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REAR-ADMIRAL EDMUND J. CHURCH in the Chair.

COAL CONSUMPTION OF SHIPS-OF-WAR.

By W. H. RILEY, Esq., R.N., Staff Engineer.

THE subject of this paper is, no doubt, of special interest to a large number of the members of the Royal United Service Institution and to naval officers generally, and also, judging from several published criticisms, would appear to have some attraction outside the Royal Navy. Under these circumstances it may not be out of place, and not without some value, to offer some remarks for discussion in this Institution on actual expenditures of coal and circumstances connected with its economy.

In the first place, a brief review will be made of the nature of the services performed by a man-of-war for which coal is consumed, and its effect on the accuracy of measuring those services and the amount of coal expended for their performance.

It is a matter of common knowledge that these services are of a much more varied and irregular character than those performed by merchant steamers. A large 1st class battle-ship, capable of developing a maximum I.H.P. of about 13,000 and a speed of 18 knots, actually on peace duty develops I.H.P.'s which vary from 9,000 to less than 900, and speeds from $16\frac{1}{2}$ knots to 6 knots. When a definite passage is made, it is often at a varied speed, and, if steaming in company with other vessels, it is necessary for all but the leading ship to continually vary the revolutions in order to keep station, these variations often taking place several times in an hour. The helm also is brought into frequent requisition, affecting speed, revolutions, and I.H.P. The continuity of a passage is also often further interrupted by evolutionary exercises, during which the variation of speed and course is so great that it is impossible to measure the propelling performance.

Besides propulsion there are also several auxiliary services to be performed, comprising distillation from sea water for drinking and washing purposes, and for making good losses of boiler feed; lighting the ship internally by electricity; pumping water from sea for sanitary and cleaning purposes, from double bottoms, bilges, and drain receptacles; ventilating and steering ship; compressing air for torpedo work; working guns by hydraulic power; hoisting purposes

and driving capstans, all of which, besides forming a varied series, are each in themselves of a more or less irregular character.

As regards propulsion, the variation described renders it extremely difficult to accurately calculate the average power developed. When the revolutions are subject to such frequent alteration, the indicator diagrams will often be taken either when the revolutions are greater or less than the average for the period the diagrams cover; and it is frequently the case that in the interval between taking the diagrams from successive cylinders the revolutions will be changed, thus giving not only unfair but inconsistent results. The principal sources of accurate data are the comparatively rare occasions when the vessels happen to be steaming independently over long distances. It must be borne in mind, however, that the results so obtained may differ considerably from the results obtained when making a passage under the varied conditions noted previously, although in the two cases the average speed of passage may be the same. When steaming irregularly a very rough approximation to the I.H.P. can be obtained by calculating the average revolutions per minute, and taking the I.H.P. corresponding to this as determined on the measured mile trials; this, however, is open to the objection that nothing is allowed for differences in the state of the weather and the ship's bottom, which circumstances are found to have a considerable effect, the exact amount of which is difficult to determine. In some few cases, the conditions as to weather and bottom may approximate to those under which the measured mile trials were made, when fairly reliable results as to average I.H.P. may be obtained in this way.

The amount of work done by the auxiliary engines and appliances is generally impossible to absolutely measure. Some of these engines are fitted with means for taking indicator diagrams, and so enable the I.H.P. developed at a given time to be calculated; but their work is generally of such an intermittent and varied character that this would afford no measure of the average I.H.P. developed. A very fair estimate of the services rendered by the electric lighting engines and the distillers can, however, be otherwise determined, the current generated by the former being measurable by electrical appliances, and the water made by the latter by the capacity of the tanks into which the fresh water for drinking and washing purposes is delivered. The other services are of such a character that they can only be valued by the amount of coal they require to perform their usual daily work.

A few remarks will now be made upon the degree of accuracy with which the coal consumed can be measured and apportioned to the several services for which it is used. The ordinary method of measuring the coal taken out of the bunkers is to fill buckets of known capacity and to record or "tally" each as it passes from the bunkers into the stokehold; one of these is occasionally weighed, both empty and when filled level with the top with coal, the difference giving the weight of coal per bucket. Of course this system of measuring in detail is open to several sources of error, such as when the buckets are not all filled to the same height as those which have

been weighed, or when every bucket is not recorded; and also any inaccuracy in the weighing machine, or from clumsiness in carrying out the operation, will be multiplied when the weight so obtained is taken as the standard for several. It is customary, in some ships, to allow a small percentage on the expenditure so obtained; to avoid a greater quantity being used than is recorded; it is, however, often found that this percentage need only be very minute when the staff has been well trained in coal tallying, and is made to understand the importance of accuracy.

As a check on this method it is the common practice to measure the capacity of the coal in the bunkers; this being an especially accurate method when steaming sufficiently long to have completely emptied one or more bunkers after having been filled. Of course, for this to be accurate, it is necessary that when the coal is taken on board, the bunkers should be evenly trimmed up to the deck beams; this practice, having also the advantage of taking on board the greatest quantity of coal, justifies the extra time taken during coaling to ensure it being done.

It has been suggested that the draught of water of the ship affords an accurate means of measuring coal expenditure; no doubt this would be so if care and trouble were taken to measure the quantity consumed of other stores, and if the ship were floating in absolutely smooth water when reading the draught. The practice is frequently adopted at Government coaling depôts, the coaling lighters used there being filled in places where the water is generally smooth and the calculations not confused by the weight of any other stores. The method is hardly necessary in ships, as the two first alluded to should be sufficient to ensure a fair degree of accuracy.

It is an important point to apportion the amount of coal used to the several services, and in some cases it requires a considerable amount of patience and trouble to attain this end. The advantage obtained, however, is worth the trouble, as in cases of high expenditure it enables the cause to be better traced.

Several ships, including all the more recent, have either an auxiliary boiler or one or more of the main boilers specially fitted for the purpose, which can be connected up only to the usual main lead of auxiliary steam pipe which supplies steam to all the auxiliary machinery. Thus the main and auxiliary machinery, although working concurrently, can be worked independently, and the coal expended for each readily determined. The amount required for each auxiliary service presents greater complications, but can be approximately obtained by having only one at a time in operation for a sufficient period to enable the coal used to be properly measured. These individual results added together will give a greater total than is obtained when all the auxiliary engines are in actual operation together, as the coal required to make good the losses by radiation from the boiler and steam pipes will have been added together several times in the former case, but should only be taken account of once. It can be practically determined from the above data, and can be further checked, if an opportunity occurs, by

stopping all the engines and noting the coal required to maintain the working pressure in the boiler and steam pipes.

When no auxiliary boiler or main boiler specially fitted for separately supplying the auxiliary services is fitted, the coal required for most purposes can be determined when in harbour, and, by subtracting an estimate formed on this basis from the total expenditure when under way, that for the main engines is obtained.

