already been carried out in the engines of one of the new steamers of the American navy, the "State of Maine," and he understood from Mr. Maw that it had for a long time been tried also in Russia. Even the Russians were therefore in advance in this respect, and they were no doubt going to work in the right way for economical slow steaming.

In page 52 reference was made to the link-motion, and also to the lead of the valve varying. In this connection the simplest rule to remember was that the link should go with the engine instead of against it: that is to say, the direction in which the link had to be shifted for starting the engine should be the same as the direction in which it was intended the crank should rotate The link then gave an increased lead for an earlier cut-off; and this he thought ought to be so, because if the earlier cut-off were accompanied by a diminished lead, the steam would be wire-drawn. The principle of crossing the rods so that the link should go with the engine, instead of against it, was carried out in Stephenson's link-motion. At one time he had thought it was an advantage to have the rods crossed the other way, giving a diminishing lead with earlier cut-off and causing the valve to remain closed when the engine was stopped; but many years ago the mistake had been pointed out to him by Mr. George Crow, of Messrs. Stephenson's, and he had then made the rule for himself that if the link went with the engine the lead was increased for earlier cut-off, but if it went against the engine the lead was diminished for earlier cut-off.

In reference to the early use of wrought-iron for steam-pipes (page 53), the first notable example of wrought-iron steam-pipes for marine engines, he believed, was that of the "Great Eastern"; but he understood it had not proved a success, because the corrosion was so extensive. The "Great Eastern" he believed had been broken up in Liverpool; and if the state of the steam-pipes could be ascertained exactly, he thought it would be found that it was not encouraging to the use of wrought-iron. Cast-iron steam-pipes had been used in steamers where the pressures were lower; but they were as liable to accidents as copper pipes. In one of the vessels so fitted, there had been a bad accident from the bursting of a pipe when the steam was admitted, owing to water lying in a depression.

Mr. Jeremiah Head, Past President, questioned the assertion that the use of small and inferior coal would be of advantage only to the coal-owner. He had recently investigated some coal mines in America, and had found that, the coal being of a friable nature, not less than half of it turned out to be small. In Staffordshire, he understood from Mr. Cochrane, there were some colleries which yielded so much small coal that they were called "slack" collieries. If the circumstances of steam navigation had hitherto been such that only half the coal produced from coal mines generally had been available for steam-ship purposes, and if now by the aid of forced draught, it was possible to use the other half consisting of small coal, the supply available was certainly doubled. How that result was going to be of no advantage whatever except to the coal-owner, he could not see. Instead of raising the price of coal, he should think it would tend to diminish it. There was the old well-known saying that any one who made two blades of grass to grow where only one blade grew before was a benefactor of the human race; and he certainly thought that engineers, who by means of forced draught or in any other way made two tons of coal available where one only could be made use of before, were equally benefactors of the human race.

Mr. W. Ford Smith remembered that as long ago as 1847 or 1848 a steamer came to Liverpool from America, in which forced draught was applied by closing the furnaces and using a blowing fan. On asking what benefit had been obtained from the plan he had been told that the advantage was great. The vessel was a large one, and was called the "United States"; and he had seen her when she was in the Liverpool docks.

Mr J. Hartley Wicksteed, Member of Council, asked the author to explain the mechanical action of the engine shown in

Fig. 20, Plate XI, in which the piston rods were connected with the crank by means of a triangular frame.

In regard to the strength of the furnace plates, considering that a beam was stiff in proportion to the square of its depth, it was clear that, if the same metal were put into a deeper form, so that it measured more from the top to the bottom of the transverse section, the beam would be stiffer to resist distortion than if the metal were distributed in a parallel form, which did not measure so much from the top to the bottom. In that way, quite apart from the question of conductivity, a furnace plate with circumferential ribs or corrugations was stiffer than it would be with the same amount of metal, or even with a much larger amount of metal, in a thicker plain cylindrical plate.

