matter; they certainly were not above learning wherever there was a lesson to be learnt.

The lightness of the machinery in the navy was partly due to the circumstance already explained, namely, that for the boiler shells of the navy such thicknesses were not adopted as were common in the mercantile marine; and so far as experience extending over several years could be taken as a guide, the change to thinner shells had been fully justified by the performances of the boilers. The lightness of the engines themselves was due in a great measure to a circumstance to which he thought sufficient importance had not been attached in the paper, but which really exercised a great influence, namely: that in regard both to the ships and to the machinery, the fullest possible advantage was taken by the Admiralty of whatever could be done in the way of progress at any time by the makers of the materials, and they were prepared to pay more in first cost, if they could get, either in the form of forgings or castings or in any other way, an arrangement of material which would give the best combination of strength with lightness. In the mercantile marine he thought the author would agree with him that in the later examples of engines a considerable improvement had been made in the same direction by the developments of steel manufacture, and particularly steel castings, which the Admiralty had consistently utilised for many years at great cost. The aim in the navy was not to carry any material that was not doing work, even if its removal had to be paid for.

While it was not an unknown occurrence to have break downs in the machinery of the navy, neither were similar accidents unknown in the mercantile marine; but to the latter it was not considered worth while to give the same prominence which was given as a matter of course to the former, and which was justified by the interest that the country took in the navy. But over a long period of years he was not aware of more than one or two cases in which the accidents in the navy had been of a serious nature or had affected the main engines. As a rule they had been confined to parts of an auxiliary or subordinate kind; and they had not occurred in parts which were commonly upposed to be so much lighter than the corresponding parts in the engines of the mercantile marine. In fairness to those who had charge of the machinery afloat it should be borne in mind that great difficulty arose from the engines being so rarely worked at full power. Reference had been made in the paper (page 43) to vessels of the cruiser class, which on an emergency could develop a maximum of over 9,000 horse-power, but as a rule were developing only from 1,000 to 1,500 horse-power. In their fleet manœuvres and in ordinary navigation the latter would be about the range of power; and only occasional trials were made of the maximum power, either quarterly or half-yearly. It would readily be understood what must therefore be the difficulty to the engineers in charge of maintaining the same efficiency and readiness in all respects for developing a high power in ships working so much below it under ordinary circumstances: as contrasted with the state of things existing in ships running from the port of Liverpool to cover a fixed distance, with their engines always doing their best. The conditions were altogether so different, that the difficulties with the naval engines were inherently considerable, no matter what care might be taken.

In the comparison of weight of machinery given in page 63 and Table 4 of the paper, he thought the weight which was in the ships of the navy was somewhat understated in relation to their power, because the relation was here based on the highest power, which was developed only under exceptional conditions. Some years ago he had himself compared the relation between the weight of the machinery in a vessel built for one of the leading steamship lines and the power ordinarily developed, with the relation which would have held good for a man-of-war built and engined by the same makers, and working under what might be called the condition of full sea-going power, which were taken to be about two-thirds of the measured-mile conditions; and the difference of relative weight when so compared was not anything considerable.

