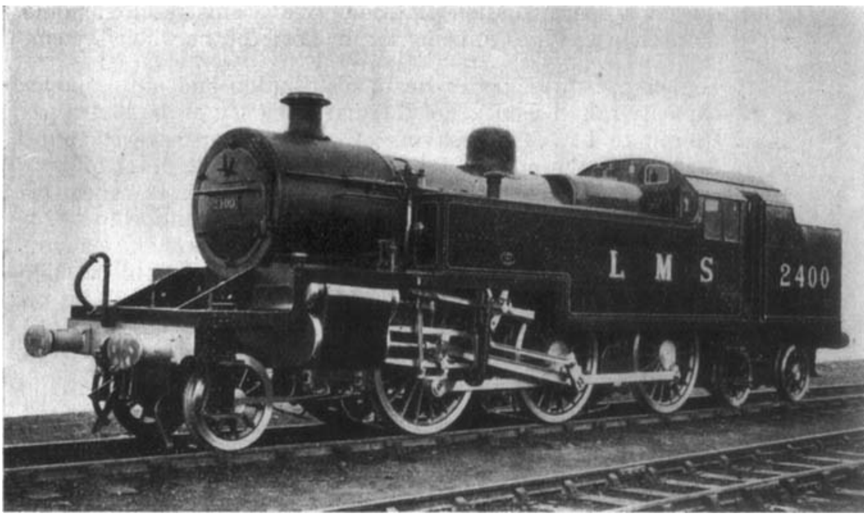


FIG. 23.
STANDARD 2-6-4 TANK ENGINE.

of the Hughes engine, so that a completely new design was prepared in 1926-7, the influence of the older engine being carried forward in the generous size of the axleboxes provided and in the long travel valve gear.

These three types have been taken as initiating a definite L.M.S. school, because unlike the other standard types, most of their main features are continuously traceable through the subsequent work of Stanier into the construction of the present day.

Conclusion.

The pattern has now been woven and it remains to assess its value to the cause of locomotive progress. Within the range of locomotive design and performance to which this paper is confined, it is of interest to pick out the highlights of this ten years of travail.

First on the credit side:—

(1) The decision to standardise on the general design and details of a single constituent Company, the Midland, and not to perpetuate non-standard types, produced quick results in the newly formed Company and by 1932 there were 2,002 new standard engines plus 1,853 more ex-Midland engines, 3,855 in all or 46% of the stock, which took standard parts. This reduced stores stock and facilitated maintenance and repair.

(2) The extensive interchange and testing of different types which was carried out, particularly in the earlier years, exploded the myth that various geographical portions of the line each required a special design of locomotive. This resulted in no more than 14 types sufficing for the needs of the whole system

(3) Higher pressures, better steam distribution and ample boiler capacity raised the level of thermal efficiency of the best types from 7 to 10%. The saving of coal per horse power at the drawbar in the new L.M.S. designs was of the order of 35% on test, and these lower consumptions were more nearly retained throughout each shopping period by attention to steam leakage past the valves. Moreover the operating efficiency of the new locomotives enabled the work of the line to be done with a smaller total stock. The combined effect of all this on coal consumption was a reduction of 682,566 tons in 1932 compared with that of 1923, a saving of 12%.

(4) Improved design led to a reduction in repair costs per mile as the various examples quoted throughout the paper will testify.

On the debit side only two entries can be made. First, purely from the operating point of view, increased efficiency had to be paid for in that some of the new designs lacked what can only be called the " guts " of some of the former types, which could be thrashed to almost any extent without drop in pressure, to meet exceptional circumstances of load and gradient, a fact to which many record runs will testify. It has always been a nice point as to where the balance between performance and economy is to be struck. When coal was cheap the former was the predominating factor. Modern design has enabled both performance and economy to move forward together, but it is always possible if too much emphasis is laid on the latter to produce a design which is shy of steam and is too sensitive to skilled handling. The new L.M.S. standard designs represented a fair compromise in this matter.

There is also a further entry, failure to appreciate earlier and more fully, the advantages of adopting all the measures outlined in Items 3 and 4 above. It is not easy, at this length of time, to appreciate the locomotive reluctance on the part of many engineers then to adopt features which are accepted practice to-day, a reluctance not by any means confined to the L.M.S. Sir William Stanier in his Presidential address to the Institution of Mechanical Engineers has referred to this, and has given some reasons for it.

It will be noted that this ten years' development did not lead to any departure from the classical form of the locomotive. Twice during the period, extensive trials were made of turbine condensing locomotives, first the Ramsay with electric drive and then the Beyer Peacock-Ljungstrom with mechanical drive. The latter was more promising than the former in that it did actually run on the main line with revenue trains for a period, but neither proved sufficiently reliable either operationally or mechanically. Diesel propulsion appeared on trial but its development into the reliable shunting units of to-day did not come until later. It will also be noted that except in the case of the L.N.W. "Claughtons," and that only to a limited extent, the policy of rebuilding existing engines was not followed. If existing designs were good enough to qualify as standards they were adopted broadly as they stood, otherwise the class was allowed to continue in substantially its original condition until scrapped. It is possible to hold divergent views on this. Such a policy avoids many mechanical troubles which occur when greater power capacity is built into an old chassis, but on the other hand improvements as they are developed and proved do not become incorporated into the body of the locomotive stock, but are confined to new construction.

The grouping happened to coincide with a general move forward into the next stage of locomotive development. It did not provoke that move, which had already been initiated in this country, by Churchward on the G.W.R., but it certainly helped to hasten it by removing barriers to the extension of knowledge and experience. There was, therefore, presented to the Engineers of that time an opportunity, limited only by some residual conservatism of outlook, to change the whole complexion of the locomotive stock and this record shows how far this was done on one railway. One cannot but feel this was an opportunity unlikely to present itself again in such full measure. The law of diminishing returns prevails, and just as no further gifts of 30% reduction in fuel consumption remain to be picked up by such inexpensive means as the adoption of superheating or long lap valve gear, so there are to-day in this country no railways full of obsolete engine types whose rapid displacement will show such a generous financial return.

The years since 1932 have seen further advance in thermal efficiency along classical lines, and its much wider permeation throughout the locomotive stock. Most recently attention has been more particularly directed towards increased availability and mileage between repairs, and it is in this latter direction that the biggest gains still lie ahead in the future of steam traction.

ACKNOWLEDGMENTS.

The author's thanks are due to Sir Harold Hartley, formerly Vice-President, L.M.S. Railway, and to the late Mr. C. E. Fairburn for permission to quote the data given in the paper, also to Messrs. J. W. Caldwell and E. V. Barker for assistance in its preparation.

The President, in proposing a vote of thanks to the Author, said that Mr. Cox had, as those who knew the quality of his work would expect, given a very fine Paper, showing in a series of scenes the development from most complicated and diverse beginnings to more recent times.

The vote of thanks was carried with acclamation.

DISCUSSION

Mr. O. V. S. Bulleid (*Past-President*), who opened the discussion, said the Paper gave one of the most interesting descriptions ever presented to the Institution of the way in which locomotives were designed. It might well raise serious doubts whether locomotives should in fact be designed in that way, and it showed the necessity for testing plant and a centralised design department, which were very much overdue. In a previous Paper the statement had been made that the C.M.E. should give place to the Locomotive Running Superintendent as the designer of locomotives, but all he could say was that the result would have been even more regrettable had anything like that happened. The Paper showed the persistence of the "geographical mind," which imagined that gradients and every other condition differed according to whether one was north or south of the Border, and varied as between different lines south of the Border, and showed the persistence of drawing office tradition, slightly modified by the personality of the C.M.E. who happened to be in office at the time. The position of the drawing office as the heart of the designing staff was not always appreciated.

The Author had also revealed certain facts which locomotive engineers had been anxious to know for a very long time. He showed that the poppet valve had, in spite of much opinion to the contrary, certain features of merit. That it should remain steam-tight in the way shown by the statistics given in the Paper must be very gratifying to Mr. Poultney and other devotees of the poppet valve, and the influence of that might permeate drawing offices to the advantage of all concerned. Personally, however, he would suggest that the full advantage of poppet valves would really come only when pressures were carried to a much higher level than in the past.

Some much-wanted information was revealed in the Paper about the mysterious compound locomotives designed for the L.M.S. In his view, the failure of the compound had been due to the use of low boiler pressures, such as 180 to 200 lb. sq. in., at which there was not the slightest necessity to have compounding at all. Compounding was required when the boiler pressure was raised above the limit that could be usefully expanded in the single cylinder, and there was no justification for the application of compounding when using moderate pressures of 180 to 220 lb. sq. in.

Apart from that, the Author might well have referred to the work of certain Great Ones who must have been behind the scenes, such as Mr. Reid. Someone must have had great strength of character to succeed in imposing the individual costings system. That system required a very considerable amount of detailed work, and there must have been somebody behind the organisation to introduce a system whereby proper account could be kept of the steam locomotive throughout its life. The Author might usefully reveal the name or names of those responsible for such an important move.

He would like to quarrel with the Author's statement that the average coal consumption of an engine was a better measure of the engine than the coal consumption obtained by scientific testing. His own view was that a locomotive was intended to burn coal, and the more coal that an efficient engine burned the better; it meant that the engine was doing more work. It was necessary to find means, by testing, so that an engine would burn coal in big quantities, produce plenty of steam, and use that steam efficiently; and then, he would suggest, the management might usefully ask why a particular engine was burning so little coal, and not, as was so frequently asked at present, why it was burning so much. From that point of view he would suggest to the Author that some of the statistics given in the Paper might in fact be rather misleading, and that figures for the lb. of coal per dbhp/hr. found by proper tests in the case of a good design which maintained the steam-tightness of the engine would be much more useful than statistics based on an estimate of the number of tons of coal put on the tender or the amount of coal put through a hopper, with no proper correlation between that amount of coal and the work done by the engine.

