

Mr. GREGORY, President, observed that, of all the branches of engineering, those which had increased the means of communication with distant parts of the world, either by land or water, had perhaps most obviously contributed to the wants and benefit of mankind. The Institution therefore hailed with satisfaction a Paper on the development of Ocean Steam Navigation.

Mr. J. GRANTHAM apologized for not having entered upon the practical features of the case as fully as he might have done; but an attack of illness had obliged him to suspend his work. He had been consequently unable to illustrate those features of the improvements in steam navigation which would have been interesting, and to prepare drawings of the different parts of the machinery illustrating the improvements of modern times. In the preparation of the Paper he found there was so large a question opened out, that he was almost insensibly led to give prominence to the commercial features of the subject. Perhaps a more fitting occasion could scarcely have arisen, inasmuch as the whole question of the navigation of the East was now open to discussion. In dealing with it, however, great caution was required, as it was still untried, and therefore open to much speculation. It was also difficult to collect those materials which would throw light upon it. He had therefore taken a wider range than was at first contemplated, and though departing somewhat from the custom of the Institution, he trusted he might be excused for having done so, and for having been led away from the more practical features, which might have been expected by many in a Paper of this description.

Mr. J. D'A. SAMUDA, M.P., quite agreed with the Author that the general features of the case were, in the present instance, the most interesting; and probably there had been no period of history in which they could have been more profitably brought forward. There could be no doubt that the recent extensive application of expansion and surface condensing to engines used for marine purposes was most important; and that without that application the development of steam navigation would become much circumscribed. On the other hand, he thought that, having acquired the means of being able considerably to extend operations, the Suez canal was another primary element for consideration, notwithstanding it was only in its early stage of experiment. He understood the Author argued that, whereas formerly, from the difficulties experienced in long voyages, the use of steam had been necessarily abandoned altogether, now materials had been obtained which would render it available for almost the entire surface of the globe.

Proceeding tentatively, and judging more by what had been done than by what might be expected to be done from theory, he
[1869-70. N.S.]

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thought it might be taken as a settled and ascertained point, that so far as the improvement in steam-vessels worked with expansion and with surface-condensing engines had been introduced, the means of working vessels with $2\frac{1}{2}$ lbs. of coal per indicated H.P. per hour had been practically acquired. He could speak with certainty to that consumption not having been exceeded in vessels plying between London and Odessa, and London and the Mediterranean, and which had carried large cargoes, in some instances as much as 2,000 tons. This low rate of consumption had brought the coal within so small a compass, that sufficient coals could be shipped in England for a continuous voyage of 4,000 miles, without practically interfering with the profitable cargo-carrying capacity of the ship. In the instances he referred to 240 tons were found sufficient for such a voyage. With the opportunity of coaling at the mouth of the Suez canal, vessels would be enabled to go through the Red Sea to Bombay; and when the lines of railway, which were now gradually concentrating the goods traffic at Bombay, were opened, the whole traffic of the East could be carried on by steam, as the Author of the Paper had pointed out, usefully and profitably as a commercial speculation with Great Britain. But the voyage to Australia by the Suez canal was not shortened by more than about 100 miles, and therefore with respect to Australia, preparation must be made to go the entire distance of 12,500 miles. He had no doubt that vessels going 11 knots an hour might perform the distance in from forty-five to forty-seven days. But 11 knots was a great speed to maintain over that distance; and, with the exception of the much more moderate voyage between New York and Liverpool, he knew of no long ocean steaming where that rate had been maintained. The Peninsular and Oriental Company, which took credit for being one of the first mail companies in the world, did not obtain a velocity of 11 knots an hour throughout the voyage to India, though they might obtain that speed on the European side. Evidence had been given before a Parliamentary committee, two sessions ago, with reference to the renewal of the mail contract which was then nearly expired, that it was considered satisfactory when the vessels attained a speed of $9\frac{1}{2}$ knots to 10 knots per hour on the Indian side. It was not to be expected that 11 knots could be maintained with such vessels as had hitherto been employed in ocean steam navigation.

He had investigated this matter at the instance of the Colonial Government of Victoria, with the view of ascertaining the proper subsidy for steam-vessels running between Australia and England, and had come to the opinion that it would require vessels of from 5,000 tons to 6,000 tons, builder's measurement, and 1,000 nominal H.P., to perform the voyage; and he thought the Author of the Paper would confirm that opinion, if he started from the same premises

as Mr. Samuda was prepared to start from, viz., the quantity of coal ascertained to be needed per H.P. and the coal required for the voyage. If the indicated power were used, to give the velocity spoken of by the Author, he thought it would be found necessary to carry upwards of 3,000 tons of coal to perform the voyage. That would entail a class of vessel which, though very useful for carrying out commercial operations for general purposes, had at present only reached the point of dealing with first-class passenger traffic carried at high speeds, and therefore requiring to be highly subsidised. He was favourably disposed to high subsidy, which, he believed, was equally useful to those who paid the subsidy as to those who received it. In his opinion there was no other way by which to encourage the development of trade, and of such results as would enable commercial operations to be carried out successfully, except by making these experiments partly at the expense of the state, so as to bring them to such conditions that the commerce of the country could afford to pay for. Therefore, at the present moment, he thought the Australian trade, at any speed approaching that spoken of, must be looked at as being beyond the remunerative power in the vessel itself.

Mr. Wigram, who had been a pioneer in the service, had introduced vessels, carrying cargo and passengers, which made the voyage, and were not subsidised; but their performances were more moderate, and their speed did not exceed 9 knots or $9\frac{1}{2}$ knots per hour, a speed, however, which he considered perfectly satisfactory. That enabled the use of the engines to be discontinued for two-thirds of the voyage. But auxiliary power was not what the Author had been attempting to shadow forth, as that which he hoped to see accomplished in the general traffic of the world. Notwithstanding recent advances, however, he thought it would be some time before the old sailing-ships could be replaced by steamships in voyages of 14,000 miles or 15,000 miles. Nothing but the highest rate of subsidy on the earnings of the ship appeared to him to be able at present to encourage and remunerate a trade of that sort; but the tendency was more and more to the accomplishment of the objects pointed out in the Paper, viz., the general application of steam. Where steam had been successfully brought into operation by paying the owners, it had superseded sailing-vessels, and he thought it might ultimately do so in these long distances. He contended that the vessels must be of greater size, and that a greater economy of coal must be effected, before they could be made remunerative, apart from government subsidies for long distances.

Mr. CLIFFORD WIGRAM said that he had given great attention lately to the question of steam navigation, more especially to the indicated power obtained by steamers at sea; and he had

come to the conclusion that owners of steam-vessels had considerably over-estimated the actual power evolved by their engines on the voyages, and consequently under-estimated the consumption of coals per indicated H.P. They thought that at sea an indicated power was obtained about four times the nominal power. He believed that was over-estimated, and that the actual indicated power at sea did not much exceed two and a half times the nominal power. Shipbuilders knew that if it was required to furnish a vessel to work on her station at a speed of 11 knots an hour, she must work to a speed on trial of about $13\frac{1}{2}$ knots. Taking the usual formula, that the power varied as the cube of the speed, he found $13\frac{1}{2}$ cubed was 2460, whereas 11 cubed was 1331. Allowing for the difference of co-efficient of low speed over high, it appeared that for a speed of 11 knots per hour, only about one-half the power was required that would be necessary for a speed of $13\frac{1}{2}$ knots, in other words, five times nominal H.P. on trial dropped down to two and a half times the nominal H.P. on the station. On this assumption he found, from the best returns he could get of the consumption of fuel at sea, that most of the steamers that performed their voyages at a high rate of speed, did so with a consumption of $2\frac{3}{4}$ lbs. of coal per indicated H.P. per hour; and it was not till the velocity was reduced to $8\frac{1}{2}$ knots or 9 knots per hour, that a consumption of $2\frac{1}{2}$ lbs. of coal per indicated H.P. per hour was attained.

It was much to be regretted that owners of steam-vessels did not have proper indicator cards taken, so as to give the exact performances at sea; but he was able to furnish some results of his own vessel, the 'Somersetshire,' which had just arrived in the port of London. He had not yet been able to obtain the results of the homeward voyage; but from the cards taken at sea on the outward voyage, he found the average H.P. for six consecutive days, when she was the whole time under steam, was 712 indicated, the nominal H.P. being 300. The speed during that time was 8 knots per hour, and the consumption of coal 18 tons a day, which gave a consumption of 2.36 lbs. per indicated H.P. per hour. That was a low speed; but it must be borne in mind that the 'Somersetshire' was essentially a sailing-ship with auxiliary power. The orders had been to keep the sails drawing; and he had no doubt the low consumption of coal was attributable to the fact that the sails materially aided the screw. The 'Somersetshire' was a vessel of 2,300 tons, rigged completely as a sailing-ship; she was fitted with engines, by Messrs. Humphrys and Tennant, not coupled, having ordinary cylinders, and surface condenser and superheater. She had a lifting screw, so that, when not in use, the vessel worked entirely under sail. The last outward voyage to Melbourne was made in fifty-eight days

and a half, on twenty-eight of which the screw was used. The full time she was under steam was equal to about twenty days out of the fifty-eight days and a half. He could not give the exact particulars of her dimensions, but the length was about $6\frac{3}{4}$ times the beam. The boilers were ordinary low-pressure tubular boilers, and the working pressure was 20 lbs. to the square inch.¹

Like Mr. Samuda, his firm had been applied to with reference to the desirability of establishing a line of powerful steamers round the Cape of Good Hope, and he had arrived at nearly the same result, viz., that it would be necessary to employ vessels of about 6,000 tons

¹ On two occasions only—both on the voyage out—did the wind appear to have been so light that she derived no assistance from her sails for more than twenty-four consecutive hours.

	1st Occasion — Wind Calm, Sea Smooth.	2nd Occasion — Wind Calm, Heavy Head Sea.
Time under Steam alone	96 hours.	168 hours.
Distance run	776 knots.	1,228 knots.
Speed per Hour	8.085 "	7.31 "
Mean Displacement	3,890 tons.	3,791 tons.
Mean Area of Section	716 feet.	696 feet.
Coals consumed	70 tons.	121½ tons.
Tons of Displacement, driven One Knot by One Pound of Coal . . .	19.25 "	17.14 "

‘Somersetshire,’ 4th Voyage. London to Melbourne and back. July to December, 1869.

Plymouth to Melbourne in 58 Days.

Steam used on 28 days.
No Steam „ 30 days.
Hours under Steam, 475.
Equal to days of 24 hours, 19 days 21 hours.
Coals consumed under Steam, 346 tons 17 cwt.
„ „ per day, 17½ tons.
„ „ per hour, 14.6 cwt.
Average Indicated H.P., 650.
Consumption of Coal, 2.53 lbs. per H.P. per hour.
Total Distance run, 13,319 knots.
Screw raised and lowered, ten times.

Melbourne to the Downs. 68 Days.

Steam used on 40 days.
No Steam „ 28 „
Hours under Steam, 788½.
Equal to days of 24 hours, 32 days 20½ hours.
Coals consumed under Steam, 610 tons 17 cwt.
„ „ per day, 18 tons 12 cwt.
„ „ per hour, 15.5 cwt.
Average Indicated H.P., 675.
Consumption of Coal, 2.55 lbs. per H.P. per hour.
Total Distance run, 13,492 knots.
Screw raised and lowered, eight times.

burden, with engines of 1,000 H.P. The consumption of coal he reckoned could not be taken at less than 75 tons per day, which for fifty days would be 3,750 tons of coals to be carried; for the passengers, crew, and the necessary provisions and water, 500 tons additional must be reckoned, and taking the displacement of the vessel at 10,000 tons, which he thought was as large as would be allowed for a vessel of 6,000 tons, builder's measurement, a displacement was left of only 700 tons to 750 tons available for cargo. Thus it would be seen how much the carrying power of the vessel was reduced owing to the large quantity of coals that had to be carried, and how dependent the traffic was upon passengers. He doubted whether, in the present state of the passenger trade between Great Britain and Melbourne, so large a number as seven hundred passengers could, as a rule, be got together at one time, and this was the smallest number that was calculated to yield a fair return for the capital invested. Therefore, to make these vessels remunerative, unless the rate of expenditure could be largely economized, it would be necessary to highly subsidise them for carrying the mails. The expenses were certain, the earnings were uncertain; and it was not easy to find thirty or forty first-class passengers, with a proportion of second and third-class passengers going at the same time, so he did not think there was a likelihood of making up the complement of seven hundred or seven hundred and fifty people for one vessel.

His views on the subject of the Suez canal entirely coincided with those of Mr. Samuda. It could evidently be made available for steamers of 20 feet to 23 feet draught of water at all times, and it could be used without material delay at either end. The whole of the Bombay trade at all events would go by that route; and the saving of time would be so great, that he had no doubt the most bulky goods would be able to pay the increased rates that would be demanded by the steamers. He thought the voyage to Bombay might be accomplished in from thirty-five days to forty days, and to Calcutta in from forty-five days to fifty days. The voyage in sailing-vessels to either of these ports at present occupied from one hundred and ten days to one hundred and twenty days, and it could not be made by steam, *via* the Cape, under from sixty-five days to seventy days. These facts were of themselves sufficient to prove that, if goods were carried by steam at all, they must be carried through the canal. Experience showed that where voyages could be performed by steam in one half the time required by sailing-vessels, steam would supersede sailing-vessels; and that conclusively proved that the whole of the trade to India would be carried through the canal, when it was made fairly workable, and when vessels could rely on passing through without discharging cargo, and without delay at either end, so as to perform the voyage in the

time he had stated. With regard to the trade to China, it was a little more problematical; the saving of distance over the Cape route was not so great, and he doubted whether steam was sufficiently far advanced to supersede the use of sails in the China seas.

Mr. STEPHENSON remarked that the Paper referred more to commercial than to mechanical matters. He had hoped it would have contained some information with regard to the new class of engine now coming into vogue; and he confessed he was disappointed at the omission, because a contest was going on between the Tyne, the Clyde, the Mersey, and the Thames, with reference to the compound engine. The ordinary engine, with surface condenser and superheater, was well known, and he had hoped to hear something more with regard to the compound engine. As far as ship building on the Tyne was concerned, there were ships, running from Liverpool to China and back, burning only 2 lbs. of coal per indicated H.P. per hour; and these ships were successful. They carried but few passengers, and were chiefly appropriated to the carriage of goods. One of them had returned lately; with a consumption of 2 lbs. of coal per H.P., she made the voyage to China in sixty-three days, and the homeward voyage in sixty-eight days and a half; and the voyage was so profitable that immediately on her return his firm received an order for five more ships like her; and he believed next week they would have instructions for three more of the same class. He was not an advocate for secrecy. The patent was not his, but it belonged to a member of the firm who worked the ships. He would shortly be prepared to give all the details of these engines and their working; and he hoped the builders on the Thames, the Mersey, and the Clyde, would bring forward facts in like manner. Let there be fair competition as to which could turn out the best engine to go to the other side of the globe and back again at the least cost. Whilst he agreed generally with Mr. Samuda, there was one matter on which he did not agree with Mr. Wigram. He did not see what difference there could be, with regard to indicated H.P., whether the vessel was at sea or in the river. If the engines were kept in good order the indicated H.P. should be the same, although the results as to speed might differ; it was evident the power given out must be the indicated H.P. The engines mentioned by Mr. Wigram might not be doing their work well; the coals might be inferior; the cylinders in a bad state, or the condensing tubes might be clogged with oil; but whatever the indicator gave out must be correct, and the engineer must ascertain where the power was lost.

