SESSION, 1891-92.

THIRTY-FIFTH PAPER

(OF TRANSACTIONS)

ON

STABILITY,

AND THE

MOTIONS OF A VESSEL AMONG WAVES

(PART II)

BY

MR. J. A. ROWE

(MEMBER).

Read on Tuesday, 12th January, 1892, in Gresham College, Basinghall Street, E.C.

Discussion continued, 26th January, 1892, at the Town Hall, Stratford.

PREFACE.

Broadway,
Stratford,
January 26th, 1892.

A Meeting of the Institute of Marine Engineers was held on Tuesday evening, January 12th, in Gresham College, Basinghall Street, E.C., by the courtesy and kind permission of the Honorary Secretary and Committee, when a Paper on "Stability, and the Motions of a Vessel among Waves," Part II, by Mr. John A. Rowe, was read.

The Meeting was presided over by Mr. J. H. Thomson. Professor Greenhill and Mr. Macfarlane Gray took part in the brief discussion which ensued.

A Meeting was held in the Town Hall, Stratford, presided over by Mr. W. H. White (Chief Constructor to the Admiralty) when the discussion on Mr. Rowe's Paper was resumed this evening.

The Author of the Paper briefly referred to the remarks made at the previous meeting, thus initiating the Discussion which was taken part in by many of the Members who were present. The Chairman made some very interesting comments on the subject, and on the remarks made in the course of the evening.

Mr. White had to leave before the close of the meeting, and a hearty vote of thanks was awarded to him and courteously responded to. Mr. Macfarlane Gray was then voted into the chair and presided till the close.

JAS. ADAMSON,
Honorary Secretary.

STABILITY,

AND THE

MOTIONS OF A VESSEL AMONG WAVES.

PART II.

In the former part of this paper it was said that though the inclining experiment enabled us to determine the length G M, (Fig. 10), it did not enable us to locate either of the points G and M. But the positions of B, G, and M may be determined by computation and experiment by the following well-known formula, which, in the form relating to so simple a figure as a balk of timber is not difficult to understand, and, if understood, enables one to think clearly when engaged in the solution of a problem of comparative stability. The distance between B and M can be found by computation thus :—

$$B\,M = \frac{\text{Moment of Inertia of Water Line area}}{\text{Volume of Displacement}} = \frac{I}{V}$$

The moment of inertia is taken about a line running fore and aft in the centre of the plane of flotation. Perhaps it will make it clearer by explaining that the water line area, or the plane of flotation, is the superficial area of the deck of a ship measured *at the water line*. And, as this area varies at different draughts of water, the moment of inertia will also vary.

The volume of displacement is, of course, the length of the ship in feet multiplied by the mean breadth and the immersion. This cubic capacity also varies with the draught, and thus the length B M, which may be said to be the measure of a vessel's stability derived from the *shape* of the hull, may, in a given ship, vary considerably at different draughts.

From what has already been said concerning the transfer of the wedge of buoyancy (Fig. 10) through a distance of $\frac{2}{3}$ the vessel's beam, the following explanation of how to determine the distance B M will be readily understood:—

Let l = length of balk
b = breadth ,,
d = depth of immersion
x = circular measure of the angle of inclination.

Imagine the balk inclined through an extremely small angle instead of a large angle, as in Fig. 10—

$$\text{Then } (BM \times x) \times l \times b \times d = \frac{\frac{b}{2} \times (\frac{b}{2} \times x)}{2} \times l \times \frac{2b}{3};$$

$$\therefore BM \times b\,d = \frac{b^3}{12},$$

$$\text{and } BM = \frac{b^2}{12\,d}.$$

In this case b = 35 feet,
and d = 6·7 feet;

$$\therefore BM = \frac{35\text{ft.} \times 35\text{ft.}}{12 \times 6{\cdot}7\text{ft.}} = 15{\cdot}23 \text{ feet.}$$

We know the position of B. It is the centre point of the rectangle H C D E. It is 3·35 feet from the bottom of the balk, and therefore M must be 3·35+15·23 = 18·58 feet above the bottom, or 5·18 feet above the top. If now, by an inclining experiment the length of G M be discovered, we shall have plotted for a given ship at a given draught the points B, M, and G. It is also possible to plot G by computation.

To find B M in vessels less simple in form than a balk of timber, a slightly different formula must be used for the following reasons. The moment of inertia of the water line area of a ship is less than that of a rectangle of the same length and breadth, on account of the fining away of the ship's bow and stern; and the ship's displacement is less than that of the rectangle for the same reason. It has been shown that in the case of a rectangle

$$B\,M = \frac{I}{V} = \frac{l\,b^3}{12\,V} = \frac{l\,b^3}{12\,lbd} = \frac{b^2}{12\,d},$$

And experience has proved that in a *very* fine vessel

$$B\,M = \frac{I}{V} = \frac{l \times \frac{b^3}{24}}{V} = \frac{l\,b^3}{24\,V},$$

Between these two extremes of fullness and fineness of form, the co-efficients will vary from 12 to 24, the mean of which, 18, will apply to the great majority of ships afloat.

From the above formulæ it may be gathered that a vessel's stability of form varies approximately as the square of the beam. If it were possible to add five feet of beam to a tender ship possessed of 30 feet beam, we should increase her stability by $\frac{35^2}{30^2} = 1\frac{1}{3}$ times.

It is sometimes stated that a vessel's stability varies as the beam cubed. This is incorrect, if the depth remains constant, for, although in the formula $B\,M = \frac{l\,b^3}{18\,V}$ the breadth *cubed* appears, it must not be forgotten that the breadth is involved in V of the denominator.

Find B M in a vessel 330 feet long, 41 feet broad, and 6,500 tons displacement weight. Use the coefficient 18.

$$B\,M = \frac{330 \times 41^3}{18\,V} = \frac{330 \times 41^3}{18 \times 6{,}500 \times 35 \text{ cubic ft.}} = 5\tfrac{1}{2} \text{ feet.}$$

Note (V, the volume of displacement = Weight of ship × 35 cubic feet.)

The formula $B\,M = \frac{I}{V}$ is worth remembering. It enables one to judge instantly what effect a vessel's change of draught will have upon her stability. If I (the moment of inertia) increase, her stability will increase. If I should increase, and V *decrease*, the stability will be still further augmented, and the converse of this will hold good.

Many of you will have read in works on Naval Architecture, and elsewhere, that a vessel's stability is increased by making the vessel fine forward and aft under the water line, and full above. The formula we have been discussing explains the meaning of this. Full lines at and near the water line will increase a vessel's moment of inertia of the water line area. Fine lines under water will diminish the volume of displacement.

CURVES OF STABILITY.
STATIC STABILITY.

It has already been said that GZ, Fig. 10, drawn from G at right angles to the direction of the force of buoyancy, is the righting arm; and its length in feet, multiplied by the weight of the vessel in tons, is her righting moment in foot tons when at the angle of inclination corresponding to the righting arm. This moment is called a vessel's static stability. An examination of Fig. 10* will show that GZ is continually increasing with the angle of roll until the edge of the deck enters the water. Soon after that it begins to diminish, and after a time, say at an angle of 60° from the vertical, it disappears, and the vessel capsizes. GZ also diminishes as the vessel approaches the vertical, and disappears in a *properly laden* ship when the masts are at right angles to the sea level. G M does not vary in this manner. Its length is constant in a given ship when the vessel rolls through moderate angles, say, not exceeding 15° from the vertical, but it diminishes to a certain extent (depending on the form of the hull) as the vessel rolls beyond the angle mentioned. The position of G does not alter if the cargo does not shift. The change must, therefore, be with the point M, and it occurs because the formula $BM = \frac{I}{V}$ for the upright position no longer holds good.

Now the changes in the length of the righting arm G Z are shown on Fig. 13, which is intended to represent the curve of stability of a somewhat tender

---

*Part I.

ship. The base line is divided into degrees, and from any point, as at 15°, 30°, and 45°, the righting arms G Z are drawn at right angles. Through the points Z a line is drawn, cutting the base line at zero and 60°. At about 30° the righting arm has attained its maximum efficiency. At 60° it is nil, and the vessel is being capsised at G_1 Z_1 by the moment of G_1 Z_1 into the ship's weight. The righting arms above the base are positive, and tend to restore the vessel to the perpendicular. The righting arm below the base is negative, and exerts a capsizing effect. The point V, where the curve crosses the base-line, is called the point of vanishing stability, and the *range* of stability is measured from this point to zero. In this case it is 60 degrees. For a special reason the writer has chosen a curve of small range and area. At the angle of 15° let G Z be ·13 of a foot; at 30° let it be ·24 of a foot. These small righting arms, corresponding to a meta-centric height of ½ foot, have, it is said, been found in steamers laden with homogeneous cargoes, and as with a given righting arm the heaviest vessel possesses the greatest righting moment, she is safer (all other things being equal) than a smaller vessel with the same length of righting arm. But the righting arms of vessels carrying homogeneous cargoes may, without great care is exercised in stowage, and prudence shown in the quantity of freight carried, become so small as to be inefficient, and, therefore, dangerous at sea in stormy weather. For if a vessel's cargo should shift, and she should acquire a permanent list of 15°, her range of stability on—in this case—the starboard roll, will be under the most favourable conditions reduced to 45°, and the maximum righting arm to about ·13 of a foot. In this condition she may not be unsafe in smooth water, but she would not long survive among stormy waves, seeing that the starboard roll would in all probability cause the water to pour over the bulwarks, and lead to a further shifting of cargo.

It is important to remember that a vessel does not cease to roll *because* her cargo has shifted. If her centre of gravity is not raised, she will roll as much as she did before, and at the same angular velocity. No doubt the centre of gravity will be slightly raised and the rolling period slightly increased, but the alteration will be too insignificant for consideration. But mark this. On the starboard side she is more open to the attack of the sea to the extent of an angle of 15°. She begins her roll to port, and to starboard, not from her old upright position, where the masts were vertical, but from the new position, where the masts are on the starboard side inclined at an angle of 75° to the water line. Hence, on the starboard roll, the righting arm will be decreased and the range reduced, as shown in Fig. 14. On the port roll the opposite effect will be produced. Unfortunately, the stability of such a ship is not measured by the superior resistance, but by the inferior; and though she may float for a time she must sooner or later succumb in stormy weather, especially with engines disabled. If grain or coal laden, she will capsize; if laden with ore, or a similar cargo that affords great stability, she will probably founder through the waves tearing her to pieces. In Fig. 14, the upright position (the zero) is not determined by the masts, but by the vertical line through the centres of gravity and buoyancy.

From what has been said it will no doubt be thought that one of the chief aims of a shipbuilder should be to construct vessels of great stability. They know how to do this better than we can tell them; why is it not done? The most important reply to this question brings us to the consideration of

DYNAMIC STABILITY AND OSCILLATIONS AMONG WAVES.

Most of you are aware that in computing the rolling period of a ship—that is, the time in seconds she will take to roll from the vertical and back again—she is somehow or other regarded as a pendulum. This is a correct view to take of the matter if the subject is approached in a proper direction. But many able men have been perplexed by what has appeared to be the contradiction between theory and practice. For instance, most of you are aware that the period T of a bob-pendulum in seconds is:

$$T = 3{\cdot}1416 \times \sqrt{\frac{\text{Length in Feet}}{\text{Gravity}}} = 3{\cdot}1416 \times \sqrt{\frac{R}{32}} = {\cdot}554 \times \sqrt{R}$$

R is the length of the pendulum in feet.

In this formula it is clear that the period of a pendulum varies as the square root of its length.

For the smooth water period of a ship the formula is somewhat different, and is as follows:—

$$T = 3.1416 \sqrt{\frac{\text{Radius of Gyration squared}}{\text{Gravity} \times \text{Meta-Centric Height}}} = {\cdot}554 \times \sqrt{\frac{R^2}{G\ M}}$$

The radius of gyration and the meta-centric height to be in feet.

An examination of this formula reveals the fact that a vessel's rolling period varies directly as the radius of gyration, and inversely as the square root of the meta-centric height. If G M be increased in length, the vessel's period will be shortened, and she will become a quicker roller than before. But practical men looking at such a diagram as Fig. 15, have reasoned thus:—"The length G M is the distance between the vessel's point of oscillation and her centre of gravity. If there is any pendulum-like motion in the ship it is of necessity about G or M, at a length G M."

But the formula $T = {\cdot}554 \times \sqrt{\frac{R^2}{G\ M}}$ shows clearly enough, as does also the formula for a simple pendulum, that R is the pendulum length and G M is something entirely different. Fig. 15 has been constructed by the writer in the hope of simplifying some points not generally understood.