The Paper was a most valuable contribution to locomotive literature. It could have been produced only by the L.M.S., and he doubted whether anyone but the Author could have presented it in such an intriguing and delightful manner.

Mr. R. C. Bond (M.) expressed the view that the Paper should be discussed mainly by those who had not been or were not connected with the L.M.S. Railway during the ten years covered by the Author. He felt that those who had been concerned with what was going on were probably living too close to the events to form a balanced judgment on the final results.

The Author had referred in some detail to the development of valve and valve gear design on the L.M.S. Railway and in that connection it might be of interest to recall some tests with the Midland 3-cylinder compound engines in the early years in which indicator diagrams were taken. Following upon these very carefully conducted trials the events of the H.P. valve gear were altered to give increased mean effective pressure at all cut offs and better distribution of work between the H.P. and L.P. cylinders. The overall performance of the locomotive was much improved thereby. In a later series of engines of the same class the cylinder diameters were increased by $\frac{1}{2}$in. with the original valve events in the anticipation that this combination would give results at least equal to those obtained on test. In practice this was not the case and it was necessary to liner the cylinders down to the original dimensions and modify the valve events in accordance with the experimental results. This experience brought home the profound effect which apparently small changes in valve events could have on locomotive performance and emphasised what Mr. Bulleid had said concerning the necessity for a scientific basis in making alterations to design.

One result of the first ten years of locomotive practice on the L.M.S. appeared to be a decided bias towards simple straightforward designs wherever possible. A number of locomotives were projected as the Author had mentioned, involving four cylinder and compound expansion, but fortunately in his opinion simplicity won the day. The general trend had been to the use of two cylinders if two would suffice and to go to three or four cylinders only when compelled to do so. That policy differed somewhat from that adopted over the same period by the other large northern railway group and he hoped that the Paper would encourage others to come forward and describe, for the benefit of locomotive engineers generally, what had happened behind the scenes on their railways.

In referring to the introduction of long travel valve gear, the Author suggests that it was little regarded by other C.M.E.s except Churchward on the G.W.R. Personally he felt that assessment of the position was hardly fair to Mr. Maunsell who followed close behind Swindon's lead in adopting long lap valves. It was, as the Author had said, difficult at this date to understand why there was, generally speaking, considerable reluctance to adopt long travel valve gear which has proved to be a factor of major importance in the successful locomotives of to-day.

Mr. E. C. Poultney, O.B.E. (M.) said the Paper did not lend itself to discussion, but it prompted him to ask a few questions. In the case of the proposed Hughes 2-10-0 locomotive, shown in Fig. 2, he would like to know which axle took the drive from the inside cylinders. In connection with the proposed Fowler 4-6-0 3-cylinder compound, shown in Fig. 6, the boiler was somewhat like that of the Royal Scot, but the tubes were of $1\frac{7}{8}$in. outside diameter with a length of 16ft. 6in. It was interesting to note that in the new standard boiler fitted to the small Scot 5X class engines the tubes were of $2\frac{1}{8}$in. outside diameter, with a length of 14ft. between tubeplates. He had often wondered why that peculiar bore-length ratio was adopted, and had been waiting to put that question to the Author.

He had always admired the Hughes 4-6-0 locomotives which originated at Horwich and were subsequently put to work on the northern part of the Western Division main line of the L.M.S., and had been at a loss to understand why they had not been more successful. They seemed to have a particularly good cylinder arrangement with exceedingly large steam chest volumes. He had never seen that cylinder design before or since, and would very much like to know whether there was anything intrinsically wrong with that arrangement. The steam chest volume, as he had said, was exceedingly large compared with that of any other design that he had seen and the very short straight ports were entirely in accordance with modern ideas. Altogether the cylinder design seemed to be almost ideal, and yet for some reason or other the engines did not appear to have been successful; they were always said to burn a great deal of coal, and the figures given in the Paper seemed to bear that out. He hoped the Author would be able to say what their weak points were.

Fig. 12 showed in graphical form the annual coal consumption of certain simple and compound locomotives, and it was extraordinary to notice the way in which the coal consumption of the compound locomotives seemed to increase with the passage of years. He thought that the Author ought to enlarge on that point. It seemed to be ascribed to the enginemen, and there might be something in that, because drivers varied very much indeed. He could recall some engines which did excellent work in the hands of two or three men, whereas the class as a whole had a bad name for not keeping time with trains. He remembered in his boyhood the Webb compound "Jeannie Deans," which used to run daily between Euston and Crewe with the old 2 o'clock Corridor, and which he occasionally saw at Crewe. This class of engine as a whole was not considered successful, but that particular engine kept very good time with a 250- to 300-ton train every day for about nine years. Other examples of a similar nature could be mentioned. He had met drivers at Camden shed who told him that they would be quite content to have a Webb "Greater Britain" compound and could do anything with it from running a coal train upwards, but other men would not be able to operate those engines at all. The Author might say something more about that. The figures of coal consumption per mile gave no indication of the work done, and therefore it was not possible to make any comparisons; for purposes of comparison one would prefer the coal consumption to be given on a ton-mile basis.

It was stated in the Paper that when the Midland 4-4-0 Class 2 passenger engine was adopted as standard on the L.M.S. for light passenger work the cylinders were entirely redesigned and their diameter reduced from 20½ to 19in. He would like to know when the original Midland engine of this type was built, because in 1907 Deeley built at Derby some 4-4-0 locomotives of the 990 class which had remarkably good cylinders with straight ports and large valves. If the original Midland and Class 2 locomotives with 20½in. diameter cylinders were built after the Deeley 990 class to which he had referred, there was no excuse for the former having bad cylinders.

He liked the outside cylinder 4-4-0 design shown in Fig. 13. It was stated in the Paper that this type could not be adopted because of the loading gauge. He imagined that smaller cylinders and a higher boiler pressure might have overcome that difficulty, and, in view of what the Author had said in a former paper when discussing axleboxes, an outside cylinder engine would probably be preferable.

With regard to poppet valves, he was very glad to hear that the horizontal type of valve was preferred. During the time he was connected with the development of poppet valves he resolutely stuck to the idea of the horizontal valve, holding it to be more accessible than the vertical type, and he was glad to find that the Author agreed with him.

The " Royal Scot " engines had done marvellous work, and he had the highest admiration for them. The figures given by Sir Henry Fowler in the discussion of Mr. Fry's paper on compound engines in 1927 bore out the excellent work that they did. The Author quoted for them a coal consumption figure of 3.25 lb. per dbhp/hr., which was a very low figure indeed, and represented, with the class of coal used, a thermal efficiency of over 6½ per cent., which could be considered most satisfactory.

He would like to conclude by showing a slide depicting two locomotives built at Crewe, both named " Princess Alexandra," one a 2-2-2 type built in 1864 and the other a streamlined Pacific built, he thought, in 1938. He came across those two pictures in turning over some photographs in the offices of the Locomotive Publishing Company some time ago, and in conjunction they showed in a nutshell the development of the locomotive over a much longer period than that covered by the Author. The 2-2-2 engined weighed 27 tons, and the Pacific 108 tons with the streamline covering and 105 tons without. The little engine developed about 500 h.p. as a maximum and had a weight of about 123 lb. per h.p., while the Pacific developed 3,000 h.p. and weighed 78 lb. per h.p. The coal consumption for the 2-2-2 was probably at least 4 lb. per dbhp/hr., and for the Pacific rather more than 3 lb. per dbhp/hr. with a light train and rather less than 3 lb. with a normal load. The low coal consumption of the larger engine extended over a wide range of power and also over a wide range of tonnage behind the tender. When operating express trains of 450 to over 500 tons between London and Glasgow, the coal consumption was less than 3 lb. per dbhp/hr., which was an excellent performance by a very beautiful engine.

Mr. H. Holcroft (M.) said the Author inferred that the dramatic appearance of the " Royal Scot " locomotives on the L.M.S. was the sequel to the trials of the G.W.R. " Castle " class locomotive between Euston and Carlisle. That, however, was not the full story, and now that, after some twenty years, the matter had passed into history, he did not think there would be the least harm in revealing something more of what took place behind the scenes in this drama, of which perhaps the Author himself was not aware. In order to explain what happened, it was necessary to go back to the year 1925, when the G.W.R. " Castle " class, by its sparkling performance on the Great Western main lines achieved a great reputation, which was enhanced by a publicity campaign from Paddington. A tactical error was made in this literature by describing the engine as the most powerful in the country, this claim being based merely on its maximum tractive effort, although, of course, the L.N.E.R. " Pacific " type, from the point of view of boiler capacity, was more powerful.

In 1926 the Southern Railway produced the four-cylinder 4-6-0 type " Lord Nelson " engine, which had a bigger boiler, more adhesive weight and more tractive effort than the Great Western engine; and, seizing upon this fact to conduct a counter campaign, the Southern Railway publicity people, by describing their new engine as the most powerful, stole the G.W.R. thunder! This, of course, had the effect of "spot-lighting" the engine and for a period it was regarded as the highest development of the 4-6-0 type and its subsequent performance was therefore all the more closely watched. It showed its capabilities by operating trains of 500 tons tare weight at an average speed of 55 m.p.h. over a fairly heavily graded road, and ten more engines were at once put in hand.