Mr. C. WIGRAM admitted that the indicated H.P. was at all times the power passing through the engines; but both shipbuilders and

engine makers did their utmost to obtain the best results on the trial. There was then no question of economy, the best coal was employed, the valve was left open to the fullest extent, and the steam was blowing off fiercely, and he believed the pressure on the boilers, and the weight on the safety valve was sometimes a little in excess of what it was in working. The result was that a much higher power was obtained on the trial than at any subsequent period; and he believed it would be found that, practically, the economical working power was about one-half what was shown on the trial trip.

Mr. BRAMWELL said, there were two matters on which he had not been able to follow Mr. Wigram; the first was in attributing the economy of fuel of 2·36 lbs. of coal consumed per hour to the fact that the sails were aiding the screw. He did not see how more H.P. could be got with the sails. The second point was the statement that the screw was at work twenty-eight days, while the ship was under steam only twenty days, making that difference between the time the screw was worked and the time the vessel was under steam.

Mr. J. R. RAVENHILL believed the subject of the Paper was one of the greatest importance to England as a commercial nation at the present moment. Until recently the marine engine, with the ordinary jet condenser, was the one acknowledged type of engine, and it had been perfected year by year by great and illustrious men; and when shipowners had been driven by competition to try the new class of engine, they at once emerged from a state of quietude into one of constant anxiety and trouble. His firm was one of the first to be employed by the Peninsular and Oriental Company to fit their vessels with surface condensers. In carrying out that system, both the company and the contractors who worked for them experienced great difficulties; and it was a matter of considerable satisfaction to those engineers who had been employed by them, to find that those difficulties had been overcome. He believed the same perfection would ultimately be obtained in marine engines fitted with surface condensers, as had been obtained in the old jet condensing engine.

One of the earliest troubles in connection with surface condensing was the effect it had upon the boilers. He inspected, at Southampton, the boilers of the 'Ripon,' after they had been at work only a few months; the plates of those boilers, especially those on the top of the furnace, were deeply pitted, and an experienced man looking at them would have said it was impossible to work them for any lengthened period. What had produced that effect? The vessel had made four or five trips between Southampton and Alexandria, and had given great satisfaction to the Company's managers; but on the previous trip, without any notice, she had

been turned round, in consequence of another vessel breaking down, and had performed two voyages from Southampton to Alexandria and back without stopping, when this pitting of the plates was first noticed. It had been the practice to blow out the boilers at Alexandria on the arrival of the vessel there, and also on her return to Southampton, filling them up at each end with fresh water; but, in consequence of the ship being suddenly required, she left Southampton with the same water in the boilers with which she had arrived; and on her return, not only were those corrosions observed, but the boilers leaked in several places. He sent some of the water obtained from the boilers to be analysed by one of the first chemists in London, with a request that, if possible, he would solve the difficulty as to what there was in the water to cause such results; but he utterly failed to do so. He could detect no copper, nor any deleterious acid. However, on careful examination, and making experiments in the laboratory, it was found that the evil had been occasioned by the use of fresh water only in tubular boilers, in connection with surface condensation. He saw bars of iron, coated with plaster of Paris, placed in fresh water; and in the course of a few minutes rapid oxidation commenced; the plaster of Paris became discoloured, and it was then seen that, in the endeavour to obtain the highest results in reference to the consumption of coal, a mistake had been made in working the boilers with fresh water. Orders had now been issued by the large steam navigation companies and by the Chief Engineer of the Royal Navy, not to allow the water in the boilers, at any time, to be less dense than sea water; if the water was kept at that density no harm followed.

Another difficulty arose from superheating. Superheating, no doubt, tended to economy of fuel; but it occasioned considerable wear and tear. The Peninsular and Oriental Company, finding that the cylinders, and slides, and slide faces, were scored and cut, adopted copper superheaters for a time, in the hope that there would be no oxidation; but the action of the soot on the copper completely destroyed the metal, so that they had to return to wrought-iron superheaters.

Such had been some of the difficulties encountered. What had been the result? He had always had the favour allowed him of access to the log books of the Peninsular and Oriental Company's vessels; and he believed he could speak positively to the fact, that the results hitherto obtained had been an average consumption of 2.4 lbs. to 2½ lbs. of coal per indicated H.P. per hour. In one or two instances it had been less; but it was difficult to speak actually as to what had been the consumption. The vessels left Southampton with clean bottoms, and with their machinery in the highest order; and under such advantageous circumstances no

doubt higher results could be shown than a long series of voyages proved. The fouling of the bottoms would always be the cause of heavy coal bills, until there was found some better protecting substance for the bottoms of iron ships than was at present known.

With regard to the future, he thought greater economy of fuel would be obtained from the combined efforts of the marine engineer and the shipbuilder. They must work together hand in hand to that end, as a great deal had yet to be done. It might be interesting to the members if he alluded to some vessels which Mr. Samuda had built, and which his firm had fitted with machinery, showing what had been jointly effected in a series of years. He admitted they were small vessels; but what was proved in a small vessel should hold good for a large one. In the course of seven years he had fitted four vessels, for a foreign steam navigation company, with an average consumption of coal on their station of 296·26. By altering the form of the engine, modifying certain parts, but keeping the size of the cylinders and the length of stroke the same, and by Mr. Samuda lengthening the hull of the vessel and improving the form, the next vessel showed a saving of 17 per cent. on ten trips, as against the previous performances of the other vessels. He considered that a satisfactory performance, as gratifying to the shipbuilder as it was to the engineer; and therefore he felt, with regard to the future, although at the present moment there might be difficulties with reference to the consumption of coal, before many years elapsed a yet greater diminution of consumption of fuel might be accomplished. It must be remembered that the consumption of 2 lbs. to $2\frac{1}{2}$ lbs. of coal over an average of voyages was effected with varying qualities of coal. Great economy might be attained by the use of hand-picked coal and the best of stores over a limited run, with everything clean; but the question was how to effect a voyage of 10,000 miles and upwards under steam. Where a vessel had to run only by steam the same efficient quality of coal could not always be procured, and coal was deteriorated by being stored away in the East; therefore, though others might be able to speak of a less consumption of coal, yet the consumption of 2·4 lbs. of coal per indicated H.P. of the Peninsular and Oriental Company's vessels, fitted with boilers carrying from 20 lbs. to 25 lbs. of steam, was as good an example as was yet known to him in marine engineering.

Mr. E. H. COWPER stated the results that had followed the adoption of a more extended system of steam jacketing than had hitherto been practised, which were of an economical and satisfactory character. It was many years since he had introduced, with good results, the steam jacketed reservoir between a high-pressure

and a low-pressure engine, with the cranks at right angles. Seven years ago he had improved upon this, and made a steam jacketed reservoir of peculiar construction. This was so arranged that the high-pressure steam, after having been expanded in the high-pressure cylinder, and thus become low-pressure steam, entered the steam jacketed reservoir without being heated, but the steam on leaving the reservoir and entering the low-pressure cylinder was heated by a peculiar arrangement of the hot steam jacketed sides of the reservoir. He was glad to see that many engineers were now adopting the system of putting the cranks of a compound marine engine at right angles. Though there were not many who had obtained all the advantage that was to be got by treating the steam as just stated, several pairs of engines were now at work on this plan. A careful trial had been made by Mr. John Taylor, Engineer to the Lambeth Water Works, with a small pair of engines of 15 H.P. each, that had been at work for some years at the Brixton Station of the Lambeth Water Works, having been put up by the late Mr. James Simpson, Past-President Inst. C.E. The engines were taken in their ordinary state of working, and were neither stopped at the beginning nor at the end of the trial, though every stroke was recorded by the counter, and the exact state of the fire was taken at the beginning and the end of the time.

DETAILED REPORT OF TRIAL by JOHN TAYLOR, C.E., of TWO ENGINES and PUMPS (Cowper's Patent) constructed by Simpson and Co., Engineers, Grosvenor Road, Pimlico, London, S.W., for the LAMBETH WATER WORKS COMPANY, Brixton Pumping Station. Duration of Trial from 12 A.M. on Wednesday, October 20, to 12 A.M. on Thursday, October 21, 1869.

Hour.	No. on Counter.	Head on Gauge.	Depth from Gauge to surface of Water in Well.	Total height to which Water is lifted.	Boiler Pressure.	Barometer.	Vacuum.	Temp. of Water entering Surface Condenser.	Temp. of Water leaving Surface Condenser.	Temp. of Hot Well.	Temp. of Feed Water.	Temp. in the Open Air.
Hours.	Revs.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.	Mean.
24	43,110	289.41	16.04	305.45	47.83	30.13	28.76	47.23	52.09	88.84	91.89	47.55

	Diameter. Ins.	Stroke. Ft. Ins.
High-pressure cylinder	12	3 0
Low-pressure cylinder	11	3 0
Steam expanded 5.34 times only.		

Bucket and plunger-pumps, one to each engine—

Bucket	$7\frac{1}{8}$	} 2 7 $\frac{1}{8}$
Plunger	$5\frac{1}{2}$	
16 cwt. 2 qrs. Welch coals burnt during trial.		

1,359,941,248 lbs. raised 1 foot high during trial.	
= 82,420,681 lbs. raised 1 foot high with 1 cwt. of coal.	
= 944,403 lbs. raised 1 foot high per minute.	
= 28·618 horse power exerted in pumps.	
Barometer (mean)	Degrees. = 30·13
Vacuum in surface condenser (mean) . . .	= 28·76
Pressure in surface condenser (mean) . . .	= 1·37
Temperature of water entering surface condenser	= 47·23
Temperature of water leaving surface condenser	= 52·09
Rise in temperature of water from condenser . .	= 4·86
Indicated horse power	= 32·071
Horse power exerted in pumps	= 28·618
Frictional horse power, including air and feed } pumps }	= 3·453
Consumption of coal per indicated horse power per hour, 2·4 lbs.	

REMARKS.

This trial was undertaken after the engines had passed through the summer duty, pumping day and night for weeks together, and previous to the trial the engines were not overhauled, so that the duty was obtained, not under exceptional circumstances, but under the ordinary working conditions incident to hard-worked pumping-engines.

All gauges and indicators were carefully tested, and the coal was accurately weighed; the quantity of fire in the boiler was exactly the same at the commencement of the trial as at the end. Every care was taken to insure accuracy in the trial.

It will be seen that a duty of 82,420,681 lbs. of water lifted one foot high, with one cwt. of Welch coal, was obtained, notwithstanding that the engines are very small ones.

These engines are provided with a surface condenser, through which passes the whole of the water pumped up by the engines. There is no water specially used for injection and thrown away to waste afterwards. This feature in the present case represents a considerable money saving, as the water supplied to these engines has already been pumped up by other engines from Thames Ditton.

It will be observed that the water is only raised 4·86 degrees in temperature, and it is kept entirely separate at all times from the grease and steam of the engine.

The vacuum regularly maintained is of course higher than with an injection condenser.

(Signed) JOHN TAYLOR.

It would thus be seen that, although small engines always had much more friction than large ones, this small pair had done a duty of 82 millions lifted one foot high, with 1 cwt. of coal, in pumping water, or 2·4 lbs. of coal per H.P. gross, per hour in regular work. The system was now finding favour with some marine engineers, and the Lords of the Admiralty had decided

upon fitting the 'Briton' with engines on this plan, of a nominal H.P. of 350, to work up to 2,100 H.P., or more.

Captain J. C. HOSEASON, R.N., said he had for some time past been impressed with the idea that ere long this subject would be brought before the Institution, for it was partly an engineering question, partly a nautical one. The purport of Mr. Grantham's Paper, as it appeared to him, was that shipowners should take stock of their knowledge, and see if by blending all the late improvements in one vessel they could not so economise fuel as to make steam navigation almost universal. Mr. Grantham had forcibly directed attention to the fact, that the primary cause of the great reduction in the expenditure of fuel was to be traced to the general adoption of a greater pressure upon the valve, and the working of this high-pressure steam far more expansively. Moreover, he had said truly that the great economy of fuel which had of late years been obtained in running given distances was not due to the engines alone, but to the form and proportions of the hull. Mr. Grantham had given instances in which this economy could alone be traced, in one company steaming to Alexandria, to the continuous increase of the length of their vessels in proportion to the beam: for high-pressure steam was not adopted in the case referred to, nor any great amount of expansion. Mr. Grantham argued that the economy arising from building vessels of increased length in proportion to the beam was, by the facts he had laid before the Institution, fully established. He agreed with the Author on all these points, and, having inspected the logs of two of the large man-of-war transports running between England and Bombay, had found that the economy in the expenditure of the fuel justified his sanguine expectations. The distance between England and Bombay was about 6,100 nautical miles; the transports running on either side of the Isthmus of Suez had about half this distance to traverse, and were identical in tonnage, in H.P., and in proportion of length to beam. The tonnage was about 4,200; nominal H.P. 700, working up to 4,200 indicated, or six times the nominal power. As the beam of these ships was 52 feet, and the length between the perpendiculars 360 feet, the length was about seven times the beam. While obtaining a mean speed of 10 knots an hour, the consumption of fuel was about 38 tons every twenty-four hours, or in round numbers, 6 miles per ton of coals; and as the stowage capability was 1,500 tons of coal, they could carry 500 tons more fuel at that velocity than would be required when the Suez canal was completed, to perform the direct voyage from England to Bombay. There was space then to carry 500 tons more of munitions of war or other government stores. This satisfactorily demonstrated the advantage of large long ships. Capt. Hoseason directed attention to the importance of considering the

number of miles obtainable by a ton of coals in vessels of equal dimensions and running at equal velocities. As the real H.P. of these large steamers nearly equalled the tonnage, the mean speed when working at full power considerably exceeded that which was here stated; consequently the steamers possessed an ample reserve of power to be used when occasion required it, but to meet the exigencies of the public service, a speed of from 9 knots to 10 knots an hour had been found to be sufficient. It was important for the mercantile navy to utilize the power of the monsoons, or periodical winds, in the Indian seas to lessen the expenditure of fuel. The N.E. monsoon commenced in October and ended in March; the S.W. commenced in April and ended in October. These winds seldom blew with equal force, and rarely exceeded the force of 7, or a moderate gale; and it was only in the middle of each monsoon that they would be found to be of the greatest strength. The S.W. monsoon was strongest between Aden and Bombay, more moderate between Point de Galle and the Island of Sumatra, and was hardly felt in the Straits of Malacca, while from Singapore to Hong Kong it was weaker still. The reverse was the case with the N.E. monsoon; in fact, as a general rule, the S.W. monsoon would be found far stronger in the Indian than in the China seas; and the N.E. monsoon far stronger in the China seas than in the Indian seas. Such being the case, the owners of steam-vessels engaged in mercantile speculations might time their departure from England, so as to have, on leaving Aden, the S.W. monsoon to aid them to China, and the N.E. monsoon for the return voyage to England. The engines of such steamers ought to be constructed to expand the steam in the cylinders to a great extent; and there was little doubt that in such long steamers, in proportion to their beam, with fine lines both forward and aft, and working at the increased pressure on the valve as proposed by Mr. Grantham, from 12 nautical miles to 14 nautical miles might be obtained from each ton of coals, consequently much space would be saved for the conveyance of cargo. A realization of such results would be found fully to justify the sanguine expectations of those who conceived that the route to India and China, *via* the Suez canal, would revolutionise the commerce of the world. He had run all over the Indian and the China seas, in command of Her Majesty's steamer 'Inflexible,' both with and against the monsoons, and had greatly profited by a judicious use of the expansive principle in conjunction with the use of the sails. It must be borne in mind that the density of water to air was as 850 to 1; it was the state of the sea, and not the force of the wind, that materially affected a steamer's velocity. When ships pitched deeply in facing an adverse wind, the vessel's draught was often doubled, and consequently the velocity of the vessel was materially retarded. He

had never encountered heavy seas, like those off Cape Horn and the Cape of Good Hope, in the Indian and China Seas; therefore, in performing the voyage to India and China *viâ* Suez, the gain was threefold over that *viâ* the Cape of Good Hope: in the first instance the geographical distance in the run to Bombay was shortened by nearly one half; secondly, the route was through a far more favourable sea for steam navigation; and, thirdly, the coal depôts were admirably placed to facilitate a rapid and economical passage. The great fall in the rates of freight to India, since the opening of the Suez canal, was a convincing proof that shipowners clearly appreciated the truth and force of these remarks.

