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Vice-Admiral E. Gardiner Fishbourne C.B.

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Ebening Meeting.

Monday, February 17, 1879.

REAR-ADMIRAL M. S. NOLLOTH, Member of Council, in the Chair.

EXCESSIVE ROLLING OF SHIPS; ITS CAUSES, CONSEQUENCES, AND CURE.

By Vice-Admiral E. GARDINER FISHBOURNE, C.B.

THIS was always a difficult subject from the number of conflicting elements. It has been made more difficult of comprehension by the circulation of dangerous theories with so much talent that sailors, though these conflicted with all their seafaring experience, have been misled.

The whole question of success or failure in naval architecture, and when the latter, of millions of money and hundreds of lives annually is involved.

Before we can arrive at a satisfactory conclusion, we must ascertain what are the causes of rolling, and what the forms and qualities that tend to limit the number and extent of the arcs of roll.

In a word we must know all the factors in each problem, and measure their respective influences.

Ships, like all bodies under the influence of gravity, when brought to rest, tend to remain so.

Our start-point in discussion must be from the state of rest—rest both of the water and of the vessel it floats.

The equilibrium of water, owing to its fluidity, is easily disturbed, but for the same reason it more immediately returns to equilibrium.

For our purpose we must consider its normal condition to be rest in equilibrium.

Gravity draws the particles towards the earth's centre, but they are supported by those immediately below; but being fluid, they need the lateral support of those around, as the body of water needs the support of the containing vessel.

The pressure of the first series of particles is equal to their weight,

that of the second is their weight and that of those immediately above, so on continuously down through each column of particles.

So, if a number of particles are taken out, the superincumbent columns around tend to press out laterally those below, and to press them up to their own level, to fill up the space vacated by those abstracted, and so on till equilibrium is re-established.

Let Fig. 1 represent columns of particles: if a skin, ab , be inserted enclosing a quantity, it will bear on its upper surface the collected pressures of the particles above it; but it will be supported by the surrounding columns pressing down, thus producing an upward pressure under the skin.

FIG. 1.

Water being homogeneous, the pressures are uniform and equal at equal depths, so the upward pressures may be considered as if there was but one passing up in a line through the centre of figure, equal to their sum, though these pressures are all actually on the enveloping skin.

The former also is true of the mass of particles above; their pressure may be treated as one passing down through the centre of figure, which is also their centre of gravity.

Let us now suppose a rigid vessel of the same weight and form as the volume of particles within ab to be lowered down on ab , as it sinks, it will push out these particles, lifting and spreading them out on either side.

This body will sink till it has displaced them all, and will occupy the space, and its skin or outer surface will take all the upward pressures that were on ab , and being of the same weight as the particles that were above ab will press down with an equal pressure with them.

These two equal and opposite pressures obtain in all floating bodies, but will vary in amount with the dimensions, or immersion, or with the specific gravity of the fluid in which the body floats.

The weights in a ship are not homogeneous, but they may be so distributed as to be referable to a common centre of gravity, so that

one weight, equal to their sum, may be treated as one passing down in a perpendicular through that centre.

When the line passing down through the above centre, and that passing up through the centre of figure, are in the same vertical straight line, these equal forces will be opposite, and the vessel at rest in the upright position, *i.e.*, if the centre of gravity is in the middle line of the vessel and is sufficiently low.

The lines of supporting pressures on the bottoms of ships virtually converge to a *locus* or point.

FIG. 2.

This is not a fixed point, but varies as the vessel is more or less immersed, also with the angle of inclination, and with the form. In a seaway it is radically changed, and continually changing.

If a vessel, as in Fig. 2, be inclined from the perpendicular to AB, the water-line, till CD becomes the water-line, then the original line of support PO will be moved over to P'O'. The point of intersection of these two lines at *m* is the metacentre.

If the centre of gravity be below *m*, say at *g*, the weight will act through the lever *gg'* to force the ship back into the upright position.

If, on the contrary, the centre of gravity be raised above *m* to *g*², then the whole weight, acting through the lever *g²g³*, will force the ship over in search of stability, and will bring it round till *g*² is below *m* bottom up, till she founders.

Consequently the less the metacentric height (which is the height of metacentre above the centre of gravity of the floating body, measured on the vertical axis) the less will be the force to keep the vessel at rest, or to bring her back to the point of rest when disturbed, the greater also the angle of inclination to which a given force will incline her.

But there are other causes of steadiness to which we must now refer.

We have seen from Fig. 1 how fast the vertical pressures increase with the depth, and how owing to the fluidity of water these press the particles against each other and against the sides and bottoms of vessels immersed in them.

When a vessel is at rest the lateral pressures are equal and opposite, and they steady the vessel in proportion as she is more immersed and her sides approach the vertical.

Suppose Fig. 3 to represent two vessels, *a* and *b*, of equal volume but of different form and immersion. In each, AB is the water-line,

FIG. 3.

C centre of figure, *g* centre of gravity: now these vessels are not kept steady simply because the lines of pressure passing through their centres are equal and opposite, but also because of the great lateral pressures in the direction of the horizontal arrows.

Now, these two vessels could not, with accuracy, be compared in respect of rolling unless due allowance were made for the very much greater lateral pressures on *b*. For, suppose them each 300 feet long, *a* to be 21.2 feet deep, and *b* to be 29 feet. The centre of pressure of *a* would give 928 lbs. to the square foot: that on *b* would be 1,152 lbs. to the square foot, *i.e.*, on *a* $300 \times 21.2 \times 928$ = about 3,140 tons; *b* $300 \times 29 \times 1,152$ lbs. = about 4,790 tons lateral pressure to limit rolling either way.

Though it may be said truly that *a* has the greater breadth and stability, yet her greater breadth entails greater leverage for the sea to disturb her.

There are various means of rolling vessels, as by racing men from

FIG. 4.

side to side. Suppose Fig. 4 to represent a vessel at rest, AB the water-line, *c* the centre of figure, *g* the centre of gravity, *m* the metacentre.

Suppose, now, her crew moved over, and ab to become the water-line, c will be moved out to c' ; but g being, so to speak, a fixture in the ship will be moved out of the perpendicular by the distance gg^2 , and when she has completed the half roll, the men to be raced over to the other side. Now c' will be moved over to c , but g^2 will be moved over to the other side and out from the perpendicular on that side to g^3 , having been forced past the perpendicular. This process will be repeated every time the men are raced across the deck.

Now, if this process be very nicely adjusted, so that the racing of the men synchronizes with the motion impressed on the ship, in this case an increased impulse will be given to the motion of the ship, but an increase will be given to her angle and time of roll; it is evident that as the angle of roll is increased, the distance that g will be carried out from the perpendicular will also be increased, and with it the length of the lever gg^2 , through which gravity acts, resisting inclination and tending to bring the vessel back with c and g in the same vertical straight line.

At the termination of any roll, gg^2 multiplied by the whole weight will give a measure of the rolling force—a measure of the resistance gravity has offered to rolling the ship—a measure of her stability at that angle, and the force that will be put forth to restore the ship to the upright when the men return to their original position. It is clear from the above that as stability is greater, the more resistance it will offer to motion, and the more it will limit the arcs of roll.

For if we raise g till g^1g^6 is only half gg^2 , then half the force will roll her through an equal angle, or lower it till g^1g^4 is double gg^2 , then double the force will be required to roll her through an equal angle.

In each case we merely move the centre of gravity, but this reduces the metacentric height; thus we have established that the less the metacentric height, the more easily the vessel will be rolled, and the greater the metacentric height, the more difficult it will be to roll her.

Moreover, the greater the metacentric height the greater must be the force to produce equal angles of inclination by frequent impulses to those produced when its height was small, consequently vessels with great metacentric height must be less subject to be rolled over by the crew racing, or by any other means.

If we suppose the ship's length to be increased, but the metacentric height to remain the same, by this the mass will be increased, as also the lateral pressures. As a consequence the increased mass, aided by the increased stability and inertia and lateral resistances, would all tend to limit both the times and arcs of roll.

It is obviously, then, most fallacious to compare ships on the bases of their equality of metacentric height when they differ widely in the two elements of mass and lateral resistances, and still more, thus to compare them, when they differ on other points as well as these two.

The question suggests itself—can the angle of roll be so increased by continued impulses by racing men from side to side in a ship till she is rolled over?

Certainly, if the metacentric height is small, certainly not, if it is

moderately great; for the lever gg^2 or the stability will increase faster with each increased angle than will the effect of the impulses, so the time will arrive when there will not be any increase of angular motion, and this will arrive earlier as the stability and lateral resistances are greater.

We have had proof of this in "swinging," when, by a muscular effort we have increased the angle of swing, the quantity becomes less and less as we approached the higher angles, because of the increased effect of gravity acting through a longer lever as we diverged more from the perpendicular.

But the immediate causes of excessive rolling when the elements in "ships" are not given in due proportion, is that which causes waves and waves, themselves.

The general causes of waves are differences of atmospheric pressures at one place over another; the effort to re-establish equilibrium produces sea and wind waves. These pressures, being vertical, impart a vertical motion to the water, which, escaping laterally, gives rise to progressive wave-motions, these starting earlier, and travelling faster than winds, give notice of their approach.

When the waves are raised the wind accelerates this motion, especially at the surface; consequently the form of the wave-face and wave-back never correspond. Neither can waves be of uniform size or motion; for besides the differences in direction and velocity of winds at the same place, nearly, and time, the waves are subject to interferences of ocean currents, tides, river streams, and lateral waves generated by smaller aerial currents from varied points.

All this shows how valueless are single observations of ships rolling, and how utterly impossible it is that amounts of roll recorded can be the result of "surface particle" motion.

Were ships only moved by such as they reach or strike them, they would be like fixed half-tide rocks, every wave would break over them and swamp them.