It was at this point that the crisis on the L.M.S. arose later in 1926 as described by the Author. Fifty 4-6-0 express locomotives had to be built to be ready for the summer traffic of 1927. There was no time for much preliminary work and plates and castings had to be ordered at once irrespective of finished drawings; it was out of the question to build a prototype and try it out before the batch was proceeded with. There was one way out of the dilemma and that was to base the design on a well-tried and successful engine of the capacity required and alter it in detail as necessary. Derby, therefore, sought the assistance of Waterloo, with the object of producing a three-cylinder version of the "Nelson," and with that ready co-operation which existed behind the scenes on the railways, a complete set of "Lord Nelson" drawings was hurriedly got together at Eastleigh and despatched direct to Glasgow to ease the situation. The extent of that timely help was, he thought, reflected in the family likeness of the two engines in their original state. Not only were they very much alike in appearance, but they were also almost the same in weight and general dimensions.

On that account he did not think that the design of the particular Great Western engine used in the trials had any direct influence on the design of the "Royal Scot," as stated by the Author, although those trials served the useful purpose of demonstrating the standard of performance attainable by the 4-6-0 type. The Great Western influence was nevertheless there, but it was exerted indirectly. Mr. Bond had already referred to Mr. R. E. L. Maunsell's adoption of Churchward practices. Mr. Maunsell incorporated the long-travel valve, the taper boiler, top feed and many other Swindon characteristics in his Ashford built engines on the S.E.C.R. from 1917 onwards, and this fact was not sufficiently appreciated and given its due importance. The practice was continued on the Southern Railway in his Eastleigh built engines, notably the "King Arthur" class and subsequently the "Lord Nelson." Such Great Western influence as was to be found in the "Royal Scot" thus came to the L.M.S. in that indirect way. Having been at Swindon during the Churchward régime himself, and passing by way of the South-Eastern and Chatham to the Southern Railway, Mr. Holcroft had been able to see development as a continuous process and not merely as a series of isolated events as it might appear to others and, therefore, he could speak with some authority on these matters and put them into what he thought was their proper perspective.

Regarding the subsequent alterations to the " Royal Scot," the Author mentioned amongst other items the strengthening of the bogie side check springs. That, he thought, was the result of the recommendations of the Ministry of Transport Inspector following the derailment of a " Royal Scot " locomotive at Weaver Junction, near Warrington. This was a most unusual derailment, because the back of the flange of the leading coupled wheel climbed the check rail, and so enabled the opposite wheel to strike the wrong side of the nose of a V-crossing and become derailed. Almost at the same time, by an extraordinary coincidence, a precisely similar accident occurred at Kent House, near Beckenham, with a " Lord Nelson " engine on the Southern Railway. The circumstances were so very much alike, the type of derailment so unusual, and the general design of the engines so very close, especially as the Southern engine was carrying a six-wheeled tender at the time, that the Ministry coupled the two enquiries and considered them together.

Mr. W. Cyril Williams (M.) described the Paper as of very great interest to all locomotive engineers, dealing as it did with a situation in which there were originally 393 different types of locomotives, which were reduced eventually at the end of a ten-year period to 230.

It was this aspect of the case that interested him in view of the various designs for almost similar work and the omission sometimes of the latest experience available at the time. Admittedly, there were many railways taken over, but even this cannot account for the costly experimenting and total absence of " getting together " and profiting from the results of others, which seems apparent.

The job done by the London Midland and Scottish Railway—whittling the classes down to fourteen standards—was therefore all the more an achievement. The Paper is put together in a masterly way and is a reminder of the great responsibility carried by Chief Mechanical Engineers, especially when one remembers that a locomotive is with us 25 to 30 years.

The Paper also explodes the myth of one engine for one job and in retrospect illustrates a lack of effort to obtain the fullest possible information of experience available at the time from other British Railways and the British Locomotive Industry.

Mr. D. C. Brown (M.) said that the influence of British main line practice on overseas railways, and particularly on railways in the Colonies, was considerable. The Colonial railways had none of the testing facilities available in this country, and due to lack of a testing plant and to the differences in gauge it was not possible to do any extensive trials in this country before shipment. Hence the adaptation of British design features to suit Colonial requirements had to rely to a large extent on analogy. Analogy, however, was dangerous unless it was possible to ascertain and analyse all the relevant facts.

That was why a Paper of the type under discussion was so helpful, as it explained the reasons and influences underlying trends in design. It also had the great virtue of dealing with features which were not entirely satisfactory as well as with those which were.

It seemed to him that before a design feature could be adapted from one railway to another, it was necessary to ask three questions:

1. What was the problem facing the railway that originated the design?
2. Did the design prove, in service, to be a good answer to that problem? That was a question which sometimes had to be asked tactfully, and a debt was due to the present Author for his clear and comprehensive statement of facts, and also to the breadth of vision of the L.M.S. Railway in allowing those facts to be published.
3. Was our problem really similar to the problem which had to be answered when the design was originated? This important question was sometimes forgotten, and even a good design could be useless if misapplied.

It was of tremendous help to the overseas railways, which normally absorbed such a large proportion of the locomotive capacity of this country, to have detailed information and data from the home railways, and naturally, the more up-to-date the information could be, the better.

Mr. R. A. Riddles, C.B.E. (M.) joined issue with the Author regarding his third conclusion on the credit side, in which he claimed that owing to the better efficiency of the standard locomotives the saving in coal in 1932 as compared with 1923 amounted to 682,566 tons, equivalent to 12 per cent. It seemed almost incredible that it was possible to reduce annual consumption of coal by so much in so short a time as ten years. It must be remembered, however, that 1932 was a very bad year—many people would recall that, because there had been a 5 per cent. cut in salaries!—and a reduced mileage was run, a large number of locomotives being laid up because there was nothing for them to do. That the saving of coal was hardly due to the better type of locomotive employed was borne out by the fact that the best type of all from that point of view, the 4-4-0 compound, showed an increased coal consumption per mile from 1927 to 1932.

The Author also said that the operating efficiency of the new locomotives enabled the work to be done with fewer engines and a reduction in stock, but the reduction in stock on the L.M.S. was primarily brought about by the better conditions in the shops and was due entirely, in his personal opinion, to the initial examination of locomotives and the setting up of an inspection department by Mr. George Hughes, and individual costing which cured many evils. The L.M.S. were spending about £3,000,000 a year on locomotive repairs, when the late Lord Stamp wanted to know where the money was going, so that individual costing was instituted to see how much money was spent on each locomotive. That provided a list of the diseases from which the various locomotives suffered. At one time if a man wanted a job of work he had only to take an engine number and put it down as "engine repairs" and get away with it, but when individual costing came in he could make only one charge on any one item for an individual locomotive, because a check was kept by the accountants. The Author's fourth point on the credit side was "improved design led to a reduction in repair costs per mile," but personally he thought that that was largely due to initial inspection and individual costing. He had worked under Mr. Ivatt when Mr. Ivatt was Works Superintendent of Derby shops in 1928, and at that time they reduced the number of engines awaiting repairs from an average of 147 to an average of 62, purely by improvements in shop practice. He did not want the idea to get abroad that all the economies referred to were due entirely to better design.

Mr. L. N. Flatt, C.I.E. (M.) said he was very much interested in the question of individual costing, and he was sure that his colleagues in India would appreciate very much some more detailed information on the subject. After all, no deduction could ever be more accurate than the data on which it was based, and the collection of accurate data on shop costs and coal consumption was of vital importance in making deductions in regard to the success of different types of locomotive. If, therefore, the Author could possibly include, as an addendum to his Paper, some of the forms which were used for the individual costing method, and also the forms on which coal consumption was recorded, the Paper would be of even greater value to locomotive engineers in India, and probably to those in the Colonies also.

He realised that this was, perhaps, somewhat outside the intended scope of the Paper, but having had experience of the prolonged labour pains attendant on the birth of standard locomotives in India he was very jealous of any administration which had been able to base its decision as to which types should be perpetuated and which eliminated upon really complete and accurate statistical data. It was clear from the Paper that the decisions as to which engines should be perpetuated, and which should not, had been based on unit costs both of repairs and of coal.

Conditions in this country were widely different from those in India. In this country the railways had an educated staff, whose reaction, when asked to do something, was to try to help. In India, he was afraid, that was not the case; in many of the grades the staff was illiterate, and the collection of accurate basic information presented considerable difficulty and involved greater expenditure than would be necessary in this country.

The Author said that it had been decided in some cases to scrap rather than rebuild types which had been in service for an appreciable period. Did that mean that it had been possible from the unit cost figures to establish a relationship between age and cost of maintenance? That would seem to be implied, and, if that had been established, and if it was possible to defend successfully the accuracy of the deductions made and the basis upon which they were made, it would be of enormous assistance to Chief Mechanical Engineers when considering whether a certain type of engine should be scrapped prematurely. The accountants and financial people naturally wanted to know where the money was going, and a proposal to condemn an engine after, say, 15 years' service, when normally, rightly or wrongly, the life of a locomotive was regarded as being about 35 years, required, even when perfectly justified, the careful preparation of a case and figures which could not be controverted in order to prove that the cost was justified.

Mr. T. Henry Turner, M.Sc. (M.), said the Author's paper helped us to study the way we had come, with a view to our deciding where to go from here.