Mr. Michael Longridge thought that much confusion arose as to the merits of forced draught from the want of a clear estimation of the kind of economy obtained by its application. That forced draught rendered it possible to burn inferior coal was beyond dispute; but that it could make a ton of inferior coal produce as much heat as a ton of the best coal was not to be believed; and therefore in estimating the economy to be realised from the use of inferior coal, a shipowner would at least have to consider the extra weight of coal to be carried and trimmed, and the increased weight of ashes to be lifted. It was also beyond dispute that a given boiler and a given quality of coal would supply more steam in a given time with forced draught than without it, because more coal could be burnt with forced draught than without it. The question was whether the consumption of coal increased more slowly, or at the same rate, or more rapidly than the production of steam; and the test was the weight and temperature of the escaping gases. Every pound of coal represented a certain number of units of heat, say for example 14,000. Of these a certain portion, say 1,000 units, would be lost by radiation; and another portion, say 1,000 units, by drawing unburnt coal out of the fires when cleaning There would thus remain, say 12,000 units of heat;

of which a part would pass through the plates into the water, and the remainder would escape up the chimney; and it was evident that, if the part carried up the chimney was increased, the part absorbed by the water would be diminished, that is to say a larger percentage of the coal would be wasted. The question then was whether the weight and temperature of the chimney gases were increased by the use of forced draught. At first sight it would appear that they must be, because with forced draught more coal was burnt per square foot of heating surface, and therefore the temperature of the chimney gases would be higher. This was the view he himself had at first taken. But experiment had led him to question its correctness. From evaporative tests of boilers in ordinary work with chimney draught he had been endeavouring to ascertain the rate of transmission of heat through boiler plates per square foot per degree of difference in temperature on the two sides, measuring carefully the coal and water and chimney gases; and he had found the transmission to vary from about 4 to 6 units per square foot per hour for each degree Fahr. of difference in temperature. He had also calculated the same coefficient from the published experiments of Professor Kennedy and Mr. Donkin and others, with the same results. Now, in the boiler of a locomotive working with a blast the rate of transmission wss supposed to be about 11 units per square foot per degree per hour, or nearly twice as great as in boilers working with an ordinary chimney draught. The difference he thought had not anything to do with the type of boiler; for one of Messrs. Kennedy and Donkin's experiments on a locomotive boiler with ordinary draught gave a coefficient rather lower than 4 units. Was the higher rate of transmission in the locomotive with the blast in any way connected with the higher velocity of the gases passing over the heating surface? It was well known that, in heating water with steam or in condensing steam, the rate of transmission or heat was materially increased by a higher velocity of the currents. If the same thing occurred in transmitting heat from gas to water through the plates or tubes of a boiler, it was possible that, with a forced draught and a high volocity through the flues, more heat might be transmitted per square foot per degree of difference in temperature than with natural draught and a lower velocity. Experiments with ordinary draught seemed to point in this direction; for the coefficient of transmission appeared to increase with the quantity of coal burnt per square foot of heating surface, and with the quantity of air burnt per pound of coal. It might therefore be possible that owing to the higher rate of transmission more coal might be burnt in a given boiler with forced draught than without it, and yet the temperature in the chimney might not be materially increased, while the percentage of heat lost by radiation, and the percentage of unburnt coal in the ashes, would undoubtedly be reduced. Hence it seemed to him that there might be some economy, or at all events no loss, from using a higher water-gauge pressure. In calculating the co-efficient of transmission a very speculative quantity had to be dealt with, namely, the temperature of the furnace. For this calculation, reference had been made by Mr Gray to Rankin's rule, which assumed that the transmission varied as the square of the difference of temperature; but he did not see that there was any more satisfactory reason for supposing that the transmission varied as the square than for assuming that it was proportional to the first power of the difference of temperature. The latter was the assumption he had made the basis of his own calculations, because it was clear that in taking the square of the difference any errors in the estimation of the furnace temperature would have a far greater influence on the results; and the co-efficients obtained would be likely to be even more erratic than they unfortunately were. On these grounds, among others, it seemed to him that theoretical reasoning, based upon a rate of transmission which was assumed to be unaffected by the velocity of the gas currents, was not conclusive; and that there might after all be some intrinsic economy in forced draught, apart from quality or price of coal and from first cost of boilers and space occupied by them.

