

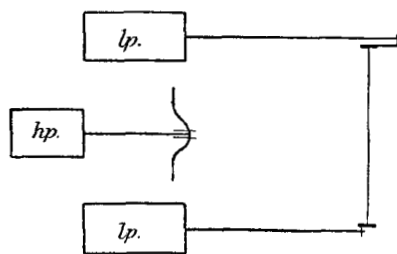
both goods and passenger, Mr. Webb's three-cylinder engines were likely to be employed, and the almost untried three-equal cylinder system gave promise of success. The four-cylinder system, while being complicated, presented advantages of the highest power and uniform well-balanced action. Mr. Worthington.

Correspondence.

Mr. W. H. BOOTH remarked that, if it was granted that the compound locomotive would supersede the present simple engines for many purposes, there remained to be considered the design which should be adopted. So far as two-cylinder compound engines were desirable, there appeared to be small room for improvement on the design of Mr. Worsdell. As it was only at low speeds that coupled engines had any advantage over single engines, it was clearly advisable to dispense with coupling-rods. Now in the Webb compound engine this was done, and Mr. Webb's engines had the tractive power of coupled engines at low speeds, and also the free running qualities of the single engine at high speeds. There were, however, disadvantages in the Webb compound engine which did not appear insurmountable. Among these was the difficulty in starting, especially should the low-pressure crank be on the dead-point, when the high-pressure wheels slipped on a greasy rail. The next disadvantage was the exceedingly disagreeable surging action for the first twenty seconds or more, after moving from a state of rest. This was distasteful to passengers, and to many had the effect usually associated with travel by water. This effect had been ridiculed; nevertheless it existed. Further, there were disadvantages connected with the manufacture of a larger cylinder, piston, &c., and a multiplication of parts not conducive to economy of make or maintenance. A long experience in compound engines had shown him that it was of the first importance to keep hot the high-, rather than the low-pressure cylinder. The general experience of engineers was rather in favour of multiplying the number of low-, rather than of high-pressure cylinders; neither of these last conditions was carried out in the Webb engine. To remedy all the defects named, he would suggest that the present cumbrous low-pressure cylinder should be superseded by a single high-pressure cylinder of the same diameter as two low-pressure cylinders of an ordinary locomotive, which should be placed outside the frames, in place of the two small cylinders of the Webb engine. Thus all three cylinders would be

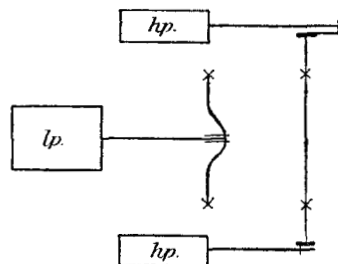
Mr. Booth. of one diameter, and their pistons, covers, and rods interchangeable. Any departure from a cylinder ratio of 1:2 would be made by means of a shorter stroke to the inside high-pressure cylinder. With such an arrangement, uniformity in shop work would be attained; the high-pressure cylinder would be kept warm in the smoke-box; the disagreeable surging motion at starting would be so mitigated as to be perhaps imperceptible, whilst none of the advantages now apparent in the Webb engine would be sacrificed. Further, with three cylinders of uniform diameter, the engine could be used as a simple engine, with boiler steam in all cylinders, and in this way would be enabled to perform an enormous duty for a short time, or for such time as the boiler would provide steam. The difficulty in starting would be overcome by the use of boiler steam in the low-pressure cylinders, the high pressure being then allowed to exhaust independently. Certain extra valves would be needed,

FIG. 4.



PROPOSED DESIGN.

FIG. 5.



WEBB TYPE.

but the complication would be less than with the present type and no appliance would be required to keep boiler-pressure off any piston. The proposed arrangement (Fig. 4) would lend itself readily to the conversion of existing locomotives of outside-cylinder type into compound engines, and it seemed to promise all the advantages of both the old simple engines and the present three-cylinder compound engines, with very few disadvantages. The elimination of coupling-rods probably answered for a very large portion of the economy of compound locomotives of the Webb type (Fig. 5).

Mr. von Borries.

Mr. A. VON BORRIES remarked that, on p. 17, the Author stated the two compound locomotives, built in 1880 for the Hanoverian State Railways, were on Mr. Mallet's system; but this was not the case, since the engines did not have Mr. Mallet's distributing-valve, but a small hole in the regulator valve-face, by which steam was admitted to the receiver, when the regulator was full open. This

