A slightly greater engine-room staff is necessary ; but this seems of little importance compared with the foregoing advantages.

Weight of Machinery relatively to Power.—It is interesting to compare the weight of machinery relatively to the power developed ; for this comparison has sometimes been adopted as the standard of excellence in design, in respect of economy in the use of material. The principle, however, on which this has generally been done is open to some objections. It has been usual to compare the weight directly with the indicated horse-power, and to express the comparison in pounds per horse-power. So long as the machinery thus compared is for vessels of the same class and working at about the same speed of revolution, no great fault can be found ; but as speed of revolution is a great factor in the development of power, and as it is often dependent on circumstances altogether external to the engine and concerning rather the speed of the ship, the engines fitted to high-speed ships will thus generally appear to greater advantage than is their due Leaving the condenser out of the question, the weight of an engine would be much better referred to cylinder capacity and working pressures where these are materially different, than directly to the indicated power. In Table 4 appended are given the relative weights of nine triple-expansion engines, according to both modes of comparison ; Nos. 1 to 6 are mercantile engines, and Nos. 7 to 9 are naval examples. It will be noticed that though the twin-screw engines Nos. 5 and 6 are the same type of engine as the single-screw engines Nos. 1 to 4, as evidenced by their weights per cubic foot of cylinder capacity, yet their engine-room weights per indicated horse-power are considerably lower by virtue of their higher speed of revolution. Comparing its predecessors with No. 9, which is a fair type of a naval engine, it will be seen that the engines usually fitted in the merchant service are about 44 per cent. heavier per unit of cylinder capacity than this engine. The low weight of boilers per unit of heating surface in Nos. 7, 8, and 9, which is about 22 per cent. less than in the mercantile examples Nos 1 to 6, is due to careful use of material, as well as to the lighter scantlings adopted for boilers by the Admiralty.

The advantages of saving weight of machinery, so long as it can be done with efficiency, are well known and acknowledged. If weight is to be reduced, it must be done by care in design, not by reduction of strength, because safety and saving of repairs are much more important than the mere capability of carrying a few tons more of paying load. It must also be done with economy; but this is a matter which generally settles itself aright, as no shipowner will pay more for a saving in weight than will bring in a remunerative interest on his outlay. In his paper on the weight of machinery in the mercantile marine (North-East Coast Institution of Engineers and Shipbuilders, vol. 6, 1889-90, page 253) Mr. William Boyd discussed this question at some length, and proposed to attain the end of reducing the weight of machinery by the legitimate method of augmenting the speed of revolution and so developing the required power with smaller engines. This method, while promising, is limited by the efficiency of the screw, but may be adopted with advantage so long as the increase in speed of revolution involves no such change in the screw as to reduce its efficiency as a propeller. But when the point is reached, beyond which a further change involves loss of propelling efficiency, it is time to stop; and the writer ventures to say that in many cargo vessels now at work the limit has been reached, while in many others it has certainly been passed.

Economy of Fuel.—Coming to the highly important question of economy of fuel, Table 5 gives the performances of twenty-eight three-stage expansion engines in ordinary work at sea. The average consumption of coal per indicated horse-power is 1·522 lbs. per hour. The average working pressure is 158·5 lbs. per square inch. Comparing this working pressure with 77·4 lbs. in 1881, a superior economy of 19 per cent. might be expected now, on account of the higher pressure; or taking the 1·828 lbs. of coal per hour per indicated horse-power in 1881, the present performance under similar conditions should be 1·48 lbs. per hour per indicated horse-power. In Table 6 the principal factors in the present performance of marine engines are compared with those of 1881, and also with those of 1872 as indicated in the table accompanying Sir Frederick Bramwell's paper. Compared on the same basis then, it appears that the working pressures have been increased twice in the last ten years, and three times in the last nineteen. The coal consumptions have been reduced 16·7 per cent. in the last ten years, and 27·9 per cent. in the last nineteen. The revolutions per minute have increased in the ratios of 100, 107, 114; and the piston speeds at 100, 124, 140. Although it is quite possible that the further investigations of the Research Committee on marine-engine trials may show that the present actual consumption of coal per indicated horse-power is understated in Table 6, yet it is hardly probable that the relative results will be affected thereby. The returns of the coal consumption have in all cases been taken in the same way and on the same basis as for Mr. Marshall's paper in 1881, so that whatever errors may affect the returns for the one year are likely to have affected those for the other. The probability of error lies in the statement of the horse-power indicated, which when taken directly from the ship's log is usually in excess of that actually indicated continuously: so that the comparison of coal consumption with power is open to objection.