Another method is to note the difference in the daily expenditure under way at low speeds (1) when a particular auxiliary engine is at work, (2) when it is stopped, all the other circumstances being as nearly as possible the same in the two cases. As, however, the disproportion between the total daily expenditure and that for one auxiliary engine is considerable, the trials should be repeated three or four times to obtain reliable results. That this system can be fairly accurate is proved by the fact that separate similar ships have obtained in this way approximately the same expenditures. A modification of this method is to note the difference between the I.H.P. developed in cases (1) and (2) when the daily expenditure of coal is the same. Knowing this difference and the coal expenditure per I.H.P., an approximate measure of the coal required by the auxiliary engine in question may be obtained. Special care must be taken in the measurement of the I.H.P., and the trials should be repeated three or four times.

By adopting one or the other or all of the above plans, vessels can approximate very closely to the expenditure for the main engines and to that for the auxiliary engines as a whole or in detail.

Besides the above expenditures there are also some others which it is necessary to distinguish from them to avoid confusing comparisons, and which are, therefore, separately accounted for. They include laying fires and raising steam, banking fires, waiting orders, and steaming when the speed is so variable that no distance can be logged, as when at target practice; there is not much difficulty, however, in measuring the coal so used with fair accuracy.

Some instances of coal expenditure by war-ships under certain circumstances were given by Admiral Long in his paper on Cruisers, read in the early part of this year at the Institution of Naval Architects. The following is one of a different character, showing a six months' expenditure incurred by a large modern battle-ship on ordinary peace service:—

	Tons.
Steaming, making good distance	869
Laying fires, banking fires, steaming when no distance is logged, &c.....	335
Culinary purposes and warming ship	112
Distilling for ship and boilers	481
Electric lighting	554
Other auxiliary purposes, as steering, pumping, working guns and torpedoes, ventilating, work-shops, &c.	211

These services comprise four short passages of about 70 knots each

and one of about 500 knots at moderately steady revolutions per minute; one passage of 500 knots at revolutions varying from 61 to 97 per minute, this including quarterly passage trials; 14 days' cruising at from 4 to 12 knots over 2,000 knots, with occasional stoppages; three occasions specially under way for target practice; one electric light engine in use constantly throughout the whole period, generating a current of from 260 to 410 amperes; a second electric light engine in use occasionally a few hours at a time; 1,950 tons of water distilled for ship purposes; and the usual ventilating, pumping, and other minor auxiliary machinery in daily use.

During war service the expenditure would probably be much increased, but would entirely depend on the service required. If called upon to steam long at high rates of speed, the increase would be very great, and coaling would have frequently to be resorted to. It would also be increased, but not nearly to the same extent, if called upon to steam for long periods at a low speed; as this is a very probable demand that will be made, the question is considered in some detail later on.

We now proceed to an analysis of the several services in greater detail, and begin with the main engines, whose object is the propulsion of the ship. The coal expended and power developed by these engines have been determined, in most ships, from definite experiments for the purpose, as well as from the ordinary occasions on which a steady speed has been maintained. The performance in a particular case may be given, that of a large battle-ship, as very full and reliable data have been obtained under definite conditions, and the engines are representative of a large number of recent construction. The following are the expenditures of coal per hour per I.H.P. :—

Percentage of full designed power.		Coal per I.H.P.
55		2.03 lbs.
28		1.82 "
22		1.93 "
14		1.76 "
7		2.2 "

There have been more economical results than these, at some of the powers, from engines of the same type, and also some worse, the expenditure being materially affected by several circumstances such as quality of coal, differences in details of construction, and differences in management. The above figures, however, may be taken as a fair performance under good conditions.

The engines of the ship in question are of the tri-compound type, which, in the Royal Navy, is the most advanced type of engine. Its principal characteristic is economy of fuel, and its adoption has been found to have reduced coal expenditure for power both at high and low powers to about an average of 20 per cent. below that required by bi-compound engines, and about 50 per cent. less than that required by simple engines.

The advance of the boilers with regard to the economical generation

of steam has not kept pace with the engines in the economical use of steam; their advance has, however, been very marked in enabling the high pressures required by the later engines to be safely obtained. The old, roomy, rectangular, low pressure boiler of 30 lbs. per sq. in. enabled a large proportion of heating surface to be introduced, facilitating the passage of heat from the fire to the water, and also large furnaces and combustion chambers which allowed the fuel to burn completely and give out a large proportion of the heat it was capable of generating. The cylindrical forms necessitated by high pressures, now up to 155 lbs. per sq. in., curtailed to some extent these constructive features, and hence there was some falling off in the amount of water evaporated by a given quantity of fuel. It has, however, been found possible, in some of these boilers, to get a high degree of economy. At moderate powers, rough measurements made on board H.M.S. "Thunderer" showed an evaporation of 9.6 lbs. of water per pound of fuel burnt, which was very good Welsh coal. There is no doubt, however, that such a result requires both very good coal and careful stoking. The temperature of the feed water was about 100° F., and the boiler pressure 110 lbs.

To obtain the best results from the steam, it is necessary that the cylinders should be steam jacketed. Steam jackets are not only of value in this respect to the tri-compound engine, but also to the bi-compound and simple engines when even a moderate rate of expansion takes place in each cylinder. The fitting is generally adopted in the navy, and consists of an annular chamber, enveloping the cylinder into which steam is admitted and maintained at a pressure about equal to the maximum acting inside the cylinder itself. This, by imparting heat to the expanding steam, aids in reducing the amount of steam liquefied. The benefit derived from these fittings depends upon circumstances, but it has been clearly shown that the amount of power developed by a given expenditure of fuel can be increased 10 per cent. by their use. In practice, the pressure in the steam jackets must not be so high as to avoid all liquefaction on the cylinder surfaces, as these surfaces, when working too dry, require a larger amount of oil to keep them efficiently lubricated. The objection to this is that a considerable quantity of the oil so used passes with the working steam into the feed water, and thence to the boilers, and increases the temperature of the heating surfaces. With this limitation, however, steam jacketing has proved of economical value.

A very important point, peculiar to the engines of a war-ship, is economical working at reduced speeds, and this point will be dealt with somewhat fully. The previously mentioned battle-ship averaged, on the runs made during six months, a speed of 8.6 knots, which is above the average of most other vessels. This speed corresponds to an I.H.P. of 1,300, smooth water and clean bottom; the actual average I.H.P. would be greater than this on general service. The "ordinary speed" of such a vessel is 9½ knots, corresponding to 1,800 I.H.P., and the most economical speed would probably be near 7 knots, 900 I.H.P.