simple arrangement answered well enough for small engines. Mr. von Borries. Also, the link-motion had not separate handles, as in Mr. Mallet's system. The compound locomotives constructed in 1888 in Germany, with two cylinders of equal diameter, but of different strokes, were built for Holland, on the designs of the Locomotive Superintendent, Mr. Middelberg. The Author's objection (p. 21), that the von Borries' method of giving a later cut-off in the low-pressure cylinder than in the high-pressure one would not do with tank-engines, which must run frequently backward, was met by another method which he had devised for such engines, that gave the same result, so far as necessary to get equal distribution of power on both pistons. This method consisted in giving less lap to the valve of the low-pressure cylinder, and suitable construction to the outside parts. In ordinary link-motions, smaller angles to the eccentrics; and in gears like Brown's and Joy's, a smaller head-end of the vertical or reciprocating lever. If the lap of the valve of the low-pressure cylinder was made 0·9 or 0·8 of that of the high-pressure cylinder by the same lead, the proportion of cut-off would be nearly as 40 : 45 or 40 : 50 per cent. in both cylinders, corresponding to a proportion of pistons of 1 : 2·2 or 1 : 2·0. This very simple method had been applied to the Alsace-Lorraine passenger tank-engine, and required only a somewhat larger travel of valve for the high-pressure cylinder to get travel enough for the low-pressure one. As to the tractive force of compound locomotives (p. 22), he recommended that the small cylinder should be equal in size to that of the single engine, if they were to have the same power. If the same boiler was kept for the compound, the high-pressure cylinder must be 1 inch larger in diameter, as proposed by the Author; but then the engine would be more powerful. Many of the compound engines now running would do still better if they had larger cylinders—large enough in proportion to the boiler-power. The gradients of German railways were only favourable in the northern plains; in the middle and southern parts, long and steep gradients were as frequent as in England. In Germany compound locomotives did as well on these heavy lines with low speed, a 39-ton goods engine taking twenty-seven coal-trucks and a brake-van, weighing some 440 tons, up a gradient of 1 in 100, at a speed of 10 miles per hour. He believed the Author was mistaken (p. 36), in thinking the compound system to be less suitable for England than for other countries. As to the cost, compound engines could be built 2 to 5 per cent. cheaper than simple engines of the same power—not of same maximum tractive force, because this power depended upon the boiler, which might be 10 to

Mr. von Borries. 15 per cent. smaller for the compound engine. If the same boiler was kept, as was commonly the case, the compound engine would be some 2 or 3 per cent. heavier, and 4 or 5 per cent. more costly than a simple one; but, with properly dimensioned cylinders, 10 to 15 per cent. more powerful than the latter. For equal work, the compound engine would thus always be the cheaper engine. For heavy fast trains on the Hanoverian State Railways, the compound engine had effected a great saving in pilot-engines, which were very costly.

Mr. Drummond. Mr. D. DRUMMOND remarked that there was great difficulty in dealing with the question of compounding locomotives, owing to the lack of information as to the conditions under which the comparative tests had been made. It was necessary, in the first place, to know if both boilers were alike, and if the engines were working under the same pressure, with the same round of duty to perform, and provided with the same quality of fuel. Unless this were so, comparisons as to fuel economy could not possibly be accepted. It might be that any economy effected was due to the larger boiler and increased boiler-pressure, and not to the principle of compounding. It was well known that, unless the boiler was sufficiently large to maintain a steady head of steam at full pressure, while the engine was working at its maximum power, there was a great waste of fuel. As an instance, six express engines had been built for the Caledonian Railway ten years ago, having cylinders 18 inches in diameter by 24 inches stroke, and wheels 7 feet in diameter, but of which the boilers were too small for the engines. He had substituted these for larger boilers, and had increased the pressure from 140 lbs to 150 lbs. per square inch; and, without any other alteration, the result was increased efficiency, and a saving of 7 lbs. of coal per train-mile. Then again, comparative statements had been made of the amount of fuel consumed per train-mile by the respective engines, on various railways, without the whole of the facts being explained. As an illustration, take the coal used on the Scotch railways; there was an average difference in the consumption between the "Slamannan" and the "Lanarkshire" of 10 lbs. per train-mile in favour of the former with the same class of engine, and the same amount of work. Take also the London, Brighton, and South Coast Railway, which was often referred to for its economic consumption of fuel, namely, 24 to 30 lbs. per train-mile. This, for the work done, was excellent; but the coal supplied was almost entirely best Welsh; and to compare this consumption of fuel with that of engines on railways north of the Thames, performing almost similar work with Derby-

shire and Yorkshire coal, would be misleading. Therefore, in discussing a question of this nature, all the circumstances should be taken into consideration. He had not been able to reconcile the principle of compounding locomotives as a sound one; for, of all engines, he thought the locomotive was the one least likely to give satisfactory results in compounding, owing to the constantly varying conditions under which it had to perform its work. The only practical experience he had with the compound locomotive was a trial on the Caledonian Railway, with one built on the Worsdell and von Borries principle, by Messrs. Dubs and Co., in 1886, for a South American railway. On that occasion the working of the engine and its consumption of fuel, compared with that of the ordinary Caledonian engines doing the same work, even after making every allowance for the engine being strange to the driver, and not worked to the best advantage, was such as to confirm his opinion of the unsuitability of compounding the locomotive-engine. The 17-foot single Caledonian engine, No. 123, built by Messrs. Neilson and Co., and exhibited at the Edinburgh Exhibition, had run the fast London express train from Carlisle to Edinburgh and *vice versa*, before and during the whole time of what was known last year as "the race to Edinburgh," and up to the present time had not lost a single journey. And its consumption in the running of this fast train, over gradients well known to be severe for a long part of the distance, had never exceeded 31·6 lbs. of Scotch coal per train-mile; and these were the same trains as worked by the compound engines on the London and North-Western Railway. A four-cylinder compound engine on the tandem system, designed by Mr. Nisbet, of the North British Railway, had been running on that line for nearly three years. It worked at a pressure of 160 lbs. per square inch, or 20 lbs. above that of the engines running in the same link; but it had not shown any advantage over the ordinary engines, and the cost of maintenance and upkeep was in proportion to the greater number of parts. It was fitted with the Joy motion, and was well designed; but the results were not such as to encourage a repetition of the experiment. To test the relative merits of compound engines as against ordinary modern engines, he should be pleased indeed to ask permission of the Directors of the Caledonian Railway to be allowed to make arrangements to enable this to be done, either with the express, passenger, or goods engines of the Company, or both, the tests to extend over a period of not less than one month. This line, with its long and steep gradients between Carlisle and Aberdeen, would be admirably suited for such a trial, and a test like this would

Mr. Drummond.