Vice-Admiral Sir E. BELCHER, K.C.B., referred to the performance of certain vessels of the Royal Navy before steam was generally introduced; and further to what experience had shown to be the advantages derivable from the use of steam power alone, or its use in long voyages as an auxiliary. At the same time he was not prepared to admit that, for general service, either in a purely naval or a purely mercantile employment, much increase of speed was obtained by deviating from the best models of crack frigates of 60 guns or 1,480 tons,—which were indeed derived from the models of De Chapman, an example of which was the old ‘Royal George’ yacht, the fastest vessel of her period.

The ships to which he specially alluded comprised three schools. First, the French, of which the ‘*Révolutionnaire*,’ of 44 guns, and the ‘*Guillaume Tell*,’ of 80 guns and 2,264 tons, were types; next, the American, an example of which was the ‘*President*,’ of 1,480 tons; and lastly, what resulted from the united abilities of British naval constructors in the class ‘*Southampton*’ and ‘*Winchester*,’ of 1,480 tons. It was his fortune to serve in, or in company with, all these types, and to participate in their races; and records were in existence proving that the speed of the former exceeded 14 knots per hour, and of the two latter over 16 knots. These facts were vouched for by Admirals Sir E. Owen and Sir E. Belcher, far separated in the East and West Indies, and demonstrated that, where wind was available, steam power, adequate for the continued chase from the British Channel to Hong Kong, was of little consequence. The speed attained by the clipper ships, racing from Shanghai to the South Foreland, tended to the same conclusion. He recollected, even in 1812, when the man who claimed a speed of 12 knots per hour under canvas was discredited; but the owners of these tea ships now claimed a speed far beyond the 14 knots or these, termed fabulous, 16 knots of the Royal Navy.

The rate of progress, which should satisfy mercantile men, was matter for the consideration of traders; but at the present day such speed as might be obtained by the aid of steam and canvas united, was equal to the ordinary demand either of the naval or the

mercantile services. He viewed anything carried beyond these bounds, unless for some important demand or special trade, as wanton expenditure of fuel.

Many seamen, having a service to execute or a cargo to carry, were satisfied, with a moderate expenditure of fuel and wear and tear of vessel and equipment, to average 200 miles per diem, or a trifle beyond 8 knots per hour. Intelligent officers, who were at the same time competent pilots, could so shape their courses up to the Cape of Good Hope, and onwards to Java Head or the Australasian ports, as to avoid a delay of more than a few hours for replenishing water. With auxiliary steam and canvas through about 600 miles, in the vicinity of the Equator, a speed exceeding 9 knots per hour might be secured by any ship of fine lines and well handled. His own experience, supported by that of many officers who had experimented on the work performed for the fuel expended on steam performance alone, satisfied him that, excepting on short runs from one coaling station to another, no dependence could be placed, unless for packet service, on any large consumption of fuel, or, he might say, resulting speed. Questions would constantly arise as to where to replenish; as to the possibility of there being an adequate store of fuel; what facilities there were for coaling; what delay would be caused; and finally, would the weather admit of it? All these were most serious matters, and he doubted when the number of miles lost by delay, as well as the attendant expenses, were fairly considered, whether the well-handled sailing-ship would not take and hold the lead. The matter of expedience to meet a mercantile speculation was, of course, the affair of particular owners or merchants. In the ordinary passage from the Cape of Good Hope towards China or Australia, for some thousand miles south of the Cape, or on the parallel of 36° S., the wind and seas, without steam, afforded exercise for earnest thought; there was as much wind as was required—indeed more; the spread of canvas was reduced to a minimum, and the rolling was violent. Supposing steam-vessels to be employed capable of attaining a speed of 14 knots or 16 knots per hour, and that there was power available to increase the speed another knot, then there would be such rolling as would be not only unsafe to the masts, but be dangerous to the vessel and cargo. Therefore he assumed that only between England and the Cape would steam be important; and he doubted whether the speed resulting would pay, as between this country and South Australia.

He was in favour of the turbine 'Nautilus' and 'Waterwitch,' and believed, as in the introduction of steam into the Navy in 1822, that it would yet become a favourite motor. In 1822 the Government adopted paddle-wheels in the 'Lightning,' 'Meteor,' and 'Comet,' to each of which he was appointed.

In 1842, Lord Haddington and Sir George Cockburn consulted him as to the screw, to which he then gave his support. In 1862 the turbine came under his notice (he having in 1818 and 1822 also dealt with it); and he hoped that in 1882 turbines would eclipse all other motors. If any type of motor succeeded in the Suez canal, he believed greater towing speed would be obtained by this mode of propulsion than by any other, and with the least wash on the banks.

With regard to the forms of ships, each form and rig seemed to be triumphant in its own waters. The Bermudian, the Virginia pilot boat, the various craft of the Mediterranean, China, and the South Seas, were all swift in their own countries; but brought to this country as specimens of swiftness, they were dull-nosed. At a regatta at Bermuda, where the gigs built by the most noted British builders in London and Deal contested, the late Admiral John Gore, after the race, challenged the winning boat in a chest built of deal, 3 feet wide, 18 inches deep and 20 feet long, and sharpened at the ends, so that midship section or entrance were entirely ignored, and he gained the prize with her. The powers of steam and canvas combined in several ships of war, fitted with storm sails of adequate strength, had been witnessed by him; and on more than one occasion vessels had clawed off a lee-shore by the auxiliary power aiding to keep up a 5-knots' speed when they were losing ground in attempting to make headway under full power head to wind. So also on the coast of Africa, when the wind was so light that steerage-way could not be obtained, on the application of one-fourth power a speed of 5 knots was obtained, and of one-half power of $7\frac{1}{4}$ knots; and unless in chase, full power never was demanded. As regarded continuous speed under steam, the work performed from New York to England by the mail steamer 'Nemesis' from the 6th to the 13th of January, 1870, both days inclusive, was respectively, 313, 310, 302, 302, 317, 347, 340 and 324 knots, or a mean of 319.4 knots per diem.

Captain SAUNDERS said he had had an experience of forty years in the eastern seas, and within the last twenty-three years he had frequently passed up and down the Red Sea in the Peninsular and Oriental Company's ships. If cargo steamers ran at low rates of freight between European ports and those of India and China, *viâ* the Suez canal, the traffic by the Cape would greatly decline. On the passage between Suez and Aden, land was nearly always visible, and bold islands dotted the broad and safe track; so that he considered the navigation particularly easy and free from danger, as long as ordinary diligence was exercised. The south-west monsoon between Bombay and Aden, also from Calcutta, from,
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say, the 15th of May to the 15th of September, would render the passage homeward long, and perhaps disappointing, to heavily-laden steamers, fitted with inadequate power. High seas and strong gales would probably reduce their speed, so as to render them very unmanageable: the rudder being merely a lever, and its power ever dependent upon the speed of the ship. He had seen Peninsular and Oriental Company's ships in that difficulty. When very long and deeply-laden vessels became unmanageable, through stress of weather, falling off probably in the trough of the sea, critical difficulties might transpire at any moment. In the China seas, the north-east monsoon, from the end of September to the end of February blew with the greatest force, and would tend to lengthen the passage of underpowered steamers bound northward. He agreed with the Author, that long ships afforded speed and carrying capacity, and were probably more profitable to the owners than shorter and broader ships; but whether they were as easily and safely handled as others of less capacity in hard gales and narrow navigation was not free from doubt.

Mr. ANDREW MURRAY, C.B., observed that the Paper embraced the whole question of steam navigation, particularly in a commercial point of view. Now, in a commercial sense success must depend upon economy, and economy depended upon details, for in details lay perfection: he would therefore refer to a few of those details. The economy recently introduced in steam-vessels was mainly attributed to three causes, viz., expansion, surface condensation, and superheating. Any economy resulting from change of form of the boilers was said to be slight, and, with regard to propellers, the further the departure from the screw the greater the loss, and the screw must be again resorted to. Of these three points, from which economy had resulted, there was no doubt that in the matter of expansion much progress had been made of late. The first great improvement was unquestionably the introduction of compound engines. Great difficulty had been found in introducing a separate expansion valve that would do its work well; and with the slide valve alone it was impossible to obtain the expansion required. The expansion of steam from a pressure of 70 lbs. or 80 lbs. to the inch, at the commencement of the stroke, to 6 lbs. or 7 lbs. above a vacuum at the end in an ordinary condensing engine made an immense difference of pressure on the piston from the first starting in the cylinder to the end of the stroke, and the power exerted at the commencement was so different from that at the end of the stroke, that the movement was necessarily irregular. The compound engine got over that difficulty; and, therefore, it appeared to him necessary to follow up that improvement if the full value of expansion was to be obtained in

marine engines. The attempt had been made by some of the leading manufacturers to effect this amount of expansion in one cylinder, using three cylinders to produce equilibrium of motion upon the propeller, and satisfactory results had been arrived at; but he believed that still better results could be obtained with the compound engine.

He did not agree with his professional brethren on the subject of surface condensation, as he could not see what there was to be gained by it. The main point looked at was the loss of fuel by blowing off the surplus water from the boilers where ordinary condensation was used. He had found so many working engineers ignorant on this point, that he would venture to refer to it. Supposing one-third of the water used to be blown off, and assuming, for the sake of convenience of illustration, that the water supplied to the boiler was at 100° and the steam 240° , the temperature of the water would first be raised from 100° to 240° ; the two-thirds of water wanted for the engine would then take up in the shape of steam their amount of latent heat, say, in round numbers, 900° , making $1,040^{\circ}$ in all, but the remaining one-third would be retained in the boiler at 240° , and form a receptacle for the impurities contained in the water evaporated. There was no more heat therefore put into the latter quantity than to raise the temperature from 100° to 240° , and it would be discharged into the sea at this temperature with the impurities of the whole of the water; and from this it was evident how little was the loss sustained in the actual blowing off. Again with surface condensation, the air-pump was still necessary, although it might be smaller, and all the valves were required as before; but the machinery was otherwise more complicated, for in addition to the ordinary condenser, 2 feet or 3 feet of pipe were needed for each indicated H.P.; so that it might be imagined how large the quantity would become in engines of great power. There was a circulating pump, with a large entrance-valve from the sea, to pump in the water to be sent out again through an equally large valve. Then with respect to the boilers, there was no saving in the valves for blowing off; they might be smaller, but they must be there. He therefore regretted that in the new vessels there had been no opportunity afforded for distinguishing separately the amount of saving by surface condensation, as compared with the other changes effected at the same time, viz., superheating and expansion. There was no question but that superheated steam led to economy of fuel if well carried out, and the difficulty it caused could no doubt be overcome by better lubrication, taking care that the steam was not heated to an extent which rendered it impossible to deal with it in the cylinder.

With regard to the engines themselves, it was commonly said that the consumption of fuel had been reduced to 2½ lbs. per indicated H.P. per hour, but in speaking thus the boilers were involved with the engines, and it ought to be considered what was due to the engines, as compared with what was due to the boilers. The engines might be economical and the boilers the reverse, or *vice versâ*; therefore to test the comparative merits of engines and their parts, it was necessary that the boilers should be the same in all the cases.

Little had been said on the differences effected by the forms of ships. Everything seemed to tend to increased length, and there was no question that great results could be obtained by increase of length alone. To judge of the effects of increase of length by surface friction was not a fair criterion of performance, because it was found that the results were nearly the same, after a length of 20 feet had been added to the midship section, when the same power was employed. Surface friction was an important element of speed, but having overcome that for a given form of bow and stern, the additional length or friction of the sides seemed to be of little moment.

Maintaining a clean bottom was unquestionably a great element of success in a ship's performance. He should have liked some definite information as to the loss of speed by different degrees of fouling, and what could be done with reference more especially to iron ships. Chemistry had failed hitherto to do what was required, and recourse must therefore again be had to mechanical resources. It was to be regretted that this difficulty should have remained so long without some further attempts being made to keep ships clean by hogging and by diving. In the French navy this was carried out to a great extent, and he was informed that one man could clean a surface of from 8 square yards to 10 square yards of a moderately-dirty ship's bottom in a day's work of from 6 hours to 8 hours. If several ladders were passed under the keel, a number of divers would in a moderate time clean the bottom of a ship.

As to the material of which ships should be built—whether of wood or of anything else than iron, the owners of the China clipper-ships seemed to think that tea, being a delicate article, was infected in some way by iron bottoms—he could not understand how that could be. It must rather be from what was put upon the iron, to protect it. They therefore took up composite ships. But such vessels appeared to him to combine all the bad elements, both of wooden ships and of iron ships. They were weak in all points, as far as he could judge. The ribs of a wooden ship from their form gave great stiffness to the frame, as a matter of course, from their section. The rib of an iron ship, merely as a rib, and to

which the planking of composite ships was attached, was weak in itself. The planks of composite ships were placed edge to edge, and not united one to another so as to give strength of themselves. The 'Spindrift,' a composite ship lately lost, went to pieces in fine weather upon a sandbank, where, he believed, a well-built iron ship would have remained sound and intact under similar circumstances.

He was glad to find that, in the course of this discussion the indicated H. P., as taken by the indicator, was admitted to afford a correct indication of the power passing through the engines. That being so, there was something definite to go upon in measuring the efficiency of vessels. This was done at present by bringing out what was termed the co-efficient, and he ventured to say that, though men accustomed to the subject comprehended this and were able to put a relative value upon the figures, yet it was not generally understood by the body of merchant shipowners; and he had had great difficulty, in speaking to them on the subject, in making them understand what was meant by the difference in co-efficients. If he had the means of telling them that so much engine-power would carry so many tons of cargo at a certain speed, they would understand it much better; and he thought an attempt should be made to bring the co-efficient into a more tangible form. It was easy to say, of two ships of different sizes, that the power required to propel them at the same speed would be as the cube roots of the squares of the displacements: so it would be; but these were hard words to use to commercial men, who were more in the habit of dealing with pounds, shillings, and pence, and who wanted to know the cost at which they could carry so many tons in their ships. Some simpler form would tend to the improvement of ocean navigation.