The vessel is shown upright on the wave-slope. In this position, the force of buoyancy, *which acts at right angles to the wave surface*, as it acts at right angles to the surface of smooth water, creates a righting arm G Z. This length in feet, multiplied by the ship's weight in tons, is what we have called the vessel's righting moment in foot tons. In the position we have shown her, it is obvious that this power, usually regarded as the power of recovery, starts the vessel rolling; and if, after she had acquired a position at right angles to the wave slope, we could instantly give a smooth surface to the sea she would roll through the angle G M O on each side of the vertical, and gradually extinguish the range of oscillation by the fluid resistance offered to the immersed portion of the hull.

Again, if G O and M T be drawn at right angles to G M, and T O drawn parallel to G M, we obtain a parallelogram of forces, whose resultant M O may be regarded as the buoyant force which equals the weight of the ship, and whose components are G M and M T. As G M is acting upward through the vessel's centre line we may disregard it, and direct our attention exclusively to the component M T, whose direction is shown by arrow, and whose amount is M O $\times$ Sine of the angle of inclination.

Let the angle of the wave slope be 9°, the vessel's weight 10,000 tons, her meta-centric height 6 feet. Find the turning moment about G, the vessel's centre of gravity.

The component M T $=$ M O $\times$ Sine of 9°,
$=$ 10,000 tons $\times$ ·156 $=$ 1,560 tons.
This force of 1,560 acts at the end of the lever G M $=$ 6ft.;
$\therefore$ The Righting, or in this case, the Turning Moment $=$ 1,560 tons $\times$ 6 feet $=$ 9,360 foot tons.

But the righting moment is the weight of the ship multiplied by the righting arm. What is the product of these quantities?

G Z, the righting arm $=$ G M $\times$ Sine of 9° $=$ 6 Ft. $\times$ ·156 $=$ ·936 Feet.
Righting moment $=$ 10,000 Tons $\times$ ·936 Feet $=$ 9360 Foot Tons.

Both calculations declare the righting moment to be 9,360 foot tons.

In other words, the weight of the ship into tho righting arm G Z = the component M T into the meta centric height. If now we plot Y as the centre of gyration, we shall be able to realise the nature of the force tending to produce motion, and the character of the resistance offered to it.

Let us for a moment suppose that G is a fixed point—the ship's fulcrum. Let us also regard the ship as a portion of a huge wheel (a portion of a flywheel) its radius of gyration being G Y.

By an examination of Fig 15 it will be seen that the greater G M is (with a given horizontal force M T) the greater is the turning moment. And the smaller the radius of gyration G Y, the smaller will be the resistance and the quicker will be the motion of oscillation. The forces necessary to produce and maintain oscillations in a heavy and in a light swing-boat respectively, will help to an understanding of this problem. The moment of the accelerating forces about the centre of suspension varies as the weight of the boat.

To obtain great stability and quick motion, we must increase the leverage G M, and reduce the pendulum length G Y : to obtain moderate stability, but a slow angular motion, and, therefore, a comfortable vessel at sea, and one offering a steady gun-platform, we must diminish the leverage G M and increase the length of G Y

With regard to G Y, which is obtained by dividing the vessel's moment of inertia about G by the sum of the weights, and extracting the square root, it is evident that it can be of great length only in a large vessel. In a small vessel, G Y can be increased by placing movable weights towards the bulwarks, but no such change as this will be sufficient to make the radius of gyration great enough to give rise to a slow rate of oscillation. An easy motion in small crafts may be obtained by shortening G M, but this may give rise to want of stability. Hence the difficulty of builders to make a perfect ship. They have to steer between Scylla and

Charybdis. Worse still, they strive to please shipowners, who know but little of the difficulties of naval architecture ; and to please themselves, with the result that they sometimes please neither.

This much is certain. Most shipbuilders, all important ones, are competent to build vessels that will be seaworthy in the fiercest storms that blow. They know more about the subject we are discussing than we can teach them, and if, when a vessel is ordered, they were informed in what trade she will be employed, they would design a craft that would yield the highest results in speed, economy, and stability. But if a vessel, expressly built for carrying iron ore, is engaged to carry grain, the builders' views are frustrated, and their scientific knowledge stultified. No man has produced a ship that is steady and stiff at the same moment. These conditions are apparently irreconcilable. By Fig. 15 we have shown them to be mutually antagonistic. Therefore, if owners find by experience that they are unable to keep their vessels in a given trade, it would be better for them to say : "Build my vessels with stability enough to be safe under the most *unfavourable* condition of loading." Further, when the vessel begins her career, her character, as far as relates to stability and motions among waves, under different assumed conditions of stowage, ought to be given by the builder to the owner for the guidance of the masters who may have to take command. A ship's points should be as well known as a horse's, and only one man can give the information required. That man is the builder.

It has often been asked : Is it not possible to build a ship of great stability whose rolling proclivities can be checked by agents external or foreign to the hull? Cannot rolling be regulated?

One important answer to this question may be seen on board several of H.M. warships, where large tanks have been built across the vessels at about the water-line. These tanks are partly filled with water when the vessels are rolling heavily, and their effect is made manifest by a reduction of the angle of roll. Such free water has been found efficacious in extinguishing small angles of roll. In other words, it is of small value when the vessel rolls 30 degrees from the upright and back again. It is serviceable to vessels passing through about half this angle or less.

Bilge keels, on the other hand, and side keels, though they offer but little resistance to rolling through small angles, are said to acquire great value when heavy rolling begins. This arises from the fact that a vessel rolls through an arc of 60° in nearly the same time that she rolls through an arc of 10° or less. Her angular velocity will be six times as great in the former as in the latter case; and if we assume that the resistance varies as the square of the velocity, it will follow that the bilge keels will offer 36 times the resistance when rolling through an arc of 60° as when rolling through an arc of 10°.

Side keels have been found more useful to check rolling than bilge keels; and *hollow* side keels fitted in short lengths are said to have been experimentally proved greatly superior to either.

At this point it may be well to consider the question of dynamic stability. You know what potential energy is. If you lift a pound weight from the ground to this table, you create potential energy. The slightest touch and the weight falls to the ground, and in falling is able to overcome resistance. Potential energy is the result of a disturbance of equilibrium. If a harp-string be struck, as in playing, the energy referred to is made visible in rebound and vibrations. The same with compressing or extending springs, raising water from the ocean to the sky as clouds, pumping water into reservoirs, bottling sunshine, &c.; all these are familiar instances of storage of energy that may be utilised if we know how. Wave action upon ships, stores wave energy *in* ships to an extent depending on their weight and stability; and the manner of ascertaining the amount of work put into a ship is as follows:—

Fig. 15. The force M T = 1,560 tons, becomes nil when the vessel's deck is parallel to the wave slope or to a smooth sea. Therefore the *mean* force acting to turn the ship at M about the centre G is $\frac{MT}{2} = \frac{1560}{2} = 780$ tons. This *mean* force acts through the space M T – M G × Tangent of the angle of inclination = 6 feet × ·158 = ·948 feet. And 780 tons × ·948 feet = 739·44 Foot Tons Dynamical Stability.

In large vessels it is not quite accurate to regard the angle of the wave profile as the *effective* slope; "it is, however, an error on the side of safety to assume that the variations in inclination and magnitude of the fluid pressure and the apparent weight of the ship may be determined from the upper surface of the wave."

Mr. W. H. White gives the following simple and useful formula:—

$$\text{Dynamic Stability} = \text{The Ship's weight} \times GM \times \frac{\text{Circular Measure}^2}{2}$$

This is the potential energy—the work—put into the ship by the waves changing the direction of the buoyant force through an angle of 9°. And this work must be taken out of the ship before she will cease rolling.

The most important agents to retard rolling are our old friends who create rolling, viz., the "shoulders." They plunge right and left into the ocean, and generate waves which rush away at right angles to the vessel's length, just as ripples rush from the hand that creates disturbance in a pond. Waves, or undulations, are forms of mechanical energy. Energy created them, and must exist in them so long as they retain the wave-form.

Storm-waves produce violent rolling in the largest of floating structures, and these structures are occasionally brought to rest by a sudden and complete expenditure of their stored energy. And the greater the energy *in* the vessel, *i.e.*, the heavier the *ship*, and the quicker the motion, the more tremendous is the blow she can inflict upon an approaching wave. But, unhappily, when the momentum of an ocean wave is not only resisted by a vessel's hull, but is increased by the dynamic energy of the ship, a climax occurs, the severity of the blow is manifested by the vessel ceasing to roll (her energy being expended), and by the wave bursting high above the decks and sweeping them from end to end. This condition of things, as about to happen, the writer wishes to convey in the rough sketch, Fig. 15, by arrows, showing the direction of the ship's oscillation and the wave's advance. Figures 15 and 16 are not by any means to scale. They roughly illustrate ideas.

That this description of the causes which lead to decks being swept, and boats and houses being carried away is required, is certain, for a common remark concerning a ship that does not roll, or rolls but little, is: "Yes, a steady ship no doubt, but like a half-tide rock;" the idea present to the speaker's mind being that waves will burst over her *because* she is steady. This is an old-time error. All other things being equal, the steady ship has the safest weather deck.

We have already calculated the dynamic stability of the vessel, Fig. 15, whose weight is 10,000 tons, metacentric height 6 feet, and angle of inclination to the wave surface 9 degrees. Such a vessel will be a quick and a heavy roller. The writer has had experience of such a craft. Assume this vessel's radius of gyration, G Y, to be 22 feet. Find her rolling period.

$$T = \cdot 554 \sqrt{\frac{R^2 \text{ or } Gy^2}{G\,M}} = \cdot 554 \sqrt{\frac{22 \times 22}{6}} = 5 \text{ seconds.}$$

That is to say, she arrives at the end of a roll once in 5 seconds, and makes 12 per minute. Each time that her momentum is resisted by the sea, and she is brought to rest before the return roll begins, racking-strains are produced upon the hull, and the riveting is severely tested. Some ships have even been lost at sea through the violence of their rolling finding out the weak spots of the hull, and causing leaks that sooner or later overcame the ship's pumping power. Hence great stability, producing as it does quick rolling, is not an unmixed blessing.

By way of comparison let us turn to an Atlantic liner of 10,000 tons weight and a meta-centric height of 1 foot. Compare her rolling period with the former vessel's. Let the radius of gyration be the same as before.

$$\text{Here } T = \cdot 554 \sqrt{\frac{22 \times 22}{1}} = 12\cdot 19 \text{ seconds.}$$

This change of meta-centric height has converted a heavy quick roller into a comfortable ship—into a ship rolling through a given arc in more than twice the time taken by the other. And more important still is the fact that instead of twelve rolls being made per minute—with the inevitable racking-strains at the end of each roll, we now have only $\frac{60}{12\cdot 19} = 4\cdot 9$; say 5 rolls per minute. Consequently if the life of a ship varied inversely as the racking-strains, and the quick roller came to grief in ten years, the life of the other would be $10 \times \frac{12}{5} = 24$ years. This computation is, of course, inapplicable, because vessels which are strained at sea are repaired in harbour, but the cost of repairs of a violent-rolling ship is sometimes enormous, and furnishes another reason for owners and builders to keep the meta-centric height as small as is consistent with safety.

The initial dynamic stability (to coin a phrase) of this slow moving vessel is, when moving broadside among Atlantic waves with a slope of $9^{\circ} = 123$ Foot Tons. This force, of course, imparts a rolling motion. It *will* impart a rolling motion if nothing is done to take the work out of the ship. It has been said that free water in cross tanks, that bilge and side keels, all exhaust the dynamic stability and arrest rolling. Is it possible by any other device to prevent the ship rolling by an almost *immediate exhaustion* of her dynamic stability?

Fig. 16 is intended to answer this question. The ship is represented on the wave slopes, &c. Hollow side-keels, K K shown distinctly in Fig. 15, are fitted on each side of the ship in short lengths at about the water-line, their function being to exhaust the wave energy in the ship. In the position shown at B, the starboard keels will be full; at C they will be empty. The length of the hollow keels each side is arranged to suit the vessel's rolling period. They must empty themselves in about the vessel's quarter period, in this case, in three seconds. The greater the angle of roll, the greater is the amount of work performed by the side keels both in the water and out of it.

Very few vessels are made to roll heavily by one passing wave. It is the energy of many which produces angles of roll of 30° and more on each side of the vertical. These hollow keels would it is supposed prevent this accumulation by partly or wholly exhausting the energy of *each* wave as it was passed into the ship. It is said of these, as compared to *solid* side-keels that in entering the water they do not produce violent shocks on the hull. Probably the reason of this is their not possessing *buoyant* or disturbing capacity, and because of their entering gradually instead of abruptly.