After considering what had been done in other forms of transport as a guide to what might have been done with railway steam locomotives, he concluded that liquid fuel, high speed engines, rotary motion and reduction gears stood out as a challenge. It was notable, therefore, that the paper referred to no experiments to replace crude run of mine coal during a decade when ships, buses, cars and aeroplanes turned to liquid fuels.

Perhaps the next paper before the Institution would make it possible to follow two other such features—rotary motion and reduction gears—on the L.M.S. turbine locomotive.

The **President** said he would like to make one comment and to ask one question. His comment was that in view of the fact that the steam locomotive consisted of two parts, a boiler and an engine, it seemed a little unwise to judge efficiencies over-all; it would be better to take them separately, and ask what steam was obtained from the coal burned, and then what use was made of the steam when it had been obtained.

Coming to his question, he noticed that the tables showed the pounds of coal burned per ton-mile including the engine, and he would like to know why the engine was included. An engine had one purpose, to haul the other vehicles, and the weight of the engine had nothing to do with its effectiveness in hauling the pay-load. If one made a very heavy engine which had so little power that it would pull only one truck, one might still get a good figure for pounds of coal per ton-mile by including the engine. It seemed him that the lighter the engine and the heavier the train the better.

WRITTEN COMMUNICATIONS.

Mr. O. S. Nock (A). Among a mass of highly interesting data one's comments seem naturally to fall under three headings:—

1. Performance of historic locomotion of the constituent companies of the L.M.S.
2. The " might-have-beens."
3. Development of modern L.M.S. practice.

So far as the London and North-Western Railway is concerned, while the " Prince of Wales " class, 246 strong, was the mainstay of the passenger service all over the system, a great deal of very hard work was being done by 4-4-0's of the " George the Fifth," and superheater " Precursor " classes; there were about 150 of these engines in service at the time of the grouping, and in haulage ability they were certainly the equal of, if not superior to, the Midland compounds, and should certainly have been Class 4 and not Class 3. I suppose their front-end design was much the same as that of the " Prince of Wales " class, but it would be most interesting if Mr. Cox could give some figures relating to their performance in the period under review, for in earlier days they showed some very good coal consumption figures. There was a test with the dynamometer car, in 1910 I believe, on which a train of over 350 tons was worked from Crewe to Euston at an average speed of 60 m.p.h. on a coal consumption of only 40 lb. per train mile.

The Author states that the most generally satisfactory of all Crewe designs were the " G1 " and " G2 " 0-8-0 goods classes, but this showing is surely due entirely to their working being at low speeds. Presumably the front-end design was similar to that of the " Prince of Wales " class, but the evil effects of restricted port openings and short-lap valves do not generally begin to show themselves seriously until the speed exceeds about 200 r.p.m.

The remarks about Caledonian engines are revealing, but I am surprised to learn that the robust 0-4-4 tank of McIntosh design failed to keep time on English schedules. If the work of this class in assisting heavy trains up the Beattock bank is anything to go by they are, even to-day, scarcely lacking in " guts," and I should be very interested to learn on what English duties they failed. The only job on which I recollect seeing one was on the Midland suburban service from St. Pancras. On the Beattock bank I have a record of one of them assisting a Midland compound, with an exceptional load, when from a standing start at Beattock Station the two engines lifted a train of 480 tons up the ten-mile climb, averaging 1 in 80, in 23½ minutes.

On the other hand, the Pickersgill two-cylinder 4-6-0's of the " 14630 " class seemed very indifferent engines in traffic, and although they do not show up too badly in the Table IV it is perhaps significant that none ever went into regular service south of Carlisle. A re-design of their link motion, on the lines of that applied to the Great Eastern " 1500 " class by the late Sir Nigel Gresley, would probably have worked wonders, both in reducing coal consumption and in giving freedom in running, but by the time the L.M.S. had definitely adopted long travel valves these Caledonian 4-6-0's had dropped out of the picture.

Turning to the " might-have-beens," I was very interested to read in the paper that under the Lemon-Beames regime there was a proposal for a 4-8-0. As illustrated on the screen this engine was shown to be a heavy freight, of moderate dimensions, but I would suggest that under modern conditions the 4-8-0 wheel arrangement might well be seriously considered for express passenger work. " Pacifics," with 40,000 lb. of traction effort, and 66 tons of adhesion, seem prone to slipping in bad weather, and with the outstanding example of the Chapelon 4-8-0's of the former P.O.-Midi line before us the possibility of improved all-weather performance on the Shap and Beattock inclines would appear to be considerable. It would be interesting to learn the Author's views on this point.

In the later history, the improvements to the "Royal Scots" as described on pages 137 and 138 make interesting reading. One cannot fail to be struck, however, by the pronounced drop in coal consumption between 1929 and 1932-3, as revealed by Fig. 12, despite the fact that on the accelerated schedules of 1932 onwards the "Royal Scots" were then doing what was probably the hardest work of their career—before the Stanier Pacifics came to take over the heaviest Anglo-Scottish workings. In addition to the alterations mentioned I have always understood that some changes were made in the valve setting, and it would be interesting if the Author could confirm that such was actually the case.

Mr. E. L. Diamond. Though there have been many locomotive histories of great literary merit and technical accuracy, Mr. Cox's paper is unique in combining these qualities with an intimate knowledge of the policies and personalities behind the actual course of events. It is seldom indeed that an author with so great a gift for writing locomotive history in the grand style has occupied a position affording knowledge of all the facts. If one regrets that his history covers only ten years on one railway, there is the compensating reflection that the period was the most interesting in all locomotive history since its beginnings, and the railway the one in which the transition from static mediocrity to progressive design the most striking.

The paper will do much to enhance the reputations of Hughes and Fowler, which have naturally suffered, especially in the case of Fowler, from the complete eclipse of their products by those of Sir William Stanier. Sir Henry Fowler was a man of very keen intellect, not original, but receptive, and singularly free from prejudices. He appreciated the ideas of others, encouraged scientific study and attainments in those under him, and was about to take full advantage of the fruits of this broadminded policy when the administrative changes following the grouping threw the whole locomotive policy of the company into a state of flux. It is true that under Fowler two influences were in conflict, and he is naturally identified with the Midland tradition because of his position after Deeley's retirement. But in the final conflict he had clearly appreciated the issues and, left to himself, would have followed the line of progress initiated by Hughes, as his four-cylinder compound designs, now revealed for the first time, clearly show.

The paper suggests that the "Royal Scot" design was the embodiment of the Operating Department's requirements as opposed to Fowler's proposals, but I would like to ask if it was not the case that despite the over-ruling of his main proposals, the details of these engines, and particularly of the valve gear, on which their success depended, were largely due to Fowler ?

It would be of great interest to know what the Author's own opinion is, in the light of his full knowledge of its details, of the probable success of the proposed Compound Pacific. In this connection Fig. 12 shows the compound in a seriously unfavourable light, and it does seem to demand a more detailed explanation than the Author offers. As the years go by and a locomotive type of any kind is relegated from long-distance express work to stopping trains, its coal consumption on a purely mileage basis is bound to rise considerably unless its efficiency at high speed is very low indeed. A policy based on Fig. 12 without a great deal more information as to the average speeds run at the different periods and the nature of the duties (*e.g.*, we are told that the Horwich compound was confined to the difficult route over Shap) might also, in the Author's own words, " go far astray." This is not intended as pleading in favour of the compound, but simply as a warning that broad overall statistics cloaking a multitude of variables can be just as misleading as technical data based on isolated trials. I would readily agree that for mixed duties under present-day conditions a compound locomotive would be unsuitable, but the Author presumably does not advocate that all locomotives should be built for mixed duty.

I very much hope that the Author will in the future extend this essay in engineering history to cover a wider field. It is at once the kind of writing that is most readable and the most informative.

Lt.-Comdr. D. R. Carling, R.N.V.R. (A.M.). The graphs of coal consumption are certainly interesting but would be even more interesting had it been possible to plot lbs./ton-mile instead of lbs./mile. Nearly all the curves are concave with minima in the worst of the slump years, possibly due to lighter loading. Can the Author remark on this feature ?

It is by no means certain that the Author's conclusions about the deterioration of compound performance would apply to the proposed larger designs, such engines being unsuitable anyway, compound or simple, for secondary duties; nor might it apply to compounds of more suitable design. Surely the correct policy is to educate and train the staff up to the best possible design of locomotive, not to design the locomotive down to an under-trained staff ? It is an arguable point, too, if locomotives should be kept in service in unsuitable duties. With ever-increasing utilisation the modern locomotive may well have completed its economic life before it is really obsolete for its original duties or something not much different.

This raises the question of repair costs. Has any allowance been made for the age of the various locomotives and classes, as repair Costs usually tend to increase with age if the work performed remains similar ? It is not without interest that the classes mentioned as having low repair costs are also those of which fairly large numbers were built not long before the dates relevant to Table V. This would probably not affect the general conclusion but might affect the degree of difference. Similarly, was it necessary to make any allowance for the type of service performed by various classes? The Author has referred to the fact that different conditions and methods of repair affected the cost but does not say if any allowance was made in arriving at the repair cost indices ?

The writer's only personal experience of the engines reviewed was the erection and running in of most of the second batch of Garratts in 1930. At the time it seemed strange that they were built without inner carrying wheels, giving very heavy loading of the rather undersized axleboxes and probably adding to flange wear. Admittedly, the axleboxes were not so severely loaded by piston forces as in the case of the inside cylinder 0-6-0 Class 4 engines. The use of the short travel valve gear seemed then, as now, quite inexplicable, especially in the second batch of engines.