Sir James N. Douglas, Vice-President, having had some experience at sea with a vessel carefully fitted with forced or assisted draught, considered that, apart from the theoretical aspect of the question, there was a great deal in it of a practical nature. A ship not provided with assisted draught was subject to all the fluctuations of the atmosphere. One day the engineer would report that there had been a capital draught, and that everything was satisfactory as far as combustion went, the coal having done its work well; while another day he could do nothing with the fires, and everything was against them, and he was simply poking the coal through the fire-bars and wasting it, especially if it was not of the first quality. Again, it was well known that sometimes the starboard boiler might be working well, while it seemed as if nothing could be done to make the port boiler work efficiently. With assisted draught a ship had the means of producing satisfactory combustion every day, which must have a great deal to do with economy; and the air pressure could be varied from ¼ inch up to 2 inches of water, to meet the contingencies. Looking at the matter from a simple practical point of view he considered there was much to be said in favour of forced draught; and if it were not attempted to carry it too far, he maintained that in its present aspect it was a valuable adjunct to ocean navigation.

Mr. Blechynden said that, in referring to the question of forced draught, Mr. Macfarlane Gray had expressed the opinion, on certain grounds of his own that there could not possibly be economy unless the temperature of the funnel gases were thereby reduced. But having learnt to place more reliance upon facts than upon opinions, he hoped to be excused for differing utterly from that view. It had been shown in the paper that in the examples given those boilers which were worked with forced draught were more economical as regarded coal consumption in relation to power indicated than those worked with natural draught. These examples were given in Table 5 and summarised in page 42; and unless it could be proved that the superior economy was due to some other cause, it would be fairly certain that forced draught would get the credit of the saving. But there might also be another source of economy, referred to afterwards by Mr. Gray, in diminishing the quantity of air supplied for combustion. It was evident that, if the quantity could be reduced by 10 per cent., the temperature of the products of combustion would be increased about 10 per cent., and as the efficiency of heating surface was in proportion to some function of the difference of temperatures upon its two sides, the economy would thereby be augmented; and facts went to show that this view was sound. To the statement that the heating surface must also be increased if economy were to be attained with forced draught, he likewise demurred on the ground of facts to the contrary. For instance, experiments had been made in one vessel having four boilers of the navy type, which were fitted with forced draught applied on the closed stokehold principle; when two of the boilers were tried under forced draught, it was found that with about one inch water-gauge of air-pressure the same power could be developed as with four boilers under natural draught with the same coal consumption, though in the first case each indicated horse-power was being developed on about 2·1 square feet of heating surface, while in the second 4·2 square feet were required. Thus a decided advantage in economy was shown for forced draught.

By the pass-over slide-valve mentioned in Table 5 was meant a valve with a port of the Allen or Trick kind, but so arranged that it made communication between the ends of the cylinder at the point of release. Thus part of the steam released from one end of the cylinder was made to fill the port and clearance at the other end, whereby an economy was effected. The particular make of this valve that was fitted in the examples referred to in Table 5 was that of Mr. John Thom.

In the engine shown in the diagram, Fig. 20, Plate XI., the triangular frame by which the two piston-rods were connected with the crank was a solid rigid frame, swinging on the end of the air-pump lever, and its two top corners were each attached by a link to the corresponding piston-rod, which was of course guided in a vertical line. Hence in the position shown in the diagram, with the crank on the top centre, the first effect of the movement of the crank in either direction would be to tilt the triangle, and to throw one piston higher up and draw the other down. Later on, both pistons would be moving down together until the crank was passing the bottom centre, when the converse effect would be produced in the motion of the pistons: after which they would both move upwards together.

The introduction of the blast-pipe in locomotives, which had been ascribed by Mr. Marshall to George Stephenson, might more justly be attributed, he thought, to Timothy Hackworth, or possibly to Trevithick; while perhaps, as regarded the origination of strictly *forced* draught for steam boilers, even a better case might be made out for Braithwaite and Ericsson, who had used bellows in the "Novelty."

All the results obtained from the screw experiments mentioned in page 59 had been carefully compared with practical results, and had been found to agree accurately therewith; and advantage had been taken of them in designing propellers on the largest scale, with marked success. It was true, however, as justly observed by Mr. Marshall, that the subject was largely empirical; and in this respect indeed it was like many other questions of considerable importance in engineering.

Attention had been called by Mr. White to the fact that the propelling machinery adopted in the navy was no lighter, relatively to its ordinary power, than that in the mercantile marine. Not only, however, was it not lighter, but it was indeed far heavier, as seen from the comparison in Table 8 between the lightest (No. 9) of the three sets of naval machinery (Nos. 7, 8, 9) in Table 4, and the machinery of some mercantile vessels.

