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Some Debatable Factors in
Locomotive Design and Practice.

BY

J. F. GAIRNS, Member, London.

With an abstract of the discussion upon the Paper.

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Some Debatable Factors in Locomotive Design and Practice.

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In all branches of engineering, practice and experience count for much more than theoretical and "paper" investigation and criticism; but in the locomotive world this fact is perhaps more strongly accentuated than in any other division. Indeed, there is considerable ground for arguing that the locomotive engineer has to develop primarily by experiment and trial, calculation and theory being secondary factors, and one may almost describe locomotive engineering as a "rule-of-thumb science." That is, it is "scientific," in that the locomotive engineer has to study his work and to investigate its problems on similar lines to those adopted in other branches of engineering; but as theory and calculation can never satisfy all the peculiar and extremely variable and in some respects unknown conditions which apply to practical railway operation, they must always be interpreted, and modified if need be, in terms of experience and trial.

Consequently, in a study of this character, it is necessary to consider throughout what is done and how it is done, rather than to speculate as to what might or ought to be done, or even to advocate or suggest that particular principles of design are better than others. Moreover, every locomotive engineer is, in a sense, a law unto himself, except as he is governed by methods and practices already in vogue on his line; while the fact that no two railways include exactly the same conditions and requirements further accounts for the insular character of individual locomotive practice. This argument that each railway must have its own methods is perhaps carried too far, for it is difficult to see why, in many

cases, considerations which apply to one line should not apply equally to certain other lines, if not generally. But facts must be taken as they are, and this suggestion of insularity accepted as one of the explanations of variations of practice which cannot be altogether appreciated on other grounds.

ENSEMBLE FACTORS.

Before dealing with individual features of practice, it will be desirable to consider matters affecting locomotive design as a whole, for which the definition of "ensemble factors" may suitably be adopted. This embraces matters governing virtually the whole design of a locomotive, or which affect several elements, as distinct from those applying only to component parts. In this category may be placed: (a) class of work for which a locomotive is designed; (b) selection of wheel type; (c) choice of controlling dimensions; and (d) adoption of special methods of operation, such as compounding, and the use of superheated steam.

A few remarks may be made in reference to each of these headings, though any or all of them would provide material for extensive and detailed study on their own account.

CLASS OF WORK.

There are a few railways where "universal" machines are most useful. On the Great North of Scotland, for example, 4-4-0 engines only are used, both for passenger and goods traffic, while on the Furness, Cambrian, Midland, and South Western Junction, and other smaller lines the engines are used more or less as convenient. But on larger railways it is necessary to classify the locomotive power, still, however, with a considerable degree of adaptability for general use. It is for the latter reason that the "single-driver" has gone out of favour rather than that it is not able to deal with present requirements. Singles always have done magnificent work, and there are many express duties which they can still perform with thorough satisfaction. But a "single" on a goods or mineral train—even the famous Great Northern 8-ft. singles have been known to work coal trains—is inconceivable as a practicable proposition, while when relegated to secondary or stopping trains they are at once more or less in difficulties. It is true that they will often manage very well under such conditions, especially if the load is not excessive, but they cannot be depended upon therefor, and we have seen the virtual disappearance of the "single."

The ordinary four-coupled engine has, however, a wider sphere of usefulness. It is better situated for miscellaneous traffic. It has sufficient tractive power for load hauling, and it can travel fast. Therefore, although designed for fast passenger traffic, with four coupled driving wheels, it is also able to deal with reasonable requirements on other duties. Perhaps the most allround useful machines are the mixed-traffic classes, with 5ft. 8in. or 6ft. coupled wheels, as they can usually travel as fast as required on ordinary services; they can, if need be, work even through special expresses very creditably, and their tractive power is sufficient for many of the goods trains.

With four or six wheels coupled, however, even the standard engine can do very well on other duties, so that many railways do not provide special engines for miscellaneous traffic, and the question becomes mainly one of suitability for the heaviest and principal duties, adaptability for various requirements being necessarily covered to a reasonable extent.

Here two main factors are involved: (1) the controlling characteristics of the railway traffic; and (2) whether the design is to meet average or special requirements. These aspects may be considered in detail as they cover much ground.

The engineering department has considerable influence here, while the traffic department is accountable in other ways. It may be that the main routes are suitable for large engines having the maximum permissible weights on the axles and that the permanent way will take heavy trains running at high speeds and hauled by big locomotives. The use of the big engines may not, however, be practical, by reason of the fact that the traffic working requires alternative routes to be followed by important trains, so that if the large locomotives cannot go almost anywhere there is little ground for their adoption. The locomotive engineer then has to do the best he can, and develop only within reasonable limits. Given, however, a system where the main lines can be operated fairly distinctly from other routes, and special engines confined hereto, or a line where virtually all possible routes are open to the big engines, and that the engineering side is up to the standard required by the locomotive department, then the controlling factors are the prevailing gradients, curves, loads, schedules and governing weather conditions.

It is a moot question even now whether the best policy is to aim at ascending difficult grades fast, or to go up

moderately well and compensate therefor on easier sections. It is generally realised that on a long grade an ascent at 40 miles an hour average instead of 50 miles an hour, involves greater loss of time than a descent at 70 instead of 60 on the other side will compensate for. At the same time it may be good policy to climb a grade at moderate speeds and make up for it by fast running beyond.

For example, one often hears the charge made that on the Great Northern the engines make too much of the climb from King's Cross to Potters Bar, but it is doubtful whether any one can seriously find fault with the habitual averages of 63 or 64 miles an hour from Potters Bar to Peterborough, unless it be those who object on principle to speeds of 75 or 80 miles an hour as frequently made through Hitchen and adjacent stations. Similarly on the South Eastern and Chatham Railway heavy trains do not usually climb to Knockholt from St. John's in very remarkable fashion, but they run very creditably beyond and yet rarely exceed 70 as a maximum rate. These are instances of policy rather than evidences of engine capability, and the same can be said of any other locations where similar running characteristics are noted and sometimes quoted as adverse arguments.

On the whole, however, it appears best to advocate that engines should be able to maintain good speeds up all but the most severe grades, if only because fast descents are not then depended upon for time-keeping. That is, fast running *may* be made on easier sections, but must not be the inevitable and unavoidable corollary to relatively slow gradient ascents. The length of a grade is, perhaps, more important than its severity. A short but very difficult section puts a heavy strain on the steaming capacity of an engine, but a longer, though easier grade, may be more liable to run the engine "out of breath."

Curves, traffic hindrances, and other factors are also accountable in a larger degree than is usually realised for the capabilities demanded of the engine. On the London, Tilbury and Southend section of the Midland Railway, for instance, an over-all average of 45 miles an hour calls for about 55 miles an hour average over the major portion of the journey, owing to the fact that the first few miles from London must be taken slowly. On the Brighton system, too, high speed is not possible until Croydon is passed, and the same may be said of several other lines out of London. On the other hand the London and North Western, Great Northern, and especially the Great Western can "begin to-

run " immediately on starting from the terminus, though in the case of the two former gradients are not favourable for some distance. On the South Eastern and Chatham traffic complications constitute very real hindrances. In fact, while it may be a relatively simple matter to maintain 55 miles an hour average where the running is straightforward, equal demands may be placed upon engines which average 45 on a corresponding run punctuated by slacks for curves and junctions, speed restrictions, possible and probable signal delays and unfavourable grades. In many cases, too, slacks are imposed at the foot of long grades, thus nullifying the value of approaching descents.

This phase of our subject, while not strictly a discussion of locomotive design, has been dealt with somewhat lengthily because it sets forth many of the factors which govern practice and design, but having given it due attention, remaining matters can be reviewed without many of the explanatory remarks which would otherwise be necessary.

As regards the selection of design and dimensions to meet average or maximum demands, there is a wide diversity of opinion and practice. There is much to be said for the argument that it is sufficient to meet average requirements, assisting engines being used in special cases, or a few special engines being provided therefor. The standard demands on many railways appear, however, to call for engines capable of any maximum work, owing to the increasing number of heavy trains to be operated on most of the great lines. Such engines are more expensive to construct, the permanent way must be built and maintained up to them, and they may be rather more costly in maintenance themselves; but they represent the price of progress and will usually offer advantages on other duties in that as everything they do, difficult or easy, is well within their capability, they can show good all-round efficiency. If smaller engines are used systematically, then it becomes necessary on occasions to "thrash" them or press them unduly and they are not relieved in a corresponding degree on medium duties. Here again policy is the governing factor.

SELECTION OF WHEEL TYPE.

In some respects this section involves the application of remarks already made. As previously indicated, the "single-driver" is virtually "out of court" as a practicable proposition nowadays. As regards the use of 4-4-0, 4-4-2 or 4-6-0 locomotives; however, we are on highly controversial ground.

