Discussion.

The Chairman. The CHAIRMAN moved a vote of thanks to the Author for his Paper.

The Author. The AUTHOR stated that since he wrote the Paper the three-cylinder engine referred to in it had been built, with a slight variation. In preparing finished designs it had been found that the clearance of the connecting-rod of the middle crank of the engine from the rail was rather too small; accordingly the stroke had been reduced to 24 inches and the cylinders increased to $19\frac{3}{4}$ inches in diameter. With that exception, the engines as built were practically the same as the design. The wagon had also been built, but not the coach.

Mr. Waring. Mr. F. J. WARING agreed with the Author that a gradient of about 1 in 25 might be taken as the extreme limit for ordinary adhesion work, but at the same time, on such a gradient, with the sharp curves that were so often found on mountain-railways, the weight of the trains must be very small and the working-expenses excessively high. For that reason he thought a considerable additional capital expenditure would be justified, in reducing the gradient wherever possible, say, to 1 in 37, as on the ghats of the Great Indian Peninsula Railway, or to 1 in 44 as on the main mountain-railways in Ceylon. While the design of the locomotive for use on mountain-railways was a question of paramount importance, yet the design of the proper stock for it to draw was also a matter of considerable importance, as it was economically useless to design an efficient machine to draw stock ill-adapted for its purpose. With regard to the passenger-stock, the comparison given in the Paper, of the tare of the first- and second-class carriages with the number of passengers they carried, appeared to him to be extremely favourable, but judging from the description of the carriages as given, and from he diagram, he did not think, generally speaking, that first-class passengers, especially on long journeys, would be at all satisfied with the accommodation. He agreed with the Author that the sharp curves on mountain-railways nearly always necessitated the use of bogie passenger-stock. Some years ago he had occasion to look into the question of the comparison between the tare of passenger-coaches and the number of passengers carried, and, taking several railways, he found that in extreme cases the tare of modern first-class carriages when full, on standard gauges, ranged from $\frac{3}{4}$ ton to $\frac{4}{5}$ ton per passenger carried. In the case of sleeping-cars the proportion of tare per passenger carried would be of course much higher, and when, as was often the case, the first- and the second-class carriages were not by any means full, the proportions he had given would be much more unfavourable. Even with the adoption of the expedient of using composite carriages, which was beneficial in two respects—first, as enabling the weight of the carriage to be somewhat reduced below that of a first-class carriage, and secondly, as very largely increasing the number of passengers carried—he still found that the tare per passenger when the carriage was full was about $\frac{1}{5}$ to $\frac{1}{4}$ ton. The Author stated that in extreme cases steel wagons had been known to whip so badly as to throw their load off on to the track. Any wagon that behaved thus must be either much too elastic, or too weak for its work, or else the road must be very bad; in any case Mr. Waring did not think that a wagon which behaved in that manner could have a very long life. The general use of bogie-vehicles for goods-traffic was of course limited, especially on mountain-railways, by the difficulty of getting good loads for the wagons in both directions. Where it was possible to get mineral-traffic in one direction and goods-traffic in large consignments in the other, bogie-wagons could be used economically. That difficulty, he felt sure, must have been brought prominently to the notice of every railway-manager and railway-engineer. On a railway with which he himself was connected, which rose from sea-level to a height of more than 6,200 feet above the sea, 12-ton wagons were generally in use, and it was found in 1908 that the average load carried per wagon was less than $3\frac{1}{2}$ tons. On that railway the weight of the traffic in the up direction was more than double that of the traffic down the gradient, and therefore the question of working the wagons to the best advantage had received particular attention. The result was noteworthy, as showing the great practical difficulty in getting good traffic in both directions. He thought the designers of goods-wagons, whether bogie or four-wheeled, should be very careful to steer a middle course; avoiding the Scylla of undue tare and the Charybdis of reducing the tare so much as to shorten the life of the wagon. On standard-gauge lines, if the carrying-capacity of a wagon was two to two-and-a-quarter times its weight in the case of covered stock, and two-and-a-quarter times to two-and-a-half times its weight in the case of open stock, the result might be considered as fairly satisfactory, and he observed that that result agreed generally with what was stated by Messrs. Shackleton, Twinberrow and Jepson in the Papers read before The Institution in 1904 and in the discussion that took place upon those Papers.[1] Mr Waring.

[1] Minutes of Proceedings Inst. C.E., vol. clvii, p. 92 *et seq.*

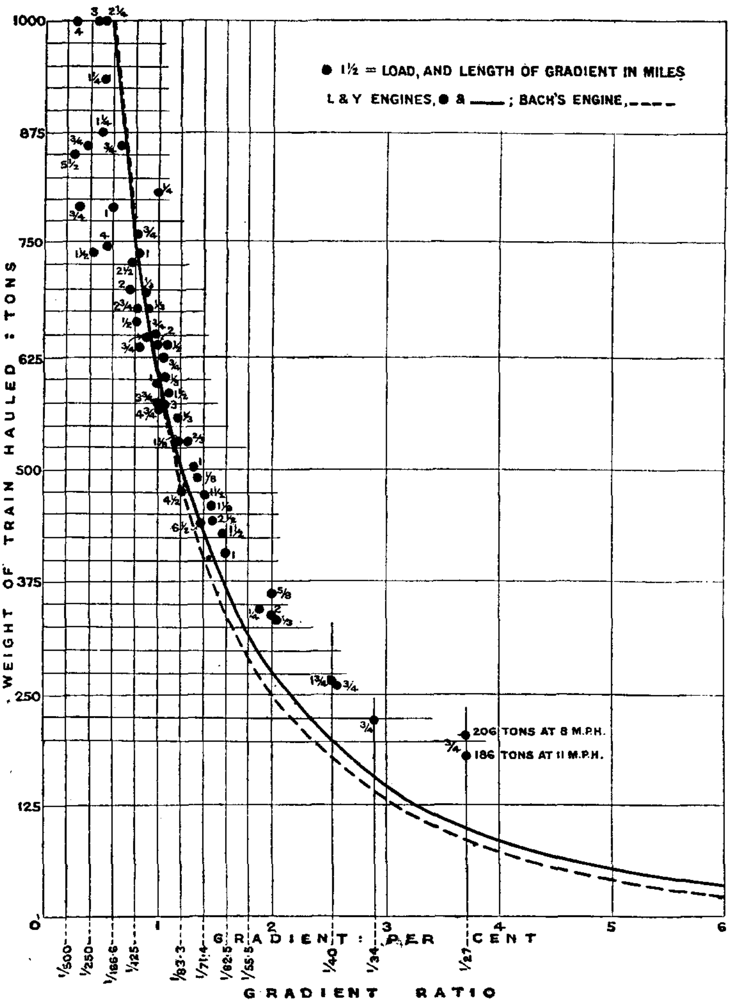
Mr. Tritton. Mr. SEYMOUR B. TRITTON thought that all engineers who had had any connection with heavy-gradient working would agree that the ordinary formulas and data, which could be relied upon for locomotive-design for ordinary gradients and ordinary working, were fallacious when applied to very steep gradients. The designer who attempted to use those formulas for steep gradients would have some disagreeable surprises in store for him when the engines were actually at work. The Author gave some notes with regard to the cut-off and the boiler-supply of the locomotives, and put forward an all-round formula which might be useful for getting the actual tractive force at the rail for mountain work. There were two points, however, which required some consideration: first, the point of cut-off taken in the cylinders, and secondly, the speed at which the train had to be hauled. The cut-off taken was 50 per cent., and he thought the locomotive superintendent would be very fortunate who could persuade his drivers to adhere to anything like 50 per cent. on inclines of 1 in 25; he was afraid that would very often be exceeded, and as the boiler-power was made to correspond with the cut-off, he would rather expect shortness of steam if the figures were followed. The Author might explain a little more fully. All engineers would agree that the boiler-power was the measure of power for a locomotive, and if that was the case in ordinary working, how much more was it so on heavy gradients, where the boiler was pressed to its extreme capacity. The question of the boiler was the *bête noire* of the designer for heavy-gradient work. Having got out his design and settled everything fairly satisfactorily, he was met with the question of the boiler, and as soon as he had provided a boiler of really sufficient capacity, he found he had exceeded his permissible axle-load, and he had to begin all over again —or, what was worse, was tempted to reduce his boiler below what was necessary. It was difficult to know how this could be overcome, but it seemed to Mr. Tritton that the solution of the problem lay largely in the direction of using superheated steam. With a superheated-steam engine, a boiler of much less capacity could be used, and the pressure could be reduced without serious loss of power. The English railways were only nibbling at the question of superheated steam at the moment, but he had had an opportunity of conversing with the Chief of the German State Railways, who stated that in Germany they had about 2,000 locomotives working under superheated steam and giving excellent results, and that they did not propose to make any more of what he somewhat scornfully designated as "saturated engines." When one thought of the 15 per cent. drop mentioned by the Author between the boiler and the cylinder, the cylinder-cocks being opened on the hills to prevent the cylinder-head from being knocked out by the water and wet steam, and the wretched attenuated diagram obtained, there was undoubted pathos in the words "saturated engine." With regard to the selection of type, he thought most engineers would agree that there must be a very strong inducement indeed to depart from what he might call the normal type of engine and to adopt the abnormal. The normal type of engine was doing excellent work, and he would call the engine shown in Fig. 7, Plate 3, a normal engine in respect of its general construction. There was of course the difficulty of the axle-load, as the Author mentioned. After distributing the load on say three axles, the time came when the limit of axle-load was exceeded and carrying wheels had to be provided. So long as those wheels were not coupled, they were of no use for propulsion; while if, on the other hand, they were coupled, difficulty immediately arose with the long coupling-rods on the sharp curves of a mountain-railway. He had had the opportunity on the Continent of seeing some very fine ten-wheeled engines in which all the five axles were coupled, and he was greatly struck by the ease with which those engines were negotiating very sharp curves—sufficiently struck, indeed, to follow the matter up. He found that no provision whatever was made for articulation, or for ball-joints on the coupling-rods; all that was done was to give excessive clearance in the leading and trailing axle-boxes of the five wheels. Compared with ordinary practice that clearance was enormous; it was something like $1\frac{3}{16}$ inch, and there were very long driving-pins in which the same clearance was given. At first sight it would appear that when an engine was going round a sharp curve, with full force applied to the coupling-rod bushes, the bush would refuse to slide transversely upon the pin; but as a matter of fact it did slide. The engines were working very well, and there was no complaint about cut tires or cut brasses, or trouble with crank-pins. He thought the explanation really was one with which all engineers were well acquainted: if a pin fitted into a hole with a very good fit (such as a motion-pin with a 0·004-inch fit), the pin could hardly be moved if pressed in straight, but if the pin was given a spiral motion it was easily moved backwards and forwards. When these engines were going round curves, the wheels moved transversely, and at the same time the coupling rod bush was going round the pin, so that there was a spiral motion. If such a simple device was really successful, it might be applicable to engines with ten wheels for mountain work. Although the ordinary type of engine should be preferred, Mr. Tritton.