The fact being that the vertical pressure, alluded to, acts deep down on ships' bottoms, lifting the side before the wave reaches it, so ships are saved if unwise men do not swamp them with loaded sides or deck loads.

I must here premise that I do not admit the correctness of the premises with which the advocates of this theory start. I argue from their stand-point to show that on their own showing they are in essential error.

The metacentric method is only approximately correct, then, only on the hypothesis that the angles of inclination are infinitely small, and that all the motions are round a fixed centre of gravity, which is never even approximately true in a seaway.

It is expressly stated by Poisson and Gregory that this method is entirely inapplicable when there is a rise of the centre of gravity and a sensible increase of the angle of inclination.

What actually takes place in a seaway is shown in Fig. 5; first the vessel is shown at rest, then the lifting effect of the wave as it approaches and turns her round A outside of her:—

1 is a wave of 16 feet high, giving out a lifting pressure on one side at the lower arrow t , equal to the difference in the height of the

columns on either side; *i.e.*, the pressure on the side of the wave is at least 1,024 lbs. per square foot, that on the other side is only 512 lbs. per square foot.

This pressure produces a vertical and onward motion of wave that lifts and rolls the vessel, starting her even before it reaches her side.

As it approaches nearer it lifts her further, as represented by waves 2, 3, and 4 in the figure, and continues to lift her while turning her round A, till the crest of the wave has passed the middle line of the ship, after which it lifts the opposite side, arrests the forward roll, and rolls her back with the assistance of gravity which, till this time, has been resisting motion.

The motion proceeds from there being greater buoyancy on the upper or right hand side of figure, so the line of upward pressure passes to the right of the centre of gravity and the still-water metacentre, and until the wave passes the middle line of the ship, then it passes over to the left or lower side, lifting up that and effecting the back roll; the locus of the line of support is along a line such as the dark curve Fig. 5, on which it traverses forward and back as the ship rolls in a seaway.

The imaginary metacentric heights, shown also in short thick lines, clearly cannot exercise any influence on the motions.

It is equally obvious that as the vessel is more inclined, g is carried further from the middle line and acts through a longer lever, and in that degree resists rolling; the lower g is the longer will be the lever, therefore the less will be the angle of inclination from a given wave.

If g be near the line of support or curve, a small force will throw the ship on her beam ends. As this rolling force passes on one side of the centre of gravity, if that be high, there is always danger apart from and besides the danger from sail, or hurricanes on the hull and masts.

This will account for the number of war and merchant vessels

thrown on their beam ends in seas, many of them without any reduction of their lower weights.

Though the still-water metacentric height is said by Messrs. Froude, Reed, and White to be a prime factor in producing motion, it is seldom, if ever, a factor in producing motion in a seaway, for the position of a ship at each moment is the result of the buoyant action of the wave acting on the ship's side next to it, and its effect is opposed and limited by the action of gravity. If a metacentric height were known in such case, as it is not, and represented factors, for it is not one itself, it would represent two opposing factors—one occasioning motion, but the other opposing it—it displays ignorance of first principles to assert that metacentric height, less or more, is a cause of motion.

There are other elements besides a low centre of gravity that limit arcs of roll; to these we must now refer, I mean depth of immersion, square form of section, and mass.

The resistance to rotation from increased immersion increases rapidly because of the increase of lateral pressures—those at 12 feet depth being 768 lbs. per square foot, but those at 24 feet are 1,516 lbs. per square foot.

From the great areas of large ships these amount to thousands of tons; bilge keels will exercise small influence in comparison, but so far as these decrease the angle of roll and increase the times, they prove that the metacentric height and time of roll are not equivalents as contended for by the above gentlemen.

To look at the figure is to be convinced that increased breadth—all other things being equal—increases the lever through which the rolling power of the wave acts, and hence increases its effects in disturbing the ship.

This wave-action commences earlier as the ship is broader and continuing a longer time, moving at an equal rate; it is longer in passing across the wider ship, therefore must produce both quicker and more extensive angles of roll.

It has been stated that weighting the sides would be favourable to limited angles of roll. If the sides are not water borne because of accumulated weight, they will not be moved so early; but it is evident that they must lift with the wave, or the wave will break on board the ship—a far greater defect than their lifting early—for one means only increased motion, the other damage or total loss. And again, having lifted her late, her greater momentum would carry her further; and the wave having passed the middle line would have more work to check the roll, and reverse its direction. Nor is this mere speculation, for it is well illustrated in the fly-wheel of a factory engine that takes up the motive force given off when a thousand spindles are thrown out of gear, not to be lost, but given out when these spindles are again brought into gear.

This is confirmed by all nautical experience, but lest this should appear to be a dictum of mine, and as there is a tendency to worship the idols of the forum, we quote two notable authorities.

Sir Spencer Robinson gave as his reason for not increasing the

armour on old ships:—"Our experience seems to show that all wholly armoured ships roll the heaviest, and that of the French corroborates it in the strongest possible manner." (See "Blue Book and Report," by Captain Hore, R.N.)

The French Admiral Paris said:—"The ironclads roll more than the old ships and bury their guns under the waves." Thus facts, authorities, as well as natural laws, contradict the dictum of Messrs. Reed and White, that it is a popular fallacy that weights on the sides tended to make vessels roll deeply.

It is accepted as an axiom by those who contend for the truth of Mr. Froude's theory, that if a ship's stability or metacentric height be great, her period of roll will accord with the period common to waves, so synchronisms and increased angles of roll will be given at each double swing till the vessel is rolled over.

Ten years my challenge has been before these gentlemen to produce one vessel where such has occurred; I will now take a step further, and say such cannot occur.

The father of inductive science says:—"A single instance is sufficient to refute the validity of a supposed law. If that which, according to our rule, ought to occur fails to occur on one occasion only, this is proof that the rule was no better than an idol."

Now, this alleged rule has failed on every occasion, and we have thousands more of negative instances against the idea of its being a rule.

We might rest here, but think it important to establish that there never was any ground for supposing that ships could be thus capsized, if only they possessed the measure of stability that had hitherto saved them from it, nor could we believe it possible, unless like some would-be philosophers, we believed that globules of water-like protoplasms, as they assume, were individually gifted with greater prescience than men, and were collectively, as it were, by a "fortuitous concourse of atoms," agreed to alter their courses and periods to overthrow unhappy vessels and drown their crews!

The system was exhaustively condemned by an experiment conducted by Mr. Froude himself.

The "Devastation" and "Sultan," two ships of 9,000 tons, were rolled in smooth water, by racing their crews across their decks forwards and backwards.

The angle reached by the "Devastation" was only 14° , and it was stated she could not be forced beyond this, while the angle reached by the "Sultan" was $29\frac{1}{2}^{\circ}$; after racing the men many times, orders were given for the men to cease running, loose things about the decks and gear not having been specially secured, for no one, it was added, anticipated such liveliness on "Sultan's" part.

The "Sultan's" period was 17.7 seconds, that of "Devastation" only 13.6. After the men had ceased, the "Sultan" made 60 oscillations before she reduced her angle of roll to 4° , but 40 oscillations brought "Devastation's" angle to seven-tenths of a degree. Thus all the evidence was in harmony with my argument and opposed to the new theory.

1. The "Sultan," with 2·4 feet of metacentric height, might not be rolled further, even with her *high* side, lest she should be rolled over. But the "Devastation," with a metacentric height of 3·5 feet, and notwithstanding her *low* side, could not be rolled to more than half the angle reached by "Sultan."

2. The vessel with the greater moments of inertia was rolled to double the angle that the vessel with the less inertia reached.

3. The "Sultan," with the higher centre of gravity by 6 inches, less stability and greater moments of inertia than "Devastation," was rolled through double the angle and was double the time in coming to rest.

But this only represents the action of ships rolled by racing their crews, yet, under the superintendence of the author of the system, who fixed the exact time for the men to race (and extreme exactness was necessary to produce even this evidence of failure as to the supposed law).

As I do not believe the particles individually or collectively to possess the intelligence to select the time when the fatal impulse is to be given, I may be permitted not to believe that any ship can be upset by many synchronisms. But I do believe that any ship, having little stability, may be caught by a rapid translatory wave and turned over, particularly if inclining, under sail, in the direction in which the wave is moving, and she possess other small elements of resistance to rotatory motion.

This is often illustrated by boats in surf, and vessels of considerable size when light being rolled over by solitary waves and bores in tidal waves.

But not to leave any point open to doubt, let us examine still further.

Let us suppose a vessel of a five-seconds period to be set rolling by waves of five-seconds period, and a synchronism to occur, and thence an increase of angle of roll, but then, as Professor Rankin says, her period will also increase, then also further synchronism would cease, unless the waves have the power to change *their* periods to preserve the law of Messrs. Froude and Reed, and to secure the needed synchronism for a capsized.

If any still contend that the waves possess this power of accommodation, to save time, I must make them a present of the argument.

I ought to allude to those wonderful surface particles that are supposed to exercise such preternatural influences on ships, that all elements, except metacentric heights, vanish, and gravity is merged in the gravity of these particles that once occupied the place the ships then occupied. So much so that it is said that "a raft representing "one or more of these would so influence an observer standing on it, "that to him the mast would appear to keep truly vertical and the "raft to remain perfectly steady, while it might be rolling through an "arc of 15° or 20° once every four or five seconds," also that "a "pendulum hung to the mast would also be affected by the wave- "motion, and would coincide in direction with the mast;" strange to

say, these same gentlemen say that a pendulum shows too great angles of roll and ought to be superseded, both cannot be correct?

Were this but half true of ships then it were unnecessary to secure anything, guns and shot, or cargo; man ropes, fiddles, and even sea legs would be surplusage, and sea sickness a thing of the past.