The most dangerous rollers are vessels possessing a period equal to the half-period of the waves they are amongst. Atlantic storm waves are said to have a period of about 12 seconds; therefore, a vessel having a period of about 6 seconds will make two rolls during the time she passes from crest to crest. Twice in that period the lateral buoyant force, developed by the wave slope, will augment rolling. On the other hand, a vessel whose period is the same as the period of the wave, will generally be steady. Occasionally she will no doubt make a heavy roll, but heavy *continuous* rolling cannot very well take place. At the same time the writer is of opinion that, for the best results to be obtained at sea, the period of the ship should be neither the period of the wave nor the half-period of the wave. If we avoid these periods we avoid the synchronism which acts on the ship to produce, and augment rolling, just as an assisting touch given to a pendulum augments its angular velocity. Fig. 16 is intended to show the relative motions of the ship and wave. The wave period is 12 seconds; the ship's period is 12 seconds.

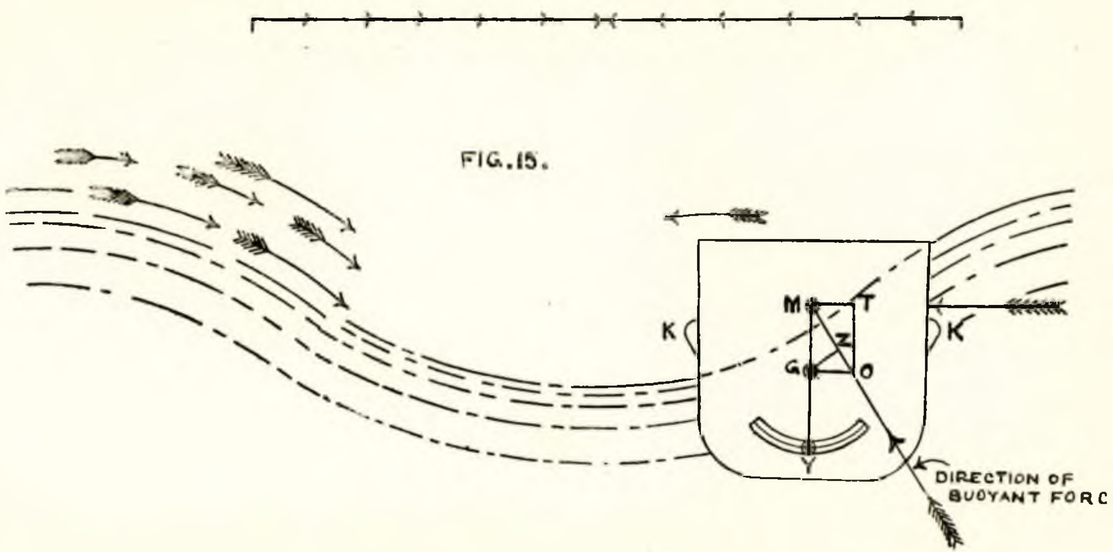
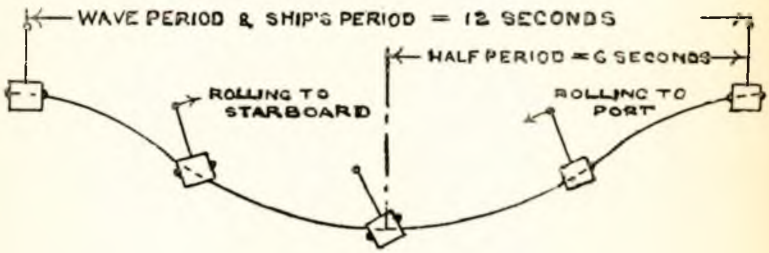


FIG. 15.

FIG. 16.


WAVE PERIOD & SHIP'S PERIOD = 12 SECONDS
HALF PERIOD = 6 SECONDS
ROLLING TO STARBOARD
ROLLING TO PORT

INSTITUTE OF MARINE ENGINEERS.

SESSION, 1891-2.

REMARKS

ON THE

THIRTY-FIRST

AND

THIRTY-FIFTH PAPERS

(OF TRANSACTIONS)

ENTITLED

STABILITY,

AND THE

MOTIONS OF A VESSEL AMONG WAVES

BY

MR. J. A. ROWE
(MEMBER).

Read at Gresham College, E.C., Tuesday, January 12th, 1892.
Discussion continued at the Town Hall, Stratford, Tuesday, January 26th, 1892.

PREFACE.

58, Romford Road,
Stratford,
January 30th, 1892.

A Meeting of the Institute of Marine Engineers was held on Tuesday evening, 26th January, in the Town Hall, Stratford, by kind permission of the Mayor and Corporation, when the Papers on "Stability and the Motions of a Vessel among Waves," contributed by Mr. J. A. Rowe (Member), were further discussed.

The chair was occupied by Mr. W. H. White (Director of Naval Construction).

The Papers on the subject under discussion were read (Part I.) on Tuesday, October 13th, 1891, in the Town Hall, and (Part II.) on Tuesday, January 12th, 1892, in Gresham College, E.C.

We are indebted to the kindness of the Editor of *The Marine Engineer* for the blocks used in illustrating the Papers, and to Messrs. McGregor & Co., Glasgow, for the illustrations printed from the blocks. This opportunity is taken to acknowledge these courtesies.

JAS. ADAMSON,
Honorary Secretary.

STABILITY.

DISCUSSION

HELD AT

GRESHAM COLLEGE.

JANUARY 12th, 1892.

THE CHAIRMAN

Mr. T. F. AUKLAND,

(Honorary Member).

Our very good friend Mr. Rowe has brought before us to-night a most interesting paper for discussion upon the extremely important subject of the Stability of Vessels carrying cargo, both outwards and homewards I mention both ways because there is such a w e difference very often between the multitudinous descriptions of cargo out and home, that captains of ships and steamers have to exercise the utmost care and supervision in dealing with the various weights of the different cargoes they are required to carry, in order that the ship or steamer they command may be able to successfully surmount all the difficulties of sea-peril which they may encounter on their journeys to and fro A vessel to be properly stowed should be in the condition of having sufficient surplus buoyancy to enable her to roll safely and easily at sea. The weights must be as equally distributed as possible, so that no part of the framework may be unduly strained, she must not be too stiff, she must not be too tender, or, in either case, disastrous results may follow. It is quite possible for a vessel to be built in such a way, that with one description of cargo she may be perfectly safe, and when at sea with such a cargo the commander may do anything reasonable with her, but with another description of cargo, this very same vessel may be most unsafe. I will give you an instance,—one of many with which I have been personally acquainted. A ship (iron), of 1,400 tons, now sailing, to my knowledge is as safe as possible when loaded with iron, or other deadweight. When full you may steer her and sail her with almost the ease of a yacht, but put a light cargo into this same ship and she will not stand up under canvas, neither steer, and is very nearly unmanageable. The reason of this is, she is built very solidly, and more particularly so up aloft, this causes her to be so very tender with a light cargo. I remember this same ship coming home twice from Colombo with 1,700 tons of cocoa-nut oil, and other light cargo, with some mineral produce as ballast, and the captain had the greatest trouble with her on the homeward passage, because directly he set sail she heeled over so much that the sail became not only useless but positively dangerous, yet outward bound full of coal she went well enough, and steered well. It is thus very important that a captain should be well acquainted with the character of his ship, so that, if requisite, when carrying a lighter cargo than usual, she should be very well ballasted. We have had many ships lost by capsizing, and this unfortunate untimely ending, in what might otherwise have been a useful career in a ship, is due to errors in judgment when loading, and possibly to even indifference of consequences in the undue haste to earn some good freight at the moment offering. Liners are mostly exempt from these difficulties, because they are generally built specially for the requirements of the trade in which they are engaged; and, further, they generally belong to owners who take every care that they shall be preserved as much as possible, and only allowed to carry as much cargo as can be readily and easily stowed. In other words, they are seldom more than well ballasted. But the tramps are required to be veritable beasts of burden—to be employed here, there, and everywhere, carrying anything and everything, whenever a freight is to be had. It is to these said tramps that we have to look for lessons in stability or instability, and to which safe rules for their guidance in loading should be applied, and, wherever necessary, rigidly enforced. I cannot help thinking that those who have tried their best to construct steamers which will pay a good dividend as tramps have much to be answerable for. At the expense of risk to life and property, they sail their vessels in such a manner as almost to court disaster; they evidently only provide against fine or moderate weather, forgetting or ignoring altogether the fact that bad weather, especially in certain parts, at certain seasons, is almost sure to be encountered, and then unable, perhaps, to rise to the seas, they either get terribly battered, and decks swept, everything movable being carried away, or, worse still, seas break over them, and they become engulphed altogether, or they, perhaps, capsize like the steamer "*Dunmurry*" in the Atlantic, lately, with a cargo of grain, when seventeen hands were drowned.

As an instance of dangerously-built steamers, some few years ago types were built very deep in proportion to their breadth, called three-deck steamers. A great many were built from the fact that it was expected they would be large carriers, on account of their depth of hold, and would not offer too much resistance in their steaming qualities by too great breadth, but of this type some eighty or ninety, in a comparatively short time, disappeared—the majority capsizing.

I feel personally (and I am sure I echo the sentiments of all present, when I say that we are all) extremely obliged to Mr. Rowe for his kindness in bringing this paper before us, considering the extreme importance of the subject, and the desirability, I may almost say the imperative necessity, that exists of obtaining and practising rules and regulations for the safety of ships, in respect to their build and stowage.

CAPTAIN HOLT

(President Ship-Masters' Society).

I have had great pleasure in listening to the paper just read by Mr. Rowe, and I may say I wish that every man who went to sea would always know the exact meta-centric height that his ship would have, whether grain-laden or otherwise. Naval architects can design any ships that are asked for, but it is not their fault if ships are badly loaded, or placed on a trade to carry cargo they never were intended for. Many shipowners never studied the question whether their ships were fitted for particular cargoes or not, and therefore I blame the shipowner and the shipmaster, not the naval architect.

In the December number of the *Shipping World*, the question was started by Mr. Metcalf, as to whether it was safe to run up ballast tanks when the ship has a heavy list. I have found directly I dipped the deck line it was then unsafe to do it. It should also be remembered that a ship in a heavy sea is not like a ship lying at rest, but is liable to be thrown violently over on her side by every wave. In this particular case it was stated that the ship's meta-centric height was only half a foot. I imagine that was only a hypothesis, as no grain-laden ship, with only six inches of meta-centric height would stand any rolling at all. I would not like to go to sea in her myself. Plenty of H.M.'s ships were tested, and in all the cases quoted they had from two to three feet of meta-centric height, to get a steady gun platform. Cargo ships must require more than half a foot, more probably they require two feet. Sir Edward Reed recommended large ships to have two feet to two feet six inches. All ships ought to be tested before going to sea. We are obliged to test compasses, why not also the meta-centric heights? I am delighted to find the Engineers' Society taking up the matter, because were shipmasters and engineers to work together, the thing would be done eventually. There is one thing that could be done for all ships—working out their stability with the centre of buoyancy and centre of gravity coinciding, and working out the curves by drawing a circle between the centre of buoyancy and the centre of gravity, found by experiment. There is nothing in Mr. Rowe's paper to actually criticise, it is so plainly and practically put before the meeting.

Mr. J. MACFARLANE GRAY

(Vice-President).

Having been absent when the first paper on Stability was read, I am not able to say anything about it now. I have already spoken to you for two evenings upon the same subject, but, I am certain you have all enjoyed Mr. Rowe's explanation more than you did mine. I shall therefore not add now to my former statements, but will merely draw attention to some of the expressions in the present paper, which, I think, are likely to be misunderstood by those not already well versed in the matter.

The expression "Moment of Inertia" in the first formula is employed by all writers on this subject, just as it is employed by Mr. Rowe. In objecting to it you will see that I am not criticising Mr. Rowe. In this formula and many others which engineers have to work with, in which the idea of inertia has no place whatever, this expression "moment of inertia" is continually employed, and in my own experience and the experience of many students known to me, this use of the word inertia has only perplexed the beginner. I mention this now because I see Professor Greenhill in the hall, and he is an authority on such matters. I suggest that the word "bi-moment" should be employed in place of the expression "moment of inertia" when inertia is not in any way implied in the quantity under consideration. The term "bi-moment" carries its own explanation, it is the moment of the moment, and that is the meaning of the expression "moment of inertia" in the present formula.

I would recommend the student to omit the word

" measured " in the statement " that the water line area, or the plane of flotation, is the superficial area of the deck of a ship measured *at the water line.*" The word " measured " is apt to be understood as implying that the area is to be dealt with as a whole, a certain amount of superficial content. I would prefer to omit the word area altogether on this account, and to write " bi-moment of water-line section."