Mr. Drummond. settle definitely the question as to which of the two descriptions of engine was the most economical in fuel and up-keep.

Mr. Edwards. Mr. R. EDWARDS observed that it was difficult to compare the economical efficiency of compound locomotives with that of certain types of compound stationary and portable engines, as the trials of the former lacked the very important item of the weight of water used, or, say, lbs. of steam per indicated HP. Until accurate trials had been conducted with this point in view, the comparative economy of locomotives must be chiefly confined to themselves, especially since it was doubtful if their indicated HP. was sufficiently accurate, as the power was so variable. In most comparisons of the efficiency of engines, reference was made to the trials of the Royal Agricultural Society; but this reference did not take into consideration the exceptional way in which the trials were conducted, which could not possibly take place in every-day use. For instance, the boiler and cylinder were swaddled, so to speak, in felt or other non-conductor, and every possible care was taken to prevent the escape of heat. The following table gave a comparison of the economy obtained at trials of some engines, compound and simple, several of which were in daily use, and which might be advantageously compared, if possible, with locomotives.

TYPE OF ENGINE.	Steam-pressure per square inch.	Steam used per indicated HP. per hour.	Welsh coal used per indicated HP. per hour.
Triple Expansion Condensing Marine Engine . . .	lbs. 165	lbs. 13·0	lbs. 1·36
Newcastle R.A.S.E. trials of Compound Portable Engines	140	18·0	1·89
Newcastle R.A.S.E. trials of Simple Portable Engines.	100	20·8	2·18
Cardiff R.A.S.E. trials of Simple Portable Engines .	80	22·5	2·37
Compound Underneath Fixed Engines, also Portable } Compound Engines, in every-day use }	140	22·5	2·37
Traction Engines, when driving machinery in every-day use }	115	32·0	3·36
Portable Engines, in every-day use	80	48·0	5·05

The consumption of coal per indicated HP. was taken on the basis of $9\frac{1}{2}$ lbs. of water being evaporated per 1 lb. of Welsh coal, which, in practice, with properly designed boilers, was generally obtained. The compound underneath fixed engine was of a type now largely used, in sizes of 20 to 150 indicated HP., for driving

electric-light machinery, and for many other industrial purposes, Mr. Edwards. the locomotive form of boiler being adopted, the working pressure being 140 lbs., and would pre-eminently be the type of fixed engine that should be used for economical comparison with locomotives, which it nearly approached in general arrangements and proportions, except, perhaps, in piston-speed, which was 360 feet per minute.

Mr. S. W. JOHNSON said that although at present he had had no Mr. Johnson. experience with compound locomotive-engines, he had watched with considerable interest the results of the working by Mr. Webb and Mr. Worsdell of their respective compound engines. He had no prejudice for or against any particular system or design of engine; but should always be in favour of the design of engine suited to the work it had to perform, which could be proved to do an equal amount of mechanical duty with the least consumption of fuel and at the lowest aggregate cost. To attain this end, comparisons should be made with engines having the same amount of tractive power, with equal working boiler-pressures, and with the same kind and quality of fuel. Comparisons under any other conditions than these were, to his mind, of little value. Great credit was due to Mr. Webb and to Mr. Worsdell for the efforts they had made, and the difficulties they had overcome in compounding locomotive-engines. It would, however, be satisfactory to compare the results obtained with the best ordinary simple arrangement of engine procurable, with those of a compound engine under the conditions he had named. In locomotive-engines increase in boiler-pressure alone had resulted in a considerable saving of fuel when working a given load. About three years ago he constructed a number of locomotive-boilers suited to a working-pressure of 160 lbs. per square inch. These engines, while doing the same work as other engines of the same design in every other respect, but with a boiler-pressure of 140 lbs. per square inch, shewed a saving of fuel of from 3 to $3\frac{1}{2}$ lbs. per train-mile, or equivalent to from 11 to 13 per cent. for the 20 lbs. increase in pressure. The engines had 18-inch cylinders, 26-inch stroke, and four coupled driving-wheels 7 feet in diameter; they worked the London and Nottingham fast trains at speeds of 50 to 53 miles per hour, using ordinary Derbyshire and Nottingham coal. As regarded the working of heavy fast main-line and Scotch trains with the same class of engine, with steam at 140 lbs. pressure per square inch, the average consumption of coal, for a number of engines over a considerable period, was 29·3 lbs. per mile on the Carlisle section with an average of $13\frac{3}{4}$ vehicles, and 30·1 lbs. per mile on the Leicester

Mr. Johnson. section with an average of $14\frac{1}{4}$ vehicles. These trains were worked at booked speeds of 48 to 50 miles per hour; and the ordinary coal of the district was used in each case. The results had been extracted from the ordinary shed coal-sheets of the Midland Railway, and included all coal burned by the engines in getting up steam, standing, &c.