That the 4-4-0 type offers considerable possibilities has been shown by the advanced practice of many railways, but it appears to have nearly reached its limits. Bigger boilers require at least another pair of wheels to carry the engine, and the question is, shall the additional wheels be carrying or coupled? In some degree, however, this question has settled itself as judged on the basis of practice, whatever may be its theoretical and controversial aspects. On the Great Northern, for example, the use of Wootton fireboxes has forced the engines to be "Atlantics," and the same applies to corresponding engines on the Brighton line. If Mr. Gresley or Mr. Billinton decide to develop the type into 4-6-0 it is almost inevitable that the Wootton firebox will not be used unless the corresponding "Pacific" type is adopted, which is decidedly improbable. Mr. Reid's North British "Atlantics" are also, in a lesser degree, restricted by their firebox dimensions. On the Great Central a corresponding design is already at work in a six-coupled form, and the North Eastern has its 4-6-0 engines, though they differ considerably. On the Great Western we have already seen the conversion of "Atlantics" into 4-6-0's.

There appears little justification for the "Atlantic" type, unless adopted for special reasons, and the fact that it restricts the adhesion weight and the number of coupled wheels seems to prejudice its value as regards large steam generative capacity in proportion to other factors. In view of what can be done with six coupled wheels, and the fact that all objections to "tied legs" have been summarily disposed of, the 4-6-0 type is able to hold its own against the "Atlantic" in any field where ten-wheeled engines can be introduced in any form. The 2-6-2 is a type which offers advantages, but is unknown in this country and has not made much headway elsewhere, so that the fact that it gives the freedom of firebox design offered by the "Atlantic" type at the expense of a pony truck instead of a bogey hardly seems to possess great value. For general traffic the "pony" truck appears satisfactory, as witness the 2-6-0 designs on the Great Western, Great Northern, and to be expected shortly on the Brighton line, while the 2-6-0 and 2-8-0 designs for goods and mineral traffic on the Great Western, and in the later form on other lines, indicate the desirability of using a pair of leading wheels even for slow heavy traffic.

As regards tank engines the governing conditions are: (1) character of traffic; (2) steaming capacity; and (3) allowable dimensions. With heavy bogey set trains, and

where a degree of main line working is involved, fairly large engines become a necessity. The 4-4-2 type is a good one when really big locomotives can be used, as they become the equivalent to a 4-4-0 main line engine, express or mixed traffic ; but for ordinary duties the 0-4-4 or 2-4-2 is more suitable. The 0-6-2 is the best six-coupled type, unless special versions—2-6-2, 0-6-4, 4-6-2 or 4-6-4—become desirable to meet special conditions. Incidentally the writer would express his disagreement with those who speak of 4-4-2, 4-6-2 or 4-6-4 engines as “Atlantic,” “Pacific” or “Baltic” tanks. These types named are associated with particular engine wheel arrangements, but as the tank classes suggested are equivalent to 4-4-0 or 4-6-0 engines with two or four wheels supporting the bunker which replaces the tender, they cannot in any sense be described as equivalents. Indeed, by far the better course is to use the numerical classification only, with the affix T or the word tank, reserving the special names for the main line engines, if employed at all.

CHOICE OF CONTROLLING DIMENSIONS.

Having settled the type which can be used in view of engineering restrictions and other considerations, the principal factors involved are : (1) the total weight ; (2) adhesion weight ; (3) coupled wheel base ; (4) total wheel base ; (5) coupled wheel diameter ; (6) cylinder dimensions ; and (7) boiler capacity. These are stated in the order in which they occur to the writer as of importance. The total weight, as governed by the engineering department, controls the degree to which a design can be developed. Thus we find 4-6-0 engines varying from about 64 tons to nearly 80 tons, so that locomotives of the same type may include important differences. The heavier weights are adopted where requirements are severe and the locomotive engineer has a relatively free hand. The lighter weights apply, for example, to the Great Eastern, where Mr. Holden had to keep strictly within limits. This factor is therefore the first controlling influence, as it governs everything that follows.

Adhesion weight enters into the question partly from the civil engineer's point of view, in consequence of permanent way and other considerations, but mainly as regards the degree to which the engine weight is to be utilised for tractive effort. Severe requirements may necessitate a larger proportion of the engine weight being utilised for adhesion, in which case the 0-6-0, 0-8-0, 2-6-0, 4-6-0, or

2-8-0 type is selected. In more ordinary cases the 4-4-0 type, or the 4-4-2, with its superior boiler capacity, may be suitably adopted. In other instances choice is made, say, of the 4-6-0 in preference to the 4-4-2 type in order to utilise adhesion weight effectively as a general policy rather than from actual necessity.

Coupled wheelbase is a controlling factor in as far as it may be of importance to keep the rigid wheelbase as short as possible, but in British practice does not, as a rule, enter much into the question. Total wheelbase may also be dismissed in the same way. Both are elements affecting the choice of type and dimensions in view of the limitations imposed by the engineering department and other considerations.

Coupled wheel diameter is, however, a matter to be decided by average requirements and conditions. If heavy pulling predominates, then a small wheel is desirable. For fast running over easy grades a fairly big wheel can be used. In practice a compromise is usually made. As far as actual speed capacity is concerned engines of all classes seem to be able to do nearly the same. Four-coupled engines have not travelled any faster than six-coupled locomotives have done, and 5ft. 9in. engines have and do realise speeds equal with those of 7ft. 6in. engines. Indeed, goods and tank engines with quite small wheels have frequently travelled considerably over 60 or even 70 miles an hour. But speaking generally, one may specify the working speed limits, apart from starting and heavy grade minimum rates, as :

6ft. 3in. to 7ft. 3in. wheels, 40 to 75 miles an hour.

5ft. 6in. to 6ft. 3in. wheels, 40 to 65 miles an hour.

4ft. 3in. to 5ft. 6in. wheels, 20 to 50 miles an hour.

The engines can do faster work than specified, but the conditions then become abnormal. For one thing they are going beyond what they are intended for, the motion is working faster than is contemplated in their design and construction, and they may be using steam at a more rapid rate than their boilers are prepared for.

The wheel diameter is selected in accordance with prevailing requirements, but may be considered to be approximately settled by practice as :

For high speed express traffic, involving only moderate difficulties, 6ft. 6in. or 6ft. 9in.

For general passenger traffic (including ordinary tank engines) and over more difficult grades, 5ft. 6in. or 5ft. 9in.

For general and goods traffic, 4ft. 6in. to 5ft.

These appear to satisfy all conditions, whether four, six, or eight-coupled, according to the class of work involved.

In the case of cylinder dimensions other factors are presented, and it is not so easy to argue on the basis of practice. Given a boiler that would supply all demands the controlling elements are :

- (1) Whether large cylinder capacity is necessitated by difficult sections of road ;
- (2) Whether a small cylinder operating frequently at a fairly late cut-off or a larger cylinder cutting-off early is contemplated as an average condition ;
- (3) The due utilisation of the boiler power so as to take full advantage of the possibilities afforded by a considerable adhesive weight.

Allowable dimensions also enter into the question in these days of very big engines, but is rather a complicating factor which does not always apply than a governing consideration affecting general remarks. Many locomotives of 20 or 30 years ago seem to have been specially designed so as to utilise steam by efficient cylinder work, and large and unusual cylinder dimensions were sometimes incorporated. But nowadays it is more usual to work up to the boiler power, or well in that direction, and less attention is paid to obtaining special results in the cylinders by early cut-off and so on. This remark may appear somewhat paradoxical, but a little explanation will make clear what is meant, even if not expressed very clearly. The point is that cylinder dimensions have, if anything, decreased, in view of those which used to be adopted, and in many cases are altogether out of proportion to the boiler power on the basis of the ratios usual 20 or 30 years ago. Therefore, it is plainly contemplated that more steam shall be used in the cylinders—that is, in fact, the necessary corollary to harder work—early cut-offs and niceties of the steam cycle not being aimed at to the same extent. That the work shall be done well and efficiently is of more importance than ideal indicator diagrams, especially if the result desired is attained with what is really good efficiency, though it requires the correlation of all factors instead of concentrating upon the cylinder conditions.

Moreover, when requirements were not so heavy it was possible to use desired cylinder dimensions more freely, as whatever duties within reason were imposed the engine could deal therewith at least fairly efficiently, whereas all-round capability counts for more than special performances

and "fancy" diagrams under certain conditions, combined with relative incapacity in other circumstances.