The believers of this theory, however, unconsciously disbelieve it, or why incur the expense of the Bessemer failure, instead of applying this raft theory? Why have recourse to the dangerous, in their estimation, expedient of giving enormous stability and low centres of gravity?

It is all well described in the language of Hamlet to Polonius, "words, words, words," facts and principles are flung away, and word-painting of imaginary things is substituted.

The moving forces of wave action are on the bottom and sides, low down; the surface particles neither represent this action, nor do they exercise more than the smallest influence, for a foot area at 3 inches depth is subject to only one-hundredth part of the pressure that there is on a foot area 26 feet down.

How could it be as is argued, that the resultant to surface particles on a wave-face should also be the resultant of all the particles displaced by a ship, seeing it is stated that the particles in every wave make a complete circuit within the height of the wave, therefore, instead of these having one resultant, there are resultants to curves all round these circles; instead, then, of a ship moving as a surface particle, she would, if at all, take a resultant due to the aggregate motions of particles moving in every direction, thus obliterating any resultant such as that assumed.

Thus, in a 24-foot wave, a vessel drawing 12 feet with 12 feet of breadth, would be entirely under the influence of the upper half of

FIG. 6.

the circle, supposing her to coincide with it, and when on the wave, one side would be subject to upward, the other to downward motion, while the portion above would have a horizontal motion in the direction the wave was moving; in the hollow it would be very limited and conflicting.

But a vessel drawing 24 feet water and 48 feet or greater breadth, would embrace two or three large circles and three or four smaller circles when on the wave, but when in the hollow scarcely any at all.

But, in truth, the whole theory is simply impossible.

The fact is Mr. Froude has overlooked that the motions of water-particles could obtain only because of their fluidity and smallness, such as are impossible to large, rigid bodies, like ships, enormously large as compared with particles.

FIG. 7.

If a floating body could take the motion of particles it must be wholly immersed, and turn over, as they do—hardly convenient either for boats or ships.

Mr. Froude has also assumed that ships and waves are moved simultaneously, yet there is no foundation for this; atmospheric pressure moves the waves directly; ships are wholly uninfluenced by this directly, their motions are derivative and later, through the waves.

His theory requires that all the particles that any ship had displaced should have had motions all in the same direction, and at the same rate; that they should move in equal parallel concentric circles simultaneously, so that the ridges of the waves should be in straight lines and equidistant, these concentric circles having a common axis, and the ridges parallel to each other. And more, that the displaced particles should, by some inconceivable means, convey to a ship occupying the space that some such particles once occupied the motions they had had before they were displaced. Moreover, that their periods should be on some self-governing sliding scale to accommodate themselves, for the purpose of synchronisms, to the different periods of ships and to the continuously differing periods of the same ship, from each new impulse, that should be the victims of the dreadful synchronism.

Anyone acquainted with the sea must know that no such parallelism of waves, nor equality of height, nor form, nor power of adaptation, ever does obtain, but the contrary; they are always more or less confused, and that the particles moving according to the law of least resistances move out more or less on one side or the other as they advance, nor can the wave-ridges be straight, for, besides the fact that the directions of winds are curvilinear, they are uneven in their action, as anyone who has sailed with a fleet of ships must have perceived.

The astonishing conclusion arrived at by Mr. Froude ought to have convinced him that he did not arrive at it by a true induction, *i.e.*,

that stability was the *lever* by which the wave sets the ship in "motion."

The lever of stability has no existence till motion ensues, therefore cannot be both cause and effect.

To say that it is, is about as reasonable as saying that the spectator on the raft, spreading his legs out to save himself from being thrown down, was the cause of the motion of the raft that no doubt disturbs his equanimity till he has got his sea legs.¹

Mr. Froude seems to have been conscious of a difficulty, for he changed the import of the word, and called stability by another name, while he appropriated stability otherwise, as Mr. Reed said for the purpose of scientific terminology, unconsciously to deceive himself and others. How foreign architects will smile at the idea that neither their countrymen nor ours were scientific, at least on nautical matters, till the "new school of thought" arose!

Mr. White, in his lecture "On the Behaviour of Ships," adopts Mr. Froude's theory, but unwittingly demonstrates its incorrectness. He gives the cross section of a ship, on which he represents his "virtual upright," which he assumes would be the resultant of *all* the forces acting on a ship, even though these embrace particles moving in four main and opposite directions with varying velocities.

FIG. 8.

He represents the ship as inclined beyond his "virtual upright," but does not tell us how she came thus, or if she dropped from the sky on to the wave in that position, for he commences his argument as if her motion only commenced with the motion, which he ascribes to stability acting through GZ, to bring the ship, as he states, up to the line NN, his virtual upright.

Let me give here Mr. Froude's fundamental proposition, for it will tend to explain why Mr. White's argument is contrary to his illustration:—

"The effort of stability is the lever by which a wave forces a ship

¹ Again, whether it be true that the particles move in circles or not in their earlier stages of wave-motion, observant sailors have seen hundreds of times that particles when running into crests, as is distinctly visible, move vertically.

The pyramidal seas in cyclones prove that winds moved in curved lines, and though there it is excessive, yet all winds and waves are influenced in their direction by the relative motions of the earth's surface through space, consequently there could not be that equality of wave-motion that would secure synchronism apart from the many other causes of disturbance, so the parts of waves would reach parts of ships at different times, angles, and heights, a turn of the wheel would serve to evade a synchronism, but nothing could ensure one.

"into motion, so that if a ship were destitute of this stability no wave that the ocean produces would serve to put her in motion whether that stability were due to a broad plane of flotation or to deeply stowed ballast."

Fig. 8 is Mr. White's Fig. 3, in reference to which he says:—"On the right hand side is shown in cross section; the instantaneous position of the virtual upright is indicated by NN, and the masts of the ship are inclined to NN at an angle GMZ, G being the centre of gravity; GZ is drawn perpendicular to NN, and instantaneously the righting moment tending to bring the masts into coincidence with NN, is given by the equation. Righting moment = apparent weight of ship $\times$ GZ."

Now in Mr. White's *argument* the ship's gravity is merged in the gravity of the particles, for he contends that the ship has only a tendency to come to NN, the assumed resultant of the wave, and *not* to a perpendicular to the earth to which the ship's gravity would bring her if allowed, but his illustration shows that the wave has produced the motion, and has carried the ship beyond his virtual upright, and it shows further that it is *gravity alone* that is resisting inclination, and as the wave recedes, urges the ship to come up to the perpendicular, not simply to a perpendicular to the wave-face NN, but to the earth!

The theory requires that stability should be the cause of motion, and so the action of the wave is ignored in the argument, but shown in the illustration, and stability, under the term "righting moment" is implicitly stated to be the originator of motion.

It is obvious from Mr. White's figure that the upper side where the water is higher by four feet which involves a lifting and rolling pressure greater there than on the right hand side, acting through the lever of half the breadth or more, consequently the righting is entirely due to the gravitation of the ship acting through a lever equal to the distance G is from the true vertical, and longer than GZ, and not in any degree to buoyant action, for this is deficient on the lower side, therefore also the metacentric height has no influence.

To assume, as has been done, that the ship's gravity ceases to act on a ship in the midst of waves, is as reasonable as supposing that gravity ceases to act on a shot while it is under the influence of exploded powder!

Mr. Reed says I have misrepresented Mr. Froude. Let me, then, give his version of Mr. Froude's views:—

Mr. Reed says:—"A ship floating among waves is obviously under the action of two forces—gravity and the centrifugal force due to her own rotation." Then asks, "What more natural, then, than that she should seek her, as her position of rest on the wave, that due to the aggregate effort of *gravity* and *centrifugal force* of all the particles for the moment displaced by her?"

- 1st. She has no rotation of her *own*. She is forced round by the wave.
2. She could not seek rest in that which is continually changing.
3. How could she merge her own gravity in the gravity of particles *displaced* by her?

Is it that, in tossing them up and out in all directions, she impresses them with some of her motion, and that they, in return, impress her, not with reactionary motion, but the centrifugal motion they had had before they were displaced?

The true explanation of the position of the ship in figure 8 and of the forces acting on her is the following:—

FIG. 9.

Suppose Fig. 9 to represent a ship at rest, m the metacentre, g the centre of gravity, gm the metacentric height. It will be observed that when the ship is upright there is no lever of stability to disturb her as is asserted; the ship is retained in this position by the force of gravity pressing down through g , and a pressure up through c acting in the same vertical straight line, and by the equal and opposite lateral pressures acting in the direction of the horizontal arrows, and she continues at rest till this power is overborne by the vertical pressure of the approaching wave acting in proportion to its greater

How difficult it is to write sense in support of a radically erroneous theory!

The writer of the above did not understand the problem. Both he and Mr. Froude have deceived themselves by confounding the *gravity* of the ship in one sentence with *gravity* which is that of the particles in the other.

The gravity of the adjacent particles occasions pressure and buoyancy which, by lifting one side at a time, rotates the ship so fast and so far only as the ship's gravity and other impediments to motion will allow.

Mr. Froude says:—"The *rationale* of my proposition is readily understood by "reflecting on the condition to which we must adhere, if we would give motion to a "board on which a marble or an adjusted level rests; or, again, to a cup brimful of "liquid, without displacing the marble or disturbing the level or spilling the liquid." Herein lies his fallacy, shown also in his fundamental experiment with a tray of water and model on it, suspended by three strings.

He supposes this model and water and tray, set in motion slowly by the hand, *i.e.*, by one force setting all the others in motion simultaneously, to be like a ship set in motion by the wave, but ship and wave-motion do not commence together, nor are their motions due to the same cause, therefore there is no analogy to his illustration, as the difference in the periods further prove. Mr. Froude admits that his theory is markedly at variance with the views which have been expressed by men whose authority deservedly ranks high on questions of naval architecture, and adds, in adopting his fundamental proposition, it is unnecessary to take separate account of the ship's centre of gravity, *e.g.*, as to whether it is *above* or *below* the water-line, or of the ship's peculiar form, as to whether it "tumbles home," or spreads out, symondite fashion, above water, for full account has been taken of them in determining the ship's scale of stability in still water.