Mr. Mallet. Mr. A. MALLET had read the Paper with much interest, and considered it remarkable from all points of view. He only regretted that the Author had not sought to become better acquainted with the actual state of the question on the Continent; he had given much attention to the engines of Mr. von Borries, and had perhaps not sufficiently noticed what had been recently done by others. The Author would soon be able to see, at the Paris Exhibition, types of compound locomotives, of the existence of which he probably had no suspicion. Mr. Mallet would correct some slight errors in the Paper which related only to his practice of some eight or ten years ago, and to begin, protested anew against the assertion that the application of the principle of continuous expansion by Samuel in 1852 was the oldest application of the compound principle to locomotives. No doubt it was the first attempt to modify the ordinary method of the employment of steam; but continuous expansion ought not to be compared with the compound principle. This system did not admit of the two essential points which constituted the advantage of the compound, namely, the reduction of pressure and the differences of initial and final temperatures in each cylinder. The point of departure of Samuel was the following, in his own words:—"It appears that a portion of the steam discharged can be spared from the blast to be subjected to a greater extent of expansion The economy in the continuous expansion consists in obtaining from such portion of the steam as can be spared from the blast the additional power of expansion remaining in it, which is thrown away in the ordinary engines, . . . between half and two-thirds of the steam supplied to the first cylinder is discharged at the pressure required to produce the blast, and the remaining steam (one-third to one-half) is expanded down in the second cylinder, so as to give out all the available power remaining in it." This was not at all what happened in a true compound locomotive, where all the steam which entered the small cylinder passed to the larger, and where it was only the steam exhausted from this large cylinder which served for draught. Why, then, this complicated arrangement, giving only an insufficient and partial expansion, employed by Samuel? Because he, like everybody at the time,

was persuaded that the draught would be insufficient if expanded Mr. Mallet steam only were employed. When Mr. Mallet proposed, in 1874, the employment in locomotives of two unequal cylinders, working as a true compound engine, it was forthwith objected that the feeble pressure of the escape, and the number of strokes of exhaust, reduced from four to two for each revolution of wheels, would not produce sufficient draught, and that the engine would be deficient in steam.¹ The trial trip made in June, 1876, at Creusot, on the first compound locomotive constructed at those works for the Bayonne and Biarritz Railway, had proved that these fears were unfounded, and that the steam from the large cylinder alone, with two exhausts per revolution, was quite sufficient to secure good draught and ample production of steam. From that time the problem of the compound locomotive was solved, and there were no more difficulties to overcome. Moreover—at least for locomotives with two cylinders—alterations had since been confined to matters of detail, for the locomotives of the Bayonne-Biarritz Railway contained, from the first, all the essentials of actual compound locomotives with two cylinders, such as the proper apparatus for each cylinder, the receiver in the smoke-box, etc. This small line had been the only one worked solely by compound locomotives from the day of its opening twelve years ago. It must be admitted that the system of continuous expansion of Samuel could not furnish any precedent, nor any example for the solution of this problem, which had been the true point of departure of compound locomotives. Mr. Mallet had, indeed, as indicated by the Author, employed many different ratios of volume between the cylinders; but it must not be thought that he had done so of set purpose; many of his compound engines were altered engines, where, to diminish the expense of alteration, one of the cylinders had been preserved, and another of the greatest diameter suitable to the engine, substituted for the other. It was this which had given rise to ratios less than 2 in some of his engines. But beyond the ratio 2·78 for the first three engines of the Bayonne and Biarritz Railway, he had always employed the ratios of 2·25 for small engines, and of 2 and 2·1 for large ones; ratios copied by the majority of engineers who had followed him, especially Mr. von Borries. There was nothing mysterious in the ratio 2·25 employed from 1877 on the two six-wheels coupled engines of the

¹ Identical objections were made when Mr. Ebenezer Kemp proposed a compound two-cylinder locomotive, in a Paper read in 1876 before the Institution of Engineers and Shipbuilders in Scotland, "On the Compounding of Locomotive and other Non-Condensing Engines." Transactions, vol. xx. p. 31.

