RESEARCH COMMITTEE ON MARINE-ENGINE TRIALS.

ABSTRACT OF RESULTS OF EXPERIMENTS ON SIX STEAMERS, AND CONCLUSIONS DRAWN THEREFROM IN REGARD TO THE EFFICIENCY OF MARINE BOILERS AND ENGINES.

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The Experiments with which the present paper deals in an abstract form are those reported at previous meetings of the Institution, and published with the discussions thereon in the Proceedings of the four years 1889–92. The six steamers, of which the engines and boilers were tested in these trials, were the "Meteor," 1889, pages 235–306; the "Fusi Yama," "Colchester," and "Tartar," 1890, pages 203–290; the "Iona," 1891, pages 200–288; and the "Ville de Douvres," 1892, pages 136–197.

Steamers.—The six steamers were of very different types; their leading dimensions and other particulars are summarised in the accompanying Table 16 (page 34).

The "Meteor" was tested during a run south from Leith to London under ordinary working conditions, that is with natural draught. Her boilers are designed to work with forced draught on the run north in order to do the run five hours quicker, the engines developing therefore much greater power than they did during the trial; in considering the results this fact must be clearly borne in mind. She was built and engined in 1887, and her engines had been overhauled about three months before the trial, which lasted 17 hours 9 minutes, with weather fair.

TABLE 16.—*Steamers; dimensions and speed on trial.*

Steamer.	Description.	Owners.	Makers of Engines.	Length.	Breadth.	Depth moulded.	Draft on trial.		Displacement on trial.	Mean Speed on trial.
				Feet.	Feet.	Feet.	Ft.	Ins.	Tons.	Knots.
Meteor	Screw; triple-expansion. Leith and London. Cargo and passengers.	London and Edinburgh Shipping Co.	J. & G. Thomson, Clydebank.	261·0	32·1	19·3	15	$1\frac{1}{2}$	2,090	14·6
Fusi Yama	Screw; compound. Cargo coaster.	Gellatly, Hankey, Sewell & Co.	M. Samuelson, Hull.	214·3	29·3	20·5	18	$11\frac{3}{4}$	2,175	—
Colchester	Twin-screw; compound. Harwich and Antwerp. Passengers.	Great Eastern Railway.	Earle's Shipbuilding & Eng. Co., Hull.	281·0	31·0	15·3	12	$0\frac{1}{2}$	1,675	14·4
Tartar	Screw; triple-expansion. Large cargo.	Gellatly, Hankey, Sewell & Co.	T. Richardson & Sons, Hartlepool.	332·0	38·0	27·0	12	0	2,250	—
Iona	Screw; triple-expansion. Large cargo.	Herskind and Woods.	W. Gray & Co., West Hartlepool.	275·1	37·3	21·8	20	$7\frac{1}{2}$	4,430	8·6
Ville de Douvres	Paddle; compound. Dover and Ostend. Mails and passengers.	Belgian Government.	Société Cockerill, Seraing.	271·0	29·0	15·5	9	$0\frac{3}{4}$	1,090	17·1

The "Fusi Yama" was tested during a run down Channel from Gravesend to Portland. Her engines were built in 1874, and immediately before the trial had been overhauled by Messrs. Rait and Gardiner on behalf of her owners, by whom she had just been purchased. As the pistons had been leaking, new spring-rings were fitted to them, but the cylinders were not re-bored; consequently it is probable that the rings had not worn down to the cylinder shape by the time of the trial. The trial lasted 14 hours 9 minutes; weather fair at first, rough at finish.

The "Colchester" had just undergone her first overhaul by Messrs. Earle's Shipbuilding and Engineering Co. Her engines were built in 1888–9. The run was made from Hull southwards and then to Harwich, the trial lasting 11 hours, weather very fine.

The "Tartar" had arrived from Australia a week before the trial. The engines and boilers, which were built in 1887, had been opened out, cleaned, and overhauled, and the cargo discharged; the trial was made therefore with the ship light, only in water ballast. The run was down Channel, and lasted 10 hours 5 minutes; the weather was rough.

The "Iona" also had just arrived from a voyage, and her engines had been overhauled by the makers immediately before the trial. She was built and engined in 1889. The trial was made on a run south from the Tyne, and lasted 16 hours, the weather being fair.

The "Ville de Douvres" before the trial had been running for about eighteen months on her regular route between Dover and Ostend, having been delivered by the builders to the Belgian Government in February 1890. She was overhauled beforehand, and was tried on a special run from Ostend up the North Sea and back. The trial lasted 9 hours, with fair weather throughout.

In summarising the results of these six trials, it will be most convenient to deal with the boilers and engines separately. The various dimensions for each will be given in a condensed form, and then the results obtained during the trials; finally from these results any conclusions which seem to be brought out by the figures will be stated, and any inferences as to the influences of the varying

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conditions on the general efficiency of the machinery. The boilers, as the generators of the steam afterwards used by the engines, will in the natural order be dealt with first.

General description of Boilers.—There were three single-ended sets, namely those of the "Fusi Yama," "Iona," and "Ville de Douvres"; and three double-ended sets, those of the "Meteor," "Colchester," and "Tartar." It seems advisable therefore to group the boilers under these two heads. Natural draught was used with all the double-ended boilers, and also with the single-ended set of the "Fusi Yama"; while forced draught was used with the other two single-ended sets. The forced draught for the boilers of the "Iona" was obtained by closing the fronts of the ash-pits, and passing air into them through gridiron valves, from a trunk into which a fan forced the air at a pressure of 0·86 inch of water; a supplementary supply from a branch trunk was also delivered into the combustion chambers through perforated plates, securing therefore small streams of air to mix with the gases after they had passed the furnace bridge, in order to promote perfect combustion in the flame-box. The "Ville de Douvres" on the other hand had closed stoke-holds, with an average air-pressure in them of 0·7 to 1·0 inch of water, the air being supplied by centrifugal fans.

The principal over-all dimensions are given in Table 17. The following additional particulars will probably be found useful in comparing the results obtained with these boilers.

"Meteor." Fox's corrugated flues are used; and the furnaces and tubes at the opposite ends of the boiler open out into common combustion-chambers, of which each boiler has three, one common to each pair of opposite furnaces. As already mentioned, the boiler has been designed to work with forced draught as well as with natural draught.

"Colchester." The boilers have large steam drums 4 feet diameter and 16 feet long; and one common combustion-chamber for each end of the boiler. The furnaces are plain flues. Henderson's fire-bars were in use, mainly with the object of securing a more rapid rate of combustion.

TABLE 17.—*Boilers.*

Steamer.		Number of Boilers.	Diameter.		Length.		Number of Furnaces in each boiler.	Fire-Grate. Width.		Fire-Grate. Length.		Tubes. External Diameter.	Tubes. Length.		Funnels. Number.	Funnels. Internal Diameter.		Funnels. Height.		Material used.
		No.	Ft.	Ins.	Ft.	Ins.	No.	Ft.	Ins.	Ft.	Ins.	Ins.	Ft.	Ins.	No.	Ft.	Ins.	Ft.	Ins.	
Meteor .	Double-ended	2	13	6	16	0	6	3	3	6	0	$2\frac{1}{2}$	6	$4\frac{1}{2}$	1	7	3	61	0	Steel
Colchester	Double-ended	2	13	0	18	3	6	3	4	5	6	$3\frac{1}{2}$	6	$7\frac{5}{8}$	2	5	5	47	0	Iron
Tartar .	Double-ended	2	13	0	14	9	4	3	8	5	6	3	5	$7\frac{1}{4}$	1	7	0	57	0	Steel
Fusi Yama	Single-ended	1	13	$3\frac{3}{4}$	11	0	3	2	$11\frac{1}{2}$	5	10	$3\frac{3}{4}$	7	5	1	4	$6\frac{1}{2}$	43	2	—
Iona .	Single-ended	2	13	3	10	0	2	3	6	3*	9	3	6	$10\frac{3}{8}$	1†	6	3	51	9	Steel
Ville de Douvres	Single-ended	4	13	0	10	0	3	3	0	6	$6\frac{3}{4}$	$2\frac{1}{2}$	7	$1\frac{5}{8}$	2	5	3	49	8	Steel shells, the rest Iron

* Length on trial 3 feet only.

† A damper is placed in funnel 17 ft. 8 ins. above fire-bars.

TABLE 18.—*Boilers, summary of observations and relations.* *See Plate* 1.

Steamer.		Meteor.	Colchester.	Tartar.	Fusi Yama.	Iona.	Ville de Douvres.
Boilers, number of main boilers		2	2	2	1	2	4
,, single-ended or double-ended		double	double	double	single	single	single
Furnaces, total number		12	12	8	3	4	12
Heating surface, total	square feet	6,648	5,820	5,226	2,257	3,160	7,340
,, ,, tubes	square feet	5,760	4,770	4,366	1,689	2,590	6,280
Grate area, total	square feet	208	220	161	52	42	236
,, ,, per furnace	square feet	17·33	18·33	20·12	17·33	10·50	19·67
Tube surface to total heating surface . .	per cent.	86·7	81·9	83·5	74·8	81·9	85·6
Total heating surface to grate area . .	ratio	32·0	26·5	32·5	43·4	75·2	31·1
Tube surface to grate area	ratio	27·7	21·7	27·1	32·5	61·7	26·6
Grate area to flue area through tubes . .	ratio	—	5·5	4·5	4·0	2·3	6·7
,, ,, to area through funnel . .	ratio	5·0	4·8	4·2	3·2	1·4	5·5
Draught, natural or forced		natural	natural	natural	natural	forced	forced
Barometric pressure . .	lbs. per square inch	14·90	15·00	14·60	14·80	14·58	14·84
Boiler pressure above atmosphere	lbs. per square inch	145·2	80·5	143·6	56·84	165·0	105·8
Fuel per hour, total	lbs.	4,005	5,742	1,920	987	942	7,380
,, per square foot of grate per hour . .	lbs.	19·25	26·10	11·93	18·98	22·4	31·3
,, per square foot of heating surface per hour .	lbs.	0·602	0·987	0·367	0·437	0·298	1·01
,, per I.H.P. per hour	lbs.	2·01	2·90	1·77	2·66	1·46	2·32
Carbon-value per I.H.P. per hour (*see Plate* 9) .	lbs.	1·76	2·65	1·82	2·33	1·49	2·30

Steamer.		Meteor.	Colchester.	Tartar.	Fusi Yama.	Iona.	Ville de Douvres.
Feed-water per sq. ft. of heating surface per hour	lbs.	4·49	7·39	4·13	3·48	2·73	9·02
„ „ per lb. of fuel	lbs.	7·46	7·49	—	7·96	9·15	8·97
„ „ „ „ from and at 212° F.	lbs.	8·21	8·53	—	8·87	10·63	9·84
„ „ „ carbon-value, from and at 212° F.	lbs.	9·62*	9·34	—	10·10	10·42	9·94
HEAT Balance-sheet. *See Plate* 2.							
Calorific value per lb. of fuel	Th. U.	12,770	13,280	14,995	12,760	14,830	14,390
Feed-water takes up	per cent.	62 0	62·0	—	67·2	69·2	66·1
Funnel gases carry away	per cent.	18·5	28·0	22·1	23·5	16·2	26·8
Imperfect combustion	per cent.	3·6	1·3	0·0	0·0	0·0	0·0
Evaporating moisture in fuel	per cent.	1·2	0·4	0·0	0·9	0·0	0·0
Unburnt carbon in ashes	per cent.	2·9	1·7	1·4	—	1·6	3·1
Balance unaccounted for (radiation)	per cent.	11·8	6·6	—	8·4	13·0	4·0
Temperature, outer air	Fahr.	—	55°	55°	55°	62°	64°
„ funnel gases	Fahr.	791°	835°	477°	578°	452°	910°
„ feed-water	Fahr.	163°	113°	101°	129·5°	106°	158°
„ boiler steam	Fahr.	363°	324°	362°	304°	373°	342°

* Allowing 3 per cent. for clinker not in chemical analysis.

"Tartar." There are two combustion chambers for each boiler, common to opposite furnaces. Fox's corrugated furnaces are used.

"Fusi Yama." The furnaces and tubes all open into one common combustion chamber; the furnaces are plain flues. A large tall steam dome is carried on the top of the boiler.

"Iona." Purves' corrugated flues are used. The fan for forced draught is driven by a Chandler single-acting high-speed engine developing about 2 H.P. Each furnace opens into its own combustion chamber.

"Ville de Douvres." The forced-draught fans are driven by two Brotherhood engines, each developing about 14 H.P. Each furnace has its own combustion chamber; the flues are plain.

In Table 18 (pages 38–9) is given a complete summary of all the important dimensions and their relation to one another, for grates, heating surface, tubes, and funnels; also the mean steam-pressures during the trials, rates of fuel combustion and water evaporation, and finally a summary of the heat account for each boiler. In Fig. 1, Plate 1, is shown the total feed-water consumption in each of the trials; in Fig. 2 the total fuel consumption; and in Fig. 3 the total revolutions. The heat balance-sheet is also shown in Plate 2, from which is seen at a glance the proportion utilized in the feed-water, the proportion lost in the funnel gases, and the rest of the losses of heat.

Observations made.—In each trial the coal was weighed in baskets hung from spring balances, and then emptied in heaps upon the stoke-hold floors; and the rate of consumption of fuel as well as the amount was determined. The feed in all the trials—except that of the "Ville de Douvres," in which meters were used—was measured by passing it on its way to the boiler through two tanks, which were filled and emptied alternately, thereby again ensuring knowledge of rate as well as of quantity used. The boiler pressures were observed at fixed intervals, as were also the temperatures of air, of feed, and of escaping furnace-gases. Lastly, samples of the furnace gases were taken at fixed times for subsequent analysis; and also samples of the coal and ashes for the same purpose. The air-pressure in the funnels &c. was measured by U water-gauges. From these data a fairly complete heat-account for the boilers can be calculated.

Fuel.—The coal used on the different trials varied considerably in quality. A summary of the chemical analysis, carbon value, calorific value, and evaporative power, is given in Table 19 (page 42) for each steamer. It will be seen that the coal used in the "Meteor," "Colchester," and "Fusi Yama" trials was much inferior to that in the case of the three other vessels; and that in the "Meteor" and "Fusi Yama" coal the moisture present was great, over 10 per cent. for the "Meteor." The calorific values are all calculated on the assumption of the complete combustion of all the hydrogen present, making allowance for the latent heat of the steam so formed.

Ashes.—The quantities and percentages of ashes weighed out at the end of the trials, with particulars as to the cleaning of the fires, are given in Table 20 (page 43). In every trial the fire was cleaned at the end, and the resulting clinker and ashes weighed; a sample was taken, and afterwards by ignition the proportion of unburnt carbon in it was estimated. In the heat balances given in the various reports no attempt has been made to estimate the proportion of loss due to the unburnt carbon present in the ashes; it may however be worth while to estimate it per pound of coal burnt, more especially as the balance unaccounted for, which must be ascribed mainly to this and to radiation, varies considerably. In Table 20 are given the total ashes and their percentage of the total fuel put on the fires; also the percentage of carbon in the ashes, and the equivalent total carbon therefore lost in the whole of the ashes. The results expressed as percentages of heat-value in the fuel vary from 1·36 to 3·10 per cent. It has been assumed that the balance of the mineral matter, found in the fuel by chemical analysis and not shown in the ashes, either went up the funnel as fine dust, or more probably remained on the fire-bars as clinker at the end of the trial. If these percentages are added to those for feed-water evaporated, loss of heat in furnace gases, imperfect combustion &c., the balance, apart from errors of observation, can be put down only to radiation.

TABLE 19.—*Fuel.*

Steamer.	Name of Coal.	Analysis of Fuel as used.					Per Pound of Fuel.		
		Carbon.	Hydrogen.	Water.	Ash.	Nitrogen, Sulphur, Oxygen, &c., by difference.	Equivalent Carbon-value.	Calorific value.	Evaporative Power. Lbs. of Water from and at 212° Fahr.
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Lb.	Th. Units.	Lbs.
Meteor	Scotch, Shawfield.	70·31	4·88	10·68	3·46	10·67	0·878	12,790	13·24
Colchester	Monk Bretton, Yorks, & Hucknall & Shireoaks, Notts.	71·89	5·42	4·25	4·08	14·36	0·913	13,280	13·75
Tartar	Welsh, Penrikyber.	87·98	4·22	1·07	3·42	3·31	1·031	14,995	15·52
Fusi Yama	West Hartley, Tyne.	70·85	4·71	8·60	5·11	10·73	0·878	12,760	13·21
Iona	Walbottle, Tyne.	82·34	5·47	1·94	2·90	7·35	1·020	14,830	15·35
Ville de Douvres	Block Fuel.*	84·65	3·98	2·41	5·30	3·66	0·99	14,390	14·90

* Made at Marcinelle and Chatelineau, Belgium.

TABLE 20.—*Ashes.*

Steamer.	Cleaning of Fires.	Ashes.		Carbon in Ashes.		Loss of heat from unburnt carbon in ashes.	
		Total.	Proportion of total Coal.	Proportion.	Total.	Per minute.	Proportion.
		Lbs.	Per cent.	Per cent.	Lbs.	Th. Units.	Per cent.
Meteor . . .	End of trial only.	4,477*	6·51	—	—	24,580§	2·88
Colchester . .	do.	2,220†	3·5	43·73	962	21,420	1·68
Tartar . . .	do.	291‡	2·2	65·53	185	6,506	1·36
Fusi Yama . .	do.	278	2·0	—	—	—	—
Iona . . .	Once during trial.	430	2·9	56·19	242	3,659	1·57
Ville de Douvres .	Once during trial.	4,760	7·2	42·86	2,040	54,930	3·10

* Consisting of 1,671 lbs. ashes and 2,806 lbs. clinker, equivalent to 2·43 and 4·08 per cent. of the total coal.

† Actual quantity weighed out, 2,890 lbs.; but this included ashes made in getting up steam, and in preliminary run before start of trial.

‡ For a period of 6 hours 53 minutes only.

§ This is an estimate of the loss owing to the fact that, in selecting lumps for chemical analysis, bad stony lumps were rejected.

Feed-Water.—There are several points of importance in the various trials, to which attention must be drawn before dealing with the actual results.

"Meteor." All the steam corresponding with the measured feed went to the main engines, and to a small Worthington pump which fed the boilers. The circulating-pump engine, dynamo engine, and all the deck engines were supplied with steam by a donkey boiler. The supplementary feed was not separately measured; it was drawn from the exhaust of the circulating-pump engine and dynamo engine. The feed was heated in the hot well up to 163·1° Fahr. by means of an apparatus devised by the chief engineer.

"Colchester." All the steam from the measured feed went to the main engines; only one feed-pump was in use; the supplementary feed was not measured separately. The circulating-pump engine and others were all worked off a donkey boiler. The mean feed temperature was 113° Fahr.

"Tartar." All the steam from the measured feed went to the main engines, the auxiliary engines being worked from the donkey boiler. One of the main feed-pumps was used at start; but later the donkey pump, drawing its steam from the main boilers; the supplementary feed was not measured separately. Mean feed temperature 101° Fahr.

"Fusi Yama." All the steam from the measured feed went to the main engines; the supplementary feed was not measured separately. The feed was supplied by the main feed-pumps. Mean feed temperature 129·5° Fahr.

"Iona." All the steam from the measured feed went to the main engines. Here the circulating pumps and feed-pumps were all worked by the main engines. The supplementary feed was separately measured. The average feed temperature was 106° Fahr.; in ordinary working the feed is heated to a much higher degree than this, by draining the jackets into the feed suction-pipe.

"Ville de Douvres." The feed, measured by a Kennedy positive piston water-meter, went to the main boilers, and supplied steam not only to the main engines but also to the auxiliary engines. The average feed temperature was 158° Fahr.; there was no feed heater.

It will be seen therefore that in some cases the circulating pump was driven by an independent engine, in others by the main engines.

TABLE 21.—*Feed-Water, in relation to Boiler and Fuel.*

Steamer.	Feed-Water used per hour.	Mean Temperature.		Heat in Boiler.		Water evaporated from and at 212° Fahr.	
		Feed-Water.	Boiler.	Taken up per lb. of Steam.	Utilized per lb. of Fuel.	Per lb. of Fuel.	Per sq. foot of heating surface per hour.
	Lbs.	Fahr.	Fahr.	Th. Units.	Th. Units.	Lbs.	Lbs.
Meteor . . .	29,860	163·1°	363°	1,062	7,922	8·21	4·94
Colchester	43,020	113·0°	324°	1,100	8,240	8·53	8·42
Tartar	21,564	101·0°	362°	1,123	—	—	—
Fusi Yama . . .	7,860	129·5°	304°	1,077	8,570	8·87	3·88
Iona	8,616	106·0°	373°	1,122	10,265	10·63	3·17
Ville de Douvres . .	66,180	158·0°	342°	1,060	9,509	9·84	9·90

As however this is a question affecting the efficiency of the engines rather than of the boilers, it will be advisable to defer any remarks on this point. In Table 21 (page 45) are given in a convenient form for reference certain data as to feed, evaporation &c. Neglecting the results of the "Tartar," it will be seen that the single-ended boilers on an average evaporate from and at 212° Fahr. 10·15 lbs. of water per lb. of carbon-value, as against only 9·48 lbs. for the double-ended boilers.

Priming.—This important subject was brought into great prominence from the results of the "Tartar" trial. In the earlier trials no attempt was made to measure the priming, because its presence was not suspected; and the results of those trials gave no reason for supposing that such an action was taking place. In the two trials after that of the "Tartar" however, it was determined to measure this factor; this was done in both trials by means of the salt test. Unfortunately with the "Iona" the apparatus broke down, and only one test was made, which showed priming to the amount of 2·87 per cent. In the "Ville de Douvres" trial more tests were made, all of which showed practically no priming.

The case of the "Tartar" is one which must be dealt with somewhat fully. It is clear that the whole of the measured feed cannot have been evaporated by the quantity of coal used; if it had been, 84·1 per cent. of the total heat of the coal would have been spent in doing it, leaving only 15·9 per cent. for loss in chimney gases, radiation, &c. The analysis of gases however, and the chimney temperature, enable us to calculate that 22·1 per cent. must have gone away in the waste gases. A careful inspection of the log sheets has revealed nothing in the least anomalous in the observations. Unless therefore nearly 20 per cent. of the feed-water which was measured through the tanks never reached the boilers at all, the author can see no other explanation than priming. The amount of the supplementary feed being normal, such a loss between feed tank and boilers would at once have shown itself in the gauge glasses; but as a matter of fact, though the water-level in the boiler did fall, it was very little, and corresponds in amount to less than 1 per cent.

of the total feed. As to conditions likely to cause priming, there is the fact recorded that the ship was light and the weather stormy, so much so that the trial was carried on with difficulty towards the end. There is every probability therefore that the water in the boilers was in a state of violent agitation, and by the action of the stays would be broken up into foam, a condition most likely to lead to priming. That there was considerable priming the author believes is shown by calculations from the indicator diagrams as to the amount of steam actually present in the cylinders. Considering first the high-pressure cylinder, there was present just after cut-off behind the piston, that is including the clearance volume, 3·39 lbs. of steam per revolution; while just before the point of release this had become 4·33 lbs., being a gain of 0·94 lb. or over 27 per cent., equivalent to 18 per cent. of the feed. There was no jacket in use on this cylinder; and on making a similar calculation for the three unjacketed engines, it is found that the total steam at the end of the stroke is almost exactly what it was at the beginning, the re-evaporation being very slight. [See also pages 73–4.] Unless therefore either the piston (see also page 139) or the valves were leaking badly, which there is no reason to suppose as the engine had just been overhauled, this increase must have been caused by evaporation of water in the cylinder itself. It seems to the author that this difference can possibly be explained by the priming; with the steam there came over in a finely divided state water intimately mixed up with the whole body of the steam. As the steam expanded after cut-off and fell in pressure, this water evaporated. This action would be confined to the core of the mass of steam; that which came in contact with the walls and surfaces would behave as usual, condensing and forming a fine film all over the surfaces, and owing to the absence of jackets would be only very slightly re-evaporated. There is some difficulty however in this explanation, as it is not clear where the heat necessary for this considerable evaporation can have come from; the loss of internal energy in the steam as it fell in pressure is not sufficient, as proved by repeated calculations. The great amount of water noted in the intermediate cylinder the author

TABLE 22.—*Funnel Gases.*

Steamer.	Analyses of Gases by weight. *See Plate* 3.				Temperature of Gases, and Height above boiler where taken. *See Plate* 4.		Dry Air per lb. of Fuel.		Specific Heat of Gases.	Heat lost in Gases. *See Plate* 4.	Chimney Draught in inches of water.
	Carbonic Acid.	Carbonic Oxide.	Oxygen.	Nitrogen.			Theoretical.	Actual. *See Plate* 4.			
	Per cent.	Per cent.	Per cent.	Per cent.	Fahr.	Feet.	Lbs.	Lbs.	Sp. Heat.	P. cent.	Inches.
Meteor* . .	18·17	0·75	5·71	75·37	791°	12	9·8	13·0	—	18·5	0·31
Colchester .	13·59	0·22	10·78	75·41	835°§	—	10·1	18·5	0·238	28·0	{0·38 F {0·34 A
Tartar . .	9·98	0·00	14·19	75·83	477°	—	11·6	31·6	0·238	22·1	0·22
Fusi Yama* .	11·17	0·00	12·48	76·35	578°	—	9·8	22·8	—	23·5	0·28
Iona . .	12·12	0·00	12·01	75·87	452°	30	11·4	24·5	0·243	16·2	0·25
Ville de Douvres	16·84	0·00	8·44	74·72	910°§	—	11·1	17·9	0·243	26·8	1·07

* Only one sample of gases from the "Meteor," and only two from the "Fusi Yama."

§ Temperature only approximate, because in about 37 per cent. of the readings in the "Colchester," and in nearly all in the "Ville de Douvres," it exceeded the limit of the thermometer.

F = Forward funnel; A = After funnel.

thinks can be explained by initial condensation in the high-pressure cylinder, apart altogether from priming; the film of water deposited on the high-pressure cylinder surfaces, and not entirely re-evaporated owing to the jacket not being in use, would be swept into the receiver and collect there, and be eventually carried into the intermediate cylinder. The whole difficulty, the author feels, points to the absolute need of priming tests in all such trials, if the results are not to be vitiated by an unknown quantity as in this case. Under normal working conditions most probably priming would be unlikely with such boilers; but the fact that it did occur proves the need of always testing for it. It is noteworthy that in the "Iona," where the one test did show priming, though less than 3 per cent., there was great condensation in the high-pressure cylinder.

Funnel Gases.—In every trial samples of the furnace gases were regularly drawn off, and afterwards analysed by Mr. Charles J. Wilson. In the "Meteor" trial the samples were unfortunately all spoiled except one: and therefore the results in this case are not so valuable as in the other trials. The temperature of the furnace gases was also measured by a special mercury thermometer. In Table 22 are given the mean chimney-draught and temperature

TABLE 23.—*Funnel Gases; Weight, Volume, and Velocity.*

Steamer.	Funnel Gases leaving tubes per min. in each boiler.		Sectional Area of Tubes in each boiler.	Velocity of Gases through tubes.	Tube Surface per lb. of gases per minute.
	Weight.	Volume.			
	Lbs.	Cub. Ft.	Sq. Feet.	Ft. p. min.	Sq. Feet.
Meteor . .	467	14,690	—	—	6·16
Colchester .	933	30,360	20·00	1,518	2·56
Tartar . .	522	12,280	17·89	686	4·19
Fusi Yama .	391	10,200	13·00	785	4·32
Iona . .	200	4,590	9·13	503	6·49
Ville de Douvres	581	20,010	8·81	2,272	2·70

and the analyses of the gases by weight; also the actual weight of air used per lb. of fuel, and the percentage of heat lost in the furnace gases. In Plate 3 are shown the analyses of the gases; also in Fig. 6, Plate 4, their temperature, and in Fig. 7 the heat they carry away, and the air actually used.

In Table 23 is given the weight of gases which must have passed up the funnel per minute from each boiler; and as the temperature of these gases immediately afterwards is known (Table 22), their volume and the velocity with which they passed out of the tubes into the smoke-box or funnel uptake can be approximately calculated.

When the figures in the fifth column of Table 23 are divided by those in the sixth, the ratios so obtained will give some idea of the relative loss of heat in the waste gases from the different boilers, as follows:—

	Ratios of Velocity of Gases through tubes to per lb. of gases Tube Surface per minute.	Percentages of total heat that are sent up funnels.
Meteor	—	18·5 per cent.
Colchester	594·0	28·0 ,, ,,
Tartar	163·9	22·1 ,, ,,
Fusi Yama	181·7	23·5 ,, ,,
Iona	77·5	16·2 ,, ,,
Ville de Douvres	841·0	26·8 ,, ,,

The temperature of the "Iona" gases was measured at a point 30 feet above the bars, and therefore the velocity through the tubes would be higher than here given, because the actual temperature just after leaving the tubes must have been much greater than that measured.

Air Supply.—In two cases there were double funnels; the air supply has therefore been calculated for each separately, and compared with the rate of combustion of the fuel on the grates, and with the chimney-draught.

In the "Colchester" the air supply per pound of coal was 16·00 lbs. for the forward funnel, and 21·90 lbs. for the aft; while the fuel burnt per square foot of grate per hour was 25·94 lbs. for the forward boiler, and 26·27 lbs. for the aft. The mean chimney-draught was 0·38 inch of water in the forward funnel, and 0·34 inch in the aft. In the forward funnel the much smaller air supply with nearly 12 per cent. more draught is marked, and seems to point to the fact that it is not possible merely from draught alone to say what are the proportionate quantities of air passing through two furnaces.

In the "Ville de Douvres" the air supply per pound of fuel was 19·07 lbs. for the forward funnel, and 16·78 lbs. for the aft; while the fuel burnt per square foot of grate per hour was 32·1 and 30·44 lbs. respectively. The mean chimney-draught in the two funnels was the same. Here again the figures point to the same conclusion as in the "Colchester."

Radiation.—In the heat balance-sheet given in Table 18, the balance unaccounted for is presumably due in the main to radiation. In order to check this, the external surfaces of the boilers, from which radiation takes place, have been calculated on the assumption that they are plain cylinders closed at each end. This supposition, though not correct, must nevertheless give fairly correct comparative figures, which are shown in Table 24.