TABLE 8.

Weight in relation to Indicated Horse-Power,

in lightest (No. 9) of three sets of naval machinery (Nos. 7, 8, 9) in Table 4,

and in mercantile machinery.

Class of Machinery.	Indicated Horse Power.			Weight of Machinery.			
	Maximum power.	Natural draught power.	Ordinary power.	Total.	Per I.H.P. for Maximum power.	Per I.H.P. for Natural-draught power.	Per I.H.P. for Ordinary power.
	I.H.P.	I H P.	I.H.P.	Tons.	Lbs.	Lbs.	Lbs.
Naval	*9,000*	7,200	1,500	691	172	215	1,030
Mail Steamer	9,625	8,000	7,000	1,414	330	396	452
Merchant Steamer . . .	1,600	,1450	1,050	262	366	405	534
Transatlantic Passenger Steamer	15,500	...	13,500	2,350	340	...	390
Do. do do.	20,000	...	18,000	2,600	292	...	324

* Specified test.

From this comparison it would appear that for the power at which it was to be worked during perhaps 95 per cent. of its whole time of running, the weight of material allowed in naval machinery was double of that allowed in the mercantile marine for the same power. Nevertheless, as the safety of the navy depended upon the certainty of the maximum power being developed without mishap, it was necessary that the allowance of weight for the full power should be efficient to ensure no part being strained beyond safe limits. With the present weights allowed, and with economical use of the material, there was no reason why, in machinery such as that represented in the first line of Table 8, any part should be strained beyond what would be considered perfectly safe in mercantile work.

The President said this paper was especially interesting in Liverpool, where marine engineering had made such rapid strides. It was also acceptable as continuing the papers of Sir Frederick Bramwell and Mr. Marshall, whereby in reality an account was given of what had taken place from the commencement of steam navigation to the present time. It was now his pleasant duty to propose a cordial vote of thanks to Mr. Blechynden for his paper; and all the Members he was sure would heartily join in according it to him.

Mr. Robert Bruce wrote that, although reference was made in the paper to the use of closed ashpits, closed stoke-holds, and mechanically induced draught, no examples were given of ships worked continuously at sea under these plans, whereby comparisons might be drawn. Artificial draught by means of exhausting apparatus in the uptake was one of the oldest methods of stimulating combustion; it was subject to the disadvantages of natural draught, inasmuch as the air drawn by the exhauster could not be made to distribute itself equally through each furnace and over the whole heating surface, and there was always a tendency for the hottest or strongest currents to absorb the cooler and weaker ones; there was consequently a lack of uniformity in temperature throughout the heating surfaces, and of a proper control over the distribution of the air supply. The exhausting arrangement had the effect of increasing the velocity of the hot gases, and thereby preventing them from imparting their heat to the heating surfaces so advantageously as with natural draught. Another disadvantage was that a fan dealing with hot gasses could not be an economical appliance as to wear and tear; and its size for exhausting from a given range of boilers would require to be at least double that of a fan dealing with air at the temperature of the atmosphere. The closed ashpit he also considered was at variance with economical working. The air admission being restricted to the under side of the fuel on the grate, there was a lack of air to consume the volatile products, and a consequent loss of heat, with great production of smoke. Where the closed stoke-hold was employed merely as an auxiliary to boilers which were already large enough for their duty with natural draught, and was brought into use only when the weather or other conditions were unfavourable for good natural draught, the rate of combustion usual with natural draught was not exceeded. When however the closed stoke-hold was adopted for boilers intended to work with a high rate of combustion and a high power per square foot of heating surface, then the injurious nature of the plan became apparent. Altogether the continuous working of the plan was surrounded with serious practical difficulty; it was costly to begin with, and any increase of power beyond that due to natural draught had to be obtained regardless of economy of fuel. When with forced draught was combined a proper method of controlling the distribution of the air to each furnace and ashpit, and also a simple mode of heating the air by the waste gases, any ship so filled was able on short notice to reduce or augment the production of steam according to the power required. In relation to the work done, strong evidence in favour of forced draught as compared with natural draught was supplied in Table 5. Comparing for instance No. 11