A stroke of 26 inches represents usual practice and may be accepted as most satisfactory for that reason. Shorter strokes for modern engines (Great Northern "Atlantics") and longer strokes (Great Eastern 4-6-0's and Great Western 4-6-0 and 4-4-0 engines) are exceptional. Similarly a diameter of or equivalent to about 19 or 19½ inches (saturated steam) satisfies most requirements. There is no object in adopting larger dimensions unless the power which can be developed can be utilised on the basis of adhesion. On the other hand small cylinders prejudice the utilisation of steam capacity. The dimensions indicated must, therefore, be adopted as a compromise under present conditions. In America and elsewhere larger cylinders are used, but the ratio to boiler power is about the same.

All these factors culminate in their effect upon boiler capacity, and are in turn governed thereby. Whatever the relative importance of each the boiler must be able to supply requirements, whether for long spells of heavy steam use, as on lengthy grades, or under steady and more or less uniform conditions. The cylinders must not be too large for the boiler, and the boiler must not be wasting steam because the engine cannot utilise it. There is, however, much to be said for the adoption of a boiler which provides a considerable reserve of steam; but this must be interpreted in reason, and, speaking generally, the opinion may be expressed that the engine should be *able* to utilise all the steam that *can* be supplied, so that in practice neither engine nor boiler need be worked in the extravagant fashion inevitable when pressed to limits.

As regards other ensemble factors, such as compounding and superheating, a few remarks will be sufficient, as each of these affords sufficient subject matter for a lengthy dissertation.

Compounding may, it is thought, be dismissed as representing one of the applications of the principle of endeavouring to realise special steam efficiency in the cylinders. It gave very satisfactory results *when engines were working substantially as intended*; but at the expense of "elasticity." With heavier and more varied requirements such niceties of design revealed their weaknesses rather too forcibly, and the compounds of the day had to go. Nowadays there is little opportunity for a compound to come to the fore unless it can satisfy all requirements, instead of concentrating its advantages upon specific elements at the

expense of general usefulness. The Webb compounds, for example, did admirably while their work was that for which they were designed. But they could not keep pace with heavier demands in the same way as the ordinary simple engine. The latter gave greater "elasticity" as compared with special designs involving features which could be either advantageous or restrictive, according to the class of work undertaken. The modern compounds of the Midland, Great Central and North Eastern companies do not militate against this explanation of the decadence of the compound. For one thing, in each case all the engines are kept fairly closely to the work for which they were designed, and they are, moreover, still working on the duties in view of which they were designed. Therefore, they are not subject to the factors which governed the situation on the London and North Western Railway, where requirements soon outclassed the engines. Moreover, it is thought that on the three railways mentioned the fact that the respective designs are in themselves good and still up-to-date accounts more for their favourable reputations than their special characteristics as compounds.

Superheating is being used nearly all over the Kingdom. It has undoubtedly come to stay, and it is thought the high degree superheater will continue to virtually and eventually entirely monopolise the field. This is not due directly to the special merits of the Schmidt, or, indeed, any other design of superheater, but it is attributable to the fact that superheating is scientific and practical when once its peculiar problems are investigated as they have been in recent years. Indeed, one may almost say that the use of saturated steam is unscientific, owing to the fact that one is then using an unstable gas which is only just formed from its liquid equivalent and which is liable to condensation on the slightest provocation.

Superheated steam is, however, a stable gas, and can be used as a gas without consideration of conflicting elements, such as liability to condensation, etc., as is the case with saturated steam. It has, however, introduced special conditions, due to its high temperature, dryness and so on, but once the new problems created are solved there is little more to be said, except that, independently of any conditions or considerations which may perhaps tend to bias, in the opinion of the writer high degree superheating has come to stay mainly because it is scientific and has been proved to be practical and satisfactory in ordinary everyday miscellaneous traffic working.

It is not, however, sufficiently realised even yet that the special feature which renders high degree superheating so satisfactory is the increase of volume. The steam has no miraculous working capabilities given to it, and its peculiar attributes are obtained strictly in accordance with the economics of fuel consumption. But by using larger cylinders and lowering the steam pressure important advantages are realised, and by the correlation of fuel consumption, steam pressures and cylinder and boiler dimensions, substantial economies in fuel and water consumption are realised or the working capacity of the engine is substantially increased.

As regards maintenance there appears to be little, if anything, to be said against the high degree superheater. In view of the results obtained the maintenance aspect is negligible, and many of the special factors, such as mechanical lubricators, the virtually compulsory use of piston valves, etc., are not peculiar to superheater engines, though they may be essential to them. The influence of the superheater upon locomotive design is actually confined to choice of cylinder dimensions, the use of slide or piston valves, selection of pressure of steam, and the construction, and to a slight degree the dimensions, of the boiler.

Brief reference may now be made to individual elements of the locomotive engine, and as so much time has been occupied already the writer purposes to confine attention to a few items only, as follows :

1. Boilers, fireboxes, and smokeboxes.
2. Cylinders and valves.
3. Valve gears.

In each case reference will necessarily be brief, and more of a review character than a dissertation upon engineering and technical considerations.

It is doubtful whether any other boiler in use is subjected to such peculiar and arduous conditions of work as is the case with the locomotive engine. Here, as part of a travelling power plant, restricted in all sorts of ways as to dimensions and even to some extent in design, it is required to place a boiler which must be able to supply steam "fast and furious" for considerable periods, and in quantities such that under stationary conditions very much more liberal dimensions would be adopted. At the same time it must give reasonable efficiency as regards fuel consumption, and yet the conditions are so continually and widely varying that one sometimes wonders how its work can be adapted to the various stages of a journey and to different duties in the

way it is. The personal element of driver and fireman is all-important, these two men having only experience to guide them as to how they work the engine, and how they correlate the use of steam by the driver and the supply of steam by the fireman. The boiler must satisfy all conditions, yet it must be simple in construction, relatively easy to remedy small defects, not liable to serious ones.

The standard multitubular design with approximately rectangular firebox, tubulous barrel and smokebox constituting the draught chamber has become virtually universal as "the survival of the fittest." It is hardly possible to mention an alternative which has realised even appreciable success in the long run, whatever may have been the case during the test period and until the defects began to manifest themselves. Other tubular and tubulous designs and combinations thereof have none of them continued, despite numerous experimental boilers, and on the authority of Mr. Hughes we gather that the theoretically ideal corrugated circular firebox presents in the course of time several decidedly undesirable features. It may be that for light duties many of these designs are satisfactory, but for real hard work we have to come back to the standard type, the only alternative relating to the selection of :

1. Round-roofed, raised, Belpaire, or wide fireboxes ;
2. Direct staying, sling stays or crown or girder stays ;
3. Relative dimensions ;
4. Numbers, sizes and spacing of tubes ;
5. Parallel or taper barrels ; and
6. Extended or medium length smokeboxes.

There are, of course, many minor and detail factors with which it is unnecessary to deal, partly in view of the lengthy consideration which would be entailed, but mainly because Mr. Bennett dealt so comprehensively with practical aspects last month, that the writer would unavoidably be endeavouring to cover much of the same ground in a considerably less satisfactory manner.

One of the principal deterring influences against the introduction of the Belpaire firebox was the difficulty of making the somewhat complicated pressed-out throat plates necessitated thereby. This is no longer a problem, but in view of the fact that the Belpaire design gives so much steam space above the firebox crown and is moreover most suitable for direct staying, it is rather difficult to understand why the round-roofed firebox still maintains its favour to the extent it does. Hardly an instance can be cited where

the round-roof firebox has been reverted to after the Belpaire type has become standard, yet on several lines there appears as strong an initial prejudice against the Belpaire firebox as there is steady support of that design on other railways. "Why this thushness" it is almost impossible to explain, except on the score of practice and preference. The round-roof outer firebox may be stronger by virtue of its circular form, but the increasing tendency to use stay bars and special sling stays attached to the roof plates seems to the writer to indicate that this is not emphasized. A large proportion of the "modern" locomotives now in use have Belpaire fireboxes; but there are sufficient equally notable designs, including round-roofed fireboxes, to qualify any definite arguments as to the alleged superiority of the Belpaire design. Personally, the writer would always advocate the Belpaire design as far as he is qualified to do so; but it is to be presumed that Mr. Raven on the North Eastern, the late Mr. Dugald Drummond on the London and South Western, Mr. McIntosh on the Caledonian, the late Mr. George Whale and other engineers knew or know their own business in using the round-roofed design.