FIG. 2. INDICATOR DIAGRAMS.
AT ABOUT ONE-HALF NATURAL DRAUGHT POWER.
— TRI-COMPOUND ENGINE.
- - - BI-COMPOUND ENGINE.

FIG. 4. TO ILLUSTRATE MR. WINGFIELD'S REMARKS.

FIG. 3.
— STEAMING WITH ONE HIGH PRESSURE CYLINDER
AND ONE LOW PRESSURE CYLINDER.
- - - STEAMING WITH ONE HIGH PRESSURE CYLINDER
AND TWO LOW PRESSURE CYLINDERS.

The low average speed is partly the consequence of the greater distance made good per ton of coal at low speeds than at high speeds, and partly because the nature of the general service does not demand a high speed. The cause of the increased economy for distance at low speeds is, no doubt, well understood, and all that need be done here is to draw attention to some of the sea speeds and consumptions determined at sea in the battle-ship in question, and which are as follows:—

I.H.P.	Speed.	Revolutions per minute.	Coal per day.	Knots per ton of coal.
7,220	13·66	63·6	tons. 157·5	2·08
3,600	10·9	68·1	70·4	3·7
2,870	9·92	62·0	59·6	4·0
1,810	8·96	51·2	34·3	6·2
900	6·77	41·2	21·6	7·5

The knots made good per ton of coal show the superiority of the lower speeds in economy of fuel, this arising from the high rate at which the power increases in comparison with the increase of speed.

An important point in connection with this question is that if the speed be reduced below a certain point the distance covered by the expenditure of a ton of coal decreases. The speed at which this change takes place is termed the "most economical speed," and is of service when the chief consideration is to steam the greatest distance for a given quantity of coal. It is always a very low speed; is rarely higher than that corresponding to 12 per cent. of the full forced-draught I.H.P., and in some vessels which have a very large proportion of power for their displacement the I.H.P. for most economical speed is a much lower proportion.

The nature of this speed and the circumstances affecting it can best be examined by means of a diagram, which is given on Fig. 1. The horizontal line OX represents the speed in knots per hour or the number of revolutions made by the engines per minute; the vertical line, quantity of coal expended in tons per day; the curve AE represents the expenditure of coal per day for any particular number of revolutions or speed. To construct this curve a number of actual runs must be made at various speeds, and the coal expenditure carefully measured in each case; the points representing the results are plotted off on the diagram, and a fair curve drawn through them. It will be found that a peculiarity of this curve is that if produced to the zero speed it will cut the line OY at some point, C, some distance from O, the distance OC representing the expenditure necessary to counteract the effects of radiation of heat from engines and boilers. The most economical speed and the consumption are represented by the point E, where the tangent drawn from O touches the curve AB, OD representing

the speed and DE the consumption. That this is so follows from the consideration that the most economical speed must be that where $\frac{ED}{DO}$ or $\frac{\text{expenditure}}{\text{speed}}$ is least. This value is constant for all points on the line OE, and is greater for all points above OE, that is, all other points on the curve AB represent a higher consumption for distance than the point E. One value of this method is that it is readily seen that for a wide range of speed about E the increase in expenditure is very trifling, the present figure showing that the speed may range from 30 to 60 revolutions, or 4 knots to $7\frac{1}{2}$ knots, without any considerable variation in the economy. In practice, it will generally be more desirable to steam at the higher speed, viz., $7\frac{1}{2}$ knots in the case considered, and this may be done without incurring any appreciable waste of fuel. The most economical speed varies with altered circumstances of weather, but when a series has been obtained under definite similar conditions they may be plotted out in the same way.

Also, in cases where it is necessary, with a given amount of coal on board, to steam the greatest distance with it, the coal used for the necessary auxiliary services must be taken into account, and can be represented on the diagram by drawing a line YY', distant OY, equal to the auxiliary expenditure per day. The "most economical speed" must be obtained by drawing the tangent to AB through the point Y, which gives a speed greater than that obtained when the auxiliary services are not taken into account.

If this coal curve be closely examined in comparison with the I.H.P. curve, one or two important points will be noticed. Starting from the higher speeds, the I.H.P. curve falls rapidly as the speeds decrease until low speeds are reached, when the fall is less rapid, and at very low speeds indeed approach the direct proportion to the speeds as the influence of the constant engine friction becomes predominant. At high and moderate speeds, the coal curve approximates to the power curve, but falls less rapidly at the lower speeds, being affected by the amount of steam necessary to overcome the back pressure on the low pressure pistons and by the heat lost by radiation, the former being practically constant at all speeds and the latter constant if the same number of boilers be in use. These two sources of waste play an important part in increasing the quantity of steam used per I.H.P. at low speeds.

To reduce the rate of this increase as much as possible is one of the considerations that has led to the adoption of a lower ratio of volumes of the low and high pressure cylinders than is the practice in the merchant service, although this entails some sacrifice of economy at the higher speeds. The case quoted will show that a high degree of economy at even very low powers can be obtained from such engines. The proportion of cylinder volumes adopted for tri-compound engines of war-ships averages, about, high pressure, 1; intermediate pressure, $2\frac{1}{4}$; low pressure, 5; while for similar engines of merchant ships it is not infrequently 1, $2\frac{3}{4}$, 7.

To obtain the best results at low powers, it is most essential that the reduction of the power should be obtained, as far as possible, by increasing the rate of expansion, thus supplying the steam to the high pressure cylinder at a high pressure and cutting off the supply at an earlier part of the piston's stroke; the jacket pressures, within the limits already referred to, being so adjusted as to avoid unnecessary liquefaction. When steam at the full boiler pressure is admitted to the cylinder and the earliest practicable cut-off employed, the engines still develop a comparatively high power, and any further reduction must be effected by throttling the steam or reducing the pressure in the boilers. The latter is the preferable plan, but cannot be reduced below that necessary to promptly handle the main engines and to work the auxiliary engines.

As an illustration of how the advantages peculiar to a more advanced type of engine may be lost, the indicator diagrams in Fig. 2 are given. These are combined in the simplest way for the sake of a more ready comparison, and represent one set of three from a tri-compound engine, 130 lbs. boiler pressure, and one set of two from a bi-compound engine, 60 lbs. boiler pressure, both engines working at about 60 per cent. of their natural draught power. The difference between them is chiefly that a much later cut-off in the high pressure engine was adopted with the tri-compound engine, resulting in reducing the total ratio of expansion to less than in the bi-compound engine; there are also evidences of greater liquefaction. The tri-compound area, which represents the work done per stroke, is rather greater than that of the bi-compound; but the quantity of steam used, as indicated on the diagrams, is also as much greater as to make the economy of steam practically the same in each case, while the actual consumption of fuel per I.H.P. was slightly greater with the tri-compound. This engine, when worked with an earlier cut-off and steam in the cylinder jackets, has a substantial advantage in economy over the particular bi-compound engine referred to.