Mr. Tritton there were lines on which the abnormal engine was really justified, and under the abnormal he would include the Fairlie, the Mallet, and the Garratt engine recently brought to notice, which seemed a promising design. He had had many years' experience in connection with the Fairlie engine, and had obtained some very successful results. On one line of 4-foot 8½-inch gauge Fairlie engines had gradually been increased in size and power until the latest engines weighed 120 tons, and engines were now being designed up to 138 tons. In engines of that size there was no doubt that the Fairlie design of boiler, with its long divided firebox and enormous length of barrel, became a very serious question. On a metre-gauge line with which he was connected an entirely new plan had been tried, of making the whole frame of the engine one large girder, and supplying it with two ordinary boilers placed back to back. That method had many advantages. In the first place, a normally constructed boiler could be used and a cheap spare boiler kept in stock, and in the event of a breakdown or trouble with the boiler on the road the engine could be worked home with one boiler. Among other details this type furnished a large airy platform for the driver, the platform in the case of the metre-gauge engine mentioned being 8 feet square, which was a consideration in a tropical climate. Both the Fairlie engines mentioned were working on a 1-in-25 gradient, giving considerable satisfaction, and had been repeated. Those, he thought, were cases in which the Fairlie engine was really justified. Rather better results were obtained than the Author claimed by his formula, because in the case of a metre-gauge engine working on a 1-in-38 gradient of which he had results, the load hauled according to the formula would be 122 tons, whereas the engines were actually hauling 148 tons; in another case, on a 1-in-25 gradient, the load by formula was 143 tons, the actual load, 160 tons. He would expect an increase of about 12 per cent. in actual working over the formula, which certainly allowed a large margin.

Mr. Hughes. Mr. GEORGE HUGHES remarked that it had been his privilege to read the Paper through the spectacles of the Chief Mechanical Engineer of an English railway, and he would like to begin his remarks by describing briefly the class of locomotive he would have in his mind throughout the whole of what he had to say, which might perhaps be followed better by bearing in mind Fig. 7, Plate 3. The locomotive he referred to was designed by Mr. John A. F. Aspinall, when Chief Engineer of the Lancashire and Yorkshire Railway—a two-cylinder engine, with cylinders 20 inches in diameter and 26 inches stroke with eight coupled 4-foot 6-inch wheels, as compared with the Author's, 4-foot wheels, and with 1 ton 15 cwt. more on the driving-wheels. Mr. Hughes. The steam-pressure was 180 lbs. per square inch and the heating-surface was 2,038 square feet, as compared with the Author's 1,510; but the total weight of the engine and tender was 3 tons less than that of the Author's engine. Therefore it was rather a lighter machine, and the cylinder-capacity was also less, although when considering the Author's design it was not easy to know exactly to what extent his cylinders were operative, by reason of the ingenious little wiredrawing apparatus for the steam. Fig. 1, Plate 3, presumably represented the paying loads hauled by four separate engines, and he thought it would add to the interest of the Paper if the Author would kindly give some of the main dimensions of those particular engines. It was well known that in addition to the severity of gradients something should also be known about their length, curvature, approaches and undulations. The Author had said something about those things, but if he would say more it would add to the value of the Paper. Knowing that the engine he had described would haul 600 tons on a gradient of 1 per cent. between 4 and 5 miles long, Mr. Hughes had been able to identify the work that the Lancashire-and-Yorkshire engine would do, and eventually had found that it corresponded more or less with the third curve from the left in Fig. 1. Starting from that, he had been able to produce the thick, black curve shown in *Fig. 10*, and subsequently he plotted the Author's curve, which was shown by a dotted line. Their agreement was very close. He had followed the matter up by selecting, more or less at random, between fifty and sixty loads hauled on various gradients by the engine he had described, and the manner in which the loads hugged the theoretical diagram was remarkable. Immediately adjoining each of the black dots there was a figure representing the length, in miles, of the gradient over which that load was hauled. He thought the diagram showed the efficiency of the Lancashire-and-Yorkshire engine, and it also served to enhance the value of the Author's diagram. He was particularly interested also in Figs. 2 and 3, Plate 3, the latter deduced from the former. It could be only presumed that those figures related to speeds of about 12½ miles per hour, or 10 to 12 miles per hour, which were the only speeds mentioned in the Paper. He thought the value of Fig. 3 would be enhanced very much by *Fig. 11*. Of course it was well known that initial pressures were not influenced to any large extent by the speed, provided that the cross-sectional area of the ports was at least one-twelfth of the area of the pistons, and it was also known that the shape of the diagram was, and consequently the mean effective pressure