The raised firebox may be dismissed as belonging to an era of practice now virtually closed, but the wide or "Wootton" firebox raises an interesting problem. Its introduction arose in consequence of the necessity for large grate area in order to burn slack coal, but in this country it is employed mainly with a view to securing a short firebox at the expense of extra width transversely. Mechanically, it is understood that the design is as satisfactory as the round-roofed and Belpaire types; but it can only be used where it can be placed over carrying wheels and unrestricted as regards width. This hampers its adoption, and it is, therefore, hardly likely to be used to any great extent. It may be continued as long as the Great Northern and Brighton companies retain "Atlantics" as standard engines; but otherwise it is doubtful whether any other than the "Pacific" or "Prairie" types will save it from disappearing entirely here, whatever its merits may be. A grate only 6ft. long may be easier to fire in some respects than one from 7 to 9 feet long; but that is, after all, only one consideration.

It will be sufficient to mention the Drummond firebox water tubes. Their employment appears highly commendable, and they are stated to be satisfactory in maintenance; but so far they are virtually confined to Drummond practice.

Methods of staying need not be referred to further and it is hardly necessary to say much more concerning firebox

dimensions, unless an extended study is undertaken. Mention, must, however, be made of the alternative practices of using narrow and deep or wide and thin fires. Special tests on the London and North Western Railway a few years ago will be remembered, the resulting conclusions being that the shallow fire "Experiments" gave better fuel efficiency than the deep fire "Precursors," but called for greater skill in firing. In practice, however, the general principle appears to be of compromise, and a reasonably deep fire in a firebox as wide as practicable, without special efforts to increase its width, serves for most designs.

Tube spacing and dimensions also need not be touched upon except to state that there is less tendency to crowd a lot of small tubes into the barrel than was shown by some of the engines of twenty years ago or so, and practice shows approximate uniformity in this respect. The taper barrel is peculiar to the Great Western Railway, and no one can deny that Mr. Churchward has produced a wonderfully satisfactory boiler by adopting this feature in combination with a very big Belpaire firebox and the non-use of a steam dome. Yet beyond slight use of the taper design on the Great Southern and Western Railway of Ireland, Mr. Churchward's practice continues to be isolated, though, as far as the writer is aware, there are no patent rights to prevent anyone else following on the same lines. The taper boiler gives extra steam space just where it is most valuable, and the practical aspects of manufacture do not appear to be prohibitive or restrictive.

The design of "front ends," to use an expressive Americanism, is a big subject on its own account. The superheater has a little to do with the length of the smokebox, but not much in the case of firetube designs, and, speaking generally, the length is a matter of practice. The extended type has many good features, particularly if a spark arrester is fitted, and considerable capacity is by many engineers regarded as an extremely desirable feature. The subject is very comprehensive, however, and must therefore be dismissed at present. Similarly mention only may be made of special aspects of the locomotive boiler problem, such as the use of large or small or adjustable blast nozzles, top feed water supply as practised on the Great Western Railway, the use or not of the steam dome, the locations of the safety valves and the regulator, types of spark arresters, shape and dimensions of chimneys, as well as more comprehensive matters, such as feed water heating apparatus and the like.

CYLINDERS AND VALVES.

A notable feature of modern practice in this country is the use of three or four high pressure cylinders. Twelve or fifteen years ago this was considered a rather reprehensible practice, an attitude justified by the disproportion of boiler power as compared with present day views. It is worthy of remark, however, that on the London and South Western Railway engines are still engaged in heavy and fast express duty which may be said to belong to the era of early modern four cylinder practice. These are the 369 series of four-driver non-coupled four-cylinder engines developed from No. 720, built by Mr. Dugald Drummond in 1897. Compared with the modern four-cylinder engines of the Great Western and Lancashire and Yorkshire Railways, one may be inclined to class them with Messrs. F. W. Webb's and James Manson's experimental four-cylinder simple engines of the same period. Yet Mr. Drummond's engines, though never multiplied beyond the total of five, and somewhat enlarged from the original design of No. 720 itself, can frequently be found working important South Western expresses. Indeed, in the case of one particular dining car express, non-stop from Salisbury to Waterloo, the writer has never seen any other class of engine employed, though six or seven journeys have been made by this train. Curiously, too, though including a non-stop run from Southampton West to Waterloo in one case, and the fastest schedule on the South Western in another, all experiences with these engines were in the up direction. Moreover, out of nine or ten journeys on such trains, not one has been unsatisfactory, and loads were fairly heavy on several occasions, though never very severe.

Otherwise multicylinder practice is exemplified only by modern big-boiler engines, six-coupled with four cylinders and 4-4-2 with three cylinders as follows :

Four Cylinder :	G.W.R.	...	4-6-0
" "	G.W.R.	...	4-6-2 (1 engine)
" "	L.Y.R.	...	4-6-0
" "	L. & S.W.R.	...	4-6-0 (2 classes)
" "	L. & N.W.R.	...	4-6-0
Three Cylinders :	N.E.R.	...	4-4-2
" "	G.C.R.	...	4-4-2 (1 engine)

The three cylinder tank engines on the Great Central and North Eastern Railways need not be considered, as they represent exceptional designs for special duties. This classification into six-coupled and "Atlantic" engines has, how-

ever, no significance to speak of, though it is somewhat curious.

The respective merits of two and three or four cylinder simple methods may be briefly set forth as follows :

(1) Multicylinder practice involves usually a reduced diameter of cylinder ; therefore there is a reduction of cylinder condensation, and different cylinder conditions may be realised. With superheated steam, however, the value of this factor is modified.

(2) Multicylinder practice improves balancing and should realise a steadier running engine, owing to the fact that the respective forces to a large extent compensate and balance one another round the crank axle instead of by the balance weights on the wheels.

(3) Multicylinder practice permits of the propelling action being divided over two axles instead of all the tractive power being applied through one axle and transmitted thence by coupling rods.

Against these must be set additional cylinders, parts, motion and incidental factors which render the employment of three or four simple cylinders considerably more expensive than two corresponding ordinary cylinders. It is all a question of whether it is worth it. The advantages above outlined constitute formidable factors to argue against, though, possibly, their value is hardly realised except from experience. On the other hand it is a moot question whether, estimating such advantages at their highest value, they are so overwhelming as compared with a corresponding two-cylinder engine. It is difficult to avoid the conclusion either that multicylinder compounding abroad has justified itself mainly on account of the mechanical features associated with its carrying out, or that multicylinder simple practice ought to be developed in this country towards compounding. Either aspect may be accepted, according to one's personal point of view. The real facts are as uncertain as they ever were, when one comes down to the bed rock of economics—that is comparing multicylinder simple practice, straightforward two-cylinder practice, and multicylinder compound practice with due regard to balancing, division of power, constructional and maintenance costs, and the various other matters involved before one gets to the bottom of the problem.

With superheating this controversy has assumed a different aspect, but it is curious that the problems involved are so misunderstood. Superheating and compounding are not, and never were, in antagonism, and the superheater

does not introduce any equivalent to the simple versus compound controversy of a decade or two since. It is rather that as superheating partly serves the same purpose as compounding, and goes further in other respects, one can proceed independently of compounding, but if other aspects of compounding are in question then superheating may be equally associated with either multiple-expansion or simple practice. One may say that the association of compounding and superheating reduces the value of one at the expense of the other ; but the situation is governed by other factors. If the mechanical features opened up by compounding or by multicylinder simple practice justify the expense and relative complication entailed, there is no reason why they should not be associated with superheating. In no single case known to the writer has the superheater been displaced by compounding, and equally, in no instance has compounding been reintroduced, with or without superheating, except in a form which realises the mechanical advantages indicated. Recent attempts to suggest that high degree superheating is set back because the Prussian State Railways have reverted to four-cylinder compound instead of four-cylinder simple engines proves nothing. It is only the old problem of simple versus compound in another guise, and should be stated as simple superheater practice versus compounding and superheating in conjunction, over-all results and comparisons counting in each case.

VALVE GEARS.

Finally, a few remarks in reference to valve gears. The link motion has for so long been in most general favour that one is hardly able to realise how insidiously the Walschäert gear is undermining its peculiarly British prestige. Several railways still adhere without exception to the Stephenson gear, and even where isolated engines or classes have the Walschäert gear, the link motion (the Joy gear on the L. & N.W. and L. & Y. Railways) still rules for the vast majority of engines. But the Walschäert valve gear is penetrating almost everywhere.

Apart from rail motor cars the following notable engines or modern classes use this motion :

G.W.R.—All four-cylinder engines.

L.N.W.R.—“ Sir Gilbert Claughton.”

L.B.S.C.R.—“ Bessborough.”

L.Y.R.—Rebuilt superheater 4-4-0's.

L.S.W.R.—4-6-0 engines and latest 4-4-0 classes.

G.N.R.—2-6-0 engines.

G.C.R.—No. 1090.