I remind you that I told you that the expression given for B M when the water-line section is a rectangle can be read as $\frac{b}{d}$ inches per foot of beam; here d is to be taken as the mean depth, and the immersed hull may have any ship-shape form, if only the water-line section be a rectangle.

There is something amiss in the second paragraph, about B M being " said to be the measure of a ship's stability derived from the *shape* of the hull." It is obvious that B M by itself cannot be regarded to be in any sense the measure of a vessel's stability. The context, however, shows the sense intended.

The author says that it is incorrect to say " that a vessel's stability varies as the beam cubed." The same meta-centric height, G M, may be found to give equal satisfaction in vessels of greatly different dimensions. The moment of statical stability in vessels of similar fineness of form will then be as the beam cubed, and this may be the meaning of the statement objected to. I observe the remark, " " if there is any pendulum-like motion in the ship it is of necessity about G or M, at a length G M." The instantaneous axis about which a vessel moves when amongst waves has not, as far as I know, been ever domonstrated or determined. In still water it is neither about G nor about M. The instantaneous axis passes through the point in which the horizontal through G cuts the vertical through F, the axis of the plane of flotation. In the study of dynamic stability the axis about which the vessel is regarded to move is the longitudinal horizontal through G. This is, however, only a convention, adopted because the problem depends upon the *relative* heights of G and the varying point B, and the radius of gyration. In dynamic stability, therefore, the centre of oscillation assumed is G, and the arm is the radius of gyration. In static stability, within meta-centric limits, it is convenient to regard M as the point of suspension of the ship as a pendulum bob at G. It must, however, be borne in mind that neither of these is actually correct.

In fig. 15 the forces acting on and in the hull are the force of buoyancy in the line O M, and the equal and parallel force of the effective weight of the hull acting downwards through G. These constitute a couple, having for the length of arm G Z. The balancing couple is the force of inertia acting at the mean arm, the radius of gyration. The couple T M·G M, is no doubt equal to the actual couple G Z·O M, and many other couples might be put forward each equal to G Z·O M, just as a ten pound note has hundreds of equivalents in coins of different denominations, but when the question is what passed between one person and another, it may be important to settle whether it was ten sovereigns or a ten pound note. In fig 15, let O M be produced upwards, and from any point whatever (*m*) in the produced part, let a straight line be drawn to G, and let *m t* and G *o* be drawn perpendicular to G *m*. Let *m o* now denote the force of buoyancy, then the author's demonstration will equally establish that *t m* is the actual force at *m*, and that the arm is *m* G, because if the arithmetical part of the proof be repeated for *t m*·G *m*, it will verify the righting force as before The point *m* may be taken at any height whatever. The force T M has, therefore, no actual existence, it is only imaginary, and introduced for supposed simplification.

At this stage in the paper I conclude my remarks. I think the author deserves the thanks of the Institution for bringing before us his setting of the principles of stability. Those of you who have sufficient patience to read my remarks as well as his, and to grasp what was in Mr. Rowe's mind and what was in mine, will appreciate the advantage of looking at the statements from different standpoints.

PROFESSOR GREENHILL.

Admitting that mathematicians deserve some strictures for their terminology, a great deal of which requires revision, at the same time there seems a lot of prejudice to overcome. I do not agree with Mr. Gray's criticism of diagram 15. To my mind it represents the state of things most accurately and in a novel manner.

Mr. GRAY.

May I ask if GM is a lever in the diagram, because, if it is a lever, then the magnitude of the force is determined, but I did not regard GM in the ship as a lever, GZ is the lever. I understand that it is meant by the author that the horizontal component is an actual force TM, and this is what I say is not the case.

PROFESSOR GREENHILL.

Mr. Rowe's statement is quite right if MO was laid off to scale. Mr. Gray was not present when Mr. Rowe said that MO was laid off to an arbitrary scale. Mr. Rowe has been discussing " steadiness and stability." The two questions are essentially distinct. The smaller amount of initial stability a vessel starts with the easier the motion of the vessel. I am pleased to hear Captain Holt's remarks about the responsibilities of the shipbuilder. The way in which a vessel is stowed makes all the difference between making good weather, and being absolutely dangerous; of course, the theory of stability has its applications on land as well as at sea. In the pictures of the old stage-coaches one could see luggage and passengers all piled on the top, the centre of gravity being raised as high as possible. Theorists would have said it spoiled the stability; on the contrary, it made the going of the carriage ever so much better. Locomotive engineers are beginning to find the same thing. In the photograph of the American engine which was supposed to have made the fastest running, the height to which the centre of gravity was raised was particularly noticeable. Mr. Rowe had drawn a diagram of the cross section of an old-fashioned ship, the sort of cross section to be seen on an old-fashioned man-of-war. I wish to ask Mr. Rowe what were supposed to be the practical advantages of that. Was it a question concerning the guns, or the stability of the man-of-war, or the seaworthiness?

Mr. ROWE.

The "Lord Warden" had that form. She was a heavy roller. She had great MC height, and the reduced breadth at the water line was probably meant to make her roll through large angles as quietly as possible. Mr. Gray has quoted me as saying:—"If there is any pendulum-like motion in the ship, it is of necessity about G or M at a length GM." Will you kindly turn to the passage, and read for yourselves what I said?

PROFESSOR GREENHILL.

I have also seen it mentioned that a ship was more liable to capsize if a little unsteady on the top of the wave. Could any explanation be given of that?

Mr. ROWE.

It is exceedingly gratifying to me to have the support of so distinguished a mathematician as Professor Greenhill in regard to diagram 15. With reference to Captain Holt's remark about men-of-war having two or three feet MCH for steady gun platforms, no doubt Captain Holt knows as well as I do that with a given radius of gyration, the greater the vessel's stability the worse she behaves as a gun platform at sea. In answer to Professor GREENHILL's question concerning the greater liability of a vessel to capsize when on the *crest* of a wave, the following explanation may suffice. The centrifugal force of the waves virtually increases a vessel's weight when she is in the wave hollow and decreases it when she is on the wave crest. Mr. W. H. WHITE, an authority universally respected, has stated that the normal weight of a vessel may on the wave crest be reduced by about $\frac{1}{5}$. It therefore follows that her righting moment for any given angle when she is on the crest of a wave, will be only $\frac{4}{5}$ the righting moment she possesses when in smooth water. This shows the need of giving a ship considerably more stability than she would appear to require when in apple-pie order in a wet dock. Circumstances are continually happening at sea to baffle the calculations and intentions of naval architects. Water sometimes cannot be pumped out of ballast tanks, water sometimes will accumulate in bilges. In both cases free water is reducing the vessel's original stability and preparing her to become an easy prey to the squall of wind that may strike her when on the crest of the wave. And now gentlemen I beg to express my hearty thanks to you all for the friendly way in which this paper has been received.

STABILITY
AND
THE MOTIONS OF A VESSEL AMONG WAVES,

BY MR. J. A. ROWE (MEMBER).

DISCUSSION
HELD IN THE
TOWN HALL, STRATFORD,
JANUARY 26th, 1892.

THE CHAIRMAN,
MR. W. H. WHITE
(DIRECTOR OF NAVAL CONSTRUCTION).

I have come to this meeting for two reasons, one being that I have the pleasure of knowing Mr. ROWE, and the other is that when Mr. MACFARLANE GRAY called on me in reference to one or two points that had arisen at the previous meeting I thought I would come down and see the society at work. I now ask Mr. ROWE to initiate the discussion.

MR. ROWE.

Mr. Chairman and Gentlemen, I have little to say that would be of service to those about to take part in the discussion. The paper has been in the hands of members for some time, and I have nothing to add to its contents. I am sure we all feel it an honour to have so great an authority on naval architecture amongst us as the Director of Naval Construction.

CAPTAIN FROUD
(SECRETARY SHIP MASTERS' SOCIETY).

I am entirely at sea regarding the scientific side of this question. I am here to learn and can only testify to the great teaching and practical value of Mr. Rowe's paper. The little I know has been acquired by rule of thumb. To show the want of knowledge which is almost universal, I may mention a fact of recent date. A vessel of five or six thousand tons burthen was loaded in the port of London and left port with 700 tons of water ballast, which gave her an extra immersion of 17 inches to propel through the water; and those controlling did not know if the ballast was necessary or not. I early learnt when fixing proportions for vessels that a certain proportion of beam to depth in steamers, fitted in all respects in the ordinary way without double bottom, might be loaded full with homogeneous cargo, and be safe at sea without ballast of any kind, and that the same vessels, when empty, were sufficiently stable, through initial stability, to be safely moved when in port, a very desirable and economical condition.

Perhaps I can put the matter a little more clearly. An ordinary cask full of tallow if put into the water will float awash, and will have no tendency to roll to the sea running past; but, if the bilge is ever so lightly touched it will turn round, it has no stability. If the same weight of iron be put inside the cask it will become stiff, will not turn round, but will roll more or less to the swell passing.

Mr. Rowe has been showing us the point of safety and ease between these conditions and how it can be ascertained.

Vessels in water ballast roll violently, and all purely passenger ships roll freely, some heavily, as generally speaking, their dead weight cargo is necessarily low down.

Mr. JOHN R. RUTHVEN

(Member of Council).

We are greatly indebted to Mr. Rowe for laying before us this most important subject. I hope this discussion will not end without some good resulting. An attempt should be made to make practical use of the knowledge we have on the subject. The subject should be well known, yet of the number of ships leaving port this day not one in a hundred has had her qualities tested, nor is her amount of safety known. It is to the advantage of everyone, both ashore and afloat, that our ships should be not only safe, but that their amount of safety should be known. I propose that a committee should be formed from the various institutions interested, and that they should collect information as to the present conditions in which ships leave port, and of their subsequent behaviour at sea; and afterwards to take steps to urge that the navigating officers should be assisted in the knowledge of stability, at least so far as to be able to measure the amount of stability of their ships in calm weather. I have no doubt owners will gladly furnish the necessary gear for the purpose, and underwriters will look favourably upon a ship where this extra caution as to safety has been attended to. If this Institute is instrumental in moving the Board of Trade to secure this extra safety, a great work will be done, which will deserve the thanks of the country.

Mr. J. MACFARLANE GRAY.

I do not at all agree with Mr. Ruthven that this Institute should take up the collecting of reports on the actual loading of vessels. We are engineers, and while we ought to have a knowledge of the principles of stability and many other subjects allied to our own calling, I think that our duty regarding such matters should end with our understanding them. We could not do what Mr. Ruthven proposes we should do, and if we were to attempt to do it we would only create ill will against the Institute. Shipmasters are equally interested in having safe boilers, but how would our members regard the appointment of a committee of the Shipmasters' Society to collect reports on the condition of steam boilers and the methods of treating them at sea.

Mr. N. K. McLEAN.

(Member).

After carefully reading Mr Rowe's first paper, and listening to the reading of the second, I can say that the subject treated by Mr. Rowe is a most interesting one to all who go to sea, for their comfort and safety. Mr. Rowe has treated the subject so well, that he leaves little room for remarks, but there is one suggestion in the paper that should have the careful consideration of all shipowners, viz., to have a diagram supplied to them by the builder, with each ship, as a guide to loading the ever-changing cargoes of the majority of our mercantile steamers, with strict orders to the captains that great attention be given to this. I believe that with care in loading and distribution of weight, all ships could be made safe and stable. As an example coming under my own notice : I joined a steamer which had a fearful character as a tremendous roller. Given a start she would keep on rolling, even in smooth water. Well, the captain was determined to try if it was not possible to make this ship behave better, and he succeeded beyond his expectations. By his own attention to the stowage, this vessel became easy and comfortable in her motions. But with a change of captain, the stowage was left to the original officer, with the result that the vessel fully merited the character previously given, for she became one of the most uncomfortable ships I ever sailed in. Naval architects can design and build a ship that would be stable under every condition of sailing, light or loaded ; but I am afraid it would be unprofitable. Few steamers are afloat that do not change their cargoes each voyage, and some cargoes are very dangerous Which of us has not seen steamers in the Red Sea and Suez Canal homeward bound, with rice cargoes, listed over to such a degree that one wondered how it was possible they passed safely across the Indian Ocean ! I have heard of the crew trying to get them, if possible, upright, by filling the boats on the high side with water, with the result that she flopped over to the other side, from port to starboard, or *vice versa*. Of course, the reason is well known. The ship leaves

Rangoon, or other rice ports, with the lower bunkers full of coals, all other spaces filled with cargo, even to the cabins. Well, the ship is a little tender when leaving, but quite safe, but after steaming a few days there is a decided list, and the engineer is requested to keep the ship upright, and not burn more coals from the one side than the other. Of course, the list increases daily, till the ship is in a most dangerous condition by the time she reaches the Red Sea. Now, why cannot the bunkers be constructed to carry their coals to the upper deck, or even have a larger quantity above, so that the vessel would become more stable each day, or, at all events, not get beyond the tender stage. Mr. Rowe has mentioned different means of preventing rolling, by bilge-chocks or side keels. I have had no experience with any. They may largely prevent heavy rolling, but it is not a cure, and I cannot understand how they ever can be. The cure must come by proper distribution of weight when stowing the cargo. When speaking of carrying the bunkers to the upper deck, I do not refer to large passenger steamers.