TABLE 24.—*Heat lost by Radiation from Boiler Surfaces.*

Steamer.	Radiating Surface.		Difference between Temperature of Steam and of Air.	Heat lost by Radiation.	Heat lost per sq. foot of surface per hour.
	Total.	Per lb. of Fuel burnt per minute.			
	Sq. Feet.	Sq. Feet.	Fahr.	Per cent.	Th. Units.
Meteor . . .	1,929	28·9	308°	11·8	3,120
Colchester . .	2,021	21·1	269°	6·6	2,470
Tartar . . .	1,735	54·2	307°	—	—
Fusi Yama . .	730	44·4	249°	8·4	1,450
Iona . . .	1,384	88·1	311°	13·0	1,430
Ville de Douvres	2,696	21·9	278°	4·0	1,580

With a boiler of the locomotive type but with only a low rate of coal consumption, the author has found a loss by radiation of 10 per cent. with a 2-inch coating of non-conducting material. The losses in Table 24 therefore are apparently what would be expected in boilers with the rates of consumption here met with. The high radiation in the "Iona" there can be no doubt is mainly due to the large size of the boilers used for the power developed, and therefore to the excessive radiation-surface per pound of fuel burnt per minute. In the "Meteor" and the "Fusi Yama" it must be remembered that the results can be considered only approximate, owing to the few samples of gas collected.

Boilers, General Conclusions.—The "Tartar," on account of the uncertainty of the amount of priming, must be omitted from consideration. The efficiency of the double-ended boilers is 62 per cent., of the single-ended 67·5; this gain is partly due to less loss in furnace gases, but more apparently to the prevention of imperfect combustion, even with a high rate of fuel consumption. The "Meteor" boilers would in all probability give a higher efficiency with forced draught, the small size of the tubes being a drawback when working with natural draught. The high efficiency of the "Iona" working with such small grates would seem to point to the fact that, by the adoption of some system of forced draught and a reduction in the length of the grates, the efficiency of the average marine boiler would be sensibly increased. At the same time the boilers of the "Ville de Douvres" show that, where a very high rate of fuel consumption has to be obtained from a given boiler, then forced draught and large grates with only the normal proportion of heating surface can be used, and the boiler will still be efficient. The greater loss incurred by sending the furnace gases away hotter is partly counterbalanced by the proportionally smaller radiation per pound of fuel. Unless some plan can be devised for utilizing the waste heat passing away through the chimney, it seems that about 70 per cent. is likely to be the maximum amount utilized of the total heat of the fuel in the present type of marine boiler.

Engines.—In three of the steamers the engines were two-cylinder compound, and in the other three triple compound. They will therefore be discussed in these two groups, and also in regard to jacketing of cylinders, and other points of general design. The two-cylinder compound sets were the "Fusi Yama" ordinary inverted vertical, the "Colchester" twin inverted vertical, both screw engines; and the "Ville de Douvres" inclined paddle engines. None of these had jacketed cylinders. The triple sets were the "Meteor" and the "Tartar" with all three cylinders jacketed, but on the trial of the "Tartar" the intermediate and low-pressure jackets only were in use; and the "Iona" with the high-pressure cylinder jacketed. All of these engines were of the ordinary inverted marine type. Table 25 (page 54) gives their leading dimensions; and Plate 5 shows the cylinder volumes and the relative clearance volumes. The following additional particulars will be of value in considering the results obtained.

"Fusi Yama." The cranks are at right angles, the low-pressure leading. Steam is distributed to each cylinder by a single slide-valve worked by ordinary link-motion. The receiver forms a belt round the high-pressure cylinder.

"Colchester." The two engines are entirely separate, a condenser between being common to both. The cranks are at right angles, the high-pressure leading. The valve-gear is ordinary link-motion. The high-pressure cylinder has a piston-valve, and the low-pressure a double-ported slide. The receiver forms a belt round the high-pressure cylinder.

"Ville de Douvres." The engines are inclined. The high-pressure crank leads, the two cranks being at right angles. The receiver encircles the high-pressure cylinder. The high-pressure cylinder is fitted with a pair of piston-valves, the low-pressure with one; and in each case the gear is the Allan link-motion.

Since there are no jackets to any of these three sets of engines, there are no liners to any of the cylinders.

"Meteor." The cranks follow in the order—high, intermediate, low. The ends of the cylinders are not jacketed, the total length of the jackets being about 4 feet. All the valves are piston-valves,

TABLE 25.—*Engines.* *See Plate 5.*

Steamer.	Cylinders.				Ratios of Volumes.*		Clearance Volumes.†			Condensing Surface. Total.	Revolutions per minute.
	Diameters.			Stroke.	Inter./High	Low/High	High.	Inter.	Low.		
	High.	Inter.	Low.								
Two-cylinder Compound.	Ins.	Ins.	Ins.	Inches.	Ratio.	Ratio.	P. cent.	P. cent.	P. cent.	Sq. Feet.	Revs.
Fusi Yama . . .	27·35		50·30	33·00		3·42	8·50		5·00		55·59
Colchester . . .	30·00		57·00	36·00		3·70	9·39		6·23	3,000	{86·00 87·10
Ville de Douvres . .	50·12		97·12	72·00		3·84	15·00		12·00	6,540	36·82
Triple Compound.											
Meteor . . .	29·37	44·03	70·12	47·94	2·35	5·89	12·40	9·30	8·02	3,200	71·78
Tartar . . .	26·03	42·03	68·95	42·00	2·64	7·16	14·51	9·25	5·10	2,250	70·00
Iona	21·88	34·02	56·95	39·00	2·46	6·93	12·41	10·11	7·64	1,360	61·10

* Ratio of Volumes swept through by pistons.

† Clearance Volumes in percentage of volumes swept through by pistons.

worked by ordinary link-motion; the valves are single for the high-pressure cylinder, double for the others.

"Tartar." The cranks rotate in the sequence—high, low, intermediate. The cylinders are fitted with jackets on the body and on both ends; except the high-pressure cylinder, which has only body and top end jacketed. The valves are piston-valves for the high-pressure and intermediate cylinders, and a double-ported slide-valve for the low-pressure, all worked by Wyllie's elliptical gear, with independent adjustment for the cut-off.

"Iona." The cranks rotate in the order—high, intermediate, low. Only the high-pressure cylinder is jacketed. The valves for the high and low-pressure cylinders are ordinary double-ported, and for the intermediate a Trick slide-valve is used. The intermediate receiver encircles the high-pressure valve-chest and part of the jacket, and the low-pressure receiver another part of the high-pressure jacket.

Observations made.—In addition to those already described in page 40, the following were also made. Indicator diagrams were taken simultaneously from both ends of every cylinder at half-hourly intervals; all engine-room and other gauges and also the counter were read at the same intervals. In the "Iona" trial, diagrams were also taken from some of the pumps and from the receivers. The diagrams were used to determine the power, initial steam-pressures, release pressures, back pressures, and also the quantity of steam present in each cylinder at various points in the stroke. Unfortunately it was not possible to measure the quantity of condensing water used, nor in several of the trials the rise of temperature of this water; there is therefore no possibility of making a complete balance-sheet for the engines, such as was given in the reports for the boilers. Considering the enormous quantity of water used for condensing purposes with such large engines, there does not seem any prospect of successfully measuring it; meters the author thinks are out of the question.

From the observations it is possible therefore to make only two calculations for the balance-sheet: one the total heat received per

TABLE 26.—*Steam Pressures.* *See Plates* 6 *and* 7.

Steamer.	Mean Steam Pressures per square inch, absolute.		Mean Effective Pressures per square inch.				Exhaust in Low-p. cylinder per square inch.		Vacuum in Condenser per square inch.	
	Boiler.	High. Initial.	High.	Inter.	Low.	Total reduced to Low.	Below atm.	Absolute.	Below atm.	Absolute.
Two-cylinder Compound.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Fusi Yama . . .	71·64	65·10	30·74		10·87	19·90	10·90	3·90	12·48	2·32
Colchester . . .	95·50	{79·30 {74·40	45·65 42·07		13·42} 12·42}	24·80	{10·60 {10·50	4·40} 4·50}	12·49	2·51
Ville de Douvres . .	120·64	104·04	55·49		15·54	30·17	8·78	6·06	10·12	4·72
Triple Compound.										
Meteor. . . .	160·10	149·30	58·46	19·50	12·38	29·90	11·60	3·30	12·17	2·73
Tartar . . .	158·20	136·00	36·89	20·07	7·18	19·80	10·50	4·10	12·90	1·70
Iona	179·58	157·08	46·65	20·44	7·16	21·13	12·74	1·84	13·88	0·70

TABLE 27.—*Power Measurement.*

Steamer.	* Piston Constants.			Indicated Horse-power. *See Plate* 8.			
	High.	Inter.	Low.	High.	Inter.	Low.	Total.
Two-cylinder Compound.	H.P.	H.P.	H.P.	I.H.P.	I.H.P.	I.H.P.	I.H.P.
Fusi Yama . . .	5·36		18·32	168·2		203·1	371·3
Colchester . . .	10·71 10 84		39·55 40·06	490·3 457·9		532·2 499·3	1,022·5 957·2
Ville de Douvres . .	25·99		98·56	1,444·0		1,533·0	2,977·0
Triple Compound.							
Meteor. . . .	11·31	26·00	66·65	662·0	507·0	825·0	1,994·0
Tartar. . . .	7·73	20·42	55 27	283·7	408·5	395·2	1,087·4
Iona	4·41	10·82	30 54	205·6	221·2	218·6	645·4

* Piston Constant = horse-power per pound of mean effective pressure per square inch on piston.

minute by the engines, including therein heat given both to the cylinder steam and to the jacket steam; and the other the useful work done per minute. The ratio of these two quantities gives the actual efficiency of the engines. Unfortunately in the only trial in which all the cylinders were jacketed, the steam condensed in them could not be measured apart from that used in them. What proportion of the heat unaccounted for in the balance-sheet was rejected in the condensing water, and what went in radiation, there is therefore not the means of stating, though by certain calculations the amount can be approximately arrived at in the "Iona" and the "Ville de Douvres."

Power Measurement.—The indicators used were as follows: in the "Meteor" trial, Crosby; in the "Fusi Yama" for the high-pressure cylinder, Darkes, and for the low-pressure, Richards; in the "Colchester," "Tartar," and "Iona" trials, McInnes; and in the "Ville de Douvres," Richards. In all cases the indicators were as close to the cylinders as possible, the connections being short large pipes, free from bends. The instructions for taking diagrams, issued to each observer engaged on this work in any trial, and printed in page 241, 1890, show what great care was taken to ensure accuracy in the diagrams. In Tables 26 and 27 (pages 56–57) are given the results obtained from the diagrams, and also the mean readings from some of the gauges. The diagram in Plate 6 shows the boiler pressure, the initial pressure in the high-pressure cylinder, the mean effective pressure in each cylinder, the exhaust pressure in the low-pressure cylinder, the condenser vacuum, and the barometric pressure. In Plate 7 are shown the whole of the mean indicator diagrams. Plate 8 shows the indicated horse-power in each cylinder.

One of the most striking features in Table 26 is the considerable difference between the average back-pressure in the low-pressure cylinder and the condenser pressure. In Table 28 is shown for each steamer the amount of this difference, and the equivalent increased horse-power which would have been obtained in the low-pressure cylinder, had its back-pressure been the same as that of the condenser; and this increase would of course have been brought about without the expenditure of any more steam.

As regards the "Ville de Douvres" however, this comparison hardly suffices, because her condenser vacuum was so bad on the day of the trial that the loss was really much more serious. Omitting the "Iona," where a remarkably good vacuum was obtained, the average absolute condenser-pressure in the other four steamers was 2·31 lbs., whilst that in the trial of the "Ville de Douvres" was as much as 4·72 lbs.; a further loss of pressure of 2·41 lbs. per square inch should therefore be allowed for this, which would increase the loss of power by 237·5 horse-power, and make the total percentage 12·4 in the "Ville de Douvres," instead of only 4·4 per cent. In every case therefore, except the "Meteor," this loss is sufficiently great to justify some attempt to diminish it by increasing the size of the

TABLE 28.

Difference between Back-Pressure in Low-pressure Cylinder and Pressure in Condenser; and equivalent Horse-power.

Steamer.	Difference between Back-Pressure in Low-pressure Cylinder and Condenser Pressure per square inch.	Equivalent Horse-power.	
		Actual.	Percentage of Total Horse-power developed.
Two-cylinder Compound.	Lbs.	H.P.	Per cent.
Fusi Yama .	1·58	28·94	7·8
Colchester .	1·94	{77·20 77·20}	7·8
Ville de Douvres	1·34	132·10	4·4
Triple Compound.			
Meteor . .	0·57	37·99	1·9
Tartar . .	2·40	132·60	12·2
Iona . .	1·14	34·82	5·4

TABLE 29.—*Feed-Water, in relation to Engine and Power.*

Steamer.	Feed-Water used in main engines.			Heat per minute.			Engine Efficiency. See Plate 9.
	Per minute.	Per hour.	Per I.H.P. per hour. *See Plate* 9.	Taken up by Feed-Water. Total.	Taken up by Feed-Water. Per I.H.P.	Turned into Work.	
Two-cylinder Compound.	Lbs.	Lbs.	Lbs.	Th. Units.	Th. Units.	Th. Units.	Per cent.
Fusi Yama	131	7,860	21·17	141,100	380·0	15,870	11·2
Colchester	717	43,020	21·73	788,700	398·4	84,630	10·7
Ville de Douvres . . .	1,103	66,180	20·77*	1,092,000	366·8	127,300	11·7
Triple Compound.							
Meteor	497·7	29,860	14·98	528,600	265·6	85,240	16·1
Tartar	359·4	21,564	19·83†	——	——	——	——
Iona	143·6	8,616	13·35	161,100	249·6	27,590	17·1

* Total, including auxiliary engines, 22·23 lbs. per I.H.P. per hour.

† This includes what was most probably priming water.

exhaust passages or other suitable means; from the results with the "Meteor" low-pressure cylinder it seems clear that it can be reduced to a very small amount. It should be stated that these calculations assume the condenser gauges to have been indicating correctly; they were tested only in the "Iona" and "Ville de Douvres."

Another notable point is the considerable wire-drawing of steam between the boiler and the high-pressure cylinder. This is no doubt largely due to the action of the valve-gear, since the gauges on the high-pressure valve-chest show a much closer agreement with the boiler; for instance, with the "Iona" the pressures are—boiler 179·58, valve-chest 174·58, initial in cylinder 157·08 lbs. per square inch. It certainly does not seem worth while to design a boiler to carry such a heavy pressure as 180 lbs. absolute, if nearly 13 per cent. of this is to be lost between the boiler and the first cylinder: though no doubt the superheating produced may lessen initial condensation, and thereby make up the loss.

Feed-Water.—This having already been dealt with very fully in connection with the boilers, it will be necessary to give only a few additional figures, referring the consumption of feed-water to the engine and to the horse-power developed. In the trials of the "Meteor" and the "Colchester" the circulating pump was driven by a separate engine deriving its steam from a separate boiler; while in the "Tartar," the "Fusi Yama," and the "Iona" it was driven by the main engine. In the "Ville de Douvres" trial, both this engine and the fan engines drew their steam from the main boilers; but supplementary trials were afterwards made to determine their steam consumption, and corrections are made in the total feed in the main trial, to allow for the steam they used. In Table 29 the figures apply to the main engines only. The actual economy of the machinery in the "Tartar," the "Fusi Yama," and the "Iona" is therefore really greater in comparison with the other engines than is shown by Table 29, because the rate of steam consumption in the auxiliary engines would be much higher than in the main engines. Plate 9, illustrating Table 29, shows the weight of feed-water used per indicated horse-power per hour, and the engine efficiency; and on

TABLE 30.—*Steam-Jackets.*

Steamer.	Cylinders Steam-Jacketed.	Absolute Steam-Pressure per square inch.						Feed used in Jackets.
		Cylinder Jackets.			High-p. Valve-chest.	No. 1 Receiver.	No. 2 Receiver.	
		High.	Inter.	Low.				
Triple Compound.		Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Per cent.
Meteor . . .	High, Inter., Low.	145·9	92·4	71·7	†149·3	51·4	21·1	—
Tartar . . .	* Inter., Low.	—	67·1	28·6	146·0	§60·7	§18·4	3·94
Iona . . .	High.	179·58	—	—	174·58	—	—	‡4·30

* High-pressure jacket was shut off; but steam leaked into it, sufficient to show pressures varying from 14·6 to over 64·6 lbs. absolute.

† This is the mean initial pressure in the high-pressure cylinder.

§ These are the pressures in the intermediate and low-pressure valve-chests, not in the receivers.

‡ In addition to this, the drain from steam-pipe and high-pressure valve-chest was 0·61 per cent. of the total feed.

the same diagram has been added from Table 18 the carbon-value of the fuel per indicated horse-power per hour.

Steam-Jackets.—None of the two-cylinder compound engines were fitted with jackets; attention is therefore confined to the triple engines for the purpose of comparison. Unfortunately it was not possible to measure separately the steam condensed in the "Meteor" jackets, but only the steam-pressure in the jackets was measured; the wetness of the steam in the cylinders is known therefore only approximately. For the other two steamers the quantity condensed in the jackets is known, and therefore the percentage of total feed so used. The necessary figures are given in Table 30. There are thus only two examples of the high-pressure cylinder jacketed, against one unjacketed or practically so. On calculating from the indicator diagrams the steam present in the high-pressure cylinder just after cut-off, it is found that the percentages of total feed so accounted for are:—"Meteor" 77·1; "Iona" 63·4; "Tartar" 45·2 per cent. In the "Tartar" it is impossible to say how much of the excessive wetness of the steam may have been due to priming, and how much to initial condensation intensified moreover by priming. In the "Iona" the percentage of total feed condensed in the steam-jacket is not high, and may to some extent explain the greater wetness of the steam than in the "Meteor," especially when it is remembered that the "Iona" jacket gave heat not only to the high-pressure cylinder but also to the second receiver.

On examining the percentages of steam present near the end of the stroke in the intermediate cylinder, the results given in the reports appear anomalous. They are:—

Meteor	80·2	per cent.	steam, or	3·1	per cent.	more than at cut-off	in high-p. cyl.
Tartar	58·2	,,	,,	13·0	,,	,, ,,	,,
Iona	74·9	,,	,,	11·5	,,	,, ,,	,,

The "Iona" having no jacket to her intermediate cylinder, it seems difficult to believe that there has been much re-evaporation in this cylinder. It has therefore been thought worth while to calculate the percentage of steam present just before release in the high-pressure cylinder, in order to detect whether there was condensation or re-evaporation going on during the stroke in that cylinder. The following are the results of the calculation :—

Tartar	63·9 per cent. steam at release, or	18·7 per cent. more than at cut-off.
Iona	65·5 „ „ „	2·1 „ „ „

These results seem to show slight re-evaporation in the "Iona" during the high-pressure stroke, and a great amount in the "Tartar": which appears extraordinary when it is remembered that the "Iona" high-pressure cylinder was well jacketed, while in the "Tartar" the jacket was practically not in use. In order to test the matter more conclusively, the total weight of steam present in the high-pressure cylinder and clearance has been calculated for two points, one just after cut-off and one just before release. The figures are given in Table 31.

The great re-evaporation in the "Tartar" the author thinks is to be explained only by the assumption of priming (see also pages 72–4); a large quantity of water must have been carried over with the steam, and afterwards evaporated. The difficulty however still remains of explaining where the heat needed for this purpose came from; and at present the author sees no way of accounting for it satisfactorily.

In Table 32 is shown for each steamer the percentage of total feed present as steam in the high-pressure cylinder after cut-off, and before release in this and the other cylinders. The diagram in Plate 10 shows the same percentages graphically, at A after cut-off in the high-pressure cylinder, at B before release in the same cylinder, at C before release in the intermediate cylinder, and at D before release in the low-pressure cylinder.

From these figures it is seen that just after cut-off in the high-pressure cylinder the unjacketed two-cylinder compound engines actually show present as steam a much greater proportion of the total feed than do the jacketed triple engines. As the only explanation which seems at all feasible is that the area of surface

TABLE 31.—*Steam in High-pressure Cylinder (including clearance) at Cut-off and at Release.*

Steamer.	High-pressure Cylinder Jacketed or Not jacketed.	Weight of Steam per rev. After Cut-off.	Weight of Steam per rev. At Release.	Gain. Per cent. on total feed.
		Lbs.	Lbs.	Per cent.
Fusi Yama . . .	Not jacketed	2·24	2·31	3·0
Colchester . .	Not jacketed	6·77	6·84	0·8
Ville de Douvres .	Not jacketed	27·02	26·36	— 0·2
Iona.	Jacketed	2·26	2·44	7·7
Tartar	Jacket not in use	3·39 †	4·33	18·3

† See also pages 72–4.

TABLE 32.—*Percentage of total feed present as Steam in Cylinders at different points in stroke. See Plate* 10.

Steamer.	High-pressure cylinder. After Cut-off.	High-pressure cylinder. Before Release.	Intermediate. Before Release.	Low-pressure. Before Release.
Two-cyl. Compound.	Per cent.	Per cent.	Per cent.	Per cent.
Fusi Yama . .	N 83·1	N 88·1	—	N 70·8
Colchester . .	N 72·0	N 75·2	—	N 52·7
Ville de Douvres	N 80·6	N 79·3	—	N 72·5
Triple Compound.				
Meteor . . .	J 77·1	J —	J 80·2	J 75·3
Tartar . . .	N 45·2 †	N 63·9	J 58·2 *	J 60·3
Iona	J 63·4	J 65·5	N 74·9	N 59·1

J = Jacketed. N = Not jacketed. * 49·1 at a much earlier point in stroke.

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TABLE 33.—*Initial Condensation in High-pressure Cylinder.*

Steamer. High-pressure Cylinder Jacketed or Not.	Feed present as Steam at cut-off.	Range of Temperature in cylinder.	Area of Cooling Surface. *See Plate* 11.			
			Total.		Per pound of entering Steam per stroke.	
			Clearance.	Barrel, up to cut-off.	Clearance.	Barrel, up to cut-off.
Triple Compound.	Per cent.	Fahr.	Square Feet.	Square Feet.	Square Feet.	Square Feet.
Meteor, jacketed . . .	77·1	77°	19·30	15·40	5·56	4·45
Iona, jacketed . . .	63·4	81°	* 21·66 *	5·58	19·34	4·98
Tartar, jacket not in use .	45·2	54°	25·40	7·15	9·90	2·79
Two-cylinder Compound.						
NOT jacketed. Fusi Yama . .	83·1	58°	17·30	9·84	14·66	8·34
NOT jacketed. Colchester . .	72·0	73°	45·20	23·54	10·92	5·69
NOT jacketed. Ville de Douvres .	80·6	79°	84·73	47·23	6·05	3·37

In the "Meteor" none of the clearance surface was jacketed, and in the "Iona" only 15 per cent.

* The clearance surfaces in the three cylinders of the "Iona,"
given in Proceedings 1891 page 222 lines 67–8–9 (and again in 1892 page 163), should be corrected to read as follows:—
high-p. cyl. 21·66 sq. ft.; inter. cyl. 36·1 sq. ft.; and low-p. cyl. 64·2 sq. ft.

in the jacketed cylinders must be greater per pound of steam entering per stroke, this has been calculated out, and the results are shown in Table 33; and graphically for the "Meteor" and "Iona" in Plate 11. An inspection of the indicator diagrams, Plate 7, shows that in almost all of them the compression in the high-pressure cylinder was carried up nearly to the initial pressure of the entering steam, except in the "Colchester" where the compression was small. It seems therefore unlikely that the clearance surfaces can have had any great effect in causing condensation of the entering steam; the difference of temperature must have been slight, and the clearance walls must have been almost dry. On the other hand the surface of the cylinder walls is exposed to a considerable range of temperature, namely from the exhaust temperature up to that of the initial steam. It is therefore to be expected that, where this surface was larger per pound of steam admitted per stroke, the condensation would be greater for a given range of temperature. The figures in Table 33 for the "Meteor" and "Iona," both jacketed, show that this expectation is fulfilled pretty closely; the anomalous figures for the "Tartar," when its small surfaces and low range of temperature are considered, can be explained only on the assumption of the enormous influence exerted by the priming water present.

In the non-jacketed engines, no explanation seems satisfactory for the high percentage of steam present in the "Fusi Yama;" judging from the large surface exposed to the entering steam, considerable initial condensation would be expected, while as a matter of fact there appears to have been but little. It is generally found that an engine with large initial condensation is uneconomical, and more so than an engine with small initial condensation; but the figures for the "Meteor" and "Iona" present an apparent discrepancy, their initial condensation being respectively 22·9 and 36·6 per cent., while the steam consumption per horse-power per hour is 14·98 and 13·35 lbs. respectively. The explanation however is most probably to be found in the much larger ratio of expansion adopted in the "Iona," and the consequent partial saving of the loss due to incomplete expansion of steam down to the back-pressure.

Expansion of Steam.—By measurement of the approximate point of cut-off from mean indicator diagrams, the total ratio of expansion has been calculated as follows:—

				Absolute.
Two-cylinder Compound.	Fusi Yama . .	6·1 times.	Boiler pressure	71·64 lbs.
	Colchester . .	6·1 ,,	,, ,,	95·50 lbs.
	Ville de Douvres .	5·7 ,,	,, ,,	120·64 lbs.
Triple Compound.	Meteor . .	10·6 ,,	,, ,,	160·10 lbs.
	Tartar . .	15·7 ,,	,, ,,	158·20 lbs.
	Iona . . .	19·0 ,,	,, ,,	179·58 lbs.

It will be seen that, except in the "Fusi Yama," the two-cylinder compound engines with their late cut-off obtain only a comparatively small ratio of expansion for the boiler pressures at which they work. Since the use of simple valve-gear seems indispensable, owing to the necessity of avoiding complications in the working of such engines, the consumption of steam per horse-power per hour is likely to remain over 20 lbs. in unjacketed engines, contrasting unfavourably with the results obtained in compound engines on land. The great

TABLE 34.

Weight of Machinery, and Indicated Horse-Power.

Steamer.	Weight of Machinery.		Indicated Horse-Power.		Net Volume of Boiler per I.H.P. See *Plate* 12.
	Total.	Per I.H.P.	Total.	Per ton. *See Plate* 12.	
Two-cylinder Compound.	Tons.	Lbs.	I.H.P.	I.H.P.	Cubic Feet.
Fusi Yama . .	100	603	371·3	3·7	4·53
Colchester . .	395	448	1979·7	5·0	2·52
Ville de Douvres	361	272	2977·0	8·2	2·09
Triple Compound.					
Meteor . . .	390·5	439	1994·0	5·1	2·72
Tartar . . .	291	599	1087·4	3·7	4·33
Iona	202	701	645·4	3·2	4·15

expansion obtained in the "Iona" with its high efficiency is a proof of the fact that economy results from such practice. It is in all probability due to this high ratio of expansion that, though a much greater initial condensation is shown in her high-pressure cylinder as compared with the "Meteor," still the consumption of steam is less.

Weight and Horse-Power.—It may be useful to give in Table 34 the actual weight of machinery when in working order, and the horse-power developed. In Plate 12 is shown the indicated horse-power per ton of machinery and per cubic foot of boiler volume.

Circulating Water.—Only in the last two trials made, namely the "Iona" and the "Ville de Douvres," was any regular measurement attempted of the temperatures of the circulating water. [See page 116.] The temperatures of the inlet and the outlet were measured, as well as the hot-well temperature. They were as follows:—

Iona	55·8° inlet and 75·5° outlet = 19·7° rise.
Ville de Douvres .	61·7° inlet and 85·0° outlet = 23·3° rise.

Calculating from the heat contained in the steam at release in the low-pressure cylinder, the quantity of circulating water per pound of steam must have been 52·5 and 43·1 lbs. respectively, with 9·47 and 5·93 square feet of condensing surface respectively per pound of steam per minute. Table 35 (page 70) gives the amount of cooling surface in the surface condensers, and the various temperatures of circulating water and condensed steam.

Conclusions.—A highly important point as to the possible economy of triple compound engines the author considers still remains undecided, namely the influence of thorough jacketing. The ratio of expansion differs so greatly in the "Meteor" and the "Iona" that it is not possible to compare them in regard to jacket influence. What is wanted to determine this point is a pair of consecutive trials on the same set of engines in which all three cylinders are jacketed,

TABLE 35.—*Condensing Surface, and Temperatures of Circulating Water and Condensed Steam.*

Steamer.	Area of Condensing Surface.			Ratio of Heating Surface to Cooling Surface.	Temperature of Circulating Water.			Temperature of Condensed Steam.
	Total.	Per I.H.P.	Per pound of Feed per minute.		Inlet.	Outlet.	Rise.	
Two-cylinder Compound.	Sq. Feet.	Sq. Feet.	Sq. Feet.		Fahr.	Fahr.	Fahr.	Fahr.
Fusi Yama . . .	—	—	—	—	—	—	—	132°
Colchester . . .	3,000	1·52	4·18	1·94	—	—	—	135°
Ville de Douvres .	6,540	2·20	5·93	1·12	61·7°	85·0°	23·3°	160°
Triple Compound.								
Meteor	3,200	1·61	6·43	2·08	—	—	—	138°
Tartar	2,250	2·07	6·26	2·32	*55·0°	89·0°	34·0°	120°
Iona	1,360	2·11	9·47	2·32	55·8°	75·5°	19·7°	90°

* Measurements taken only once or twice during the trial.

one trial with none of the jackets in use, the other with all three in use. If the "Iona" engines had been thoroughly jacketed, still greater economy the author believes would have been obtained, when her great expansion is considered.

One of the chief objects of the Committee was to show that it is perfectly practicable to carry out a complete test of the propelling machinery of a steamer without seriously interfering in any way with the ordinary working; this the author thinks has been decisively proved. Further the trial of the "Ville de Douvres" has shown that by using a meter the measurement of the feed may be made as simply and easily as the weighing of the coal. If indicator diagrams are taken at regular intervals, and fuel and feed measured over a given time, the absolute efficiencies of both boilers and engines are determined with as much accuracy on board ship as on land, though of course as a rule with more discomfort to the observers. The work of the Committee the author therefore trusts will induce shipowners to have systematic tests made of the propelling machinery of their steamers, as is now done on land by millowners and other large users of steam power.

Discussion.