G. & S.W.R.—Mr. Peter Drummond's forthcoming 4-4-0 locomotives.

It is a peculiarly efficient gear, as shown by its virtually universal employment on the Continent, but the present situation is not altogether due to its special qualities as regards steam distribution. In America the fact that it enables weights of eccentrics and links to be reduced and that it clears the space between the frames of gearing, explains mainly why it is used there ; and similar considerations are at least factors here, though, of course, they are not so all-important as they are across the Atlantic. The link motion can hold its own as regards steam efficiency and working conditions, though the Walschäert may be an equally satisfactory alternative. But when considerations of weight, space, rubbing surfaces, accessibility and the like come into question, the Walschäert gear meets the case in a way which the link motion cannot do. The Joy gear is in rather a different category, but as far as can be ascertained the Walschäert motion offers certain advantages which somewhat alter the situation.

There are many other factors which might be referred to, but enough has been said to provide at least a ground for discussion, and other subjects can be left for another occasion and possibly for more competent critics and authorities to deal with.

DISCUSSION.

The Chairman, **Mr. Wardlaw**: In opening the discussion, I should like to say that there are just a few notes that I made during the reading of Mr. Gairns' paper, the first of which is with regard to the use of mechanical lubricators where superheated steam is employed. I think there are one or two instances in the country, notably on the Tilbury Division of the Midland Railway, where an ordinary sight feed lubricator has been tried, and is giving most excellent results, so far as I can hear. It was also tried, I believe, on the Lancashire and Yorkshire Railway, and gave equally good results. It is a very much cheaper device, of course, to purchase in the first place, and is much more easily managed than the mechanical lubricator and less liable to get out of order, especially when provided with the flat

sight-feed glasses and not the round tubular ones; and, according to all accounts, it seems to be giving just as good results as the mechanical type.

Another item, also in connection with superheated steam, is the use of the piston valve and of the common slide valve. The last time I happened to be at Horwich, I understood that some of their engines fitted with Schmidt's superheaters and with ordinary slide valves were giving exceptionally good results, with less cost for maintenance and less first cost than those engines with the piston valves. I do not know that they have been applied or used elsewhere, but, if I understood Mr. Gairns correctly, he said that the piston valve was an essential requisite with superheated steam—in other words, that the slide valve was prohibited; but we have these instances where they have been used on some railways and are giving excellent results.

Another point was the taper boiler. This, I believe, was borrowed from the other side of the water. It has been in use there a number of years, and, if I am not mistaken, there are quite a number of them in use to-day.

Another point was the boiler feed. The introduction of the feed water through the steam space on the top, generally by top feeds attached to the safety-valve mounting, is, I believe, peculiar to the G.W.R. They claim great advantages and economy from its use, and certainly do away with a serious trouble in the older methods of feeding.

For instance, boilers fed with combination injectors passing through the boiler face-plate are all provided with a long delivery pipe from the boiler face-plate through the steam-space, and curving down to the water-space. These pipes are necessarily always full of water, and the conditions present are ideal for the deposition of salts of magnesia and calcium; and in consequence are getting continually filled and choked up, so that at times the hole through them is scarcely larger than the diameter of a pencil, and sometimes they are choked up altogether. Taking care of these pipes is a great source of expense and worry, and this is entirely obviated by the top boiler feed.

Mr. Garratt: I have listened with very great interest to Mr. Gairns' paper, but, of course, I feel a certain diffidence in talking about locomotive design, because I presume you will take it for granted that I am a bit prejudiced on account of my own.

But one point did strike me in Mr. Gairns' paper, and that was the question of large and small engines for varying traffic. Now, it seems to me, from what I can

observe of railway working, that you cannot have an engine too big for any work you have to handle. Of course, a railway that has all types of engines, including a good many of the old-fashioned ones, must make use of what it has ; but it strikes me it would pay the English railways to scrap a great many of their smaller engines and go on building bigger ones ; because, if you are forcing a small engine to work up to its limit, it is burning coal at a much greater rate than your bigger engine, and I fancy that fact will come to be recognised here by-and-by, and also this, that, if it was possible, it would pay the railway companies to standardise a large type of engine, that could deal with **anything**, either fast traffic or slow traffic. If you have a big engine running a light train, it is burning very little coal, you are firing only a few shovelful in a big firebox, you are not throwing any coal away up the chimney ; the engine is absolutely master of the job, and, if it is wanted to go off the light train on to a bigger one, it is ready for the work. I believe, in my own mind, the tendency will be, for the sake of economy in operation, to adopt the most powerful type of engine, and standardise as far as possible. It sounds, perhaps, an exaggerated idea, but I do not think it is. In cases of emergency, your big engine is ready for anything that comes along, and I put it to the meeting that I think there is something in the idea that the day of the little engine is past. The little engine has to struggle with its work, and if you put half-a-dozen extra waggons on a goods train, she may not be able to take it ; but if you put motive power in front of the train that will handle anything that comes along, I fancy money would be saved in coal consumption, lack of delays, and in the handling of the traffic generally.

Mr. Bennett : I have listened to Mr. Gairns' paper with great interest, and I consider, taking it all in all, that it is a most comprehensive paper. In fact, it is such a paper that, if time permitted, it is quite possible that we should have had a discussion that would have dwarfed any other we have ever had at our meetings.

The first thing I noticed particularly in Mr. Gairns' paper was the matter of the track—the different tracks and the varying times engines take on different railways to do a certain journey. A gentleman was speaking to me on Tuesday last, in London, and he was talking about the building of engines and the speed at which the various engines run ; and he said : “ I cannot quite make it out how the engineers talk about building engines that will

run up to 85 and even 90 miles an hour, and then, when you look down the train services, you find, to cite a case, that they take you down to Brighton from London in an hour. If you can run at 83 and 84 miles an hour, how is it that you take so long to get 52½ miles to Brighton?" Well, I went into a little explanation with him as regards the road, and he replied: "That is not the point the travelling public looks at. We do not want to know your worries and troubles. We want to get to Brighton in three-quarters of an hour. When are we going to do it?" That appears to be the general idea of the travelling public. They do not take into consideration any of the locomotive engineers' troubles at all, they simply want to get there; and I take it that is a point now for engineers to consider.

As regards the cost of maintenance of boilers fitted with superheater: I consider myself that the upkeep of such a boiler will eventually become more expensive than the old type of boiler, for this reason. We are getting, in many places, considerably more tube trouble, more stay trouble, quicker wearing away of plates, and general fractures, than we got before in the ordinary type boiler, although they worked at a much higher pressure.

Then, again, Mr. Gairns spoke about the taper barrel, as used on the G.W.R. The taper barrel, in my opinion, is not all that is to be desired. It may be a good thing as regards storage of steam; but why run away from the parallel boiler and the dome? When you come to consider the fact that you have got something out of the ordinary, as regards direct pressures, it is quite possible that you get more than the ordinary stress and strain, and it may be that you are more liable to set up a certain amount of fracture in the taper barrel than you would in a parallel one; and probably, when the enhanced size of the big end of the taper is considered, you may find more trouble in the taper barrel than you would in the parallel one. Then, again, to consider the round crown boiler against the Belpaire. There is no doubt, in my opinion, that the Belpaire boiler, after manufacture, is the cheapest in upkeep. I say "after manufacture" advisedly, because the round crown type of boiler can be built considerably cheaper than any Belpaire that has ever been made, but afterwards, in the maintenance of the boiler, I think the Belpaire more than pays for itself; in this way: In the round crown we get considerable trouble in the breaking of the roof bolts where the boilers are direct stayed, and also elongation of tubeholes across the corners leading upward to the crown, and eventually this causes cracks between the bridges; and on the solid-barred boilers

or hollow type bar boilers the tube-holes begin to work and go elliptical horizontally across the tubeplate, and thus cause cracking ; but there is very little of this found in the Belpaire boilers. It seems to me that the casing works in conjunction with the firebox, and so it does not seem to have so much stress and strain as the round crown boiler has.

Mr. Gairns also mentioned the Wootton type of firebox. My experience of the boilers fitted with the Wootton type of firebox is that in service they are the cheapest and most economical, and I might say that I consider the Wootton type boiler is the best. We have some on the Brighton which have been in work now about $7\frac{1}{2}$ years, and during that period the only trouble that we have had with them is that we have had to re-stay them once or twice. The tube-plates have stood remarkably well, although some of the holes, I grant, are now beginning to get slightly elliptical up in the top corners, otherwise they are in good general condition, and, considering the heavy work these boilers have done, I think it speaks highly for them.

Mr. McKie: I think it is a great pity we did not have an advance copy of the paper, as it is one which, as its title suggests, lends itself to a great amount of discussion ; any detail about a locomotive could form a subject for debate.

With regard to piston valves and slide valves : I understand that Mr. Hughes, L. & Y. R., has a new slide valve, also piston valve with relief valves combined, which are giving very good results, and reduce the back pressure in the cylinders considerably. He claims that, by the use of either of these valves, steam can be shut off very much earlier when approaching stations, and therefore they effect considerable saving in steam, and are very economical in working.