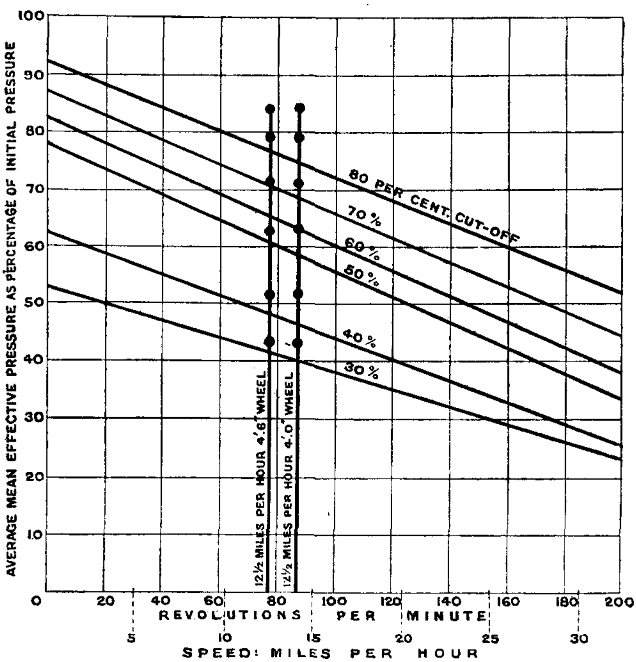
Mr. Hughes. and its relation to the initial pressure. Therefore he had taken 400 diagrams from engines of the class he had described, and from these

Fig. 10.



had plotted the mean effective pressures at speeds up to something over 30 miles per hour. The two vertical lines with round dots were the points where the Author's experience and his own met; they did not exactly coincide, and it was hardly to be expected that they would, when it was remembered that the Author's experience had been obtained in South America and his own in Great Britain. The main object in exhibiting that diagram was to show a fact which everybody knew, but which was extremely difficult to demonstrate because a vast number of experiments had to be carried out before any result could be arrived at. The Author spoke of a drop of $7\frac{1}{2}$ per cent. between the boiler-pressure and the initial pressure. Mr. Hughes's experience was about 5 per cent. Mr. Hughes.

Fig. 11.



with rather higher speeds, and with a cut-off of about 45 per cent. for goods-engines and 20 per cent. for passenger-engines. When the Author dealt with the selection of type he depreciated the tank-engine and enumerated its disadvantages; but at home there were at least 9,000 or 10,000 tank-engines doing valuable work every day, and tank-engines were continually being built. He could not conceive why derailments and tank-engines should appear to be synonymous terms. Anyone searching the records of the Board of Trade—the only criterion available—would find that during the

Mr. Hughes. past 20 years there had been at least as many tender-engine derailments as there had been tank-engine derailments; and going back for 30 years it would be found there were more tender-engine derailments than tank-engine derailments. The Author stated that a tank-engine could be redesigned as a tender-engine with only about 5 per cent. additional weight. In England, however, it would probably be between 15 and 20 per cent. It was quite true, of course, that when the tanks and bunkers were half empty there was 10 per cent. less weight on the wheels—at any rate, that was so in the Lancashire-and-Yorkshire engines. The Author also stated that 1 square foot of heating-surface was sufficient for 15 lbs. of available tractive force. It would be interesting to give some comparative figures from the Lancashire and Yorkshire Railway. In the case of passenger-engines it was 1 square foot for 9 to 13 lbs. of available tractive force; for tank-engines it was 1 square foot for 11 to 13 lbs. of available tractive force; and for goods-engines 1 square foot for 16 to 18 lbs. In each case the adhesion was four to five times the amount of the tractive force. He was particularly interested in the automatic governor, and a more detailed drawing and a description of it would be valuable. There appeared to be something behind it in the sense that if the governor were not there the boiler shown would never be able to supply three 19-inch cylinders. It was known, of course, that engines frequently stopped with one piston at the end of the stroke and one piston at the middle of the stroke, and consequently valve-gears had to be designed to give sufficient port-opening for any position of the piston; hence it was necessary to have some throttling to commence with, otherwise there would be a very serious amount of slipping. With regard to the coal-chart, it should be remembered that the Author allowed only 10 lbs. per ton for journal-, rail-, and atmospheric friction, which was rather a low figure. Mr. Hughes had applied the diagram to his own case, and it gave rather higher consumptions than he was accustomed to on the Lancashire and Yorkshire Railway. Possibly the reason was that the gradients on the Lancashire and Yorkshire Railway, although rather severe, were not so continuous as those on the railways mentioned by the Author. On the whole, he thought the remarks he had ventured to make might be regarded as constructive criticism; the Author warned his readers to be careful in using his data, and every sentence in the Paper appeared to have more meaning than was on its face. Certainly the diagrams were such as every leading draughtsman revelled in when carrying out the designs of his superior.

Mr. DAVID SIMSON remarked that the Paper raised points of the greatest importance to those connected with mountain-railway working, and he could testify that the Author could not have gained his experience in a better school than the Peruvian railway-system, where there were some of the steepest inclines in the world. On the Antofagasta, Chili and Bolivia Railway, though it rose to between 16,000 and 17,000 feet above the sea, much flatter gradients were used, the maximum being 3 per cent. (1 in 33·3), but the figures of coal-consumption, he was pleased to say, bore out very closely the Author's coefficient for obtaining coal-consumption on the up and down journeys. From his own experience of mountain-railways in the Andes, the question of sharp curvature was much more important than steep gradients. With a sufficiently sharp curve the gradient could be kept down in the neighbourhood of 3 per cent., and therefore he did not quite agree with the Author as to the engine described, with a long fixed wheel-base, being more useful than one of the types of articulated engine that had been mentioned. For instance, on the Antofagasta railway the Kitson-Meyer type of engine was being used with a 7-foot fixed wheel-base, and it was found that it caused much less wear and tear on the curves and hauled very well. On the Taltal railway, where he first saw one of these engines working, he himself had been on the foot-plate of an engine hauling over 125 tons behind the tender up a 4-per cent. gradient with curves of 90 metres ($4\frac{1}{2}$ chains) radius. With regard to the question of the rolling stock of the Antofagasta railway, referred to by the Author, although the wagons were marked 20 tons they carried up to 25 tons of minerals. Even the covered goods-wagons on that railway did not weigh more than 7 tons; and in respect of the passenger-stock he could fully bear out what the Author said. Sleeping-coaches were now being used on the Antofagasta railway which weighed well under 20 tons, with two-berth compartments; they were 8 feet wide on a 2-foot 6-inch gauge. With regard to the question of braking, he quite agreed with the Author that a steam-brake was very necessary on the engine, but at the same time it could be used only as an emergency-brake. He had found that using the engine-brake continuously on down-hill roads heated the tires so much that they became loose, and the practice on the Antofagasta railway was to brake down with the train-brakes, using the engine-brake only in an emergency. They were now adopting the Westinghouse brake, and intended to fit it on to all the stock. Mr. Simson.

Mr. C. O. BURGE pointed out that all through the Paper the gradients were noted in the American fashion, namely, as a percentage, but as the Paper would appeal to many engineers in Mr. Burge.

Mr. Burge. the British Empire to whom the English notation was much more familiar, he suggested that in all cases the Author should add the gradients in the English form of 1 in 25, and so on. With the exception of Canada, the British form of gradient was almost universal throughout the Empire. As an old railway man he knew what was meant by 1 in 75, but had to think out the meaning of 1·33 per cent.