But there is another method, which is less objectionable, and from a shipowner's point of view the better of the two: namely to take the coal burnt as a measure of the power expended in propulsion. Thus for similar ships at similar speeds, the quotient, $\sqrt[3]{(\text{displacement}^2)} \times \text{speed}^3 \div \text{coal per day}$, gives a co-efficient of performance which represents the comparative cost of propulsion in coal expended; and this co-efficient for the present year, when compared with that for 1881, will show the advance in efficiency of propulsion, and should include the improvements of both ships and machinery.

The tabular statements in Table 7 appended are from a series of reliable examples of performances at sea. If now the later performance coefficient, 14,810 in 1890, be compared with the earlier, 11,710 about 1881, it will be seen that the relative coal economies are as 79 to 100, or that to-day the coal economy is 21 per cent. superior to that of 1881. Against this comparison an objection may be raised that the present best practice is here compared with vessels and machinery at work in 1881, which were perhaps by no means the best practice of that date. This is true; but on the other hand it seems hardly fair to mix up with the existing class of three-stage expansion engines, which have for some years past been the standard, the two-cylinder or compound engines, which as a class have become practically obsolete so far as present manufacture is concerned. In Table 7 it will also be observed that the vessels taken as examples of present performance are somewhat larger than those for 1881: which will probably affect slightly the exact figures of the comparison, but certainly not the broad general facts.

Dimensions.—In the matter of the power put into individual vessels, considerable strides have been made. In 1881 probably the greatest power which had been put into one vesssel was in the case of the "Arizona," whose machinery indicated about 6,360 horse-power. The following Table 3 gives an idea of the dimensions and power of the larger machinery in the later passenger vessels.

General Conclusions.—The progress made during the last ten years having been sketched out, however roughly, the general conclusions may be stated briefly as follows. First, the working pressure has been about doubled. Second, the increase of working pressure and other improvements have brought with them their equivalent in economy of coal, which is about 20 per cent. Third, marked progress has been made in the direction of dimension, more than twice the the power having been put into individual vessels. Fourth, substantial advance has been made in the scientific principles of engineering.

It only remains for the writer to thank the various friends who have so kindly furnished him with data for some of the tables which have been given; and to express the hope that the next ten years may be marked by such progress as has been witnessed in the past. But it must be remembered that, if future progress be equal in merit or ratio, it may well be less in quantity, because advance becomes more difficult of achievement as perfection is more nearly approached.

TABLE 3.

Dimensions and Power of Machinery in later Passenger Vessels.

Year.	Name of Vessel.	Diameters of Cylinders.	Length of Stroke.	Indicated Horse-Power.
		Inches.	Inches.	I H.P.
1881	Alaska - -	68, 100, 100.	72	10,686
1881	City of Rome -	46, 86; 46, 86; 46, 86.	72	11,800
1881	Servia - -	72, 100, 100.	78	10,300
1881	Livadia Yacht -	{ 60, 78, 78; 60, 78, 78; 60, 78, 78. }	39	12,500
1883	Oregon - -	70, 104, 104.	72	13,300
1884	Umbria - -	} 71, 105, 105.	72	14,320
1884	Etruria - -			
1888	City of New York	} 45, 71, 113;	60	20,000 about
1889	City of Paris -	45, 71, 113.		
1889	Majestic - -	} 43, 68, 110;	60	18,000
1889	Teutonic - -	43, 68, 110.		

In war vessels the increase has been equally marked. In 1881 the maximum power seems to have been in the "Inflexible," namely 8,485 indicated horse-power. The following will give an idea of the recent advance made:—

"Howe" (Admiral class) - - - -	11,600 I.H.P.
"Italia" and "Lepanto" - - -	19,000 ,,
"Re Umberto" - - - - - -	19.000 ,,
"Blake" and "Blenheim" (building) -	20.000 ,,
"Sardegna" (building) - - -	22,800 ,,

It is thus evident that there are vessels at work to-day having about three times the maximum power of any before 1881.