The subject of twin screws was one with which he had been personally concerned about thirteen years ago; and at that time he had ventured to predict that there was coming a period in Atlantic navigation when the conditions which then existed in the navy would be reached in the mercantile marine, and that twin screws would be adopted as a matter of necessity and as a distinct advantage. That prediction, which at the time had been to some extent a speculation, had now been verified by experience with twin screws in vessels from the size of torpedo boats of less than 100 tons up to vessels of 13,000 tons displacement, and for speeds varying from 26 to 15 knots; and so far as could be ascertained under the difficulty of making exact comparisons with single screws, the balance of advantage in regard to efficiency of propulsion was on the side of the twin screws. The swiftest vessels that had yet been built, including torpedo boats, had twin screws. He had himself taken the times of a torpedo boat propelled by twin screws, which made six runs over the measured mile at a speed of $26\frac{1}{4}$ knots an hour; he did not know of any single-screw boat which had done the same. In one instance he remembered such grave doubts had been entertained of twin screws that the speed for a twin-screw vessel had been specified two knots below that which would have been guaranteed with a single screw; and at the end of the trial it was found that the speed actually attained had been one knot above what the single screw would have given. At the present time the tendency was to subdivide the power still further in war-ships. There was now building in France a vessel of great speed and great power, in which there were three sets of engines and three screws; and in the United States the same thing was being done. The matter had been carefully looked into at the Admiralty many years ago; and while recognising the possibility that the time would come when three screws might have to be substituted for two on a limited draught of water, he thought the balance of advantage was not sufficiently decided in favour of the change. That was one way however in which the French and American designers thought they were going to get over the inherent difficulty of the great range of power through which the engines in a war-ship were required to be capable of working. In the "Blake" and "Blenheim" (page 67), in which the power was 20,000 I.H.P., there were four sets of engines, two on each screw shaft. This was a plan which had formerly been devised in the Admiralty, before it had been applied in any war-ships that he knew of; but it had then been set aside as an arrangement which would come in whenever much greater powers were required. Now that these higher powers had been reached, the plan had been brought into use; and it would be interesting to see what would be the best manner of dealing with these engines, which were so arranged that they could be separated for working under ordinary conditions. It was clear that, if the after set of engines on either shaft were to be continuously running, great care would have to be taken to keep the shaft in a true line with the forward set of engines which were being used only occasionally; and this matter was not escaping attention. The problem of working at low speeds by throwing certain cylinders out of action was also one that had by no means been overlooked. Seven or eight years ago, when he was not in the Admiralty service, he well remembered going thoroughly into this matter, with Mr. Marshall he believed, to see if it could be contrived to throw one cylinder out of action, so as to work the engines at the low powers as a two-cylinder compound instead of triple-expansion. It was found to be perfectly feasible; and their experiments at low powers showed that even large engines when so treated did not indicate quite so much waste as might be imagined. The greatest difficulty in a war-ship was one that had no concern with engineering, but altogether with tactics: namely that, even when the power had been brought down low, it was still necessary to have a large reserve of power in readiness for immediate use. It might be that for the low power one boiler would give all the steam required, and more; but the possible demands for variations in speed, necessary for station-keeping and purposes of that kind, compelled the engineers to keep other boilers alight, in order that, when the signal was suddenly given from the bridge to increase the revolutions, say from 45 to 60 per minute for keeping-station, it might be obeyed without hesitation. In statements as to coal consumption during manœuvres in which the speed of the fleet was perhaps only eight knots, while the possible speed that the ship possessed in order to keep station would be ten or eleven knots, he had often found that the lower power required for only eight knots was reported, instead of the higher power which would represent ten knots. As the expenditure of power varied nearly as the cube of the speed, it followed that, when nominally working at only eight knots but ready at any moment for the possibility of ten knots, the boilers must practically be generating twice as much steam as was being actually used except at occasional intervals when a spurt became necessary. This was a matter of great interest to those engaged in designing war-ships.

Not being himself engaged in the design of marine engines, he would only add that the mercantile marine and the war fleets of this country and of the rest of the world owed a great debt of gratitude to marine engineers for what they had done during the last twenty years in the way of promoting commerce, cheapening ocean transit, and giving the power ef performing long voyages at high speeds.

Mr. Edward Reynolds remarked that the proposal made by Mr. Marshall to use cast-iron steam-pipes in ships might to some appear heretical; but in corroboration of their sufficient elasticity he might mention that his own firm had experienced no difficulty whatever in using cast-iron steam-pipes for steam-hammers. There had not been a breakage for many years, either with 15-ton hammers having 9 feet stroke, the top of which swung considerably if they struck an oblique blow; or with small hammers making 450 strokes a minute, where the vibration of the pipes was exceedingly rapid: the connection with these small hammers was made rigidly, all the movement being provided for by the elasticity of the pipes.

Mr. CHARLES COCHRANE, Past President, in connection with the reference made to weldless steel tubes spun out of solid bars, mentioned that he had recently seen a specimen of steel tubing which had been spun in a different way out of the molten metal by a rapid rovolution, in conjunction with a gradual tilting of the vessel containing the molten steel, until at last the liquid metal took its solid form within the revolving casing, in the shape of a hollow block or cylinder from which the tube was afterwards drawn. By that plan the hopes of getting rid of the occluded gases, as he believed they were called, seemed to be great; for one of the little blocks so formed, hollow in itself, which was ready to be drawn out into a tube, had been turned down most carefully, and it revealed no signs whatever of the minute blow-holes, which had been mentioned as such a source of danger in solid-drawn pipes produced from copper ingots. He had himself seen and examined the specimen so turned down, but had not witnessed the process by which the hollow block had itself been spun from the molten steel for making a weldless tube.