Mr. Mallet. Bayonne and Biarritz Railway. It was simply from the ratio of the sections of the pistons whose diameters were $1\frac{1}{2}$ and 1, round numbers, and convenient to employ. He had used the ratio 2.04 since 1879, in the alteration of the engines of the Russian South Western Railways; it was the ratio of the sections of cylinders of which the diameter was $16\frac{1}{2}$ inches, the diameter of the original cylinders of the engines, and of $23\frac{1}{2}$ inches, the largest diameter that the construction of the engine allowed. It was evident besides that the ratio should be near 2, since as it would be a question of comparative trial between the altered engine and the others, it was necessary that the total volume of expansion of the cylinders should remain sensibly the same in the two cases. In regard to the altered engine of the Russian South Western Railways, the reason it had received steam-jacketed cylinders was that it might serve for special experiments in regard to steam jackets; but it was the only engine that had been so fitted, and he had never allowed steam-jackets in his practice, as had been wrongly asserted by several authors. He had at first employed the starting valve (Plate 3, Fig. 38); but he had for a long time substituted, especially for large engines, a less bulky apparatus, with a more direct passage, and automatic action, in which there was a retaining valve like that of Mr. von Borries, but combined with a small exhaust-valve, so that when the steam from the boiler came directly to the receiver, and closed the principal valve, the steam which escaped from the small cylinder passed outside, and did not produce back-pressure. This system had the advantage of prolonging as much as might be desired the period of starting without counter-pressure on the small cylinder, which with the arrangement of Messrs. von Borries and Worsdell was confined to a half revolution of the wheels, or nearly so. Further, great safety was thus obtained, because in case of accident the engine could proceed with one or other of the cylinders alone. The engine could produce the same effect as an ordinary engine in which the two cylinders had the same diameter as the small cylinder of the compound engine, so that if, as the Author said, the maximum effect took place at starting, there would be no need to make the small cylinder greater than the cylinders of an ordinary engine. From this there resulted a marked economy in the conversion of existing engines into compound ones—an operation which Mr. Mallet had carried out on a considerable scale. He had adopted in a certain number of engines a system of reversing-gear,¹ which

¹ Institution of Mechanical Engineers. Proceedings, 1879. Plate 37.

the Author had wrongly described as two independent reversing-gears, for the two gears could be either dependent or independent, like the arrangement of Mr. Webb; it was rather a sort of differential motion. As, with this system, engine-drivers could make a mistake, and not give to the cylinders the best relative cut-off, Mr. Mallet had for several years substituted an automatic arrangement which regulated, without the intervention of the driver, the cut-off to the two cylinders, after a rate similar to that of Mr. von Borries's, but avoiding the inconvenience, justly marked by the Author, of sacrificing the back stroke to the forward stroke. In this arrangement, both very simple and very efficacious, the relative cut-off to the two cylinders was the same before and behind, and the dead centre was common. This arrangement would be seen at the forthcoming Exhibition in Paris in a large compound locomotive for the French State Railways. Mr. Mallet had always approved of two rather than of three or four cylinders for a compound locomotive, as it led to greater simplicity and less weight, and the cooling surface of the cylinders, by contact with which the condensation of steam and re-evaporation were produced, causes of injurious loss of caloric, were thereby reduced to a minimum. Two cylinders were sufficient in nearly all cases. Mr. Borodin had recently altered locomotives to compound engines with four axles coupled, by substituting for one of the cylinders $19\frac{1}{2}$ inches in diameter another of 28 inches. These dimensions were almost exactly the same as had been given ten years ago by Mr. Mallet,¹ just as some others² very closely resembled those constructed recently by Mr. Worsdell. Mr. Mallet was likewise of opinion that if more than two cylinders were employed, an attempt should be made to realise something more than the compound principle, and to take advantage of the supplemental cylinders to suppress the connecting-rods, as Mr. Webb had done, or to distribute the weight of the engine over a greater number of axles, and to give flexibility to the whole, as he had himself done in the system of articulated locomotives, of which a considerable number had already been constructed. These engines were of great convenience on narrow-gauge lines, particularly on Decauville's portable railways. He might instance the interior railway of the Paris Exhibition of 1 foot $11\frac{1}{2}$ inches gauge, with rails weighing 19 lbs. per yard, on which travelled engines of 12 tons with four driving-axles. These engines were much more simple than the Fairlie engines, and traversed curves

¹ Institution of Mechanical Engineers. Proceedings, 1879. Plate 40, Fig. 14.

² *Ibid.*, Figs. 11 and 12.

Mr. Mallet. of like small radius. They possessed the great advantage over the latter in that the high-pressure piping was fixed as in ordinary engines, and that there was only a single turning-joint, establishing communication between the two groups of cylinders, and only containing steam of 50 lbs. pressure or thereabouts. There had also been constructed for metre-gauge lines engines on the same pattern, weighing 24 to 30 tons when equipped, and engines had been designed for the normal road with six axles weighing 80 tons. Mr. Mallet did not share the opinion of the Author that the maintenance of compound locomotives would be necessarily higher than that of ordinary locomotives. The kind of engine must evidently be taken into account. If this was a two-cylinder engine there was no reason why the maintenance and the lubrication should be greater, but the contrary. There were not more steam-joints, and the half only of the joints were high-pressure. The slide-valves had less load to bear and were less worn. Mr. Mallet had for a long time maintained, supported by his own experience, that the true way of making a balanced slide-valve as simple as an ordinary valve was to compound the engine. As to lubrication, he would cite the following instance. For seven similar goods locomotives, except that one of them had been altered to a compound, of which in the last three months of 1888 the mileage had been altogether 43,740 miles (72,000 kilometres) on the Western of Switzerland Railways, the average consumption of lubricants had been 0.097 lb. per mile (0.0274 kilogram per kilometre), the compound engine had expended 0.089 lb. (0.0252 kilogram), the least consumption had been 0.081 lb. per mile (0.0227 kilogram per kilometre), but as the compound had a total load 4 or 5 per cent. higher than the engine which had consumed least, it might be said that the expenditure for the two engines had been practically the same. Anyhow, there resulted a less expenditure on the compound than the average of the other engines. If the engines had three or four cylinders and as many gears, the expenses of lubrication and of maintenance would necessarily be slightly raised, but if these arrangements had, as indicated above, the object of securing certain advantages for the engine, besides working compound, these advantages might more than compensate the excess of expenditure for lubrication and maintenance, which excess should not be exaggerated. Thus he would cite one of his articulated engines for a metre gauge, which, compared with ordinary engines of the same weight, used nearly one-third to one-half more lubricant, but as the former drew, for a like weight, a load 150 per cent. heavier, or drew an equal load with an economy of 20 per cent. at least of