In the "Blake" and "Blenheim," whose engines are designed to develop exceptionally high powers, special arrangements have been made to keep down the coal expenditure at very low powers, and consist, as is generally known, in fitting two separate sets of engines to each of the two propeller shafts. In peace-time, it was intended that the forward engines should be disconnected, and the two after ones alone used. Thus, when steaming at a comparatively low rate of speed with the after engines only, the proportion of the corresponding I.H.P. to the full power would be half what it would be if all the engines were in use. From experience with the "Blake" under the two conditions, the consequent reduction in coal expenditure per knot at 9.6 knots has proved to be substantial.

In some ships the maximum power of the engines during peace service has been reduced by fitting a special slide valve with increased lap to the high pressure engines, the eccentrics being suitably adjusted. This arrangement has only been applied to some recent ships, and sufficient experience has not yet been obtained to show the effect on the economy of steam.

With regard to adapting the boilers to low speed steaming, the subdivision into several boilers, necessary in most ships from other considerations, enables the boiler power to be properly proportioned over a large range to the actual power to be developed by the engines. The usual conditions of men-of-war steaming, however, render it generally necessary to have steam up in a greater number of boilers than is required to develop the average I.H.P. economically, as the variation in revolutions and auxiliary work above referred to demands that steam should be quickly available for the maximum requirements. This not only increases the waste arising from radiation, but also from the irregular firing necessary to meet the varying demands of the engines.

When the number of boilers in use is much above the average requirements of the engines, and the maximum is not wanted to be exerted too suddenly, recourse is frequently had to the reduction of the grate area. This, by increasing the proportion of heating surface to grate area, and by affording a larger space for the combustion of the coal gases, tends to greater economy. This reduction of grate can be readily effected by allowing the back bars to become clinkered over, or, in some cases, the service renders it possible to brick over these bars; vertical plates have also been used, placed in the ash pits transversely so as to prevent air having access to the length of fire bars behind, and have been found to be beneficial in some cases.

It has often been suggested that, at low powers, the use of only one engine and screw of a twin-screw ship might be more economical than using both engines. This has been tried by many ships, with the result that, down to powers as low as 10 per cent. of the natural draught power, there is no saving of fuel, and often a substantial loss. These show that the falling off in speed caused by the resistance of the rudder and idle screw is so great as to more than counteract the increased efficiency produced by developing the whole of the power in one engine, and the reduced waste caused by the elimination of the engine resistance and back pressure of the engine which is stopped. In most of the trials the idle screws were not disconnected from the engines, but, if they had been, there is sufficient experience to make it probable that they would not have revolved at that power, and the practice is also open to the strong objection that the control of the ship is seriously impaired. An average result from a battle-ship may be quoted, where the one-tenth I.H.P. was 900, the speed with two screws 6.8 knots, the speed with one screw 5.3 knots, the distance made good per ton of coal with two screws $7\frac{1}{2}$ knots, and that for one screw $5\frac{1}{2}$ knots. The percentage of loss was therefore 30, and a reduced speed of $1\frac{1}{2}$ knots into the bargain. At higher speeds the single screw method is still more unfavourable.

There have been a few cases where some economy has been obtained at from 3 to 5 per cent. of the natural draught power, due apparently to the circumstance that at extremely low powers the inefficiency of the engines rapidly increases. The corresponding speed is, however, so low that it may be doubted whether it would prove of any practical value. Even at these low powers it would

appear that the economy is largely dependent upon conditions of weather, and if economy were proved in a given ship under certain circumstances, it would probably disappear if the circumstances were even slightly altered.

A proposal has been made to disconnect the L.P. cylinder of a triple expansion engine at low powers, and thus develop a higher proportion of full power, say 30 per cent. in a bi-compound engine of cylinder ratio $2\frac{1}{4} : 1$, instead of 20 per cent. in a tri-compound engine of double that ratio. This proposal is based, however, on the supposition that the loss of efficiency of tri-compound engines is very great at low powers; but experience generally in the navy engines, including the example already quoted, shows that, over a wide range of power, this is not the case; and that the coal expended per I.H.P. when using all three cylinders is materially below that of a bi-compound engine having a comparatively low ratio of cylinders, although the low power developed is in a somewhat higher proportion to the full power in the latter case than in the former. This difference in coal per I.H.P., in favour of working with three cylinders, is also found to be sufficient to counteract the loss sustained by the engine friction of the L.P. cylinder, and thus leads to the conclusion that no economical advantage is to be gained by the adoption of the proposal under consideration.

An instance of some interest may be given, although it only indirectly bears upon the question. It is, however, a case where a comparatively low power was developed with a cylinder ratio reduced to half the total ratio of the complete engine. The vessel referred to had bi-compound engines of the three-cylinder type, one H.P. and two L.P., the total ratio of volumes being $3\cdot72 : 1$. One of the L.P. engines became disabled, and the ship steamed 6,000 knots at about $\frac{1}{4}$ power with only one H.P. and one L.P. cylinder, the ratios being then $1\cdot86 : 1$. The practical result was a coal expenditure per hour per I.H.P. of 3·5 lbs. against 2·4 lbs. when all cylinders were in use, developing the same power. Indicator diagrams to show the distribution of steam when using two cylinders are given in Fig. 3, and also, for comparison, a set when using about the same quantity of steam per stroke when all engines were in use. These show that part of the increased coal expenditure was due to increase of back pressure, due apparently in some measure to the whole of the steam entering at one end of the condenser; but, making an allowance for this, the expenditure of steam was much greater than when using the whole of the engines.

The coal expenditure for auxiliary purposes is a very material item in war-ships compared with the quantity used for propulsion. In the course of a year the larger modern ships generally burn as much or more for the first as the last; this is partly absolute, on account of the increase in the number of auxiliary services for which coal is used, and partly relative, on account of the low average speed and time under way, as compared with a merchant steamer. The proportion becomes considerably lessened in the case of a passage at a fairly high power, say at half the full power, the proportion between

the coal for auxiliary services and that for propulsion being then about 9 per cent.

To afford an idea of the magnitude of the auxiliary engines on board a modern ship, it may be stated that on one of the most important there are 58 distinct engines, not including boat engines, the I.H.P. amounting in the aggregate to quite 2,000. This, if continuously developed, would mean an enormous expenditure and considerably beyond what is actually incurred. As a matter of fact, several of these engines are only duplicates of others, and would not be used at the same time with them; and many are only used intermittently.