In answer to Mr. Shorey, I may say I have experimented a little by using up the coals in the lower bunkers first, then filling up, say, at Port Said, and commenced with the 'tween-deck bunkers, and I have invariably found that, with general cargo outward, the ship's motion was much easier when the 'tween-deck bunkers were full. In the case mentioned of the ship loaded with rice, the captain could not help himself, as the ship had no ballast tanks, and he had to carry the quantity. The construction of bunkers was in fault.

Mr. R. LESLIE

(Honorary Treasurer).

I consider that the captains in charge of large steamers ought to have instruments with which they could immediately before going to sea test the stability of the steamers under their command. This they could easily have in the form of tanks on either side of the vessel which could be used just the same as the weights are used at present. On the engine room bulkhead could be fitted a movable pendulum. This would enable the chief engineer with the captain to test the stability of the ship at any time before sailing. The captain could then arrange the trim of his ship so as to know that if he burnt 500 to 700 tons of coals out of his lower bunkers he would still have a good deal of stability to spare. I have known a steamer to pass through heavy weather just after leaving port, and I may say that she was, comparatively speaking, very steady, but after ten or twelve days' steaming just a light swell would make the ship roll from side to side. I maintain that all steamers ought to have their cross bunkers carried up as high as possible and not confined to the bottom of the ship. The chief engineer has all the necessary instruments for testing his engines in every way, and I certainly am of opinion that so responsible a person as the captain of a steamer ought also to have the necessary instruments always at hand for testing the stability of the ship under his charge. He is, at present, to a great extent in the dark, as his only item of information is a plan of the curves of displacement and stability. These, of course, are nicely framed and hung in the chart room, and there I fear the matter ends. I should be very pleased to see this matter of stability thoroughly gone into by our members, and I am sure that those of us who may be well up in the subject would be very glad to impart any points of interest to all who may be willing to learn.

Mr. J. H. THOMSON

(Member of Council).

I would not allow any vessel to leave port without the stability being properly known, just as a boiler cannot be put on board without the fact of its safety being known A great deal seems to depend upon the way in which a vessel is loaded The waves across the Bay of Biscay in a storm do not agree with Mr. Rowe's diagram, for they may come to counter, beam, or bow. A diagram showing a wave following and striking a vessel on the quarter and rolling up the side, putting her over, then as she rights, for the next wave to come tumbling on board, would be useful, for should a ship's factor of safety be known to withstand that, there would be no fear of going to sea in her.

THE CHAIRMAN.

(Mr. W. H. WHITE)

If no one else has anything to say I should like to make a few remarks. I have read Mr. Rowe's two papers. The subject is one with which I am necessarily familiar. I take it that Mr. Rowe's intention in writing these papers was a very modest and praiseworthy one. He did not profess to give us any additions to established principles or to add to available information, but sought to bring the information in what he conceived to be a practical and simple form before the members of this Institution, some of whom, from what has been said to-night, would not have been prepared to consider the matter from the mathematical side. I have endeavoured myself to do a good deal in the same direction. Nearly 20 years ago, when professor at the Naval College, I found myself continually met by officers in the navy with enquiries such as I have heard here to-night. It is the business of seamen to navigate ships, but they may be quite ignorant of the principles of stability and of the behaviour of ships. The result of this intercourse with naval officers was that I, although a landsman, set to work. Being familiar with the mathematical theory of the subject I had to try and put into such a form as could be understood by gentlemen with limited mathematical information, the result of investigation which had occupied the ability and tasked the ingenuity of some of the best men of this century. It is not an easy matter for any one to deal with questions of the stability and behaviour of ships in an exact and complete fashion. I am a landsman as I have said, but it has been my fortune to be at sea, and I quite endorse what Mr. Thomson said as to the actual waves of the sea not being as shown on the diagram. Gales blow from all quarters, and it is often difficult to tell the direction whence waves are coming when the sea is "confused." But what is the use of taking the worst phases of a difficult problem in beginning, instead of the simplest case shown on the diagram. If the latter looks beautifully simple on paper it does not yet admit of exact scientific solution. All that can be done is to approximate to the behaviour of actual ships among actual waves from what we know would be the case when each wave is of the same character as the one going before it. It is possible to put down drawings of a series of waves superposed upon each other and thus to get infinite varieties of combination. But the principles embodied in the simplest investigation are the principles which must govern the behaviour of all ships in the most confused sea ever seen. Now take this simple diagram, just conceive what has to be dealt with by the investigator; he has a ship heaving up and down or else she would be overwhelmed. At the same time she is rolling and very often pitching, she is suspended in water which, being in the form of waves, has every particle at varying depths, and varying positions moving in different directions and with different velocities. That is the problem the mathematician has to endeavour to solve. It can only be done approximately and with very great effort. What has been done in the last century, in fact in the last 30 years, is to lay down some important general conditions which experience has verified. For example, one gentleman spoke about a ship, where the coal had been burnt out, being set rolling by a moderate swell. That is a problem which half a century ago would have been difficult to explain. It is now well known that if the lower coal is burnt out the ship may have less stability. If floating in smooth water it would take less force to incline her than with the lower coal in. On the other hand it is absolutely proved by experience that as many ships become less stiff, they improve in behaviour. The explanation of that is to be found in the fact, that the speed at which waves pass a ship (which speed is determined by their length) must influence largely the ratio of that speed to the speed of the oscillation of the ship. Some years ago the Channel fleet was outside Lisbon, and in that fleet there were some "stiff" ships which had rolled

45° on each side of the vertical when crossing the Bay of Biscay, when other ships with much less stiffness did not roll more than 3° or 4° on each side of the vertical. Outside Lisbon the squadron got into a long low swell in which boats could move about with perfect comfort. Then the ships that had been wallowing in the Bay of Biscay rolled little, while the ships with less stability rolled heavily. Now these are facts entirely to be understood when you know one simple law, viz., that if a ship in swinging, gets an impulse every time she reaches the end of the roll, her motion will gradually become greater.

In relation to the motions of ships at sea, we have not learned any golden rule; nor does the problem admit of any general solution. But we have learned this, that certain meta-centric heights in association with certain freeboards and positions of the centre of gravity, in ships are essential to safety. It cannot be said that any particular meta-centric height gives absolute safety or good behaviour; it is only one element in the problem. One must also know how the weights are stowed. A gentleman said, in the discussion, that in the same ship the same amount of cargo (and, I presume, about the same dead weight), differently stowed, made all the difference in the behaviour. Well, the shipbuilder has nothing to do with the stowage, so that to look to the shipbuilder to give this guarantee of safety is asking more than experience justifies. For example, take a cargo-carrying ship. The builder produces a ship which, with the machinery, and everything in her complete, weighs about one-third of the total weight she goes to sea with; the cargo weighing twice as much as the fixed weights with which the shipbuilder has to deal. Over that cargo, and its stowage, the shipbuilder has no power. Now, how can you go to the shipbuilder and ask him to deal with the safety of the vessel under these circumstances. The utmost he can do is to say, that if you fill the ship up with a homogeneous cargo to the maximum load lines, she will have such and such conditions of stability Builders are now giving to owners that sort of information as to cargoes and their stowage. In many cases the data thus given is doubtless treated in the way we have heard mentioned – it is framed, glazed, hung up, and not understood. The difficulty is to give information in a form readily to be understood. But as a matter of fact, there have been, within the last ten years, to my knowledge, at least two or three practical plans brought forward, by which the actual stability of ships when laden could be easily ascertained. One of these was brought out by Mr. Taylor, on the Tyne, about 1882, exactly of the character mentioned here to-night. There were two tanks amidships, of known capacity, which were to be filled with water, and an apparatus, which noted the heel of the ship. If the ship had gone to sea at one constant water line, the thing would have been very simple. You could have had a gauge to measure off the meta-centric heights. The difficulty in practice is the varying draughts. Mr. Taylor introduced a very simple sort of scale, by which he approximated to the extreme conditions. There is not, believe me, any want of apparatus or want of interest on the part of shipbuilders. What is wanted is that the apparatus, or information, once supplied will actually be made use of in practice by those who have charge of ships.

The President of this Institution is Mr. PETER DENNY, whose firm supply every ship which they build with a book of "Ship's Qualities." In that book they give the means of estimating the stability, as well as all particulars relating to trim and stowage of cargo. Mr. ARCHIBALD DENNY, who has had much to do with that matter, and was a pupil of mine in former years, has said, publicly, that the first books they prepared were quite a disappointment. The very wealth of information seemed to frighten officers, and little use was made of these books. But that was only a matter of time. Mr. MACFARLANE GRAY will pardon me in differing from him as to the necessity of treating this matter experimentally. It will induce owners, before many years are past, to insist on commanding officers understanding the use of such apparatus and the conditions of stability. Another thing of almost equal importance to determining the meta-centric height, is making a ship swing, and knowing what time she takes to swing. A ship may have the same meta-centric height on two voyages and very different behaviour. Mr. Rowe has well pointed out that the behaviour depends upon the disposition of the weights round the centre of gravity of the ship. In this book of "Qualities," which Messrs. Denny are accustomed to supply, they deal also with the case which was mentioned just now of where coal consumption causes the changes in stability; and with what is equally important in practice, viz., the addition of water-ballast, which ought to be made in order to counteract the consumption of coal. I take it, it is not the shipbuilders' province to make a ship that not even the greatest fool who could be placed in command could make dangerous. If the shipbuilder followed this course, the ship would be unworkable, and possibly ridiculous. What he has to do is to make a ship properly safe when efficiently handled, giving instructions as to her working, in a form which will be useful to intelligent and experienced seamen. If it were to be laid down absolutely that no coal consumption should prejudice a ship's stability, then certain types now found profitable would not be able to engage in certain trades; but if commanding officers are given the information that after burning out coal to a certain extent the admission of a certain amount of water ballast is necessary, there is no excuse if they neglect to use water ballast in counteracting the effects of consumption of coal.

In the navy we always give, and have, for many years past, given to our ships "Statements of Stability," and, with warships which have known weights to carry, it is sufficient to give particulars for the fully laden condition and the extreme light condition. All other conditions practically lie between these two. In some classes great weights of coal are carried high up for defensive purposes, and when necessary in such cases we say burn so much out below before touching the upper bunkers, but when you have burned so much of the lower, transfer from above. It is not necessary for the gentlemen who are in command to consider why this is so, they have to follow certain clear and definite instructions. The suggestion which Mr. Ruthven made as to the tabulation of information has been made again and again; it is a thing which can only be carried out by the action of shipowners and commanding officers. The Committee of the Institute of Naval Architects made identical recommendations to the shipowners in 1867; nothing came of the suggestion. Until officers and shipowners set themselves to give us the information we shall not know very much about it. I remember one case I investigated some years ago, which is of very great interest. A ship capsized on the bar at San Francisco, grain laden, in weather not at all such as one would expect to cause the loss of a large well-found ship. It was alleged she was over laden, or badly laden. I was asked to investigate the matter, and given access to the ship's logs, I found not only that she had made previous voyages at deeper draft in safety, but with homogeneous cargoes. It was, at first, a little difficult to see how the case worked out as it did. But when I came to construct the curves of stability I found that in the grain laden condition the density of the cargo was such that with a given dead weight the 'tween decks were nearly filled. An equal or greater weight of other homogeneous cargoes, such as sugar, could be stowed in the lower hold, very little having to be carried in the 'tween decks. Consequently in the latter case, although the ship might have less freeboard, she was safer. If the facts of any ship are stated to a naval architect, he can always give the information as to stability, but the possible combinations which can be made of the *fixed* weights of the ship and machinery, and the *varying* weight of cargo put in, make it impossible for the shipbuilder to do more than give to those using ships the means of ascertaining for themselves what the stability of the ships may be on any particular voyage. If Mr. Rowe's paper, as I hope it will, has the effect of stimulating interest amongst those who can deal with these matters, inducing them to set to work to get data, then I am sure the paper will have served a good and useful purpose.