fuel, this excess of the cost of lubricant could be tolerated, particularly if account was taken of the fact that the compound engine, thanks to its articulated construction, did not unduly wear its tires on curves of 328 feet (100 metres) radius, and tried the line much less than ordinary engines. It was right, moreover, to say that the increased expenditure on lubrication in this case was not entirely due to the adoption of the compound principle, but suited the general plan of the engine, of which the object was to secure other advantages than the economy of fuel.

Mr. J. MANSON observed that balanced slide-valves had been in use on the Great North of Scotland Railway for over twenty years. Forty-one outside-cylinder and fourteen inside-cylinder engines were at the present time fitted with them. Inside cylinders, with the valve-casing between them, were fitted with a division plate on which the balance rings worked. Nine new inside-cylinder engines built in 1888 had the cylinders cast together, the balanced valves being placed on the top. These were worked by a special arrangement of the link-motion, in which the front end of the valve-rod carried a small die-block, for working the lower end of a rocking arm moving freely on a fixed shaft carried by the motion plate; the upper end of the rocking arm was connected to the valve-spindle by a link. This arrangement had given entire satisfaction, and the valves worked with so little friction, that the drivers could easily notch up the reversing-lever when the boiler-pressure was 150 lbs. per square inch, and the regulating valve full open.

Mr. W. MARRIOTT remarked that the Author seemed rather uncertain as to the extra capital cost, as well as whether there would be any extra charge under the head of repairs and renewals, by the adoption of compound locomotives. It would be interesting to learn if the compound engines ran with the same allowance of oil per 100 miles as the simple engines. Until some definite information was given on these points, it would be difficult to determine at what point in the price of coal compounding would be an economy, the Author rightly admitting that there were instances where the economy estimated would not pay for the extra cost of the compound engine. Although the Webb system seemed to have advantages which the Worsdell system had not, yet as a simple engine was so adaptable to the Worsdell type, this would seem to be the most adapted for alterations. On many lines, where the capital account was virtually closed, an alteration to the latter system could be effected at a comparatively small expense.

Mr. Stirling. Mr. JAMES STIRLING stated that he had not yet seen any results, obtained by compound locomotives, which could induce him to recommend their adoption on the South Eastern Railway. Considerable economy of fuel had been claimed for them on the London and North Western, and the North Eastern Railways. But on other railways compound locomotives had not been able to do the work so well as ordinary engines, nor had they been able to do it so economically. He believed he was right in saying that these remarks applied to the trials on the Manchester, Sheffield, and Lincolnshire, the London and South Western, and Metropolitan Railways. In 1873, while locomotive engineer of the Glasgow and South Western Railway, he designed a 7-foot coupled-engine, having a bogie in front, with inside cylinders, 18 inches in diameter by 26 inches stroke, and the valves between; and he was so much pleased with the results, with a steam-pressure of 140 lbs. per square inch, that he continued to build engines of this class so long as he was with that company. He might thus be considered an early exponent of the advantages of large cylinders for locomotive-engines. In 1883, he further increased the diameter of the cylinders to 19 inches, and there were now a large number of engines with cylinders of this size running on the South Eastern Railway, showing the most satisfactory performances, and doing some very heavy work. The following results had been obtained from a gang of six of these engines, stationed at Dover, working mail and express trains between London and Dover. The engines changed trains daily, and each ran about 1,000 train-miles per week. The steam-pressure was 150 lbs. per square inch. All the fuel used in lighting up, shunting, and light mileage was debited to the train-miles. Three months, at different seasons of the year, gave, he thought, a fair idea of the influences of weather, load, and working generally. *May, 1887.*—Average load, twelve vehicles, 120 tons; engine and tender, 70 tons. Total load, 190 tons; fuel 27·62 lbs. per train-mile. *August, 1887.*—Average load, fifteen vehicles, 152 tons; engine and tender, 70 tons. Total load, 220 tons; fuel, 28·70 lbs. per train-mile. *November, 1887.*—Average load, twelve vehicles, 120 tons; engine and tender, 70 tons. Total load, 190 tons; fuel, 30·37 lbs. per train-mile. He should like to test one of Mr. Webb's or Mr. Worsdell's compound engines alongside one of his large-cylinder engines for a month, under the most careful supervision, burning the same kind of fuel, and his engine working at the same pressure as the compound. In this way a comparison between compound and large-cylinder engines could be obtained, which, he felt sure, would satisfy the minds of locomotive engineers

who were in doubt as to the advantage of compounding Mr. Stirling locomotives.