It should be mentioned here that the auxiliary engines here referred to are only those which are used for purposes distinct from propulsion. The coal expenditure for such engines as the main circulating engines, main feed engines, and starting engines is included with that for propulsion. Many of the auxiliary engines do not lend themselves to economical working, as some are necessarily so far removed from the source of steam that considerable condensation takes place in transit, also they receive their steam supply at a reduced pressure and exhaust it against a comparatively high pressure. The work of some is of such a character that it is impossible to employ any material degree of expansion or to compound the cylinders. To obtain the greatest economy possible, those which can be so treated are compounded, and also a separate auxiliary boiler is fitted where one of the main boilers is too large for the work; or, in some cases where the main boilers are of the double-ended type, for one of these, two single-ended boilers have been substituted.

The electric light engines deserve special consideration, as one or more are in use in many ships practically all the year round, and necessitate, consequently, a considerable total expenditure of coal. These are now made, and have been for some years past, on the compound principle, and a very early cut-off employed in the high pressure cylinders, thus allowing of a high total rate of expansion. Every engine is tried carefully at a Government dockyard to determine the quantity of steam it consumes, and a certain standard of economy must be attained. These trials afford some useful facts as to their consumption under the trial conditions, but, as will be supposed, this will be subject to some modification when in use on board ship. On these trials no account is taken of the steam used by the feed pump, nor of the condensation which takes place in long leads of steam pipe, nor of the amount of coal used when fires are cleaned. With regard to the condensation in steam pipes, it is found on the trials on shore of the electric light engines that an amount of water is collected at the engine end of the supply pipe to the extent of 7 to 13 per cent. of the total steam used, although the length of pipe is comparatively short and is well lagged.

A case of the expenditures on board a battle-ship and on trial in the dockyard may be quoted; the steam consumption on trial was found to be for one electric light engine generating a current of 400 amperes such as to require a daily expenditure of 2.6 tons of

Welsh coal of good average quality. The reported expenditure from the ship is 3 tons per day; and the number of lights in use such as to require from one half to the full power of one engine. The case of "Warspite," 8,400 tons displacement, especially mentioned by Admiral Long, in his recent paper, showed an expenditure for lighting on passage out to her station of over 4 tons per day. This amount was perhaps larger than that really used, insufficient opportunities having occurred to enable it to be accurately determined. Later results showed an expenditure of about 3 tons and less per day, a reduction probably assisted by economy in the number of lights and length of time in use. The reduced expenditure, however, does not appear excessive when it is considered that the engines are of the simple type.

Distillation of sea water is also an important item of coal expenditure. On a large ship fresh water is often required to the extent of about 12 tons per day for drinking, cooking, and washing, and about $\frac{1}{4}$ ton of water per ton of coal burnt in the boilers to make up losses of steam and water from the boilers, engines, pipes, joints, valves, &c. Both of these amounts are of a very elastic nature, and in many cases it has been found possible to materially reduce them below these figures. When direct distillation from the boilers was employed, as in the older ships, a very fair return was obtained for 1 ton of coal, averaging about $7\frac{1}{2}$ to 8 tons of fresh water. When, to avoid large quantities of scale being deposited in the boilers, double distillers were adopted, the quantity of fresh water obtained for 1 ton of coal was reduced to about 5 to $5\frac{1}{2}$, the loss resulting principally from condensation of primary steam on its way to the evaporator and to the high temperature it possessed when escaping as water from the evaporator. Compound double distillers were tried and found to result in a considerable gain in the quantity of water produced for a given expenditure of fuel, and in recent ships a pair of double distillers is so fitted that they may be worked in this way. It is arranged, however, that each distiller can be worked separately when urgency requires the greatest output to be made. It may be said here, in connection with this point, that it not infrequently happens that economy of fuel and economy of weight and space do not go together, and hence, in a man-of-war, where economy of weight and space is of such importance, economy of fuel must often to some extent be sacrificed.

Under some circumstances of naval work, economy of coal may be of such importance that, beyond working the machinery so as to fulfil its services with the least expenditure of coal, it may be desirable and possible to dispense with some of them altogether. The character of the work must determine which of them can be dispensed with, but those which appear to lend themselves to this are the steering and electric lighting engines. Both of these use up considerable quantities of coal, which can be saved for other purposes by steering with the hand gear and using oil and candles for lighting purposes.

The exact advantage to be gained by this course depends upon the service, and is greater the slower the rate of speed. A large cruiser,

say, carries 1,000 tons of coal; at 10 knots speed under good conditions this will carry her, with all the ordinary auxiliary purposes in use, about 7,700 knots; if the steam steering and electric lighting engines be stopped, she will be able to cover about 8,700 knots, a gain in distance of 1,000 knots, or $\frac{1}{10}$ th more. At a high power, say, 60 per cent. of the natural draught, she may steam about 3,000 knots in the one case, and 3,100 in the other, the gain in distance being only 100 knots, or $\frac{1}{30}$ th more.

Before concluding this paper, the progress of the coal question may be illustrated by giving some particulars of the passage of three vessels, fitted with progressive types of machinery, out to the same distant station. The first had simple engines and very little auxiliary machinery, and steamed the distance of 7,082 knots at an average speed of 5.5 knots; 1,575 knots were made under steam only, 5,071 under steam and sail, and 436 under sail only; the total coal expenditure was 1,046 tons. The effect in this case of using sail power when steaming, besides increasing the speed $1\frac{1}{2}$ knots, was to reduce the coal expenditure per knot to less than one half what it was when the vessel was under steam only. The second vessel had bi-compound engines, boiler pressure 90 lbs. per sq. in., was fitted with a large amount of auxiliary machinery up to modern requirements, and steamed 6,985 knots at an average speed of 7.7 knots, with a total coal expenditure of 1,533 tons; this includes a considerable fraction for the main engines for purposes other than making good distance. The third vessel, a new ship, it is estimated from actual experience with similar types of engines, triple compound, 155 lbs. steam pressure, will steam the distance of 7,000 knots for 1,200 tons of coal at an average speed of $12\frac{1}{2}$ knots. To afford an idea of the comparative power to propel these ships, it may be stated that the H.P.'s required to drive them at 10 knots per hour are respectively 1,500, 1,500, and 1,350, smooth water and clean bottoms.

The first two cases showed a very material reduction in the coal expenditure for power developed in favour of the bi-compound engine; but the total amount of coal went up considerably. This is almost fully accounted for by the facts that she had no help from sails, steamed at a higher average speed, and had a greatly increased amount of auxiliary machinery in use. The expenditure for the tri-compound engines should show a still further economy for work done, but it is not likely that the total expenditure will fall below that of the ship fitted with simple engines, on account of the very much larger amount of work to be performed by the machinery.