It is very interesting that in all those cases where test figures and long period averages are given for coal per mile for passenger locomotives and where the journey covered on test can be taken as closely representative of the general duties the long period consumption is almost exactly 4/3 times the test figure, *i.e.*, 1.363, 1.360, 1.364, 1.356, 1.328 (almost too consistent !), while other values 1.09, 1.495 and 1.462 are not strictly comparable.

This increase is presumed to be due partly to the fact that the long-term figure contains bad as well as good conditions, that the generality even of top link drivers are not as skilful as the test drivers and that the tests are carried out with carefully selected coal, as is necessary if the figures are to mean anything. The consistency, however, gives authority to any forecast based on the test results.

Mr. D. W. Peacock (A.M.). Towards the end of his interesting paper, the Author says that in some of the L.M.S. standard engines increased efficiency has to be paid for by lack of " guts," or overload capacity, as compared with the older types. While in some cases this may be so, it would be interesting to have the Author's reasons why he considers efficiency must necessarily penalise overload capacity.

A comparison of boiler and cylinder dimensions of standard and pre-grouping engines is given in the table below, most of the data being taken from Table II of the paper. The last column is headed " Boiler Demand Factor," and is computed as

$$\frac{(\text{cyl. dia.})^2 \text{ x stroke x boiler pressure}}{\text{total evaporative heating surface}}$$

(for a two-cyl. engine), and gives a simple comparison of boiler and cylinder dimensions.

Engine		Cylinders inch Dia. × inch stroke D S	Boiler pressure lb./sq.in. P	Total Evaporative Heating Surface sq. ft. He.	Boiler Demand Factor $\frac{D^2SP}{He.}$
Royal Scot	3	18 x 26	250	2,081	1,518
5X 3-cylr.	3	18 x 26	200	1,633	1,548
Class 2 4-4-0 ...	2	19 x 26	180	1,158	1,459
2-6-4 Tank	2	19 x 26	200	1,090	1,722
Class 7 0-8-0 ...	2	19.1/2 x 26	200	1,552	1,274
Class 5 2-6-0 ...	2	21 x 26	180	1,505	1,371
Class 4 0-6-0 ...	2	20 x 26	175	1,158	1,572
L. & Y. Class 5 4-6-0	4	16.1/2 x 26	180	1,910	1,334
L.N.W. Prince of Wales	2	20.1/2 x 26	180	1,512	1,301
L.N.W. George V ...	2	20.1/2 x 26	180	1,488	1,322
L.N.W. G.2 0-8-0 ...	2	20.1/2 x 24	175	1,663	1,061

On the whole the standard engines have higher boiler demand factor in comparison with equivalent older engines. This does not infer that the engines are relatively over-cylindered, but is a necessary consequence of the habitual early cut-off working, with lower mean effective pressures. It follows that, in comparison with the older engines, a standard engine needs larger cylinders to do the same work.

Comparing a hypothetical modern and an older engine with the same boiler, and working at the same evaporation rate, the modern engine, with its larger cylinders, would be working at an earlier cut-off and lower back pressure, consequently the blast arrangement would require to be more efficient than that of the older engine. The same general principle is presumably true for the two groups of engines, namely: standard (mostly long valve travel) and pre-grouping (mostly short valve travel). If, therefore, a standard engine steams satisfactory in normal working, it should be capable of equal or even greater overload than an older engine, since overload capacity is mainly a question of the boiler supplying the steam to cylinders, which are always capable of using it.

It is true that some performances made by pre-grouping engines in the past (when in first-class condition) show remarkable power of overloading, of which, incidentally, the same engines appear to be incapable to-day. Part of the explanation of the Author's contention may perhaps be that the modern engines are not asked to put up similar performances when overloaded, and for this reason (and others), many drivers are not often disposed to get the utmost out of them. Certain special runs made shortly before the war would seem to suggest that modern engines can put up remarkable records when driven all out.

AUTHOR'S REPLY.

The Author agreed with *Mr. Bulleid* that improvement in efficiency due to compounding would be much more marked at higher pressures, but all the other problems connected with compounding remained, whatever the pressure, and he could not imagine that the various disabilities which had shown themselves in previous applications would vanish merely with a rise in working pressure. He thought he was right in saying that it was the late Sir Josiah Stamp who was principally responsible for the introduction of individual costing. Turning to Mr. Bulleid's comments on methods of assessing an engine's value, the Author thoroughly agreed with the necessity of making scientific tests, but he did feel that a continuous back check from daily service was also essential, and the coal per mile figures from the individual costing had in fact given a remarkably reliable index to the relative value of the different engine classes.

He could not agree that the more coal an efficient engine burned the better, for the simple reason that however efficient the use of the steam in the cylinders, the efficiency of the locomotive type boiler fell inexorably by a straight line law as the rate of combustion went up.

In other words, an " efficient " locomotive did not stay efficient if it was made to burn coal at high rates of combustion.

He thanked *Mr. Bond* for his interesting supplementary remarks regarding the Midland compound. He was glad Mr. Bond had referred to Maunsell's early adoption of the long lap valve. Churchward was first at the turn of the century but only with saturated steam or later low degree superheat. Hughes was first to combine long lap with high degree superheat in his four 4-4-0 engines in 1908, and Maunsell made the next application on his 2-6-0 and 2-6-4 T in 1917. Hughes re-introduced the combination on to the L.M.S. in 1926 with the 2-6-0 engines described in the paper.

In reply to *Mr. Poultney*, the inside cylinders of the 2-10-0 locomotive shown in Fig. 2 were to drive the second axle. With regard to the tube size on the proposed three-cylinder 4-6-0 compound shown in Fig. 6, an outside diameter of $1\frac{7}{8}$ in. and a length of 16 ft. 6 in. happened to be in accord with what were now considered to be reasonable proportions. The locomotive with the tubes $2\frac{1}{8}$ in. diameter and 14 ft. long had rather suffered in its maximum steam production from that tube ratio, which was not as favourable as it should be. Why the Hughes 4-6-0 engines were not more successful was a question which many people had asked over a long period. In many respects they appeared to embody all the elements of success, and one might have expected them to put up a performance not very different from that of the Great Western engines, except that Hughes always clung to a low pressure for the sake of low boiler maintenance. It could now be definitely stated, he thought, that their lack of success was due to two causes. The first was the valves with which they were fitted, which allowed serious steam leakage to occur past the balls, so that the valves were not steam-tight. The second was that although the cylinder design was admirable, with its large ports and passages, the connection of the exhaust lead from the outside cylinders into the smokebox was defective, and by drawing air into the smokebox continually interfered with good steaming. The Midland 4-4-0 locomotive with cylinders $20\frac{1}{2}$ in. in diameter which was the forerunner of the L.M.S. Class 2, was designed about 1912, after the 990 Class to which Mr. Poultney referred. Unfortunately, the history of locomotive design in those days bristled with examples of where a good thing was found but, its advantages not being fully realised, was afterwards lost and had to be discovered over again.

The Author had introduced Fig. 12 as a record of fact and had suggested an explanation in the paper. He unfortunately had no further data which would enable him to enlarge on that.

He had been interested in *Mr. Holcroft's* revelations about the " Royal Scot " engine, but he himself had been closely associated with the design of that engine at the time, and is quite unable to agree. With the single exception of the firebox, no other part of the Scot was modelled in any way from the Nelson. Anyone really familiar with the two classes could see at a glance the utter dissimilarity of the detail design, and indeed, until possibly the recent re-building of the Nelson, the performance of the Scot has always been very different from that of the latter engine. The facts in the paper are correct. The main conception of a 4-6-0 with high boiler pressure, simple expansion and long lap valve gear derived from the observed performance of the G.W.R. "Castle" on L.M.S. metals. The choice of three-cylinders was mainly due to J. E. Anderson. General detail design was based on that of the 2-6-4 tank engine already well forward in design at Derby before the Scot was decided upon. As the L.M.S. had had no previous experience with steel firebox stays it was glad to avail itself of Southern Railway knowledge in that respect. This is not to belittle in any way the very valued gesture of the Southern Railway in making its detail drawings available, it is only to correct any wrong impression to which Mr. Holcroft's words may have given rise.

He agreed with *Mr. Williams* that some bad things were done in the bad old days. It was, of course, easy to be wise after the event, and perhaps there were many reasons, not all of them set out in the paper, for the excessive conservatism of those days. He agreed that it was a pity that the Garratt engines were handicapped from the first by old-fashioned features from which they had suffered ever since. If they had had modern valve gear and adequate bearings, he felt sure that their performance would have been very much more satisfactory.

He would like to thank *Mr. Brown* for his remarks. *Mr. Riddles* drew attention to certain other factors which entered into the question of coal saving and reduced coal consumption, and he thoroughly agreed with him. One of his difficulties in writing the paper was that in order to keep it within reasonable dimensions he had had to leave out all reference to the repair side and the importance of the repair organisation and shop methods. That might well be the subject of a separate paper. Mr. Riddles' remarks about the development of individual costing were an interesting supplement to the paper.

Mr. Flatt had asked whether details of the forms and methods used in individual costing could be added as a supplement to the paper. The Author was afraid that to do justice to the subject would take up too much space, but he had no doubt his Company would be ready to give particulars to any other railway which was interested. It should be pointed out, however, that the principal object of the individual costing having been attained, its scope had been very much cut down just prior to the war. If costing was continued for a long enough period it was, of course, possible to establish a relationship between age and cost, but the more valuable feature during these years of rationalisation had been the throwing up of those classes which gave rise to heavy maintenance costs, irrespective of age, and in some cases as indicated in the paper, it was found profitable to withdraw even relatively modern engines which had been poorly designed.