Mr. Bamber. Mr. H. KELWAY BAMBER observed that he had had no experience whatever of mountain-railways, but there were one or two things in connection with the Paper which were extremely interesting to a Carriage and Wagon Superintendent, a position which he had occupied in India for some years. The first was the diagram showing the variation in tractive force for every revolution of the wheel: he thought he saw in that something which accounted for the enormous breakage of draw-springs. If that variation was taking place four times during each revolution of the wheel on a heavy gradient the springs were practically put to an inspection-test over the whole of the run. As the carriage had not been built he would make no remarks about it, but the wagon filled him with delight, because it had no sides or ends. The damage to sides and ends of wagons in India was the bugbear of the carriage-superintendent, and if they could be removed from all wagons the maintenance-charges and the necessity for such large wagon repair-shops and staff would be greatly diminished. When he mentioned that new wagons, just out of the shops—four-wheeled vehicles carrying 24 tons, with a tare of 8 tons, or 16 tons per axle loaded—frequently came in within a week or 10 days with the ends out, it would be understood that the ends had considerable work to do. He noticed in the Author's wagon that 20 tons were carried without any ends at all, and he thought it was a pity that the classes of goods carried were not mentioned. The floor-area of the wagon shown was 170 square feet, and taking coal at $40\frac{1}{2}$ cubic feet to the ton, the wagon would have to be piled to a height of 5 feet to carry the load; and if, as was said, some wagons whipped in such a way as to act like springs, he fancied that the ratio of the paying load to the tare by the end of the journey would be exceedingly small. He hoped the Author would say how he got that load down-hill. Even supposing it was such a material as road-metal or limestone, which was fairly heavy, the wagon had to be loaded, if it was set absolutely square, to a height of 2 feet 6 inches; so that he did not see how that load would be carried on such a wagon without sides. The carriage-superintendents of India would be delighted if the Author could assure them that sides and ends were unnecessary. He drew attention to what he thought must be a printer's error in Fig. 1, with regard to the paying load per ton; he thought that meant gross load per ton, because the Author was speaking of total haulage. With regard to the axle-loads, he noticed that the engine axle-loads were 13 tons, and he presumed that the same load was not carried on the wagons on account of the difficulties explained with reference to braking down-hill. He wished to know what the Author had to say about that, because in India they were now working new wagons on the main line up to the same axle-loads as the engines, and high efficiency was thereby obtained. The axle-load on the descending journey was, according to the Paper, limited to 8 tons—a possible 13 tons and an actual 8 tons; it seemed very alarming, but he supposed that also was unavoidable, even by the use of larger brake-blocks and larger wheels, presenting greater surface for radiation. He could not help feeling there must be something wrong about the design of the wagons that were said to unload themselves automatically—the wagons that whipped so much that the load came off—because it did not say much for wagon-design if a wagon-builder could not build a wagon, of any gauge, which would carry a load with a ratio of 3 to 1 without its falling off. Some mention was made in the Paper of the trussing that was desirable—that it was not possible to truss light vehicles. It was extraordinary what strength could be obtained by forming a plate in the proper way, and there were many examples of that among existing stock. He would like to hear something about the difficulty of lubrication. It was a matter he had had to deal with in India, and it appealed to him very much. He thought the difficulty referred to must be caused by the heating of the bearings resulting from uneven block-pressure. If the diagram had shown the positions of the blocks, it would have been possible to consider the matter more fully, and he thought it was a pity such an indication was not given. In India, when it came to the question of braking the stock, there was a great temptation—in the desire to add as little as possible to the tare—to put the blocks on one side of the wheel only. With a block-pressure of $2\frac{1}{2}$ tons—5 tons on a pair of wheels—it was not difficult to see that the bearing would very likely lose its alignment and rapidly become heated; so that in spite of a good deal of opposition it was necessary to insist upon getting the block-pressure evenly on both sides of the wheels, and thus troubles with hot axles were eliminated. Those who unfortunately had brake-blocks on one side were suffering from heated axles. The possible loosening of tires, owing to the expansion due to the heating resulting from braking, was, of course, a very serious difficulty. He had seen, on gradients of 1 in 25, the tires and brake- Mr. Bamber.

Mr. Bamber. blocks cherry red, even in daylight. It was no doubt true, as the Author said, that there were objections to overcoming the difficulty by using larger wheels of chilled iron, but there were wheels obtainable up to 42 or 43 inches in diameter which were rolled solid, with the tires and centres in one piece, and which would give increased braking-efficiency, a much larger radiating area, and altogether a longer life and more satisfactory results. The question of wheel-diameter was very important. In India it had been necessary to consider the question of lightening the wagons as much as possible. They were four-wheeled stock, weighed 8 tons, and carried 24 tons. The authorities were always anxious to reduce the weight, and it had been thought that that could be done by reducing the diameter of the wheels. Accordingly, several hundred wagons were brought out with a 37-inch wheel against a 42-inch. The drivers complained that they could not get out of the yards, and engine-assistance was required in getting the trains away. That led to some practical tests, which were carried out in the shops under his own supervision, with wagons hauled from rest by dead loads; that was to say, a weight was suspended over a pulley and its pull was transmitted horizontally to the drawbar, and weights were added so as to find the force required to move the wagons from rest for different loads and different wheel-diameters. The difference in force required to move a wheel of 33 inches diameter as compared with one of 42 inches was extraordinary, 35 to 40 per cent. more force being required with the smaller wheel. That was a very serious matter, either in starting initially or when stopped on the route. In all the cases, whatever the diameter of the wheel, whatever the load, and whatever the power required to start a wagon, all the wagons rolled almost exactly the same distance —about 80 feet. It was accordingly decided not to go on with the 37-inch wheels, owing to the difficulty of starting, and to forgo the advantage of the larger wheel when in motion. Finally there was the difficulty about braking. At heavy expenditure the rolling stock of India was being power-braked to-day, but unfortunately it was impossible to brake it to more than 80 per cent. of the tare of the wagon. It cost very little more to give a leverage of 80 per cent. of the full load of the wagons. It seemed to him there was a great opening for an inventor who could produce a brake that would answer the requirements of empty and loaded vehicles alike. He trusted the Author would not think that the remarks he had made about the wagon without sides were at all discourteous; it had simply struck him as an astonishing thing that the Author was able to get 20 tons on a vehicle of that kind. The Paper had given him great satisfaction and much food for thought.

Mr. SEYMOUR B. TRITTON wished to add a few words on the question of the speed of haulage up heavy gradients. Some time ago he had some special experiments carried out with a view to determine not the maximum but the minimum speed that could be employed, and it was found that about 8 miles per hour was practically the minimum that could be used, and that at anything below that there was a danger of the engine being stalled and failing to start again on the heavy gradient. The Author assumed a speed of 15 miles per hour in his formula; Mr. Tritton concluded that that would be the maximum, and that probably the most economical speed would be found somewhere between the two speeds mentioned. The Author also stated that, owing to the great trouble with the steam-pipes of Fairlie engines, those engines had been abandoned in many cases. That might have been so many years ago, and it might be so now with some engines, but on the railways with which Mr. Tritton was connected they had entirely overcome that difficulty by a specially designed joint. They had had reports on Fairlie engines with regard to every conceivable detail, some very favourable and some hardly so favourable, but one thing never mentioned was the steam-pipe joint —at any rate during the last 4 or 5 years. He thought the secret of that lay in the very simple contrivance of forming a "step" in the conical portion of the steam-pipe and backing it up with some lead washers. They had tried many devices, but the "step" with the lead washers had got over all trouble from leakage. Mr. Tritton.

Mr. J. D. TWINBERROW thought that the interest of the Paper might have been enhanced if it had contained a few particulars with reference to modern European practice in working steep gradients by adhesion. It was true, of course, that for the most part the conditions were not so severe as upon some of the interesting railways with which the Author had been connected, but at the same time, in Switzerland, Italy, and the South of France there were railways which had considerable lengths of gradient, practically continuous, at an inclination of 3·3 per cent. or 1 in 30. In Switzerland, on the Federal State lines, the three-cylinder compound locomotive had been practically the standard for many years, but lately it had given place to the four-cylinder type, and now he understood there was a reversion to the three-cylinder pattern, in a design providing three equal cylinders, using superheated steam, with cranks at equal angles. In the South of France some interesting trials had been carried out, comparing compound with superheating engines upon a length of line which, at any rate for 10 miles, had a continuous gradient of practically 1 in 30. The eight-coupled, four-cylinder compounds had a normal train-load of 187 tons, and that was the train-load Mr. Twinberrow.