Professor BEARE mentioned that this paper had originally been prepared and announced for the meeting in April of last year; but owing to want of time for the reading and discussion at that meeting it had been deferred until the present meeting. During the interval he had seen reason to modify his views materially with regard to the important question of the behaviour of the "Tartar" during her trial. Originally he had been strongly disposed to reject as untenable the assumption that priming must have taken place to a large extent; and he had considered that some explanation of the perplexity might be found in an unsuspected loss between the feed-tanks and the boilers. The arrangement of the numerous pipes was naturally complicated enough to begin with; and as alterations had to be made for the trial, it seemed possible that by some mischance water might

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have been allowed to escape at some undetected point. Yet if that had been so, the loss must have been found out by examination of the records, which would have revealed the fact that there was an unduly large amount of supplementary feed-water; otherwise the boiler level must have fallen, because the water measured in the feed-tanks was only the condensed steam from the main engines together with the supplementary feed, assuming of course that the condenser was tight. He had therefore examined the records again most carefully, and had found in them nothing whatever to justify the assumption that there was an undue supplementary feed. The only fact he had come across was a solitary note made by Mr. Edwards in one of the log sheets, to the effect that at a certain time in the trial, namely at 8.2 p.m., "the steering engine was now exhausting into the condenser, along with the donkey." This was the only note in the record of the supplementary feed; and it appeared to him that the small quantity of steam condensed from those two engines could not at all make up anything like the large loss he wanted to account for. He had accordingly had to give up the idea that the explanation could be found in loss of water between the feed-tanks and the boilers. Casting about therefore for some other explanation, he had hit upon the idea of calculating from the indicator diagrams the quantity of steam actually present in the cylinders at different points of the stroke. The results of this calculation were given in page 47 and Table 31, from which it would be noticed that there was a much larger quantity of steam present in the high-pressure cylinder just before release than just after cut-off. The increase could have arisen only either from evaporation or rather re-evaporation, or else from leakage past the valve. As the engines had been overhauled immediately before the trial, it seemed inconceivable that so large an amount of leakage could take place past the valve; and he had therefore concluded that the cause must be re-evaporation. It was true that careful calculations of the quantity of heat present at the two points had failed to show where the heat could have come from to account for the supposed re-evaporation. Yet at that time he did not see any other explanation for the increase in the quantity

of steam present. In this connection too he remembered the curious effects he had seen in Mr. Donkin's glass "revealer," in which on admission of steam into the glass cylinder the whole body of it immediately became cloudy, and then as the stroke proceeded in the engine cylinder the cloudiness gradually disappeared from within the glass. While inclining towards this explanation, he was nevertheless doubtful about it, owing to the fact already mentioned that by no calculation could he make out where the heat could come from for this amount of evaporation or of re-evaporation. The calculations of the quantity of steam present at different points of the stroke he had recently verified by repetition, and the results thereby arrived at were illustrated in the indicator diagram, Plate 7. The 3·39 lbs. weight of steam per revolution, mentioned in page 47, was calculated at the point A just after cut-off, and included the clearance volume; this was the point which had been chosen in the original report (1890 page 235) for making the calculation of the steam present in the cylinder. At B, just before release at the end of the stroke, the weight of steam present was 4·33 lbs., being an increase of 0·94 lb. The heat contained in the steam and in the water present in the cylinder at A amounted to 4,580 thermal units per revolution, while at B it had risen to 5,322, showing a gain of 742. Where this gain came from was the puzzle. It did not seem possible that it could have come from the jacket, because ostensibly the jacket was not in use on the high-pressure cylinder; even if it had been, it hardly seemed conceivable that so large a quantity of heat per revolution could have passed from the jacket into the cylinder. The indicator diagram showed that at the point A the pressure of steam in the cylinder was 115·4 lbs. per square inch above the atmosphere. On carefully examining the diagrams it looked very much as if the valve had not really cut off the steam at the point A, notwithstanding that according to the setting of the valve gear the cut-off had already taken place. This conclusion that the cut-off had not really taken place at the point A was confirmed by calculating the quantity of steam present at a point C, a little further down the expansion curve, where it was certain the cut-off must have taken place. Here the quantity of

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steam present was found to be within 8 per cent. of the 4·33 lbs. present at B just before release; and therefore the great bulk of the increase of 0·94 lb. or over 27 per cent. between A and B seemed to have nothing whatever to do with the question of priming or re-evaporation, but to be due simply to the steam continuing to pass into the cylinder after the nominal cut-off, through the valve closing badly and slowly. Considering now the bearing of this view upon the question of priming, the weight of steam present at A in the cylinder proper, after deducting the steam of the clearance space, was 2·32 lbs. per revolution; and adding the increase of 0·94 lb. between A and B, this gave 3·26 lbs. as the weight of steam actually present in the cylinder per revolution at the point B just before release, after deducting that filling the clearance volume. The total feed being 5·13 lbs. per revolution, 3·26 lbs. amounted to 64 per cent. of it: so that there was left for priming and for initial condensation in the cylinder 36 per cent. of the total feed. In Table 32 it would be seen that in the "Iona," where there was some priming certainly, but only to a slight extent, the percentage of total feed present as steam in the high-pressure cylinder was almost identically the same as this, not only just before release but also just after cut-off. Hence he had found himself brought back again face to face with the original perplexity in regard to priming in the "Tartar." That priming must have been taking place seemed certain from the heat account of the boiler; but initial condensation and priming together amounted to only 36 per cent. of the total feed, taking account of the extra steam which must have passed into the cylinder after the nominal point of cut-off had been reached; therefore apparently the initial condensation must have been normal in amount.

Mr. W. H. WHITE, C.B., Member of Council, thought that perhaps some acknowledgment of the value of this paper, and of the work of the Research Committee on whose labours it was based, might come better from one who like himself was engaged in designing steamships, than from those who were engaged in the design and manufacture of their propelling apparatus. It appeared to him that the work which had been done by the author was of the greatest value to the Institution and to all connected with the use of steam. The preparation of the paper had of course involved dealing with a great mass of facts, and of figures representing supposed facts; and therefore the wonder seemed to him to be, not that there were some difficulties of agreement and interpretation, but that under the circumstances there were not a great many more. The high value of the work done by the Research Committee on marine-engine trials, which had been so well digested and analysed by Professor Beare, appeared to him to lie, not so much in the detailed statements of the performances of the several kinds of engines which had been tested during their working, as in the arrangement of the methods followed, and the description of the observations made, in conducting the trials; these methods would no doubt admit of extensive application and amplification in the future. The Institution he was sure would recognise that there was one gentleman in particular to whom both the organisation of this research and its practical conduct were owing, and that was their new President who had just taken the chair. Remembering what was the condition of the engine-room and stoke-hold under some circumstances at sea, it might well be imagined that neither Professor Kennedy nor those who had assisted him in the trials had always enjoyed themselves afloat; and it seemed possible therefore that some of the difficulties which Professor Beare had encountered in dealing with the figures recorded in the log sheets might be accounted for by temporary absence or incapacity on the part of the observers. But notwithstanding any such possibility, he nevertheless considered that in this extended series of trials, which in the present paper had been digested and analysed in so admirable a manner, the Institution had through the Research Committee rendered a great service to the engineering world. It was not supposed of course that observations made under such conditions as these and over comparatively short periods could be regarded as substitutes for actual experience gained in long-distance steaming at sea. Because such observations did not represent all the conditions of actual service, they were sometimes treated as of little value; but considering the infinite variations in

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the conditions which might occur in actual service, and the inherent difficulties of these questions, all engineers must agree that it was of the greatest service to have some trials made under fairly definite conditions, eliminating circumstances which no doubt affected practical results, but which were not necessarily present, and which had little or nothing to do with the designing of the machinery and boilers in steamships. Exactly the same criticism had been made with regard to steamship speed-trials: the measured-mile trials had been pronounced perfectly useless, because they did not represent sea performance. Nobody supposed that they did; but for purposes of design, everyone who was concerned with steamship construction would know that the measured-mile trials were absolutely necessary, both for determining the approximate power required for the speed in a new ship, and also for ascertaining the relative efficiencies of different forms of propellers. Hence it appeared to him that out of the facts dealt with in the present paper must come beneficial results in future practice, especially if these trials were made models for many others. The recommendation made at the end of the paper, that steamship owners should have the courage to look facts in the face and to make such trials in their own vessels and for their own information, was one that he had no doubt would be adopted and acted upon. The Institution he considered was much indebted to the shipowners who had placed their steamers at the disposal of the Research Committee for these trials; and in considering the results obtained he was sure it would be the feeling of all the members that they must distinguish between scientific analysis of the performances, and any tendency to criticise the results as representing the work of particular firms or the capabilities of particular engines. These trials were suggestive examples, which would not have been obtained at all, had it not been for the courtesy and courage of the owners of these steamers, and of those concerned in the construction of their machinery, in placing them at the disposal of the Institution.

In looking through the paper, what struck him most as a naval architect was that there was no particular kind of engine or of boiler which could be regarded as absolutely the best. There were some striking examples which showed how for special services the necessary and governing condition was success in the total effort made. The ships had to be considered as built for different services, running over different distances, some of them working with a limited draft of water, and others intended for over-sea voyages at moderate speeds, where economy of coal consumption was of the utmost importance. This consideration of course explained the circumstance that from Table 18 (page 38) it would be found that the area of total heating surface in the boilers ranged from as low as 2½ square feet per indicated horse-power up to more than double that amount; while again from Table 34 (page 68) it would be found that the weight of the machinery—which he understood to include both the engines and the boilers, all in working order—ranged from as much as 700 lbs. per indicated horse-power down to only 272 lbs. Whilst for marine engineers the economy of steam and fuel naturally attracted most attention, yet from the naval architect's and ship-builder's point of view the question of the weight of the propelling apparatus in proportion to the power was the most important, and could not be overlooked. Then again from the engine designer's side it was important to remark in Table 18 that one of the two-cylinder compound engines required 2·90 lbs. of coal per indicated horse-power per hour, while one of the triple-expansion engines took exactly half that amount; and on the other hand from Table 34 it was seen that the weight of machinery per indicated horse-power was only 448 lbs. in the former case, but as much as 700 lbs. in the latter. It was well known that claims were made for remarkable economy in coal consumption in the mercantile marine, as compared for example with war-ships; and there could be no doubt that there was some considerable ground for such claims. It was needless to enter into an explanation of why it was so; it was necessarily so. But on the other hand, in view of such differences as the above—namely between 1·46 lb. per indicated horse-power per hour in the triple-expansion engine and 2·90 lbs. in the two-cylinder compound—it was obvious that there was a good deal more to be taken into account than merely the greater expansion in the triple engine. Formerly he had himself been inclined to be somewhat incredulous as to the claims

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for remarkable economy in merchant ships; but the trials made by the Research Committee had established the fact beyond doubt that the great economy alleged was really attained in some vessels in actual service. In the Royal Navy trials had recently been made which were in their way quite as remarkable. The "Thunderer" with triple-expansion engines ran out to Madeira and home again, developing all the way about 80 per cent. of the power she had attained in the contractor's trial; and her consumption of coal out and home was only about $1\frac{2}{3}$ lb. per indicated horse-power per hour. That was of course a fine result, which did great credit to the makers of the machinery. The "Royal Sovereign" also with triple-expansion engines ran from Plymouth to Gibraltar at a mean speed of 15 knots, with a consumption of 1·84 lb. of coal per indicated horse-power per hour. On the other hand in war-ships working at reduced powers, as they had to do when cruising, the rate of coal consumption increased largely, because here the conditions of working were not fixed and steady as they were in merchant ships.

These were only a few of the many points which had naturally occurred to him in looking through the paper. They might serve to illustrate the interest, which as in some respect an outsider he felt in the subject, and to show his personal sense of obligation to the active members of the Research Committee and to the author of the paper.

Mr. FREDERICK EDWARDS mentioned that in a discussion last year at the Institution of Naval Architects (1893, vol. xxxiv, page 229) he had drawn attention to the circumstance that in the mean indicator diagrams from the "Iona" the steam line in the intermediate cylinder overlapped the exhaust line in the high-pressure cylinder; and he had interpreted this overlapping as showing that these mean diagrams were not really "a true set," meaning thereby that they had not been taken all three at exactly the same moment. Subsequently he had learnt that his meaning had been misunderstood to imply that these diagrams were not reliable. On the contrary, as he had mentioned at the time, he had referred to them because he believed the results obtained from the "Iona" were the most economical and reliable which had been published. Since then however in regard to this overlapping he had been in communication with Mr. Mudd, who was prepared to offer an explanation which he thought might be of interest to the members. The "Iona" diagrams were so reliable and so well known that he had intentionally selected them for reference, as he thought they were more interesting than any others he could choose.

Mr. THOMAS MUDD explained that, in the ordinary way of showing the indicator diagrams from two-cylinder compound or triple-expansion engines, by making the same vertical line serve for the commencement of the stroke in each cylinder, as in Plate 7, the overlapping of the diagrams from the successive cylinders did not involve any suspicion of incongruity. But when the diagrams were placed in their true sequence in point of time, and it was found that they overlapped, the impression at first derived from the overlapping was that the diagrams could not have been taken simultaneously, or, as Mr. Edwards had expressed it, that they were not a true set. There were one or two facts however which appeared to him to offer evidence that the contrary was the case: that is to say, that the overlapping of the diagrams did not necessarily prove that they were not a true set. The first fact was that the diagrams taken from other engines than the "Iona's," when placed in their proper sequence, did frequently overlap, even when the greatest care had been taken to ensure their being a truly simultaneous set. Having been present himself unofficially in the trial of the "Iona," he knew the greatest care had been taken in this case that each set of the indicator diagrams should be simultaneous from the three cylinders; and the indicator springs, as mentioned in the report of the trial (Proceedings 1891 page 211), had all been carefully tested before the trial.

The second fact to which he would call attention was illustrated by Plate 13, where the indicator diagrams from the high-pressure and intermediate cylinders of the "Iona" were placed in their true sequence of time in a straight diagram, and the horizontal length was divided into equal intervals of time or equal arcs in the

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revolution of the crank, instead of into equal parts of the piston-stroke. Here it was seen how, as he had endeavoured to show some years ago in the discussion upon Mr. Wyllie's paper by means of the indicator diagrams from the "Abeona" (Proceedings 1886 pages 511–17, and 1887 pages 47–51), the exhaust line of the high-pressure diagram came down so low that it ran into the steam line of the intermediate diagram, and then quickly rose till it got clear again above the intermediate diagram. The point so naturally raised by Mr. Edwards was, whether this overlapping did not denote some error in the diagrams; or if it did not, how was it to be satisfactorily accounted for. Taking the diagrams to be correct, they plainly showed that at the place of overlapping the receiver pressure was really higher than the exhaust pressure in the high-pressure cylinder, and that just at this time there was a sort of back rush of steam from the receiver into the high-pressure cylinder, clearly indicated at AA in Plate 13, by the hump in the exhaust line or the local rise of pressure in the steam out of its natural curve, soon after release. The diagrams seemed to him to carry on their face sufficient evidence of their truth in this respect; for it was clear that the pressure in the high-pressure cylinder rushed down immediately on release to a pressure below that of the receiver, and then attempted to get back again to the receiver pressure. Of these apparent facts he had only one explanation to offer, to which the Members would give the amount of consideration it might seem to them to deserve. Although, as remarked in the paper (page 55), only the high-pressure cylinder was steam-jacketed in the "Iona," the fact must not be overlooked that the high-pressure steam-chest stood wholly in the intermediate receiver, and therefore to the receiver at all events it formed a good steam-jacket, although situated inside the receiver instead of outside. The steam exhausting from the high-pressure cylinder into the intermediate cylinder rushed all round the high-pressure steam-chest on its way, and must thereby abstract some heat from the boiler steam in the high-pressure steam-chest, which thus acted as a re-heater to the steam in the receiver. Perhaps this fact might explain also something else that had been difficult to understand hitherto: namely the cause of what had been regarded as the high initial condensation in the high-pressure cylinder of the "Iona," which was represented by something like 36 per cent. of the total feed present as water in the high-pressure cylinder at the point of cut-off, although there was practically no priming that could be detected. There was however this fact to be borne in mind: that, although the steam going from the boiler into the high-pressure steam-chest showed no presence of intermixed water, it was going into a steam-chest which was enclosed within the intermediate receiver, and which was therefore losing heat all round, with consequent formation of moisture in the steam contained in the steam-chest. A large proportion of the water found in the high-pressure cylinder at the point of cut-off he therefore thought could not be truly regarded as due to initial condensation in the cylinder, that is, as water resulting from condensation of what had been dry steam at the moment it entered the cylinder; but it was like priming water, or moisture contained in the steam before it entered the cylinder, and was caused by the high-pressure steam-chest giving up heat to the intermediate receiver, and producing the very effect of overlapping which was seen in the indicator diagrams. These facts therefore seemed to account for the wetness of the steam in the high-pressure cylinder and its dryness in the intermediate, in spite of the circumstance that nominally the high-pressure cylinder was jacketed and the intermediate not jacketed.

In the heat balance-sheet given in Table 18, page 39, there seemed to him to be needed some slight modification in the division of the loss, so far as regarded the temperature of the funnel gases in the "Iona." For practical reasons the temperature had in that case been taken rather high up the funnel, at a point 30 feet above the fire-grate, as mentioned in page 50; and the loss of heat given in the balance-sheet was the heat carried away from the boilers by the funnel gases on the assumption that the gases were escaping at the temperature measured at that high point. Obviously however the loss began much lower down; as soon as ever the gases escaped from the boiler tubes into the smoke-box they were done with for all

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practical purposes in the boiler. In the Chief Engineer's subsequent trial (Proceedings 1891, pages 217 and 222) the temperature had been taken in the smoke-box in front of the tubes, with the result that it had been found to be some 220° higher than in the Research Committee's trial. Consequently the thermal loss in the funnel gases, instead of being only 16·2 per cent. as given in Table 18, would be something like 24 per cent.; and instead of there being 13 per cent. loss unaccounted for—which the author had assumed (page 51) to be due in the main to radiation, owing to the large size of the boilers in the "Iona" (page 52)—the loss unaccounted for wanted considerably reducing, to correspond with the considerable increase in the heat actually escaping up the funnel.

Capt. H. RIALL SANKEY noticed that in pages 63–4 of the paper there were some interesting calculations with regard to the percentage of steam present in the several cylinders at different points of the stroke; and some further information on this subject had also been given by the author (pages 72–4). This and other matters could be conveniently exhibited in a graphic form by transferring the ordinary indicator diagram, that is the *pv* or pressure-volume diagram, on to the well known theta-phi or temperature-entropy chart * worked out by Mr. Macfarlane Gray; and he wished to show how this could be done by a method which he had himself employed for some time past, but which he had only lately succeeded in perfecting. In this way he hoped also it might be possible to throw some light upon the difficulty dwelt upon by Professor Beare, as regarded the excessive amount of water present in the high-pressure cylinder of the "Tartar."

* To avoid confusion, it is proposed to reserve the term θ ϕ *diagram* for the diagram transferred from the indicator diagram: thus the high-pressure θ ϕ diagram, the intermediate θ ϕ diagram, and the low-pressure θ ϕ diagram will be appropriate terms corresponding with the respective indicator diagrams. What has hitherto been generally known as the θ ϕ diagram it is proposed to call the θ ϕ *chart*, Mr. Macfarlane Gray having originally described it as a heat chart (Proceedings 1889, pages 412–413).

The method * he now referred to required that a series of curves representing constant volumes should first be drawn upon the $\theta\ \phi$ chart, representing successive volumes in cubic feet, as shown in Fig. 17, Plate 14; and also lines of constant pressure, which for steam not superheated were horizontal straight lines, because they coincided of course with the corresponding horizontal temperature lines drawn from the equally divided vertical scale of temperature. In Plate 14 the numbers placed along the steam saturation curve SS showed the cubic feet occupied by one pound weight of saturated steam at various pressures and corresponding temperatures: for instance, at approximately 150 lbs. absolute pressure per square inch the volume of one pound of steam was 3 cubic feet; and following this particular curve of constant volume to the point C, it would be seen that, when only one-half of the pound of H_2O† had been evaporated, the other half still remaining water, the pressure was about 70 lbs. Similarly the volume, pressure, and temperature of that portion of the pound of H_2O which was steam could be read off from the $\theta\ \phi$ chart for any point whatever within the limits of the chart. The construction of the $\theta\ \phi$ chart, it would also be remembered, was such that the distance measured horizontally from any point P in Plate 14 to the saturation curve SS represented the proportion by weight still remaining water in the pound of H_2O; and the horizontal distance from the same point P to the water curve W W represented the proportion present as steam. In other words the ratio of the length W P to the total length W S across the chart was the dryness fraction of the steam at the point P.

The first step towards transferring the indicator diagram to the $\theta\ \phi$ chart was to obtain, by the ordinary method of calculation, the dryness fraction at some point p in the expansion of the steam, Fig. 18, Plate 15. The point p should be chosen sufficiently beyond the cut-off to ensure that the valve was completely closed, so that no

* In compliance with Mr. Cowper's subsequent request (page 109), the description of the mode of transferring the indicator diagram on to the $\theta\ \phi$ chart has here been amplified.

† It is proposed to use the chemical symbol H_2O to denote the substance when it is present partly as water and partly as steam.

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more steam could enter the cylinder. The absolute pressure having been measured at the point p on the indicator diagram, and the dryness fraction having been obtained, the corresponding point P of the θ ϕ diagram, Fig. 19, could then evidently be plotted on the chart. The volume at the point P was then found by interpolation from the constant-volume curves; in the present example it was 3·8 cubic feet. The actual volume in the cylinder, including the clearance, was then determined from the dimensions of the engine for the point p, Fig. 18, namely 69 cubic feet; and the ratio of these two volumes gave a volume factor of 18·16, by which to divide the actual cylinder-volumes on the indicator diagram in order to obtain the volumes on the θ ϕ diagram. In other words the weight of H_2O in the cylinder and clearance of the actual engine was 18·16 lbs., instead of only 1 lb. as taken on the θ ϕ diagram.

The next step was to measure the volume and absolute pressure for a number of points on the indicator diagram; the volumes were then divided by the volume factor, and the points could then be transferred to the θ ϕ chart; on joining them the θ ϕ diagram corresponding with the indicator diagram was obtained. As above mentioned, the starting point p should be chosen after cut-off; but in some cases the indicator diagram did not show the point of cut-off clearly, and the point selected might then happen to be before cut-off had taken place. In such a case the error would become apparent on plotting the θ ϕ diagram; and moreover the correct point of cut-off would be shown, so that a fresh start could be made with a new point p. The area of the θ ϕ diagram multiplied by the volume factor and by Joule's equivalent was of course equal to the area of the pv or indicator diagram expressed in foot-pounds; and this could be used as a check on the accuracy of the work. [See also pages 132–3.]

In this manner the mean indicator diagrams of the "Ville de Douvres," the "Iona," and the "Tartar" had been transferred to the θ ϕ chart, as shown in Plates 15, 16, and 17; the measurements had been taken from the mean indicator diagrams published in the Proceedings, namely:—"Ville de Douvres" 1892, Plate 15; "Iona" 1891, Plate 47; "Tartar" 1890, Plate 100. Referring to Fig. 19,

Plate 15, for the "Ville de Douvres," it would be seen that AB on the $\theta\ \phi$ diagram corresponded with the admission line *ab* on the indicator diagram, Fig. 18; BC with the expansion curve *bc*; CD with the release *cd*; DE with the exhaust *de*; and finally EA with the compression curve *ea*, and with that part of the admission which took place at practically constant volume, when the crank was passing the centre. For further enabling the comparison of the two kinds of diagrams to be readily made, the percentages of the stroke had also been marked at a few points on the $\theta\ \phi$ diagrams; thus in Fig. 19, at A zero, at B 62 per cent., and at D 100. [See also page 130.]

As already explained, the position of a point on the $\theta\ \phi$ chart determined the proportion of water and steam present in one pound of H_2O; and this law would hold good for every point of the $\theta\ \phi$ diagrams just described, if the changes in the cylinder were produced by the alternate applications of a hot and of a cold body, as described by Rankine. But in an actual engine these changes were brought about by the alternate admission and exhaust of steam: so that in its entirety the law evidently held good only for the expansion part of the stroke, that is, whilst the cylinder was closed and contained one pound of H_2O. For all other points on the diagrams the chart showed only the volume of steam present in the cylinder; and no conclusion could be drawn as to the quantity of water present. It followed that the position of the point of cut-off B on the $\theta\ \phi$ chart, Plate 15, enabled the proportion of water in the cylinder at that point in the stroke to be determined. If there were no priming, leakage, conduction, or radiation, the whole of this water would be due solely to initial condensation; that is to say, it must originally have entered the cylinder as steam, which had afterwards been condensed in the cylinder; and all the heat in the steam from which it had been condensed would of necessity be stored in the cylinder walls &c. and in the water present in the cylinder. If during expansion the whole of this heat could be recovered, the expansion line of the $\theta\ \phi$ diagram would follow the dotted line BR, which was found by the method explained in Mr. Willans' paper on steam-engine trials, read before the Institution of Civil Engineers

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in April 1893 (Proceedings vol. cxiv, page 36). On the other hand, if the whole of the water shown to be present in the cylinder at cut-off had come into it originally as water at the temperature of the point B, namely 325°—that is, had not been produced by condensation during admission, and therefore had not parted with heat to the cylinder walls &c.—the heat-recovery possible during expansion would evidently be far less, and would be shown by the dotted line B*r*. The point *r* could be obtained as follows. The vertical strip of the breadth *mn*, extending down to absolute zero and including the triangle *m*W*n*, represented the heat given to one pound of water in raising it from the exhaust temperature near D to the cut-off temperature at B. If *mn* were divided at *x* in the ratio BS to BW, the vertical strip of the breadth *xn*, together with the triangle *x*W*n*, would pretty closely represent the heat which, during the same rise of temperature, would be given to the priming water present at cut-off. Hence a similar vertical strip, in which the breadth *lr* was equal to *xn*, would represent the heat given out to the steam by the priming water in cooling from the cut-off temperature to the release temperature. The two dotted lines BR and B*r* might be called the lines of condensation-water heat-recovery and of priming-water heat-recovery respectively. Evidently therefore the expansion curve of an actual engine ought to lie somewhere between these two extreme lines, provided that during expansion no heat was either introduced into the cylinder or taken out of it; and thus the position of the actual expansion curve in relation to these two extreme limits would give valuable information as to what was going on in the cylinder during expansion. It was possible to show the θ ϕ diagram which an ideal engine would produce, if working perfectly within the limits of the conditions imposed upon the actual engine; and the same might be done for each cylinder separately: this was a question he was still investigating. In this connection it was necessary to guard against a possible misunderstanding which might arise. When showing the thermal losses of an actual engine in comparison with a theoretical engine working within the same range of temperature, Mr. Willans had preferred not to show the clearance steam; and in that case the area of the θ ϕ diagrams gave

the thermal efficiency of the actual engine by direct comparison with the heat units utilised by the theoretical engine. In the present enquiry however the clearance steam was shown; and consequently the areas of the $\theta\ \phi$ diagrams did not directly give the thermal efficiency, but had first to be multiplied by the ratio of the volume of the total steam at cut-off to that of the working steam. This was a disadvantage which arose from showing the clearance steam; but on the whole he was at present of opinion that it was better to include it, at any rate for the purposes now under consideration.

In the high-pressure $\theta\ \phi$ diagram for the "Ville de Douvres," Fig. 19, Plate 15, it would be observed that the expansion curve BC, falling away as it did to the left of the priming-water heat-recovery line B*r*, showed a distinct loss of heat from the cylinder during the expansion. The loss was easily accounted for by the fact that, as pointed out in the paper (page 53), the high-pressure cylinder was surrounded by the receiver; and therefore heat was flowing out from the hotter steam in the cylinder into the cooler steam in the receiver, and the flow would be much facilitated by the cylinder walls being no doubt wet both inside and out. It would also be noticed that there was a considerable loss from incomplete expansion in this cylinder, due to the release at C taking place too soon, thereby cutting a piece off the toe of the indicator diagram, Fig. 18, and also off the $\theta\ \phi$ diagram, Fig. 19; but the amount of the loss was more clearly shown on the $\theta\ \phi$ diagram. The loss could evidently have been obviated by making the cut-off in the low-pressure cylinder somewhat earlier, so as to get rather a higher pressure in the receiver, and thereby raise the back-pressure curve of the high-pressure cylinder. The loss from incomplete expansion in the low-pressure cylinder, as well as from bad vacuum, was also evident.

In the $\theta\ \phi$ diagrams of the "Iona," Plate 16, the difference between the expansion curves in the high-pressure and low-pressure cylinders was very marked, and was no doubt due to the former being jacketed and the latter not. In the high-pressure cylinder the expansion curve came fairly close to the line BR of condensation-water heat-recovery. But on turning to the

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intermediate cylinder, which was not jacketed, it was seen that, instead of the expansion curve falling further away, as it might have been expected to do, it actually went slightly beyond the condensation-water heat-recovery line. This could take place only as the consequence of heat having come into the cylinder in some unusual way after cut-off; and in this case he thought it might possibly be due to leakage of steam through the valve. It was true that, owing to the construction of the engine, the steam was reheated in the receiver: the effect of which was clearly shown in the $\theta\ \phi$ diagram by the admission line of the intermediate cylinder being at a higher temperature than the exhaust line of the high-pressure cylinder, but more particularly by the marked increase in the dryness fraction at cut-off in the intermediate cylinder; this however in no way accounted for the heat received after cut-off. The idea that this effect was due to a leaky valve received confirmation from the fact that when, instead of plotting the expansion curve shown by the full line in Plate 16 from the mean indicator diagram of the intermediate cylinder, the two indicator diagrams for the top and bottom of the cylinder were plotted separately, the form of the expansion curve *b* for the bottom was such as might be expected for a non-jacketed cylinder, as would be seen by comparing it with the expansion curve for the non-jacketed low-pressure cylinder, plotted from the mean indicator diagram; but the expansion curve *t* for the top went so far beyond the condensation-water heat-recovery line that it appeared to him to denote clearly a leakage at the valve admitting steam into the top of the cylinder. The $\theta\ \phi$ diagram for the low-pressure cylinder showed the advantage derived from a good vacuum; if the vacuum had been the same as in the "Tartar," for instance, the portion of the low-pressure $\theta\ \phi$ diagram below the line MN would have been lost.