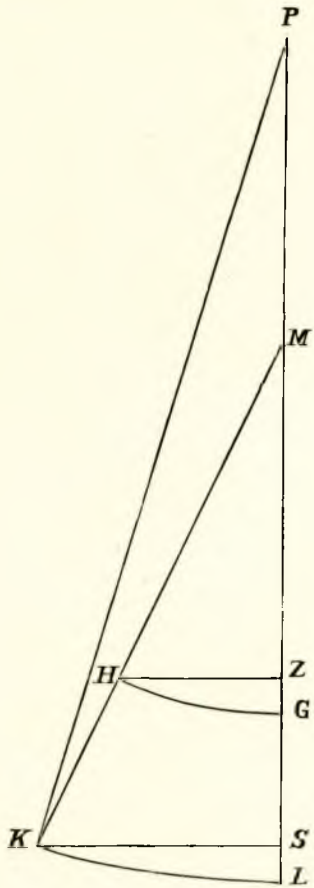
Gentlemen, I came here this evening and have taken part in these proceedings with great interest, and I hope the Institute will flourish and increase even more than it has done.

Mr. ROWE.

Mr. Chairman and Gentlemen, Captain Froud's remarks are those of a practical sailor, possessed of intuitive knowledge of his profession. I should feel very comfortable indeed in a vessel commanded by him. I am sure that no shipowner is pecuniarily benefited by possessing tender ships, some of which when without ballast tanks (as in the *Erato's* case) cost a little fortune in ballasting to keep them upright in harbour.

Mr. McLean's remarks are very instructive, and, coming from one who has had experience of tender steamships, should have weight amongst shipowners. Again referring to the pecuniary aspect of this question, let me repeat that "tender" ships in port or at sea are calculated to rob shareholders of dividends. If they do not capsize they diminish profits. A moment's reflection will convince the most sceptical that the machinery of a ship is in a state of *minimum* efficiency when she is heeled to an angle of from 10 to 15 degrees. Under such circumstances, the water level in the boilers has to be guessed at, the fires are imperfectly fed, the boilers may prime, the pistons exert an unwonted pressure upon the lee walls of the cylinders, the bilge pumps act with difficulty, and such water as may accumulate in the bilges bind the vessel to the angle of inclination she has assumed. It is better for all concerned to build ships possessed of ample stability, and then load them so as to move easily among waves. Bilge keels and side keels do not add to a vessel's stability, but they quickly extinguish rolling. The *hollow* side keels, or "troughs," I have referred to, and have experimented with, are wonderfully efficient agents to reduce rolling; and I hope one day to learn that torpedo-boats and other uncomfortable small crafts have been rendered habitable in rough weather by the use of *hollow* side keels of suitable dimensions.

I agree with Mr. RUTHVEN's opinion that underwriters would look favourably upon vessels whose stability had been tested and proved satisfactory, and whose commanders knew whether their ships were stiff or tender, and were able to take the right steps to rectify an error in the one direction or the other. A shipmaster at sea is an autocrat. In calms, in storms, in clear weather, or in fogs, he can steam what course he pleases, and adopt any speed he may think fit. No one on board need be taken into his councils, either as regards the condition of the hull and equipments, or the efficiency of the propelling power. A careful captain would no doubt consult those around him in a moment of supreme difficulty; but a very great deal depends upon the moral and social aspect of the case; for if in piping times of peace the relations between the captain and officers, and between officers and engineers (why not call these "engineer-officers"?) have been strained, but little consultation is likely to take place in moments of peril, and vessels are said to have been lost because the eye would not inform the arm, and the arm would not reveal to the eye its inability to cope with surrounding difficulties. Through such internecine quarrels Ancient Greece—the Greece that conquered at Marathon and Platæa, the Greece that produced the greatest men the world has any record of—fell into the degradation of slavery. She was conquered by Roman discipline, not by superiority of race; and discipline in this connection is merely another name for unanimity of sentiment. Is it too much to ask that everything reasonable should be done by shipowners to make every soul in the ship work together for the common weal? Nelson won his country's battles because he first won his sailor's hearts, and every shipowner and shipmaster should be as dear to the crew as Nelson was to his seamen. Further, seeing that many lives, and much valuable property, depend upon a shipmaster's knowledge of stability, he ought without external pressure to make himself master of the subject. The following diagram explains the construction of the *equivalent* pendulum used in the rolling period formula in a way that will, I think, commend itself to your judgment, as it has to mine. Mr. GRAY has been good enough to hand it to me.



In this diagram M G = metacentric height.

" " M K = radius of gyration.

" " P K = P L = length of equivalent pendulum.

Within metacentric limits, the exchange of energy going on in rolling, is that represented by the rise-and-fall of the whole ship swinging as a pendulum bob at G about M as a fixed centre, giving motion to the ship as if its radius of motion were the radius of gyration. The equivalent pendulum is, therefore, one whose rise-and-fall is that due to radius M G, and whose sweep of swing is that due to M K. Set off L S = G Z, and find P the centre of the circular arc passing through L and K, then will P L be the length of the equivalent pendulum. When the angle is small L P + P S = 2 P L nearly, and M G + M Z = 2 M G nearly. We

can then write $\frac{HZ^2}{2MG} = \frac{KS^2}{2PL}$

therefore $\frac{PL}{MG} = \frac{KS^2}{HZ^2} = \frac{MK^2}{MG^2}$

or $PL = \frac{MK^2}{MG} = \frac{R^2}{GM}$ on page 11.*

In conclusion, I again beg to tender my thanks to Mr. White for having taken the chair on this occasion; I hope it is not the last time he will visit the Institution. I am sure he will always receive a hearty and respectful welcome.

THE HONORARY SECRETARY

The papers on the subject of "Stability" contributed by Mr. Rowe are well worthy of the votes of thanks which were accorded to him at the previous meetings, and I am sure that those present will endorse what has been said in respect to this, and again unite in expressing our appreciation of the work undertaken by Mr. Rowe to place this subject before us in the pleasing manner he has done

---

* Page 11 in the second part of Mr. Rowe's paper.

Mr. CHAS. McEACHRAN

(Member).

In seconding the vote of thanks proposed to Mr. J. A. Rowe for the papers which he has read before us, I wish to say that I have followed him throughout with great interest, and I hope that the time is not far distant when the Board of Trade will take the matter up, and have the stability of all ships of which there may be any doubt tested before they are allowed to proceed to sea, as I consider the present system of freeboard gives very little, if any, guarantee for the safety of the ship at sea.

I will try and explain to you my reasons for saying that there is no guarantee for the safety of the ship with the present system of freeboard. Let us suppose that there are two sister ships going out of dock on a winter's voyage across the Atlantic, the ships and their machinery in the same state of efficiency. The one is loaded to the maximum draft allowed by the present Board of Trade rules, but this might be carefully distributed in the holds, which insures the stability of the ship. The other ship is loaded with general cargo, and the centre of the load disc is, say, 9 inches from the water, and to all outward appearances more seaworthy than the former. But let us look for a moment into the manner in which this ship has been loaded. The light cargo which is first alongside is put into the lower holds, and last comes a heavy consignment of machinery which has to be stowed in the 'tween decks, with the result that the ship is rendered top-heavy. Now I should like to ask which of these two ships anyone would prefer to go to sea in? For my part I would most decidedly prefer the deep ship. But, on the other hand, if the stability of the light ship had been tested by the simple method which Mr. Rowe has shown to us to-night, it would be at once found out that the ship was not safe for a winter voyage across the Atlantic until some of the heavy weight on the top had been removed, and the stability of the ship made good, a precaution which can never be taken with the present system of freeboard which the Board of Trade so strictly adhere to.

Our Chairman invites any of the Members present to give expression to any means they could suggest which would lead to the prevention of ships capsizing at sea. I think I have already suggested a means that would prevent this in most cases, viz, the testing of the stability of the ship before proceeding to sea. But while there are so many insurance companies in this country willing to take any risk almost on any conditions, I am afraid it will be a difficult matter to alter the present system, therefore we must be prepared to hear of an occasional ship going to sea and never heard of again.

Another cause which in my opinion leads to the capsizing of steamers at sea is (if I am correct in my belief) that some owners of cargo steamers insure the machinery and fittings of their ships against accidents, which may or might lead to some neglect in the attention that should be given to the repairs required to the machinery, knowing that if the engines break down at sea the insurance company will have to make good the defects, and forgetting that the stopping of the engines in a heavy sea may cause the loss of the ship, through falling into the trough of the sea and rolling over, going down with all hands. But until the Board of Trade takes this matter up, and insurance companies cease to take such blindfold risks, I fear we cannot expect to see any alteration in the present system. It gives me great pleasure to second the vote of thanks proposed to Mr. Rowe for the paper which he has read to us, and trust that it is only the first of many such papers on the same subject.

THE HONORARY SECRETARY.

Before closing the discussion, I would remark that it must be gratifying to the author of these papers to note the amount of interest which has been taken in them both at home and abroad, showing that the objects held in view while writing them have been appreciated, and, to some extent, fulfilled.

By special request, and by permission of the Council, the Editor of the "Hanza" (Hamburgh) had the papers translated and published in that journal.

SESSION, 1891-2.

CATALOGUES

OF THE

Malcolm Campbell Memorial

AND THE

INSTITUTE LIBRARIES,

WITH

REGULATIONS FOR THE

CIRCULATING LIBRARY

CIRCULATING LIBRARY.

REGULATIONS.

I. The application for the loan of any volume in the Library must be made at the Reading Room, in a book provided for the purpose, and duly signed by a Member of Council, the number of the Book, as per catalogue, to be entered. The Book required will then be issued, subject to the approval of the Council, as per Rule VII.

A Member of Council is present every evening, as a rule; but, to prevent disappointment and loss of time, it will be well to communicate with one beforehand, naming the volume required.

II. No Book may be removed from the Reading Room without compliance with the foregoing rule.

III. Should it be desired to retain a volume for longer than a week, the application must be renewed, and the Book returned that it may be re-entered, when it will be re-issued for a second week, should there be no prior application.

IV. In the event of a Book not being returned on the day appointed, a fine of 6d. may be imposed, for a week or any portion of a week; such fines will be devoted to the Library Repair Fund.

V. The privileges of the Circulating Library may only be enjoyed by those who have fulfilled all the stipulated engagements in connection with their grade of membership in the Institute, as per By-Laws.

VI. All loss or damage to Books must be made good by the borrower to the satisfaction of the Council.

VII. While the Council is anxious to place all the Books within the use of everyone connected with the Institute, as far as possible, there are certain volumes, the right of which, allowing to leave the premises, is reserved by the Council.

VIII. On any volume being returned to the premises, notification and an entry to that effect shall be made in the Book provided for the purpose, and duly initialed.

INSTITUTE OF MARINE ENGINEERS.

LIBRARY CATALOGUE.

No.	Description.	Presented by
1	Useful Information for Engineers (Fairbairn) ..	J. M. Gray
2	do. do. 2nd series	do.
3	do. do. 3rd series	do.
4	The Steam Engine (Bourne)	do.
5	Voltaic Electricity (Tyndall)	do.
6	Link and Valve Motions (Auchinclass)	do.
7	Once a Week, vol. 1 ..	do.
8	do. vol. 2 ..	do.
9	do. vol. 3 ..	do.
10	do. vol. 4 ..	do.
11	do. vol. 5 ..	do.
12	do. vol. 6 ..	do.
13	do. vol. 7 ..	do.
14	do. vol. 8 ..	do.
15	do. vol. 9 ..	do.
16	do. vol. 10 ..	do.
17	do. vol. 11 ..	do.
18	do. vol. 12 ..	do.
19	do. vol. 13 ..	do.
20	Marine Engines and Boilers, vol. 1	R. Leslie
21	do. vol. 2	do.
22	Malit's Construction of Artillery	J. M. Gray
23	Encyclopædia (Beeton's) vol. 1	D. Greer
24	do. vol. 2	do.
25	do. vol. 3	do.
26	do. vol. 4	do.
27	March of the Strikers (J. Bevan)	A. Campbell
28	Madame Midas (Fergus Hume)	do.