With regard to the " Stumpf " engine that was mentioned, I should like to know if a comparison between it and an engine of the same dimensions with ordinary cylinders has been made. I have seen it claimed that " Stumpf " cylinders were as economical as a superheater due to the cylinder heat being maintained by exhausting the cooler steam just where it finishes its work, instead of travelling back again through the hotter parts of the cylinder. This claim, however, is surely exaggerated, otherwise the results have been obtained in a very simple manner.

Mr. Rodgers: As far as I am aware, the railways in the Argentine Republic still adhere to two-cylinder compounds, unless they have departed under the present super-

heating system during the last twelve months. They have been giving large orders for compound engines, and have been getting these locomotives now for a great number of years, so they must be giving very great satisfaction indeed. I do not think it is altogether on one railway, but all over the railways of the Argentine Republic. Why compounding has not been more tried, and has not been a greater success in our own countries, is rather, I think, because compound engines have not been given the same tests as have been given on the Continent and in South America.

The limitations of the line have a great deal to do with the limitations of the engines. Take a boiler from, might I say, a draughtsman's point of view. When he is limited by the engineers to a certain rail weight when getting out an engine which is to do a great amount of work, he has to keep down the weight, and a tapered boiler certainly has that advantage; there is saving in plate and saving in water; but it presents difficulties of construction, and although in contract shops they have made all sorts of boilers, the tapered boiler is never really advocated unless the saving of some particular thing is secured by its use. The conical plates are not so easy to roll and to make up as an ordinary plate, so far as I am aware.

Then the construction of the fireboxes. I think Mr. Gairns has struck a very good note regarding design of fireboxes, Belpaire and round top. Again, from the draughtsman's point of view, the Belpaire box presents difficulties on some of the lines regarding loading gauges (when you have a large engine, the boiler height goes up), and you are cutting away a good deal of the cab light; but still, these are not insurmountable difficulties, and the Belpaire box gives better steam space, provided that the barrel is designed suitably to let the steam out of its space, because, very often, you get a large volume immediately above the firebox, but it is choked as it enters the barrel. There, again, the tapered boiler gives an advantage over the parallel boiler. With the Belpaire box, I understand that we have tubeplate trouble more than in the round top boxes. Of course, we necessarily have a wider and flatter surface; but that, again, I believe, has been pretty well got over by the wider spacing of the tubes, and very often alternative tubes left out near the sides, giving strength just where it is wanted.

There is one design of boiler which Mr. Gairns has not touched upon, and that is used in South Africa, and, I believe, in America, where there is a chamber part of the firebox carried into the boiler a distance of, say, 2 or 2½ feet.

I understand this is giving very great satisfaction. It is perhaps a little more expensive boiler to build, but I believe this combustion chamber is doing very well.

There is another form of combustion chamber, which is used on the Natal railways, and it is built with the fire-brick arch to throw the gases over to this combustion chamber, but it necessitates a short waterleg.

That is a type of engine which has not come to our own British railways, where we have, say, an eight-wheel-coupled engine, with boiler standing above the wheels. Necessarily, on a narrow gauge, you want to keep the centre of gravity down, and have the big boilers very low and the fireboxes very shallow. These, being different types, give their own peculiar troubles.

Another point was regarding the question of lubrication, which our Chairman has referred to. I have also heard, I believe it was in South Africa, that they have given over the mechanical lubricator and put on the Detroit, which has given pretty good satisfaction with superheated steam.

Mr. Nethercot: A gentleman just now mentioned about the combustion chamber in the firebox that he did not think there were any in England. Some years ago, I think it would be about eighteen or nineteen, the G.W.R. made ten, which were at that time commonly called the "Kruger" type, and Mr. Gairns has a photo of one of them here. Only ten were made, and they gave very good results at the time, but the copper was worn away to such a great extent in such a short time that they have never made any more of them. The copper inside on the edge of the combustion chamber at the end of a month was worn away practically to a knife edge. At the bottom there was a valve, where air could be let in to cause a greater draught; but that had to be stopped up. The boilers practically wore themselves out, and were never replaced.

Mr. Burtt: Like most of the members who have already spoken to-night, I deplore the fact that we have not had an opportunity of reading the paper beforehand, but I hope at the end of this year to be in a position to recommend the Council to have copies of the paper printed and distributed before the date of reading, which will give members a better opportunity of discussing it.

I have listened with much interest to Mr Gairns' paper, but it is difficult to follow the paper, make notes of what has been said, and listen to what is going to be said. There are several points which I should like to refer to, and the first is with reference to superheating and com-

pounding. On the Paris, Lyons, and Mediterranean Railway, two or three years ago they built some Pacific type engines, which were four-cylinder simple high-pressure engines; and they also built a set of four-cylinder compound superheaters. Most elaborate trials were run with these engines. There were various sets of men put on them, so that one man was not confined to one engine; and the result was that the compound superheated were decidedly preferable to the simple non-superheater, with the result that the simple non-superheaters were brought into the shops and converted into compound superheaters.

As Mr. Garratt said with reference to the big engines, I do not think there is any question but that the big engine is *the* engine. If you have a big engine you always have a reserve of power. The wear and tear on the engines is less, they are not burning so much coal, and it is more economical all round. Another important point with the big engine is, they have done away with the very high speed down the banks. Instead of crawling up a bank at 30 to 35 miles per hour, and running at 65 to 70 the other side, you have 45 miles per hour up, and down the other side at the same rate.

Regarding the Belpaire fireboxes; this type of firebox was first introduced in Belgium in 1864, and every engine in Belgium was built with a Belpaire firebox up to about four or five years ago; consequently, what they did not know about Belpaire fireboxes perhaps was not worth knowing. Anyhow, it had certainly taken them a long time to find it, but they had come to the conclusion that the round top was the better. Being in correspondence some time ago with M. Flamme, of the Belgian State Railways, on the question as to why the Belpaire was being discarded, he told me it was cheaper to make, and it gave far better results, with the result that the Belpaire firebox is now scrapped or is being scrapped in Belgium, and all the old engines as they go through the shops are having round top fireboxes put in. And he also told me, when I raised the question of extra steam capacity, that he was of opinion that, with an ordinary engine, the amount of extra steam which you had in the crown was manufactured in a second of time; it was not worth considering sufficiently to advise making Belpaire fireboxes.

A remark was made about the lubricators. On most of the French railways they are using Detroit lubricators on all their superheater engines.

Regarding the taper barrel, Mr. Gairns said he thought

only the G.W.R. are using it. With reference to the boilers in Belgium, that is now the standard design for all the big engines that are being built. Mr. Gairns also said that he did not think the wide or Wootton firebox would last very long in this country, and would probably be confined to the Atlantics. Well, there is no doubt we shall all see that practically every line will have Pacific engines sooner or later, as occasion demands, and there is no reason why Wootton fireboxes should not be used. If you can get a good square box it is better than a long one.

He also referred to the Atlantic type. Of course, we all know that the class of engine is built for the work it has to do, and, speaking with regard to the Atlantics and the Brighton Railway, these engines have proved a success; they are undoubtedly the best main-line engines for their size, especially with regard to boilers.

There was another remark, with reference to compounding and superheating. It is now becoming the standard practice in France on most roads to build four-cylinder compound superheaters; in fact, old engines, as they go through the shops, in many instances are being converted into superheaters.

Mr. Nethercot: What Mr. Burtt said about the Belgians having built Belpaires since about 1860, and having only just recently started building round tops, did not seem very logical. We may admit that what they do not know about Belpaires may not be worth knowing, but then the same thing applies over here about the round top. If they had their experience and ours, too, the argument might hold good.

Mr. Burtt: Mr. Nethercot's remark does not altogether apply. Probably it came about in this way in Belgium. About eight to ten years ago they had some engines from Scotland of Mr. McIntosh's type. There was no difference whatever, and, of course, they had round top fireboxes; and they probably found, after they had been running five or six years, that the round top firebox was giving less trouble than the Belpaire type. Consequently, they had some ground to go on. But we cannot say the same in England, because we have not had such long experience to go on over here.

Mr. Bennett: Is it Mr. Burtt's suggestion that we shall have to go to Belgium to get proper designs for boilers, and, because Belgium had the Belpaire type of boiler, and used it for many years, that we have just followed the idea

like a flock of sheep, and that we shall go back to the round crown, after trying the Belpaire, because Belgium has done so?