The $\theta\ \phi$ diagrams had also been made out for the "Tartar" in Plate 17. In the diagram for the high-pressure cylinder he thought the points dwelt upon by Professor Beare were pretty clearly brought out in a graphic form, and his conclusions confirmed. The actual re-evaporation in this cylinder, instead of being so considerable as would appear from the figures given in the report of the trial before they had been corrected by the author, was seen from the θ ϕ diagram to have been really small. The reason for the difference was that given by Professor Beare (page 73), that the point assumed as the point of cut-off was too early in the stroke. What might be called the mechanical cut-off might have occurred at about one-third of the stroke; and from this point to half stroke the admission line on the θ ϕ diagram showed considerable wire-drawing, due probably to the valve closing too slowly, so that the steam was really cut off only at about half stroke. It would be noticed on the indicator diagram that the wire-drawing was so considerable as to make this part of the admission line look like the beginning of the expansion curve; the θ ϕ diagram however discriminated between the two. That the valve did not merely leak was distinctly shown by the fact that the expansion curve did not project much beyond the priming-water heat-recovery line; whereas, if there had been a leakage of steam going on continuously, the expansion curve would have been found to bulge outwards from the first, much in the same way that it was observed to do in the θ ϕ diagram for the intermediate cylinder of the "Iona," Plate 16. The dryness fraction of the steam at half stroke, which appeared to be about the true cut-off, was 59·1 per cent. as obtained from the θ ϕ diagram, instead of 45·2 per cent. as given in the report (1890 page 235). This went a long way towards explaining the great discrepancy between the feed and the steam as shown by the indicator; but it did not account for the apparently excessive evaporation of the boilers, which he thought could be explained only on the supposition that unevaporated water was bodily ejected from the boilers. As a possible cause he would suggest that the oscillation of the water in the boilers might have synchronised with the rolling of the ship, and thus have led to violent commotion of the water in the boilers. The dryness fraction of the steam as it issued from the boiler, calculated on the assumption that the boiler efficiency was 68 per cent., came out as low as 75 per cent., or 25 per cent. priming; on the assumption that the boiler efficiency was as high as 75 per cent., the dryness fraction would be increased to

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82 per cent., and the priming reduced to 18 per cent.* The lower dryness fraction of 75 per cent. did not appear unlikely, and was plotted on the θ ϕ chart at the point Y, Plate 17, so that YS represented the water coming as water from the boiler. The remainder BY of the water shown at cut-off was therefore due to initial condensation, and on measurement turned out to be 21 per cent. of the steam WY coming into the cylinder: quite a reasonable percentage for the range of temperature and the speed of revolution. The true theoretical heat-recovery line, being due partly to priming water and partly to initial condensation, would therefore lie somewhere between the two extreme heat-recovery lines, as shown by the intermediate dotted line BH; and the difference between this line and the expansion curve was a measure of the loss due to conduction, radiation, and leakage. Coming to the intermediate and low-pressure cylinders, the effect of their steam-jackets was immediately seen in Plate 17; their expansion curves followed somewhat closely the condensation-water heat-recovery line. It was noticeable however that the dryness fraction was nearly constant throughout all three diagrams in Plate 17, showing that no material improvement had been effected in the quality of the steam by the jacketing of the intermediate and low-pressure cylinders: the high-pressure cylinder had done badly, and the other two followed suit, their jackets being unable to cope with the large quantity of water coming from the first cylinder. The curve FF of equal dryness-fraction had been drawn through the half-stroke cut-off in the high-pressure cylinder, and it was thereby seen that the quality of the steam continued practically the same, both at the 40 per cent. cut-off in the intermediate cylinder and at the half-stroke cut-off in the low-pressure.

In regard to the increased horse-power which, as shown in Table 28, would have been obtained in the low-pressure cylinder, had its back-pressure been the same as that of the condenser, it was stated in page 59 that this increase would have been brought about without

* In compliance with Professor Beare's subsequent request (page 124) these percentages have been re-calculated, and are found to be correct for the boiler efficiencies assumed.

the expenditure of any more steam. This statement he thought required a little qualification, because a reduction in the back-pressure caused an increase in the range of temperature in the cylinders, and thereby increased the initial condensation: so that really more steam would be required in order to obtain the increase in horse-power. This was clearly seen from the $\theta\ \phi$ diagram of the "Ville de Douvres," Plate 15, because, had the back-pressure in the low-pressure cylinder been the same as in the condenser, the low-pressure diagram would have been increased by the dotted portion shown in Plate 15, equivalent to 132 horse-power, as given in Table 28; but the total range of temperature in the engine would have been increased by 10½°, which would have produced slightly greater initial condensation, and would thus have reduced the area of both the high-pressure and the low-pressure $\theta\ \phi$ diagram. These losses however would have been less than the gain.

Again in page 69 it was said that the great expansion obtained in the "Iona" with its high efficiency was a proof of the fact that economy resulted from such practice. The economy here spoken of he thought should be defined as economy in feed-water per indicated horse-power; for it did not necessarily follow that economy per brake horse-power would result. Turning to Table 34, the indicated horse-power obtained per ton of the machinery rather pointed to this distinction; for in the "Iona" the indicated horse-power obtained per ton was no more than 3·2, whereas in the "Ville de Douvres" it was as much as 8·2: showing that the greater expansion required a much larger engine, which meant increased engine-friction. [See also page 130.]

Mr. JOHN PHILLIPS asked how far Mr. Mudd's view (page 81) respecting the loss of heat in the funnel gases would be modified by the position of the damper at a height of 17 ft. 8 ins. above the fire-grate in the "Iona," and by the effect of forced draught producing a plenum of pressure below the damper and a vacuum above it.

Mr. MUDD replied that he had been dealing with the point at which the temperature of the funnel gases had been taken in the

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Committee's trial, namely 30 feet above the fire-grate. That was considerably higher up in the funnel than the damper. The position of the damper and the use of forced draught he thought did not affect what he had tried to bring out, namely that the temperature of the gases escaping from the boiler tubes must have been much higher than it was at the point where it had been measured in the trial.

In Capt. Sankey's remarks (page 88) it seemed to have been assumed that the intermediate valve of the "Iona" must have been *leaking steam*, because there was an accession of heat that could not otherwise be accounted for. In the explanation however which he had already offered (pages 80–81) he had endeavoured to make it clear that, whilst there was leakage of heat, if it might so be called, there was no leakage of steam: that is, at the time the steam was going into the intermediate cylinder it was receiving an accession of heat direct from the boiler through the walls of the high-pressure steam-chest.

Mr. JEREMIAH HEAD, Past-President, noticed that, while the series of marine-engine trials which had been made at the cost and on the initiative of the Institution had in the present interesting and able paper been put into a condensed, and to a considerable extent a useful and systematic form, the paper still consisted of a record of a large number of interesting facts, upon which opinions had been somewhat charily expressed by the author, probably for the reason that it was desired to elicit the opinions of the members, who might be more likely to consider what these facts might lead to, if they had not a set of opinions placed before them ready cut and dried. In view of so many interesting tables and of the facts recorded in them, a few ideas and suggestions could not fail to occur to him, although they might perhaps be of a rather crude nature, because it required a long time to assimilate such a large mass of experimental facts and draw any conclusions from them. Confining himself however to the last two trials, namely those of the "Iona" and the "Ville de Douvres," a comparison he thought might advantageously be drawn between these, because they seemed to him to typify two leading classes of steam vessels in this country. Thus the "Iona" was an excellent example of a cargo vessel, a class which was sometimes looked down upon by those who stigmatised them as "ocean tramps." The "Ville de Douvres" was a type of vessel of much finer lines, which was intended to go at a very high speed indeed, and to carry only passengers and mails.

In comparing these two steamers it would be seen from Table 16 that the displacement of the "Iona" was four times that of the "Ville de Douvres." If too the immersed midship section were considered, that is, the breadth multiplied by the draft, it would be found that the "Iona" had just three times the immersed midship section of the "Ville de Douvres," although four times the displacement. This showed at once that the "Iona" could not have had anything like such fine lines as the "Ville de Douvres": indeed the speed of the "Iona" was just half that of the "Ville de Douvres." The indicated horse-power which drove the four-fold tonnage of the "Iona" through the water was in the ratio of 1 to $4\frac{1}{2}$ in comparison with the power in the "Ville de Douvres," Table 27; or taking the indicated horse-power (Table 27) per ton of displacement (Table 16), it would be found that the "Iona" had only 1-7th of a horse-power per ton, while the "Ville de Douvres" had $2\frac{3}{4}$ horse-power. Hence the "Ville de Douvres" had 18·7 times the power of the "Iona" per ton of displacement, and her higher power propelled her at only twice the speed. The relation however between the indicated horse-power and the tons of displacement seemed to vary largely; and it was a most interesting relation indeed, because it showed the great cost at which high speeds were attained. Turning for instance to a few other well-known vessels apart from those dealt with in the paper, it would be found that the "Teutonic," which went at 21 knots per hour, had a little more than 1 I.HP. per ton of displacement; the "Campania," which went at $21\frac{1}{2}$ knots per hour, had 1·6 I.HP. per ton of displacement; the Argentine cruiser called the "Ninth of July," built by Armstrong, Mitchell and Co., which made 22 knots per hour, had 4·1 I.HP. per ton of displacement; the torpedo boat "Ariete," built by Thornycroft, which went at 26·18 knots per hour, had 14 I.HP. per ton of displacement; and the last effort in that line, the "Havoc," which

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on its trial went at 26·89 knots per hour, had 17 I.HP. per ton of displacement. The range from the cargo steamer "Iona," which had only 1-7th of a horse-power per ton of displacement, up to the "Havoc," which had 17, was 1 to 119, which was indeed extraordinarily wide.

The cargo boats or ocean tramps, as he had already intimated, had been somewhat looked down upon as scarcely examples of the highest kind of marine engineering. Nevertheless in the way of economy they had realised some wonderful performances, of which in one or two instances he happened to know the particulars. The screw-steamer "Westoe," built at Hartlepool, which carried 3,500 tons dead weight at 9 knots per hour, used only 0·64 oz. or two-thirds of an ounce of coal per ton per knot, at the cost of 1-500th of a penny. The "Oscar II.," a rather larger cargo boat also built at Hartlepool, which carried 4,600 tons dead weight on 14 tons of coal per day of 24 hours at 9 knots per hour, used exactly 0·50 oz. or only half an ounce per ton per knot. Another boat rather larger still, the "Aldworth," which carried 5,000 tons dead weight on 15 tons of coal per day at 8·9 knots per hour, did it also on 0·50 oz. or half an ounce per ton per knot. Therefore it seemed this was rather a convenient figure to remember, that produce could be taken across the ocean in such vessels with a consumption of only half an ounce of coal per ton per knot.

Looking next at the boilers and fuel, the coal used by the "Iona" seemed from Table 19 to have had 3 per cent. more heating power in it than that used by the "Ville de Douvres"; while from Table 18, in respect of the evaporation per lb. of carbon-value of the coal, which was the test of the boiler efficiency, still the boilers of the "Iona" were 5 per cent. better than those of the "Ville de Douvres." From Table 34 the indicated horse-power per cubic foot of boiler volume in the "Iona" as compared with the "Ville de Douvres" was as nearly as possible as 1 to 2; that is, the boilers of the "Iona" were only half as hard worked, or in other words the "Iona" had ample boiler-power. The higher steam-pressure in the "Iona" was of course one of the things that gave her an advantage; from Table 26 her boiler pressure (absolute) was 49 per cent. higher than in the "Ville de Douvres," being 180 lbs. per square inch as compared with 121, thereby enabling a much greater expansion to be realised.

From the heat balance-sheet in Table 18 it would be noticed that, while in the "Iona" 69·2 per cent. of the thermal units went into the feed-water as against only 66·1 in the "Ville de Douvres," on the other hand only 16·2 per cent. of the thermal units went to waste in the funnel gases as against 26·8 per cent. in the "Ville de Douvres": showing that in the "Iona" more heat went into the feed-water and less into the funnel gases. Again in the "Iona" only 1·6 per cent. of the thermal units was lost in unburnt carbon in the ashes, and double that amount in the "Ville de Douvres": showing that in the latter somehow or other more coal was let fall through the grate, probably by forcing the fires. Nevertheless the thermal units unaccounted for in the "Iona" were as much as 13 per cent. of the whole, and only 4 per cent. in the "Ville de Douvres." Professor Beare's idea he thought was that this was owing to the larger proportionate surface of boiler and the consequent larger loss by radiation in the "Iona." Yet, if this theory was correct, the conditions and the evaporation of the steam were notwithstanding altogether better in the "Iona" than in the "Ville de Douvres."

There was one rather peculiar circumstance about the amount of air that was used for the combustion of the fuel. It must have occurred to many others besides himself that when forced draught was used with marine boilers it might be expected that a great deal more air would be forced through the furnaces and wasted, than with the natural chimney draught, with which latter the air was allowed more to take its own time, as it were, in uniting with the fuel. The trials of the "Iona" and the "Ville de Douvres" were both made with forced draught, and all the other four trials were with natural or chimney draught. The air pressure with the forced draught in the "Iona" was 0·86 inch of water (page 36), and in the "Ville de Douvres" from 0·7 to 1·0 or say an average of 0·85 inch, being thus practically the same in each steamer. In the chimney however the "Iona" had a draught of only a quarter of an inch of water (Table 22), while the "Ville

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de Douvres" had more than one inch; but the latter he presumed was owing both to the much greater heat going to waste in the chimney of the "Ville de Douvres," and also perhaps to the smaller tubes causing more obstruction to the passage of the gases through them. Turning now to the weight of dry air actually used per lb. of fuel, the average of the four steamers that had only chimney draught was found from Table 22 to be 21·5 lbs. of dry air; and though it would be expected that there would be more in the "Iona" and the "Ville de Douvres" with their forced draught, nevertheless the average of these two was only 21·2 lbs. This seemed to show that there was not any greater excess of air passing through the furnaces under the influence of the forced draught than with the natural or chimney draught. Looking also at the analysis of the gases in Table 22, and taking first the nitrogen—which he considered fairly represented the air, because this gas alone went through the furnace uncombined, and therefore unaltered in quantity, and whether the oxygen came out mixed with it or combined with the carbon as carbonic acid did not much matter; the nitrogen was there all the same, and therefore the weight of nitrogen in the funnel gases must truly represent the weight of air going through—it was found that the average of the nitrogen in the first four steamers with their chimney draught was 75·78 per cent.; while in the last two with their forced draught it was 75·29 per cent., or rather less than in the others. This confirmed the conclusion arrived at from the weight of dry air. Not only so, but in respect also of the oxygen it would be found that in the first four the average was 10·79 per cent., while in the "Iona" and the "Ville de Douvres" the average was 10·22 per cent.; that is, there was rather less oxygen with the forced draught than with the chimney draught, just as there was rather less nitrogen. Therefore it might be taken as evident that there was rather less air altogether with the forced draught. Looking at the carbonic acid in the funnel gases, the average of the four steamers with chimney draught was 13·23 per cent., and of the two with forced draught 14·48 per cent. This seemed to him to be in favour of the forced draught, as showing that there had been more perfect combustion. Therefore on the whole the conclusion

appeared to him to be that the forced draught neither allowed more air to pass through the furnace nor permitted of more imperfect combustion; but that really the combustion was rather better and on rather less air than when the forced draught was not used.

With regard to the total weight of machinery, to which attention had already been drawn by Mr. White (page 77), it would be seen from Table 34 that the "Iona" gave 3·2 indicated horse-power per ton and the "Ville de Douvres" 8·2, showing that the "Iona's" engines were as much as 2·56 times heavier than those of the "Ville de Douvres." At the same time the ratio of expansion in the "Iona" was 19·0 times, and in the "Ville de Douvres" 5·7; that is, 3·33 times as much in the former as in the latter. Therefore if a high degree of expansion were wanted, it must be expected that rather big and heavy engines would be needed. The feed-water per indicated horse-power per hour (Table 29) was in the proportion of 100 in the "Iona" to 155 in the "Ville de Douvres"; that is, it was 55 per cent. more in the latter. From Table 29 also the efficiency of the engines corresponded very nearly with what was arrived at from the fuel consumption in Table 18: it was as 146 to 100 in favour of the "Iona," while the carbon-value of the fuel consumption per indicated horse-power per hour was as 100 in the "Iona" to 159 in the "Ville de Douvres."

The results of these trials, and the attention which had been given to them, the time they had occupied, and the energy that had been bestowed upon them, would constitute he hoped a kind of epoch in marine engineering. In this country so much depended on the efficiency of our steamers — even our very food supplies — that anything which could be done in the way of increasing their efficiency was like increasing our daily bread in more ways than one: not only in bringing food cheaply across the seas, but also in enabling this country, in the building of ships and engines, to keep the lead which it had so long enjoyed, which it still held, and which he trusted it would always continue to hold. The simple apparatus which had been described, wherewith these trials had been carried out, and the ease with which it was applied, would he hoped encourage shipowners, wherever they could do so, to keep it always on board, so that the

(Mr. Jeremiah Head.)

engineers could try their engines in as thorough and systematic a way as possible, not only at the beginning of a voyage, but also during its course and at the end, so as to see whether there was any deterioration in their working; and if any such statistics so gathered were forwarded for record to one place, as for instance to this Institution, they would he was sure be of the greatest possible value.

In connection with the extraordinary variation of 1 to 119, which he had shown (page 94) to exist in the amount of power put into steamers per ton of displacement, the question naturally arose whether so remarkably small an amount of power as that in some cargo ships, going down to as low as one-seventh of an indicated horse-power per ton of displacement, was really enough under the trying circumstances which sometimes arose at sea. Within two months past there had been at least one terrible storm, causing a considerable number of cargo boats to be lost, and nobody knew exactly in what way they had been lost. When however the story was remembered of the hurricane which took place at Samoa five years ago, wherein the cruiser "Calliope" with her strong and excellent engines of enormous power was the only steamer which was able to go against the storm and to make her way out to sea in safety, the other vessels in the harbour being all driven ashore and lost; when the enormous power was borne in mind which had to be exerted in that ship to steam against the hurricane; and when the number of cargo vessels was contemplated which in heavy weather had been lost and never heard of again:—he could not help suspecting that shipbuilders and marine engineers might perhaps have gone almost too far in keeping down the power in those vessels, and it no doubt behoved them to consider this matter seriously. It was not enough he considered that goods should be carried across the sea at such exceedingly economical rates as he had shown (page 94) had now been attained, if the whole vessel was liable to be wrecked, and the lives it carried to be lost, in the event of one of the furious gales which occurred every now and then. Even at the sacrifice of some expense in the transit of goods, there ought to be sufficient power he thought on board every ship to be able to bring her safely to port, whatever happened.

Mr. ALFRED SAXON thought that, from a land engineer's point of view, if all marine engines had as much reserve power stored up in them as had the engines of the "Iona" at the time when the indicator diagrams were taken in the trial, no fear need be felt for the safety of cargo steamers as far as power was concerned. It was shown in Table 26 that the "Iona" with a boiler pressure of 179·58 lbs. absolute per square inch had been developing a mean effective pressure referred to the low-pressure cylinder of only 21·13 lbs. per square inch, whereas the "Ville de Douvres" with a lower boiler pressure of only 120·64 lbs. had been developing as much as 30·17 lbs. The triple-expansion engines in the "Meteor," which might also be taken for comparison with those in the "Iona," had been doing practically the same effective work as the engines in the "Ville de Douvres," their mean effective pressure referred to the low-pressure cylinder being 29·90 lbs., while that in the "Ville de Douvres" was 30·17 lbs. It was therefore seen that in the triple-expansion engines of the "Iona" there was a considerable reserve of power before reaching these higher effective pressures in the low-pressure cylinder: so that the indicated horse-power of the "Iona" ought scarcely to be compared he thought with that of the "Ville de Douvres," as had been done by Mr. Head, when the engines of the "Iona" were not working at their full capacity.

The loss of steam pressure between the boiler and the valve-chest in the "Iona" was seen from page 61 to be but small, amounting to only 5 lbs., thereby proving that the supply pipes to that valve-chest were of pretty good size, although perhaps they might be still further enlarged with advantage. He enquired whether the valve-chest pressure had been taken with an indicator, as well as with a pressure gauge; and if so, whether the indicator diagram so produced was a straight line, or a fluctuating diagram such as was often obtained from valve-chests to which the supply pipes were too small. From an examination of the indicator diagrams taken from the cylinders of the "Iona" it would be seen that the capacities of ports and pipes and passages generally all through were well designed, because the loss of pressure at both ends was so small: at one end between the boiler and the high-pressure valve-chest, and at the other end between

(Mr. Alfred Saxon.)

the low-pressure cylinder and the condenser. In the "Tartar" there was about 11 lbs. loss of pressure between the boiler and the valve-chest, Plate 7, and again about the same between the latter and the high-pressure cylinder; and it appeared to him that in this steamer the engines were crippled all through in regard to size of pipes, valves, and port openings. Where the pipes and ports were not quite large enough, the point of cut-off was not so easy to determine in an indicator diagram; and this consideration seemed to him to confirm Professor Beare's explanation (pages 73–4) in regard to the "Tartar" engines. In the "Colchester," where there was a considerable loss of pressure between the boiler and the high-pressure cylinder, the steam-chest pressure was not given; but from the indicator diagrams he thought it would be found that the cut-off in the high-pressure cylinder was not arranged at the best point for utilizing as much of the boiler pressure as possible. In his own experience at any rate he had found that, where slide-valves or piston-valves did not give an effective cut-off, the cylinder pressure did not approximate so closely to the boiler pressure as it did if the cut-off were effective. The conclusion the author arrived at on this point he believed was correct (page 61), namely that there was little use in carrying high boiler-pressures where such a great deal of loss, as much as nearly 13 per cent. in one instance, occurred between the boiler and the high-pressure cylinder.

Reverting once more to the comparison he had already made of the "Ville de Douvres" with the "Meteor," a two-cylinder compound engine with a triple-expansion—although it was hardly fair to compare them unless they had been working at the same boiler pressure—it would be seen that considerably more power could be developed from the triple-expansion engine than from the other, because the two engines were here practically doing the same effective work, as measured by the mean effective pressure in their low-pressure cylinders (Table 26), but with a smaller consumption of feed-water in the "Meteor" per indicated horse-power per hour (Table 29). This was one great advantage resulting from the use of the higher steam-pressure and of triple expansion, which together allowed of the development of the power with greater economy.

Mr. CHARLES COCHRANE, Past-President, referring to the loss of steam pressure in the "Iona" between the boiler and the high-pressure cylinder, considered that with the boiler pressure of 179·58 lbs. per square inch the loss of 5 lbs. between the boiler and the high-pressure steam-chest (page 61) clearly arose from the pipe being too small which conveyed the steam from the boiler to the steam-chest. Then there was a further loss of 17½ lbs. between the pressure in the valve-chest and the initial pressure in the cylinder, which must arise from the ports being too small or else from some movements of the valve-gear that were not perfectly correct. When it was suggested (page 61) that a boiler should not be constructed for such a high pressure as 180 lbs. if nearly 13 per cent. of this was to be lost between the boiler and the first cylinder, he would urge that, in view of the defects in steam pipes and ports and valve gear, it was absolutely necessary and most important to construct the boiler for 180 lbs. pressure, in order to get in the cylinder the initial pressure of 157 lbs. which was needed for developing the power required.

In regard to the relation of condensing water to condensed, the observations in page 69 of the paper appeared to him to contain much material for the future development of the whole subject, seeing that attention had also most properly been called in page 55 to the difficulty of measuring the large quantity of condensing water so as to compare it with that condensed. The best means he believed of ascertaining the quantity at the present time, where no direct measurement was as yet possible with a tank or meter, was to note the heating effect produced upon the condensing water, and to compare this with the measured temperature of the condensed water which was carefully weighed. By this means a pretty close approximation to the actual weight of condensing water employed would be arrived at. The only error he could see in such a calculation was that due to radiation from the condensing vessel. In the "Iona" and the "Ville de Douvres," which had been so ably compared by Mr. Head, there were certain points in connection with the relation of the condensing water to the condensed, which he thought ought to attract closer attention. In the "Iona" the vacuum obtained in the condenser was no less than 13·88 lbs. per square

(Mr. Charles Cochrane.)
inch (Table 26), whereas in the "Ville de Douvres" it was only 10·12 lbs. Why was this? The "Iona" had 9·47 square feet of condensing surface (page 69), over which passed 52·5 lbs. of condensing water per pound of steam condensed; whereas the "Ville de Douvres" had a diminished condensing surface of only 5·93 square feet, over which passed only 43·1 lbs. of condensing water per pound of steam. What then could be expected to be obtained in the latter case but such a low vacuum as 10·12 lbs.? The explanation given at the time of the trial he understood had been that everything was sacrificed to speed in the "Ville de Douvres"; but without presuming to criticise the design of her engines, he could not help thinking that the same speed might have been obtained with some greater economy by a modification in the arrangements of the condenser. With this view he was the more impressed on contrasting the temperatures of the circulating water in the two steamers, as measured at the inlet and outlet (page 69). From these it was seen that the "Ville de Douvres" had the further disadvantage of starting with the inlet water at 61·7°, while in the "Iona" it was only 55·8°, or something like 6° cooler. Moreover the rise of temperature in the "Iona," from 55·8° at the inlet, was only to 75·5° at the outlet; while in the "Ville de Douvres," commencing at the higher temperature of 61·7°, the water passed out at 85°, which was naturally a serious disadvantage to the economy of fuel.

In reference to the paper, he could not refrain from remarking what great praise was due to the author for the able way in which he had criticised the trials of these six vessels. Only a few years ago all that was depended upon in ocean traffic was the amount of coal consumption in any voyage; and there was no attempt to separate the duty of the boiler from that of the engine. This Institution had the credit for having originated and carried out the series of trials so ably superintended by their President, Professor Kennedy, which had led to the adoption of accurate methods for determining the duty both of engines and of boilers, in place of the rough and ready and inaccurate methods formerly followed.

Mr. DRUITT HALPIN was glad allusion had been made in the concluding paragraph of the paper to the simple and easy mode of measuring the feed-water in the "Ville de Douvres" by means of a meter. In the discussion upon some of the earlier trials (1889 page 296, and 1891 page 247), he had himself called attention to this mode of measurement, because he thought the substitution of a meter in place of cumbersome measuring tanks would help to popularise these trials amongst shipowners, seeing that trials could thereby be carried out with so little trouble. The late Mr. Sennett, a short time before he left the Admiralty in 1889, had put a meter to measure the feed in one of the large rams or cruisers, for enabling him to separate the duty of the boilers from that of the engines. Whether any experiments had been made with it he did not know; but as Mr. White appeared to think so highly of the present trials in regard to what the merchant navy had done, he hoped that perhaps the Royal Navy might now be looked to for some similar results. In a paper contributed to this Institution seven years ago from another branch of the public service, it had been shown that as much as from 34 to 39 lbs. of water per indicated horse-power per hour had passed through a stationary steam-engine experimented upon at Woolwich, when condensing, and from 40 to 51 lbs. when non-condensing (Proceedings 1887, page 494). Though he did not suppose anything of this kind was going on in the Navy, it would be interesting to know what really was the consumption of feed-water, now that it was shown it could be so readily measured by a meter.

The loss of steam pressure between the boiler and the first cylinder (Table 26), which had been already commented upon in the discussion as well as in the paper (page 61), was in his opinion a most serious matter, and he considered that not under any circumstances ought a boiler to be constructed to carry so high a pressure as 180 lbs., in order to get only 157 lbs. initial pressure in the cylinder. Some time ago in a compound engine working with a boiler pressure of somewhere about 160 lbs. this point had been accurately tested by stopping the engine on the dead centre, and then turning on the steam to enter through the lead of the valve and

(Mr. Druitt Halpin.)
fill the cylinder. The pressure in the cylinder was then marked by the indicator, and agreed correctly with that shown by the gauge on the boiler, which kept dead steady. There was therefore no question of the steam pipes in that particular instance; evidently they were amply large enough. But as soon as ever the engine was started, the result was that, although the boiler pressure remained steady at the same amount as before, there was at once a drop of 14 lbs. in the initial pressure in the cylinder. This was cured in a simple way and in a short time. The engine had an expansion-slide with variable stroke on the back of the main slide-valve; and the ports in the expansion-slide were of the ordinary form, that is, parallel through the whole thickness of the plate. The only alteration made consisted in cutting away the back edges of these ports with a chisel, so as to widen the ports out towards the back of the expansion-slide, roughly in the form of a "vena contracta," thereby facilitating the entrance of the steam through them. This had the immediate result of bringing up the initial pressure in the cylinder to the extent of some 11 lbs., that is, to within about 3 lbs. of the boiler pressure.

In Table 24, showing the heat lost by radiation from the boiler surfaces, the author had been good enough to give, in addition to the percentage lost, the rate of transmission also of the escaping heat in thermal units per square foot of surface per hour; and as in another column the difference of temperature between the steam and the air was given, all the required data were here furnished for comparing the rates of radiation, and the results were certainly most extraordinary. In the "Meteor" the thermal units escaping per square foot of heating surface per hour and per degree of difference in temperature were 10·1; in the "Colchester" 9·2; in the "Fusi Yama" 5·8; in the "Iona" 4·6; and in the "Ville de Douvres" 5·7. All of these, even the lowest, seemed extremely high results, because it might be taken generally that the transmission of heat either from steam-heated or from water-heated pipes into air was not more than about 2 thermal units per square foot per hour per degree of difference in temperature; and in some of the published experiments made by the President with his usual care it would be found that, taking 75 per cent. as the efficiency of the stationary boilers experimented upon, the radiation amounted to only about 75 thermal units, instead of the large losses given in Table 24, ranging from 1,430 up to as much as 3,120 thermal units. The small loss he had mentioned of only 2 thermal units per degree pertained of course to ordinary cases where there was no strong draught; but by the production of a strong draught either artificially or accidentally the radiation might be increased up to five or six times as much. Although in the stoke-holds of marine boilers there was usually a great draught, he did not see how there could possibly be any draught strong enough to account for such an abnormal radiation. Presuming that the figures given were correct, he could not understand how such large losses by radiation were brought about, even including all the uncovered surfaces of the smoke-boxes, funnels, and all other parts.

In referring to the condensing water, it had been remarked by Mr. Cochrane that from the known weight of the relatively small quantity of steam going through the engine, and from the measured temperature of the condensed water and the rise in temperature of the condensing water, the quantity of the condensing water could be calculated, the only loss to be allowed for being that from radiation (page 101). If this were all, then in the same way, taking 15,000 thermal units in one lb. of coal, it might be practicable at once to calculate the evaporation in a boiler; but he did not see how the evaporation could be obtained from this one factor alone, because it would vary with different kinds of boilers and under different circumstances of combustion, and could be arrived at only by direct experiment in each particular case. By a rough and ready rule, from 25 to 30 times the weight of water was required for condensing the steam passing through the engine; but if the rise of temperature in the condensing water and the heat given off by the condensed steam were the only factors that were reckoned, it would be found that much less condensing water was wanted. The fact was that in condensing with jet condensers there was not steam alone to be dealt with, but also large and unknown quantities of air; and with surface condensers, instead of only

(Mr. Druitt Halpin.)
radiation from the condenser there were also large losses in transmission to be dealt with, causing the whole apparatus to be less efficient. [See also page 138.]

Mr. JOSIAH McGREGOR said no one could appreciate the trials dealt with in the paper more highly than he did, having himself been connected with the design, construction, and working of marine engines for a lengthened period, during which there had been a great number of changes in the methods of procedure, due as much he believed to trial and error as to a better understanding of the principles involved. There were few engineers who had had anything to do with the subject who had not been brought frequently in contact with questions upon which the present paper shed a flood of light. Sometimes they had made experiments on their own account; but usually such experiments had been conducted under circumstances which prevented reliable data from being obtained.

In the trials here dealt with there were indeed some peculiar and interesting results in regard to the boilers. Gauging the performance of a boiler by the pounds of feed-water per square foot of heating surface per hour, he noticed in Table 18 (page 39) a variation from 9·02 lbs. in the "Ville de Douvres" to 2·73 lbs. in the "Iona." The significance of this variation was perhaps more apparent on considering that, if the boilers of the "Iona" had been worked as those of the "Ville de Douvres" were, then fewer boilers in the ratio of one for every three would have been sufficient: which was certainly curious. This great extravagance of boiler power in the "Iona" was accompanied by no corresponding advantage in the performance; for he noticed that the efficiency of the boilers in these two steamers, as represented by the percentage of heat taken up by the feed-water, varied only from 69·2 per cent. in the "Iona" to 66·1 per cent. in the "Ville de Douvres." These trials showed that the percentage of heat taken up by the feed-water varied from 62·0 to 69·2 per cent. And the transmission of heat by the boilers varied nearly as the heat supplied; this he had himself found to be the case in a number of trials he had made in the Bay of Bengal with the steamer "Satara" belonging to the British India Steam Navigation Co., at a rate of heat supply intermediate between that in the "Meteor" or "Colchester" and that in the "Iona," which were the two widest apart in the present series.