The Author had spoken of ships travelling 11 knots an hour between England and Australia; and instances were given of the passage being made by steamers in from sixty-five days to seventy days, the distance being 13,500 miles; while sailing-vessels occupied one hundred and ten days or one hundred and twenty days on the voyage; the rate of speed being 8 knots per hour for the steam-ship and 5 knots for the sailing-vessel. With so great a difference between 5 knots and 8 knots upon a long voyage, much remained to be done in the way of less auxiliary power than what had hitherto been put into ships. The difficulty of working the engines, and of getting competent commanders to supervise those who had to do with them, was much less than it was twenty years or thirty years ago. Probably, in the future, vessels with auxiliary power would take up the traffic of the world rather than vessels of high power and great speed. It must be remembered how important was the part which the electric telegraph

bore in the transmission of intelligence to the mercantile community from the remotest parts of the world ; and with regard to the transit of passengers, although there were some people who did not object to pay large sums to save a few days at sea, the great bulk of passengers did not require great speed on a long voyage. The question of combining steam with sails had not been much entered upon ; it was a difficult question no doubt, and was a subject worthy of a Paper by itself. Admiral Sir Edward Belcher had spoken of vessels going 12 knots an hour under sails, and had asked what was the use of the screw to help a vessel with a speed of 12 knots. Yet fast sailers, with the help of the screw, went still faster.

The use of the hydraulic propeller, as an auxiliary, had been referred to as still in embryo, and not yet developed. Agreeing upon that, he would say a word on what appeared to him to be the peculiar excellence of the system as an auxiliary power. The water being taken into the ship, there was no doubt but that the water so taken up by the hydraulic pump or turbine, had the speed of the vessel imparted to it upon being received into the ship. The motion subsequently given to it by the pump then became a separate question, and as when a man threw anything from the bow of a ship in motion, towards the stern, the speed of the ship practically made no difference, so it appeared to him that the speed of a ship under canvas would make no difference to the force of recoil given out by the water issuing from the nozzles or pipes at the side ; and the whole steam power of the ship would be available for an increase of speed beyond the speed that was being obtained by the ship under canvas alone, however high that speed might be. If that were so, he thought that a higher velocity under canvas and steam combined might be obtained by a continuation of this mode of propulsion with sails than had ever been obtained as yet by any ship.

Mr. T. A. ROCHUSSEN remarked that the Paper was so extensive that he could not touch upon more than one or two points. He might have treated of the large steamers carrying on the traffic between England and America—the great postal steamers, which for the most part derived their passengers from the luxurious classes of England and America, and were provided with accommodation which made them more like floating hotels than steamers for carrying on the general traffic between the two countries ; but he would confine his observations as much as possible to those steamers engaged in the rough and ready work of the daily trade, and not lay so much stress upon the excessive speed which was now arrived at in the large mail steamers. What in steam navigation was required, as well as high speed, was regularity at sea ; it was not so important to the merchant to possess the cargo in his warehouse as to know precisely when it would arrive, and

have it represented by bills-of-lading, which he could cover by a policy of insurance, and which was as valuable to him as the goods actually in dock—in some instances of greater value, inasmuch as it afforded him the choice of several markets, and he could keep his policy a secret. He was, at one period, a small steamship owner: at that time it was difficult to obtain a vessel capable of carrying coals for steaming a distance of more than 3,800 miles: ultimately the coaling capacity was extended to about 5,600 miles. The whole economy of steam navigation turned mainly on two points, viz., the relation between the engines and the ship, and that of the ship and engines combined, to the freight that had to be carried. As the result of some considerable attention to these matters he had noticed some startling facts. He particularly observed that the best paying ships—such as those of the Pacific Mail Steam Navigation Company, running from Panama to the south-west coast of America, the Cape Mail line, the Royal African Mail from Liverpool to Fernando Po, the Hamburg American, the Bremen American and Mexican, or North German Lloyd's, and the British and African, all did their work, if not at the high speeds of the Cunard line, the Peninsular and Oriental Company, and the Royal Mail Steam Company, yet remarkably well, and paid handsome dividends; and they were invariably built and engined by the same people, in the same yards; so that, in the construction of steamers at least, division of labour did not appear to be attended with beneficial results, but harmony in construction had practically been best carried out in the same hands. All the steamers to which he had alluded combined superheating—an advantage beyond all question—and with expansion and surface condensation carried to the degree which gave the most economical results. He could imagine that the reason why, in the Royal Navy, surface condensation was not so much appreciated as in the merchant service, was because, in the former, the engines being placed lower in the ship, the surface condenser would occupy more room than the ordinary condenser. In merchant steamers the engines were for the most part of the inverted vertical class, which left ample space for the surface condenser. In ocean steam navigation, especially with the view of its further development, Mr. Grantham had pointed out as highly probable and likely to follow, that under all circumstances attention must be paid to the advantages which a ship derives from its sails, in the trade winds; and what was so ably pointed out by Captain Hoseason should certainly be considered as one great element in the saving of coal; inasmuch as in many seas, such as off the north-east coast of Africa, and the Indian Archipelago, the fires might be banked up and a speed of 8 knots an hour be obtained under sail. Steamers rigged as sailing-ships had an additional advantage in

a cross sea; the square sails steadied the ship. With a head sea on, when a steamer was not running under mail contract, it was better to bank up the fires, unless she could make 5 knots an hour, and lay to on fore-and-aft canvas, and when the weather moderated run on under steam again. In Indian navigation it would not be safe to do without steam power at hand.

In 1838, in the early days of Indian steam navigation, the first steam man-of-war, the 'Calypso,' a paddle-wheel corvette of 600 tons, carrying 4 guns, was sent out by the Dutch Government, especially with a view to the suppression of piracy in those seas. One day in passing through the Straits of Lombok to the east of Java, she got ashore. The tide was falling at the time, and she was rapidly surrounded by a fleet of piratical junks and proas. The starboard guns of the vessel being depressed, were of no use, and the larboard guns being pointed upwards could not be directed against the craft within so short a range. In this position the vessel was in danger of falling a prey to the pirates, which would have entailed not only the destruction of the crew and the vessel itself, but the loss of prestige of European arms conveyed in a new form of navigation in those waters. But the vessel was built of iron, and the engineer had placed in her a contrivance which was not unworthy of consideration in the present day, with a view to remedy the rapid fouling of the bottoms of ships in tropical seas by the accumulation of barnacles and marine plants. The blow-off cocks of the boilers ran down from the engine-room into the bilge, and by the discharge of the hot water the iron skin of the ship could be heated to such an extent as to clear the outer portion of all animal and vegetable life. This contrivance was the means of saving the ship in the moment of peril, inasmuch as the boiling water, pumped by a donkey engine from the boilers through the deck hose, in a very short space of time cleared the ship of her assailants. He mentioned this as a simple contrivance for effectual defence against unforeseen attack; a contrivance which cost nothing, took up no room, and with no patent rights to pay for. In the case referred to the expedient was sufficient to keep the pirates at a distance at which they were unable to use their stink-pots—the most dangerous weapons in the China seas.

In analyzing the accounts of the successful vessels to which he had alluded, he found that the proportion of engine power to the ship's registered tonnage varied from one to four and a half and five times the net register; also that the consumption of coal was not so low at sea as was indicated by the results of the trial trips: that 3 lbs. of coal developed 1 H.P.; and that the displacement of steamers, which had made the best voyages within the last six months, was about three times the net registered tonnage.

The earnings of a ship could only be ascertained by dissecting the items of expenditure. He found that steamers would pay their expenses if for every thousand miles run—assuming the coals to cost 20s. per ton—she earned 15s. 8d. per ton register. It then became the business of the shipowner, if he could divide that tonnage register, to make the best bargain he could with his customers both for weight and measurement cargo. A vessel of 1,000 tons register would carry 700 tons of heavy goods and 800 of measurement cargo, 40 cubic feet being now the measurement of a ton, whereas formerly only about 8 cwt. of Manchester goods could be packed in that space; but by pressing the weight was now raised to 14 cwt. or 19 cwt. Having stated this unit of 15s. 8d. upon a basis of 20s. per ton for coal, if freights got higher the owner could afford to pay more for his coal, or he could coal on the voyage; but it must not be forgotten that the coal was carried out to intermediate ports in sailing-vessels, and when the freights were good, those vessels, having discharged the coal, might prove dangerous rivals to the steamers by taking back a cargo on the return voyage. As regarded iron ships or steel ships, the question of a vessel passing or being unable to pass through the Suez canal depended upon a few inches' draught of water; and it might be the case that a vessel arriving at Port Said would have to do penance there, from the fact of her draught of water being greater than it would have been if she had been built of steel plates instead of iron.

The Author of the Paper foreshadowed that important disclosures were about to be made in the raising of steam power, by cheaper means than those now employed; and Mr. Rochussen ventured to hint at one of them. Coal was now used on the assumption that it was the cheapest material, (he was not now referring to liquid fuel). In burning coal, a large amount of oxygen was consumed; and it was imagined that the greatest amount of heat was developed with oxygen in conjunction with coal. In the Bessemer furnace of 5 tons' capacity 3 cwt. of carbon and a small quantity of iron and silicon developed far more steam than was produced by carbon burnt with oxygen; and further, the heat was augmented by manganate of iron, which latter metal took up less oxygen than iron in the proportion of 11 to 20. Again, in the manufacture of zinc oxide, it would be found that a pound of zinc would raise more heat and evaporate more water than a pound of coal; and the metal was not burnt to waste, because a valuable oxide was produced which reduced the cost; and the oxide could be reconverted, by simply heating it with coal, when the vessel arrived at her destination. This reduction of coal space would give more room for cargo, and was a source of economy in fuel worthy of further investigation.

Mr. G. H. PHIPPS said that he regretted not being able to agree with so good an authority as Mr. Murray in some of the observations he had made. For instance, with regard to surface condensation, he thought that, although on the question of the adoption of this and other additions to the usual mechanism, the amount of care at disposal ought perhaps to be the guide rather than the actual amount of saving accomplished, yet when such method and care existed, as he supposed it did in the Royal Navy, the advantage of a 5 per cent. saving in fuel, representing as it did an addition of one day's steaming in every twenty days, or 240 knots at a speed of 10 knots, was far too great an advantage to be thrown away. From a calculation he had made of the relative power required on the ordinary system, or on the system of surface condensation employed in H. M. S. 'Hercules,' of 8,000 indicated H.P., he found the saving to be very nearly 5 per cent.

On the question of surface friction, so intimately connected with the proper proportion of length, breadth, and depth of ships, Mr. Murray appeared to think, that the absence of increased resistance observed in several instances of the lengthening of ships, by the insertion of a new section at the midships, proved a difference to exist in the co-efficient of friction at the midships from that at other places. But he thought that, whilst this theory would certainly account for a smaller increase of resistance than under a constant co-efficient, it could not account for a total absence of increase; and if not, that the difference might be attributable to diminished minus resistance at the stern of the longer vessel, a view which he had mentioned to the Institution in relation to the ship 'Candia,'¹ and was also in accordance with Beaufoy's experiments, which always showed diminished resistance when his models were lengthened, of whatever form they might be. He was prepared to concede (in accordance with some recently published views of Mr. Froude) the probability of a difference in the co-efficient of friction of different units of surface of a ship, namely, smaller the farther aft, but he was still inclined to attribute the larger part of the set-off to the resistance of the increased surface, to the cause above alluded to.

With regard to the opinion expressed by Admiral Belcher, as to the probable advantage of the hydraulic system of propulsion for towing purposes, he had, on a former occasion, expressed the same view as to its application on canals,² as whenever the speed of the vessel was low, the loss by slip, either with the paddle or the screw, became very great; and in such case, the hydraulic propeller's power of steering gave it a great superiority. He attributed a large

¹ *Vide Minutes of Proceedings Inst. C.E., vol. xxiii., p. 324.*

² *Ibid., vol. xxvi., p. 22.*

part of the loss of power of the hydraulic system to the necessity of using some instrument, as the centrifugal wheel, in the nature of a pump, to give to the issuing water the requisite velocity, equivalent to raising it to a corresponding height. It was as if the power of a steam-engine, to do any given work, had to be first applied to pump up water, at a loss (with the centrifugal wheel) of from 30 per cent. to 40 per cent., and the remainder were then applied as a prime mover. Notwithstanding its defects, however, he thought that more work was done in the 'Nautilus,' a vessel still running on the Thames, of about the size of the penny iron boats, and built immediately before the 'Waterwitch,' than corresponded with theoretic calculation, and he suggested that this might be attributable to the aid afforded by the water discharged in diminishing the minus resistance of the vessel.

Mr. BRAMWELL said, the Author of the Paper appeared to regard Ocean Steam Navigation as only really successful when, for passenger traffic, a speed of 11 knots an hour was obtained. Looking at the Author's large experience, he felt some diffidence in expressing an opinion differing from his; but was such a speed really necessary for success? He hoped not, for (leaving out of consideration the subject of railways) it might be said that when steam was applied to perform any other work than that of the propulsion of vessels, the same total work was required whether the operation were performed slowly or quickly; but, as was known in the case of steam-vessels, this was not so, for there speed could only be attained by the employment, not merely of a greater power in a given time, but of a greater total power. To perform a given voyage at 10 knots an hour, a certain expenditure of coal was required; but if for the same voyage the speed was $12\frac{1}{2}$ knots per hour, the expenditure of fuel would be half as much again; that was, supposing the old rule of the resistance being inversely as the square of the speed held good. He had referred to a Paper discussed before this Institution in 1857, when numerous speakers affirmed the truth of that rule;¹ so that, if in lieu of completing a journey in seven days, or a multiple of seven, it was insisted upon completing it in six, or a multiple of six, a vessel could only go $\frac{3}{4}$ ths of the distance with the same fuel which she could go if the voyage were performed in seven days, or in some multiple of seven. That was a matter not to be lost sight of in considering whether steamers could successfully compete with sailing-ships. After all, was not the right system to pursue on voyages what was called auxiliary propulsion? An eminent ship-owner had remarked that the captains of his vessels (of the voyages of which he gave the records) had orders to keep the sails always

¹ *Vide Minutes of Proceedings Inst. C.E., vol. xvi., p. 327, et seq.*

drawing. That was to say, if the wind were in such a direction that the ship could not "lay" her course under steam and sails combined, she was not to take in her canvas, but was to use it in conjunction with the steam by "tacking," as a sailing-vessel would "tack." Following this system, it was found that, out of a voyage of sixty-three days, thirty-two were under canvas, and thirty under steam and canvas combined, except six days of the thirty, which were days of entire calm. The speed of the whole voyage was 9 knots an hour.

Mr. Andrew Murray had observed that the Paper did not deal with details, though details were the life of all mechanical improvements; and the Paper dealt more with matters of a commercial nature than with matters connected with engineering. It seemed that the improvements in steam navigation were due to the screw propeller, to greater expansion, and to superheating. Thirteen years ago, the late Mr. Humphrys, M. Inst. C.E., than whom, in later years, there was no more ardent advocate of expansion, mentioned an instance of H.M.S. 'Desperate' in which there were four cylinders, and in which he had experimented upon high expansion with unfavourable results, compared with the use of steam but very slightly expanded, employed in but two cylinders only, and the tenor of Mr. Humphrys' observations was to discourage the pursuit of high expansion. There could be little doubt, however, that the unfavourable results obtained in the instance quoted were due to the absence of steam jackets (the use and theory of which were then but little understood), and to the large loss by radiation. It was now a well-recognised fact, that steam jacketing was an absolutely indispensable adjunct to high expansion.