Mr. Nethercot: It seems to me that, after having the Belpaire for so many years, and then, as you said, only recently having decided to scrap the Belpaire and take on round crown fireboxes, that the Belgians might have had a good experience of the Belpaire, and knew all its defects, and so on; but, at the same time, they could not possibly have had the two experiences—that is, the Belpaire and the round top; so that I do not see that they are in a position to say, any more than we to-day, that the round top is better than a square top, or *vice versa*. As a matter of fact, on the G.W. we have built Belpaires for twenty years, and I say that, in England, they have had a good experience of both round crowns and Belpaires, but that the Belgians have only had an experience of round tops during the last ten years.

Mr. Gairns: Mr. McIntosh has stuck to the round top. Is the merit in the boiler, as distinguished from the type of firebox?

Mr. Rodgers: I think the engines supplied to Belgium were McIntosh "Dunalistir" 4-6-0 type. They had round top boxes. Has not the matter of Belpaire and round top boxes developed from the round top to the Belpaire? In the original round top boxes we had the majority stayed by roof bars, and then it developed gradually from the roof bar to the direct stay. Unless the round top box is watched carefully, you get rather serious trouble with direct stays, owing to the angle at which the stay has to be screwed into the copper box and the round top casing. I think, then, that the development was from the round top box to the Belpaire box on a great many lines; and, strange to say, on the Indian State Railways, that development took place as the engines increased in power and larger boilers were wanted, and so forth. They departed from the round top boxes, and Belpaire boxes are now generally used in all standard engines, both for narrow and broad gauge. I think there is a good deal of history attached to the development from round top to Belpaire—I mean history of defects and peculiar features of both the round top and the Belpaire.

Mr. Burt: With reference to Mr. Rodgers' remarks about the Belpaire developing from the round top, it is going back again, because, over in France, they are going back to round tops where they have been using Belpaire;

they have come from round to Belpaire, and are going back to round.

Mr. Nethercot: That is the practice of boiler construction from start to finish. I remember, when starting my apprenticeship, there were direct-stayed boilers. Then I remember having to take the direct stays out and put in solid bars, and then take these out and put in hollow bars. The cycle has gone round again, until we come to direct stays now; it is quite possible that we may come to solid bars again.

Mr. Garratt: I believe, as a matter of fact, that the Belpaire firebox is a commonsense one. If you are going to construct two chambers, one to contain the water and the other to contain the fire, why should you put a square fire chamber in a round steam and water chamber? If you are going to put the two together, why not make them symmetrical? Of course, the question of the difficulty of the throatplates is absolutely out of it. They can be stamped out in the press in a few minutes. The Belpaire throatplate is made as easily as any other sort of thing. The Belpaire is a common-sense firebox, and both the box and the casing can be admirably stayed together. I believe I am absolutely correct in stating that the cost, as compared with the round top outer shell, is cheaper, from the manufacturing point of view.

Mr. Tilling: Mr. Gairns was speaking of the non-coupled engines of the S.W. being employed on the best trains. If I remember rightly, the N.W. had all their non-coupled compounds running on the best trains, until their designer, Mr. Webb, retired, when they rapidly disappeared. Now Mr. Drummond has died, I think we are likely to see the early withdrawal of his non-coupled bogies. As to Mr. Nethercot's remark that the Belgians have had no experience with round top fireboxes, there are hundreds of six-coupled goods engines of the Caledonian type working in Belgium, built during the last dozen or so years, all with round top fireboxes. So I should say they have had ample experience now of both types of firebox.

Mr. Gairns, after thanking the members for their appreciative remarks, replied to the discussion as follows:—

There is one explanation I must make to begin with, especially seeing the trend the discussion has taken, and that is that, although my subject had no limits as regards what country or any country it covered, the paper was mainly written in view of this country's practice; so that,

where I did not mention things outside this country, and other people have mentioned them, they were usually matters that I knew of; but I do not think they altogether alter the point of my remarks, in the sense that I made it fairly clear as to what were the limits I was observing.

As regards the Chairman's remarks re mechanical versus Detroit lubricators, I knew of the Midland "Tilbury" tanks having the Detroit lubricators, and I am interested to know that one or two of the other lines are trying them, but it is a very close struggle actually between the mechanical and the sight feed lubricators. The mechanical is simply "out of court" in American and Canadian practice, and it has been stated that, with the higher degrees of superheat, the Detroit is entirely satisfactory. It is still a moot point as to whether the sight feed lubricator does, in the long run, give satisfaction, and we have to see how it works out in British practice. I was not aware that it is being used as much as it is for Colonial work as compared with the mechanical, but in this country we have very little sight feed experience for high superheat to go on. For moderate superheat, perhaps up to about 200 deg., then, of course, the question is not really at issue, because the ordinary recognised sight feed lubricators go a great deal of the way before the question of whether the mechanical lubricator must or should be substituted becomes a controlling factor.

As regards slide valves, we have a number of slide valve engines working with high superheat. One of the five 4-4-0 rebuilt superheater engines on the L. & Y. retains the slide valves, and I think there are two superheater engines on the G.E. which do so also. I understand, too, that one of the five "Precursors"—I think it is "Precursor" herself—fitted with superheaters on the North Western still retains her slide valves. They are stated to work fairly well; but my recollection of some remarks that Mr. Hughes made is that the slide valve is satisfactory, but it wants very careful looking after; that it takes very little for the slide valve to cause trouble with a superheater engine, and, therefore, while you may say that the slide valve used with high superheat will work, one would hardly advocate its retention. If it is a case of cost of alterations and that sort of thing, and you want to keep that down, it may be worth while to keep to the slide valve; but, if possible, use piston valves, and you will be better off in the long run. The piston valve, while not actually essential, is desirable. I would point out that my remark in the paper

was rather that mechanical lubrication and the use of piston valves are not things which you must entirely put down to superheating. My point was rather that they may be good and desirable features on their own account, and therefore you must not blame superheating entirely because it entails them.

As regards the taper boiler, there is the American waggon type boiler, for example, and there are the Belgian and other boilers, in which the taper feature is included, but I did not claim exactly that Mr. Churchward invented them, but rather that he introduced them; and here, again, of course, I was thinking more of British practice than of what may have been done abroad.

As regards Mr. Garratt's remarks about the systematic use of big engines, I take it that he would desire his remarks to be interpreted on a reasonable, as distinct from a universal, basis. I presume that one does not expect big engines for doing anything and everything on a railway. Mr. Garratt's point is rather that, for all duties where heavy requirements may be involved, big engines should be available, because they would be cheaper in the long run; but, of course, on every railway there is any amount of secondary duty, even on the main lines, and there are many links in which it is a relatively simple matter to work a certain series of trains with the engines working well within their powers, although they may be relatively small.

Mr. Garratt: I meant to say that it would be far more economical for a railway to have a majority of big engines, doing away with the small ones, instead of continuing to repeat the smaller ones.

Mr. Gairns: Incidentally, if you remember, Mr. Hughes made a remark not very long ago (I think it must have been based on some criticisms about his big 4-6-0 four-cylinder engines pulling three bogies on 40-minute expresses between Liverpool and Manchester—G.N. "Atlantics" have similar work to do occasionally), that, while this sort of thing came within their day's work, actually the engines were working more economically than the smaller ones which might have been employed, which supports Mr. Garratt's case.

I was rather interested in Mr. Bennett's remarks that the cost of the upkeep of superheater boilers is, in the long run, greater than that of ordinary boilers. Of course, that must always be interpreted in the sense that one does not get something for nothing. It has to be paid for in some way or to some extent. The main argument in favour of a high degree of superheating, I think, if you summarise it,

is this, that you get a big gain for a relatively small addition; but you have got your price to pay; you do not get something for nothing. Exactly how this factor works out in practice I do not know. Mr. Bennett rather indicated that he thought it would be a serious matter. Two or three locomotive engineers, who have had a good deal of superheating experience, have said to me that they thought, in view of what they gained, that the initial cost and the cost of maintenance of superheater engines over and above the ordinary engines was not worth speaking about. They did not mean to say that there was not any cost, but, in view of the results obtained, they were pretty well in the same position as if they had introduced bigger engines of the saturated steam type free from extra cost due to superheating. On the other hand, I did see some remarkable figures prepared by another Locomotive Superintendent, which seemed to indicate that his railway would soon be bankrupt if superheaters were adopted.

Mr. Bennett's objections to the use of the taper barrel are, in a sense, those which naturally suggested themselves when first introduced, and which, we have been given to understand, Mr. Churchward has overcome. We know that there must be a special plate shape for the taper section; it must be more difficult to make, and I believe they require special rolls and sundry matters like that. Mr. Churchward is using the taper barrel systematically, and, therefore, I take it, it has been worth his while to introduce the necessary material and appliances, but, after all, the point to which I referred in the paper was that, if the design has so many advantages, and is worth having, why is it it has not appealed more to other people?