From the particulars given of these trials it was interesting to estimate the temperatures of the fires. He had thus found that the temperature in the "Meteor" was the highest, namely about 3,855° Fahr.; in the "Ville de Douvres" it was 3,241°; while in the "Iona" it was 2,465°. If the same method of estimating temperature was applied to the gases in the chimney, the results varied considerably from the temperatures actually found: which seemed to show that a considerable error existed somewhere. The air supply he suspected was chiefly accountable for the discrepancy. From Table 22 he inferred that the air was estimated from the chemical analysis of the gases in the chimney: he supposed from the quantity of oxygen found in the chimney. If all the oxygen found in the chimney was procured from the air, and it all went to oxidise the carbon and hydrogen, then of course the result would be correct; but he noticed that none of the hydrogen in the analysis of the fuel itself (Table 19) was accounted for in the chimney. That there must be some uncertainty about the air supplied was evident from the difference obtained with two precisely similar boilers in the same steamer: in the "Colchester" (page 50) the after funnel had 37 per cent. more air than the forward, with 10 per cent. less draught, the effect of which was only $1\frac{1}{4}$ per cent. greater consumption of fuel. Hence it was clear that considerable latitude must be given to the results recorded.

From Table 29 it was seen that the engines of the "Iona" consumed 13·35 lbs. of steam per indicated horse-power per hour, while those of the "Villé de Douvres" took as much as 20·77 lbs. of steam. A convenient way of estimating the size of an engine in relation to its power was to take the cylinder capacity per indicated horse-power per minute; and when this calculation was made from the figures given in the paper, it was found that the "Iona's" performance was obtained with a size of engine equal to 16·25 cubic feet of cylinder capacity per indicated horse-power per minute, while the "Ville de Douvres" had only 9·61 cubic feet: so that proportionately the engines of the "Iona" were nearly double the size of those of the "Ville de Douvres."

(Mr. Josiah McGregor.)

The defective vacuum in the "Ville de Douvres" he thought was to be accounted for most probably by some undetected leak; for the condenser appeared to have been supplied with a full quantity of water, and it extracted its full quantity of heat. From the data previously given (Proceedings 1892, page 163, line 80) he calculated that as much as 4·29 lbs. of circulating water was supplied per hundred thermal units, and in the "Iona" 5·07 lbs.; so that the difference was not so considerable as to account for the difference in vacuum. One cause which might account for a part, but only a part, of the deficient vacuum in the "Ville de Douvres" was the small air-pump capacity, amounting to only 0·80 cubic foot per pound of feed-water, whereas the "Iona" had 1·45 cubic foot. The great deficiency in vacuum in the "Ville de Douvres" must therefore be accounted for by some other cause than had hitherto been assigned for it.

Mr. BRYAN DONKIN believed that meters were now used in the French and German navies for measuring the feed-water.

It might be interesting to draw attention to the maximum and minimum results of the six trials reported, three of two-cylinder compound engines and three of triple-expansion. The pressures of steam varied from 70 to 180 lbs. absolute per square inch (Table 18). The boiler efficiencies varied but little, only from 62 to 69 per cent. The feed-water evaporated from and at 212° Fahr. varied per lb. of coal from $8\frac{1}{4}$ up to as high as $10\frac{5}{8}$ lbs.; and per square foot of heating surface from $3\frac{1}{4}$ to nearly 10 lbs. per hour (Table 21). The consumption of coal per square foot of grate per hour varied $2\frac{1}{2}$ times, namely from 12 to 31 lbs. The engine efficiency (Table 29) varied from only 11 per cent. up to 17 per cent.; the revolutions (Table 25) from 37 to 87 per minute; and the indicated horse-power (Table 27) from 370 to 3,000. The feed-water per indicated horse-power per hour, of course with different pressures of steam, varied as much as $1\frac{1}{2}$ times, namely from $21\frac{3}{4}$ lbs. in the "Colchester" to $13\frac{1}{3}$ lbs. in the "Iona." From the "Iona" trial, which seemed to have been the best of all, the following were some of the principal results. The consumption of coal per square foot of grate per hour was about $22\frac{1}{2}$ lbs., and per indicated horse-power per hour $1\frac{1}{2}$ lb. The feed-water evaporated from and at 212° Fahr. per square foot of heating surface per hour was $3\frac{1}{5}$ lbs., and per lb. of coal $10\frac{5}{8}$ lbs.; and the boiler efficiency 69 per cent. The funnel temperature was the lowest of any, namely 452°. The velocity of the gases through the tubes (Table 23) was also the lowest, namely 500 feet per minute. The revolutions were 61 per minute. The boiler pressure was the highest of any, being 180 lbs. absolute per square inch; and at the same time the condenser vacuum was the best, being only $\frac{3}{4}$ lb. absolute, or $13\frac{7}{8}$ lbs. below the atmosphere. The indicated horse-power was one of the lowest, 645; and the feed-water per indicated horse-power per hour was the lowest, $13\frac{1}{3}$ lbs. The engine efficiency was the highest, namely 17 per cent. These results seemed to be due to the great expansion used, namely 19 times (page 68), notwithstanding that the high-pressure cylinder alone was jacketed. An interesting addition to the paper would be the proportion of total jacketed surface to the total internal surface touched by the steam. If possible in any future trial of a good marine engine, it would be desirable to try the engines with all the jackets in use, and with none. Such an engine ought to have a jacket surface of at least from 60 to 70 per cent. of its total surface exposed to the steam; whereas engines were often called jacketed when they had no more than only 30 or 40 per cent. of their surfaces jacketed. The conclusion to be drawn from the whole of these careful and accurate trials seemed to him to be that, in order to obtain the best economy, there should be larger heating surface in the boilers, greater expansion, higher pressures of steam, and hotter cylinder walls or thoroughly jacketed cylinders, especially the cylinder covers.

Mr. CHARLES E. COWPER suggested that Capt. Sankey should be asked to give some explanation* of the method by which the ordinary indicator diagrams were transferred to the theta-phi chart so as to produce the theta-phi diagrams. The literature on this

* See footnote on page 83.

(Mr. Charles E. Cowper.)

subject he believed was at present limited to three papers:—the original paper read by Mr. Macfarlane Gray at the Paris Meeting of this Institution (Proceedings 1889, page 411), which treated the matter entirely from a theoretical point of view; a paper read by Mr. Willans to the Institution of Civil Engineers in 1888 (Proceedings vol. xciii page 133, and vol. xcvi page 240), in which he introduced the chart; and his further posthumous paper in last year (vol. cxiv page 8). The late Mr. Willans was a practical engineer and maker of steam engines, and believed thoroughly in the θ ϕ chart; and their present President had at the Paris Meeting expressed his admiration of it (Proceedings 1889, page 458). On the occasion of the discussion last year at the Institution of Civil Engineers (vol. cxiv page 87) he had himself worked out a numerical example from the usual test-book formula for work due in heat units, and had shown the agreement between the result so obtained and the area representing the same in the θ ϕ chart. Capt. Sankey had now made a great step in advance by adding the constant-volume curves to the original θ ϕ chart; and, with the assistance of these curves, drawing on the chart θ ϕ diagrams representing actual indicator diagrams. In the early days of the steam engine, indicator diagrams had no doubt looked to the majority of engineers almost as unintelligible as the new θ ϕ diagrams seemed at present; but every mechanical engineer conversant with steam engines now knew the meaning of every part of an indicator diagram, and appreciated the information which it afforded. Who could tell therefore what might not be done in the future with the θ ϕ chart and diagram?

The PRESIDENT was sure that the Members must all be as desirous as himself to hear something from Mr. Macfarlane Gray on the subject of his theta-phi diagram, of which the high practical value was now rendered so clearly apparent from the illustrations furnished by Capt. Sankey.

Mr. J. MACFARLANE GRAY regretted that he was not able to offer any remarks on this subject, steam-engine performance being one of the subjects about which the Board of Trade had made a rule that the individual opinion of any of their engineer officers must not be made public. His application that an exception might be made in this instance had today been refused.

Mr. JOHN PHILLIPS remembered that on the occasion of the first report of the Committee upon these Marine-Engine Trials it had been pointed out by the President (Proceedings 1889, page 253) that the object of the trials was not to form a basis on which to criticize the design or construction of the machinery, but to ascertain the results obtained from its working. The fact that these results were now grouped together in the present paper he therefore thought did not afford ground for any comparison between the different kinds of machinery, except in regard to what each had done. A comparison had been drawn (page 100) between the "Tartar" and the "Iona," and it had been stated that in the former the engines were crippled by the steam-pipes, ports, and valve-gear; and attention had been called to the fall of pressure between the boiler and the high-pressure slide-valve casing as being so much more than in the "Iona." This did not appear to him to be a correct inference to draw from Table 26; for if the boiler pressure and the initial pressure in the high-pressure cylinder were compared, it would be found that the fall in pressure in the "Tartar" was 22·20 lbs. and in the "Iona" 22·50 lbs., or practically the same in both. This difference of pressure however really showed in his opinion no defect of construction in either engine. In the "Iona" the true explanation he considered was that the engine was throttled and linked up to such an extent as was found best for the speed at which it was intended to run, and thereby the initial pressure was correspondingly reduced in the high-pressure cylinder. Referring to the question raised in the paper (page 61) as to the use of a boiler pressure so high as 180 lbs. absolute when the initial pressure in the high-pressure cylinder was not more than 157 lbs., it had been stated by Mr. Mudd on a former occasion (Proceedings 1891 page 278) that there was economy in this plan of working the steam; and in this view he coincided. Neither in the "Tartar" nor in the "Iona" were the engines working at full power; and therefore no proper

(Mr. John Phillips.)
comparison could be made between these vessels and the "Colchester," the "Ville de Douvres," and the "Meteor," because the weight of the machinery per indicated horse-power, as seen in Table 34, must necessarily be greater when an engine was working below its intended power than when the same engine was working up to its full power.

By way of attempting to diminish the difficulty of arriving at a conclusion as to the supposed priming in the "Tartar," he enquired whether the chimney of that steamer had a damper, and whether the temperatures of the funnel gases were taken on deck at about the same level as in the "Iona."

Mr. FREDERICK EDWARDS replied that there was a damper in the chimney of the "Tartar;" and the point at which the temperature of the gases was taken was above the damper, about at the level of the deck he believed, but he was not certain.

The PRESIDENT explained that the temperature of the gases was taken lower down in the "Tartar" than in the "Iona." For some practical reasons which he did not remember, it was necessary in the "Iona" to go higher up the funnel for measuring the temperature of the gases.

Mr. PHILLIPS doubted whether the heat supposed to be carried away in the funnel gases could be rightly regarded as the reason why so much of the heat was not utilized in evaporating the water. In his own experience as a sea-going engineer, he had never found smoke-box doors in a marine boiler which did not let more or less air leak in all round them; and of course the larger the door, the greater was the length of joint and attendant leakage. There were also other places in which air leakage could occur. If therefore the samples of the funnel gases were taken at any height above the tubes, where the entering air from all these leakages had had an opportunity of mixing with the gases escaping from the tubes, it seemed to him that no conclusion drawn from an analysis of the gases could correctly represent what had actually taken place in the combustion of the fuel. It was with great diffidence that he mentioned this point, implying as it did a possible error in regard to some of the conclusions in the Committee's report of one of the trials.

A suggestion was made in page 47 of the paper that the rolling of the "Tartar" during the trial had caused priming. Having however been at sea both in bad weather and in good weather, he had never found a boiler prime because the ship was rolling. Moreover the water in the boiler, especially with engines having surface condensers, contained comparatively but little air; and as far as he was aware water agitated without air in it did not foam in the same way it was supposed to do when it contained its normal quantity of air. This he thought was another reason why priming had not actually taken place. In the report of the "Tartar" trial (Proceedings 1890, page 232) it was stated that the steam-jacket of the high-pressure cylinder could not be used; but no satisfactory reason was given for this. This led him to think, from what had happened to himself and others in the use of steam-jacketed cylinders, that without any disparagement whatever of these engines there might have been a leak in the joint of the cylinder liner, and water or steam could consequently have leaked into or out of the cylinder and the jacket, the pressure in the jacket ranging from nothing up to 50 lbs. above the atmosphere; there must have been a loss of heat in some way, for when the jacket was not heating the cylinder steam it was cooling it. These various points required careful consideration before coming to the conclusion that priming had occurred. Any condensation that might take place between the boilers and the high-pressure slide-valve casing would appear as water in the cylinder, but it would not of necessity be priming water.

Mr. E. C. DE SEGUNDO, referring to the anomaly in the water consumption during the trial on board the "Tartar," was personally conscious of the fact that there was water in the intermediate cylinder, for he happened to be one of the members of the observing staff and was scalded several times. But he was hardly able to accept as satisfactory the explanation offered by Mr. Phillips, inasmuch as the conclusion could not be avoided that, if all the

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feed-water had been evaporated by the boiler, it would have meant an extraordinary evaporative power in the boiler per pound of fuel. The larger water consumption in the "Tartar" might be due to leakage of steam past the valve; and from the figures given by Professor Beare there was no doubt in his own mind that there had been such a leakage, and this might have been sufficient in amount to account for the higher consumption of water. The difficulty yet remained that in spite of this the coal consumption was so small. The latter might be explained in two ways: one was that the whole of the water passing through the measuring tanks might not have reached the boilers; the other was that, owing to the pitching and rolling of the steamer, some error might have occurred in reading the indications of the spring balance with which the coal was weighed; or possibly the Lascar firemen might occasionally have shovelled coal direct from the bunkers without its having been weighed. A comparison of the results of the "Meteor" and "Tartar" trials showed that, while the engines were similar in size and the boiler pressure about the same, the "Tartar" was working under load conditions extremely unfavourable to economy. The coal consumption per square foot of grate per hour was 11·93 lbs. in the "Tartar" as against 19·25 lbs. in the "Meteor" (Table 18). But in spite of this the coal burnt per indicated horse-power per hour was 1·77 lb. in the "Tartar" as compared with 2·01 lbs. in the "Meteor," while the apparent water consumption per indicated horse-power per hour (Table 29) was about 25 per cent. higher in the "Tartar" than in the "Meteor."

Mr. FREDERICK EDWARDS wished to thank the author for the great trouble he had taken, and the great amount of work he had done in preparing the present paper; and also to point out the great importance of the work that had been done by the Committee. If engineers would take these results to heart, and do their best to improve their engines, thousands of tons of coal would be saved.

With regard to the "Fusi Yama" trial, as he had mentioned once before (Proceedings 1890, page 257), the run during which it took place (page 35) was not an ordinary voyage, but was her first voyage under his supervision, and just after she had been overhauled. The pistons had been fitted with new spring rings, but the cylinders had not been newly bored out; the consequence was there was considerable leakage past the pistons. In this connection it might be of interest to mention how he tested the steam-tightness of the pistons in steamers under his charge. As soon as the steamer came in, the top covers of the cylinders were lifted, and the tops of the cylinders were filled with hot water; the bottom cover of the large cylinder was also removed, and the pistons being then moved slowly up and down in the cylinders, any leakage past them was seen running out below. This was collected and measured, and a record was thus obtained of how much the piston leaked in a given time. The plan was found to save a good deal of trouble, and had often proved that a piston leaked badly in particular positions, although its appearance and general condition gave the impression that it was in good order and steam-tight. The indicator diagrams did not afford the means of discriminating accurately between leakage at the valves and leakage at the pistons; and the best way of ascertaining the latter he considered was by means of water, according to the method just described.

With regard to the supposed priming in the "Tartar," he could not think that the boilers were priming as mentioned in the report. As he had said before (1890, page 259), these boilers had more steam space in proportion than any of the other boilers under his care. As a rule they were always worked with the main feed-pumps, with which, except during the trial, there had never been any trouble; and the trial had been started with the main feed-pumps pumping water into the boilers. When it was found however that the feed-pumps were not feeding as regularly as could be wished, recourse was had to the donkey, which was used as a stand-by for pumping water into the boilers. He had since asked the chief engineer whether it was possible for any of the water to have been going overboard; and he had understood from him that there might have been a slight leak in some of the donkey connections, and that possibly some of the water might have been going in the wrong direction.

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(Mr. Frederick Edwards.)

As to the consumption of coal in the "Tartar" (page 114), the firemen he thought would not have had any inclination at all to use unweighed coal out of the bunkers. As he believed the author had gone through the log sheets carefully, he would doubtless be able to state whether he had found any variation between the two stoke-holds in regard to rate of coal consumption, on comparing one stoke-hold with the other at the opposite end of the boilers: because of course the log sheets would not be likely to show the same rate of consumption in both equally, if unmeasured coal had been used in either or in both.

Professor BEARE said as far as he could make out from the log sheets and from plotting the consumption of coal there had not been much variation between the two stoke-holds. In the latter part of the trial there had been rather more coal burnt in the after stoke-hold; but it had been a gradual and uniform increase, and did not in the least suggest possible errors of measurement. The rates of coal consumption appeared to have been fairly uniform in all the boilers.

Mr. EDWARDS felt satisfied that the records of the coal consumption were correct.

As some of the faults brought to light by the aid of the theta-phi diagram had been pointed out by Capt. Sankey (page 89), it would be highly interesting if he would kindly show further how the engines were to be put right in those particulars.

The temperatures of the circulating water at the inlet and the outlet, which were mentioned in page 69 as having been taken only in the "Iona" and the "Ville de Douvres," were measured also in the "Tartar." They were 55° at the inlet and 89° at the outlet, showing a rise of 34°.

With regard to the back-pressure in the low-pressure cylinder, he had taken a great deal of trouble to get it lower in his steamers than even in the "Iona," and he was glad to say his endeavours had now been rewarded. Some engineers with whom he had discussed the question of back-pressure seemed not to appreciate the importance of a good vacuum, but rather to think it was better to work with a little less vacuum and have the feed-water hotter. Having gone carefully into this matter he had found that, taking a triple-expansion engine with 74-inch low-pressure piston and 54 inches stroke, and supposing the engine to be working at 55 revolutions per minute with about 3 inches of mercury or about $1\frac{1}{2}$ lb. per square inch more back-pressure than was necessary, this would be equivalent to a loss of about 96 horse-power. The practical question therefore was, what did it cost to save this 96 horse-power. The steam consumption was 14 lbs. per I.H.P. per hour, and each pound weight of steam took up 1,122 thermal units. Allowing 35° for the loss in temperature of the feed-water, the thermal units required per I.H.P. per hour for the 96 horse-power would be about 8,166: whereas the bulk of the power, or say 1,600 horse-power, cost 15,708 thermal units per I.H.P. per hour. In other words the extra power obtained by working with a 3-inch better vacuum in the condenser cost a little more than half what the original power cost per I.H.P. If however the difference between the back-pressure in the cylinder and the absolute pressure in the condenser were reduced to the same extent, it cost practically nothing to save the same amount of power, because the temperature of the feed-water was not reduced This difference he had frequently found to amount to 2 or 3 lbs. per square inch, apart from the absolute pressure in the condenser. In some cases indicator diagrams had been sent him showing as much as 7 lbs. back-pressure in the low-pressure cylinder, owing to the importance of reducing it not having been understood. According to his own experience the vacuum gauges in ordinary use were untrustworthy for accurate work; and he had found it necessary to put indicators upon the condensers in order to check the gauges. Nine months ago he had sent a ship away which had now just come back. She had been furnished with two vacuum gauges of the ordinary kind, the best he could get, which he had had specially tested beforehand; but during the whole of the voyage the chief engineer reported that they had differed by about one inch of mercury or $\frac{1}{2}$ lb. per square inch. It was of course highly important to be able to know what the vacuum really was, otherwise it could not be ascertained whether the back-pressure arose between

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the cylinder and the condenser, or whether it was absolute pressure in the condenser; and he was now fitting mercurial gauges on the condensers, so as to find out the absolute back-pressure that there was in them.

Professor DAVID S. CAPPER, referring to the suggestion just made by Mr. Edwards that some of the difference between the back-pressure in the low-pressure cylinder and the pressure in the condenser might be due to errors in the vacuum gauges, had no doubt this was the case, though an equally possible source of error might be incorrect indicator-readings. Having tested many indicators he had almost invariably found backlash present in the pencil levers. Errors due to this cause seemed to be more marked at high than at low pressures; but he had frequently found backlash sufficient to account for variations of at least one pound per square inch at atmospheric pressure. These indicators were tested under steam upon a mercury column specially designed for the purpose in the engineering laboratory at King's College. It was worthy of remark that the kind of indicator which he had hitherto found as free from this defect as any that he had tested was that used in the "Meteor" trial, where the variation between low-pressure cylinder and condenser was least.

One other point, to which attention had not been specially drawn, was shown with remarkable clearness by these trials: namely the influence of jacketing upon the dryness of steam, especially with reference to slow piston-speeds and high ratios of expansion. Of the three sets of triple-expansion engines mentioned in the paper, two had the intermediate and low-pressure cylinders jacketed, and one, the "Iona's," had neither jacketed. In the former the dryness fraction remained fairly constant, in the "Meteor" slightly dropping between the intermediate and low-pressure cylinders, and in the "Tartar" somewhat increasing in value. But in the "Iona" there was a marked drop in the percentage of steam present, namely from 75 per cent. before release in the intermediate cylinder down to only 59 per cent. before release in the low-pressure cylinder (Table 32). Comparing this result with the three two-cylinder compounds, all non-jacketed, there was the same large condensation shown in the low-pressure cylinder in two out of the three. In the third, namely the "Ville de Douvres," a marked difference was noticeable, for the drop between the end of the high-pressure stroke and the end of the low-pressure stroke was only from 79½ down to 72½ per cent. of steam present. The explanation of this variation would appear if comparison were made between the several piston-speeds (Table 25), areas of cooling surface per pound of entering steam per stroke (Table 33), and ratios of expansion (page 68). In the "Iona," with a piston speed of 397 feet per minute and a large area of cooling surface per pound of entering steam per stroke, namely 24·32 square feet up to cut-off in the high-pressure cylinder, there was a ratio of expansion of 19 times with steam pressure of 180 lbs. absolute. Whereas in the "Ville de Douvres" the higher piston-speed of 442 feet per minute was united with the lower cooling area of 9·42 square feet per pound of entering steam up to cut-off in the high-pressure cylinder, and the much lower expansion of only 5·7 times with 120 lbs. steam pressure. These trials therefore again emphasized the fact that the most important cylinder to jacket was the low-pressure cylinder, especially in triple compound engines with high ratios of expansion and slow piston-speeds. As would of course be expected, jackets were of less importance with high speeds and low ratios of expansion.

Mr. WILLIAM SCHÖNHEYDER, having had some experience both in the manufacture and in the use of water meters, had found no difficulty in getting accurate results with them; a number of his own were now in use for feeding boilers and for other purposes, both with hot and with cold water. Through the late Mr. Sennett, as already mentioned (page 103), a meter had some years ago been placed by the Admiralty on board the "Medusa"; and since then, after careful and prolonged tests, the Admiralty had adopted several of his own meters both for cold water and for hot, and he believed they had been used on board ship with entire success. But as to measuring the circulating water from the surface condensers, he did not see any possibility of doing so by means of a water meter; the

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volume was of course far too big to be measured by an ordinary meter. But it might be measured he thought by a method similar to that adopted on land for measuring large volumes, namely by a weir: not an open weir, but a closed weir, that is, a hole in the side of a tank specially provided. The water from the circulating pump after passing through the condenser would be discharged into the tank, which should be closed at the top; and care should be taken that air was admitted into the upper part, while the lower part should have a hole in a gauge-plate in the side of the tank. The pressure might be taken by some kind of continuous indicator placed alongside the hole. In this way accurate results might be obtained, although he was not sure that any great gain would result from the measurement. Space on board ship was so cramped that in many cases it might be difficult to adopt such a plan; but in some instances it might be adopted if found desirable.

Mr. W. G. WALKER thought it would be difficult to say which was the most efficient steamer in these six trials, because the total efficiency was made up of so many factors, all of which would have to be taken into consideration. There were the thermal efficiencies of the boilers and of the engines, the mechanical efficiency of the engines, and the efficiency of the screw propellers, besides many others. In thermal efficiency Table 29 certainly showed that the triple engines headed the list, the "Iona" having the high efficiency of 17·1 per cent.; but to take this one single efficiency or any other single factor as an indication of the ultimate efficiency of the vessel would be misleading. Another way was to compare the indicated horse-power per ton of machinery, as in Table 34, where it was seen that the "Iona" came out last with only 3·2 indicated horse-power per ton; this comparison was good so long as the piston speeds were equal, but when they varied it was useless. A better method he thought would be to compare the "indicated thrust" in lbs. per ton of machinery—using the term "indicated thrust," introduced by the late Mr. Froude (Institution of Naval Architects, 1876, vol. xvii, pages 168–9), to denote what would be the thrust of the propeller if the indicated horse-power were employed wholly in creating thrust: so that indicated thrust = indicated horse-power × 33,000 ÷ (pitch of screw propeller × revolutions per minute). Having calculated the indicated thrust by this formula for each of the six steamers tried, he had found that the "Fusi Yama" stood first, with an indicated thrust of 135 lbs. per ton of machinery; next came the "Ville de Douvres" 127 lbs., the "Iona" 119 lbs., the "Meteor" 102 lbs., the "Tartar" 98 lbs., and the "Colchester" with 94 lbs. thrust per ton of machinery. It was of interest to notice that in this mode of measurement the indicated thrust per ton of machinery became reduced with an increase in the number of cylinders. Last summer he had carried out some experiments with an engine of rather large size, having a single cylinder 56 inches diameter with 72 inches stroke, in the "Ravenswood," a paddle-wheel passenger steamer used on the Bristol Channel service. She was 220 feet in length, with a displacement of about 420 tons, and was fitted with two haystack boilers working at 60 lbs. pressure. Her speed was 17 knots, with 1,600 indicated horse-power. The thrust he had calculated to be 158 lbs. per ton of machinery, which was higher than any of those he had just given. It certainly seemed to show that, if the number of cylinders or the number of expansions were increased, the performance fell off; and that in considering the number of expansions it was also necessary to bear in mind what was lost by increased weight of machinery. The effect of back-pressure had been strongly brought under his notice in the "Ravenswood," where he had found that there was a difference in back-pressure of 5½ lbs. per square inch between the cylinder and the condenser. On tracing it by taking indicator diagrams at various points from the cylinder to the condenser, he had found that nearly the whole falling off occurred in the valves; the loss between the exhaust pipe and the condenser was very small compared with that between the cylinder and the exhaust pipe: there was a difference of about 4 lbs. between the back-pressure in the cylinder and the pressure in the exhaust pipe. In one or two other steamers with similar single-cylinder engines his experience had been the same, that the back-pressure always appeared to occur between the cylinder and the exhaust pipe. If the back-pressure was reduced, he agreed

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with Capt. Sankey (page 91) that it was not all gain, although on the whole there was a gain of power. From Table 28 and page 59 of the paper it looked as though a reduction of the back-pressure was regarded as all gain; but in the "Ravenswood" he had found clearly that it was not all gain, because the conditions in the cylinder were so completely altered. On reducing the back-pressure by $1\frac{1}{2}$ lb. per square inch, which he had done by increasing the ports, he had found that the steam pressure above the atmospheric line was slightly reduced, although there was a considerable gain in power: the horse-power was increased by about 150, with corresponding increase of speed.

Mr. LESLIE S. ROBINSON wished the Committee could yet extend their labours by conducting a series of progressive trials in regard to power, like those conducted in the navy with regard to speed. The engines dealt with in some of the six trials had been working pretty nearly up to the full power they were designed to work at. The engines in the navy seldom did so, and under ordinary circumstances would be running perhaps at a fifth to a tenth of their full power. It would be a great help to those who had to do with designing marine engines for economical working if the Committee could with the aid of the Admiralty conduct a series of experiments progressing from a speed of say ten knots up to the maximum speed when the engines were working at their full power. Another point, which had not yet been alluded to beyond the mention made of it in page 36, was the difference between the closed ash-pits in the "Iona" and the closed stoke-holds in the "Ville de Douvres." These two plans of using forced draught produced somewhat different results, as seen from Tables 18 and 21; but the boilers differed so greatly that it was impossible for any practical conclusions to be drawn: although certainly as the figures stood they were in favour of the closed ash-pits adopted in the "Iona."

Mr. MARK ROBINSON observed that on board ship the indicated horse-power only could be ascertained; it would be of advantage to marine engineers if attention could be fixed also upon consumption per effective horse-power, as it had to be in the trials of electric-light engines. While the "Iona," profiting by her 19 expansions (page 68), might fully deserve her high place, it was probable that the "Meteor," for instance, with her 10·6 expansions and her relatively small cylinder and piston-ring friction, would have held a better position if the steam used could have been measured per effective horse-power; and the remaining difference would be to some extent balanced by a fair allowance to the "Meteor" for her relatively lighter and cheaper engines. There were points to be borne in mind upon the other side, such as the lighter and cheaper boilers required, for an equal horse-power, to give steam to the more economical but heavier and costlier engines; and in seeking for a low consumption per indicated horse-power it might perhaps not be the case that any marine engineer had yet gone beyond the limit at which there was also a gain per effective horse-power. But in land engines he believed this had been done; and the subject was worthy of attention, for frictional loss in the engine was one of the factors that entered into the complex formula by which the marine-engine designer had to be guided, and unhappily too little was known about it. At the works of his firm at Thames Ditton they hoped soon to be able to test land engines upon the brake up to at least 700 horse-power. Might it be hoped that large marine engines of various types would some day be tested in the same way?

Professor BEARE desired to acknowledge the kind way in which Mr. White (page 75) had spoken about the paper; and to thank him for supporting the suggestion offered at the end of the paper that shipowners should have systematic tests made of the machinery in their steamers. He could not quite concur in the explanation given by Mr. Mudd (page 81) as to the large initial condensation in the high-pressure cylinder of the "Iona," which he had accounted for as probably due to the high-pressure valve-chest acting as a jacket to the intermediate receiver, whereby a good deal of steam was condensed in the valve-chest, producing some of the wetness observed in the cylinder. This explanation seemed to him not fully to cover the facts, because the steam-chest was drained, so that any steam

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condensed in it from its jacket action would mostly have been drained off, and would probably not pass in any considerable amount into the cylinder. Moreover if the steam-chest had not had the receiver on the outside of it, it would have had the atmosphere, and the temperature of the atmosphere was lower than that of the receiver; therefore it would have radiated heat into the atmosphere just as it did into the receiver, with consequent condensation. External radiation of course took place from every valve-chest.