A review of some of the remarks in this paper will show that much has been done in the construction of the machinery of war-ships to enable economy of fuel to be obtained, but that the realization of this economy depends materially upon its use and treatment on actual service. So great is the influence of the latter, that improved treatment has been known to have nearly doubled the radius of action of a vessel that was obtained when the treatment was not so satisfactory. Some difficulties in the way of economical working have been considered, and it has been shown that the principal of these can be over-

come to such an extent as to obtain good results on actual service. Many of these difficulties are such as to be out of the control of officers in charge of the machinery, and it is in these respects that officers in command of ships may exercise material influence on coal expenditure, especially in such matters as economy in the use of auxiliary services and in steady running, and generally in the encouragement of those under them to use every effort to keep down expenditure to the lowest limit consistent with efficiency.

Mr. WINFIELD: I have been very much struck with the ingenuity of the diagrams, which are entirely new to me, showing a very simple method of finding out from a series of trials the intervals between those experiments at which the ship would be steaming at the most economical rate. Diagrams are always more satisfactory for taking averages than simple arithmetic. You may approximate by an ordinary average, but if the experiments are reliable, you can get the absolutely correct point by means of a diagram, and I must congratulate the author upon the very ingenious arrangement that he has hit upon. Mr. Barnaby has just informed me that an American engineer, Mr. Hollis, has pointed out that there are two speeds at which the same economy is realized, and I see this diagram also clearly shows this to be a fact if the ship is not running at precisely the most economical speed. For instance, if the engines are running at 20 revolutions, the coal consumption is shown on the figure by E'D'.¹ A line drawn through O and E' will, if produced, cut the curve again at E'', which is perpendicularly above 80 revolutions on the scale. The author has pointed out that, at any point on such a line as this, you are burning the same coal per nautical mile, hence a given distance can be run by the ship, whose performance is represented by this diagram, with the same weight of coals, whether running at 20 or at 80 revolutions. That is, the distance will be done in one-fourth the time at the higher speed, without any larger expenditure of coal. It is evident then that, if not quite sure what is the most economical speed, it is better to err on the fast side rather than on the slow, and, when cruising, orders should be given to run as near the economical speed as possible, but never at a less speed unless circumstances require it. Whenever a ship runs at a speed less than that of maximum economy, she is wasting time as there is another higher speed of equal economy. I think the great importance of this fact is self-evident. The coal per nautical mile = $DE/24DO$; as the triangles D'E'O and D''E''O are similar, it is evident that, as stated above, all points, such as E', E'' on the slant line, represent equal weights per nautical mile, or equal radii of action for a given weight of coal burnt. The distance run per ton of coal is, of course, $24 \frac{OD}{DE}$. There is one

little point about the mode of action of the steam jacket. I think there are very few people who have studied the steam engine who doubt the great economy often realized by the use of the jacket. Opinions differ, however, as to the cause of this economy. I see the author speaks of the jacket imparting heat to the steam. I doubt if it is possible for the jacket to heat the steam much, if at all, except, of course, the very small proportion of the steam which happens to be in actual contact with the sides of the cylinder. The makers of superheating apparatus know this so well that they use small tubes, so as to cause as much of the steam to come in contact with the metal as possible. A very rough analogy may be found in the following hypothetical case:—Suppose we imagine an inclined plane made of some absorbent material, such as blotting paper. A current of air is passing under it, and keeps it dry, so that a drop of water, if let fall on the upper surface, will sink in and be dried up almost instantaneously. A number of bubbles are now poured on to the upper end of the plane, and are allowed to roll down it and off at the lower end. It is an object to secure as many bubbles at the end as possible out of the total number poured on. As the blotting paper is kept dry by the current of air

¹ A figure illustrative of Mr. Winfield's remarks will be found in Plate 26.—EDITOR.

beneath it, those bubbles next it will burst and make way for another layer, which will also burst, and, the moisture being conducted away through the absorbent surface, layer after layer is destroyed. Only those bubbles touching the surface are, however, affected, and a certain percentage glide over them, and are caught as they fall from the lower end of the plane. These bubbles may be taken to remotely resemble the molecules of steam in their action, if heat is substituted for moisture. The layer of steam molecules next the cooler cylinder walls is condensed on entering the cylinder, and collapses, making room for another, and so on, but the steam in the centre of the cylinder is not affected. To return to the bubbles. Since the dryness (coldness) of the surface causes their collapse (condensation), it is evident that water (heat) must be substituted for the current of air (radiation and conduction). When the surface is thus kept moist (hot) the layer of bubbles (steam molecules) next it do not collapse, and serve as a cushion to keep the others from contact. A much larger proportion of the bubbles (steam) remains, therefore, at the end of the inclined plane (point of cut-off). Here, again, it is only the layer of bubbles (steam) next the surface which is directly affected; the rest is indirectly affected, as it is kept from contact by the uncollapsed (uncondensed) cushion of bubbles (steam). In the case of the engine, the jacket having done its work by keeping the sides of cylinder free from water, the loss during expansion, due to re-evaporation, does not take place. It is sometimes supposed that great losses occur from the exhaust steam conducting heat from the jackets. Steam is too poor a conductor to do this. Water will, and the jackets should be hot enough to prevent its accumulation before expansion commences. To sum up: the great gain derived from jackets is by preventing condensation and subsequent evaporation on the sides of the cylinder, and not by heating the mass of steam flowing into the cylinder. It follows that jackets are of most use where, as in small engines, the area of the sides bears a large proportion to the cubic capacity of the cylinders. In conclusion, I wish again to express my very great admiration of the author's diagram, which will, I am sure, be most useful.

Mr. WHITE: The concluding sentences of this paper sum up the lessons which should be learnt from its study. The paper will be of enormous value to the Service afloat. It is not merely a remarkable collection of illustrative examples of causes affecting coal expenditure, but contains also very valuable suggestions as to means whereby economies may be effected. Mr. Riley has made this matter one of the closest study. The paper will be circulated throughout the fleet in the Journal of this Institution, and I believe that it will lead to considerable practical benefit both to the Service and outside the Service. When we have it shown that by means of greater skill or experience in management the radius of action for a given coal supply may be doubled, we can see how important it is that both officers in command and those in charge of the engine room staff shall know in what direction to work in order to obtain economy. Mr. Riley does not make speculative statements, but deals with records of fact. In the same ship, at different periods of service, he shows that the radius of action has been doubled by savings due to better management alone. If I may venture to emphasize the statement made by Mr. Riley, I should wish to dwell upon the increased expenditure which may be involved in rapid variations of speed, or in uncertainty as to speed, or in the extended use of auxiliary services of various kinds. Sensible economies in coal may be effected by commanding officers if they set themselves the task of assisting engineer officers as much as possible. When I was afloat in the manœuvres of 1889, I made as close a study as I could of the conditions obtaining in a squadron on service. In that division of the fleet in which I was embarked, when we were at steam tactics at 8 knots, every ship had steam ready for at least 10 knots. Sometimes, in watching the manœuvres, I found ships were moving for a time at as high a speed as 12 knots in order to keep station. But the average speed of the tactical movements was only 8 knots. Clearly, such a command of steam and speed is absolutely necessary when a fleet is performing evolutions. Mr. Riley has well pointed out that there are conditions of service when considerations of economy in coal expenditure must give way to other considerations. But when a vessel is proceeding independently on a long voyage, by suitable arrangements much may be done in the way of coal economy. Take the illustration Mr. Riley gives of what