He was sorry to hear Mr. Murray express doubts of the utility of surface condensing, and to treat it more as a matter of fashion than of real use; he had stated that practical engineers believed if one-third of the water in the boiler was blown out, they lost one-third of the coal; while the fact was, that when one-third of the water was blown out, only 7 per cent., or $\frac{1}{15}$ th of the coal was lost. He did not believe practical engineers, as a rule, were so far unacquainted with the subject as to hold the erroneous opinions attributed to them; but he thought the loss was greater than that stated by Mr. Murray, because, in fact, it was the custom to blow off more than one-third. He had known many cases in which one-half the water pumped in was blown out; this would increase the loss of fuel, as compared with the blowing out of $\frac{1}{3}$ rd, by just one hundred per cent., or from $\frac{1}{15}$ th to $\frac{2}{5}$ ths, because, in the first supposed instance, for three parts pumped in, two were utilised and one was wasted; while in the second supposed instance, for four parts pumped in, still two only were utilised and two were wasted

instead of one. Irrespective of this question, however, he believed surface condensation to be of use because it dispensed with the drawing into the condenser of sea water, which being charged with air impaired the vacuum. A better vacuum was obtained with surface condensers than with injection condensers; and a gain of even 1 lb. to the inch on the vacuum was of great value, when working with high expansion; because the average pressure over the indicator diagram being small, 1 lb. all over the diagram was a large percentage of the average pressure, and therefore was most important to obtain. In order not to use sea water in injection condensers, Mr. Howard, in his 'Quicksilver' boat, although he had injection, used the same water over and over again, by cooling it down, which was a great improvement; and, notwithstanding what had been said by a high authority, Mr. Bramwell was compelled still to think that surface condensers were preferable to jet condensers. Mr. Phipps had expressed an opinion that they were delicate instruments, requiring the supervision of persons of high mechanical skill; but he, on the contrary, thought they were quite as simple in their working as the ordinary injection condensers.

Mr. Bramwell feared that the Author of the Paper was somewhat too sanguine in basing his proposed plans upon a consumption of coal of 2 lbs. per indicated H.P. per hour when actually at sea, inasmuch as 2 lbs. per indicated H.P. meant 112 millions of duty. It was recorded, in 'Lean's Engine Reporter and Advertiser' for the month of January 1870, that the best Cornish engine, with slow combustion boilers of large size, was doing only 69.1 millions of duty. Mr. Grantham had treated marine boilers as being so used in respect of the rate of combustion, that the gases escaped up their funnels at 1000° of temperature. This would carry off $\frac{1}{3}$ rd of the total heating effect of the fuel. He did not understand, therefore, how Mr. Grantham hoped to obtain, under such circumstances, a duty equal to 112 millions, when nothing like that duty was obtained in the slow combustion boilers working Cornish engines. He believed that in reckoning the coals consumed per indicated H.P. in steam-vessels, a mistake of the nature he was about to describe was very commonly made; that mistake was, that when the vessel was tried for speed at the measured mile, the highest possible power was got out of her wholly irrespective of the coals consumed; that on the voyage far less power was, as a fact, developed; the coals consumed were ascertained; but as a divisor the H.P. of the measured mile was assumed, and not the H.P. really produced by the combustion of the coals consumed during the voyage. He thought that this appeared, even in certain instances given in the Paper. As an example, the Author had quoted the case of the 'Peru,' a vessel

with double cylinder engines: she was 350 nominal H.P., and made the voyage from Glasgow to Liverpool at a speed of 14 knots an hour; the vessel was light, and her engines made 26 revolutions per minute; the consumption of fuel was not stated. The Author stated her indicated H.P. to be 1,400, or four times her nominal. He then gave the result of a voyage from Liverpool into the Pacific, showing that 24 tons 1 cwt. of coal were burned per day, which he valued as giving about 2 lbs. per indicated H.P. This would have been true if the engines had continued to develop the 1,400 H.P., but what were the facts?—that the vessel, instead of going 14 knots an hour, went only 9·8 knots; a result which should be obtained by the exertion of 410 H.P. only, assuming the draft to have been what it was in the trial trip; but even allowing for extra draft on the voyage, it was quite certain that with so low a speed as 9·8 nothing like the 1,400 H.P. could have been developed, and therefore the probabilities were that the true consumption was much more like 4 lbs. or 5 lbs. per indicated H.P. per hour than the 2 lbs. arrived at by the Author.

In vessels intended to use both sails and steam, either together or separately, two things were necessary as regards the propeller; the one, the ability to feather it, so as to get the blades fore and aft when employing canvas alone, and thus to obviate the necessity of a lifting screw; the other, the ability, when the propeller had to be used in conjunction with the sails, to make its pitch more coarse than that of its ordinary steaming position.

He had been requested by Mr. Griffiths, whose name was so well known in connection with the screw propeller, to call attention to a diagram and two models which showed Mr. Griffiths's means of accomplishing these two ends. Hitherto in the attempts that had been made to construct a feathering screw, the alteration of the pitch of the blades had to be done by manual labour, but Mr. Griffiths had devised a means by which the engines themselves were employed as the power for effecting the alteration in the position of the blades. When required, this was attained by merely stopping the engines, and then applying a break to the break surface provided in the screw, when a few revolutions of the engine in one direction or the other made the pitch finer or coarser. He believed that Mr. Griffiths had devised an implement which was mechanically practicable, and which would give these long-desired results.

Mr. J. F. SPENCER remarked, with reference to the carrying trade by sea, that it was not a question of what was the most economical speed for the shipowner, but what speed the public required. Companies that, a few years ago, built steam-ships for a speed of 9 knots and 10 knots an hour, were now building vessels for a speed of 11 knots and 12 knots. The necessities of the

sea carrying trade were such, that notwithstanding the cost of high speed, it would be increasingly in demand, and hence economy of fuel was of the utmost importance.

The steam-ships running between Liverpool and the United States might be taken as fair samples of large ocean steam-ships. In investigating their efficiency and performances, as a basis for a new mail steam-ship, he ascertained that with surface condensers, no steam-jackets, and the utmost expansion obtainable with the ordinary link motion, the Welch fuel required for 1,700 indicated H.P. was 55 tons per day, or 3 lbs. per indicated H.P. per hour. These ships were 320 feet long, 40 feet beam, and 20 feet draught of water; and with the power named and a total displacement of 5,000 tons, the speed was from 11 knots to $11\frac{1}{2}$ knots per hour over the whole voyage. It followed, therefore, that upwards of 25 tons of dead weight were carried 1 knot at the rate of 11 knots per hour for the cost of $\frac{1}{4}$ d. for fuel; and if the speed was reduced to 9 knots per hour, 50 tons could be propelled 1 mile for $\frac{1}{4}$ d. for fuel, or 5,000 tons could be propelled 1 knot at the rate of 11 knots per hour by the expenditure of 3s. 9d. in fuel. Compared with other modes of transit these results might be considered very satisfactory. When, however, the gross total of fuel required by large steam-ship companies was considered, even minute reductions per indicated H.P. represented large annual savings. To give some idea of the great importance of economy of fuel at sea, he might state, that in the large steam-ships before referred to, $\frac{1}{10}$ lb. of coal per indicated H.P. per hour represented in each vessel a cost of fuel to the owner of upwards of £250 per annum, or £2,000 per annum for a weekly service each way; hence it followed that any improvement that reduced the fuel per indicated H.P. per hour by $\frac{1}{10}$ lb. placed the sums named on the credit side of the ledger.

There were numerous difficulties in estimating the efficiency of marine engines and the economy of sea transit; several distinct and separate elements being so mixed together in stating results, that it was almost impossible to estimate distinctly the value of each element of power. There was the boiler ever varying in the cost of producing 1 lb. of steam. In one case 10 lbs. of water were evaporated per lb. of fuel, and in another only $7\frac{1}{2}$ lbs., the difference representing a loss or gain to a steam-ship company of not less than £20,000 per annum. Then the engine might require only 16 lbs. of steam per indicated H.P. or it might require 30 lbs., or anything intermediate between these amounts, representing a loss or gain to the company as the case might be. In estimating the comparative efficiency of steam-ships, the form of the immersed hull and the resistances of water, weather, wind, &c., had also to be considered. Nothing would more lead to improvement and a right

judgment than, in all cases, to record the results of the boiler and the engine separately. He advocated expansion in one cylinder in preference to the compound system, unless the higher pressures created mechanical difficulties, removable by adopting the compound system. As a matter of economy each system should give the same indicated result, but the friction should be greatest with the compound engines. To make a fair comparison between the two systems, the capacity of the cylinders should be the same in each case, whereas the compound system had generally the advantage of a much larger capacity per indicated H.P.

Mr. STEPHENSON agreed generally with what Mr. Bramwell had said, except as to the consumption of fuel. He had the results, not merely of experiments, but of a long voyage, showing that nearly 2 lbs. per indicated H.P. per hour was the expenditure of coal. The vessel, which he had alluded to as having accomplished the voyage to China in sixty-eight days and the return voyage in sixty-three and a half days, was the 'Nestor,' and was built by Leslie on the Tyne; the engines were constructed by R. Stephenson and Co., and the voyages were accomplished with an average consumption of coal of 1.97 lb. per indicated H.P. per hour, at an average speed of 9.7 knots per hour. The pressure of steam was 75 lbs. per square inch. He was much surprised that Mr. Murray did not approve of surface condensation. In the case of a 70-H.P. engine there was a saving of $2\frac{3}{4}$ cwt. to 3 cwt. of coals per hour, the consumption being only $9\frac{1}{4}$ cwt.; whereas under the ordinary condensing system it would have been 14 cwt.

He thought superheating might be carried too far; injury ensued if the packing of the glands was burnt; but, on the other hand, it was desirable that the loose particles in the boiler should be taken up and changed into steam in passing through the superheater. He had worked up to 75 lbs. pressure on the square inch, and, after four years' or five years' working, he could confidently state that no ill effects were produced either in the boilers or the cylinders. High-pressure boilers generally began to fail where the stays were screwed into the plates. By using surface condensation with careful working, a film of salt was deposited on the boiler which protected it from the evil effects of surface condensation; and it had come under his notice that a boiler was perfectly clean after five years' working.

Mr. Wigram had stated that, on the trial-trips, his vessels had averaged about $5\frac{1}{2}$ times their nominal H.P., but that, after they had been on their stations for some time, they fell back to $3\frac{1}{2}$ times, and this he attributed to marine engine-builders and shipbuilders trying every expedient to get the greatest amount out of the ship on the measured mile. As far as that was concerned, it was his own practice; but the measured mile was scarcely a trial-trip,

Mr. Wigram should have added, taking into consideration the quantity of fuel expended for the speed obtained.

Mr. Stephenson then directed attention to two diagrams, one being the indicator diagram of the 'Great Eastern' on her trial-trip in the Channel, and the other when that vessel had been nine days at sea.¹ Her engines were designed, and watched over, by one of the most able men of his day, Mr. Brunel, Vice-President Inst. C.E., and also by Mr. Scott Russell, M. Inst. C.E., himself an eminent shipbuilder: it might, therefore, be taken for granted that the engines were first-class. He wanted to point out to Mr. Wigram where this change of indicated H.P. took place, and for that purpose referred to the diagrams. These showed a great loss of H.P. by the alteration of the valves after the trial-trip. But there were other circumstances to account for the diminution of indicated H.P. As soon as a ship and her engines went from the builders into the hands of the shipowner, the latter found out that if he reduced the speed he made a saving in the working, and by cutting off steam more quickly reduced the indicated H.P. at once. He had caused a small model to be prepared, which he begged to present to the Institution, to give the Students an opportunity of testing the setting of the valves. It was the ordinary slide with the expansion-valve attached to it, and by placing a piece of cardboard on the valve, any lap could be made. An indicator diagram would show at once whether the valves of an engine were set right or not, and where, if any, the fault was.

Mr. D. Thomson said the principal advantage of surface condensation was that it enabled marine engines to work at much higher pressures than without it; and he believed one reason why it had not been more generally adopted, when introduced, was that people did not then understand how to work high pressure on board ship, and, in the absence of high pressure, surface condensers were not of material service compared with the additional complication they caused. The same remark applied to double-cylinder and single-cylinder engines. If the pressure amounted to only 40 lbs. or even 50 lbs. per square inch, he did not doubt the single-cylinder engine could be made to work as economically as the double-cylinder engine; but under the high pressures of 60 lbs., 70 lbs., or 100 lbs. per square inch the expansion could be carried to twelve times or fourteen times, which was practically impossible with the single engine; and by having the large cylinder and the small one connected upon the same shaft, double cylinders caused scarcely more complication than single ones.

Mr. A. MURRAY, C.B., explained that he was not opposed to

¹ Vide Ainsley's Engineers' Manual of the Local Marine Board Examinations 2nd edition. 8vo. pp. 154, 160 and 163. South Shields, 1868.
[1869-70. N.S.]

surface condensation as a system from which good results could not be obtained, but he doubted whether any benefit, that could be distinctly proved to be due to it alone, and not to any other improvements or changes introduced at the same time, was worth the extra number of moving parts—the extra weight and the extra first cost that were consequent upon its use. It had been said during the discussion that high-pressure steam could not be used without it, but he thought that this was not so, as the system adopted for condensing the steam after it left the cylinder had nothing to do with the means used for admitting it into the cylinder and regulating its expansion, and there was no reason why the vacuum should not be as good in the one case as in the other, if the air-pumps were properly made. And with respect to the boilers, surface condensation was not necessary to enable high-pressure steam to be used, as there were many examples of boilers carrying 60 lbs. steam, and using water from the hot wells of ordinary condensers, or direct from the sea, which had lasted well. Many boilers of the gun-boats of the Royal Navy, for example, had given excellent results in this respect under the good management of those in charge.