As to the overlapping of the indicator diagrams from the high-pressure and intermediate cylinders when plotted on a time base, Mr. Mudd's explanation (pages 79–80) seemed to apply only to the particular case of the "Iona," and not to be a general explanation. In regard to the boiler radiation (page 82), he would point out that, although perhaps some of the 13 per cent. loss put down as unaccounted for could have been accounted for by taking the temperature of the gases at a lower level, say at the smoke-box, yet it would still have remained a loss due to radiation, being then due to radiation from surfaces between the smoke-box and the higher level at which the temperature was actually measured.

In connection with the most interesting remarks made by Capt. Sankey, and the heat diagrams he had given for three of the steamers, he hoped, if it was not asking too much, that he would also kindly prepare similar diagrams for the other three steamers. [See page 130.] The results so brought out in regard to the trial of the "Tartar" seemed to him to confirm what he had himself arrived at in his later investigations, though Capt. Sankey's calculation (page 89) of from 18 to 25 per cent. as the amount of priming seemed to go even beyond the amount apparently to be accounted for. It would be a satisfaction therefore if this percentage could be re-calculated, in order to make sure that the figures were right in showing so great an amount of priming. It had been suggested by Capt. Sankey (page 89) that, if the oscillations of the water in the boiler synchronised with the rolling of the ship, a violent disturbance might have been produced at the surface of the water in the "Tartar" boilers; and therefore the explanation in page 47 that the priming was probably promoted by the rolling of the ship seemed to be not so much out of the way (page 113).

The saving of the back-pressure between the condenser and the low-pressure cylinder had also been referred to by Capt. Sankey (page 91) as not being wholly economical. Any reduction of back-pressure meant of course increased range of temperature in the cylinder, and therefore probably greater initial condensation, reducing the apparent saving shown in Table 28. Whether this difference of pressure between the cylinder and the condenser was always a real fact, or whether it was partly or wholly due to gauge or indicator errors, as suggested by Mr. Edwards (page 117) and Professor Capper (page 118), he was not certain. The calculations made by Mr. Edwards (page 117) were highly interesting, as showing the benefit of a good vacuum with cooler feed-water in comparison with a bad vacuum and hotter feed-water. How the latter could be the more economical he failed to see, notwithstanding that there was of course an advantage in the feed-water going hotter into the boiler, not merely for economy's sake, but also for the better working of the boiler.

In the heat balance-sheet given in Table 18, the balance unaccounted for was put down as mainly due to radiation (page 95). It was this which gave the appearance of such a large amount of radiation per square foot of cooling surface of the boiler, as seen in Table 24, which was referred to by Mr. Halpin (page 104). In this particular however he did not in the least pretend that Table 24 was absolutely accurate. As some sort of check, the figures in Table 24 had been calculated on the supposition that the area of radiating surface was just that of the shell of a plain cylindrical boiler with the addition of its two ends. There was however a large amount of additional radiating surface besides, inasmuch as in every trial the funnel temperatures were taken at some height above the boilers, and in one or two of the trials at a pretty considerable height above; and from all this additional surface, having on one side of it the highly heated gases from the furnaces, the loss by radiation would be much greater than from the boiler shell itself. The estimate in Table 24 therefore, including no more than the boiler shell, was intended only as an approximation; and his idea in framing it was that the figures should be taken

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not as absolute but as comparative, as a test whether the heat balance-sheet in Table 18 might be regarded as fairly accurate in other respects, apart from the loss by radiation. In some experiments of his own on the radiation from the surface of a boiler well clothed with non-conducting composition, he had found the loss from the shell and ends only to be about 350 thermal units per square foot per hour; in the same boiler uncovered it was 750. These were losses in a closed boiler-room absolutely free from currents of air, with a steam pressure of about 100 lbs., and an air temperature of about 100° Fahr. in the case in which the boiler was uncovered, and 80° in the other.

The pressure in the valve-chest of the "Iona" he believed had not been taken with an indicator (page 99); it had been taken with gauges, and the gauges had been checked. No calculation had been made as to the velocity of the steam in the pipes in any of the trials. So long as it was certain that there would be a loss of steam pressure (page 101) between the boiler and the engine, as had been the case under the conditions of trial in the "Iona," a boiler carrying 180 lbs. absolute pressure was of course necessary, in order to obtain the required pressure in the engine. What he had meant to convey by the remark in page 61 of the paper was that it seemed to him feasible for engineers in some way or other to alter the design of their engines, either in the stop valves or in the steam pipes or in the valve-chests and cylinder ports, so that such a great loss of pressure might be saved. The same point had been referred to by Mr. Phillips in connection with the linking up of the engines when not working at their full power (page 111); but though he could not pretend to go behind what the maker of the engines found most suitable for their working, he failed to see how it could be economical to generate steam at a high pressure in the boiler, and then to use it in the cylinder at a considerably lower pressure. The only advantage he could concede was that mentioned in page 61: that the wire-drawing of the steam produced superheating, whereby initial condensation might to a certain extent be prevented. It was a point however which he thought deserved some consideration on the part of the designers of mairne engines; and he was glad that his views had been supported by Mr. Cochrane (page 101) and Mr. Halpin (page 103).

Attention had been called by Mr. McGregor (page 106) to the remarkable disparity between the "Iona" and the "Ville de Douvres" in many of their conditions, and yet their closely similar boiler efficiency. It must be remembered that the "Iona" was designed for long voyages, and the "Ville de Douvres" for only short voyages of a few hours; and he thought it was questionable whether, if the boilers of a steamer such as the "Ville de Douvres" were to be driven for weeks together at the rate at which they were actually driven in one of her short voyages, their economy would be anything like what it was during her short passages across the channel. In judging the performance of each steamer it was always necessary to bear in mind the particular service for which she was designed.

In the analyses of the funnel gases, referred to by Mr. McGregor (page 107), no corrections were necessary to allow for the oxygen used in the combustion of the hydrogen in the fuel, because the analyses, as given in Table 22, were for the dry funnel gases. But the weight of dry air per pound of fuel, both theoretical and actual, was also stated; and in this the oxygen required to burn the hydrogen was included. The analyses given of the gases did not profess to be analyses of the whole contents of the funnels, but only of the dry gases which passed away through them; there was no practical way in which the steam produced by the combustion of the hydrogen in the fuel could be collected along with the dry gases. Its weight however was easily calculated, and therefore the amount of oxygen used in its production. As to the great difference in the air supply to the aft and forward boilers in the "Colchester" and also again to some extent in the "Ville de Douvres," he could not offer any explanation. The fact was there, and he had no reason to doubt that it was recorded correctly.

It was most important he thought to have proved, as pointed out by Mr. Head (page 97), that forced draught gave as perfect a combustion of the fuel as natural draught with the same weight of air per pound of fuel.

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The proportion of jacketed surface to the total surface touched by the steam up to the point of cut-off (page 109) in the jacketed cylinders of the "Meteor" and the "Iona" had been ascertained from the makers of the engines, and was shown graphically in Plate 11.

With regard to the theta-phi diagram, in addition to the three papers mentioned by Mr. Cowper (page 110), a description of it would also be found in the second edition of Cotterill's "Steam Engine" (pages 223–30), together with an account of how it was obtained.

The possibility that the figures given for the funnel gas analyses might be vitiated by air leaking in had been suggested by Mr. Phillips (page 112). Where the point at which the chimney temperature had been measured, and at which the samples of the funnel gases had been collected, was high up in the funnel, some leakage of air must of course have crept in; therefore the analysis of funnel gas collected at some height above the boiler must always include a certain amount of air leakage. But he imagined that the quantity of air leaking in could not be large; and the leakage would tend in a measure to correct itself in the calculations, because it would reduce the temperature of the escaping gases. No serious error therefore he thought could have arisen from this cause.

To himself it was a peculiarly interesting coincidence that it should have fallen to his lot to present the first paper read to this Institution during the presidency of Professor Kennedy, when he remembered that their President had been his teacher and his chief, and that it was to him he owed whatever scientific knowledge he possessed. It was still more interesting to recall that this paper was merely a summary of the splendid series of elaborate trials carried out by the Research Committee of this Institution under the chairmanship of their present President; and Professor Kennedy had not merely directed and supervised the whole of the arrangements, but had himself been the very life and soul of the Committee. In expressing how great a debt of gratitude he himself owed to their President, he felt sure he was also expressing the feeling of the whole profession that they as engineers owed him a similar debt for these important trials, and for the amount of labour and energy he had bestowed upon them as Chairman of the Committee, and for the valuable reports which had been presented to the Institution.

The PRESIDENT, in thanking Professor Beare for what he had just said, could assure him that the feelings he had expressed were most cordially reciprocated by himself. The work of these marine-engine trials, with which he had throughout been connected, had been not only a work of great labour, but also certainly a work of love, on the part of all who had carried them out. While nominally he had himself been at the head of this research, he considered that actually he had been by no means the hardest worker therein; and he was glad to believe that the work done had turned out to be of great practical importance. When this subject was first broached by himself at Leeds (Proceedings 1886, pages 505–8), he well remembered hearing both in public and in private that it was impracticable to carry on any such trials of marine engines without interrupting the whole work of a steamer, and that in fact it was not possible to measure the feed-water at all; the whole notion indeed was regarded as merely academic. Many members of the Institution however did not agree with that view; and the result had been the carrying out of these trials, which he hoped might be the precursors of many others to be conducted in future by shipowners and engine-builders themselves. The Committee's view had been clearly expressed both by Mr. White (page 76) and by Mr. Phillips (page 111), that any comparison of the engines ought to be made entirely in what might be called a scientific sense, and not as a question between different makers, or as though in any case one engine could be pronounced better than another. The matter was far too complicated for any decision of that kind to be arrived at, and it was not desirable that it should be attempted. The Committee were greatly indebted to the shipowners and engineers who had so handsomely placed their ships and engines at their disposal. The thanks of the Institution had

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already been given to them, and the Members had had the pleasure on many occasions of seeing them present at their meetings, and hearing what they had to say about the trials.

It was now his pleasant duty to propose that a hearty vote of thanks be given to Professor Beare for preparing the paper which had been read and discussed. This resolution he was sure would be adopted by all the Members with great cordiality.

Capt. H. RIALL SANKEY, in continuation of his remarks at the meeting (pages 82–91), wrote that, in connection with the θ ϕ diagrams for the "Iona," Plate 16, exception had been taken by Mr. Mudd (page 92) to the conclusion arrived at by the writer (page 88) that there was a leaky valve admitting steam into the top of the intermediate cylinder. By means of the cyclogram diagrams Mr. Mudd had himself shown (page 80) that heat was added to the steam in the intermediate receiver; and the θ ϕ diagrams fully confirmed this by the admission line of the intermediate cylinder overlapping the exhaust line of the high-pressure, as well as by the considerable improvement in the dryness of the steam. The evidence however as to there being a leaky valve for the steam admission at the top of the intermediate cylinder was afforded by the shape of the θ ϕ expansion curve of this cylinder in Plate 16, and had nothing to do with the reheating of the steam in the receiver.

In compliance with Professor Beare's request (page 124), he had had the mean indicator diagrams of the "Colchester" and of the "Fusi Yama" transferred to the θ ϕ chart, as shown in Plates 18 and 19. Unfortunately the same could not be done for the "Meteor," because the jacket steam had not been separately measured, and it was therefore not possible to obtain the dryness fraction in each cylinder at some point in the expansion; thus the position of the initial point on the θ ϕ chart could not be plotted.

The θ ϕ diagrams for the "Colchester," Plate 18, were on the whole similar to those for the "Ville de Douvres," Plate 15. The difference lay in the expansion curves of the high-pressure cylinders: in the "Colchester" the closeness of this curve to the condensation-water heat-recovery line showed that a considerable quantity of heat had been added to the steam in this cylinder after cut-off; and as there was no jacket, a leak past the valve was a possible explanation. But in this instance another explanation might be given. From the indicator diagrams (1890, Plates 94 and 95) it would be observed that the pressure during admission, especially for the top end of each high-pressure cylinder, was considerably below the boiler pressure. This difference in pressure would impart kinetic energy to the steam on entering the cylinder; a portion of this energy would be re-converted into heat, and would tend to superheat the steam; and the rest would remain as kinetic energy in the form of eddies; and the energy in these eddies would, at any rate partly, reappear as heat during expansion, doing work on the piston. The dryness fraction at cut-off, namely at about 60 per cent. of the stroke, was seen to be practically the same in the high-pressure cylinders of the "Colchester" as in the "Ville de Douvres;" but the total range of temperature was somewhat greater in the latter. As read off the $\theta\ \phi$ diagrams by means of the temperature scale, the range in the "Ville de Douvres" was from 334° down to 248°, or 86 degrees; and for the "Colchester" from 310° down to 234°, or 76 degrees. The range of temperature to which the admission surface was exposed was seen to be less in the "Ville de Douvres," namely from 334° down to 324° or 10 degrees, as compared with 310° down to 264° or 46 degrees in the "Colchester." On these grounds therefore greater initial condensation was to be expected in the "Colchester"; but the higher speed of revolution in this steamer, namely 86·5 revs. per minute as against 36·8 in the "Ville de Douvres," was probably the principal cause of the condensation being about the same in both. The superheating already mentioned no doubt contributed also to this result. The loss in the high-pressure cylinder due to incomplete expansion was as noticeable in the "Colchester" as in the "Ville de Douvres"; a portion however of this loss was recovered in the low-pressure cylinders of both steamers, as was clearly shown in the $\theta\ \phi$ diagrams by the marked improvement in the dryness fraction at cut-off in the

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low-pressure cylinders of both engines: an improvement due to the kinetic energy imparted to the steam at release from the high-pressure cylinder, which formed eddies and reappeared partially as heat in the low-pressure cylinder.

The θ ϕ diagrams for the "Fusi Yama," Plate 19, were in marked contrast with those for the "Colchester" and the "Ville de Douvres." The dryness fraction at cut-off in the high-pressure cylinder was remarkably high, namely 89·5 per cent., and considerably higher than could have been expected even with the smaller range of temperature, namely from 298½° down to 235° or 63½ degrees, especially as this cylinder was not jacketed. The most striking point of difference however was the considerable falling off in the dryness of the steam in the low-pressure cylinder, instead of the improvement in the "Colchester" and the "Ville de Douvres." It would also be observed that there was a great difference of pressure between the exhaust of the high-pressure cylinder and the admission of the low-pressure. This, together with the reduction in the dryness fraction, suggested a leak from the valve-chest of the low-pressure cylinder into the exhaust; and an examination of the sectional plan (1890, Plate 105) showed that such a leak was quite possible.

In order to check the accuracy with which the indicator diagrams had been transferred to the θ ϕ chart, the heat units turned into work by each engine had been calculated from the θ ϕ diagrams as follows. The area of each θ ϕ diagram having been ascertained by the planimeter, the corresponding heat units could at once be obtained, the number of thermal units represented by one square inch of the chart being known; and these heat units were marked against each of the θ ϕ diagrams given in Plates 15 to 19. The volume-factor was also marked for each diagram. By multiplying these heat units by the corresponding volume-factor, the heat units accounted for per stroke in each cylinder were obtained, and were given in line 3 of the accompanying Table 36. A glance at lines 4 to 7 of the table would show how thence to obtain the heat units turned into work per minute by each engine; and line 8 gave for comparison the corresponding figure taken from Table 29 (page 60); it would be seen that the agreement was as close as could be expected.

TABLE 36.—*Heat turned into Work, as calculated from θ φ diagrams.*
See Plates 15 to 19.

Name of Steamer	"Tartar."			"Iona."			"Colchester."		"Fusi Yama."		"Ville de Douvres."	
Plate showing θ φ diagrams	Plate 17.			Plate 16.			Plate 18.		Plate 19.		Plate 15.	
Cylinder — High-pressure, Intermediate, or Low-p.	High	Inter	Low	High	Inter	Low	High	Low	High	Low	High	Low
1. Heat in θ φ diagrams, Th. U.	26·4	41·0	46·0	44·3	54·0	63·0	52·3	57·5	50·0	58·4	48·5	50·7
2. Volume-factor ratio	3·435	3·020	2·640	1·630	1·450	1·220	2·260	2·180	1·288	1·303	18·16	17·01
3. Heat per stroke Th. U.	90·68	123·82	121·44	72·21	78·30	76·86	118·19	125·35	64·40	76·09	881	862
4. Heat per revolution Th. U.	181·36	247·64	242·88	144·42	156·60	153·72	236·38	250·70	128·80	152·19	1762	1724
5. Heat per revolution, total for engine Th. U.	671·88			454·74			487·08		280·99		3486	
6. Revolutions per minute	70 revs.			61·1 revs.			86·0 87·1	86·55	55·59 revs.		36·82 revs.	
7. Heat per minute, total for engine Th. U.	47,032			27,765			Two engines 84,314		15,620		128,354	
8. Heat per minute, total for engine, as given in Table 29 Th. U.	46,490*			27,590			84,630		15,870		127,300	

* From Proceedings 1890, page 240, Table 6, line 56.

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He hoped he had succeeded in showing that, by this method of transferring the indicator diagrams of any engine to the $\theta\ \phi$ chart, valuable information as to the behaviour of the steam might be obtained. Moreover the various losses might be traced to the places of their occurrence, and their magnitude exhibited; then by reference to the design or construction of the engine the cause of these losses might be ascertained. Besides the few points to which he had called attention in relation to the expansion curves and the release, many other questions of interest arose in connection with the admission, exhaust, and compression lines. For the calculations required in transferring the indicator diagrams to the $\theta\ \phi$ chart he was indebted to his assistant, Mr. H. O. Beckh.

Mr. W. R. CUMMINS wrote that, in summarizing the results of the six trials carried out by the Institution, Professor Beare had separated the efficiency of the boilers from that of the engines. Since the amount of priming was measured in only the one instance of the "Ville de Douvres," and this measurement was made by means of the salt test, about the accuracy of which doubts have been raised, the absolute accuracy of the boiler efficiency cannot be relied upon. The possible error in the efficiency is measured by the possible amount of priming; and as this may amount to as much as 20 per cent. of the total feed, and may not be suspected at the trial, the heat balance-sheet should be taken with a certain amount of reserve. For instance, the amount debited to radiation is dependent for its accuracy upon the assumption that the whole of the feed-water was turned into steam. By separating the efficiency of the boilers and engines, and neglecting possible priming, the boiler efficiency may be exalted at the expense of the engine efficiency. One of the most significant results obtained from these trials is contained in Table 18 in the line showing the carbon-value of the fuel per indicated horse-power per hour: though this does not separate the efficiency of the boilers from that of the engines. On re-arranging these carbon-values in connection with the boiler pressure and the ratio of expansion, as in the accompanying Table 37, it is seen at a glance how the efficiency runs up with increased pressure and

TABLE 37.—*Boiler Pressure, Expansion, and Carbon-value of fuel.*

Steamer.	Boiler Pressure absolute.	Expansion. Number of times.	Carbon-value per I.H.P. per hour.
	Lbs. per sq. inch.		Lbs.
Iona . .	179·58	19·0	1·49
Meteor . .	160·10	10·6	1·76
Tartar . .	158·20	15·7	1·82
Ville de Douvres	120·64	5·7	2·30
Fusi Yama .	71·64	6·1	2·33
Colchester .	95·50	6·1	2·65

expansion. Even the "Tartar" with so much water in the cylinders is 30 per cent. more economical than the "Colchester."

With regard to the increase in weight of steam after cut-off in the high-pressure cylinder of the "Tartar," suspicion naturally falls first upon the piston-valve. The piston itself is also mentioned by the author (page 47) as possibly leaking too; but obviously, if the piston were leaking, the weight of steam should become less, inasmuch as during expansion the other side of the piston is open to the exhaust. If the piston-valve on the high-pressure cylinder was fitted with a solid ring, it would be quite capable of passing steam after slight wear.

If leakage is out of the question, the only reasonable alternative is re-evaporation, for which the heat required could come only from the cylinder walls: that is to say, it would be heat that had been stored in the walls by initial condensation. It may further be readily supposed that wet steam would absorb heat from metallic surfaces more quickly than dry steam. Under ordinary conditions the re-evaporation of the initially condensed steam would not be finished until compression began in the return stroke; but with wetter steam the greater part of the re-evaporation might possibly take place during the period of expansion. There is no difficulty about time, inasmuch as the whole of the condensation

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takes place during the period of admission, which in the case of the "Tartar" is about the same as the period of expansion. The great amount of water noted in the intermediate cylinder of the "Tartar" the author thinks (pages 47–9) can be explained by initial condensation in the high-pressure cylinder, apart altogether from priming; the film of water deposited on the high-pressure cylinder surfaces, and not entirely re-evaporated owing to the jacket not being in use, he says would eventually be carried into the intermediate cylinder. This seems to the writer to be highly improbable. For condensation and re-evaporation must exactly balance each other, provided the engines are working under steady conditions; the whole of the steam condensed during admission must be re-evaporated before compression begins; and this action is quite independent of the steam-jacket. If at the end of each stroke some of the initially condensed steam were to remain not re-evaporated, then the cylinder walls would be accumulating heat in each successive stroke. Hence it follows that the only water which can be delivered from the high-pressure cylinder to the intermediate is that due to priming, and to the liquefaction consequent upon the performance of the work done, and to any condensation resulting from radiation. The most rational explanation therefore of the "Tartar" results appears to the writer to be that, owing to excessive priming and consequent wetness of steam, nearly the whole re-evaporation of the initially condensed steam took place during the expansion; and also that the priming water, as well as that due to liquefaction by work, was transferred into the intermediate cylinder.

When treating of the effects of steam-jackets and re-evaporation (pages 63–5), the author gives weights of steam as present in the cylinder at certain points in the stroke. The weight given however is not the actual weight present in the cylinder alone at the point named, but is the weight of steam passing through the cylinder as measured from the indicator diagram; that is to say, it is the actual weight of steam present in the cylinder at the point named, including clearance as in Table 31, but minus the weight of steam present in the cylinder and clearance when the pressure in the return stroke has risen by compression to the same pressure as that at the point named in the steam stroke. The expression "present in the cylinder" is apt to be misleading without this explanation. When this method of estimating the weight of steam in the cylinder is applied to testing the amount of re-evaporation during expansion, a correct result can be obtained only when the weight of steam shut in by compression does not vary during the period of compression. The only reliable method of arriving at the re-evaporation during expansion is to calculate the actual weight of steam present just after cut-off, and to compare it with the actual weight present just before release. No doubt this method would considerably modify the author's figures, if it has not been followed in Table 31. If it has, then for the "Tartar" it will be necessary to fall back upon the explanation already attempted. In Table 32 it is evident that all the percentages there given represent steam passing through the cylinder as calculated from the indicator diagrams; and this must be duly allowed for before drawing any conclusions as to the actual amount of cylinder condensation and the relative weight of steam in each cylinder.

To arrive at the actual weight of steam condensed initially in a cylinder is no easy matter; and if no tests for priming have been made, accuracy is out of the question. Starting at the point of compression beginning, there is a known weight of steam shut in, which remains in the cylinder until release. With this steam will in most cases be mixed a certain amount of water; and the only way to test the amount is to apply a calorimeter to the exhaust. Failing this, it must be estimated from the priming water and the water of liquefaction. The weight of the mixture of steam and water must be added to the weight of feed-water per stroke, after subtracting from the latter the weight supplied to steam-jackets if any; the net sum is then the total weight of mixture present in the cylinder after cut-off. The actual weight of steam present in the mixture just after cut-off can be calculated from the indicator diagram; the water constituting the balance must either have been condensed in the cylinder initially or supplied to the cylinder as water. The quantity supplied to the cylinder as water is tested by the calorimeter; and the remainder must therefore have been condensed initially on the clearance and cylinder surfaces. This last quantity is the total

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weight condensed; that is, it results from the condensation of the clearance steam as well as of the new steam supplied in each stroke. The amount of clearance steam condensed can be calculated from the indicator diagram by comparing the weights at the beginning and the end of compression. It will then be known what proportion of the new steam supplied to the cylinder has been condensed; and this appears to be what should be called "initial condensation." With this definition the figures given in Table 32 do not correspond. Furthermore, when comparing weights of steam in two different cylinders—for example (Table 32) in the "Iona" 65·5 per cent. of total feed in the high-pressure cylinder before release and 74·9 per cent. in the intermediate cylinder before release—it might be imagined from these figures that there was 14 per cent. more steam in the intermediate cylinder than there ought to be; whereas the seeming difference is due solely to the method of estimating the weights, and to the fact that there was more compression in the high-pressure cylinder than in the intermediate.

Mr. Druitt Halpin wrote that in the discussion of M. Marié's paper on the consumption of fuel in locomotives (Proceedings 1884, page 111) he had suggested a "figure of merit," by which the total efficiency of boilers might be measured:—namely the product of the weight of water evaporated per hour per square foot of heating surface, which measured the rapidity of evaporation, multiplied by the weight of water evaporated per pound of fuel, from and at 212° Fahr. in both cases. If however, instead of being multiplied by the evaporation per pound of fuel, which did not take into account the calorific value of the fuel, the weight of water evaporated per hour per square foot of heating surface was multiplied by the percentage of heat in the fuel taken up by the feed-water, the following results were obtained from Table 18 (page 39):—

	Meteor.	Colchester.	Fusi Yama.	Iona.	Ville de Douvres.
Evaporation per hour per square foot of heating surface	4·49	7·39	3·48	2·73	9·02
Percentage of heat in fuel taken up by feed-water	62·0	62·0	67·2	69·2	66·1
Total efficiency of boilers	278	458	234	189	596

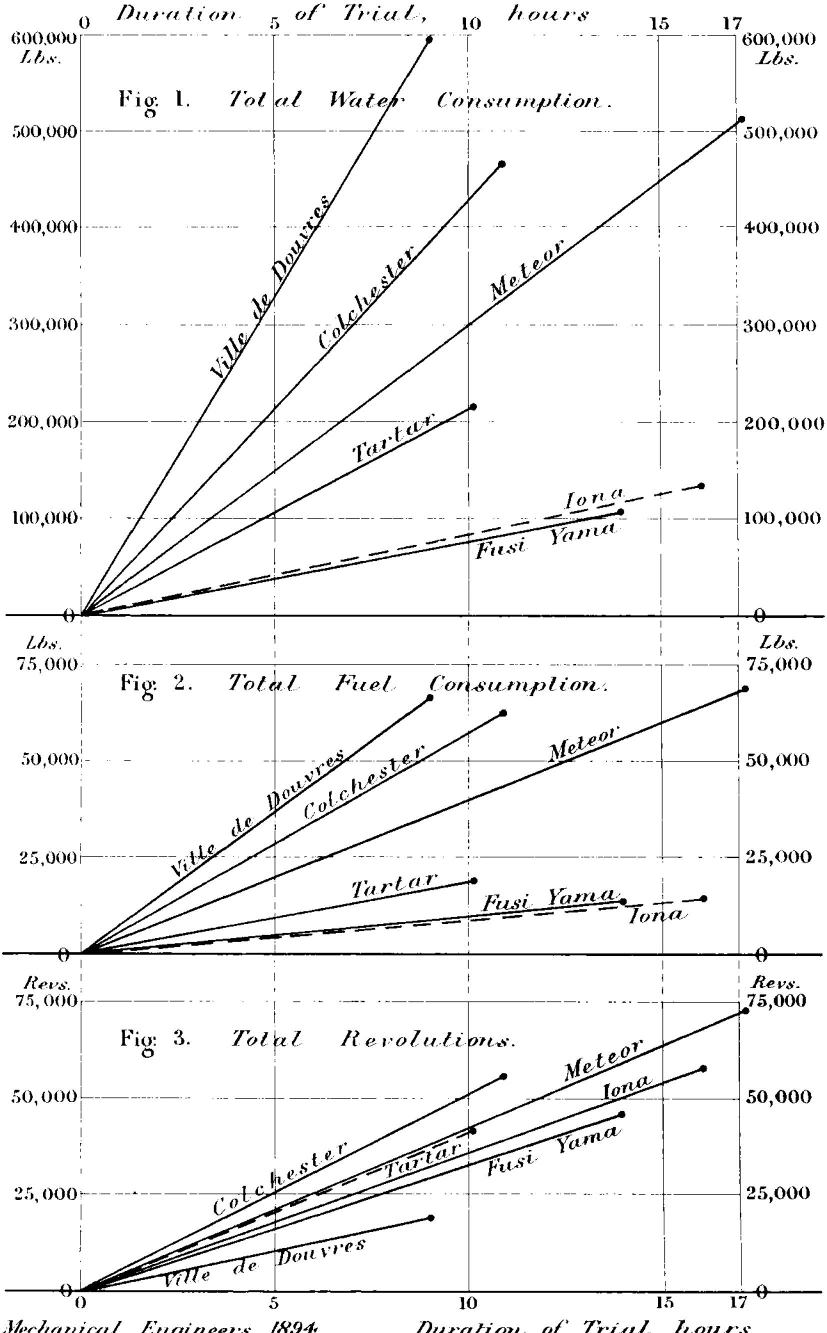
Professor BEARE wrote that he desired again to thank Capt. Sankey for the great amount of time and trouble he had taken in preparing the $\theta\,\phi$ diagrams, and for the valuable and interesting explanation he had given of their construction from the indicator diagrams, and of their use in discovering defects in the working of engines. For instance the $\theta\,\phi$ diagrams of the "Iona" were interesting, as showing that the increased dryness-fraction in the intermediate cylinder, referred to in page 63, was in all probability due to a leaky valve.

The remark as to leakage past the piston in the "Tartar" (page 47) was a slip, to which attention had been drawn by Mr. Cummins (page 135). In regard to initial condensation, radiation seemed to have been forgotten in the remark (page 136) that all the steam condensed in the cylinder must be re-evaporated before the end of the release, or else the cylinder walls would accumulate heat: although reference was made a little later to radiation producing condensation. It was well known that in unjacketed cylinders a large proportion of the heat given up to the walls during initial condensation was radiated away by the walls, and that therefore initial condensation and re-evaporation by no means balanced each other; the same action occurred even in jacketed cylinders, because the jacketing was never perfect. The assumption therefore that only priming water, and steam liquefied by doing work, passed into the intermediate cylinder, could hardly be considered as accurate. In the calculations given in Table 31, as stated in page 64, the figures were the actual weights of steam in the cylinder and clearance, without any deduction for weight of steam shut up in compression; the criticism in pages 136–7 seemed therefore hardly to apply. Table 32 had been compiled from the several reports, and was the usual way in which such figures were given.

MARINE-ENGINE TRIALS.

Plate 1.

Total Water, Fuel, and Revolutions.



Mechanical Engineers 1894.