No.	Description.	Presented by
29	Taken from Life (Henry Pettitt)	A. Campbell
30	The Crime of the Opera House	do.
31	Zeph (G. R. Sims)	do.
32	Without a Home (E. P. Roe)	do.
33	Coral Pin	do.
34	Zoroaster (F. M. Crawford)	do.
35	Souls and Cities	do.
36	Two Years Ago (Charles Kingsley)	do.
37	Notes on Lilies (Dr. Wallace)	do.
38	Crime and Punishment ..	do.
39	India Re-visited (Edwin Arnold)	R. Leslie
40	All the Year Round, vol. 1	J. M. Gray
41	do. vol. 2	do.
42	do. vol. 3	do.
43	do. vol. 4	do.
44	do. vol. 5	do.
45	do. vol. 6	do.
46	do. vol. 7	do.
47	do. vol. 8	do.
48	do. vol. 9	do.
49	do. vol. 10	do.
50	do. vol. 11	do.
51	do. vol. 12	do.
52	do. vol. 13	do.
53	do. vol. 14	do.
54	do. vol. 15	do.
55	do. vol. 16	do.
56	do. vol. 17	do.
57	do. vol. 18	do.
58	Good Words, 1860	do.
59	do. 1861	do.
60	do. 1862	do.
60a	do. 1864	do.
60b	do. 1865	do.
60c	do. 1866	do.
61	Electricity (John T. Sprague)	H. Chisholm

No.	Description.	Presented by
62	Elementary Engineering (J. Sherran Brewer) ..	A. W. Robertson
63	Machine Drawing and Design (Ripper)	do.
64	Hydraulic Motors (G. R. Bodmer)	J. Lockie
65	Engineering Socially Considered (Haldane) ..	H. Hammett
66	Steam Boilers (R. D. Munro)	M. C. McKellar
67	The Steam Engine (W. H. Northcott)	The Author
68	Geometric Turning Simplified (W. H. Northcott) ..	do.
69	On Lathes and Turning do.	do.
69a	Examples on Lathes and Turning (W. H. Northcott)	do.
70	Into all the World (John Scarth)	do.
71	The Life of William Denny (A. B. Bruce)	P. M. Black
72	Webster's Dictionary ..	Purchased
73	S. S. House Flags	do.
74	A Text Book on Steam and Steam Engines (Professor Jamieson)	M. C. McKellar
75	The Engineer's Sketch Book (T. W. Barber)	do.
76	Mine Engineering Plates (G. C. Greenwell)	A. McMurchy
77	Ditto do. do. ..	do.
78	Haddon Hall	Capt. Angove
79	Only a Butterfly	do.
80	Deux Parisiennes	do.
81	Adventures or a Phæton (Wm. Black)	do.
82	Leyton Hall (Mark Lemon)	do.
83	Barren Honour	do.
84	Under which King (William Johnston, M. P.)	do.

No.	Description.	Presented by
85	Against Wind and Tide (Holme Lee) ..	Capt. Angove
86	Roba Di Roma (W. W. Story)	do.
87	Devereux (Lord Lytton) ..	do.
88	Fortunes of Nigel (Sir W. Scott)	do.
89	Tales of Three Cities (Henry James)	do.
90	Dumbleton Common (Hon. E. Eden)	do.
91	Hostages to Fortune (Braddon)	do.
92	Frank Sinclair's Wife, vol. 2 (Mrs. Riddell)	D. Gillespie
93	Mandolinette	Capt. Angove
94	Prosper Randoce (Victor Cherbuliez)	do.
95	Mary Gresley (Anthony Trollope)	do.
96	Willing to Die (J. S. Le Fanu)	do.
97	In Pastures Green (Gibbon)	do.
98	The Cure of Souls (Cobban)	D. Gillespie
99	At Her Mercy (Jas. Payne)	do.
99a	The Woman in Red (Hayward)	do.
100	The Tropical Agriculturalist, 1881-2	do.
101	La Morte (Octave Feuillet)..	Capt. Angove
102	Ready-Money Mortiboy (W. Besant and J. Rice) ..	do.
103	Henrietta Temple (Earl of Beaconsfield)	do.
104	Crownow's Recollections ..	do.
105	Dick's Wandering (Julian Sturgis)	do.
106	London: Its celebrated characters, &c.	do.

No.	Description.	Presented by
107	La San-Felice	Capt. Angrove
108	Two Duchesses (F. P. Clark)	do.
109	The Girls of Feversham (Florence Marryat) ..	do.
110	Joan (Rhoda Broughton) ..	do.
111	Laurence Sterne, vol 2 (P. Fitzgerald)	do.
112	White Chief (Capt. Mayne Reid)	do.
113	Bella Donna (Gilbert Dyce)	do.
114	Les Drames de la Foret (Alexis Bouvier)	do.
115	The Disowned (Lord Lytton)	do.
116	Blount Tempest (Rev. J. C. M. Bellew)	do.
117	Austin Elliot	do.
118	Condoned (Ann C. Steele) ..	do.
119	The Six Chief Lives—Poets (M. Arnold)	do.
120	L'Uscoque (Geo. Sand) ..	do.
121	The Gun, Ram, and Torpedo (G. H. Noal)	do.
122	Ravenshoe (H. Kingsley) ..	do.
123	How he won Her (Mrs. Eiloart)	do.
124	The Contemporary Review (January-June, 1882) ..	do.
125	The Fortnightly Review (1882)	do.
126	Island Life (A. R. Wallace)	do.
127	Spon's Dictionary of Engineering Div. 1	Purchased
128	do. do. Div. 2	do.
129	do. do. Div. 3	do.
130	do. do. Div. 4	do.
131	do. do. Div. 5	do.
132	do. do. Div. 6	do.
133	do. do. Div. 7	do.
134	do. do. Div. 8	do.
135	Burgh's Pocket Book on Compound Engines	J. H. Thomson

No.	Description.	Presented by
136	The Steam Engine, vol. 1 (D. K. Clark)	A. W. Robertson
137	do. vol. 2	do.
137a	do. vol. 3	do.
137b	do. vol. 4	do.
138	The Marine Engineer— vol. 1, 1879-80	J. W. Richardson
139	do. vol. 2, 1880-81	do.
140	do. vol 3, 1881-82	do.
141	do. vol. 4, 1882-83	do.
142	do. vol. 5, 1883-84	do.
143	do. vol. 6, 1884-85	do.
144	do. vol. 7, 1885-86	do.
145	do. vol. 8, 1886-87	do.
146	do. vol. 9, 1887-88	do.
147	do. vol. 10, 1888-89	do.
148	Marine Engineering News, 1876	do.
149	do. 1877	do.
150	do. 1878	do.
151	The Foreman Engineer, 1877	do.
152	do. 1879	do.
153	do. 1880	do.
154	Handbook for Steam Users (M. P. Bale)	The Author
155	Marine Engines and Boilers (Geo. C. V. Holmes) ..	A. Lawrie
156	Theory of Heat (Maxwell) ..	J. H. Thompson
157	Conversion of Heat into Work (Anderson)	A. Lawrie
158	Heat a mode of Motion (Tyndall)	do.
159	A Practical Treatise on Heat (Box)	do.
160	The Engineer's & Machinist's Drawing Book	H. Prior
161	Imperial Cyclopædia of Machinery	do.
162	Iron Ship Building (J. Grantham)	Jas. Adamson

No.	Description.	Presented by
163	The Shipping World, 1890	Purchased
164	Shipbuilding—Plates ..	Jas. Adamson
165	The Graphic, vol. 2, 1889 ..	Purchased
166	Illustrated London News, vol. 2, 1889	do.
167	Year Book of Scientific Societies—1890	do.
168	Ditto 1891	do.
169	Hydro-Statics & Pneumatics (Magnus)	J. Taylor
170	Elementary Mechanics (Magnus)	do.
171	Naval Architecture (Thearle) Text	do.
172	Naval Architecture (Thearle) Plates	do.
173	Engineering, 1877	Jas. Stewart
174	do. 1877	do.
175	do. 1878	do.
176	do. 1878	do.
177	The Marine Transport of Petroleum (Little) ..	The Author
178	Shakespeare, vol. 1, Comedies	Robert Adam
179	do. vol. 2, Tragedies	do.
180	do. vol. 3, Histories	do.
181*	From Keel to Truck ..	Purchased
182	Mechanical Graphics (G. Halliday)	James Phillips
183	Strength of Materials and Structures (J. Anderson) ..	Henry Prior
184	Steam and its Uses (D. Lardner)	do.
185	Electricity (Ferguson) ..	do.
186	Millwright and Engineer's Companion (Sempleton) ..	do.
187	Service Chemistry (V. B. Lewes)	C. A. Crook
188	Bell's System of Geography	J. W. Richardson
189	do. ..	do.

* Bristol Channel Centre.

No.	Description.	Presented by
190	Bell's System of Geography	J. W. Richardson
191	do. ..	do.
192	do. ..	do.
193	do. ..	do
194	Engineering, July to Dec., 1884	R. W. Kingswood
195	Scientific American.. ..	E. H. Minns
196	do. ..	do.
197	do. ..	do.
198	do. ..	do.
199	do. ..	do.
200	do. ..	do.
201	do. ..	do.
202	do. ..	do.
203	do. ..	do.
204	do. ..	do.
205	Chairman's Handbook (Palgrave)	C. Noble
206	Electricity and Magnetism (Dunman)	do.
207	The Effects of Liquids on Iron (Phillips)	The Author
208	The Relative Corrosion of Iron and Steel (Phillips)..	do.
209	The Steamship, vol. 1, 1889-90	The Editor
210	Once a Week, vol. 4, 1867..	J. M. Gray
211	Harold, the Last of the Saxon Kings	Captain Angove
212	Lizzie Lorton of Greyrigg ..	do.
213	Electrical Dictionary (Houston)	P. Macphail
214	Great Industries of Great Britain vol. 1 ..	J. W. Smith
215	do. vol. 2 ..	do.
216	do. vol. 3 ..	do.
217	Institution of Mechanical Engineers Transactions, 1887	C. A. Crook
218	do. 1888 ..	do.
219	do. 1889 ..	do.

No.	Description.	Presented by
220	Handbook of Engine and Boiler Trials (Thurston) ..	W. Hossack
221	Handbook on Direct Acting Pumping Engines.. ..	T. Drewry
222	Lectures on Electricity (Forbes)	do.
223	The Steam Engine Indicator &c. (Beamont)	do.
224	From Keel to Truck ..	A. Black
225	Marine Encyclopædia ..	C. E. Hudson
226	Weale's Quarterly Papers on Engineering, part 1. ..	H. W. Holman
227	do. part 2. ..	do.
228	do. part 3. ..	do.
229	do. part 4. ..	do.
230	do. part 5. ..	do.
231	do. part 6. ..	do.
232	do. part 7. ..	do.
233	do. part 8. ..	do.
234	do. part 9. ..	do.
235	do. part 12. ..	do.
236	Sound, Light, and Heat (Wright)	John Whyte
237	Kitty Trevylyan	do.
238	The Steam Engine (Cotterill)	Purchased
239	English Magazine	J. Y. Lowe
240	Scribner's do.	do.
241	do. do.	do.
242	Electrical Engineering (Slingo and Brooker) ..	
243	Engineering vol. 14, 1862	J. W. Bryden
244	do. vol. 15, 1863	do.
245*	Transactions of I. Mar. E., vol. 1.	The Council
246*	Illustrated Marine Encyclopædia	Purchased
247	Solutions to Engineers' First-class Questions (E. J. M. Davies)	do.

* Bristol Channel Centre.

No.	Description.	Presented by
248	Treatise on Future Naval Battles (Admiral Elliott)..	M. W. Ruthven
249	The Scottish Nation vol. 1..	P. Boyd
250	do. vol. 2..	do.
251	do. vol. 3..	do.
252	do. vol. 4..	do.
253	do. vol. 5..	do.
254	do. vol. 6..	do.
255	do. vol. 7..	do.
256	do. vol. 8..	do.
257	do. vol. 9..	do.
258	Dynamo-Electric Machinery (S. P. Thompson).. ..	M. C. Storrar
259	Charter and List of Members Inst. of Civil Engineers ..	D. Phillips
260	Minutes of Proceedings of Inst. of Civil Engineers vol. 63 ..	do.
261	do. vol. 64 ..	do.
262	do. vol. 65 ..	do.
263	do. vol. 66 ..	do.
264	do. vol. 67 ..	do.
265	do. vol. 68 ..	do.
266	do. vol. 69 ..	do.
267	do. vol. 70 ..	do.
268	do. vol. 71 ..	do.
269	do. vol. 72 ..	do.
270	do. vol. 73 ..	do.
271	do. vol. 74 ..	do.
272	do. vol. 75 ..	do.
273	do. vol. 76 ..	do.
274	do. vol. 77 ..	do.
275	do. vol. 78 ..	do.
276	do. vol. 79 ..	do.
277	do. vol. 80 ..	do.
278	do. vol. 81 ..	do.
279	do. vol. 82 ..	do.
280	do. vol. 83 ..	do.
281	do. vol. 84 ..	do.