Mr. Twinberrow. used for trial purposes, contained in 20-ton and 50-ton wagons. The trials were run at speeds ranging from 9·3 to 10 miles per hour, and when cutting off at 70 per cent. in the high-pressure and 60 per cent. in the low-pressure cylinder, the coal-consumption was 174½ lbs. per mile up-hill. Comparing that with the Author's Table, it would be seen that for equivalent work his allowance was about 38 per cent. greater, but in addition Fig. 5, Plate 3, included in the train-load the weight of the locomotive, and the coal-consumption was the inclusive average for the round trip, both up and down. Further trials were made with the type of engine to which Mr. Tritton had referred, the ten-coupled Schwartzkopff tank-engine, in which all the wheels were available for adhesion, the first, third, and fifth having a full inch of lateral play, so that the whole wheel-base would accommodate a versed sine of fully 2 inches.[1] The engines weighed 65·4 tons empty, and had accommodation for about 20 tons of fuel and water. The heating-surface was 2,000 square feet, including the superheating-surface, and the grate-area 29·8 square feet, which gave a ratio of 68 to 1, a value it was never desirable to exceed, because the small economy that was possible would not be in proportion to the extra cost and weight of the additional heating-surface, unless two-stage heating were introduced. That also gave a surface of about 30·6 square feet for every ton of weight, which was a favourable result for a tank-engine and compared favourably with the 35 to 36 feet per ton which was generally found in Continental practice for tender-engines. He noticed that the Author's locomotive worked out at about 27 square feet per ton, and that suggested either that the heating-surface was a little short, or that there was a possibility of reducing the mass without sacrificing the robustness of character. The cylinders of the ten-coupled engine were 24·8 inches in diameter by 26 inches stroke, which gave about 14 per cent. more cylinder-volume than the Author's example, but the grate-area and heating-surface were 33 per cent. more. When the engine was tried with a standard train of 187 tons it could do the journey up-hill with a cut-off of 40 per cent., the coal-consumption being 160 lbs. per mile. On the down-hill journey, when worked with the counterpressure brake, the consumption was 45 lbs. per mile. The load being increased to 275 tons, it was necessary to lengthen the cut-off to about 48 or 50 per cent., and the coal-consumption rose to 245 lbs. per mile. Taking the up and down

[1] *Revue générale des Chemins de Fer*, vol. xxxii, pt. ii (1909), p. 3.

journeys the coal-consumption for the round trip was 145 lbs., and adding the mean weight of the engine to the 275 tons of train, a total of 350 tons was obtained, which, on the basis of the Author's Table, would have required three times the coal-consumption which was actually recorded in the French trials. He did not agree with the doctrine that working on steep gradients must necessarily involve the abandonment of expansion, heavy back pressure and incomplete combustion. No doubt the adoption of three cylinders was a desirable thing if it did not add too much to the weight, but in that connection he would suggest that the Author's design was susceptible of improvement if the boiler-pressure were cut down and a suitable superheater installed, and if the cut-off in full gear were altered so as to give a maximum of about 55 per cent., which would be ample to secure a sufficient starting-torque, and would enable the reducing-valve, etc., to be put out of service. The Author's allowance of 10 lbs. per ton on the level for the resistance of rolling stock appeared rather high, and was probably a direct consequence of the adoption of light axle-loads and small wagons. A four-wheeled 20-ton wagon, with efficient oil-boxes, would run with a resistance of about 5½ lbs. per ton. A 40-ton wagon, with 15 to 16 tons of tare, would run with a resistance of about 3½ lbs. per ton. It seemed to him to be a fundamental error to limit the capacity of the rolling stock and the possible output of the road by the rate at which the brake-blocks could absorb work. If an engine were suitably designed for working with superheated steam it would control any train it could haul up the incline, by means of a suitably arranged counterpressure brake, without calling on the brake-blocks. It was necessary, however, that the brake-blocks should be there to absorb the total work developed in case of need, and in that case he thought it would be advisable to remove them from the tires, which were too costly to be worn away by excessive braking-action, and to apply them to brake-drums on the axle, as was usually done in the case of rack-railways. With respect to the Author's use of the term "high capacity," Mr. Twinberrow thought that "high capacity" was sometimes used as a synonym for "big," and that it was thought that if a wagon was big it must therefore be a high-capacity wagon. He wished to dissociate himself from that view, because he thought high capacity was intended to indicate a high ratio of earning-capacity to total cost of movement, which did not necessarily mean a large wagon. It was obvious that additions might be made to the load to be carried without necessitating anything like a proportionate addition to the weight of the structure to support that load.

Mr. Twinberrow.

Mr. Twinberrow. Taking the case of the Author's wagon, obviously the structure was a very small matter, but had the Author worked to British Standards his wheels and axle-boxes would have weighed 4 tons, his bogies with the brake-work would have weighed 2 tons 7 cwt. or thereabouts, and his draw-gear would have weighed 13 cwt.; he would thus have a total of 7 tons before he got any underframe or body at all. That indicated the fallacious character of comparisons which were drawn between different classes of rolling stock without taking into account those fundamental differences in the patterns of running-gear, and so on, which characterized them. If he might be permitted to make a reference to the designs with which his name was more or less connected, he would instance a low-sided wagon which had about 427 square feet of platform-area and which was provided with 43-inch wheels, axles, draw-gear, and other conditions suited for the 5-foot 6-inch Indian gauge. That wagon had a tare of about $13\frac{3}{4}$ tons. With a standard 33-inch wheel, and with axles, etc., made to suit the 4-foot $8\frac{1}{2}$-inch gauge, the tare would not exceed 12 tons, and the carrying-capacity would be fully 25 per cent. more than that of two of the Author's wagons, whilst the resistance per gross ton would be much less. The fact that the light axle-load had not eliminated axle-box troubles was, he thought, sufficient ground for suggesting that the problem might be attacked from another point of view. If the French railways experienced no difficulty in working their practically continuous gradients of 3·3 per cent. with four-wheeled wagons of 20 and bogie-wagons of 50 metric tons capacity, he did not see why the same methods should not enter into the policy of railways in other parts of the world. The Author's remarkable experience of the whipping of wagons might possibly be paralleled by other instances that had come to the notice of many railway-engineers, where the trussing had been hopelessly inadequate to carry the load; and, in some cases, long special wagons had been treated in a drastic manner by cutting 10 feet out of their length and joining them up again. But such things were always obvious from inspection of the drawings, and would never get into practice if rolling-stock engineers would recognize that success in producing progressive designs was to be achieved by reliance on the practical application of natural laws rather than by depending solely upon precedent, which precedent would never contain all the variables of the new problem under consideration.