TABLE 4 (*continued on next page*).

Dimensions, Indicated Horse-Power, and Cylinder Capacity of Three-stage Expansion Engines in nine steamers.

No. of Steamer	Single or Twin Screws.	Cylinders. Diameters.	Cylinders. Stroke.	Revolutions per minute.	Boiler Pressure per sq. inch.	Indicated Horse-Power.	Cylinder Capacity.	Heating Surface. Total.	Heating Surface. Per I.H.P.
No.		Inches.	Inches.	Revs.	Lbs.	I.H.P.	Cub. Feet.	Sq. Feet.	Sq. Feet
1	Single	40 66 100	72	64·5	160	6,751	522	17,640	2·62
2	Single	39 61 97	66	67·8	160	5,525	436	15,107	2·73
3	Single	23 38 61	42	83	160	1,450	109	3,973	2·73
4	Single	17 26½ 42	24	90	150	510	30	1,403	2·75
5	Twin	32 54 82	54	88	160	9,625	508	20,193	2·10
6	Twin	15 24 38	27	113	150	1,194	55	3,200	2·68
7	Single	20 30 45	24	191	145	1,265	36 3	2,227	1·76
8	Twin	18½ 29 43	24	182·5	140	2,105	66·2	3,928	1·87
9	Twin	33½ 49 74	39	145	150	9,400	319	15,882	1·62

Nos. 7 and 8 had navy boilers. No. 9 had three double-ended and two single-ended boilers.

TABLE 4 *(continued from opposite page)*.

Weight of Three-stage Expansion Engines in nine steamers in relation to Indicated Horse-Power and to Cylinder Capacity.

No. of Steamer.	Weight of Machinery.			Relative Weight of Machinery.					Type of Machinery.
				Per Indicated Horse-Power.					
	Engine room.	Boiler room.	Total.	Engine room.	Boiler room.	Total.	Engine room Per cub. ft of Cyl capacity.	Boiler room Per 100 sq. ft. of Heating surf.	
No.	Tons.	Tons.	Tons.	Lbs.	Lbs.	Lbs.	Tons.	Tons.	
1	681	662	1,343	226	220	446	1·30	3·75	Mercantile
2	638	619	1,257	259	251	510	1·46	4·10	do.
3	134	128	262	207	198	405	1·23	3·23	do.
4	38·8	46·2	85	170	203	373	1·29	3·30	do.
5	719	695	1,414	167	162	329	1·41	3·44	do.
6	75·2	107·8	183	141	202	343	1·37	3·37	do.
7	44	61	105	77	108	185	1·21	2·72	Naval Horizontal
8	73·5	109	182·5	78	116	194	1·11	2·78	do.
9	262	429	691	62·5	102	165	0·82	2·70	Naval Vertical.

Nos. 7 and 8 had navy boilers. No. 9 had three double-ended and two single-ended boilers.

TABLE 5 (*continued on next page*).

Particulars of THREE-STAGE EXPANSION ENGINES *in twenty-eight Steamers.*

No. of Steamer.	Cylinders.				Condenser.	Propeller.			
	Diameters.			Stroke.	Cooling Surface.	Diameter.		Pitch.	
No.	Inches.			Inches.	Sq. Feet.	Ft.	Ins.	Ft.	Ins.
1	40	66	100	72	11,586	22	0	28	6
2	40	66	100	72	11,586	22	0	28	6
3	39	61	97	66	11,000	20	10	26	0
4	39	61	97	66	11,000	20	10	26	0
5	23	38	61	42	2,008	16	0	17	6
6	25½	42	70	51	3,209	16	6	20	0
7	21	34	55½	36	1,447	14	0	17	6
8	22	35	59	39	1,430	15	6	15	6
9	29	45	74	54	3,900	19	6	20	0
10	31	48	82	54	4,150	19	0	19	0
11	25	41	67	48	2,800				
12	21½	36	59	42	2,000	15	0	16	6
13	32	51	82	54	12,562	16	6	23	0
14	27	44	71	48	2,800	17	9	17	6
15	29	45	74	60	4,020	19	0	24	0
16	29	45	74	54	3,850	18	0	21	0
17	23	37	64	48	2,400	16	6	18	0
18	28	44	74	51	3,700	17	9	22	9
19	23	36½	58	36	2,218	15	0	15	6
20	17,17	38	60	42	2,900	15	6	15	6
21	25	39	62	36	2,700	14	0	16	3
22	31	46	72	51	3,713	16	3	22	6
23	22½	35½	58½	39	1,750	14	7	16	6
24	25	42	68½	48	2,763	16	10	17	9
25	22¼	35¾	58½	48	3,530	15	6	18	0
26	31	50	83	60	6,860	19	0	23	0
27	32	53	87½	60	7,500	19	0	23	9
28	28½	46	75	42	3,450	16	0	21	0