Were his view correct, Mozeley and Atwood would have written in vain; the last showed the defectives of the metacentric method to measure either of the above conditions it is said to take account of; Mozeley gave a formula for determining the stability by the rise or fall of centre of gravity from the cause of falling out or tumbling home!

height and nearness, and acting through a lever greater than the half breadth lifting her into the position 2, Fig. 9, in this a lever is developed by g , being carried out to g^1 , and when lifted to 3, Fig. 9, is carried further to g^2 , and so lifted further till the crest of the wave passes the middle line of the ship, then the wave commences to lift the other side, during the whole time the wave was inclining the ship's gravity was resisting, and more so as g was moved first to g^1 , then to g^2 , but the moment the wave commences to lift the other side, gravity helps to bring the ship upright, but when the wave inclines the ship beyond that, then gravity begins again and increasingly resists inclination. Finally the ship is brought into the position of 4, Fig. 9, the position represented by Mr. White; therefore the wave and not gravity, nor stability are disturbers.

Now I have but to show by illustrations the truth of all the foregoing, and that neither one nor both, nor high centre of gravity, nor a small metacentric height, occasion small angles of roll, but the contrary:—

1. The "Superb" and "Vanguard," both old and sister ships; the former was immersed one foot more by a greater quantity of ballast, provisions, and water, therefore having a *lower* centre of gravity and a greater metacentric height, yet she sailed *faster*, rolled through *smaller arcs* and more *slowly* than "Vanguard!"

Her longer period and smaller arcs were due to her greater immersion which gave her a practical keel of 186 feet area resisting motion, involving a pressure of nearly 120 tons against rolling!

2. The following table of oscillations is given by the Constructors of the Navy, but I have added metacentric heights:—

	Meta- centric height.	May, 1865.						
		6.	7.	8.	9.	10.	11.	12.
"Edgar".....	4.5	°	°	9.8	9.25	8.83	6.03	°
"Achilles".....	3.0	6.45	7.1	9.87	11.27	10.37	10.0	6.4
"Hector".....	4.6	11.5	11.37	10.29	11.74	10.53	9.28	3.33
"Prince Con- sort".....	6.0	13.9	10.41	9.66	12.05	12.2	10.07	8.66 ¹

¹ In the report on the "Monarch" by the Constructors of the Navy, who gave the above table:—

"Thus under various conditions of winds and weather, under steam alone, and with both combined, the 'Prince Consort' rolled more quickly, and far more deeply than the 'Achilles.'

"It was known that the metacentric height in these ships was in 'Achilles,' 3.1 feet, and in 'Prince Consort,' 6 feet; and we are furnished with a most complete and remarkable illustration of the correctness of the scientific view of the case."

Here, as usual, it is assumed that there are no differences in these ships that would account for the differences in times and angle of roll recorded, but that of the differences in this metacentric height, yet they differed in weight, 900 tons, in

On the only occasions on which oscillations of "Edgar" are recorded, they are less than those of any other ship, yet she had as great or greater metacentric than all but one. Moreover, she was smaller than any, and much smaller than "Achilles," that had the smallest metacentric height.

On one occasion the "Prince Consort" rolls *less* than "Achilles," on another occasion these are *equal*, and there is little difference on two other occasions, and yet her metacentric height is *double* that of "Achilles!"

The "Hector" on two occasions rolls less than "Achilles," and yet she has a much greater metacentric height.

This table proves that there are other elements that are ignored by the advocates of the new theory that produce these results. It is not science to ignore any factor in a problem.

The superiority of "Edgar" is because she did not carry armour, therefore armour causes ships to roll more *deeply*.

The following table is given by Mr. White to prove that there is a necessary connection between short periods and large arcs:—

Squadron of 1871.	Still-water period.	Mean arcs of oscillation, doubtless should be maximum arcs.
	Seconds.	Degrees.
"Lord Warden"	5 to 5½	62
"Caledonia"		57
"Defence"		49
"Prince Consort"		46
"Northumberland"	7 to 7½	38
"Minotaur"		35
"Hercules"	8	25
"Topaze"	5	22

It will hardly be credited that a gentleman professing to be a master in the science of naval architecture should compare these ships on the bases of their periods alone, and attribute the angles of roll to the difference in that respect, since they vary in masses from 330 tons to 4,500 tons; in length, from 7 to 127 feet; in draught of water from 4 to 18 inches, and in weight of armour from 300 to 1,100 tons.

Moreover, he omitted from this official table the little "Topaze," that rolled only 22°, though she had a period of only five seconds, which is entirely adverse to this theory.

Her superiority was because they carried from 600 to 1,770 tons of

length 107, and in draught of water 15 inches, which besides the effect of the great difference in mass, means 3,000 square feet of vertical longitudinal area, or a pressure of 1,600 tons greater on "Achilles" to limit her times and arcs of roll!

Yet this is called the "scientific view!" Science does not overlook any factor in a problem, still less does it ignore every influential factor, and assume that the results observed are due to that which is not a factor, or if it represents factors in a measure, they are opposing factors from which their result would be negative!

armour, and she had none; she was better than the "Hercules," though the latter had a greater lateral pressure, resisting rolling by 1,500 tons!

Then to carry armour is a disadvantage! The "Northumberland" rolls less than the "Lord Warden," but she is 3,000 tons larger, 120 feet longer, and has a greater lateral pressure by 1,500 tons to prevent rolling either way.

Here is another table given to prove that long periods necessarily give short arcs. It is true we are not troubled with their metacentric heights, but the period is assumed to be an equivalent. Nor is this the only assumption, for it is supposed that a difference in metacentric heights makes the differences in angles of roll, and nothing else; all other differences are ignored, the plan is convenient, if not accurate; you must not expect everything to be correct!

Detached Squadron of 1875.	Approximate still-water period.	Arcs of oscillation.
	Seconds.	Degrees.
"Newcastle".....	5	29·6
"Topaze".....		22·6
"Immortalité".....		20
"Narcissus".....		19·6
"Doris".....		18·7
"Raleigh".....	8	5·8

It is not sought to be explained how the angle of "Newcastle" with the same period as "Doris" is $29\cdot6^\circ$, while that of "Doris" is only $18\cdot7^\circ$, *i.e.*, no difference in period, which is said to be the prime factor in rolling, produces 11° of angle, *i.e.*, a great effect without a cause!

Or to compare "Narcissus" with "Raleigh," a difference of three seconds of period only produces 13° of angle, *i.e.*, a great cause, if we are to believe the arguments but not the illustrations of these theorists, without an adequate effect!

The "Raleigh" is longer than any of those she is compared with from 40 to 70 feet, from 1 to 3 feet less beam, and draws more water from 2 to 3·8 feet, and in mass exceeds them by from 1,200 to 1,600 tons, and has a lateral pressure of 900 tons greater than "Narcissus." These explain "the differences" without having recourse to the groundless idea that difference in metacentric height is the cause. I need not waste your time by further comparison.

Now we come to an entirely different table, to which I must beg your special attention, as illustrating the *opposite* of Mr. White's argument.

Heretofore he has assumed that period and metacentric height were equivalents, if that idea is not given up, there is something he wants to disguise from himself. He gives the complement of period and the metacentric heights, I add the angle of roll and period.

	Rolls per minute.	Metacentric height.	Angle of roll.	Period.
	Times.	Feet.	Degrees.	Seconds.
"Prince Consort".....	12	6·5	46	5
"Miantonomoh" ¹	20	14·0	10	3
"Sultan" ¹	7 or 8	2·5	29½	7 or 8
"Hercules" ¹	7 or 8	2·7	25	7 or 8

We have here the most emphatic contradiction of the theory of Messrs. Froude and Reed; for we have by much the greatest metacentric height associated with by much the smallest angle of roll, and more, we have by much the greatest metacentric height with much the shortest period.

Had there been any truth in the theory the "Miantonomoh" must have capsized within sight of her own shores, as she possesses six times the amount of metacentric height that "Sultan" and "Hercules" had, and that were said only to be safe from rolling over because they had so little!

The explanation is that she drew 11 feet less water than the "Hercules" and was 75 feet shorter; this involved lateral pressures as follows:—On "Hercules," 4,200 tons; on "Miantonomoh," 900 tons, or four times the amount of lateral pressure on "Hercules" to arrest rolling motion either way.

The "Miantonomoh," though she had only 3 feet of freeboard, passed through heavy seas and did not capsize, proving what I said here relative to the "Captain," that she was *not* lost because of her 6-foot side, but because of the deep empty bottom given her by Mr. Reed.

An Officer of the American vessel was asked if she was steady, and answered, "Why, Sir, when it was blowing furiously I took a bottle and turned it upside down with its cork on that in another bottle on the table and it never moved." Doubtless he was poking fun at those who thought, and perhaps still think, she ought to capsize; or if they contend that this was a proof of the correctness of the raft theory, that she was rolling 15 or 20°, but neither the bottle nor the Officer knew it; but still the advocates of the raft theory must establish a change of law to explain how with 14 feet of metacentric height and a three-second period she should have rolled only 10°, or abandon their assumed law. I do not see any other alternative but that of supposing that the Americans have omitted a cypher—100° instead of 10° roll—a cypher is not much, and everyone is open to make mistakes.