It is interesting to hear Mr. Bennett's remarks and his opinion that the Belpaire firebox costs more to make at first (which does not quite agree with Mr. Garratt's opinion), but that it is cheaper in the long run; also his favourable remarks re the Wootton type are worth attention. Whether, as Mr. Burt suggested afterwards, we shall find the "Atlantic" type develop to the "Pacific," and the Wootton retained under these circumstances—well! we shall see what we shall see. But I hardly think we shall see many "Pacifics" yet awhile. As I said in the paper, the difficulty with the Wootton firebox is that, whatever its good features may be, and however satisfactory it may be, it seems to carry with it the virtual necessity of having a pair of carrying wheels under it. I expressed the opinion that the general tendency was that, if you are going as far as ten wheels

for the engine, it is the best course to make as much use as you can of the adhesion weight. Of course, on the G.N. and the Brighton, the question, even now, is whether the adoption of the Wootton firebox was not governed by the fact of the engines being "Atlantics." They are good engines—splendid ones, everyone knows—and I would emphasize all the advantageous claims made for them; but, still, the G.W. practice and that of several other lines seems to be that it is really better to take advantage of the possibilities that the 4-6-0 type offers than to use only approximately two-fifths of the adhesion weight, merely for the sake of getting a big boiler; it is largely a matter of opinion and practice.

I think Mr. McKie spoke of my figures about the speeds for small wheels. I did not altogether catch what his query exactly was. If you noticed, I gave for 5ft. 6in. to 6ft. 3in. 40 to 65 miles per hour; and 4ft. 3in. to 5ft. 6in. 20 to 50 miles per hour. I was not saying that the small-wheeled engines habitually travel at about 20 miles per hour, but rather that those mentioned are the usual working speeds they get in traffic.

Mr. Garratt: I gathered from Mr. McKie's remarks that he wanted a high piston speed, which, I thought, was a thing we somewhat avoided.

Mr. McKie: I did not fully catch Mr. Gairns' remarks before about the 20 to 50 miles per hour.

Mr. Gairns: As regards the "Stumpf" engine, we have not heard anything about what the results are. The chief drawback to the "Stumpf" arrangement, as carried out on the North Eastern, is that they have combined it with the superheater, which, in a sense, nullifies the presumed advantage it should render. On the other hand, if it can show advantages with high superheat, then, of course, the case is much stronger than it is against ordinary practice. The engine is really equivalent to the ordinary 20in. by 26in. cylinders. It is only a matter of the method of using steam and the necessary use of big cylinders to obtain this advantage; otherwise the engine is supposed to be equivalent to the 4-6-0 engines, 20in. by 26in. cylinders, that they have already in use.

As regards the Argentine, I do not think you will find the retention of two-cylinder compounds applies all the way through, but I forget the railways which adhere to two-cylinder compounds so strongly; I fancy there are at least two. It is remarkable that they have retained it for so

long. There is one thing I am given to understand, that the traffic in the Argentine, as in a good many of those countries, is largely of a steady, straightforward character—the sort of work where, we will say, the weaknesses, if there are any, of a compound would not be brought out. The engine is kept fairly steadily to the kind of work for which it is intended.

As regards the suggestion that the Belpaire boiler interferes with the look-out, I do not think, if one looks at most modern engines, that that question is considered of very much account. I think there are few engines where you can get a good look-out, if one expects it other than straight ahead. You can hardly see across many of the big engines, whether they have round roof, Wootton, or Belpaire fireboxes, and the modern look-out is nothing like what one used to find in the old days. I do not think the objection would carry very much weight as regards selecting the round roof or the Belpaire.

As regards the combustion chamber, here, again, of course, I was considering mainly home practice, and this point did not come into account. I knew of the G.W. having something of that sort, and Mr. Webb had something like it on the L.N.W. I think the combustion chamber must rather be considered as a Colonial or American means to get over the difficulty that, if your boiler is to be big enough for the wheel-base, you must have something to assist the firebox; and, to avoid having such an enormous length of tube barrel, without anything to assist the distribution of the furnace gases, you carry the furnace gases into the combustion chamber, and, therefore, you are getting a bigger firebox, a bigger furnace surface in the engine, and you are also reducing the extent to which you depend upon the length of the tubes to transfer the heat to the water in the barrel.

Mr. Garratt: I think also one of the supposed advantages was that, if the tubeplate went wrong, instead of having to change the high tubeplate right down to the foundation ring, all you had to do was to renew the comparatively small plate at the end of the combustion chamber.

Mr. Gairns: There are many factors like that; but, even taking these criticisms and remarks into account, I do not think they virtually affect my remarks, or, rather, my omission of definite reference to them, because they must all be classed as special designs, which, even if they have attained a reasonable use, have still not become standard and relatively representative practice.

I am obliged for Mr. Nethercot's remarks re the G.W. boilers.

As regards Mr. Burt's remarks on the French compounds and superheaters, they rather bear out my contention that, if you are going in for four cylinders for economical advantages, you might just as well go in for compounding, unless a good case could be made out the other way. Also, it brings us once more to the simple versus compounding argument, and the tendency I referred to to mix it up with superheating, as if it was a case of superheating versus compounding, whereas it is not, because superheating is used in each case.

As regards the Belpaire firebox, it seems to me there is an opening for historical reference. There is one thing which no one has properly brought out. The Belgian Belpaire firebox is not the Belpaire we have here. It certainly was different in the earlier Belgian engines, though towards the end of the Belpaire period there were some square boxes, but coming out very much over the frames. However, in doing away with the enormous Belpaire firebox (I do not remember that they have had any particular experience with our form of Belpaire firebox, narrow at the bottom), they were starting to meet conditions involved when narrow fireboxes down between the frames became a necessity. When they bought the Scotch engines, they were starting fireboxes between coupled wheels—and fair-sized coupled wheels, too, 6ft. 6in. Before that, their biggest engines, which, I think, had 7ft. wheels, were still 2-4-2. Their Belpaire firebox is in the same category as the Wootton—it must virtually have carrying wheels under it. Now they have got big six-coupled 4-6-0, naturally, the conditions were more or less the same, or, at all events, similar, and they proceeded with their Scotch experience, which, apparently, was the only experience they had on these lines. Furthermore, as I incidentally remarked before, Mr. McIntosh has adhered to his round roof design, and one may ask whether, as he has found no reason to alter his opinion in Scotland, this might not have something to do with the situation in Belgium. It is a very good boiler, and a very good firebox, and, therefore, there is no reason to depart from it. The Belgians have some 4-6-2 engines, and enormous machines they are. Here, they have more or less kept to the round top design, although they have a carrying axle under the firebox. How far that is merely a development of the practice already in vogue remains to be seen. There is one question—the main object of using the Belpaire firebox in its earlier form was to get, not only

a big grate, but an enormous grate, because of the rubbish they frequently had to burn; that was the sole reason for introducing the Belpaire in those early days. What fuel do they use now? I understand it is largely briquettes. I do not think it is of a very wonderful quality even now, and one may ask how they get on with the round roof firebox, which is what we use with really good coal.

I think that a fair number of these variations of policy and practice can be explained by the suggestion of conservatism on the one hand, and "follow my leader" on the other, to be seen in our railway service; and things which cannot be explained in any other way, either in this country or abroad, must be explained on that basis. But one speaker suggested that the foreigners were so much more progressive than we are here. One thing we always forget, and that is that Europe and America are very big areas, and, after all, we have only two little islands to make up the United Kingdom. If you carry things down to the basis of railway administrations, or railway areas, or national areas, I do not think we make a bad show. We are inclined to say, on the one hand, "Europe has done more than we have here." We entirely forget that Europe is some fifty to sixty times bigger, and that the influence of one engineer must count for a great deal more, because, in many cases, you have State systems carrying the influence of the chief officers through a much bigger area. There is a tendency to experiment there, but some of those things which we call progress are, after all, mere experiments.

There was another gentleman who spoke of the four-cylinder engines of the South Western, Mr. Webb's, and so on. I was not speaking of compounds. Mr. Webb had one four-cylinder simple altered to compound. There was one four-cylinder simple on the G. & S.W., and I think she finished herself out as such. The only time I saw her was shunting at Carlisle. After the initial period, she did not seem to have much to do. On the South Western the "360 Series" engines, after all these years, are still engaged on principal heavy work, and they are the only ones which have lasted from the early four-cylinder simple period. With their uncoupled drivers, relatively small cylinders, and relatively small boilers (they are fairly big, but small to what we associate now with four-cylinder engines), they are still taking their part in working principal West of England and Bournemouth road expresses.

The meeting closed, after a vote of thanks, moved by Mr. Bennett, and seconded by Mr. Garratt, had been passed to Mr. Gairns, who suitably replied.