No.	Description.	Presented by
282	Minutes of Proceedings of Inst. of Civil Engineers vol. 85 ..	D. Phillips
283	do. vol. 86 ..	do.
284	do. vol. 87 ..	do.
285	do. vol. 88 ..	do.
286	do. vol. 89 ..	do.
287	do. vol. 90 ..	do.
288	do. vol. 91 ..	do.
289	do. vol. 92 ..	do.
290	do. vol. 93 ..	do.
291	do. vol. 94 ..	do.
292	do. vol. 95 ..	do.
293	do. vol. 96 ..	do.
294	do. vol. 97 ..	do.
295	do. vol. 98 ..	do.
296	do. vol. 99 ..	do.
297	do. vol. 100 ..	do.
298	do. vol. 101 ..	do.
299	do. vol. 102 ..	do.
300	Knight Errant (Edna Lyall)	F. Colsell
301	In the Golden Days (do.) ..	do.
302	We Two (do.) ..	do.
303	Hardy Norseman (do.) ..	do.
304	Won by Waiting (do.) ..	do.
305	Donovan (do.) ..	do.
306	Steam Boiler Construction (Hutton)	C. McEachran
307	The Steam Engine (D. K. Clark) vol. 1 ..	Geo. Wells
308	do. vol. 2 ..	do.
309	do. vol. 3 ..	do.
310	do. vol. 4 ..	do.
311	Transactions, I. Mar. E., vol. 2	Property of Inst.
312	Outside the Class Room (W. H. Bailey)	do.
313	Elements of Mechanism (Goodeve)	G. W. Buckwell

No.	Description.	Presented by
314	Steam Boiler Construction (W. S. Hutton)	C. J. J. Jones
315	One and All (Duty of Richard Tangye)	Jno. Nicoll
316	History of Steam Navigation	Geo. Buckwell
317	Marine Engineer's Drawing Book (Lockie)	Jno. Lockie
318	Practical Engineer's Handbook	Editor
319	Trans. Hull and District Institution of Engineers and Naval Architects, vol. 1 ..	The Council of the Institution
320	do. vol. 3 ..	do.
321	do. vol. 4 ..	do.
322	do. vol. 5 ..	do.
323	do. vol. 6 ..	do.
324	Trans. N.E. Coast Institute Engineers and Shipbuilders vol. 1 ..	do.
325	do. vol. 2 ..	do.
326	do. vol. 3 ..	do.
327	do. vol. 4 ..	do.
328	do. vol. 5 ..	do.
329	do. vol. 6 ..	do.
330	do. vol. 7 ..	do.
331	Engineering Magazine ..	Horace See, New York
332	The Century Magazine ..	J. Y. Lowe
333	The English Magazine, 1885	do.
334	do. do. 1887	do.
335	Trans. Institute Mechanical Engineers, 1889	The Council of the I. Mech. E.
336	do. 1890 . ..	do.
337	do. 1891	do.
338	Naval Architecture (Scott Russell)	E. B. Caird
339	do. do. ..	do.
340	do. do. ..	do.

Malcolm Campbell Memorial.

LIBRARY CATALOGUE.

LOAN COLLECTION.

No.	Description.	Lent by
1	Boilers (Deterioration of) ..	Jas. Adamson
2	do. do. Report	do.
3	Marine Engines, Modern American	J. H. Thomson
4	Marine Architecture (Charnock) .. .. vol. 1	J. Adamson
5	do. do. vol. 2	do.
6	do. do. vol. 3	do.
7	Shipbuilding (A.F.B.Craize)	do.
8	Naval Architecture (D. Steel)	do.
9	Screw Propeller (J. Bourne, C.E.)	J. H. Thomson
10	Mercantile Navy List ..	Jas. Adamson
11	Society of Engineers, Transactions 1876	do.
12	do. do. 1879	do.
13	do. do. 1880	do.
14	do. do. 1881	do.
15	do. do. 1882	do.
16	do. do. 1883	do.
17	Mechanics' Magazine (Glasgow) .. .. vol. 2	do.
18	do. do. vol. 3	do.
19	do. do. vol. 4	do.
20	do. do. vol. 5	do.
21	Pattern Making (Foreman Pattern Maker)	Campbell Trustees

No.	Description.	Lent by
22	Civil Engineers (proceedings) vol. 87	Jas. Adamson
23	Dictionary of Arts, &c. (Dr. Ure's), vol. 1	J. H. Thomson
24	do. do. vol. 2	do.
25	do. do. vol. 3	do.
26	do. do. vol. 4	do.
27	Microscopic Objects (Davies)	Jas. Adamson
28	Steam Engine (J. Bourne, C.E.)	do.
29	Engineering, vol. 1 } 1869	do.
30	do. vol. 2 } 1869	
31	do. vol. 1 } 1870	do.
32	do. vol. 2 } 1870	
33	do. vol. 1 } 1871	do.
34	do. vol. 2 } 1871	
35	do. vol. 1 } 1872	do.
36	do. vol. 2 } 1872	
37	do. vol. 1 } 1873	do.
38	do. vol. 2 } 1873	
39	Dictionary of Engineering (Spons') .. .. vol. 1	A. Beldam
40	do. do. vol. 2	do.
41	do. do. vol. 3	do.
42	Carpenter's Guide (Nicholson)	Jas. Adamson
43	Engineer, Surveyor, and Architect	do.
44	Steam Boilers (Peattie) ..	do.
45	Strength of Materials (T. Box)	Campbell Trustees
46	Physics (Ganot's)	do.
47	Applied Mechanics (Rankine)	do.
48	Steam Engine do.	do.
49	Rules and Tables do.	do.
50	Lives of the Engineers, vol. 1 (Smiles)	do.
51	do. vol. 2 do.	do.
52	do. vol. 3 do.	do.
53	do. vol. 4 do.	do.
54	do. vol. 5 do.	do.
55	Practical Engineer (Hutton)	do.

No.	Description.	Lent by
56	Works Manager (Hutton) ..	Campbell Trustees
57	MarineSteamEngine(Sennett)	do.
58	Marine Engineering (Seaton)	do.
59	Valve Gears (Zeuner) ..	do.
60	Hydraulic, Steam and Hand Power	do.
61	ModernSteamPractice (Winton) vol. 1	do.
62	do. do. vol. 2	do.
63	Shipbuilding (Rankine) ..	do.
64	Engineers' Drawing (Le Blanc)	do.
65	Nautical Magazine, 1836 ..	Jas. Adamson
66	do. 1837 ..	do.
67	do. 1838 ..	do.
68	do. 1839 ..	do.
69	do. 1840 ..	do.
70	do. 1841 ..	do.
71	do. 1842 ..	do.
72	do. 1843 ..	do.
73	do. 1844 ..	do.
74	do. 1845 ..	do.
75	do. 1846 ..	do.
76	do. 1847 ..	do.
77	do. 1848 ..	do.
78	do. 1849 ..	do.
79	do. 1850 ..	do.
80	do. 1851 ..	do.
81	do. 1852 ..	do.
82	do. 1853 ..	do.
83	do. 1854 ..	do.
84	do. 1855 ..	do.
85	do. 1856 ..	do.
86	do. 1857 ..	do.
87	do. 1858 ..	do.
88	do. 1859 ..	do.
89	Boilers,Constructionof(Traill)	Campbell Trustees
90	Indicator (Richards) ..	do.
91	Treatise on the Indicator (Graham)	do.

No.	Description.	Lent by
92	Marine Propellers (Barnaby)	Campbell Trustees
93	Metals (Bloxam and Huntingdon)	do.
94	Chemistry of Metals (Thorpe)	do.
95	Chemistry Non-Metals (do.)	do.
96	Lectures on Electricity (Forbes)	do.
97	Practical Electric Lighting (Holmes)	do.
98	Dynamo Electric Machinery (Thompson)	do.
99	Casting and Founding ..	do.
100	Extra First Class Examination (Reed)	do.
101	James Nasmyth (Smiles) ..	do.
102	Duty (Smiles)	do.
103	Thrift (Smiles)	do.
104	Scotch Naturalist (Smiles) ..	do.
105	Life and Labour	do.
106	Industrial Biography (Smiles)	do.
107	Self Help (Smiles)	do.
108	Invention and Industry (Smiles)	do.
109	Character (Smiles)	do.
110	Round the World (Smiles)	do.
111	George Moore (Smiles) ..	do.
112	Robert Dick, Geologist (Smiles)	do.
113	Human Physiology (Landvis and Stirling)	do. do.
114	Outlines of Geology (James Geikie)	do.
115	Geography (Physical) old issue	do.
116	The Steamship, vol. 1 ..	do.
117	do. vol. 2 ..	do.
118	On the Human Understanding (Locke)	do.
119	Deterioration of Boilers, &c., vol. 1	James Girvin
120	do. do. vol. 2	do.
121	do. do. vol. 3	do.

No.	Description.		Lent by
122	Merchant Shipping, History of (Lindsay) .. vol. 1		Campbell Trustees
123	do. do. vol. 2		do.
124	do. do. vol. 3		do.
125	do. do. vol. 4		do.
126	Engineering, vol. 17	1874	do.
127	do. vol. 18		
128	do. vol. 19	1875	do.
129	do. vol. 20		
130	do. vol. 21	1876	do.
131	do. vol. 22		
132	do. vol. 23	1877	do.
133	do. vol. 24		
134	do. vol. 25	1878	do.
135	do. vol. 26		
136	do. vol. 27	1879	do.
137	do. vol. 28		
138	do. vol. 29	1880	do.
139	do. vol. 30		
140	do. vol. 31	1881	do.
141	do. vol. 32		
142	do. vol. 33	1882	do.
143	do. vol. 34		
144	do. vol. 35	1883	do.
145	do. vol. 36		
146	do. vol. 37	1884	do.
147	do. vol. 38		
148	do. vol. 39	1885	do.
149	do. vol. 40		
150	Inst. of Engineers and Shipbuilders in Scotland Transactions		Jas. Adamson
151	Steam and the Steam Engine (Evers)		do.
152	Thomson's Engineering Guide to Local Marine Board Examinations		do.
153	The Clyde from its Source to the Sea (W. J. Millar)..		Campbell Trustees
154	The Steam Engine (Holmes)		do.

No.	Description.	Lent by
155	Joan, the Maid (a story of the 15th Century) ..	Mrs. Campbell
156	Science in Sport made Philosophy in Earnest.. ..	do.
157	In New Granada (W. H. G. Kingston)	do.
158	Annals of a Quiet Neighbourhood	do.
159	Discoveries and Inventions of the 19th Century	do.
160	The Giant of the North (R. M. Ballantyne) ..	do.
161	Count Renneberg's Treason (H. E. Burch)	do.
162	London Society, vol. 2 ..	do.
163	do. vol. 4 ..	do.
164	do. vol. 5 ..	do.
165	do. vol. 7 ..	do.
166	The Sixpenny Magazine, vol. 5	do.
167	Little Folks, vol. 11-12 ..	do.
168	Cassell's Family Magazine, 1884	do.
169	Tit-Bits, vol. 14	do.
170	Cassell's Saturday Journal, 1883-4	do.
171	do. do. 1884-5	do.
172	Family Herald, vol. 42-43..	do.
173	do. vol. 46-47..	do.
174	Whitaker's Almanack, 1887	do.
175	Engineer's Magazine, vol. 2	Jas. Adamson
176	Rules and Regulations Lloyds' Register	do.
177*	The Steamship, 1889-90, vol. 1	The Council Inst. Mar. Engineers
178*	The Bailie, 1889	do.
179*	Illustrated London News, vol. 95, 1889	do.
180*	do. do. vol. 96	do.
181*	The Graphic, vol. 40, 1889..	do.
182*	do. vol. 41 do. ..	do.

* Presented to the Malcolm Campbell Memorial by the Institute, unbound; and bound by the Trustees for the Library.

No.	Description.	Lent by
183*	Iron and Coal Trades Review, vol. 39 ..	The Council Inst. Mar. Engineers
184*	do. vol. 40 ..	do.
185*	Industries vol. 7 ..	do.
186*	do. vol. 8 ..	do.
187*	do. vol. 9 ..	do.
188*	Mechanical World, vol. 5 ..	do.
189*	Fairplay vol. 1 ..	do.
190*	do. vol. 2 ..	do.
191*	Shipping World vol. 7 ..	do.
192*	Engineer vol. 68 ..	do.
193*	do. vol. 69 ..	do.
194*	do. vol. 70 ..	do.
195*	Forth Bridge	do.
196*	Pen and Pencil	do.
197*	Practical Engineer, vol. 3 ..	do.
198*	Industries vol. 10 ..	do.
199*	Iron and Coal Trades Review, vol. 42 ..	do.
200*	The Graphic, 1891	do.
201*	The Illustrated London News vol. 98 ..	do.
202*	Engineer vol. 70 ..	do.
203*	do. vol. 70 ..	do.
204*	Engineering vol. 47 ..	do.
205*	do. vol. 58 ..	do.
206	The Elements and Practice of Rigging and Seamanship ..	J. Adamson
207	Scribner's Magazine, 1889 ..	J. Y. Lowe
208	" " 1890 ..	do.

* Presented to the Malcolm Campbell Memorial by the Institute unbound, and bound by the Trustees of the Library.