The Captain of the "Crocodile" reported that when lying alongside "Warrior" she rolled 30° sometimes 40°, while the latter was apparently motionless; the "Warrior's" metacentric height was 3·5 feet, the "Crocodile's" less than 2·7 feet, for she was very light. The

¹ The "Sultan" maximum roll is avowedly not recorded, and I doubt if that of "Hercules" is either.

explanation is that the "Warrior" drew 25 feet, the "Crocodile" about 15 feet.

The "Serapis" was reported to have rolled helplessly on her side through large arcs when hoisted. Short of coals, provisions, and water, she also had little stability and of comparatively small draught, having, according to the theory, a most desirably long period, probably ten seconds. Then, if the waves had a five-second period she would have made half a roll, the effect of one wave, when another would come up and throw her back on her side; under such circumstances her sails could have been only of the least service to her, she had to be towed into harbour.

The French wooden ship "Montcalm" was said to have rolled 20° when our "Audacious" rolled only 2°. It was not said whether they were equally light or loaded, or one in one condition, the other in another, or whether they were brought beam to the sea at the same time or in the same relation to the wave; yet there is a right and a wrong time to do this.

There was no appreciable difference in their metacentric heights, but the "Audacious" had 350 tons of ballast on her floors; she was nearly double the size; she drew 15 inches more water; she had bilge keels, and carried 160 tons less proportion of armour than "Montcalm." I apprehend that credit has been put on the wrong side of the account here.

Mr. Reed said, at the Royal Institution, that the double bottoms were made expressly large to facilitate raising their weights, as it had been found that this tended to "check" rolling, and vessels have been supposed to illustrate the advantage. Except in two cases this raising of weights does not appear to have been done. Metacentres have been lowered, but that is radically different and much more safe.

In general, the old ships had their centres of gravity little below the load water-line.

The "Penelope" had hers 1·35 *above* the load water-line, she rolled 60°. The "Pallas" had hers ·4 of a foot *below*, she rolled 68°. The "Iron Duke" had it ·6 below, but she was one of those that had to be ballasted, by which it was lowered from its original design about a foot.

The "Conqueror" had hers ·8 below, an old ship. She was thrown on her beam ends by a sea without having any sail set. The "Hercules" has hers 1·38 below, she is bad to steer in a seaway. The "Achilles" has hers 1·52 feet, "Minotaur" 1·99 feet, "Warrior" 2·28 feet, "Sultan" 2·35 feet, "Devastation" 2·84 feet, "Thunderer" 2·84 feet.

That is, though contrary to their theory, the centres of gravity, instead of being raised, are wisely being lowered and the theory abandoned.

The following table will throw light on our subject.

	Period of roll.	Meta- centric height.	Maxi- mum angle of roll.	Height of centre of gravity.	Weight of armour.	Displace- ment.
	Seconds.	Feet.	Degrees.	Feet.	Tons.	Tons.
"Pallas"	probably 5	4·5	68	·4 below	560	3,656
"Penelope" ¹	probably 5	3·5	60	1·35 above		
"Miantonomoh" ²	3	14·0	10			
"Hercules".....	8	2·7	25 ²	1·38 below	1,481	8,700
"Prince Consort"....	5½	6·5	46	2·15 below	941	6,600
"Devastation".....	7½	3·5	27½ ²	2·84 below		
"Raleigh".....	8	2·4	63½		None	5,200

If we compare "Pallas" and "Miantonomoh" as to period and metacentric height, we learn that these are not equivalents as contended for in Mr. White's tables.

The same also, if we compare "Pallas" and "Prince Consort," or "Penelope" and "Devastation," or "Hercules" and "Raleigh," or "Miantonomoh" with any of them.

Again, if we compare "Pallas" with "Prince Consort," on the supposition that greater metacentric height produces greater angles of roll, they afford a distinct contradiction of the idea, or if we compare "Penelope" with "Devastation," or "Miantonomoh" with any other on the same point, they all contradict the idea.

Nor do we find that a high centre of gravity contributes to small angles of roll, for the vessel with the highest centre of gravity rolls 60°, and the next highest, "Pallas," rolling 68°, and those with low centres of gravity are the least rollers, "Devastation" and "Raleigh."

It is contended that weight on the sides of ships contributed to small angles of roll; were that correct "Pallas" ought to have rolled less than "Prince Consort," and "Hercules" more than "Miantonomoh" and "Raleigh."

Had "Pallas's" excessive rolling been attributed to her stupid form, which involves rolling round a diagonal axis, and to her high centre of gravity, there would have been reason in it; while these exercise a baneful influence, that which is the main cause was her small lateral resistance, great weight of armour, and undue proportion of breadth to length.

The lateral pressures were about as follows:—

¹ The great disproportion between half breadth and immersed depth in "Penelope" and "Miantonomoh" makes them eccentric wheels, in rolling, from which there is an unusually great rise and fall of their axis, hence, also, rapid and large angles of roll.

² Maximum angle of roll not recorded; this is probably the same of "Hercules"—why?

" Miantonomoh "	900 tons.	" Penelope "	1,300 tons.
" Pallas "	1,900 "	" Raleigh "	3,060 "
" Devastation " ..	3,600 "	" Hercules "	4,200 "

Mr. Reed, who designed "Pallas" and "Hercules," while insisting on the necessity for a high centre of gravity, lowered that of "Hercules" below that of the "Pallas" by nearly 1 foot, and reduced her disturbing element of breadth from 1 to 4·5 in "Pallas," to 1·55 in "Hercules," while he largely increased the mass of the latter as compared with her length and breadth.

The "Hercules" has a greater disturbing element than "Raleigh," and carries a large weight of armour, "Raleigh" not having any, and has a further advantage in 180 tons of ballast on her floor.

On the contrary, the following vessels have all been thrown on their beam ends, "Algerine," "Raleigh" (old), "Camilla," "Sappho," "Ariel," "Star," "Nerbudda," "Victor," "Racer," the "Blanche" frigate, and the "Conqueror," 90 guns, and many merchant ships every year; not one while in their normal condition and not till their stabilities were reduced by the consumption of stores and their centres of gravity raised! Yet, according to the new theory, this was the condition in which they would have been most safe!!

The use of bilge keels proves that the reduction of stabilities has not produced the effects claimed for it, and notwithstanding so much has been done affecting the safety of ships and their crews, in opposition to received principles, nothing but irrelevant facts are offered in justification; when a real test has offered for truly determining the question, it is passed over without notice—I mean that of so much ballast having been placed in a number of ships, "Sultan" and her sisters, "Invincible" and her sisters "Raleigh," "Volage," "Inconstant," and others; by which their centres of gravity were lowered and their stabilities greatly increased.

It was no doubt conclusive against this theory, or Mr. Froude and his Committee would not have recommended the "Inflexible's" stability, which is represented by 8·7 feet, nearly four times that of the "Monarch," to be doubled in new designs, *i.e.*, giving them a metacentric height of 17 feet; greater than that of the "Miantonomoh," so condemned by Mr. White. It is not to be doubted but that the "Sultan" was improved by the addition of 150 tons to her previous 450.

We have seen that the "Invincible," when without ballast and subject only to a moderate wind on her bare masts, when turning, went over 17°, had she had sail on her or had a surface current carrying her upper part in the same direction, while the water below was motionless, thus tripping her up, a state of things not uncommon, she would have capsized, so also "Sultan" and her sisters if without ballast.

It is necessary to dwell on this, as it has been recommended to leave out this ballast or keep out weight *below* in new designs, without giving them any real equivalent, for that proposed is not such. But it is demonstrable that this would be fatal.

The following French ships afford equal testimony to the correctness of the views I have set forth.

	Period in seconds.	Angle of roll.	Metacentric height.	Weight of armour.	Displace- ment.
			Feet.	Tons.	Tons.
"Normandie"...	5 to 5½	43° 6	6·5	980	5,600
"Invincible"...		41° 4	6·4	980	5,600
"Couronne"...		37° 7	5·4	710	6,000
"Magenta"...	7 to 7½	36	5·0	1,003	6,700
"Solferino"...		35	4·5	1,003	6,700

Sir Spencer Robinson gave their metacentric heights as showing that the difference in these was the cause of the difference in their angles of roll, Mr. White affirmed it and gave their periods of roll, I add their weight of armour and displacements.

They assumed that there is no difference that could account for the differences in their angle of roll, practically that they are alike in all else, yet they differ in size from 400 to 1,200 tons, in proportionate weight of armour 170 tons, the two smallest ships carrying the greatest proportion, in length 28 feet; in breadth 2 feet; in immersion 3 feet; in vertical longitudinal area 1,300 square feet; all influential factors in favour of "Solferino," as against all the others, but mostly against "Normandie" and "Invincible."

With a difference of a foot in metacentric height there is only a difference of $\frac{1}{2}$ a second in period!

With a difference of .4 of metacentric height there is a difference in period of $1\frac{1}{2}$ seconds!

And with a difference of $1\frac{1}{2}$ seconds in period there is only a difference in angle of roll of $1\cdot7^{\circ}$!

Yet with *no* difference in period in English ships, there is a difference of angle of roll of 16° , a great effect without a cause!!

Clearly establishing that, to say that metacentric height is the measure or cause of steadiness or otherwise, is as reasonable as saying it produces the differences in size, in form, and weight of armour!

It is due to the French to repeat Sir S. Robinson's testimony before the Committee on Designs—"It is also remarkable, that while the "number of oscillations per minute is almost invariable in the French "ships, whatever the amount of rolling may be, the greatest possible "variation in this respect is recorded by *each ship* of the English "squadron."

Could anything be more conclusive against the metacentric height theory than this? for it really amounts to his saying, "Give me the "choice of days, let me select my table of recorded angles of roll, and "I will give you proof of any view you like on the subject."

Manifestly there is a scientific adjustment of the elements in French ships that does not obtain in ours—the French ships represent law, the English ships absence of law—any way you please, and

yet this is supposed to give evidence of a fixed law on which to build a safe theory.