Capt. J. SELWYN, R.N., remarked, through the Secretary, that the improvement of Ocean Steam Navigation appeared most likely to be effected by economies. These economies admitted of broad division under two principal heads, namely, those which affected the production of the motive agency—steam, and those which might accompany its use. Hitherto, far more attention had been given to the latter than to the former. But since no saving of steam that had not been produced could be effected, the economical production of steam was the first subject to be attended to. No doubt this might be called a truism, but neglected truisms were precisely the things best worth acknowledgment and practice. What were the facts? Half of the fuel burnt in ocean steamships was dead waste. Taking the component parts of steam coal as carbon .85, hydrogen .05, and oxygen .06, the combustion of a pound of coal ought to evaporate 15.5 lbs. of water; whereas generally only 7 lbs. were evaporated, exceptionally, 8 lbs.; and notwithstanding what had been said, most rarely 10 lbs. He was sure that in the average of steam-ships each pound of fuel raised not more in steam than 7.5 lbs. of water throughout the voyage. It might be thought that, in aiming at so high a result, he was bringing forward Utopian views; therefore without going much into the subject of liquid fuel, which some day might deserve a Paper to itself, he would glance at the fact that, in the late official experiments which the Admiralty had enabled him to conduct, where the theoretic calorific value, calculated as for coal, was 17.52 lbs., or, more correctly perhaps, 17.02 lbs., of water vaporizable by 1

pound of creosote oil from a normal temperature of 212° feed, actual experience, with a marine boiler of 130 nominal H.P. of the ordinary type, had given an evaporation of $16\cdot9$ lbs. There were no residual products of combustion in this case, neither smoke, soot, nor ashes, and the temperature of the funnel was lower than that of the water in the boiler. How could it be expected to obtain the full duty with coal so long as clouds of smoke rose into the air, heaps of ashes were thrown overboard, soot choked the tubes and covered the heating surface, and waste heat burnt the funnels! It could not be asserted that all precautions had been taken against waste, when the temperature of a stoke-hole was such as to distress the engine men and stokers. The steam-pressure in the cylinders was often materially different to that in the boilers; and he had frequently, indeed generally, found that owing to an unwise jealousy of the space occupied by the boilers, there was first a necessity for heavy stoking, which meant waste of fuel and destruction of boilers, and next, even with that objectionable practice, a deficiency of steam. He would urge that some sacrifice of coal space should be made to give boiler room, in order that what fuel was carried might be more economically burnt. He had no doubt that the present practice of marine engineers would always give a sufficiency, even a surplus, of steam under the conditions of a trial-trip, or with first-rate fuel. But these conditions were never to be expected during the actual service of steam-ships abroad. Bad coals had to be burnt, worse stokers had to be engaged, and then the destruction and waste went rapidly on. In fact, it would be the wisest of expenditures if steam-ship owners were to institute a searching investigation, through scientific men, into the question of the best kinds of fuel, and the boilers best adapted to its economical use. In order to obtain the high economical result with oil, before alluded to, he had to sacrifice for the moment all consideration of quantity, and only 59 cubic feet of water were evaporated per hour with 1702 square feet of heating surface. When, in that boiler, the full quantity of 180 cubic feet was evaporated, the economy sank to $12\cdot02$ lbs. of water vaporized, from a feed of 212° , instead of $16\cdot9$ lbs. as before by each pound of creosote, and the funnel temperature rose to 800° . Thus the insufficiency of heating-surface was conclusively demonstrated, as also its defective arrangement, at any rate for burning liquid fuel. Under long Cornish boilers the oil had been giving satisfactory results for the past three years in large factories. He had heard with much pleasure from high authority that 2 lbs. of coal per indicated H.P. per hour might now be considered as an accomplished fact, since that would mean that with 800 nominal H.P. instead of the old calculation of $\frac{1}{10}$ nominal H.P. representing nearly the expenditure of coals in tons per day, say for such a size 75 tons, about half

this would be sufficient. Acknowledging that this result went far towards the accomplishment of the second division of possible economies with which he had started, he must yet urge another and most important problem as remaining to be solved, namely, the preservation of the bottom of iron ships from fouling, without resorting to such expedients as building a wooden ship outside an iron one, and a copper or zinc one outside that. There were several applications or coatings of the iron under trial and, from what he had heard, there seemed reason to expect success. When that was proved, it would be necessary for steam-ship owners to pay attention to their use, for there was a reduction of speed from foul bottoms which was fatal to economical steam navigation. There was a tendency to ignore, or at least to decry, the use of proper sail power which he was sorry to see. Important economy could often be effected by the use of sail power if, in steam-ships, it was considered how to make the masts, sails, and yards more manageable and more adapted to modern use, instead of accepting without question the assertion that they were too cumbrous or caused too much resistance in a head wind, or required too much manual power to be supplied where they might be seldom used. With properly constructed tubular steel masts no rigging need be used, the sails might be much simplified if they were only required for fair winds; and yet something more than the sticks which now disfigured the finest steamers might be, and ought to be, supplied. These would materially ease the rolling and consequent straining of the vessels, as well as be useful auxiliaries under many circumstances; and he had no hesitation in saying that there was no real reason why a full rig should be incompatible with full steaming power. Mr. McConnell had observed to him that very day—"The dividends of steam-ship owners lie in the coal bunkers of their steam-ships."

Mr. VIGNOLES, President, said the discussion had branched more into an economical than an engineering question. There was one point, however, on which he thought there had been some confusion, or rather there had not been given that clear mathematical definition, which ought to be made, of the proportion between resistance and the power of overcoming resistance. The resistance, simply considered, was as the square of the velocity; but in the discussion it had frequently been spoken of as the cube of the velocity. That was a wrong expression. The power to overcome the resistances was as the cubes of the velocity; the resistances themselves were simply as the squares. He thought if that were kept in mind it would lead to simple rules by which a set of tables might be calculated, whereby the various resistances arising from foul bottoms, or otherwise, might be made matters of comparison, the power exerted being the same.

Mr. W. BROCK communicated through the Secretary, by permission of Messrs. R. Napier and Sons, the results obtained from the trials of two steam-ships, the 'Europe' and the 'Afrique,' designed and constructed by Messrs. Napier in 1869 (Plate 5). These vessels were sister ships, and were built for the well-known steam-ship owners of Marseilles, MM. Fraissinet, Père et Fils. When ordered, they were intended for the trade from Marseilles to Bombay, and the East, *via* the Suez canal, on which route they were now actually employed.

The vessels were of the following dimensions:—

Length between perpendiculars	307 feet.
" over all	315 "
Breadth moulded	37 " 6 inches.
Depth moulded to spar deck	29 " 4 "
Tonnage, gross register	2,242 tons.

The conditions of the contract were, that the vessels should have an average sea-going speed of at least $9\frac{1}{2}$ knots per hour, carrying a dead-weight cargo of 2,200 tons, on a consumption of coal not exceeding $19\frac{1}{2}$ tons per twenty-four hours; and it was further stipulated that, carrying the same dead-weight cargo, the speed of the vessels should be upwards of 11 knots per hour, irrespective, however, of consumption of fuel.

Fulfilment of the first condition was to be ascertained by a twelve hours' test at sea; and the second by six several runs at the measured mile in the Frith of Clyde. Each vessel was fitted with a pair of compound, inverted cylinder engines, the high and the low-pressure cylinders acting on cranks placed at right angles to each other. The diameter of the low-pressure cylinder was 68 inches, and of the high-pressure cylinder $39\frac{1}{2}$ inches, and the length of stroke of both pistons was 3 feet 6 inches. The cylinders, cylinder-bottoms, and covers were steam-jacketed, and the engines were fitted with a surface condenser.

The two boilers were cylindrical, tubular, and fired from both ends. The working pressure was from 60 lbs. to 65 lbs. per square inch.

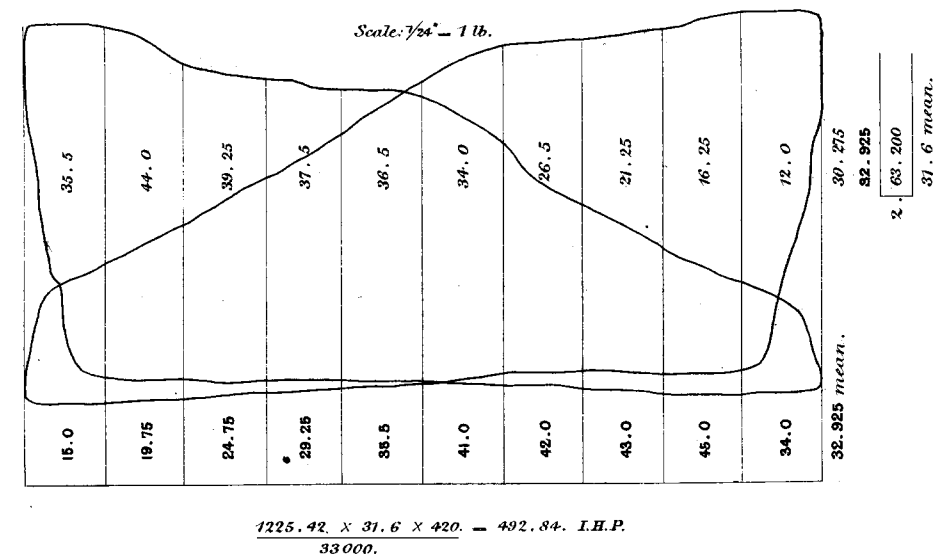
The 'Europe' was completed early in September, 1869, and on the 11th of that month proceeded on her full or extreme power trial. The vessel was loaded with upwards of 2,200 tons of coal and iron. The mean draft of water was 19 feet $4\frac{1}{2}$ inches. The immersed mid-area was 615 square feet, and the displacement 3,680 tons. The average of six runs, at the Admiralty measured knot at Skel-morlie, gave a true mean speed of 11.1 knots per hour, the weather being severe, and scarcely suitable for a trial of the kind.

On the 14th of the same month the 'Europe' proceeded on her twelve hours' trial, to test the consumption of fuel at her

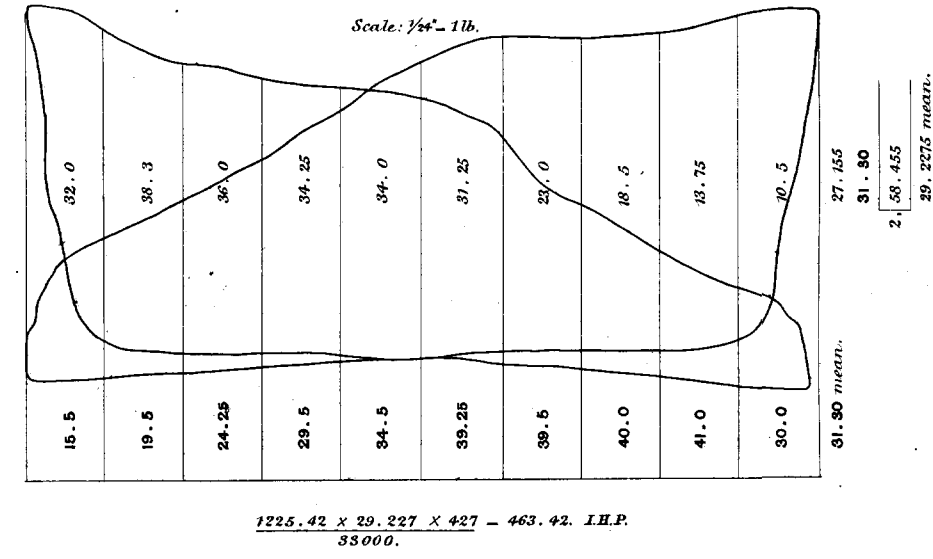
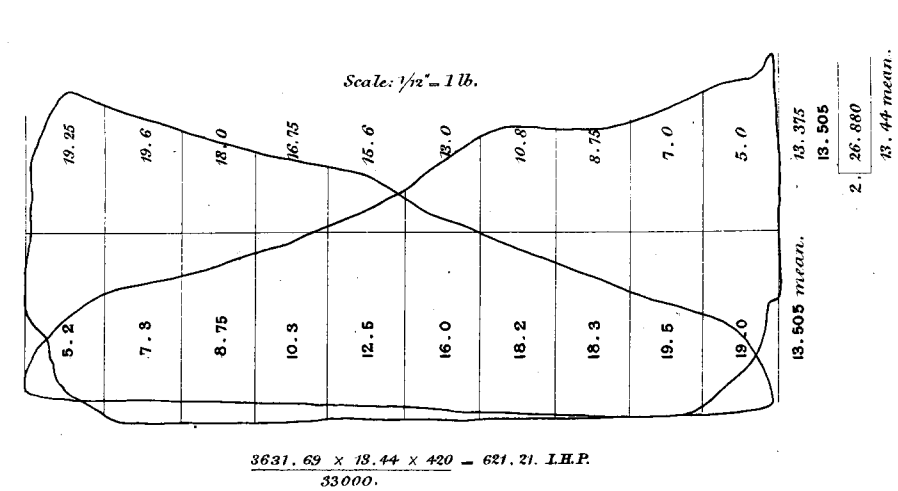
sea-going speed. On this occasion she had the same dead weight on board as before, and had, consequently, the same immersed mid-area and displacement. As it was a matter of great importance to ascertain accurately the mean speed of the vessel during the twelve hours of trial, considerable attention was given to this point, and it was ultimately agreed to take the distance between the Cloch and Cumbræ Lighthouses, on the Frith of Clyde, as a base, and to make as many runs between them in opposite directions as could be accomplished in twelve hours, measures being taken by the owners to ascertain for themselves that the speed of the engines was maintained at a uniform rate, whether the vessel was on the distance, or when coming round at either end to begin a new run. This was accordingly done. By observations at the commencement and at the conclusion of the trial, the number of revolutions made by the engines was ascertained by the counter. At the beginning and the end of each run the number of revolutions made during the run was similarly ascertained, and at the conclusion of the trial, it was found that the average revolutions per minute for the entire twelve hours, as given by the counter, agreed practically with the average made during the runs that were accomplished between the lighthouses, the figures being, for the entire time, 51·7, and for the time spent on the measured distance 51·84. It seemed, therefore, a fair conclusion that the mean speed, ascertained from the duration of the various runs, was maintained throughout the entire trial, especially as out of the twelve hours nearly nine were occupied in running between the known points. The distance between the two lighthouses was precisely $13\frac{2}{3}$ nautical miles; and six complete runs, in alternate directions, were made between them. The true mean speed of the vessel was thus ascertained to be 9·6 knots per hour. During the trial twenty sets of indicator figures were taken, and the mean indicated power was found from them to be 750 H.P. The coal was carefully weighed on deck, by the officers of the ship, on the part of the owners, and then passed down into the stoke-hole. At the conclusion of the trial it was found that the consumption had been at the rate of 17·3 tons per twenty-four hours, or equal to 2·15 lbs. per H.P. per hour. This consumption was fully 2 tons per day under what the contractors had guaranteed, and entitled them to a large premium, which the owners paid with the greatest cordiality.

This trial of the 'Europe' for speed and consumption of fuel was deemed by Messrs. Fraissinet so satisfactory, and under the capabilities of the ship (it blew an equinoctial gale during the whole time of the trial), that they dispensed with this trial in the case of the 'Afrique,' and at the same time paid to the Messrs. Napier a premium equal to that gained by the 'Europe' with a considerable addition. The 'Afrique' was, therefore, only tried

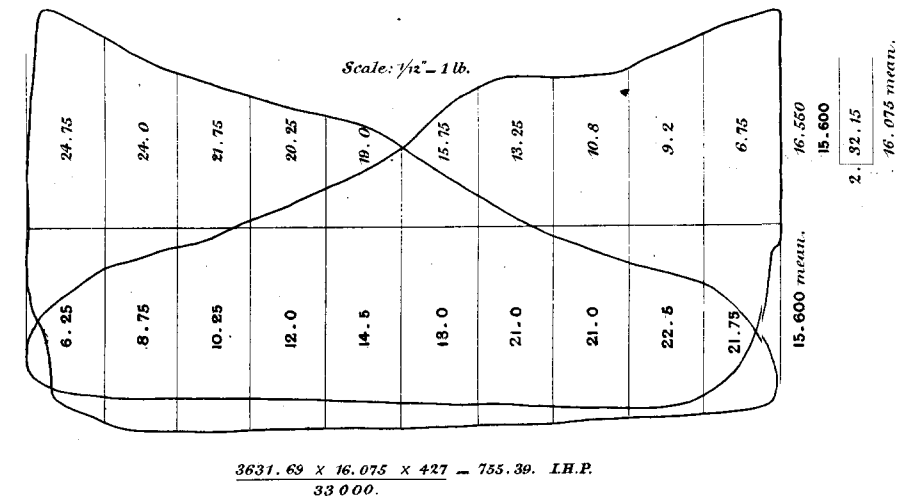
Official Trial at Skelmorlie, Sep^r 11th 1869.
Speed, 11.1 knots per hour.