With regard to some of the modern developments which *Mr. Turner* mentioned, he would no doubt recall Sir William Stanier's presidential address, in which many of the considerations which had led locomotive engineers hitherto to keep away from some of the developments mentioned were described. But progress continued and, as Mr. Turner mentioned, at a later meeting one might hope to hear something about one at any rate of those developments.

He agreed with the *President* that the only true way to study locomotive efficiency in order to promote future design was to separate the boiler and the engine and to examine them in detail. They hoped to be able to do that to a greater extent than hitherto when the Rugby test plant came into use. The President's criticism of the use of the figure of pounds per ton mile including the engine was just. In the L.M.S. test records they gave the figure both including and excluding the engine. It was possible to pick holes in either method from some points of view. Actually he preferred the coal consumption per unit of power.

In reply to *Mr. Nock,* Table V in the paper gives comparative coal and repair values for the Crewe " George V " 4-4-0 class. In spite of excellent performances in the past, it was at the time of grouping inferior on all counts to either the " Prince of Wales " or Midland compound. It can be agreed that the " G2 " 0-8-0 engines gained some advantage from low speed of operation, but they compared very favourably with many other classes running at the same speeds. The Caledonian 0-4-4 tank engines were, as Mr. Nock points out, tried on the St. Pancras—Luton suburban service, but were unable to cope with the fast non-stop morning and evening trains which are interspersed amongst the stopping trains. The Author would not agree that the 4-8-0 was a suitable type for heavy power since it requires a long narrow firebox. While astounding performances have been coaxed out of the French 4-8-0's, for practical purposes under British conditions the wide firebox is the only sensible development for grate areas beyond 32 sq. ft. As regards the improvement in the Royal Scot coal consumption, this was 90 per cent. due to improving the steam tightness of the valves, and only 10 per cent. due to the quite minor adjustments which were made in the valve setting.

The reply to Mr. Holcroft has partly answered *Mr. Diamond's* first question. The details of the Royal Scot class, including the valve gear were pure Fowler based on the 2-6-4 tank design. As regards the probable success of the Compound Pacific, had it been built, the Author's personal opinion is that it would have proved far inferior to the " Scot." There were features in the boiler design which were not above criticsm, the bearing surfaces were rather inadequate, and based on what the Author has seen of the French Compounds the availability might have been relatively low. As the design of cylinders and ports was pre-Chapelon, it is doubtful even if the coal consumption would have been really good by modern standards. Regarding Mr. Diamond's last point, if high annual mileages and availability are to be obtained, then all future locomotive designs should be available for mixed duty, a trend observable in many parts of the world and one more consideration which seems to rule the Compound out of court.

Mr. Carling suggests that ton-mile figures might have been given in the long term comparisons, but these are not available. The fact that some of the years indicated in Fig. 12 may have been slump years affected all the engine types concerned equally. Mr. Carling raises a similar point to that made by Mr. Diamond regarding compound engines. Under present-day conditions it is essential that a locomotive type must be able to tackle any kind of work it is necessary to put it on and to be driven by the kind of footplate staff available. In that the compound cannot meet these requirements, it stands self-condemned for use in this country. He could see no reason why the Fowler Compounds would have been any different in this respect. Generally speaking, repair costs do not materially increase with age after the first few years, by which time a regular cycle of tyre, cylinder and firebox heavy repairs or renewals has set in. Type of service has, of course, to be allowed for in making these comparisons, and only engines of like power classification should be set side by side in making decisions based on repair costs.

The Author would refer *Mr. Peacock* to his reply to Mr. Bulleid. A locomotive is designed to operate normally at a certain rate of combustion. Overload implies an increase on that rate with a direct consequent lowering of boiler and therefore overall efficiency. The older types were often so designed that these high rates of combustion were also obtained only by the use of excessive back pressure, thus lowering cylinder efficiency, combining to form a double debit to overall efficiency. Conversely to maintain the designed rate of combustion plus a high cylinder efficiency, it is necessary to avoid overloading. Efficiency and overloading are contrary terms.

Steam production depends not only on size of boiler but also on velocity of gas through the tubes. Efficiency apart and considering only maximum output, the older engines with ample exhaust clearance were able to sustain higher rates of combustion on given cut-offs than on more modern types, at any rate of the period under review. The advent of the double or "kylchap" exhaust has, however, modified this in more recent practice.

MEETING IN DERBY, 17th JANUARY, 1946.

The Fourth Ordinary General Meeting of the Birmingham Centre was held at the Midland Hotel, Derby, on Thursday, the 17th of January, 1946, at 7 p.m., the chair being taken by Mr. J. Rankin.

The minutes of the meeting held on the 12th of December, 1945, were read, approved and signed as correct.

The Chairman then introduced Mr. E. S. Cox, who read his paper, entitled "A Modern Locomotive History—Ten Years' Development on the L.M.S.—1923 to 1932.

This was followed by a discussion.

DISCUSSION.

Mr. J. Rankin (Chairman) said that the Author had given a very good summary of his very interesting paper and he said everyone would look forward to a further paper on the development of locomotive design on the L.M.S. during the ensuing ten years !

The Author inferred that better design and better operating efficiency had enabled a reduction to be made in the L.M.S. stock. But it must be remembered that during this period, by improvement in works organisation and methods, it was found possible to reduce the average time engines were in the shops for repairs from three months to three weeks. This had enabled a large number of engines to be released.

Mr. H. Kelway-Bamber (P.P.) said that the paper emphasised the advisability of keeping in touch with the practice of other railways, which was made clear by the results which attended the working of the G.W.R. " Castle " engine loaned to the L.M.S. during a period of emergency in 1926.

Mr. J. C. Loach (A.M.) said the paper was full of information which had not previously been available generally to locomotive engineers. In the past, there had been many arguments and discussions among budding locomotive engineers which have been inconclusive because of lack of data; he was sure many of those points of debate would be settled by the figures which the Author had given. There seemed to be two main themes running through the paper, one was that, in the early years of amalgamation, the power demanded from engines working on divisions other than the Midland was not fully appreciated. So it was rather surprising that, despite the Midland tradition for having small engines, no standard small passenger tank engine was provided in quantity during this period, apart perhaps from the 2-6-2 tank which, as stated, was not provided with a boiler large enough for the job. Even now that another 13 years had passed since the period under review, he thought the L.M.S. still lacked a small smart tank engine. During these last 13 years, the 2-6-2 tank design had been perpetuated and it was regrettable that the taper boiler which Sir William Stanier put on it was again very undersized; this had been admitted more recently since the engines were now being fitted with bigger boilers. Another disadvantage of the type was the possibility of derailment of the bissel-trucks, of which the 2-6-2 had two, of course. There were also 2-6-4 tank engines, 2-8-0's, etc., but this feature of bissel-trucks easily coming off the road was well known in 1932 when there were 70 2-6-2 and 85 2-6-4 tank engines running on the L.M.S. Where then could the justification have been in pursuing the idea of a 2-6-2, even though the design of the bissel-truck was modified by Sir William Stanier to incorporate bolster bearing pads and check springs instead of the swing link arrangements used in the earlier engines ?

When the 2-6-2 tanke engine was designed, the speaker said he wondered why the fixed wheelbase was as long as 16 ft. 6 in. Such a wheelbase might be quite suitable for 0-6-0, but when the frames were extended to incorporate carrying wheels at the ends the overhang was appreciable and the throwover of the bissel-trucks was considerable. With driving wheels only 5 ft. 3 in. diameter he failed to understand the objections, if any, to a fixed wheelbase of 14 ft. 0 in. or 14 ft. 6 in. and then the overhang on curves would have been somewhat less.

The other theme running through the paper was the advantage to be gained from a long-travel valve, but he would like to suggest that a large diameter valve was another necessary feature to bring about good steam distribution. For instance, an 8 in. diameter valve for a $20\frac{1}{2}$ in. diameter cylinder would not be very satisfactory, because when valves had long travel it was more usual to run the engines well notched up. When in mid-gear itself, the port opened only by the amount of lead, say $\frac{5}{16}$ in. or $\frac{3}{8}$ in., and so quite a lot of wire-drawing could still take place unless the valve has a large circumference and that, in turn, meant a large diameter. He thought it would be wiser to consider the ratio of piston valve circumference to main piston area rather than the ratio of piston valve diameter to cylinder diameter when deciding upon the size of piston valve and, when doing so, it would be seen that as the size of cylinder increased, for the former ratio to retain its value, the latter ratio increased. Thus for the same efficiency of distribution to prevail in a 21 in. diameter cylinder as occurred in an 18 in. diameter cylinder having a 9 in. piston valve, the piston valve diameter (based on the ratio suggested) would have to be $12\frac{1}{4}$ in. diameter, the ratio of diameters of valve to cylinder then being nearly 0.6. It seemed as though the ratio of piston valve circumference to main piston area should be at least 1 : 10, the ratio 1 : 9 on the 4-6-0 Royal Scot was better.