Mr. Halpin. Mr. Druitt Halpin observed that the absence of sides in the Author's wagon might be merely an omission in the drawing, but there was one other point of the same kind on which he would like to ask a question. In the second coupled wheels of Figs. 7, Plate 3, there was a very peculiar axle. Whether that was an error in the drawing or whether it was put there for some particular purpose he would like to know, because it was not repeated in the trailing axle, nor was it in the leading axle. Mr. Bamber had also stated that on looking at the torque-diagrams he could see at once why so many draw-springs were broken. Such diagrams were often put in that longitudinal way, but it was a very unpleasant way of looking at them. If they were put in the usual way, as circular diagrams, the variation would not appear so startling, and the facts would be equally clear. One thing he thought Mr. Bamber had overlooked in his remark about the breaking of the springs, namely, that between the torque on the driving-axles and the draw-springs there was the inertia of the whole engine and tender and the inertia of the rolling stock. He thought that draw-springs broken in that way were largely the result of trying to do too much mechanical work with a very small part, and, for the sake of economy, adopting little spiral springs which perhaps might have the metal actually working up to the elastic limit. Formerly, when springs of sufficient weight and substance were used, like coach-springs which went right across and took the buffers as well, there was very little of that kind of trouble. Although the material then was not as good as that of to-day, the older springs were good enough for their work. They had the disadvantage that if a draw-bar were broken and got out through the headstock a coach came off the road. Mr. Halpin had often discussed with Mr. Fairlie the difficulty with the steam-pipes in connection with the Fairlie engine. Unless some special packing was used, it seemed to him the trouble would be much worse to-day than it was in the old days, on account of the higher pressures used and the greater difficulty in keeping the joint tight. Mr. Tritton had shown a photograph of a locomotive he had adopted, in which there were two distinct engines which were of as bad a design as possible, but were rendered very satisfactory in practice by combining them with one frame, giving all the flexibility that was wanted, and enabling small, cheap, light boilers to be used. The engines were perfectly distinct, so that if anything happened to one of them it could easily be taken out. The boilers were very much cheaper than the enormous boiler of the old Fairlie engine. One day, in 1872, he was travelling from London in a train with three other members of The Institution, two of whom were locomotive-manufacturers, and a conversation took place on the question of the Fairlie engine and the possibility of getting greater power. He actually sketched then and there an engine Mr. Halpin.

Mr. Halpin. exactly similar to that shown by Mr. Tritton's photographs. His companions admired it exceedingly, discussed all the various details, and thought it exceedingly good and efficient; and a couple of days afterwards they paid him the compliment of patenting it.[1] He quite agreed with Mr. Burge that it was much better to stick to the usual English way of designating gradients, 1 in 100, or whatever it might be, instead of as a percentage. The American system had the further disadvantage that for anything flatter than 1 in 100 decimals had to be used. With regard to the regulator-valve, although he had studied it carefully he could not make anything of it, and he hoped the Author would see his way to give more information about it and also a detailed drawing when the Paper was printed. He did not know that such a reducing-valve might be altogether a legitimate mechanical application, because a man always had the regulator in his hand or so close to his hand that practically nothing could happen. With regard to working on heavy gradients in Europe, he wondered why the Author had not referred to what was being done on the Continent, and had been done for the last 40 or 50 years, with the Le Chatelier brake. In Fig. 2, Plate 3, the Author gave mean pressures, allowing a drop of 15 lbs. per square inch between the boiler and the initial pressure in the cylinder. That was a liberal allowance, and with a suitable steam-pipe one would hope not to have more than the 15 lbs. drop; but the Author did not mention whether the curves were supposed to include back pressure and compression after the valve closed, and perhaps he would add that information. The Author spoke of a frictional loss of 10 per cent. between the cylinder and the rail. That was useful information as far as it went, but what was required to be known was not the loss between the cylinder and the rail but the loss between the cylinder and the tender drawbar, and Mr. Halpin did not think that would be represented by anything like so low a figure as 10 per cent. The engine and tender had to be looked upon as carriages, and in eight-coupled engines there was enormous friction of side rods owing to the fact that it was practically impossible to keep them mathematically true, and to keep the wheels true. Some American draw-bar experiments had shown about 40 per cent. He was bearing in mind, of course, that, as the Author said, the percentages varied a great deal with different circumstances, which was quite natural; but 10 per cent. must be regarded as applying strictly to the wheel. The Author also said that in his torque-diagrams he did not make any allowance for the inertia of

[1] British patent No. 1364, of 1872.

Mr. Halpin.

the parts on account of the low speed. The speed of the train might be relatively low, but as the wheels were relatively small, the speed of revolution, which was the governing factor, might be a matter of great consideration, and probably when the Author came to take his weights into account, even at the speeds he spoke of, he would find the torque-diagrams modified very considerably, particularly as the effect would be proportional to the square of the number of the revolutions. With regard to sanding, in a case such as that dealt with by the Author, sanding was a very important matter. The sand might be dry at starting, but after climbing 10,000 feet to 15,000 feet, although near to the equator, there would probably be a good deal of Scotch mist, and the sand would be very damp before it was used. It had always seemed to him that there was a better place for sand-boxes than where they were generally put. He remembered that in 1860, on the Cologne-Minden railway, there were some engines, built by Stephenson, which had perfectly square smoke-boxes—which, however, did not interfere with the sight in any way. If engines were made with square smoke-boxes and the sand-box—an independent cast-iron box—were put into the triangle and kept clear of the sides, the maximum heat would be obtained for keeping the sand dry in damp climates. In a recent number of *The Engineer* a leading article had appeared recommending wet sand. That, of course, was all very well if it could be obtained where it was wanted, but the advantage of dry sand, especially when used in connection with steam- and air-pressure brakes, was that very little was required, and that little was used exactly where it was wanted. One of the chief features in the engine shown by the Author was its three cylinders. Three-cylinder engines were very good for heavy work. The Great Central Railway had had them for some time for one of their large shunting-yards, and the North Eastern Railway had also some very good three-cylinder engines. About 25 years ago the late Mr. David Joy, who invented a number of highly efficient valve-gears, now largely used, discovered that by putting an ordinary link-motion on the two outer cranks of a three-cylinder engine with three cranks at 120°, it was possible off those two crank-motions to drive, without any additional cost, a floating lever which would give a correct valve-motion for the inside cylinder. No three-cylinder locomotives existed in those days except Mr. Webb's; they were coupled at right angles only on the high-pressure side, and the low-pressure was only steam-coupled, so that the system could not be applied there. The only place where its application was practicable was in steamers, where there were a good many triple-expansion engines, even then. But Mr. Joy could not get any shipowners to adopt it, Mr. Halpin. because they were afraid that if anything broke the ship might be lost, which, of course, was a very serious consideration, having regard to human life. That matter, however, would not have to be considered in connection with locomotives, and he thought the arrangement would make a much cheaper and simpler job. There was not too much room for two motions, and it was very difficult to get in a third. With regard to the unconsumed fuel spoken of by the Author, Mr. Thomas Whitelegg, the locomotive-engineer of the London, Tilbury and Southend Railway, had shown an engine a fortnight ago with an elegant device for getting rid of that difficulty. He coupled on a large needle plug, which went into the exhaust, varying as the links were lifted or lowered, and which acted automatically and kept the proper proportion all through the varying degrees of expansion.[1] With regard to the coach shown in Figs. 8, Plate 3, the Author stated that a girder was used in the side, below the side lights, and side pillars were taken up in some way or other from that girder. He thought that in making the whole side into a true girder there should be some way of getting over the difficulty with the diagonals, by running the girder in one piece right up to the top. As far as he could understand from the description, the bottom part of each pillar was merely fastened to an angle-bar forming the top of the girder. If there was anything like the flexibility in the coaches that there was in the wagons, there was sure to be a solution of continuity along that line which otherwise would be the neutral axis.