MARINE-ENGINE TRIALS. *Plate 2.*

Fig. 4. *Heat Balance-sheet. See Table 18.*

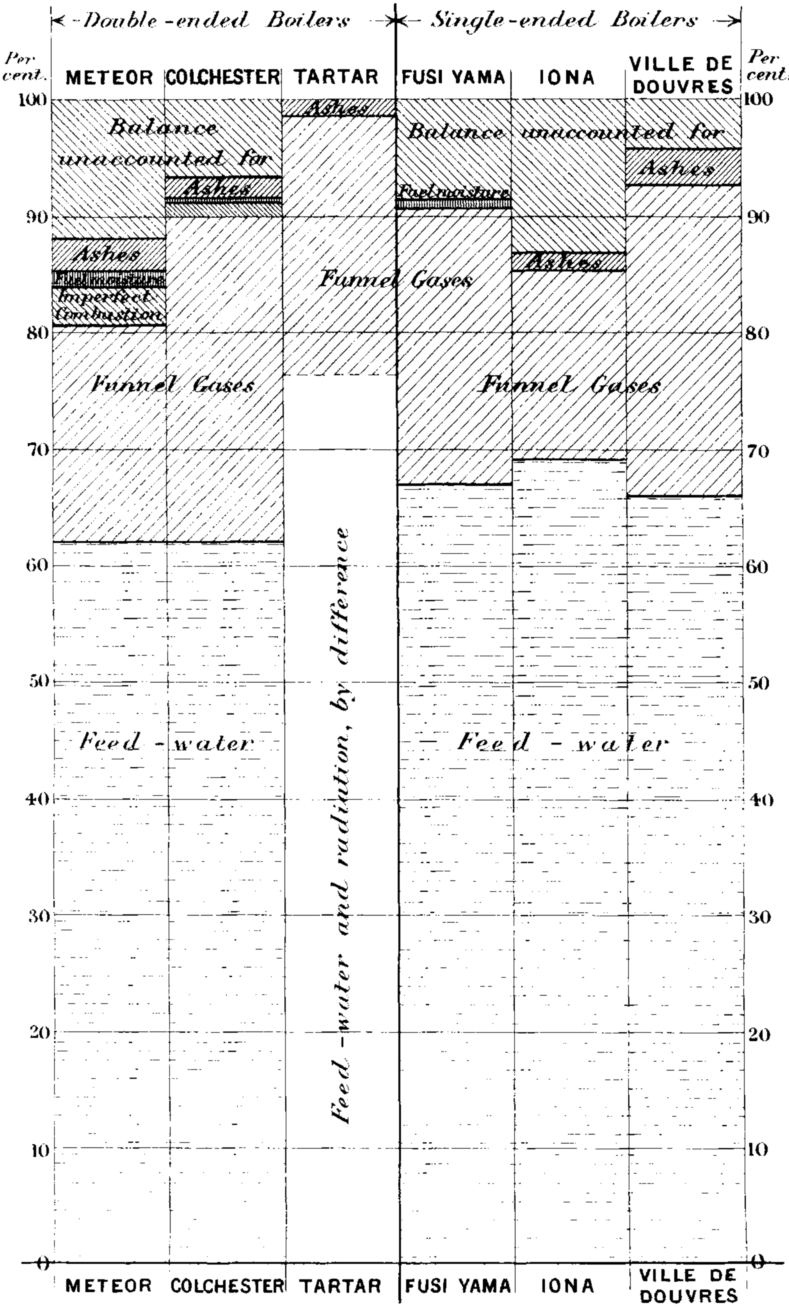
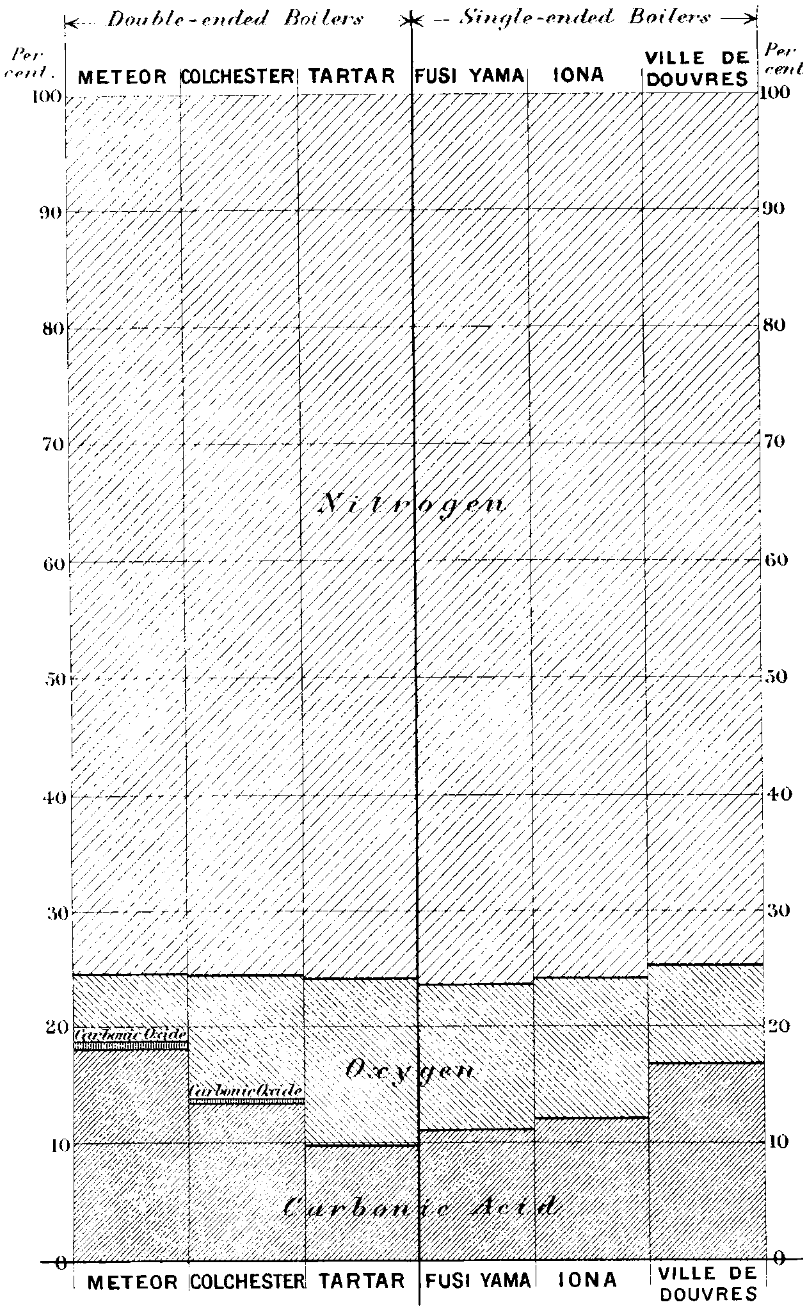
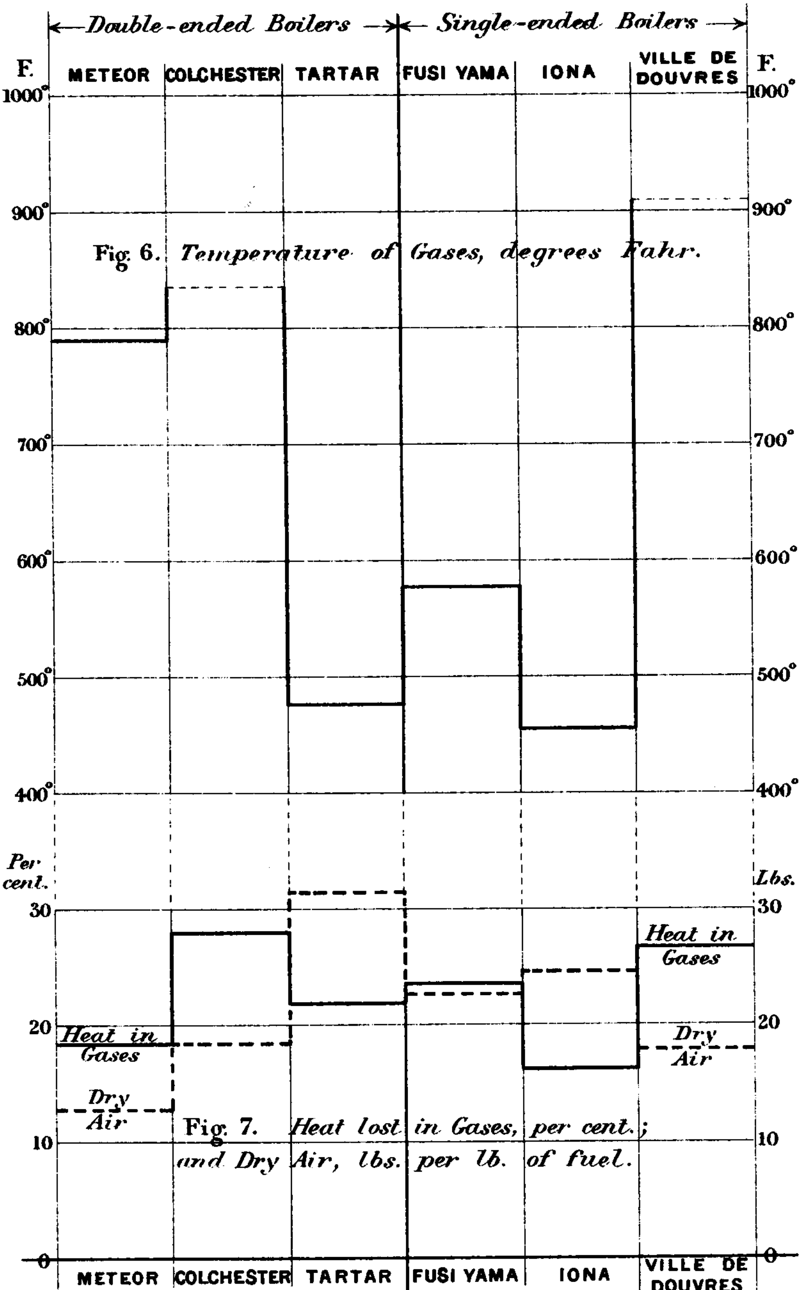


Fig. 5. *Analyses of Funnel Gases. See Table 22.*

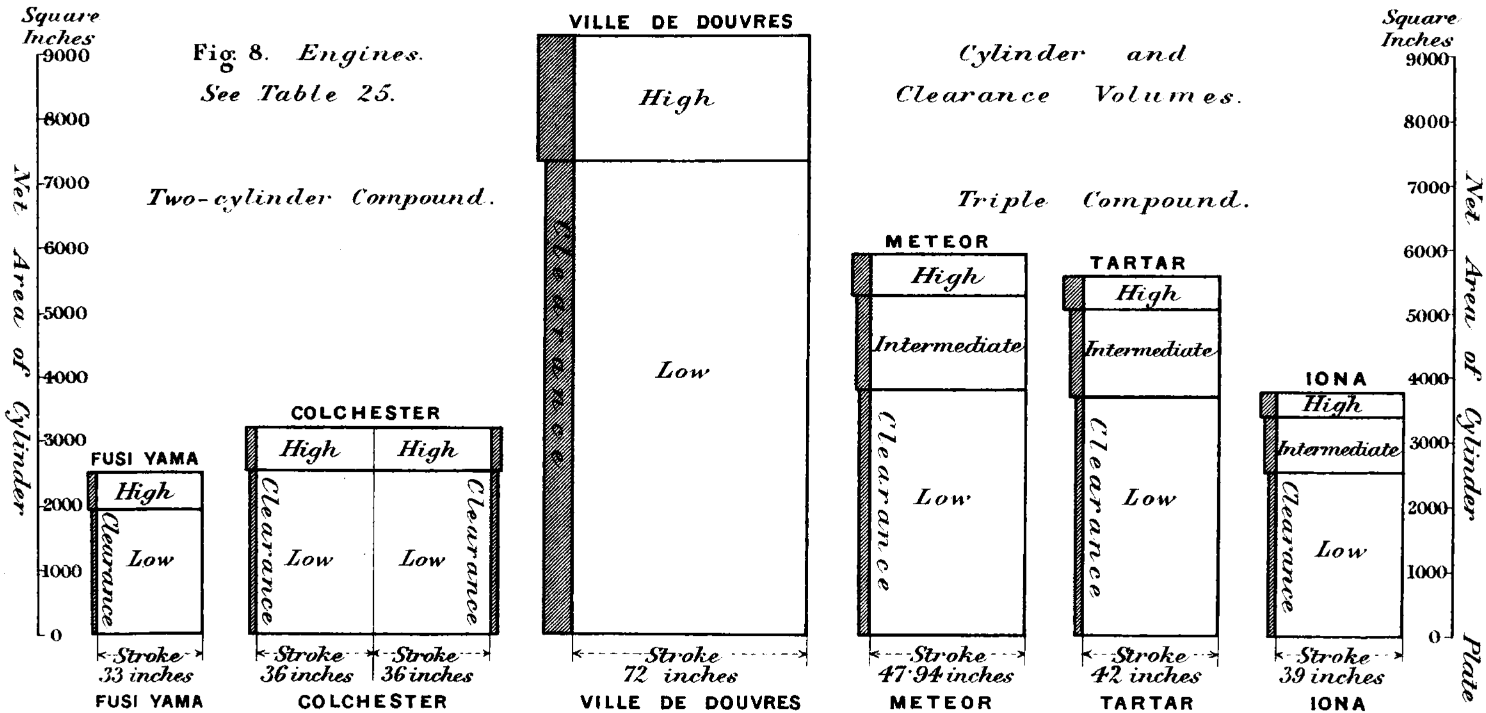


Temperature and Heat of Funnel Gases. See Table 22.



MARINE-ENGINE TRIALS.

Plate 5.



Mechanical Engineers 1894.

Fig. 9. *Steam Pressures. See Table 26.*

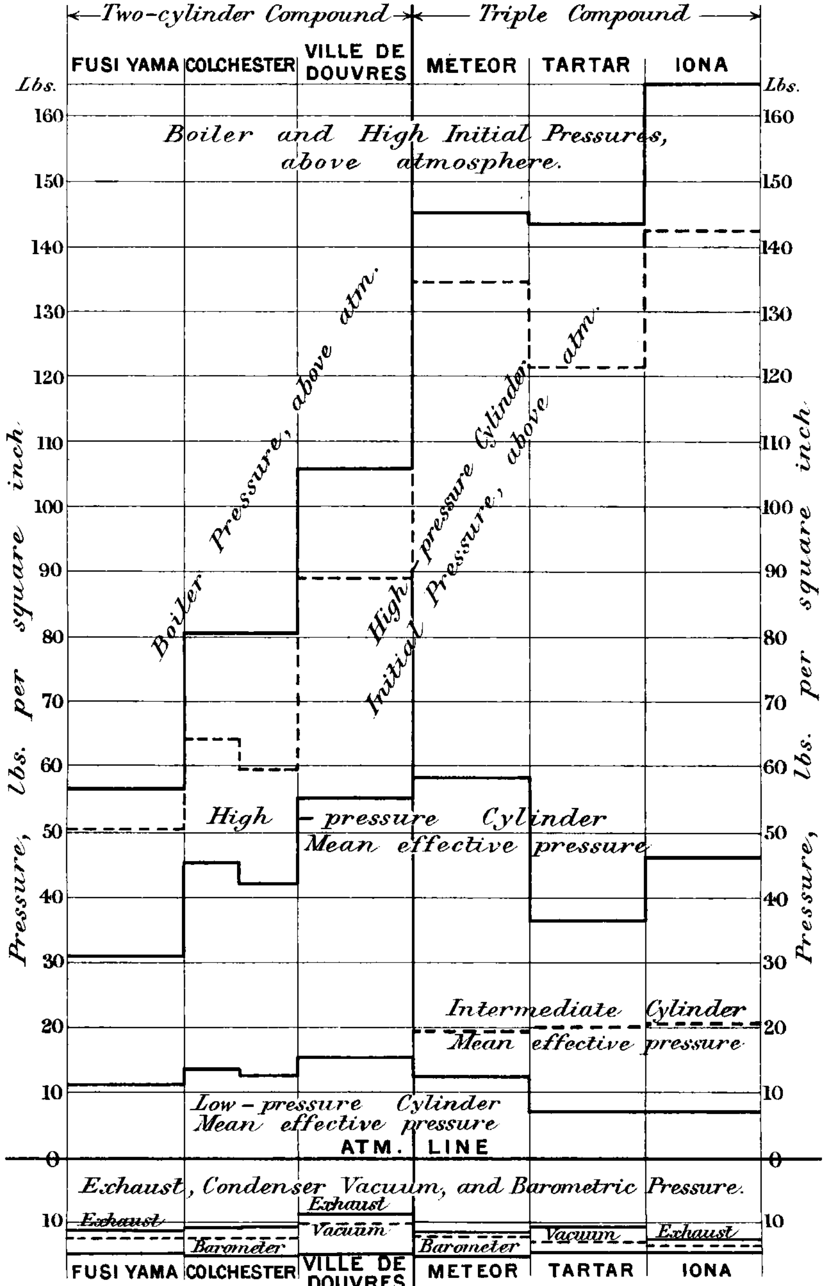


Fig. 10. *Indicator Diagrams. See Tables 26 and 30.*

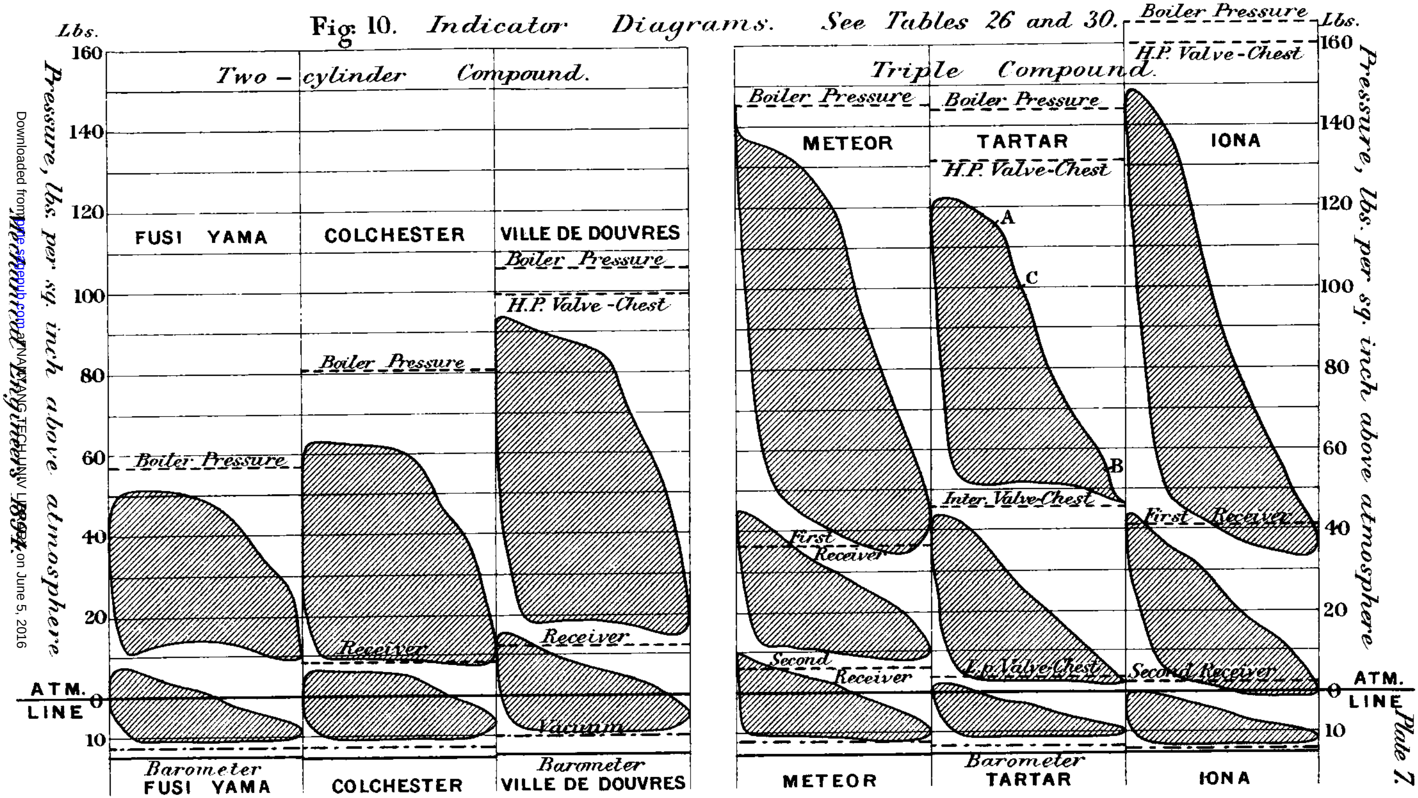
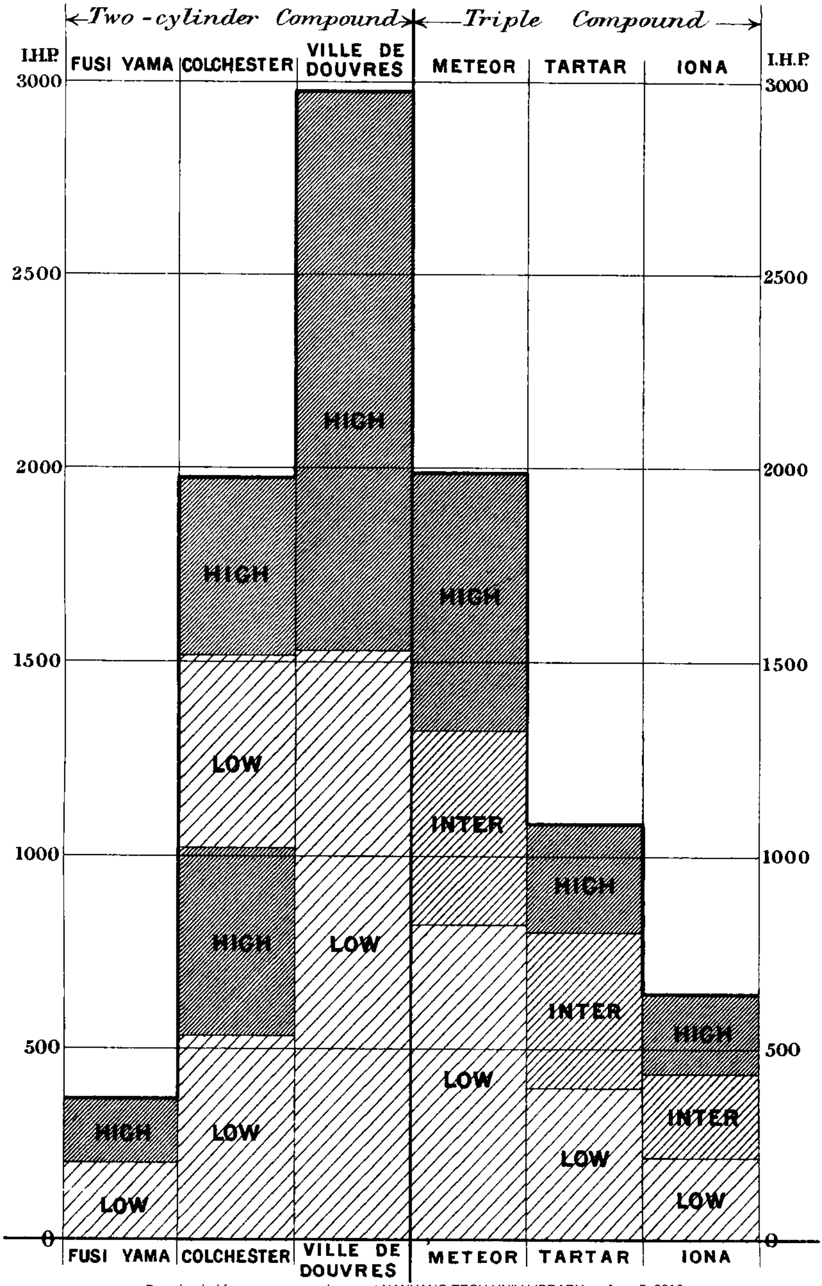


Plate 7.

Fig. 11. *Indicated Horse-power. See Table 27.*



MARINE-ENGINE TRIALS. *Plate 9.*

Fig. 12. *Feed-Water, Engine Efficiency, and Carbon-value.*
See Tables 29 and 18.

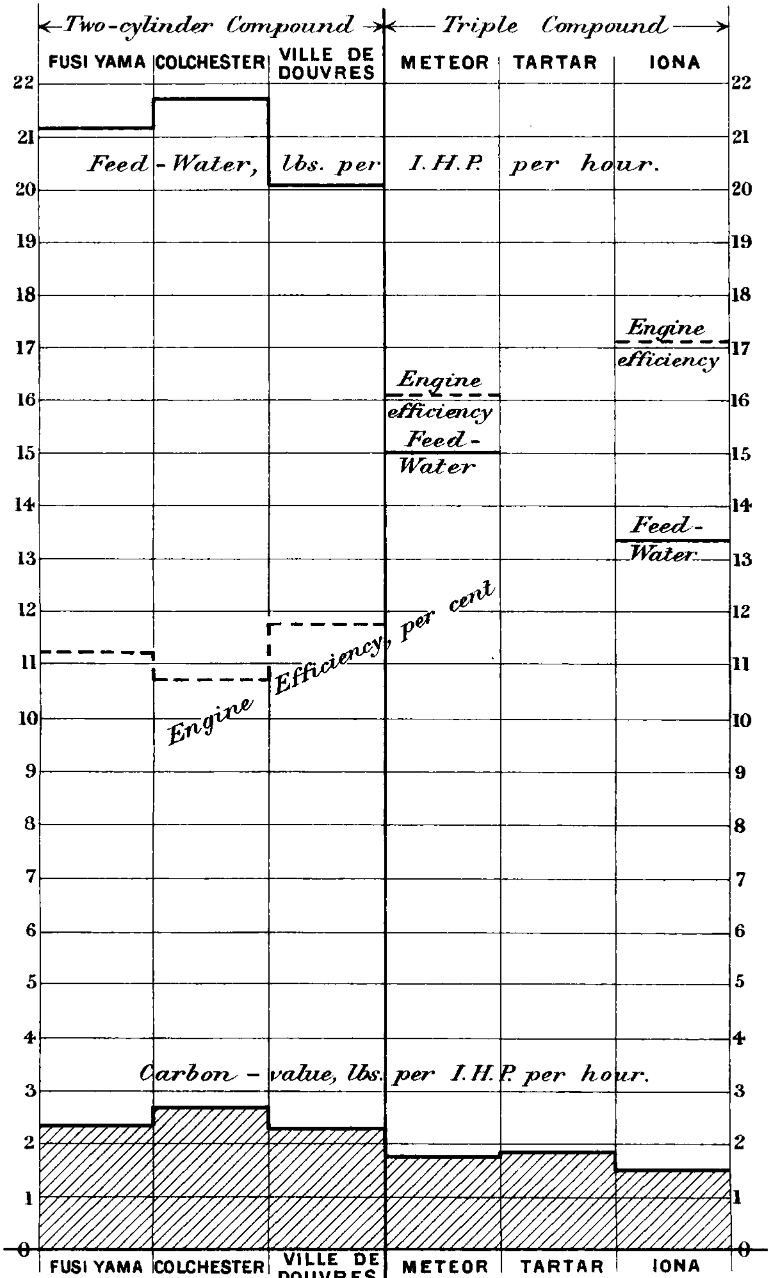


Fig. 13. *Percentage of total feed present as Steam in Cylinders at different points in stroke. See Table 32.*

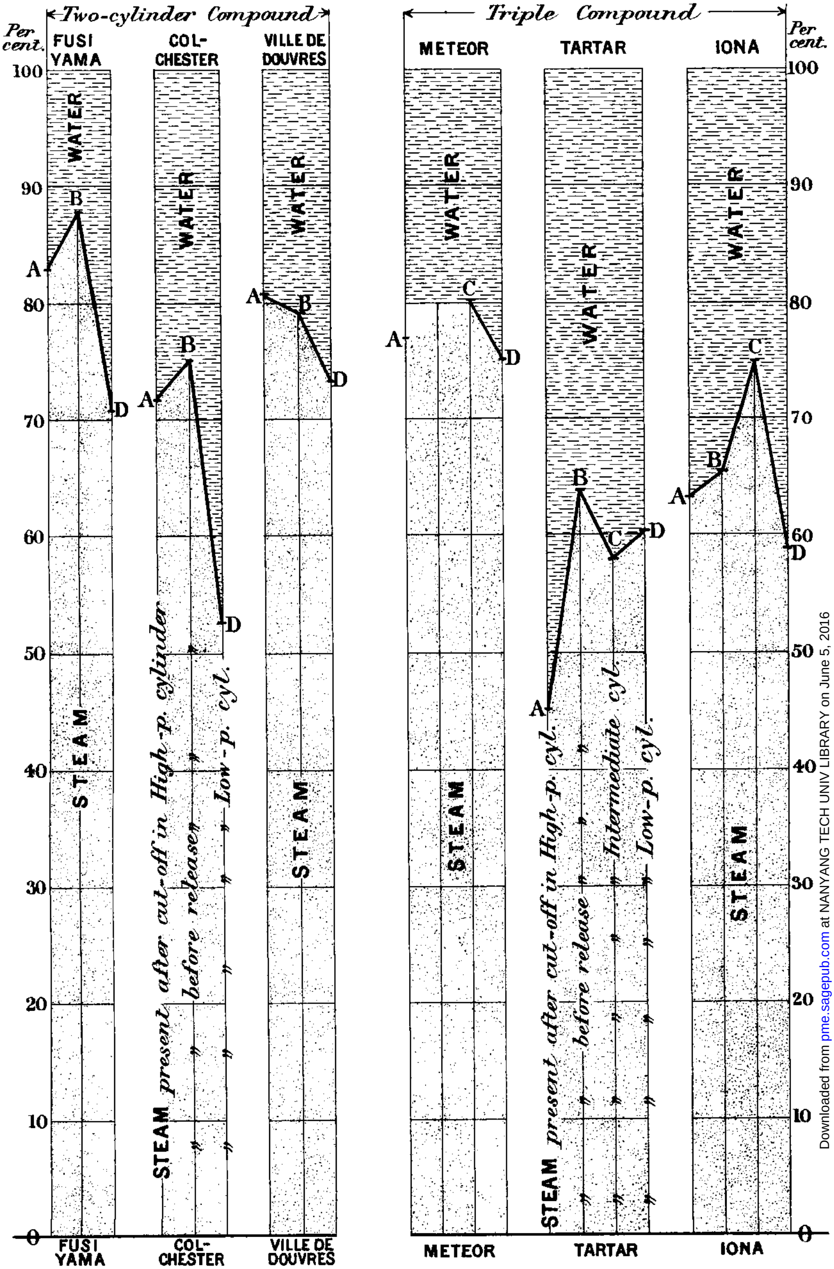


Fig. 14. *Clearance plus cylinder surfaces exposed to steam at point of Cut-off. See Table 33.*