The Author compared the Lentz valve gear with the Walschaert gear on 2-6-0 engines. (In that respect he would suggest that there was a figure incorrectly printed in Table III; the last figure of the last column should, he thought, be 8.96. Alternatively, some of the other figures are incorrect.) In Table III, the relative performance of the two valve gears were based on coal consumption. For the figure extending over six years coal consumption was the only one available, no doubt, but when considering the test figures he did not see why the Author had not made use of the water consumption figures which were obtained. The efficiency of the two parts of the locomotive—the boiler and the engine—could be separately assessed in that way. So in two locomotives which had identical boilers, and only differed by the valve gear, there was an excellent opportunity to make a direct comparison between them. The water consumption figures suggested that the Lentz gear was not quite so efficient a distributor as the well-designed Walschaert gear and the only reason why the coal consumption figures on the test runs were in favour of the Lentz gear engine was because its boiler evaporated 4 per cent. more efficiently than the boiler on the Walschaert gear engine and so outweighed the 2.4 per cent. distribution deficiency of its valve gear.

However, perhaps test results on locomotives in service should only be regarded as an indication of the behaviour of the parts under test, and, viewed in this light, the test figures themselves suggest that there is precious little between them. He would like to ask the Author if he would kindly and quite seriously consider adding the water consumption figures to Table VII so that the merits of the Caprotti gear and modified Claughton class engines could be similarly assessed. Similarly, the value of Table VIII would be greatly enhanced if, in addition to the " On test " coal consumption comparisons, water consumption comparisons were also quoted. Lastly, he would also like to see the water consumption figures added to the tests given in Table IV; it would make the data so much more interesting. He hoped that when the tables were finally printed in the Journal of the Institution, the Author would have been able to see his way to incorporate this additional information which would add to the value of his already excellent and otherwise comprehensive paper.

Mr. D. W. Sanford (M.) said it had been very pleasant to hear the Author recall the very interesting years that followed the formation of the L.M.S., particularly for those who were there at the time. It seemed to him that the three English locomotive centres had very different outlooks. At Derby the nice little engines were made pets of. They were housed in nice clean sheds, and were very lightly loaded. There must have been a Royal Society for the Prevention of Cruelty to Engines in existence. At Horwich they had gone all scientific and talked in " thous.", although apparently some of their work was to the nearest half-inch. At Crewe they just didn't care so long as their engines could roar and rattle along with a good paying load, which they usually did. As regard Horwich contribution, he thought that mention should have been made of the very excellent Dynamometer Car which was designed and constructed by the old L. & Y. That was far in advance of anything used in this country, and its accuracy was as good as that of the modern cars since built abroad. Its utility to the L.M.S. in making the tests referred to could not be over-estimated.

As regards individual costing and coal consumption, he believed that these were on a mileage basis, and not on the ton-miles. Hence a sturdy engine which could work a heavy train would appear at a disadvantage as regards cost of repairs and coal, although probably a better commercial proposition. Concerning constant speed tests, he agreed that these are more scientific but they would not have served the purpose as well as the ordinary test run to the timetable. Results obtained by constant speed tests involved months of calculation in order to get the coal consumption when working an actual train.

Whilst it would appear that Crewe design was largely inspired by Mr. Heath Robinson, it must be admitted that the Western Division of the L.M.S. took heavy loads, although servicing facilities at the sheds were poor. From this point of view the old L.N.W. engines put up a remarkable performance although the casualities were rather high.

As regards the proposed large compounds, he thought that one factor which led to the abandonment was the realisation that it takes a long time to design a successful compound. The proper ratio of work done in the H.P. and L.P. cylinders (which incidentally should remain the same whether working heavily or lightly) could only be determined by experiment. It was not only the question of the correct cut-offs and cylinder volumes, as the relative resistance of the ports also had an important influence. One had to build an engine, indicate it and get it right by trial and error. Hence, if the engines were required in a hurry by the Operating Department, it was far safer to build simple expansion engines. He could not agree that the long travel valve was the greatest improvement that has been made. He would say that the elimination of leakages past piston valves had been even more beneficial. He remembered a Royal Scot engine which had its coal consumption reduced from 70 lb. to 35 lb. per mile on the same job, by replacing the old Schmidt rings by narrow rings. The old Crewe valve with trick ports was even worse, and when one of the Claughtons was fitted with narrow rings, its performances were as good as the Caprotti engines. Thus, this question of piston valve leakage was of great importance and he believed that there was still room for improvement in valve events.

It was also of interest to note that long travel is by no means a new idea. Colburn described its advantages, and Benjamin Connor fitted it to his Caledonian engines in 1859. It was the advent of piston valves and improved lubrication that made it worth while, as with flat slide valves the wear was too great. He felt that the principle aim of locomotive designers should be to produce general utility engines which thus had a high availability together with simplicity and a sufficient amount of standardisation of details to produce the necessary stock of spare parts.

Mr. G. F. Horne (M.) said the Horwich 4-6-0 engine was a well-balanced machine and very good indeed in the hauling of heavy trains. With a little more development for freer steaming, and larger piston valves, he was sure it would have ranked as a distinctive class.

The development of the modern locomotive had not had due consideration in respect of firebox grate areas. The tendency had been to keep them as small as possible. Surely the operating of the engine with many kinds of coal should emphasise the necessity for due allowance to cover such cases, as well as helping in the free steaming of the boiler, which takes first place in the mind of the enginemen.

Mr. W. Bradley (A.M.) said the Author had marshalled his facts into a very impressive account. His opinions, too, were well reasoned and the paper must rank as a valuable one for students of past events. More important still, it carried a message for the future by defining pitfalls to avoid.

The early difficulties of amalgamation were rather lightly passed over. In creating the body the operators at times were in danger of producing a Frankenstein Monster; certain it was that limbs were added without the insertion of sinovial fluid. The staff of each constituent company were guilty, if guilty is the right word, of intense loyalty to their original company. Often this loyalty was carried to an extreme bias against ideas other than these of their company. Unfortunately, examples were found at all levels.

Only experience, wide experience, was the cure for such an attitude, together with careful selection of the right individual. Not every billposter carried the brush of a Michael Angelo or a Botticelli in his bag.

The Author made the point that Mr. Hughes was in advance of the Operating people. Since railways were primarily an engineering concern, surely such was to be expected. Was it not true to say that the greatest progress had been made when engineers were in charge ?

He had always regarded the 2-6-0 engine as the father of the modern L.M.S. stock. This engine was highly criticised when in the design stage and was forecast a failure. It took some two years of successful running to convince the critics.

The term " Midlandisation " was used. It should be remembered that at the time referred to, mixing of the staffs of the various constituent companies had taken place, and some semblance of an L.M.S. staff was beginning to emerge. It would be unfair and incorrect to infer that the other constituent companies had at that time no influence in the trends of design. To get a clear picture of how much each company contributed to the whole, he had tried to imagine what would have been the locomotive in use in 1932 by each of the separate companies, had there been no amalgamation. The results were rather surprising and he ventured to suggest that the L.N.W. probably would not have occupied the lowly role that the Author had assigned to it.

It must be conceded that their pre-grouping engines were heavy coal consumers. Twenty years ago, on his first introduction to L.N.W. main line engines, he remembered a feeling of amazement when boarding a Prince of Wales engine at Carnforth to travel to Carlisle. Whilst standing in the station the fireman put 28 shovels of coal into the firebox. Three minutes later he put another 14 on and carried on in this way to Carlisle. Running down Shap at 72 miles per hour, the oscillation was so great that the fireman was unable to find the firehole. It cannot be denied, however, that the L.N.W. had a real job of work to do and did it. Mr. Bradley showed a photograph of a Royal Scot engine, the title stated: " One of the engines which daily performs the world's record longest non-stop run, Euston to Carlisle, 299$\frac{1}{4}$ miles "; and another photograph of the L.N.W. three-cylinder Ionic which on September 8th, 1895, took a train from Euston to Carlisle without a stop at an average speed of 51 miles per hour. It ran 750,952 miles to December, 1905.

The Author made but little mention of the Co-ordination of Design Committee which was formed early after the amalgamation. These people examined various engine fittings of all companies with a view to adopting the best as standard. The Caledonian whistle was one example, and was finally made standard. Having seen other recommendations of this committee, I feel convinced that much good would have come from its efforts had they been put to use. Perhaps the Author can give us an insight as to what happened to their proposals.

Mr. F. G. Carrier (A.M.) said in regard to the compound engine, that it would surely be correct to say that the higher coal consumption was not entirely due to the fact that the engine was run-down or badly handled, but because it was taken off non-stop runs and used on stopping trains which entailed a high proportion of simple engine working.

Referring to pony truck derailments, it was most probable that the new short wheelbase engines would show an improvement, as the rigid coupled wheelbase would be more free on the small radius curves on which derailments most often occurred.

The Author suggested that the main weakness of the large compound 4-6-2 engine would be the small size of coupled axle bearings. Would it not be correct to assume that a compound would successfully run with smaller journals than an equivalent simple, due to the more uniform mean effective pressure in the high and low pressure cylinders giving a lower pressure variation on the bearing.

Mr. W. R. Carslake said that the Author's paper showed how slowly new ideas are adopted on English railways. After spending nearly two years on the Continent during the war, he was surprised that such commonplace fittings as rocker grates and hopper ashpans should only now be finding their way into British practice. Both the French and Germans had developed specialised sections to deal with locomotive design in its widest sense. The French giving particular study to this at their testing plant at Vitry. They could only look forward to the completion of the Rugby plant when the L.M.S. and the L.N.E. could proceed with experimental design with full possibilities for practical testing.

AUTHOR'S REPLY

Author agreed with *Mr. J. Rankin* that works organisation and methods had had a very important influence in allowing reductions in the locomotive stock to be made. That was a big subject worthy of a separate paper, but limitations of space had prevented him dealing with it.