(*continued on next page*) TABLE 5.

Particulars of BOILERS

in twenty-eight Steamers.

No. of Steamer.	Number.	Diameter.		Length.		Heating Surface. Total.	Fire-grate Area.	Steam Pressure. Lbs. per sq. inch.
No.	No.	Ft.	Ins.	Ft.	Ins.	Sq. Feet.	Sq. Feet.	Lbs.
1	Six	13	6	18	0	17,640	626	155
2	Six	13	6	18	0	17,640	626	155
3	Five	13	6	18	0	15,107	540	155
4	Five	13	6	18	0	15,107	540	155
5	Two	14	6	10	4½	3,972	133	160
6	Two	13	0	17	6	6,162	193	180
7	Two	13	6	10	0	3,350	99	160
8	Two	13	4	9	9	3,324	102	160
9	Three	12	5	16	9	6,875	240	160
10	Three	12	6	18	6	8,000	260	160
11	Two	12	6	16	4	4,645	142	160
12	Three	12	0	10	3	3,852	122	160
13	Four	16	0	19	0	20,192	710	160
14	Two	13	6	16	6	6,164	220	150
15	Two	14	8	16	8	6,950	196	150
16	Two	14	3	17	0	6,960	216	160
17	Two	11	9	17	0	4,715	144	180
18	Two	14	3	18	0	8,000	264	150
19	One	14	10	15	5	3,271	126	160
20	Two	12	0	15	2	4,400	168	150
21	Two	12	2	14	0	4,000	150	160
22	Three	13	0	11	4	5,076	110	150
23	One	15	0	11	9	2,338	50	160
24	Two	14	3	11	6	4,346	84	160
25	Two	13	0	11	4	3,486	63	160
26	Two	16	3¼	12	0	6,438	154	150
27	Four	14	6	11	6	8,571	210	160
28	Three	14	3¼	9	11	6,618	188	160

TABLE 5 (*concluded from preceding page*).