Mr. ROBERT WILSON observed that, according to the Paper, the Mr. Wilson. adoption of the principle of compounding to locomotive-engines had effected a saving of fuel to the extent of 15 to 20 per cent. upon that consumed by high-pressure locomotives doing equal duty. Such results were quite as favourable as most engineers versed in locomotive and general engine practice would anticipate, taking into consideration the conditions under which a locomotive performed work, which were widely different to those giving most favourable results in the case of pumping, mill, or marine compound engines. These were usually at work during comparatively long periods of uninterrupted motion combined with a steady velocity, and developed a given power, for which was designed the relative sizes of the high and low-pressure cylinders, together with the period of cut-off in each. The conditions under which a locomotive was called upon to work were very different; there were the frequent stoppages, with possible variation of speed between each; the exigencies of traffic, which on many lines might necessitate a considerable difference of loads to more or less than the normal; and the different gradients on the line, over which the engine had to travel, might be such as would necessitate a wide variation of power between the minimum and maximum. To many it would no doubt appear a difficult problem to design a compound locomotive to work equally advantageously when subjected to these varying conditions, and many questions, raised by theory, would have to be answered by practice. One of these was, whether it was possible, by the present arrangement of valve-motion, to obtain an equal power from the high and the low-pressure cylinders, and to maintain this equal power throughout all changing conditions? If this was not possible, then he thought the two-cylinder compound engines might be subject to a lurching action, which might set up an oscillation which at high speeds might affect the cost of maintenance of the engine and of the permanent way. The three-cylinder compound engine should be free from this defect, as the two outside cylinders would balance each other, being both high-pressure; and the strain from the low-pressure being central with the engine, would be neutral with respect to any oscillation; any difference in power, between the high and the low-pressure cylinders, might be absorbed in slips, or be productive of slight jerks imperceptible at high speeds. It was, therefore, probable that the maintenance of the two systems would be much the same, as the extra cylinder in the one would com-

Mr. Wilson. pensate any increased cost, due to rolling in the two-cylinder type. It was quite probable that compound engines might prove more economical than high-pressure engines, when compared upon the duty demanded from them upon lines in this country, together with the prices paid for skilled labour, materials for repairs, and fuel; and the results showed still more favourably with low charges for maintenance combined with exceptionally high cost of fuel. But it was reasonable to suppose that conditions might exist, where the saving in fuel would be more than absorbed by the increased charges against maintenance and capital: for instance, the New Zealand Government lines. In that colony the cost of skilled labour and manufactured materials was very high, combined with coal at a comparatively moderate price. The New Zealand Public Works statement for the financial year, March 1887 to March 1888, showed an expenditure on fuel of £34,434, and upon the maintenance and renewals of locomotives of £54,466, with a train-mileage of 3,008,948, being equal to 2·98*d.* per train-mile for fuel, and 4·10*d.* for maintenance and renewals, making fuel and maintenance together equal to 7·08*d.* per train-mile. Without specific data it was impossible to arrive at a true comparative estimate of the cost of working two different types of locomotives; but an approximate idea might be gained by assumptions which would, possibly, not be far wide of the truth. Taking for comparison the three-cylinder compounds, it might be assumed that the increased cost of maintenance would be caused by an extra cylinder, valve and motion, piston and rod, reversing-lever connections, connecting-rod, &c.; but as no coupling-rods were required, the connecting-rod, single-throw crank, steam-pipes, &c., might be set off against these. To arrive at the details of maintenance, not having them separated on the New Zealand lines, he would take those upon the New York Central and Hudson River Railroad, as being nearer the conditions in New Zealand than any English main line:—

	Per cent.
Motive machinery	33·9
Wheels, tires and axles	11·8
Bogie, smith work, &c.	18·3
Boiler tubes, &c.	26·1
Woodwork, fittings, &c.	4·7
Painting	5·2

Then 33·9 per cent. of 4·1*d.* = 1·6359*d.*; taking $\frac{1}{2}$ instead of $\frac{1}{3}$ extra maintenance on motive machinery for the extra cylinder and fittings = 33 per cent. of 1·6359 = 0·539 + 4·1 = 4·639*d.* for new maintenance. Fuel per train-mile less 15 per cent. saved.

by compounding = $2.98d. - 0.447$, new fuel cost + $2.533d.$; Mr. Wilson. this + $4.639d.$ new maintenance = $7.172d.$, against the present figure $7.08d.$, which was unfavourable to the compound locomotive, without taking into account the interest on extra cost of the new type of engine, or any extra maintenance due to increased pressures. Such an assumed comparison, though possibly of little practical value, might serve the purpose of pointing out, to those most interested in the introduction of the compound principle to locomotive-engines, that it was to their interest to afford trustworthy data, upon which such a comparison as the above might be based. Engineers in general, more especially those interested in locomotive practice, would look forward to, and welcome the publication of, details which would not only show the saving of fuel, but also the comparative cost of maintenance and capital charges of compound and high-pressure engines.