may be done by stopping the electric light, or the steam steering. The latter plan of course involves some more manual labour, but I have been more than once on board a battle-ship which was steered with perfect ease and success in making a passage by manual power. To show what can be done, I may add that in the case of the "Blake" or "Blenheim" the ship was steered by hand up to a speed of 18 knots. It is much more convenient, no doubt, to have one or two men only at a steam steering wheel, rather than many men at the hand steering wheel. But if economy of coal in making passages is aimed at, then in these, and in many other ways which Mr. Riley has hinted at, very much may be done. I do not desire to say more on this occasion, because my hope in coming was to hear the opinion of naval officers; but having closely read this paper, I must repeat the opinion that it is one of great practical value to the Naval Service. That value will be manifest more and more when the paper comes to be studied by officers afloat.

Admiral COLOMB: As naval officers are called upon to say something, I may say a word or two, because Mr. Riley is an old shipmate of mine, and I have no doubt that in times gone by we have talked over these questions in their earlier stages. There are one or two matters I am reminded of,—for instance, the economy of using one of two screws. I do not know whether Mr. Riley has data to show how the economy of using a single screw varies according to the direction of the wind. I do not know how it may be with the more recent classes of ships, but with the older classes of twin screws that I had to do with it was almost invariably found that when the wind blew 3 or 4 points on the bow, the economy of using the weather screw rose considerably over what the use of one screw did for instance when the wind was right ahead. The effect of the change of wind in that way was to require the ship, supposing she had been using the two screws, to carry rather more weather helm. The use of the single screw effected the purpose which so much weather helm did, and the consequence was that with the single screw you were able to keep the helm more in mid-ships. I hoped that we should have had in the paper some remarks on matters which have been a good deal before us recently—strongly before us in Lord Brassey's "Naval Annual" this year. I mean the vexed question of the effect of auxiliary services on the radius of action. Complaints are raised, I do not think myself properly raised, that the radius of action given in the tables represents a greater radius than really exists on account of the auxiliary engines. But it seems to me that what is wanted in the Service is some sort of factor, some sort of divisor which would discount the figures given, which I understand have simply to do with the powers of propulsion of the engines without taking anything else into account,—that if, corresponding to the different classes of ships, some discounting figure could be given, it would be always easy to tell at once what amount of deduction must be made from the nominal radius of action. I very much agree with Mr. White as to this paper being of the greatest possible value to the Service. I told my friend, on entering, that I had read the greater part of it and that it was a paper which could not provoke much discussion in this theatre, but that it certainly would provoke in the Service a great deal of very useful thought. I am glad to hear Mr. White attack the too great use of machinery on board ship. Where man-power is capable of doing the work I cannot help thinking it is very much better on board war-ships that the man-power should do it. I used to be made very low in my spirits with watching the machinery weighing the anchor when there was plenty of man-power to have done it, and the mass of man-power was looking on idly at the machine. In the same way with steering. It would be better for the Service if machinery should only be used for those purposes for which it is absolutely necessary, and that we should fall back on the muscular power which we are bound to have on board for fighting purposes so far as it can possibly be used. I must congratulate Mr. Riley on the excellence of the paper he has produced.

Mr. LIVERSEDGE, R.N.: I should like to point out a means of testing the accuracy with which coal has been measured. Suppose the H.P. is constant throughout the trial, then, if a line of coal consumption be plotted of which the "abscissa" is the total time and the "ordinate" the total coal used, the line should be a straight line; but if any error has been made in counting the number or weight of the buckets it would show itself by an alteration of slope of the

straight line. That method has been used by the Committee of Mechanical Engineers, and was found useful by them. The author, on page 3, gives the result of a special trial in which the consumption of coal per H.P. was measured at different percentages of full power. Professor Unwin, in a lecture to the Society of Arts, in January, gave curves showing that if the H.P. was decreased by decreasing speed or boiler pressure, the consumption per H.P. was increased at the reduced power; but if on the other hand the power was reduced by increasing the expansion the consumption per H.P. decreased. These results of the author's seem to fall under the latter head, and this result of Professor Unwin's would support the view taken by the author that the power should be reduced by increasing the expansion. It should be noted that the expansion should not be so great that the pressure at release in the low pressure cylinder is less than the sum of the back pressure together with the friction pressure. The expansion should not be carried on so far that the pressure at release in the low pressure cylinder falls below about 6 lbs., as Mr. Williams gives it, otherwise there will be a loss from excessive expansion. Then with regard to the steam jacket; the Committee appointed by the mechanical engineers recommended that the jacket should be so adjusted that the steam at release in the cylinder should be dry. This will agree with the author's condition that there should be some moisture on the sides during the stroke, since the release will not occur till about 0.8 to 0.95 of the stroke, and up to that point the steam will have contained a certain diminishing amount of moisture. Finally, I should like to ask the author a question. He gives the performance of the "Thunderer's" boilers as 9.6 lbs. of water evaporated per pound of fuel burnt. To make that information definite, I should like to ask the temperature of the feed water and the pressure of the boiler?

H.S.H. Prince LOUIS OF BATTENBERG: I should like to make a few remarks from the point of view of captain of a ship, and to deal *seriatim* with a few of the hints which were thrown out, more especially as regards effecting economy in coal by restricting the expenditure for auxiliary purposes. I thought the matter over a great deal when I was in command of one of those small ships full of engines, and I came to the conclusion that really the only point in which you could possibly effect economy was electric lighting. Steering by hand is no doubt another point, but it should not be forgotten what, to my mind at least, is the chief advantage of steering by steam, viz.: the rapidity with which you can put the helm over to avoid danger. Under certain conditions no doubt you could steer equally well by hand, but if you get anywhere within frequented waters, working in a squadron or anything of the sort, I do not see how you could possibly do it. That and electric lighting are the only two items of expenditure which are pretty well permanent and constantly recurring, because, after all, the pumping machinery for torpedoes, weighing, stowing anchors, and so on, are intermittent. As Admiral Colomb said, as regards weighing the anchor no doubt you would have plenty of "beef" to do it without machinery, but then the question of time comes in. After all I take it you could do a great many things by hand in a ship: if you have unlimited time you have usually plenty of men to do it. In the "Dreadnought," we could load and trim our turrets by hand; it would take us about half an hour as against five minutes by machinery, and the same argument, I take it, applies wherever you use steam. With regard to the question Admiral Colomb raised about using one screw with the wind on the bow, I tried it and I found it certainly was so. It was the only point where we could use one screw, I would not say with advantage, but where it appeared to me to be really possible to use it. I am much struck by this diagram, Fig. 1. I assume that the author is the originator of it; I have never seen it before. It is very ingenious and also brings out how difficult it is to narrow down the economical speed. There must be for all practical purposes a large margin. Of course the faster you can do it for the same amount the better. After all, the captain of a ship is rather hampered in giving effect to economies in coal consumption, on the lines thrown out by Mr. White, for instance. As he rightly said: in the squadron you must have an excess of speed for tactical purposes and even for ordinary station-keeping purposes. But, in these days, the moment you are away from the flag there are two conditions: either you are told to go to a certain place at a certain speed, or else you are told to cruise within certain waters at your