Mr. Burnett. Mr. R. H. BURNETT observed that he had not had any experience of working on such a gradient as that dealt with by the Author—one that might be taken as the limit of smooth-rail working, namely, 1 in 25—but as Locomotive Engineer of the Government Railways of New South Wales he had had experience of very long gradients of 1 in 30. The main lines of those railways passed over the Blue Mountains at elevations of 3,000 to 4,000 feet, and as the ruling gradient for several hundred miles was 1 in 40, the character of the line could be imagined. There were points raised in the Paper which seemed to him to be rather elementary in dealing with the construction of locomotives, and he would not like it to be supposed that they were subjects of difficulty at the present day: these points were, first, tank- versus tender-engines; secondly, estimating the tractive force of the locomotive; thirdly, varying torque; fourthly, three cylinders versus two; and lastly, articulated engines. With regard to tank-engines versus tender-engines, it

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[1] *Engineering*, vol. lxxxviii (1909), p. 882.

seemed to him to be the old question of the position of the water-stations. If the water-stations were near together, and the water was good, then it was most economical to work a very steep incline with a tank-engine, as it would save the extra dead load which a tender-engine necessarily involved. This was spoken of in the Paper as being 5 per cent., but he was quite sure it was impossible to have a tender for 5 per cent. of the total weight of the locomotive. It was therefore a question of water-stations. In New South Wales some of the water was so bad that one would not use it in a locomotive if it could be avoided, and therefore it was necessary to work the steep gradients with tender-engines, as sufficient water could not be carried on tank-engines. If suitable water could have been readily obtained, the heavy gradients would certainly have been worked with tank-engines. With regard to estimating the tractive force, he was quite sure that the late Mr. D. K. Clark's ordinary formula $\left(\frac{\text{Cylinder-diam.}^2 \times \text{stroke}}{\text{Diam. of driving-wheel}}\right)$ might safely be used, and three-quarters of the boiler-pressure taken. The tractive force at the draw-bar could be calculated in that way, with some margin to spare. It must be a very complicated locomotive indeed, absorbing an exceptional amount in friction, if 15 lbs. per ton of its own weight would not give an ample margin for the power lost by the friction of the locomotive itself. Another point raised in the Paper was with regard to the difficulty of cutting off steam early enough. In his opinion the way to get over that difficulty was the following. Given the load and the gradient, the power of the boiler required to work the train up the hill at any desired speed was first calculated. The next thing was to find the size of cylinders required to develop, with a given boiler-pressure, the necessary tractive force; and assuming, for example, that a pair of cylinders 16½ inches by 24 inches stroke were required for ordinary gradients and conditions of working, then the way to get over the expansion-difficulty was simply to use cylinders of 18 inches diameter, which enabled the cut-off to be made earlier in the stroke. It might be said that with such cylinders the boiler would be "pumped dry," but that was the business of the engine-driver; he must turn on the steam with the necessary caution when starting, and once he had started, he could notch up his engine and get the expansion necessary out of the larger diameter of cylinder. The cylinder-dimensions he had given by way of illustration had reference to engines used years ago, as it was some time since his connection with the New South Wales Government railways ceased, and engines had increased very much in size since then. Mr. Burnett.

Mr. Burnett. The next question was with regard to unequal torque. There were diagrams on the wall which seemed to show that a locomotive engine could not work at all. He was not criticizing the Author in any unfriendly spirit, but only mentioning points that he thought required explanation. The Author said that the torque of a two-cylinder engine varied considerably, and that loads must be limited by the minimum and not by the average torque. He thought it would be equally incorrect to say that a single-cylinder stationary engine ought not to work because it was twice on the dead centre in each revolution. But to help it over a fly-wheel was provided. The locomotive was not a stationary but a moving engine, and its own momentum rendered a fly-wheel unnecessary, as it helped itself over its dead centres. Besides, a loaded train was not started upon the maximum gradient: if it came to rest there it was likely to stop there indefinitely. Only an incompetent engine-driver would stop a heavy train on the steepest part of the line. The engine started on the level or on a gradient much less than the maximum, and thus had plenty of tractive power to start the train; and when once it was started the matter of the difference of torque did not enter into consideration at all, and there was no need to trouble about the fact that there was great variation of torque in the two-cylinder locomotive. The question was whether, in order to get over the theoretical objection, three cylinders should be used. He had been trained by a man well known in connection with the locomotive engine, Mr. Beyer, who was all for simplicity. Simplicity was everything in railway-working. To go in for the complexity of three cylinders if two would do, with all the extra valve-motion and other parts, was to go opposite to the direction of small maintenance-costs. Therefore his advice was to keep to the two-cylinder locomotive as long as possible. Then it was said that there was a great variation in the axle-load with tank-engines, due to the consumption of water and fuel. It amounted probably to a ton per axle at the most, and that did not matter much. It would be found that with an inclined cylinder such as that shown in Figs. 7, Plate 3, there would be a variation of load on the axles due to the inclined cylinder. With regard to articulated locomotives, he had no experience of their actual working, but had heard criticisms of the Fairlie engine and the steam-pipe. The steam-pipe no doubt was a difficulty, but what was worse in the design of the Fairlie engine was the peculiar boiler with the fire-box in the middle, and the barrels in either direction. In hot countries the driver could not get away from the fire on the one side, and the fireman was roasted on the other. It was not alone the articulated steam-pipe which was an objection in the

Fairlie engine, seeing that objections of that kind, if the main feature of the locomotive design was right, could be got over by a variety of contrivances such as had been referred to by a previous speaker, as for example strong spring-washers under the joint-bolts, and so on. He had lately had the opportunity of seeing at work the Garratt articulated engine: to that engine the objection of the steam-pipe no doubt applied, but the main feature and great advantage of the engine was its ordinary simple boiler. He thought the Garratt engine had come to stay, where heavy "collar-work" was required on steep gradients with sharp curves. Mr. Burnett.

The AUTHOR, in reply, observed that the remarks upon the Paper had gone so much into detail that he found some difficulty in dealing with them on general lines. With regard to the question of the whipping of wagons, he could only say that it was not at all an unknown thing in lines not connected with mountain working. He had found it in the Argentine. The wagons to which he referred in the Paper were working on heavy gradients, of 3-foot gauge, and were amply strong enough for their work; but at the same time they were not stiff enough. They were open wagons, working without any sides or ends, and they actually threw their loads of sugar-bags on to the track. The first speaker had remarked that a $2\frac{1}{2}$ or $2\frac{1}{4}$ ratio between the load and the tare should be satisfactory. That might be possible practice for working on ordinary gradients, but the man who tried to work a mountain-railway on that basis was likely to come to grief. Mr. Simson had referred to the wagons of the Antofagasta railway as having been put up 5 tons in loading, the wagons weighing 6·3 tons and actually carrying 25 tons. The great importance of that was one of the things to which he wished to call special attention. The coal-bill on mountain-railways was something like $\frac{1}{6}d.$ per ton-mile. An extra ton of weight added £4 per annum for every wagon to the coal-bill, absolutely unnecessarily. Then the earning-power of the wagon was very much reduced. The actual figure was about £78 per annum, taking 16 miles per day for the wagon. So with the engine: the question of three cylinders had to be considered in relation to the reduction which could be made in its tare, amounting to about 8 per cent., which meant a saving on coal of something like £80 a year; and adding 4 tons to an engine of that size meant a reduction of the earning-power of the engine by £860 a year. Mr. Waring had found that 12-ton wagons ran with only about 3 tons on an average: that might be so on low-gradient work, but in mountain working it was necessary to strive to get the wagon-load up to the last ounce that the engine could pull. Mr. Tritton considered that with a 50 per The Author.