It has been said that the French naval architects have endorsed Mr. Froude's views, and have adopted the practice introduced by Mr. Reed into our Navy. If so it is something new in their history; generally we have followed them. If they have been misled by the strong reports from this side to go a little in that direction, I have no doubt they will be modified or not adopted wholesale before they will have been proved to be dangerous.

But I should like to have plain answers to the following questions:—

1. Have they accepted the theory that a ship should be treated as a surface particle? That when at rest she should be recognized as a solid body, but when in the midst of waves she should be taken out of this category and become subject to the laws of motion in fluid particles?

2. Have they accepted the dictum that the ship's gravity is to be held to be distinct from that of the particles when she is at rest, but when in the midst of waves it is to be merged in the gravity of the particles she had displaced?

3. Have they accepted the dictum, the basis of this new theory, that "stability is the lever by which the waves set ships in motion, whether that stability be due to a broad plane of flotation or to deeply stowed ballast, and that if ships were destitute of this stability no wave would serve to put them in motion?"

4. Have they adopted the practice of raising the inner bottoms 4 or 5 feet above the lower floor to facilitate raising the weights from a belief that this has been found to check rolling?

5. Have they accepted the theory that weight concentrated on the sides and above tends to reduce angles of roll?

6. Is it their experience that in proportion as their ships have had greater stability of any kind, they have been found to roll over?

7. And as logically flowing out of the above if they have accepted them; do they teach that the proper distribution of cargo, &c., for safety and the integrity of the fabrics, is to place the heavy weights at the sides and above, and the light weights amidships and below, but not at the bottom; that there should be large empty spaces up to 5 feet in depth, according to the size of the ship?

Relying on their ancient fame we might answer in the negative; but the table given of their ships and their performances, proves that their constructors have not fallen short of the science of their predecessors. Two or three points may be mentioned in contrast with ours, but which happily we seem to be following.

Sufficient stability to make them safe and manageable, and this increased in proportion as the top weights are increased, and low centres of gravity, in all the ships mentioned, more than 3 feet below the load water-line, while ours range from 1·35 feet above to 2·8 feet only below!

Having submitted these questions to a French authority, I give the substance of his answer. "Our rule for full masted steamers is un-

changed, it is to give the amount of stability that has long been our custom. For steamers without sails to obtain a stable platform, we can either increase the moments of inertia or diminish stability. The former is seldom possible as this increases the amplitude of roll and takes away the advantage we seek. Thus, generally we seek to reduce stability, but this must be done with great prudence." Thus they hold that danger comes with little stability, while the Froude theory is that safety comes with little stability.

The damaging consequences of excessive rolling may be illustrated by the following—supposing "Penelope" and "Pallas" periods to be 5 seconds. These ships would roll through these degrees in an hour.

"Pallas"	48,000 degrees.
"Penelope"	42,000 "
"Albion" (old)	39,000 "
"Hercules"	12,000 "
"Miantonomoh"	12,000 "
"Raleigh"	3,000 "

Excessive rolling must disintegrate the fabrics, occasion great wear and tear and cost, and must militate against extended usefulness. The remedy proposed by Mr. Reed was said by Mr. J. Scott Russell to be worse than the disease, the loss of the "Captain" and "Eurydice" with 1,000 lives has fully justified this.

The "Miantonomoh" no doubt rolls 20 times in a minute, but as it is only through 10° it is not faster than "Hercules"— $8 \times 25 = 200$ and $20 \times 10 = 200$!

From a small damage "Hercules" would capsize, having only 2.7 feet of metacentric height; but "Miantonomoh" would be still safe after much damage, having 14 feet of metacentric height.

These facts are entirely in favour of my argument, for if very limited areas of bilge keels reduce the angle of roll and increase the periods, *à fortiori*, the greater areas of resistance to rolling, the result of differences in length, varying from 100 to 200 feet, and in depth from 12 to 20 feet, must produce vastly greater results in the same direction!

Thus I have established that all other things being equal, and science always recognises the *cæteris paribus*:—

1. That stability does not originate motion, nor cause larger arcs of roll.

2. That little stability is dangerous as facilitating a capsize, and makes vessels unmanageable.

3. That breadth in proportion, as it is great, increases the lever by which the waves disturb vessels.

4. That a high centre of gravity occasions greater arcs of roll, and is dangerous. That whenever the centre of gravity has been high, and the stability small, and the one has been lowered and the other increased by ballast low down without any other alteration, the ships have been benefited not only in rolling less, but made more safe and improved in other essentials.

5. That weights on the sides tend to occasion longer arcs of roll.

7. That ships do not move, nor can be treated of as moving, as a surface particle in the wave that floats them.

7. That ships' gravity cannot be merged in that of the gravity of the displaced or any other particles of water.

8. That great metacentric height is not incompatible with small angles of roll, as has been taught, for the "Miantonomoh" with the greatest, *i.e.*, 14 feet, has nearly the smallest angle of roll, 5° ; when the "Augusta," said to be a remarkably steady ship, and steadied by sail, with waves of 20 and 25 feet rolled 18° !

9. That a ship does not drop down on the wave as was suggested as possible in "Naval Science," nor become an integral part of the wave!

Lastly, that the system which rejected that which had been found ever since the present laws of nature have existed, as being the safest and most effective, for that of minimizing stability, by raising the centre of gravity, giving deep empty spaces at the bottom, and loading the sides, was founded on an entire misapprehension of the problem, and did not have a single pertinent fact that could be logically brought to justify it, so that much talent and money has been spent in hunting myths—an innocent amusement, if it had not led to experiments that have proved fatal to many ships and their crews. For if the weights in the "Captain" had been dropped down into the void space in her bottom, her stability would have been so increased that, in all human probability, her name would still have been on our Navy List, and her crew amongst us.

In one case, twelve vessels were capsized in the same *pampiro* from insufficiency of stability.

The cure is obvious from what has been shown, and that which would produce safe ships that would sail well, carry large engines, with sufficient coals for long distances, and be manageable with all, *viz.*, breadth not to exceed one-fifth of the length, not less than 6 feet of metacentric height (greater if subject to damage or having to carry unusual weight above, such as armour), and a low centre of gravity, and great proportionate displacement, for dimensions, by great proportionate immersion, when admissible, according to the service purposed for them.

Much of the casiness of "Raleigh" arose from the fact that she was immersed nearly 2 feet more than was intended, some of this by 180 tons of ballast placed on her floor, by which her centre of gravity was lowered and her stability increased, she would be a safer and better ship from more ballast.

Nothing will compensate, in certain not uncommon circumstances, for the absence of a low centre of gravity and weight on the floor equal to one-tenth of the nominal tonnage.

The great French architect, Sané, showed that he understood the problem, when he placed large quantities of ballast on the floor of his designs, and designed them to tumble home above.

His ballast in steamers should be substituted by engines.

In conclusion, this new theory of stability in a sea-way, and its alleged effects, no less than the theory of rolling, is in direct contra-

diction to the teaching of facts, and authorities so distinguished as Poisson, Bernoulli, Chapman, Inman, and Mozely; and of living authorities, as Puy de Lôme and Scott Russell, who has steadily opposed this system as erroneous and dangerous.

It is claimed that this is the scientific system and its advocates eminently scientific; but science ignores no factors in any problem, still less does it ignore all influential factors while attributing the observed results as to rolling, to that which is *not* a factor, but merely a mathematical incident!

I should fail in my duty if I did not protest against this system being taught at Greenwich, and more, against ships and their crews being further made the subject of experiments involving so much danger, experiments, the success of which never had a probability, much less any reason to warrant a departure from a long approved and established system!

Captain COLOMB, R.N.: I do not presume to follow the enormous mass of facts and figures that have been put before us; but one of the ships mentioned—the “Audacious”—I happen to have commanded for over three years, and the lecturer has stated that her easiness, absence of rolling, or whatever we may call it, is mainly due to the 360 tons of ballast which had been placed in her. Now, the initial stability of that ship is accordingly small, so small that a few hands passing from one side to the other on her battery will give her a slight list. It is difficult, in fact, to keep her exactly upright. But, on the other hand, the fact remains that, during the time I commanded her I hardly ever succeeded in getting a rolling experiment. I never could ascertain what the period of the ship was, because the rolling was so exceedingly small, generally within one degree, that we could not register. Admiral Fishbourne seems to say that the modern theory tells you that the more you reduce the metacentric height, so much the safer does the ship become. I have never heard that stated except in this theatre.

Admiral FISHBOURNE: I quote from Mr. Froude’s own pamphlet.

Captain COLOMB: I have not seen the pamphlet. I have always heard it stated that the readiest way—under conditions—of getting a steady platform for your guns is the reduction of the metacentric height, roughly speaking, and the proposition is not that we gain greater safety by that reduction, but the problem is, how far you can reduce it with safety? There is no question but that in the “Audacious,” whatever the cause was, the object was attained. The ship was apparently a perfectly safe ship, and she had this wonderfully steady gun platform.

Mr. W. H. WHITE: Before I make any observations, will you allow me to ask Admiral Fishbourne a question or two as to the figures he has given in the second table on page 9 of proof (202), and the table on page 10 (205), because I shall be guided much in what I have to say by his replies. In the first place I should like to know if the ships named in the table on page 10 have ever been at sea together, and, further, upon what authority the maximum angles of roll, say, for the “Miantonomoh,” the “Pallas,” and “Penelope” are based? Also, in what publication of my own, the second table, on page 9 of proof (203), with which I am credited—comparing “Prince Consort,” “Miantonomoh,” “Sultan,” and “Hercules”—can be found?

Admiral FISHBOURNE: I did not say that was your table. The first columns are taken from your book; the third and fourth columns, “Angle of Roll” and “Period,” are added by me. I distinctly stated so in my paper. Neither have I represented that the ships in the table referred to have ever been at sea together. The maximum angles of roll for the “Miantonomoh,” the “Pallas,” and “Penelope” are taken from the Blue Books at different times.