The reference made in page 58 to the important matter of keeping the water pure in the boilers of sea-going steamers he considered was equally applicable to many land boilers, where impure water had to be dealt with. In connection with the evaporators, a point which had not been referred to was that, by employing two or three of them in succession, the number of "effects," as they were called, could be multiplied. By diminishing the pressure from one to the other consecutively, a definite weight of steam to begin with could be made to evaporate an equal weight in the first effect, barring the loss by radiation: a similar weight in the second, by the steam coming off from the first; and again a similar weight in the third, by the steam coming off from the second. Thus with one initial quantity of steam three or four times the quantity of distilled water could be produced, compared with that obtained from a single still. This he thought was an important point in connection with land engines as well as marine engines.

The employment of twin screws he believed was attended with a collateral advantage in the opportunity which they afforded for dividing the vessel by a longitudinal bulkhead, instead of by transverse bulkheads only, in order thereby to consult the safety of the public and to make the ship unsinkable. In discussing this matter recently with the captain of one of the Union Line steamers, the latter had laughingly asked, "What about the poor captain with his vessel all on one side?" and had added that he thought he would rather see his ship go to the bottom than have to manage her when she was heeled over on one side. That of course was a difficulty with regard to which experience would have to be acquired; and perhaps it might be met by making some arrangement for filling another compartment on the other side of the ship.

Mr. J. Macfarlane Gray considered the paper now read was a most valuable one, which would often be referred to for many years to come. It appeared that the author had no interests of his own to bias his views; and his whole object seemed to be to enable others to advance yet further in improving their practice.

In regard to the economy of forced draught, (page 43), there might be convenience in it, but there could not possibly be economy unless the elevation of the temperature of the funnel gases was thereby reduced. The heating of the air was not mentioned at all in the paper, but it was said that the use of forced draught was equivalent to an economy of 15 per cent. It was properly added, however, that part of this economy might be due to the other heat-saving appliances with which the steamers using forced draught were fitted. In considering forced draught he thought it was important to have a clear appreciation of the advantage it really possessed. In economy of coal the only advantage which could be gained was the saving of heat from some waste source. Nearly enough for all commercial considerations, it might be taken that the calorific effect of coal, as ascertained by laboratory evaporation tests, was equivalent to 2,500° Fahr. elevation of temperature in the products of combustion on an ordinary firegrate, whatever the quality of the fuel might be. Every 25° difference of temperature represented therefore one per cent. of the calorific value of the fuel; or the percentage lost of the calorific value of the coal by the elevation of temperature in the funnel gases was always equal to 4 per cent. of that elevation of temperature in degrees Fahr. The unit in this comparison was the total heat value of the fuel, as in a laboratory experiment. In comparing natural draught with forced draught, say that the air was obtained at 80°, and that at the extremity of the heating surface, whether in the boiler or in the funnel, the temperature of the gases was 705° with the natural draught and 580° with the forced draught. The comparison then worked out thus:—the elevations of temperature were respectively 625° and 500°; with natural draught 25 per cent. was wasted, leaving 75 per cent., while with forced draught 20 per cent. was wasted, leaving 80 per cent. The difference was therefore 5 on 75, or $6\frac{2}{3}$ per cent. in favour of forced draught. This was a good result, but it was less than half of 15 per cent. In this example the temperature of the chimney gas was reduced 125°, and that of the ashpit air increased 125°; but the saving in elevation of temperature must not be regarded as 250°, because the 125° could be counted only once. If the air were supplied by forced draught the great difference of temperature between the funnel and the atmosphere was no longer required for producing the draught, and the temperature in the funnel might therefore be reduced by increasing the heating surface in the boiler. Advantage could not well be taken both of forced draught and of heated air to increase thermal economy, because if the temperature in the funnel were reduced, a larger extent of heatfng surface would be required for producing only a small increase of temperature in the entering air. If the quantity of air admitted per pound of coal were reduced, that would in itself be a source of economy; but then, the smaller the quantity of air, the less gain would there be by reducing the waste temperature. If the air were reduced to the theoretical quantity absolutely required for chemical union, say 12 lbs. of air per lb. of coal, it would require 48° increase of temperature in order to make a difference equal to one per cent. of the heat of the fuel. There was no doubt an economy in forced draught if cheaper coal could be got. But if this was called progress, what was the goal towards which it was tending? and would it be altogether an advantage? Apart from the Admiralty requirements, which were imperative in demanding forced draught, the goal appeared to him to be an increase in the price of the slack which was at present wasted: so that ultimately the advantage would all be with the coal-owner.