Results of TRIAL *of Twenty-eight Steamers.*

No. of Steamer.	Revolutions per minute.	Piston Speed. Feet per min'te.	Indicated Horse-Power.	Heating Surface. Per I.H.P.	Heating Surface. Per lb. of Coal per hour.	Indicated Horse-Power per sq. foot of grate	Coal burnt per sq. foot: of grate per hour.	Coal burnt per I.H.P. per hour.	Remarks.
No.	Revs.	Feet.	I.H.P.	Sq. Ft.	Sq. Ft.	I.H.P.	Lbs.	Lbs.	
1	52·2	627	4,295	4·11	2·46	6·86	11·45	1·67	H
2	51·3	616	4,402	4·04	2·55	7·03	11·14	1·584	H
3	57·3	630	3,587	4·21	2·22	6·65	12·60	1·896	H
4	57·4	631	3,822	3·95	2·14	7·08	13·02	1·841	H
5	61	427	1,120	3·54	2·02	8·43	14·75	1·75	
6	61·3	521	1,700	3·62	2·40	8·82	13·25	1·505	
7	64	384	900	3·72	2·31	9·09	14·67	1·612	H
8	70	455	1,065	3·12	2·38	10·42	13·70	1·312	
9	56	504	2,250	3·055	2·04	9·38	14·00	1·494	H
10	61·5	553	2,600	3·075	2·04	10·00	15·10	1·505	H
11	58	464	1,300	3·57	2·26	9·16	14·46	1·580	
12	67	469	1,100	3·50	2·29	9·02	13·79	1·529	
13	58·5	526	3,670	5·50	3·64	5·17	7·80	1·510	H
14	63	504	1,680	3·67	2·12	7·65	13·18	1·723	H
15	53·8	538	2,360	2·94	1·78	12·03	19·85	1·650	
16	64	576	2,550	2·73	1·82	11·80	17·70	1·500	
17	62	496	1,500	3·14	2·00	10·40	16·31	1·568	
18	62	527	1,727	4·63	2·85	10·53	17·06	1·620	
19	76	456	1,269	2·58	1·84	10·07	14·10	1·400	P
20	75	525	1,530	2·875	1·96	9·11	13·32	1·464	P
21	73	438	1,250	3·20	2·40	8·35	11·13	1·330	P
22	72	612	2,513	2·02	1·34	22·85	33·95	1·488	D H
23	76	494	1,350	1·73	1·28	27·00	36·42	1·350	D H P
24	65	520	1,800	2·41	1·94	21·42	26·62	1·242	D H P
25	69·5	552	1,360	2·56	1·91	21.59	28·90	1·338	D H P
26	59	590	2,600	2·435	1·78	16·88	23·05	1·365	D H P
27	66	660	3,400	2·52	2·04	16·18	19·97	1·234	D H P
28	73	511	2,058	3·215	2·05	17·10	10·92	1·565	
Average of all twenty-eight				3·275	2·14	11·22	17·08	1·522	
Average of Natural Draught				3·560	2·25	8·91	13·92	1·573	
Average of Forced Draught				2·412	1·72	20·98	28·15	1·336	

D = Forced Draught. H = Feed Heater. P = Pass-over Slide-Valve.

TABLE 6.

Actual and Comparative Results of Working of Marine Engines in three years, 1872, 1881, 1891.

Boilers, Engines, and Coal.	Actual Results.			Compared with 1872.			Compared with 1881.		
	1872	1881	1891	1872	1881	1891	1872	1881	1891
Boiler Pressure lb. per sq, inch	52·4	77·4	158·5	1·000	1·477	3·025	0·677	1·000	2·048
Heating Surface per horse power, sq. feet	4·410	3·917	3·275	1·000	0·889	0·743	1·125	1·000	0·837
Revolutions per minute revs.	55·67	59·76	63·75	1·000	1·074	1·145	0·932	1·000	1·062
Piston Speed feet per minute	376	467	529	1·000	1·242	1·406	0·805	1·000	1·132
Coal per horse-power per hour lbs.	2·110	1·828	1·522	1·000	0·866	0·721	1·154	1·000	0·833

TABLE 7.

Performance of Machinery relatively to Coal Consumption.

$$\text{Coefficient of Performance} = \frac{\sqrt[3]{(\text{Displacement}^2)} \times (\text{Speed in knots})^3}{\text{Tons of Coal in 24 hours.}}$$

No. of Vessels.	Length in Feet.	Coefficients of Displacements. Block.	Coefficients of Displacements. Prismatic.	Speed in knots, divided by square root of Length in feet.	Working Pressure. Lbs. per sq. inch.	Coefficient of Performance.
Seventeen Vessels with Two-stage Expansion Engines; date about 1881.						
1–17	260 to 320	0·751	0·774	0·539	83	11,710
Sixteen Vessels with Three-stage Expansion Engines; date 1890.						
1	440	0·633	0·666	0·600	155	15,590
2	400	0·703	0·775	0·520	180	15,750
3	312	0·710	0·805	0·555	160	13,300
4	300	0·635	0·691	0·566	160	14,250
5	295	0·697	0·769	0·536	160	12,150
6	460	0·617	0·708	0·633	155	14,850
7	460	0·618	0·710	0·621	155	14,210
8	430	0·623	0·699	0·638	155	13,650
9	430	0·626	0·701	0·641	155	13,450
10	300	0·730	0·765	0·579	160	15,200
11	400	0·770	0·804	0·550	160	14,410
12	336	0·756	0·780	0·545	160	16,600
13	275	0·772	0·780	0·633	160	16,700
14	370	0·779	0·810	0·546	150	15,600
15	422	0·745	0·774	0·555	150	15,400
16	345	0·770	0·792	0·554	180	14,690
Means.		0·699	0·752	0·579	159	14,810