Mr. WHITE: There are two principal sets of observations that I wish to make. First, I must decline to admit, with all respect for the Admiral, that he has fairly represented what we are accustomed to call the modern theory of rolling. In proof

of that, I will refer you to his own statement:—"It is accepted as an axiom by those who contend for the truth of Mr. Froude's theory, that if a ship's stability or metacentric height be great, her period of roll will accord with the period common to waves, so synchronisms and increased angles of roll will be given at each double swing till the vessel is rolled over." The words in italics are those to which I take exception. Mr. Froude never said so, and in his first paper you will find he has stated the distinct contrary. Mr. Froude said that, apart from the effect of fluid resistance, the vessel which fell in with waves having a period equal to her own period would be rolled over; but that in practice the tendency to accumulate rolling would be checked by the influence of fluid resistances, such as the resistance to rolling motion offered by flat surfaces and the frictional resistance of the bottom. If anyone will take the trouble to refer to Mr. Froude's paper, he will find that my statement is correct. He will also find that in the paper which I read two years ago so far was I from giving the tables as positive proofs of the influence of the "periods" of ships upon their behaviour at sea, that I headed those tables with these words:—"General experience confirms the teachings of theory that on the whole the ships with the longest still-water periods are steadiest in a sea-way." That is all I said, and I guarded myself further by enumerating the three principal influences which govern the ship's behaviour at sea, putting first the period of still-water oscillation, and then the magnitude of the fluid resistance. Those tables were given as illustrations of the general statement that "on the whole ships with the longest still-water period are the steadiest," and not as exact scientific evidence of a theory. As I stated then, those tables were but selections. Take, for instance, the table for the detached squadron, where the "Raleigh" compares so favourably with the other frigates. I stated distinctly that this table was one of a great many tables of that kind; and I may add that the heavier the weather became, the greater was the superiority of the ship of the longer period. I quite admit the justice of the Admiral's statement that the "Raleigh" had other points of superiority besides her long period; but I contend that a very influential thing in the superior behaviour of the "Raleigh" was her long period. The loss of the "Eurydice" has in some way been connected with the modern theory by the Admiral. Now, she is a vessel built long before Mr. Froude read his paper, and was designed by a gentleman having no knowledge of Mr. Froude's theory. You will find by the evidence given at the court-martial that when fitted as a training-ship she was equipped as nearly as possible as she had been before, so that she was sent to sea in almost the same condition as that in which she had successfully served beforehand. Coming more particularly to the question of fluid resistance, it will be seen that Admiral Fishbourne connects fluid resistance to rolling with the static pressures on the fore and aft or diametral plane. I take exception to that view entirely, and I think everyone who has studied the subject of motion in a resisting medium will know that the matter is quite distinct from static pressure. I can give you a very simple illustration. Suppose one takes a circular cylinder, and places it with its length horizontally in the water; you know with what ease it can be made to rotate in the water, like a log of timber, simply because it has only to overcome frictional resistance. But suppose one takes a vessel of triangular cross section having the same draught and longitudinal central section as the circular cylindrical ship, the lateral pressures would be the same on both; but the resistance to rolling would be immensely greater in the vessel with the triangular cross section. In fact, the figures given by Admiral Fishbourne are most misleading as evidence of the resistance to rolling of these different ships. Those resistances to rolling, I submit, are governed by three considerations:—(1) the area of the flat surfaces immersed, the dead-wood, keels, and bilge-keels; (2) there will be the approximately cylindrical parts, which will give frictional resistance; (3) the further element of surface disturbance, which may be very great indeed with vessels like monitors. These are the influences which govern resistance to rolling when associated with the rate at which the rolling motion is performed. It is not a question of static pressure, it is not a question of depth of immersion into the water. The figures given in the paper have a most formidable look, but one need not be afraid of them. My conclusion as to fluid resistance is therefore as follows:—I fully agree with the Admiral as to the importance of fluid resistance; but I entirely differ from him as to the mode of estimating that resistance. It has always been a principle

with me in studying this question, and attempting to analyze figures, which naval Officers have been kind enough to place at my disposal, never to compare ships which were not exposed, so far as I could learn, to the same conditions of wind and sea. I ask if Admiral Fishbourne's tables on pages 9 and 15 of proof are based on a fair method of comparison, or whether any scientific argument can be based upon them. Moreover, I happen to know that in the "*Miantonomoh*" they never made an observation except with the pendulum. Admiral Fishbourne has made great fun of our objection to the pendulum as a means of recording rolling; but I ask any naval Officer if he believes the pendulum to be a correct means of recording rolling in a ship, for I never met with the naval Officer who did. Moreover, one has only to turn to the reports of the rolling of the Channel Squadron to find evidence that the pendulum does not give a correct measure of rolling. The "*Miantonomoh*" is put as rolling ten degrees. I do not know what she rolled, and I defy anybody to say what she rolled. Moreover, I strongly object to being brought forward as an opponent of the "*Miantonomoh*." I thoroughly believe that she was a ship which did not acquire large angles of oscillation in a sea-way, and there were special circumstances, such as lowness of deck and great quickness of motion, which led me to express long ago the opinion that she ought not to roll heavily in a sea-way. Therefore I object to being represented as an opponent of that class of ship. Admiral Fishbourne has made much of my omission of any reference to the "mass" of ships. Now I beg to state that in obtaining an expression for the period of oscillation for a rigid body the mass does not come in at all, or rather it comes in on both sides of the equation, and therefore disappears; so that the tremendous figures of displacement which appear in the Admiral's tables only have a meaning as they relate to the *distribution* of the weights and the consequent moments of inertia. I thoroughly agree with every word written by the French authority who has been quoted. No truer description could be given of the practice of English naval architects than was given in the letter which Admiral Fishbourne read. One other word I should like to say, and it is on a matter of some importance. In discussions on the safety of the "*Eurydice*" I find the greatest importance attached to a mode of fixing the position of the centre of gravity, which I look upon as most unsound. A ship has a certain total depth. She has a certain part immersed in the water. The Admiral gives us the position of the centre of gravity in relation to that load water-line. So long as one is dealing with ships which have the same ratio of in-water part to out-of-water part, I have no objection; but directly you alter the ratio—that is, vary the freeboard—that method of referring to the centre of gravity at the load-line becomes most misleading. In the case of the "*Eurydice*" this was particularly true. Admiral Fishbourne gives a table, on page 10 of proof, showing apparently that the centre of gravity has been lowered in recent ships, fixing that point in relation to the water-line; but any gentleman who has a knowledge of the ships, and takes the total depth—for instance, that of the "*Derastation*"—from keel to upper deck, and fixes the centre of gravity in relation to that total depth without any relation to the load-line, will find that the centre of gravity in the "*Derastation*" is not in such an exceptionally low position as would appear from the table. I am sure that Admiral Fishbourne will believe that although I am not convinced by what he has written, I have the greatest respect for his opinions.

MR. WATT: I agree with what Admiral Fishbourne has said, that is, as far as I am able to follow him. I read in the *Times* newspaper that a member of the Admiralty went down to Portsmouth, and listed the ship with a certain quantity of ballast, and then reported that the stability was perfectly satisfactory. The ship goes to sea and capsizes, for a very obvious reason. I should like to ask Mr. White what is the value of the scientific theory of finding a ship's stability, if she capsizes and drowns all hands?

MR. CHAS. F. HENWOOD, Naval Architect: I think our thanks are greatly due to Admiral Fishbourne for his admirable paper. I do not think that Mr. White has at all answered the essence of the paper. Some of the details have been criticised by him, but the main points have not been touched. When you are speaking of stability it is neither proper nor right to refer the centre of gravity to the depth of the ship, that is taking it in relation to the upper deck or the keel—that is all very well when you are looking at the centre of gravity in relation to the ship herself: but

inasmuch as stability refers or is relative to the load water-line, or plane of flotation, and nothing else, the plane of flotation is the proper and only basis to which, in such case, the centre of gravity is to be referred. The great difference between the scientific aspect has been referred to, and it is said that the "modern theory" has not been fairly represented; but I do not suppose there is any difference at all in science, because none of us claim to have invented a new science; science is a knowledge of laws obtained by reasoning on combined facts, formulated and tabulated for us by our fathers, and we have learned it in our youth from books: or it means *certainly* grounded on facts and demonstrations. It is, however, the misapplication of science which is the cause of the difference which has arisen between naval architects of the present day. A certain theory was introduced by Mr. Froude, but its supporters are now apparently "backing down" from the original stand-point, and so before long they will, no doubt, come back to the old level, for it is now merely alleged that, "*on the whole*, ships with the longest still-water periods are the steadiest." That may be so under certain conditions, but that does not prove the theory at all; and I think the facts brought forward by Admiral Fishbourne to-night thoroughly upset the theory introduced by Mr. Froude. We have also been told this evening, that the "Eurydice" was sent to sea in nearly as possible her original state. That may be perfectly true; she was sent to sea I believe practically in the same state as she was originally, but at the time she capsized, she was in a condition in which she had never been before. When she went to sea she had on board a larger amount of consumable stores, and a more numerous crew to consume the stores; and so when she arrived at the back of the Isle of Wight her condition was one in which she had never been in previously. She was then very much lighter, her draught of water was very much less, and her centre of gravity very much higher than it had ever previously been as a frigate. The fact was, that her Officers, who might reasonably have supposed that they had under them the old "Eurydice," had really a very different ship. I am also sorry that Captain Colomb did not give us a little more information with respect to the "Audacious." We should like to know whether she ever got into bad weather.

Captain COLOMB: Very often.