In page 44 it was remarked, in reference to the construction of boilers for working with forced draught, that the extent of the heating surfaces of the furnaces and combustion chambers must be sufficient to absorb a large proportion of the heat before the products of combustion reached the tubes; otherwise the use of forced draught would result in burning more coal than corresponded with the limit of heat which the surfaces were capable of taking up and transmitting to the water. For the efficiency of the heating surface in a boiler, Professor Rankine had given the formula $(T_1 - T)^2 \div A$, where T_1 and T were the temperatures in the hot gases and in the water respectively, and A was a constant ranging from 160 to 200: that is, the heat units absorbed per hour per square foot of heating surface were represented by the square of the difference of the two temperatures divided by 160 to 200. That was a plain rule, and the only question was whether it was right; it had been thought out by Professor Rankine, who no doubt had had a good reason for stating it; but he did not know that it had as yet been verified. A useful formula with narrower range of constant was desirable.

As to the lightness of engines and boilers, this of course was a question of importance to the navy, especially the lightness of boilers; but he thought it would be a great pity to make them any lighter than they now were in the shells. The shipowner who first went in for lighter boilers would have a little advantage for a time, but he would also be running a risk. Even if he were right, the temporary advantage would be taken from him by his neighbours as soon as they saw that he had been successful; and it would be no advantage to him ultimately.

In the use of corrugated flues for furnaces he had found it had commonly been supposed that all the advantage consisted in getting an increased extent of heating surface in the corrugations, and that, if the additional strength required were obtained by making the plate thicker the conductivity of the iron would thereby be diminished. Those, however, he considered were two fallacies. Although there was indeed an increase of surface, yet there was no increase of heating surface in the corrugations, because the heat received by the crown of the furnace from the incandescent fuel was almost entirely radiant heat, and radiant heat moved in straight lines; and just as in the case of rainfall upon an uneven surface, no more heat would fall upon the corrugation or would be received by it than would be received by a plane surface which covered the corrugation. The notion that the conductivity of the metal was greatly impaired by its thickness was also a fallacy. It used to be believed that the thickness of the metal was a matter of importance in this respect, but the modern view, which was now held by all who had studied the subject, was as stated in the paper (page 47), that the resistance to the transmission of heat through a metal plate consisted almost entirely in the resistance which the heat met with at the surface in trying to pass from one medium into another, that is, in getting from the air into the iron, and again in getting from the iron into the water. It was as if the heat wavelets had to change their step. They were proceeding at a certain step in the air, and then they had to change their step to get into the iron. It seemed as if they had to think about it, and hesitated before they changed step and got into the iron; and then they had to change again, and hesitated again in getting into the water. It was there that the resistance occurred. He did not know that there was any rule directly limiting the thickness of furnace-plates of steel or ingot iron to 5-8ths inch (page 47). There was a crushing limit stated, about two tons per square inch on steel furnace-plates, and as this was reached at 5-8ths inch thickness with furnaces 6 feet long, perhaps what the author meant was that up to say 5-8ths inch the pressure allowed was proportional to the square of the thickness, and above this thickness it was proportional to the thickness simply.

In page 50 his name had been mentioned in connection with a proposal for cutting off the low-pressure cylinder for working at low power; and in reference to Mr. White's remarks on this subject, he understood it had not been attempted to experiment in the navy with leaving off the low-pressure cylinder, but one of the other cylinders. This was a matter which was looked at differently by different people. By one eminent engineer he had been told that it was downright nonsense to propose anything of the kind, while another engineer had taken a great interest in the plan, in connection with the steamers which were sent out to China for tea. He stated that it did not matter how slowly they went out, but they had to come home at a high speed; hitherto they had failed to gain anything by going out slowly, and he now intended, if he could arrange it for the pumps, to disconnect the connecting-rod of the low-pressure cylinder when they went out next season. This arrangement he had been informed had