Mr. E. WORTHINGTON, in reply to correspondence, remarked that Mr. Booth might be right in advocating the three-cylinder system with one high-pressure and two low-pressure cylinders, but some of his reasons for so doing were not very convincing. Would not the single unbalanced high-pressure cylinder, taking its steam direct from the boiler, be apt to aggravate rather than to "mitigate" "the disagreeable surging motion at starting?" It acted immediately the engine commenced to move, whereas Mr. Webb's unbalanced low-pressure cylinder did not usually come into full action until the engine had moved about its own length. Again, it was well known that in compound locomotives running with a light load, the high-pressure cylinder or cylinders did by far the greater part of the work. In the three-equal-cylinder engine this would be done by the single unbalanced cylinder, but in Mr. Webb's engine it was done with greater uniformity by the pair of high-pressure cylinders. It would probably be found advisable, in the three-equal-cylinder engine, to cut off steam in the low-pressure cylinders earlier than in Mr. Webb's engine, and this could be accomplished with reversing-gears at present in use, if no further difficulty were met in getting rid of the exhaust-steam. The advantage of this engine over the two-cylinder compound, in the interchangeability of its parts, would not extend much beyond the piston-heads; for in the existing two-cylinder compound engines the piston-rods, back-cylinder covers and machinery were the same for both high-pressure and low-pressure engines. In the proposed engine, if the machinery of the two low-pressure engines were made duplicate with that of the high-pressure engine, as recommended by Mr. Booth, they must all three be made capable

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Mr. Worthington. of resisting the boiler-pressure on their pistons. But this would render the low-pressure engines clumsy for their common duty. It was not clear why any very large proportion of the economy in compounding was due to the absence of coupling-rods; for this economy, in fuel at any rate, had followed the adoption of both two-cylinder and four-cylinder compound engines, all of which had coupling-rods. Again, the valves required to start the three-equal-cylinder engine would be more complicated than those for the Webb engine, and, when all was considered, the chief superiority of the engine recommended by Mr. Booth appeared to be the avoidance of very large cylinders. Mr. von Borries, in referring to the cost of simple and of compound locomotives, was comparing engines of the same tractive power at high speeds, when the boiler of the compound engine might be 10 to 15 per cent. less in size. One of the great advantages of the system applied on the North-Eastern Railway was found to be the heavy trains which these engines could take at high speeds, compared with ordinary engines of equal boiler-power, and hence arose the very large HP. daily indicated by Mr. Worsdell's engines. But when climbing at low speeds, the compound engine required the additional cylinder-power described on p. 24, and, the blast being softer, it was doubtful whether a boiler 10 to 15 per cent. smaller than that of a simple engine would supply enough steam for this larger cylinder. It was for this reason that the Author compared the tractive power at low speeds in estimating the relative cost. Mr. Drummond's experience of the value of large boilers and his statements of the impossibility of making exact comparisons between engines working on different railways were interesting, but they hardly affected the arguments relating to compound locomotives. In no case, in Table VII of the fuel-consumption of compound locomotives, had the performance of an engine on one railway been compared with the performance of an engine on another railway. In order to make accurate comparisons between one type of engine and another, all variable local conditions should be eliminated as far as possible, and to do this careful treatment in an exceptional manner was necessary. Moreover, the locomotive was so different from any other type of engine, that even such comparisons would not be of much practical value, however much light they might throw on the general question of steam-engines. The comparison proposed by Mr. Edwards, between the compound underneath fixed engine and the compound locomotive, would be of this character, inasmuch as the average HP. of a locomotive was from 400 to 500, and its piston-speed often reached 1,000 feet per minute—a power and a speed never

attained by the fixed engine. Mr. Johnson's experience further confirmed the conclusion that considerable economy in fuel could be obtained by increasing the boiler-pressure in simple engines; but, even on Mr. Johnson's own showing, the amount of that economy was only about two-thirds of the average of the savings of compound locomotives enumerated in Table VII. It was unfortunate that the trials of three-cylinder compound locomotives on the London and South-Western and the Manchester, Sheffield and Lincolnshire Railways were not made with engines as powerful as those daily working the trains; but this should not stand in the way of an unbiassed judgment between equally powerful engines doing the same amount of work. Mr. J. Stirling possibly referred only to the disagreeable motion on starting, when he stated that compound locomotives had not answered so well as ordinary engines on the Metropolitan Railways; for on the outer circle Mr. Webb's compound engine was working the traffic with an expenditure of coal and water about 25 per cent. less than that of the other engines. This saving was of more value, in a city traffic, than the mere cost of fuel and water. It was perhaps unnecessary to point out that Table VII contained particulars of about twenty railways on which compound locomotives had succeeded in effecting an economy of fuel. The problem named by Mr. Wilson had been solved on the North-Eastern Railway, where Mr. Worsdell had taken large numbers of indicator diagrams from his express and goods engines at several speeds, and points of cut-off, which showed that the HP. developed in each cylinder was practically the same. Mr. Mallet's system of compounding, the more recent developments of which had not received adequate notice in the Paper, were described in his interesting communication, and the Author was indebted to Mr. Mallet for some additional particulars of Continental engines, placed at the end of Table I, which thus now contained a list of about five hundred and sixty-nine compound locomotives.

Mr. Worthington.

15 and 22 January, 1889.

SIR GEORGE B. BRUCE, President,
in the Chair.

The discussion on the Paper, by Mr. Edgar Worthington, on "The Compound Principle Applied to Locomotives," occupied both evenings.