He would refer *Mr. Loach* to Fig. 15 in the paper which showed a compact small tank engine proposed in 1928 which would have met the point. For the reasons given in the paper the more rambling 2-6-2 tank was finally chosen. A new series of smaller 2-6-2's are, however, to be turned out on the 1946 L.M.S. programme which will provide a modern replacement for the many old Class 2 tank engines now being broken up.

The Author was well aware that there was a period when a certain number of derailments had occurred with pony trucks on particular track formation, but these were seldom heard of to-day. He could not agree that the pony truck as such was inherently prone to derailments. It is in universal use all over the world with complete satisfaction. The use of the 16 ft. 6 in. wheelbase was simply an "old Spanish custom" in the Derby drawing office, and both 2-6-4 and 2-6-2 tank engines are now being constructed with shorter wheelbases, with advantage to the negotiation of sharp curves.

He agreed that a generous piston valve diameter within reasonable limits was an advantage and this was generally provided for in modern design. Where water consumption had not been quoted in the tables in the paper, reliable figures had not been obtained, and he regretted that it was therefore not possible to supplement the information given.

Mr. Sanford's remarks, supplementing his own on the abandonment of the large compounds were of value. Steam leakage past the valves was of great importance but was a separate matter from that of distribution, and the long lap valve had made a big additional contribution. It was not new, but like so many other early inventions had to be re-discovered in a time when available metals and lubrication were more favourable to it.

Mr. Horne had referred to the paradoxical performance of the Horwich 4-6-0. In almost all other bad performers the reason was plain to see, but on paper the Horwich engine should have been but little inferior to the G.W. "Castle." In practice it was far otherwise and the reason was given in the reply to Mr. Poultney in the discussion at the London meeting. Certainly it had been the besetting sin of British design to under-boiler. If only an engine would steam freely much else was forgiven it, but gradually we were coming to understand the importance of this and to provide for it.

Mr. Bradley entered very controversial ground on to which the Author would not care to follow. In the role of prophesy he claimed equal standing with Mr. Bradley, but his conclusions would be far different. On grouping, a Co-ordination of Design Committee was set up and a good deal of preliminary ground was covered. So gigantic were the immediate problems requiring solution, however, that it had to give way to more arbitrary methods and, while the decision to standardise Midland detail fittings can be criticised, it did present the new company quickly with a clear-cut line of action, and one which it has had no cause to regret subsequently.

Mr. Carrier is correct. Putting the compounds on semi-fast and stopping train work was a major reason for increased coal consumption. The Author's point was, however, that simple engines similarly treated do not materially increase their consumption. He doubted if a four-cylinder compound would show any lower axlebox loadings than a four-cylinder simple. Both were much better than any other type. However, French compounds with small bearings gave what we should consider a poor traffic availability, while L.M.S. 4-6-2's with large bearings were much better. It is reasonable to think, therefore, that the big compounds with small bearings would have suffered accordingly.

In reply to *Mr. Carslake*, care had to be taken in ascribing too much relative advance to Continental countries. In certain directions advance had been made but taken all round, neither German nor

French design was ahead of our own. The influence of Vitry on French design had not so far been clear cut since all Chapelon's work which had had such a profound influence all over the world, had been carried out independently of Vitry.

MEETING AT NEWCASTLE, 27th FEBRUARY, 1946.

The Fourth Ordinary General Meeting of the Newcastle-on-Tyne Centre was held at the Lecture Theatre, Newe House, Pilgrim Street, on Wednesday, the 27th of February, 1946, at 6 p.m., the Chair being taken by Mr. R. A. Smeddle.

The Minutes of the Meeting held on the 30th of January, 1946, were read, approved and signed as correct.

The Chairman then introduced Mr. E. S. Cox who read his Paper, entitled " A Modern Locomotive History, Ten Years' Development on the L.M.S."

This was followed by a discussion.

DISCUSSION.

The Chairman, Mr. R. A. Smeddle (M.), in thanking the Author for reading his Paper, said the remarks respecting the controversies between the various Chief Mechanical Engineers which arose when the grouping took place, especially from the operating point of view of loading and bridge stresses, had been rather interesting. Probably the Author knew as much about development on the old Midland Railway Company as anyone else.

Mr. Smeddle thought it more or less the general opinion, at any rate at one time, that what was done at Derby was quite all right, whereas what was done at Crewe was not always quite as good, but no doubt this state of affairs did not exist to-day. Mr. Smeddle stated the Midland Railway was not the only Company troubled in that respect. To a lesser extent his own Company had been tarred with the same brush, but the old N.E. Railway did not have the same rivalry to face simply because they were not confronted in their group with constituent Companies approaching their equal in the same way as was the Midland Company by the L.N.W. Company.

The Chairman mentioned that everyone present would be most interested in the reference which had been made regarding the development of the " Royal Scot " locomotive and recalled that he was invited to have a look at the first engine which was completed at the N.B. Locomotive Works, Glasgow. It was certainly a most impressive locomotive which performed its work very well between Glasgow and Euston, to some extent taking over the work done previously by the old "Claughtons."

With regard to the " poppet " valves, the Author's remarks were most interesting and no doubt he was aware that on the L.N.E.R. they had a number of engines running with both oscillating and rotary Lentz gears and it was thought from a valve gear point of view the Lentz type on the whole probably gave less trouble than the ordinary type of valve gear, either Walschaert or Stevenson, but he would like to ask the Author if he could confirm this.

With regard to Mr. Cox's remarks in connection with long valve travel, it was a surprise to himself that it had been tried so many years ago, but it was not really until 1926 that other Companies decided to copy what was apparently standard G.W. practice at that time.

Mr. J. J. Lovatt (M.), expressed his high appreciation of the Paper and thought that papers relating to each of the other main railways would be welcomed.

In regard to the poppet valves, Mr. Lovatt stated that for many reasons he favoured these valves, but thought that they must be further developed to compete successfully with piston valves. He was of the opinion that at very high speeds the timing of the valves was not definite as they were spring loaded and their inertia was such that the closing to steam and exhaust was delayed beyond the designed time. The design was excellent from the point of view of the shed maintenance staff.

A great disadvantage of the poppet valve engine in his opinion was the large cylinder clearance probably due to the cavity around the valve. This could be reduced by so designing the cavity that no steam passed by the steam valve except in the direction towards the cylinder. He remembered that in the paper read by the C.M.E. of the L.M.S. it was claimed that this practice, applied to piston valves, had made a considerable economy and he wondered if this economy had been maintained and had the design been applied to all new classes of locomotives with beneficial results? It did seem that it was wrong to let any steam pass any valve in a direction away from the cylinder thus causing heavy eddy currents whilst reversing the direction of flow. At the moment before the opening of a piston valve the motion of the steam was just that of the horizontal motion of the valve, but the instant the valve opened the steam became radial and steam passing by the valve on the side away from the cylinder must impinge on the port wall and waste energy before reversing its direction of flow.

He thought that the improvement in design would reduce eddy currents in the flow of exhaust steam in addition to the gain with the live steam flow.

Mr. H. W. Davis (M.), stated that he was interested in the compound engines of the Midland Railway and recollected one type with 21in. low pressure cylinders. The cylinders were eventually reduced to 20in. diameter, and Mr. Davis questioned why this reduction was made.

Having had a number of De Glehn compounds under his supervision he fully endorsed what had been said about the handling and maintenance of compound locomotives. Mishandling by bad drivers had a very marked effect in running up the coal consumption.

Our difficulty now with the power required in applying the compound system was to keep the cylinders within the loading gauge.

Mr. G. W. McArd (M.), said he was very interested in the slides showing the Baltic type tank engines designed by Mr. George Hughes, and remembering two other tank engines of the same classification which the L.M. & S. Railway took over, viz., that for the Furness Railway built by Kitsons, and the other for the G. & S.W. Railway built by the N.B. Locomotive Company, he would like to know if these also came under the axe?

AUTHOR'S REPLY

In reply to *Mr. Smeddle,* the Author said that the seeming confusions and contradiction of the early days were inescapable under the simultaneous amalgamation of so many large and strongly individual concerns. Looking back he was unable to see how mere mortals could have done much better under the prevailing circumstances, but in the last resort in his opinion, the best undoubtedly came to the top. Throughout the 14 years the L.M.S. has had the 5-rotary Lentz type gears, negligible mechanical trouble has been experienced, but of course well designed link type valve gears are very trouble free too.

It was true as *Mr. Lovatt* pointed out that there was with poppet valves the possibility of inertia effects affecting the distribution, but this only arose as the weight of the valve increased. American experience indicated that it was better to multiply the valves for higher power outputs rather than increase the size and weight of the valve itself. There seemed no reason why with suitable design the clearance volume should be materially increased, but of course the design of the port immediately surrounding the valve, whether of piston or poppet type, was of the greatest importance to ensure direct steam flow without eddy currents. All new designs had particular attention paid to this feature.

In reply to *Mr. Davis,* 21in. was the standard diameter of the L.P. cylinder of the Midland compound, but one series of 20 engines built just after grouping had the diameter increased to 21½in., but the engines dealt with did not steam as well as the standard and the modification was abandoned.

Mr. McArd asked about " Baltic " tank engines, a type which has not had much success in this country. Its fault is that it makes a very heavy engine in relation to the kind of traffic such engines can expect to be employed on. The G.S.W. Baltics were quickly broken up, being heavy on coal and repairs, while the Furness engines used saturated steam, and were not considered worth converting.