Mr. HENWOOD: Then she is a very remarkable ship, and she equals the "Miantonomoh" in steadiness. Of course we must take these statements as facts, and although they are apparently inexplicable, we must accept them and endeavour to find some explanation.

Mr. WHITE: If the evidence given before the court-martial is examined, it will be seen that Mr. Henwood is mistaken as to the ship having been worse off, as regards stability, when she was rid of her consumable stores than she had been in her previous commissions. I am not giving any information which is not accessible to the public; but happened to be present at the court-martial when distinct evidence to this effect was given by those who should know.¹

Mr. SCOTT RUSSELL, F.R.S.: I have little to do except to express the satisfaction with which in this Institution I always listen to the knowledge which commanders of ships have acquired in the circumstances in which alone you can judge the good qualities of ships, namely, by long experience of their behaviour at sea. I am delighted to hear that there is such a ship as Captain Colomb has described, that there is a vessel in our possession which, put her under what circumstances you like, will not roll. That I think we should assume as the model ship of the future, and naval architects and sailors could do nothing better for us than to investigate that ship to the very bottom. She is certainly a model ship. Perhaps Captain Colomb must have had something to do with selecting the kind of waves and selecting the particular seas, and selecting the good weather, under which that ship passed those happy three years of her and his life, because I am afraid that whatever "periods of roll" your ships have, they will often meet with waves at sea which will not be very courteous to them, and their periods of roll, and therefore

¹ NOTE.—I here refer to the evidence of Mr. Barnaby (Director of Naval Construction), and of Mr. Robinson, Chief Constructor of Portsmouth Yard.—W. H. W.

I am afraid that the dexterous Captain kept her most cleverly out of circumstances in which she would roll. With regard to Admiral Fishbourne's collection of facts, I think it extremely instructive, because conclusions can be drawn from them extremely different to those which have hitherto been drawn from such experiments. When I was young I was educated in a school of practical construction, which had, as one of its ideas, giving a ship extremely small metacentric height, and those ships, built to meet certain circumstances, not adapted to a theory at all, were a source of great danger and sorrow to all who had to do with them. I call a ship of small metacentric height, I am afraid, offensively, a "crank" ship, and a "crank" ship may and will be, in certain circumstances, a very gentle roller, and may have a very stable platform; therefore if the circumstances are wisely chosen by a very clever sailor, she will have most wonderful qualities; but put her out of those conditions, and according to my experience, you will find her the worst and most dangerous ship you ever saw. I therefore call attention to the fact that in every ship you build, you must provide two kinds of stability for two totally different sets of circumstances. This low stability is delightful for smooth water, for gentle, moderate, and well regulated waves, such as you could manage to have in a nicely sheltered sea; but I put it to the profession whether they attach the slightest value to a sea-going ship, though her behaviour is ever so good in smooth water, if, when it comes to heavy cross seas and heavy storms, she is incapable of maintaining her position on the sea. That is the case of these small metacentric height ships in such groups of waves as I have witnessed in the Bay of Biscay. If Captain Colomb had brought the "Audacious" safely through such a sea as that, it would have been a triumph for the Captain, and for the ship. I think Admiral Fishbourne is quite right in saying that the low metacentric height is a false light which has been by some constructors blindly followed, and has led us into various mistakes. Old constructors, such as the eminent Sané of the French Navy, and eminent Spanish writers on this subject, and other eminent naval constructors, have handed down to us sound principles for the construction of ships with seaworthy qualities, and with the right kind of stability; and I sit down by stating that there are two radically different sorts of stability, that the one is the stability of smooth water, and the other the stability in rough water, and that the kind of stability against which Admiral Fishbourne has spoken so strongly, is the kind of stability which is good for smooth water and fair weather, but utterly ruinous when you come to ships whose test of utility is to be their seaworthiness, their stability, and good qualities in a storm.

Captain CURTIS: It seems to me that, with a low metacentre, you could not work your ship off a lee shore. Supposing any of our cruisers got short of coal, and had to work off a lee shore, I do not know how they would do it. With regard to the sails, I can quite understand a vessel rolling slowly, but I cannot understand how the "Audacious" would act under her double-reefed topsail, as compared with an ordinary frigate—whether it would affect her listing.

Captain COLOMB: I can tell you how it was in the "Audacious." When you could just carry double-reefed topsails, and were obliged to take the top-gallant sails in, just at that point the ship heeled 8 degrees.¹

Captain CURTIS: As compared to an ordinary frigate, I mean.

Captain COLOMB: I could not say, because there was no frigate with us in the same position. My own impression is, that the ship was remarkably stiff after the first few degrees of heel, and so strongly have I felt this, that I have officially suggested that the ballast should be removed. No doubt, the gallant Admiral will tell you the only good thing about her was the ballast. I should not like it to go forth to the public that Her Majesty's ship "Audacious" was under my control in any way as to avoiding or getting into any sea. As it happened, she was several times in pretty heavy seas, and the absence of rolling was remarked upon by us all.

¹ NOTE.—I find, on reference to my diary, the following note on the occasion referred, August 3rd, 1876:—"Ship under plain sail, less royal, flying jib and "spanker, wind abeam; went 8-2! Wind freshened; took in two reefs of top-sails. . . . Beam sea. . . . No rolling. 4° to 6° heel, with double-reefed "topsails and courses."—P. H. C.

On one particular occasion, I remember that she broached to after running before the wind, her behaviour was then so remarkable, and she was so exceedingly steady, that the Admiral made a special report to the Admiralty on the subject. The "Iron Duke," her sister vessel, was certainly in one, if not two, typhoons in the China Sea. Such circumstances ought to try the ship.

Mr. SCOTT RUSSELL: I am delighted to withdraw my observations in which I gave the gallant Officer all the credit of having arranged for the proper behaviour of the ship, and I must attribute the credit to the excellent ballast. It is just what I should have recommended in the circumstances of such a ship, to correct completely all her bad qualities; they were so corrected, and I am more content than before.

Admiral FISHBOURNE: The description Captain Colomb gives of the "Audacious" lowers her in my estimation very much. It is very clear that her condition is very nearly approaching to indifferent stability. He says, a very few men going on one side of a 6,000-ton ship incline her, and she is so indifferent that she does not seem to care to move in any direction. Now, I say, there are circumstances in which she may be placed, for instance, at the Cape of Good Hope, on the Agullas bank, with a current running to windward in a gale; she would be in excessive danger of tumbling over one of those wall seas found there. The only reason why she appeared to have great stability was the excessive disproportion between her masts and her hull—a 6,000-ton ship with the masts of a 2,000-ton frigate. The "Nerbudda," a vessel of great breadth of beam and great initial stability, was tumbled over on one of those wall seas. She was no doubt light, and out of provisions, but the same thing might occur with the "Audacious." As for carrying sail, it could be of no use to her. And more, she could not steer; and this is an essential quality. Mr. White seems to think that I have misrepresented the new theory. I suppose Dr. Woolley understands it. He said Mr. Froude has established that, for safety, it was necessary that a ship should have a very little initial stability. I can understand this in no other sense than this, that he meant to say that, by a series of synchronisms, vessels would be rolled over if they had a large amount of initial stability.

Captain COLOMB: Where is it to be found?

Admiral FISHBOURNE: I quoted it in my last paper. Of course, if Mr. Froude abandons it, I am content, and am only happy that he should do so.

Mr. WHITE: In Mr. Froude's first paper, to which, I believe, the Admiral is referring, those statements will be found which I referred to as to the effect of resistance. The two things are mentioned—unresisted rolling, which would give the danger of upsetting, but limited by resistance.

Admiral FISHBOURNE: I have quoted his exact words, as given in a note written by himself to myself, and substantially the same will be found in his pamphlet, which I have also. I will read it:—"The effort of stability is the lever by which a wave forces a ship into motion; if a ship were destitute of this stability, no wave that the ocean produces would serve to put her in motion, whether that stability were due to a broad plane of flotation, or to deeply stowed ballast." If he does not mean that now, it would be an act of humanity to withdraw it, because its tendency has been to induce the Constructors of the Navy to reduce the stability of ships to a degree that is absolutely unsafe. I have no hesitation in saying that, if, in a crisis, we had put 2,000 men upon each one of those ships mentioned, and they had gone out, they would have tumbled them out into the sea—not like the mud barges, to come back for another cargo, for these ships would have turned right over and have gone down. As to this table to the left, I have brought these facts into contiguity for convenience. The story of the "Eurydice" is too long to go into now. I hope at some future time to be able to show what was really the cause of her capsizing. I admit that the court-martial had no right to assume anything else than that she had enough stability, because the ship was given over to its Officers; with this assurance, therefore, they were not to blame in assuming that she had sufficient stability; that she had not, the fault did not lie with the Officers. It was not a court-martial to try the Construction Officers of the Admiralty, though I believe they ought to be put on their trial as well as Officers, when ships are lost and men are drowned. As to resistance to rolling, it stands to reason, if you are rolling a

cylinder round a fixed axis, there is only the friction; but that is a totally different thing to a ship. If the difference of immersion makes no difference, why have they put bilge keels? Every argument for them is in favour of my argument. Mr. White has not objected to a single principle that I have brought forward; he has merely referred to technical details of no importance. My argument, as shown in the diagram, is, that it is the wave which has brought the ship into that position, and not stability. Stability is an opposing motion till the ship is on the back roll; then the two concur, till a new lever is brought out in the opposite direction to resist her further inclination in that direction. Mr. White admits the influence of greater mass in his own paper. How then object? He also will find in Mr. Reed's work, "Our Ironclads," such records as—ships rolling according to their masses the heaviest, slowest, and least.

The CHAIRMAN: We must all feel thankful to Admiral Fishbourne for his able and well-considered paper; and I think I may take it for granted it is your wish that I should convey to him your thanks.