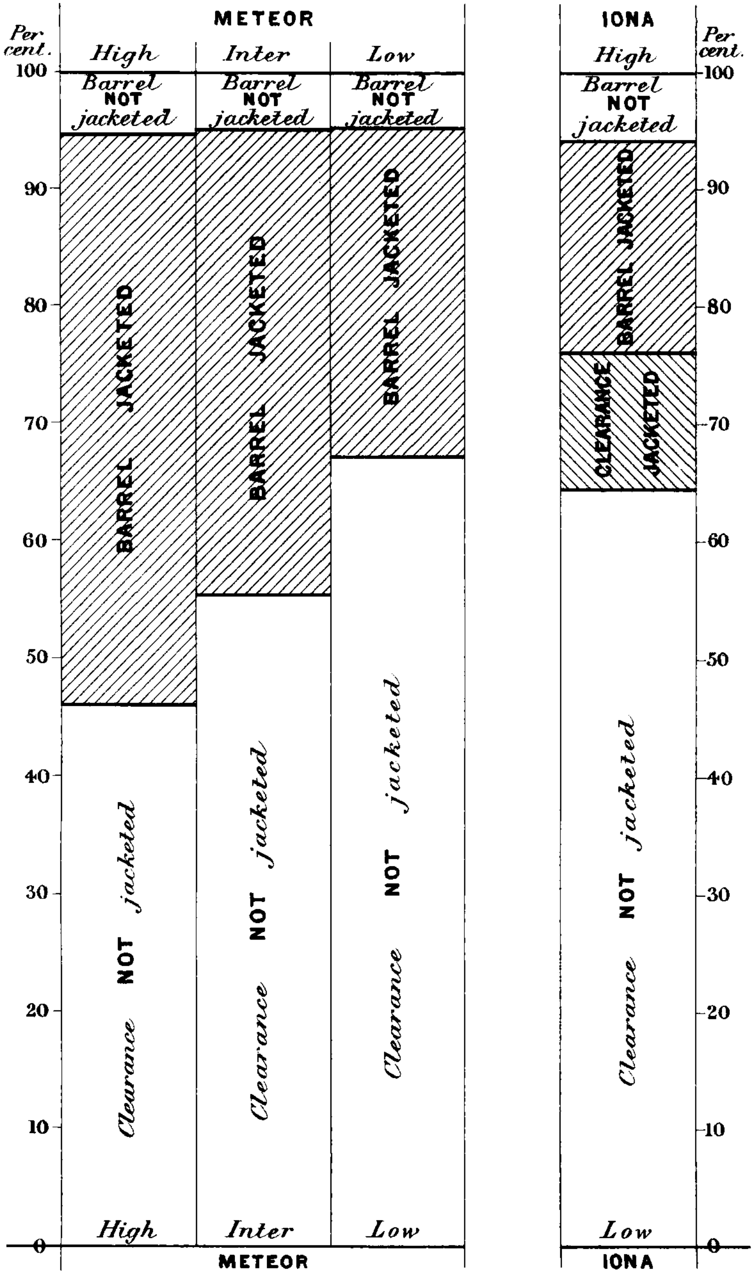
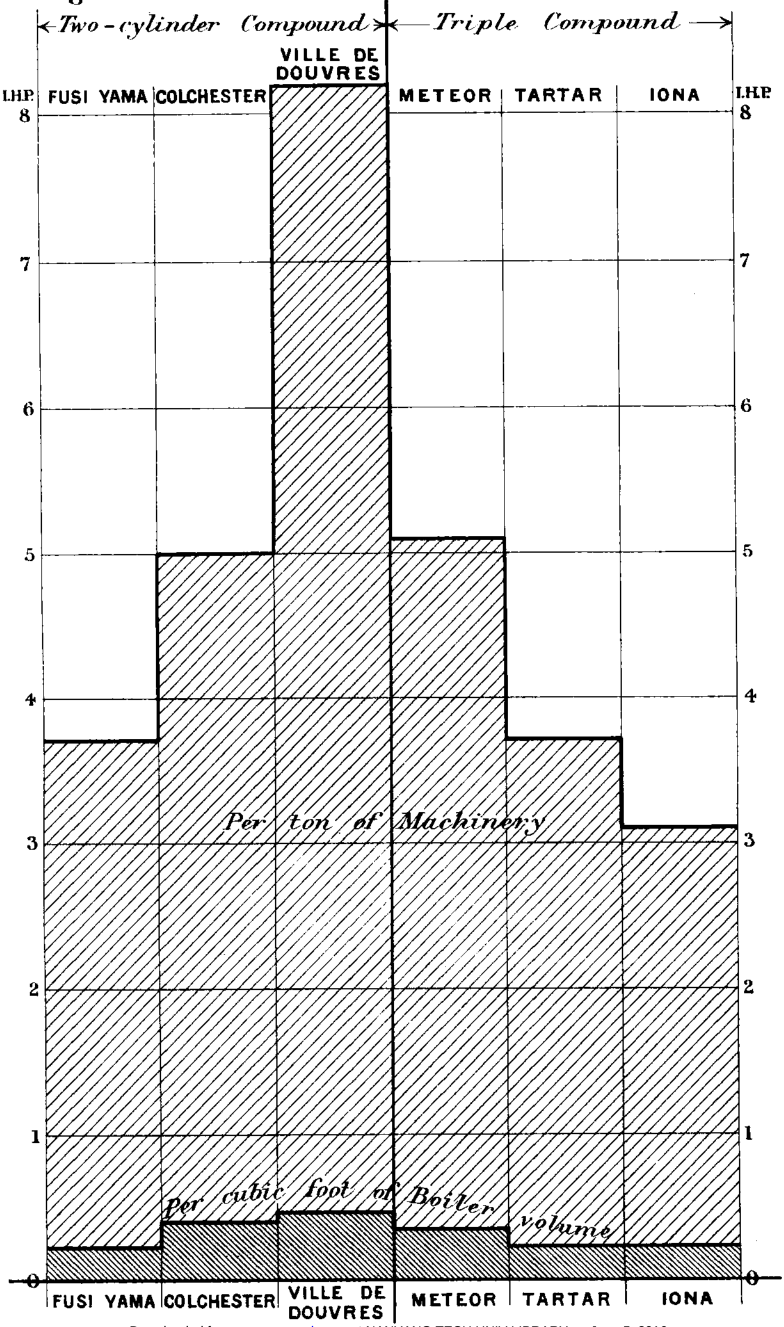


Fig. 15. *Indicated Horse-power. See Table 34.*



MARINE - ENGINE TRIALS.

Fig. 16. *Continuous Development of Indicator Diagrams from "Iona." See Plate 46, Proceedings 1891.*

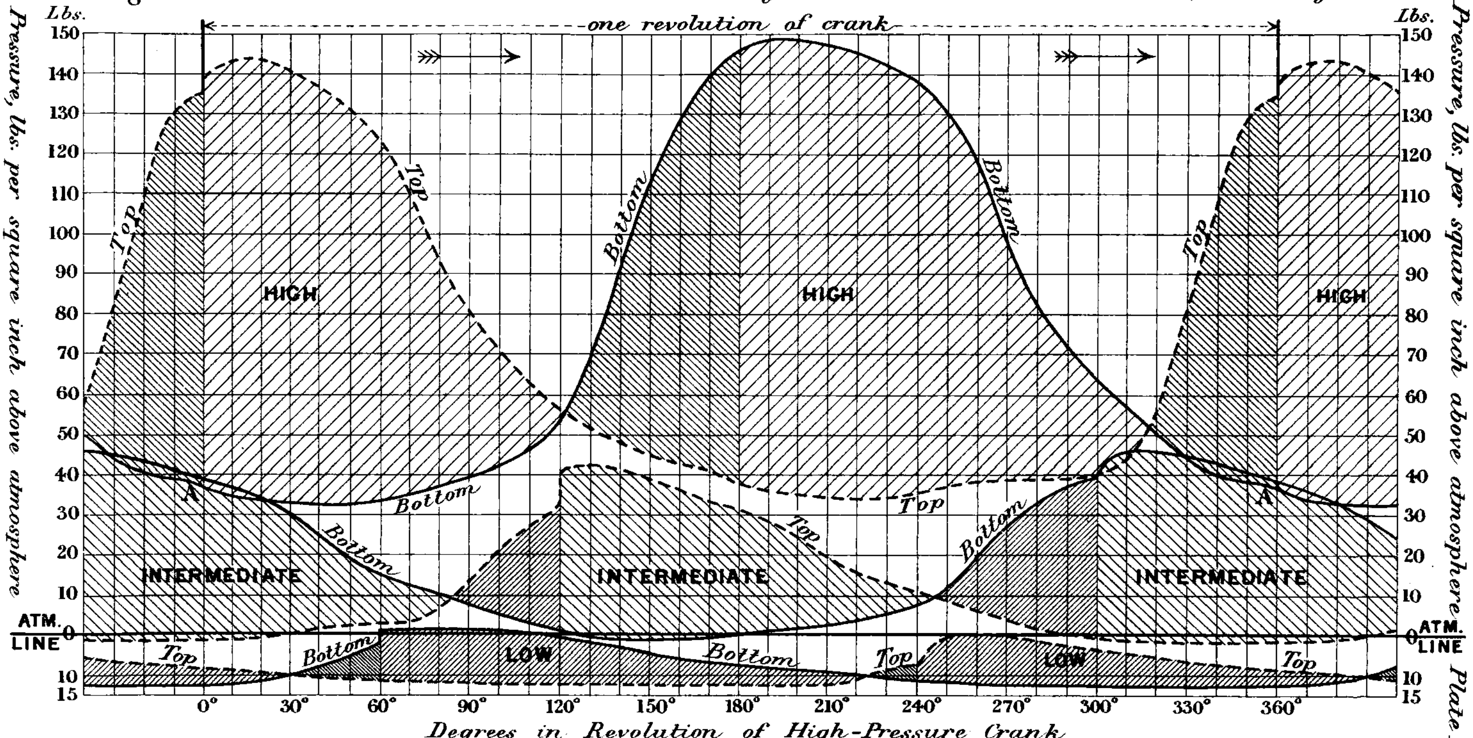
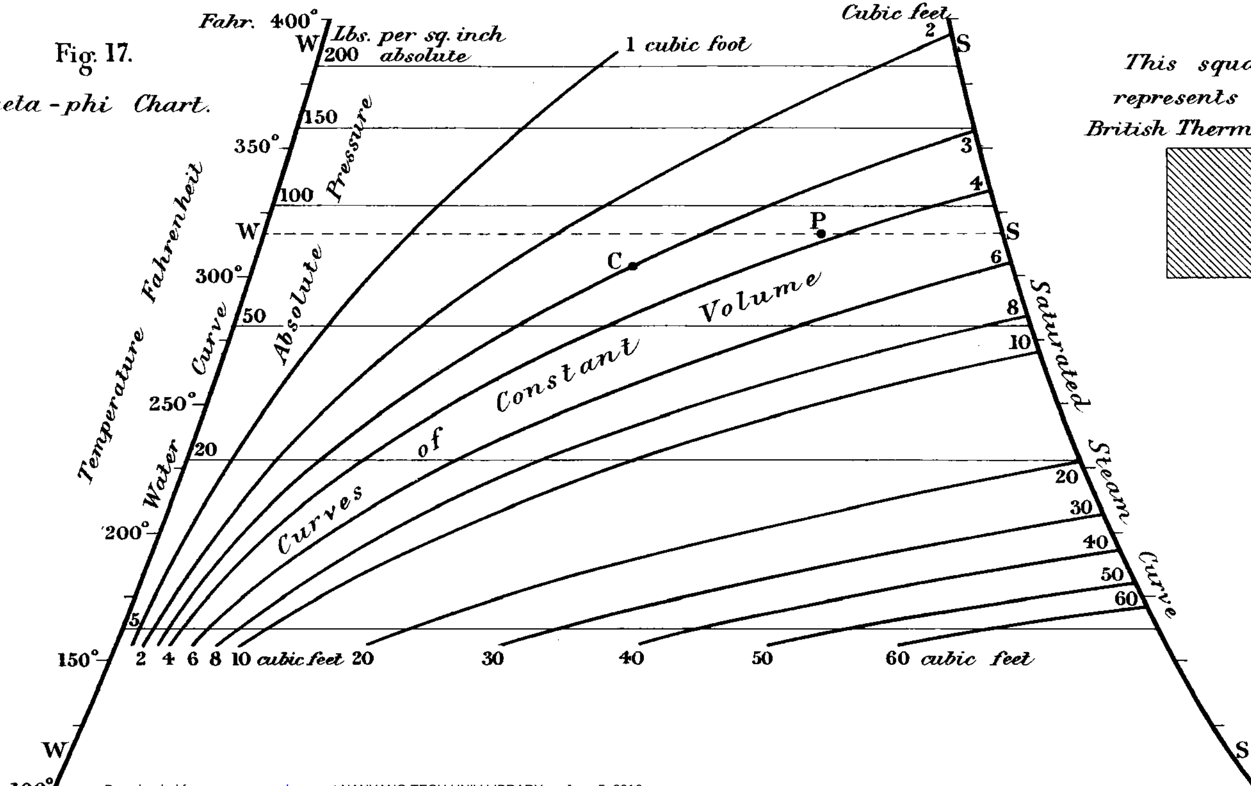


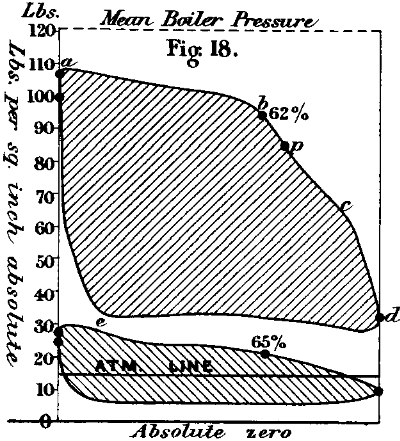
Plate 13.

Fig. 17.

Theta-phi Chart.



This square represents **TEN** *British Thermal Units.*



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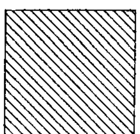
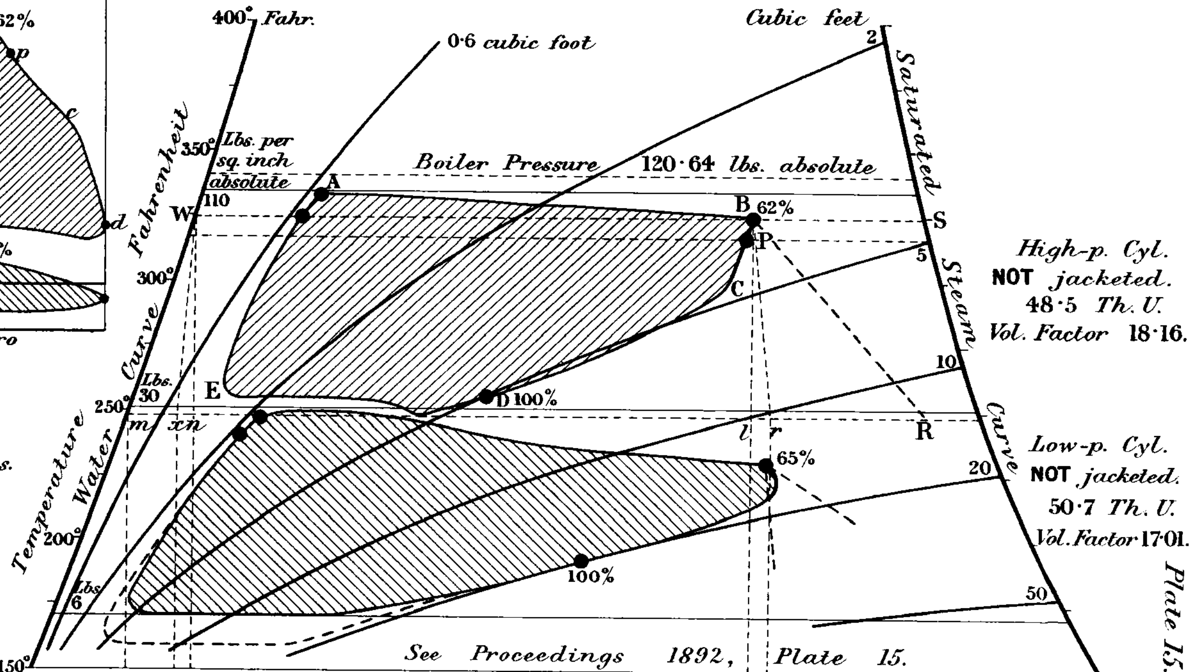


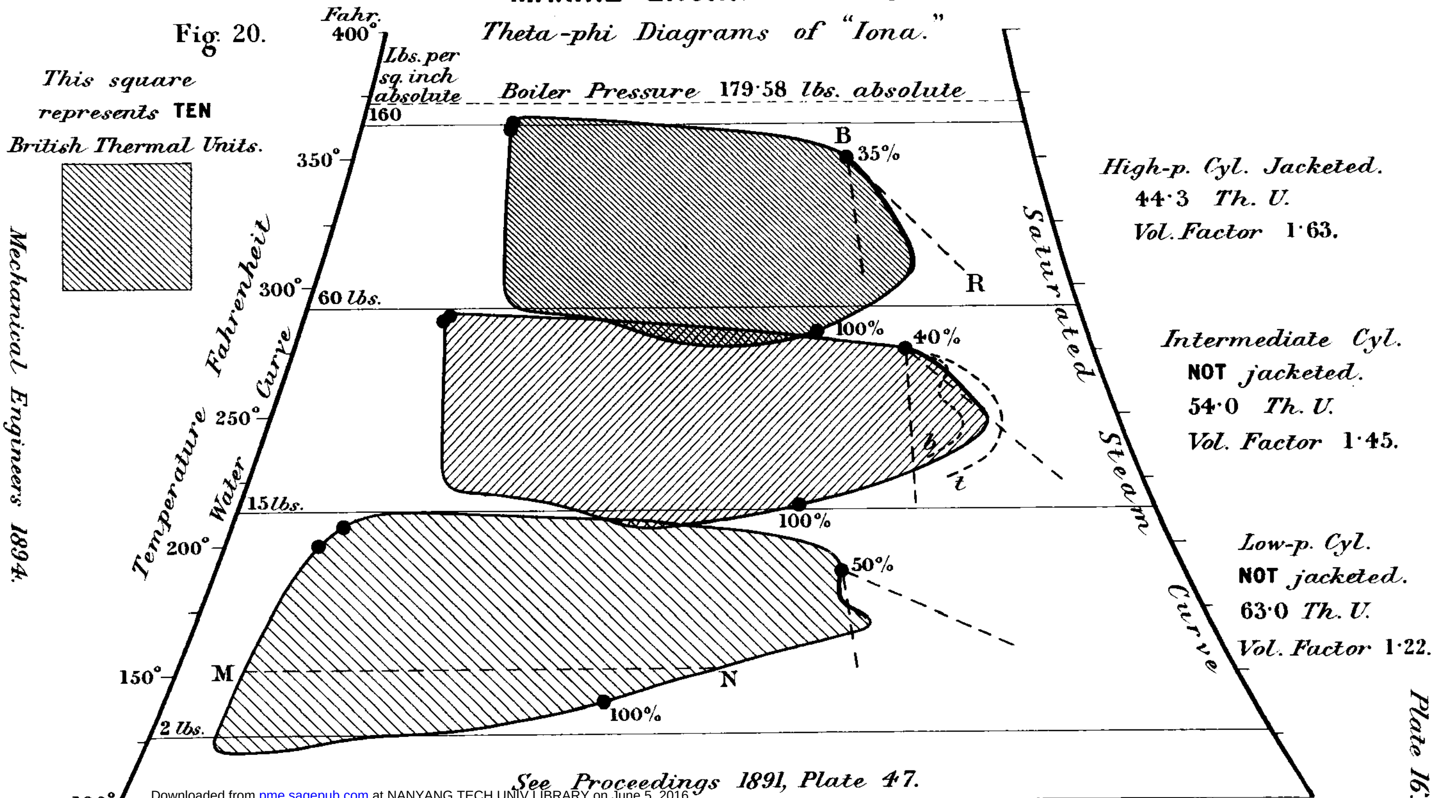
Fig. 19. *Theta-phi Diagrams of "Ville de Douvres."*



Mechanical Engineers 1894.

Plate 15.

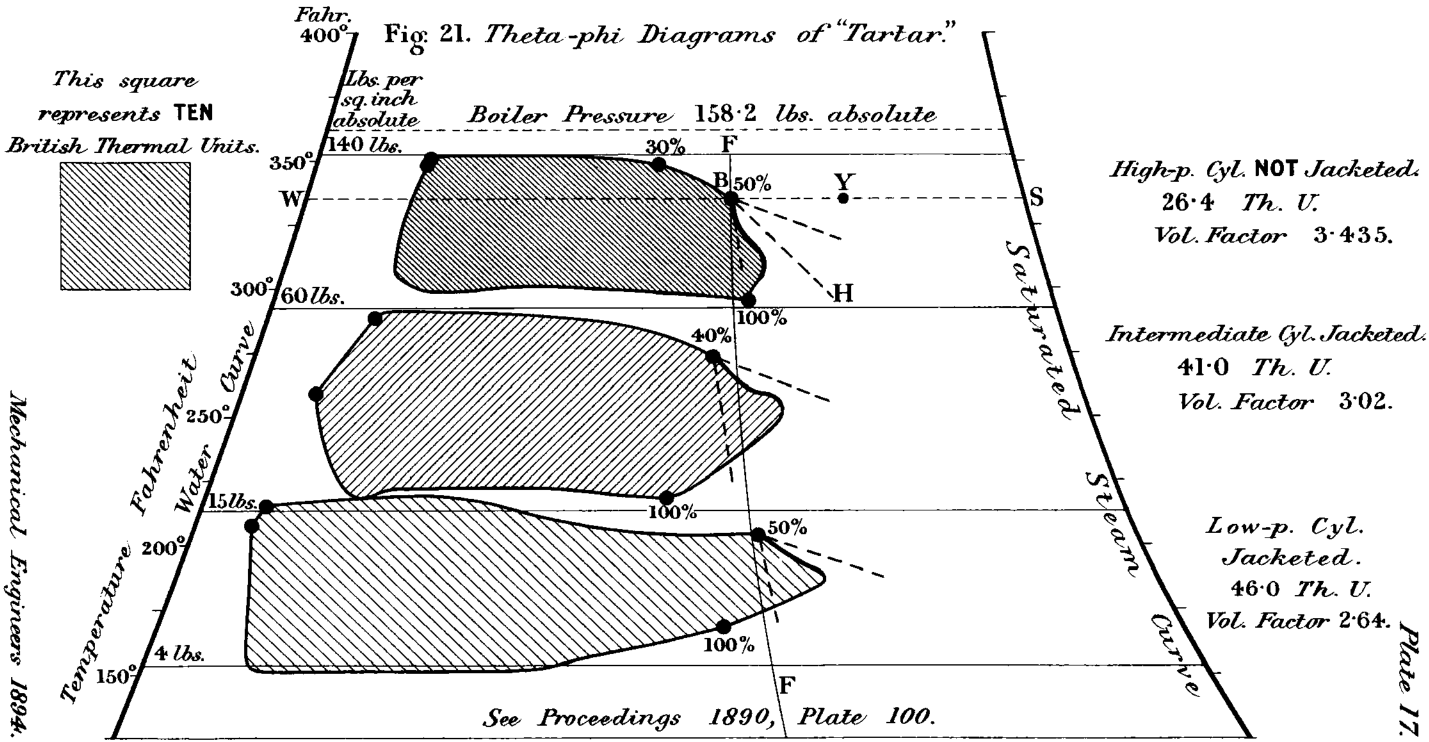
MARINE-ENGINE TRIALS.



See Proceedings 1891, Plate 47.

Plate 16.

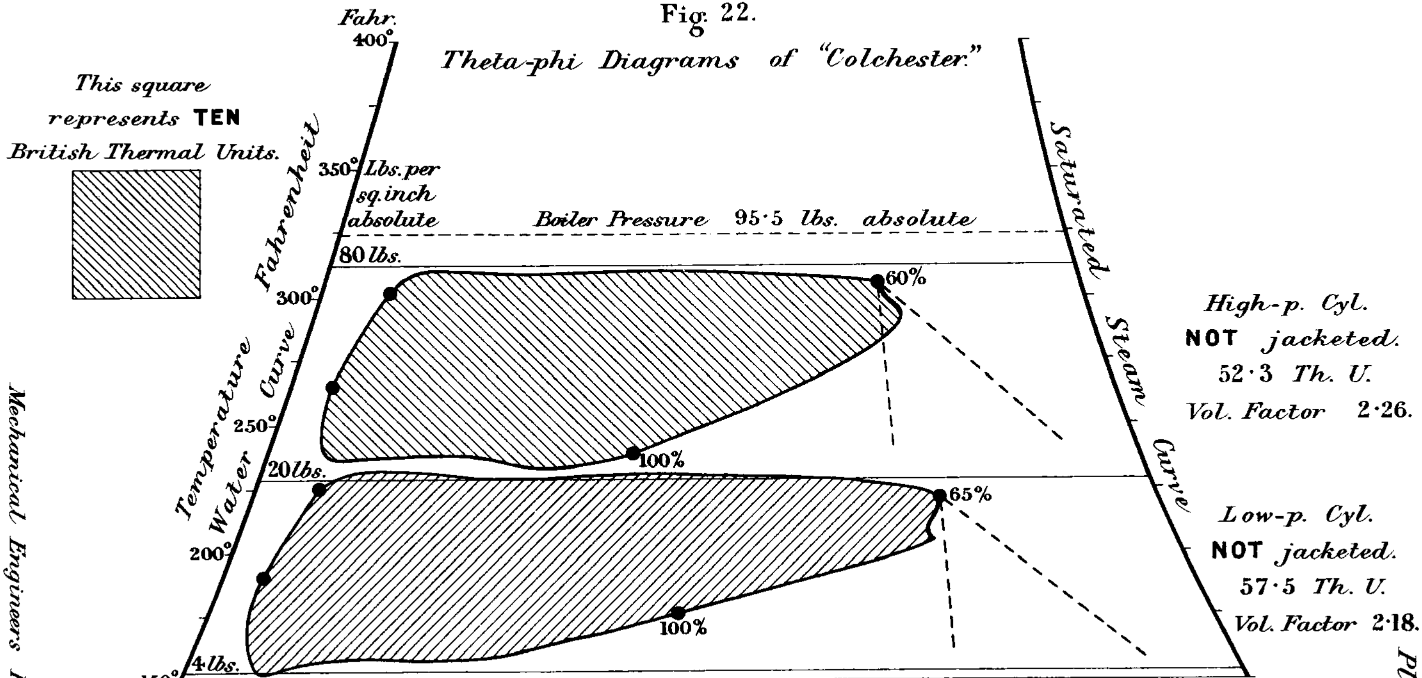
Fig. 21. *Theta-phi Diagrams of "Tartar."*



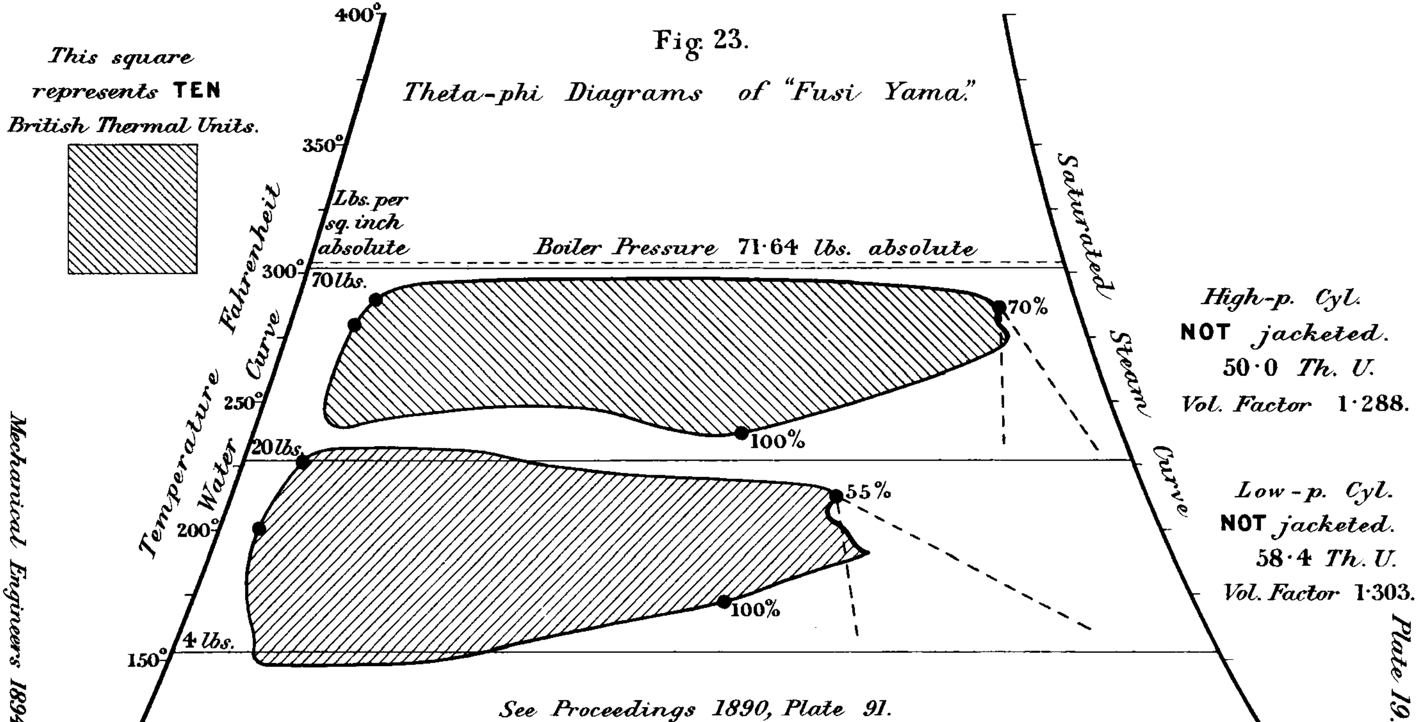
See Proceedings 1890, Plate 100.

MARINE-ENGINE TRIALS.

Fig. 22.



See Proceedings 1890, Plate 96.


This square represents TEN British Thermal Units.
Fig. 23.
Theta-phi Diagrams of "Fusi Yama."
400°
350°
300°
250°
200°
150°
Temperature Fahrenheit
Water Curve
Lbs. per sq. inch absolute
Boiler Pressure 71·64 lbs. absolute
70 lbs.
20 lbs.
4 lbs.
70%
100%
55%
100%
Saturated Steam Curve
High-p. Cyl.
NOT jacketed.
50·0 Th. U.
Vol. Factor 1·288.
Low-p. Cyl.
NOT jacketed.
58·4 Th. U.
Vol. Factor 1·303.
See Proceedings 1890, Plate 91.