The Author. cent. cut-off there would be shortness of steam; but the old Mogul engines on the Oroya railway would maintain steam at a speed of $12\frac{1}{2}$ miles per hour with just over 50 per cent. cut-off. The question of superheating did not affect the question of the relation between the two- and the three-cylinder engine—the advantage of one over the other. The particulars that had been given in regard to the five axles coupled he found very interesting, and they had a bearing, of course, upon what Mr. Simson had said with regard to the use of articulated engines, because of the curves. He had never gone beyond four axles coupled, but those could be handled perfectly well on sharp curves, and that experience was borne out by the fact that the five-axle coupled engine was working quite successfully on very sharp curves in Switzerland. On the Cerro de Pasco railway there was a curve of 200 feet radius, which was worked with four-wheel coupled engines, with a 14-foot fixed wheel-base; the curve was laid 1 inch slack, and there had never been a derailment yet. The gauge was 4 feet $8\frac{1}{2}$ inches. The diagrams of the working on the Lancashire and Yorkshire Railway answered many of the criticisms that had been put forward with regard to the diagrams in the Paper, and the way in which the loads clustered round the curve in *Fig. 10* was in his opinion remarkable. The diagram taken from 400 diagrams on the Lancashire and Yorkshire Railway showed that his system of working out the tractive force of an engine was certainly sound. Some remarks had been passed with regard to his giving the gradients in the American form, but in many cases they were given in both forms in the proof, and Mr. Burge's suggestion would be carried out before the Paper was printed. With regard to the question of the sides and ends of the wagon, wagons were worked whenever possible without sides and ends, and did a great deal of work in this state. Where sides and ends were required, a rough board bolted to stakes was dropped in. The term "mineral-wagon" was perhaps misleading, because "mineral-wagon" in England meant a wagon largely used for the transport of coal. The load on the line referred to, however, was copper ore and copper ingots; 90 per cent. of the down traffic was of this kind, and the wagon would take 20 tons without the slightest trouble. It also took machinery to the mines, and two wagons coupled together would take 35 tons of rails, or sleepers and other timber. A question which seemed to be rather misunderstood was the impossibility of overtrussing. Undertrussing on a wagon would not stop whipping unless the undertruss was of such a form that it could take compressive stress. The usual round bar was quite useless for checking movement in the upward direction, The Author

and the only way was to stiffen the sections to the necessary extent. The lubrication-troubles were not due in any way to friction, but entirely to the heating of the wheels under the severe braking, on 1-in-25 gradients, down 90 miles of line. The problem of descending inclines was a much more difficult one to solve than that of ascending. The question of large wheels had been raised by more than one speaker. Large wheels meant an increase in tare, and he had tried to show that tare was one of the most important features to be kept in mind. He did not for one moment urge that Fairlie engines had been abandoned because of steam-pipe joints; he simply raised that as one objection. There were objections on the score of cost, maintenance, and so on, and where a simple engine could be used he quite agreed it should be. With regard to the question of resistance, the 10 lbs. resistance included everything—atmospheric resistance, friction of rails and journals, etc.—and he did not think it was excessive as a rough figure. British Standards for working such traffic as he referred to in the Paper were quite out of the question. Starting with 7 tons and working up to get in standard details, one would get a wagon that weighed more than the wagon referred to, and the annual cost involved would be very heavy. Mr. Twinberrow had rather taken him to task for not referring to individual instances of what had been done on the Continent. He had expressly stated that he objected altogether to that system of dealing with the question; he had tried to give generalities which could be applied to the Continent or anywhere else where similar conditions obtained. He had cited the cases not for their value in solving the problem, but to illustrate the Paper. With regard to the carriage shown, it was not possible to make the side into a girder for its entire depth. The ordinary custom was not to use the side at all except for very long coaches. He had advocated that, for quite small coaches, with a 44-foot body, the side should be turned into a girder, thus reducing the weight considerably. The one thing he wanted was to reduce weight. With regard to the regulator-valve, what was shown was simply the preliminary design of the engine; the regulator-valve as made did not follow the details shown. The design was nothing more than an ordinary reducing-valve in which the spring was coupled to the reversing-lever in such a fashion that it could be varied: it was absolutely necessary in an engine that was over-cylindered, on mountain work, because the adhesion could not be increased up to the cylinder-power, and as the adhesion had to be kept down very low the pressure of steam must be kept low, and that was

The Author. accomplished by means of the valve. It was not necessary in English shunting-engines, as they had very heavy axle-loads. The design of tank- versus tender-engines was, of course, a question of water, but he maintained that, starting with a given axle-load, a given weight of water, and a given weight of coal, it was quite possible to design tender-engines weighing only 5 per cent. more than corresponding tank-engines, and he had done it himself more than once. As a matter of fact much more coal and water was generally put in. Considerable difference of opinion had been expressed as to the point of cut-off at which steam could be continuously maintained. Some members seemed to consider the 50-per cent. cut-off assumed as rather high, even for low speeds; whilst Mr. Burnett's 75 per cent. of the boiler-pressure (taken as mean effective pressure) implied a 65-per cent. cut-off. There could be little doubt that very few engines indeed could maintain steam under such circumstances. The suggested use of larger cylinders to get over expansion-difficulties neglected the factor of uneven torque of two-cylinder engines with an early cut-off; and at low speeds, when climbing heavy gradients, the inertia of the engine was useless for overcoming this, as was pointed out in the Paper and confirmed by the figures given by Mr. Britton. There was no printer's error in Fig. 1, Plate 3, which showed the relative loads hauled by the same engine up different gradients. Tare and total weight remaining at the same ratio, the paying load and the train load (engine and tender being eliminated) would follow the same curve. The coal-consumption diagram (Fig. 5) was intended, as explained in the Paper, for estimating consumption in general working (including such items as lighting-up, blowing-down, standing, etc.) for heavily loaded mountain locomotives, working at low rates of expansion. To use this Table for comparison with results of short special trials, with compound locomotives fitted with superheaters, etc., was of course only provocative of confusion. It was nevertheless evident that Mr. Twinberrow had misread the diagram (Fig. 5). As explained on pp. 81 and 82, the average gradient in the diagram was given in terms of the entire journey. An average gradient of 1 in 30 over an up and down journey meant an actual ascending gradient of 1 in 15. Mr. Twinberrow had taken for the coal-consumption an average of the up and down trips, but had read the gradient of the up journey only. The consumption he mentioned, of three times 245 lbs. per mile, would take a 350-ton (gross) train up a gradient of about 1 in 17, according to the diagram. The comparison of cylinder-volumes alone as a basis of fixing a heating-surface was unlikely to be made a practical question. Piston-speed, The Author.

boiler-pressure, and point of cut-off at which steam must be maintained, were all equally as important as the cylinder-volume. The term "high capacity," as used in the Paper, referred to the capacity of the wagons, not to their ratio of load to tare. A wagon of standard gauge, having 427 square feet of platform-area, carrying 50 tons, and only weighing 12 tons, was certainly something outside the experience of the Author. But even this phenomenally light vehicle would have an axle-load of 15½ tons, and its safe speed descending 4 per cent. gradients would be only about 6½ miles per hour; whereas the wagon illustrated in the Paper could safely travel down the same gradient at about 15 miles per hour. For down-hill working the multiplication of axles was very desirable, and even low tare should be sacrificed to obtain it; but for ratio of tare to load, the Antofagasta wagon, with a ratio of 6·3 to 25, or 20 per cent. of the total load, would be very hard to beat.

Correspondence.

Mr. Abt.

Mr. ROMAN ABT, of Lucerne, observed that the question of what form of locomotive was best suited for use on mountain-railways had already been dealt with innumerable times. A gradual understanding of the various points had come about, but unanimity was not easily attained. The reasons for this were not only personal preferences and a liking for the productions of one's own brain, but, as could easily be understood, special circumstances arose, not the least of these being climatic conditions. For example, a maximum gradient of 4 per cent. (1 in 25) for ordinary adhesion-working would hardly be specified for a European country. The great mountain-railways of Europe rightly confined themselves to a gradient of about 2·5 per cent. (1 in 40), and only in exceptional circumstances did they venture on one of 3 per cent. (1 in 33·3). Also a coefficient of adhesion of 1 : 5·6 would certainly be adopted, and only under exceptional circumstances a more favourable one; moreover, the calculations would be based on a ratio of 1:7. This assumption was essential, on account of the changes of weather taking place not only day by day, but very often hour by hour, and during a single train-journey. The reasons advanced to show that three-cylinder locomotives gave greater adhesion than two-cylinder locomotives between wheel and rail did not seem sufficient. Specialists in electric traction often advanced, as the particular advantage of their method, the argument that it enabled locomotives