discretion. Your other instructions tell you that when you are cruising you are to use what is called the "ordinary speed" according to the scale laid down, provided it is not faster than the most economical speed; so that in either case you are practically tied down by instructions, apart from the expediency of using your most economical speed. I should like to revert again, for a moment, to the question of electric lighting. In the "Scout," for example, we were peculiarly situated. We were the only ship in the Service then fitted with accumulator batteries. I was very much in favour of them after we found out how to work them. My engineers were, however, not very fond of them, as it gave them a great deal of extra trouble. I have never been able to clearly satisfy myself that it was more economical to use them as far as the coal consumption went. Practically it meant a great deal more. In the Mediterranean summer cruise, where you frequently anchored for five or six days, she was the only ship in the squadron which put the whole of her fires out on anchoring, and it affected us more because we had no auxiliary boiler. Now besides being able to keep the boilers cleaner it reduced the temperature of the whole ship, and conduced to comfort and cleanliness generally. Lighting by accumulators could only be done by strictly economizing lights; we made rigid rules as to the use of incandescent lights, which worked very successfully.¹ As regards internal lighting generally, it has always struck me that nowadays, where formerly you burnt a purser's dip, you are not satisfied unless you have a 50-candle power light. Surely there must be some medium between the two. It is all very well turning night into day, but you would nowadays turn night into more than day itself ever can be. My impression is that the incandescent lights are somewhat recklessly used on board ship. It reduces their life and means of course increased expenditure of coal. That is a point on which, I am sure, by strict attention and going carefully into it, coal can be economized very largely.² The figures which Mr. Riley gives are quite extraordinary, as showing the difference in the radius and distance with and without the electric light, and they are well worthy of consideration. In fact this paper, I think, ought to do in that respect a great deal of good. I beg to congratulate Mr. Riley on having given us this very interesting and suggestive paper.

Mr. W. H. RILEY: I am very much obliged to the meeting for the way in which they have received my paper. I understood Mr. Wingfield to say that he did not put very much faith in the value of steam jackets, and he gave a very ingenious explanation of their action. I know that the action going on inside the steam jacket and in the cylinder is very much a matter of conjecture, and, therefore, I was careful to confine myself to established facts. There have been trials made with naval engines under certain conditions, with and without the steam jacket in use, and it has been shown that steam jackets are of economical value. In a particular case I have in my mind of a bi-compound engine, the steam expanding about three times in each cylinder, the increase in horse-power was quite 10 per cent. with the same expenditure of fuel. The circumstances under which this trial was carried out were of a trustworthy character; and, moreover, the result is borne out by other cases in which an equal degree of economy was obtained. With regard to the point raised by Admiral Colomb, and confirmed by Prince Louis of Battenberg, of the effect of the direction of the wind on coal expenditure when steaming with one screw of a twin screw ship, I may say that there have been several cases reported where the change of the wind from the port to the starboard bow, or *vice versa*, has turned an economical performance with one screw into a wasteful one compared with the results obtained when using both screws. This was one of the circumstances I had in view when inserting in that part of the paper dealing with this subject that "economy is largely dependent upon conditions of weather,

¹ I am afraid I strayed rather away from the point under discussion by mentioning accumulators. Their value has no doubt been decreased by the more general introduction of auxiliary boilers.—L. B.

² I meant to have added that I do not advocate any restriction in coal expenditure for internal lighting, fresh water for cleaning purposes, generally, &c., in times of peace. Coal is always to be had, and its generous use for the purposes enumerated undoubtedly adds vastly to the general well-being on board ship.—L. B.

&c." I did not go very deeply into the question of the effect of the auxiliary services on the radius of action, but the case I quoted I thought would be sufficient to show what was the effect in the special cases of the steering engine and the electric light. Any one may, from the diagram, Fig. 1, and knowing the total quantity of coal that can be carried, find what is the radius of action for each speed. This diagram represents an actual case, and gives the speed, the tons of coal expended per day for steaming, and also that for auxiliary purposes, and from these particulars other curves of radius of action can be plotted which would at once indicate the effect of the coal expended for auxiliary purposes. Mr. Liversedge anticipates that the economy at reduced power, in the case I have quoted, was produced by increasing the rate of expansion; that was so. As the power was reduced so the cut-off was made to take place earlier and the jacket pressure at the same time suitably adjusted. Undoubtedly this increased rate of expansion was an important factor in obtaining the economy at the lower power. I have not the figures at present as to the temperature of feed water in the case of the "Thunderer," when she evaporated 9·6 lbs. of water for each lb. of fuel; the temperature of the feed water is, however, that at which it was supplied to the boilers on board. I think I may say roughly it did not exceed 100°, and the boiler pressure was 110 lbs.¹

The CHAIRMAN (Admiral Church): It is my duty now to bring this discussion to a close. I perfectly agree with Mr. White as to the great value of this paper, particularly to the executive officers of the fleet, more especially the officers in command of Her Majesty's ships. My opinion most entirely coincides with what has fallen from Prince Louis of Battenberg about the economy made in the auxiliary engines. There is no doubt that these engines are put into the ships to make them more efficient for the war purposes for which they are built, and if too much economy is observed in peace-time we should not be well up to working those very engines which we should have to use in war-time. I think it is absolutely necessary to use these engines in peace-time as we shall have to do in war. There is no doubt that in war-time the electric lighting of cabins and of the mess rooms will be dispensed with, but I do not see, myself, what other economy in that respect we could carry out. I think we are very much indebted to Mr. Riley for this admirable paper so cleverly drawn up, and also particularly for the diagrams which he has given us and which will be most useful in future. I am sure I am fulfilling the wishes of all present when I thank Mr. Riley very much for his paper.

¹ Since reading this paper I have been made aware that the method described in it of obtaining the most economical speed is not new.—W. H. R.