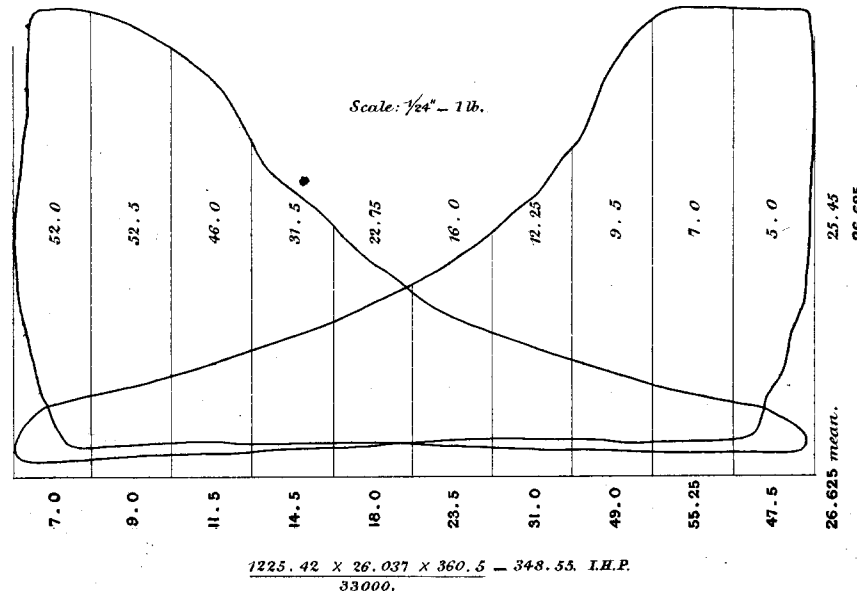
Steam = 64 lbs.
Vacuum = 27 ins.
Revolutions = 60.



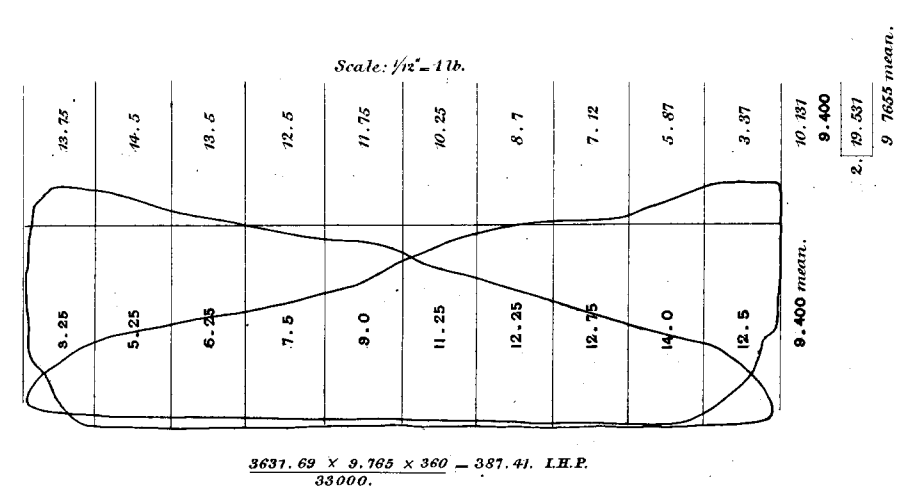
Steam = 65 lbs.
Vacuum = 27 ins.
Revolutions = 61.



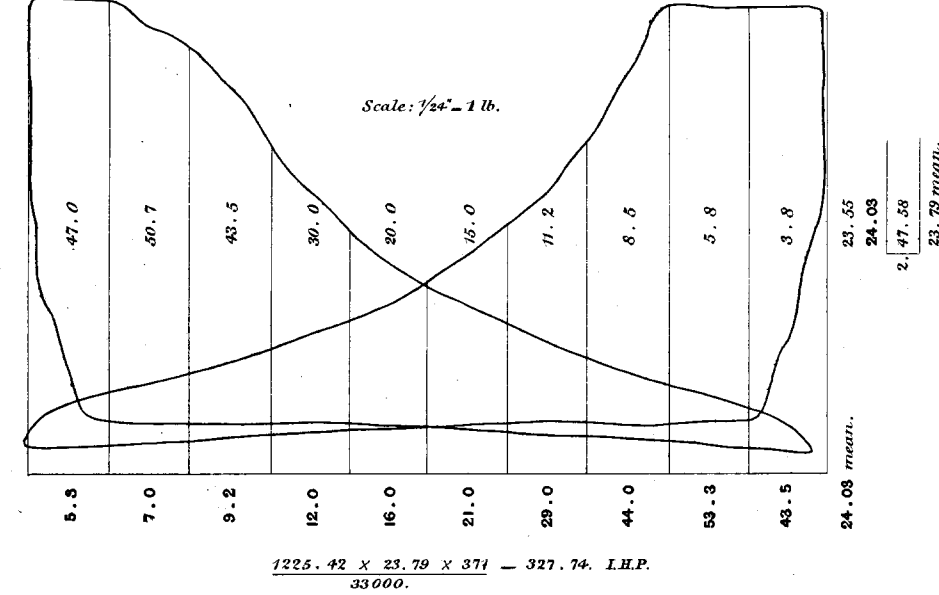
Diameter of Large Cylinder = 68"
" " Small " = 39"
Length of Stroke = 3' 6"



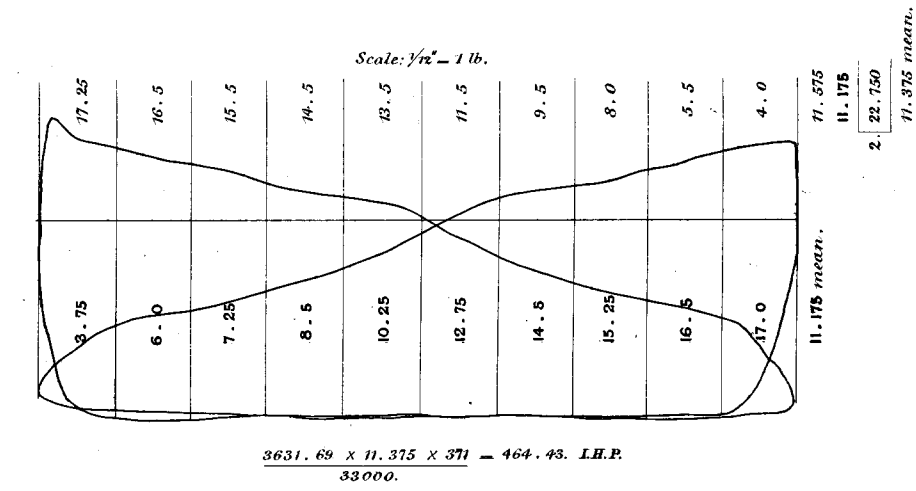
Steam = 65 lbs.
Vacuum = 27 ins.
Revolutions = 51½



Official Trial, Cloch to Cumbræ, Sep^r 14th 1869.
Speed, 9.6 knots per hour.

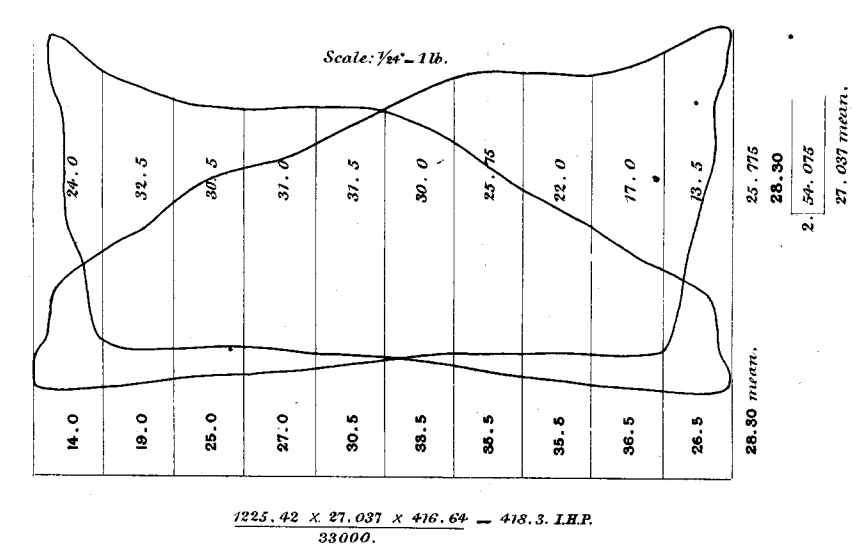


Steam = 66 lbs.
Vacuum = 27 ins.
Revolutions = 53.

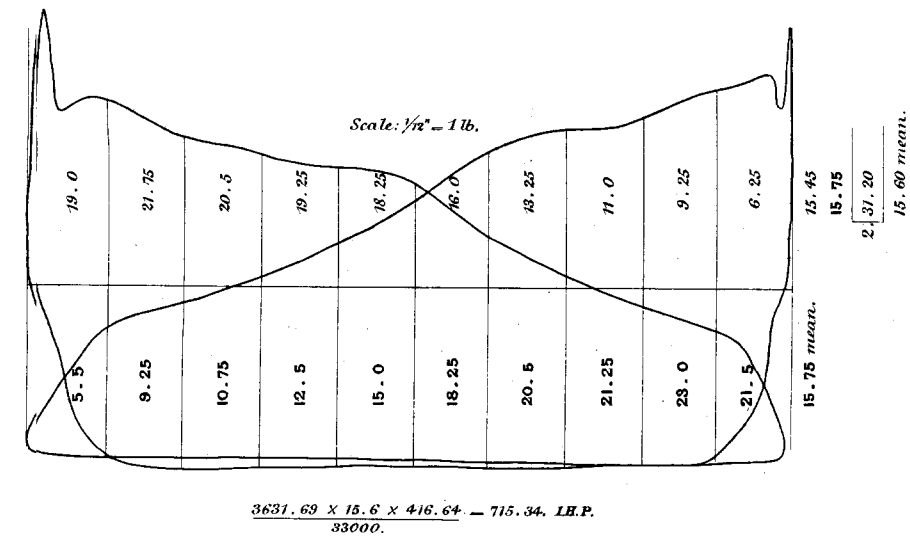


S.S. "AFRIQUE".

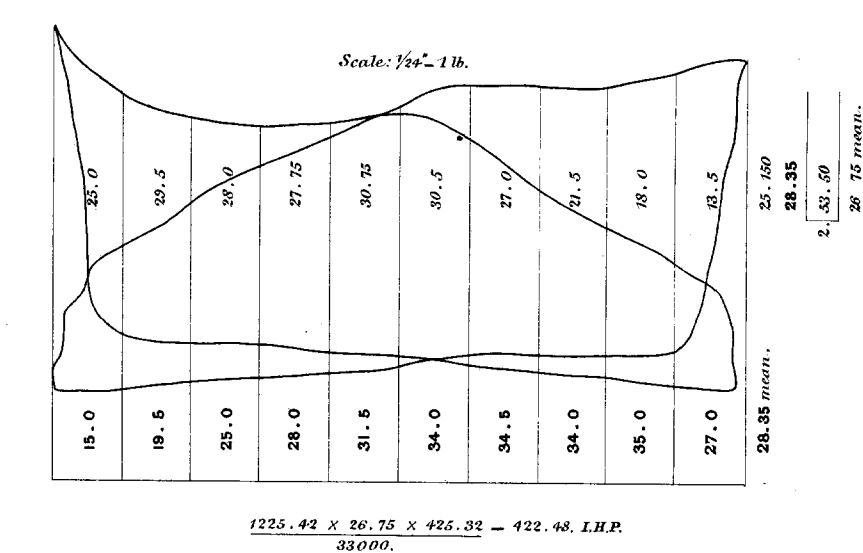
Official full power Trial at Skelmorlie, Jan^y 4th 1870.



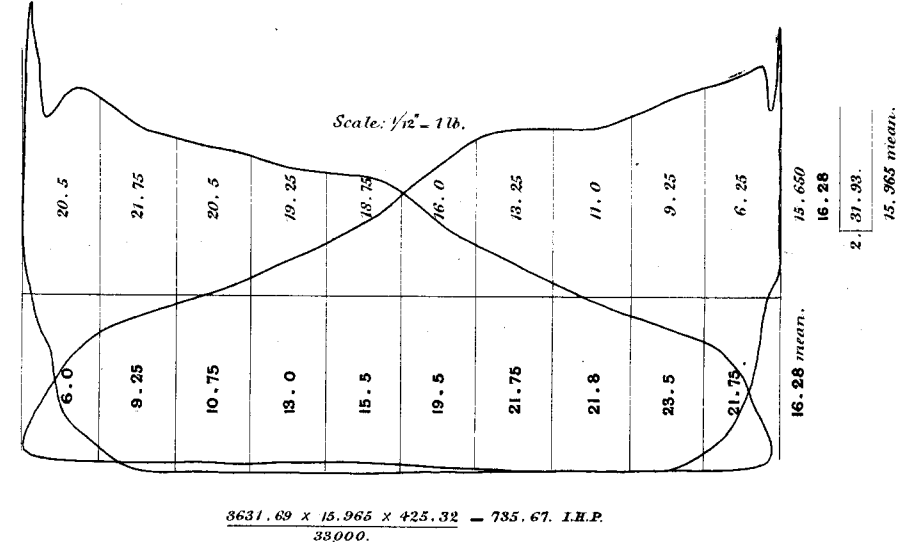
Steam = 57½ lbs.
Vacuum = 27 ins.
Revolutions = 53.52.



Diameter of Large Cylinder = 68"
" " Small " = 39½"
Length of Stroke = 3' 6"



Steam = 55 lbs.
Vacuum = 24 ins.
Revolutions = 60.76



for full power. On the 4th of January, 1860, she made six runs at the Skelmorlie mile, giving a true mean speed of 11·39 knots per hour. The mean draft of water was 16 feet 11 inches; the immersed mid-area 520 square feet; the displacement 3,040 tons; and the indicated H.P. 1,107.

Mr. Brock caused the coal to be carefully weighed on this occasion, and the consumption was found considerably under 2 lbs. per indicated H.P. per hour; but, inasmuch as the trial only lasted three hours, there was room for some error, from the difficulty of judging accurately the quantity of coal in the furnaces at the beginning and end of the trial. Making all allowance for this and other errors, he was satisfied that the consumption of coal in this case did not amount to so much as 2 lbs. per H.P. per hour.

The trial of the 'Europe' was conducted with the most scrupulous care, and, on account of its long duration under actual sea-going conditions, afforded reliable results, which had subsequently been borne out by the performance of the vessel in two voyages from Marseilles to Alexandria and back.

Mr. J. GRANTHAM, in reply upon the discussion, said that some remarks which occurred in the opening address of the President, were an indirect vindication of the form he had adopted in the Paper. Mr. Vignoles said: "I have always inculcated the doctrine that the success of an Engineer is best insured by the pecuniary benefits accruing from his works, as commercial transactions." He thoroughly endorsed that view, and had therefore treated the question with reference to its bearing on the commercial interests of Great Britain. To have treated it simply as a scientific question would have taken more time than he could have devoted to it, and would have involved the necessity of much that was elementary. Besides which, each of the large questions, such as the construction, form, and equipment of an ocean steam-ship, the boilers, valves, cylinders, condensers, and propellers, of the machinery department, with the varied opinions, and various adaptations of each department, could only be embraced in a series of lectures; and some of these subjects, taken by themselves, would have alone occupied more than an evening in discussion.

Mr. Samuda had spoken principally upon the kind of vessel necessary to steam direct to Australia; and had expressed the opinion that it would require a vessel of 6,000 tons and 1,000 H.P. to perform the voyage in about fifty days, steaming, Mr. Grantham presumed, the whole way. He also expressed the opinion, that except on the line from England to New York, no vessels attained an average speed of 11 knots an hour. This was not so: more than one vessel belonging to the Royal West India Mail Company averaged 11·5 knots to 11·75 knots per hour on the whole voyage of 10,000 miles, at a very moderate consumption of

fuel. On the New York line, where fuel was not so much considered, the average speed of some of the best vessels exceeded 12 knots.

Mr. Wigram had spoken of the steam-ship the 'Somersetshire,' of about 2,300 tons, which had just arrived from Melbourne in fifty-eight and a half days, about thirty days under steam, and twenty-eight and a half under canvas. This, being a new ship, must be taken as the type of what he recommended as the best description of vessel for an Australian voyage. The 'Somersetshire' was a fully rigged ship, with moderate power, like the 'Great Britain,' and $6\frac{3}{4}$ beams for the length. Indeed, the performances of these two vessels seemed to correspond in many respects. By referring to data supplied in the Paper, he thought it would be found that better results were already produced by much smaller vessels than had been mentioned by Mr. Samuda. In making statements as to the future development of the system, he had taken as the basis of calculations, vessels showing the best results and the highest capabilities, provided the best qualities of each vessel were such as could be transferred to the cases in question. He had given the general dimensions of such a vessel as he thought could perform the Australian voyage, and had added what he considered would be the result, provided all modern improvements were combined in that vessel. This ship should be about 4,000 tons B.M., 700 nominal H.P., working up to 2,800 actual H.P., or four times the nominal H.P., and he had allowed 2 lbs. per H.P. per hour as the consumption of fuel. It would be found that these figures worked out to about 60 tons a day, or 2,700 tons for forty-five days.

The 'Neva,' one of the last new ships of the Royal West India Mail Company, to which he had referred in the Paper, had been running about twelve months, and her qualities were now well understood. He had examined the private logs, which were admirably kept; these gave the distance run, the amount of coals consumed over the whole voyage, including coals for cooking, for banking up fires at several stations, and for every purpose, and the time of steaming. In the first voyage, the distance out and home, 9,559 knots, was performed at an average speed for the whole distance of 12.37 knots an hour, and the consumption for all purposes was 2,055 tons, or 62 tons a day. The indicated H.P. for this voyage was not given. On the subsequent voyages the vessel had not been driven so hard, and she had now settled down to an average speed of about 11.5 knots to 11.75 knots, and the consumption of fuel was under 50 tons a day, the pressure of steam about 21 lbs., and the indicated H.P. 1,550, or rather less than 3 lbs. of coal per H.P. per hour. The voyage, by some new arrangement in the postal service, was now increased to a round of nearly 10,000 miles, approximating to the length of an

Australian voyage. It would be observed that in this vessel the pressure on the boilers was only 21 lbs. per square inch, and not 75 lbs. as given by Mr. Stephenson for the new China ships, and therefore the expansive principle was not carried so far as in many modern ships. The 'Neva' had probably 3 degrees of expansion, whereas the later vessels had 8 degrees, 10 degrees, and even 12 degrees.

Transferring these data to the ship he had proposed for the Australian route, and allowing for the advantage of increased pressure, for a more extensive use of canvas in the trade-winds, and for several smaller items of economy now being employed, he thought it would be seen that the calculation he had given would be fully borne out.

He regretted that he had not had time to examine the arrangement proposed by Mr. Cowper, for employing steam expansively by which he obtained a more equable action on the piston, and greater economy, but he had no doubt it possessed some advantages.

Sir Edward Belcher claimed 16 knots per hour as a speed attained by some of the best frigates, and thought the speed of China clippers might equal $12\frac{1}{2}$ knots per hour on the average; these ships, however, with all the stimulus that high freights could give, with all the advantages of scientific and experienced commanders, were considered to have made a rapid voyage from China when it did not exceed ninety-five days; while the average length of voyages of the China ships was upwards of one hundred days. By looking at the table annexed to the Paper, and at the greatly reduced rate of only $10\frac{1}{2}$ knots per hour, as the average speed of a steamer on that route, it would be seen that the voyage required only fifty-eight days; and well-known steam-ship owners were now offering to perform the voyage, under a penalty, in fifty-five days.

He admitted that, when tested simply by figures, the results obtained by surface condensers did not materially counterbalance the cost and complexity involved in their adoption; but there was a point at which the surface condenser was considered essential to the economical use of steam. With high pressure, more rapid evaporation in circular boilers, and with a reduced amount of water, surface condensation alone would save the boilers from rapid incrustation.

He thought the remedy, proposed by Mr. Murray, for cleaning the bottoms of vessels by divers would not prove efficacious, as ocean steam-ships had an external surface under water of from 3,000 square yards to 4,000 square yards, which would require a large number of divers, and even then there would be time, in tropical climates, for the parts first cleaned to become foul again, before the whole was finished. The Government had now extensively adopted his plans

of sheathing iron ships with copper, and would soon have experience of its utility. He did not see an opening for the introduction of any fuel, or means of generating heat, likely to supersede coal; and believed there were, at present, no known chemical combinations that held out any expectations, that coal would cease to be employed.

Mr. Bramwell had misunderstood his remarks about the speed of steam-vessels, in supposing he considered that to be successful they must attain 11 knots an hour; he had not said so; but had only quoted the actual performance of some of the best passenger ships, and had shown that, in the future of ocean navigation, similar results should be looked for; and he was fully convinced that neither the public, nor the post-office would be satisfied with less. As regarded mere cargo ships, he had given a much lower speed, but even with these the value of speed was well known; it was that which insured regularity when heavy weather was encountered. It was not alone the extra consumption of fuel which ruled this question; various other considerations entered into the calculation, and formed a large set-off against the cost of fuel. Mr. Bramwell had quoted the performance of Cornish engines to show that the expectations, as regarded ocean steam-ships working with 2 lbs. of coal per indicated H.P. per hour were fallacious. He had observed that 2 lbs. per H.P. per hour was an expression for 112,000,000 of foot pounds, and that the average of the best Cornish engines, as taken from recent tables, was about 60,000,000 foot pounds. Now this was proving too much, for it indicated that the average duty of the best pumping-engines was only equal to 4 lbs. per H.P., and as, added to this, he claimed an advantage for the slow combustion of those engines, and for a low temperature in the chimney, it followed (if pumping-engines were to be a guide in the estimate for the consumption of fuel in steam-ships) that 4 lbs. would be too low for the latter, which had a rapid consumption. But this conclusion was against the facts which he had given, and which were attested beyond all question. It was well known that, from certain causes, Cornish engines now performed a lower duty than they did many years ago; and it was yet to be proved that slow combustion gave the highest results. Certainly, in ships and locomotives, the duty performed was very high, and they were far from having a slow combustion. But there were abundant facts to prove that a consumption of 2 lbs. of fuel, and less than 2 lbs., was now being attained, and that engineers were contracting to supply engines having this condition attached, under heavy penalties; and a well-known authority on the Clyde did not hesitate to endorse the opinion that a still greater reduction would shortly be attained. This was not a question of speed of ship, or a development of more or less

indicated H.P. for a given size of engine; it was a question of the duty performed as shown by the indicator, whether little or much, by a given amount of fuel. Mr. Bramwell had also questioned these results for another reason, viz., that a great loss must arise in consequence of the high temperature at which the heated gases passed out of the chimneys of steam-vessels, as recorded in the Paper; but Mr. Grantham had given the fact to prove that a great saving could be derived from this source by the introduction of superheaters, a system now universally applied in the best vessels.

He regretted that no allusion had been made in the discussion to the Suez canal. It had, as he had shown, a most decided bearing on the question of Ocean Steam Navigation, and was, beyond all comparison, the most important single event that had ever occurred in the shipping interest of the world, but *par excellence* to the steam shipping interest, and the marine engineering works of Great Britain. When the early calculations for this undertaking were made, a large item of the estimated receipts was to be derived from sailing-ships, on the supposition that they would be sent in that direction, to avoid the stormy and circuitous route of the Cape of Good Hope, but this view had been entirely altered; and whereas of the tonnage which had rounded the Cape, in the direct voyage from Europe to the East, only about 1 per cent. had been performed by steam-ships, it was now highly probable that the scale would be reversed, and that 1 per cent. would represent all the sailing-ships that would pay toll to the canal. It was surprising to see the apathy with which, till lately, this great undertaking had been viewed: it was a work in which Englishmen had probably more interest than all the other nations of the world combined.

Mr. W. LAIRD furnished, through the Secretary, an account of the performance of the steam-ship 'Belgian,' when loaded, on a voyage from Liverpool to London. The engines on the trial trip indicated 740 H.P.:—

Length	280	feet.
Breadth	38·5	„
Depth, outside	27	„
Tonnage	2,104	O.M.
Load draft	19·6	feet.
Displacement	3,262	tons.
Area of section	617	feet.
Speed in knots for whole voyage	7·8	
Nominal H.P.	160	H.P.
Indicated do., about	580 to 600	„
I.H.P. per ton of displacement	·18	
Do. per foot of section	·97	
Consumption of coal per 24 hours, as reported by the engineer	12	tons.

WEIGHTS.				Tons.
Hull and fittings complete.	.	.	.	1,250
Outfit	.	.	.	75
Engines, with water in boilers, spare-gear and fittings	.	.	.	175
Total, excluding cargo or coal.				1,500
Coal in bunkers	.	.	.	450
Cargo	.	.	.	1,300
Total displacement (tons)				3,250

Mr. DOUGLAS HEBSON observed, through the Secretary, that notwithstanding the great improvements which had been made within the last few years in the economical and efficient construction and working of steam-vessels, whereby the longest voyages had been proved to be practicable and, he thought, profitable, by properly adapted steam-ships, the prospect of still further improvement was as great and encouraging as it had been for many years. Thirty years ago steamers were, for the most part, built of wood, and fitted with side-lever paddle-wheel engines and long-flued boilers, working at a pressure of 6 lbs. or 8 lbs. per square inch, with an enormous consumption of coal as compared with the work done, but little room being left in the vessel for passengers and cargo. By the introduction of iron vessels, and the substitution of the screw for the paddle-wheel, much was done to increase the earnings as well as to diminish the expenses of steam-vessels; but, in addition to this, the length of the ships in proportion to their breadth had been increased from five or six times to ten or eleven times the beam, with little if any increase of resistance; and at the same time, by the use of tubular boilers and engines working at a higher pressure and greater speed of piston, and less consumption of coal, there had been a decrease in the space allotted to the propelling power, so that the carrying capacity and the earnings of the vessel had been increased as compared with the cost of propulsion. Passing over the minor changes which had been introduced in marine engines, he attached the greatest importance to the economy to be obtained by the use of steam at a high pressure; and now that the apprehension of the owners and the public of the danger in using high-pressure steam had in some measure subsided, the substitution of high-pressure boilers, working at 60 lbs. or 70 lbs., with combined high-pressure and low-pressure engines, was taking place rapidly on all sides, with most satisfactory results. So long as steam of a pressure not exceeding 30 lbs. per square inch was used, the expansion required for the economical use of the steam could be obtained with as much advantage in one cylinder as with combined cylinders; but with higher pressures, involving an earlier 'cut-off' and a great inequality of pressure at various parts of the stroke, some practical

evils had been experienced, owing to the more rapid wearing of the cylinders at the two ends than in the middle, and to the increased vibration in the vessel, from the irregularity of the strain of the propelling power at different parts of the revolution of the engines. He thought it was possible to diminish or remove these objections by judicious arrangements of the engines; but the combined cylinder arrangements could be made so simple that, for the present at any rate, it received, and perhaps deserved, a preference. The theoretical advantage to be obtained by the use of steam at high pressures had long been understood by scientific engineers; and now that it was being applied to marine engines, he looked for a rapid increase in its use, and that too at far higher pressures than were now generally adopted. So long ago as the years 1861-1862, three steamers for service in India were fitted by Messrs. R. Stephenson and Co., of Newcastle, with engines and boilers working at a pressure of 130 lbs. per square inch. These were tested before shipment, and realized 1 indicated H.P., with a consumption of 1.78 lb. of Newcastle coal. The consumption in India had been very moderate; but owing to the use of native and other coal of inferior quality, he could not give an exact statement of the amount per indicated H.P. By the last information that he had received, the boilers of two of these boats were in excellent order. Those of the third had been injured by the water having got too low, but were still in use; and he was not aware that any danger or evil consequences had arisen further than the leakage from the seams, and the buckling of the parts which had been overheated. The boilers were tested about a year ago, and passed by the Government surveyor. From what he had learned of these vessels, and others working at 85 lbs. to 100 lbs. pressure, with boilers specially adapted for the purpose, such as Rowan's cellular boiler and Ramsden's boiler, he felt sure that the public would not long be satisfied with the use of steam at lower pressures, and, in fact, he looked forward to much higher pressures. In his more recent experience he had also obtained satisfactory results in economy of fuel from the use of high-pressure steam with combined engines, both specially constructed, and with engines originally constructed and used for many years with low pressure only, which he had adapted to work on the compound system, by the addition of high-pressure cylinders and surface-condensers with new boilers, at 60 lbs. to 70 lbs. pressure, retaining the old working parts almost unaltered. In one instance, a saving in coal of from 40 per cent. to 50 per cent. had been effected, the vessel and screw-propeller remaining as before, and the original valve-gear, shafts, &c., working with even less wear and tear, owing, as he supposed, to the shock at the turn of the stroke being absolutely less than it was when steam of 15 lbs. to 20 lbs. pressure was admitted direct

to the low-pressure cylinders, which now only received it after it had passed through, and been partially expanded in, the high-pressure cylinders. In another case, simultaneous with the alteration of the engines, the vessel was lengthened 48 feet 6 inches amidships, and a spar deck, about 200 feet long, was fitted from the poop to the forecastle, thus greatly increasing the capacity of the vessel. The result had been an increase of speed of nearly 1 mile per hour on the average over the voyage, notwithstanding the larger cargo, and this, too, with a saving of 20 per cent. of fuel as compared with that formerly consumed. The engines in this case also worked with ease and apparent absence of any undue straining, although giving off 25 per cent. more power. He had quoted these instances as affording a direct comparison of the new and the old systems, and he thought that it was scarcely possible to overestimate the importance of the revolution which must take place in steam navigation. If, in combination with economical engines, such as those referred to, the vessels were built of a lighter material in proportion to its strength, such as steel, he was persuaded that results would be obtained which would revolutionize the ocean carrying trade of the world.

December 14, 1869.

CHARLES HUTTON GREGORY, President,
in the Chair.

The discussion upon the Paper, No. 1,236, "Ocean Steam Navigation," by Mr. Grantham, occupied the whole evening, to the exclusion of any other subject.
