ON CIRCULAR IRON-CLADS.*

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In venturing to address this distinguished professional Meeting, I am quite conscious of my own inability to deal with this subject in a manner which its importance deserves, especially after the excellent lecture delivered by Mr. E. J. Reed, C.B., M.P., in the Royal United Service Institution, and after what has been written by him previously to the *Times* on the subject. But I deeply wished that these present Meetings should not pass over without registering the birth, or acknowledging the development and the existence at sea, of such typical new vessels as the "Popoffkas," or the circular iron-clads of Russia; and it is only for this reason that I have with pleasure accepted the proposal to prepare a Paper for these Meetings.

It was in the beginning of the year 1869, that the idea of circular ships such as they are, or very little differing from what they are at present, was conceived by the distinguished Admiral Popoff, of the Russian Navy, and, having had the honour of working under him at the time, I can bear witness to the considerations which induced him to choose such circular form for the ships, which ultimately have become known by his name. It was chosen after many years of experience and study of the behaviour of the long ordinary ships at sea; after the careful study of the development of iron-clad construction, to which few persons have paid so much attention as Admiral Popoff did, and it has been chosen principally in consequence of the very important results obtained in this country by Mr. Reed, with his well-known broad and short ships, which superseded the narrow and long iron-clads of early date. Admiral Popoff argued that results of still greater advantage would be ensured if Mr. Reed's principle of broadening and shortening ships were followed still further, and therefore it is to this principle, which has been fully appreciated and mastered by Admiral Popoff, that the circular

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iron-clads owe their existence. It is the continual consideration and analysis of the results acquired with such ships as the *Pallas*, *Bellerophon*, *Hercules*, and others, that induced Admiral Popoff to broaden all the ships of his own design, and to decide as early as in the year 1868, the breadth of his ship, *Peter the Great*, as 64 feet, in order to supply her with the power of carrying 40-ton guns and 16-inch armour—unprecedented until then. Lately, with the same ideas in view, the Admiral has proposed plans for broadening the existing narrow and weakly-armoured ships, built during the earlier period of the iron-clad era, by cutting them longitudinally along the plane of keel, separating the two halves, and inserting between them a new portion of the bottom, thus being able, with a very small additional weight of hull, to get very great additional displacement for carrying guns of the increased size, and additional layer or layers of armour. These plans were exhaustively discussed by Admiral Popoff with Mr. Reed, and when the reconstruction of old iron-clads into ships equally powerful with modern ones may be found necessary, Mr. Reed will be able to bring these plans forward, and apply them to practice better than anybody else. My object in mentioning this here is to give additional proof that circular-ship construction, as well as many of Admiral Popoff's other labours, were based mainly upon Mr. Reed's principle of broadening and shortening ships, and that the circular form is the development of that principle to the extreme limit.

One of the most important conditions for the defence of the Black Sea coasts limited the draught of the vessels to about 13 feet. The only then existing type of vessel which fulfilled this condition was that of unarmoured gunboats, since any armoured ship, if built of ordinary form, and if designed to carry heavy guns and thick armour, required much greater immersion. Unarmoured gun boats, however, were not considered efficient, because a single shot from an insignificant gun is sufficient to penetrate their sides and sink them with all hands on board. Therefore an entirely new class of vessel was requisite to admit of the heavy guns and efficient armour protection, combined with the very small draught of water. To satisfy those conditions, no type of vessel could have been better adopted than the circular, because with no hull of any other form and of the same weight could so great a displacement upon the same draught of water have been obtained.

The head of the Navy, His Imperial Highness the Grand Duke Constantine, with his usual wisdom, appreciated the value of such considerations, and accordingly two circular ships of 96 feet in diameter, and 12 feet 6 inches draught, were ordered to be built. The displacement which such small dimensions gave has yet enabled them to carry two 28-ton guns mounted in a turret, protected, as well as the sides at the water-line, by armour equivalent to 11 inches in thickness. They were meant strictly for coast defence purposes, and, therefore, no great speed was required from them. They have open turrets, because being intended for the defence of certain narrow straits and entrances they can, when in action, occupy positions behind some defensive protection, such as submerged torpedoes; and, when attacked, can choose their own distance from the enemy, placing themselves always beyond the reach of rifle-fire. The precision of firing from guns so mounted, and other reasons, have settled the adoption of open turrets on board these circular ships.

The form of these vessels is sufficiently illustrated by the diagrams (Plate I.) and the model, which by the kind permission of the Lords of the Admiralty I am able to bring before your notice; the curvature of the bilge being the arc of a circle, and the

	Novgorod.		*Admiral Popoff.*	
	Feet.	Inches.	Feet.	Inches.
Extreme diameter	101	0	121	0
Diameter of flat bottom	76	0	96	0
Depth in hold at centre, from underside of beam to top of the frames of the double bottom ...	13	9	14	0
Draught of water ... ... Forward ...	13	2	12	0
Draught of water ... ... Aft ...	13	2	14	0
Draught of water ... ... Mean ...	13	2	13	0
Height of barbette tower from load water-line ...	12	0	13	3
Diameter of barbette tower outside	30	0	34	0
Height of upper deck at side, from load water-line amidships	1	6	1	6
Displacement in tons	2,490		3,550	
Area of midship-section in square feet	1,170		1,416	
Engines, nominal horse-power	480		640	
Coal supply in tons	200		250	
Propellers, screw, in number	6		6	
Complement of officers and men, number ...	110		120	
Armament, breech-loading guns two in number, each weighing, in tons	28		41	
Smaller guns in unarmoured breastwork	...		4	
	Feet.	Inches.	Feet.	Inches.
Height of armour on side above water	1	6	1	6
Depth of ditto below load water-line amidships ...	4	6	4	6
Thickness of armour on sides (including equivalent thickness for the hollow iron girders behind armour) upper strake	0	11	1	6
Ditto lower strake	0	9	1	4
Ditto on barbette tower	0	11	1	6
Thickness of deck plating	0	$2\frac{3}{4}$	0	$2\frac{3}{4}$

bottom flat. During the construction, the dimensions of the first ship completed, the *Novgorod*, were slightly modified by sheathing the outside iron skin and the side armour with wood and copper, and this has brought the dimensions of the ship to those which are given in the Table.

The guns, mounted in the *Novgorod's* turret, can with their carriages revolve completely round, and the carriages are so constructed as to admit of each gun being trained independently of the other through a certain angle. The height of the breastwork, or turret, entirely covers the men working the guns. The upper deck outside the breastwork is heavily plated.

These are the chief points of the design of the *Novgorod*, to which I consider it necessary to draw your attention. From want of time it would be preferable to pass over the description of the details of construction, as these have been given fully enough on several previous occasions. I will glance only hastily at one more important feature peculiar to that ship. I refer to the arrangements of engines and the way of working them.

There are two isolated boiler rooms, containing four boilers each. These supply six engines each of 80 horse-power (nominal), compound, horizontal, working each an independent screw of 10 feet 6 inches in diameter. All the shafts of the screws are parallel to each other. The pitch of the screws varies according to their positions: beginning from the screw nearest to the middle of the ship, on each side, their respective pitch is 10, 11 and 12. These were found to be the most advantageous, according to carefully-conducted trials. Steam from each set of boilers is conducted into a separator, and from there it is distributed between the engines. There is one engineer for each side of the engine room, and both of them are stationed on a common platform upon which the starting and reversing gear, &c., for all the engines are fitted. Voice-pipes from above are led to this platform to transmit the captain's orders. The engines are supplied with Hearson's strophometers, so as to show at any moment the number of revolutions which each engine is making, and to regulate the uniformity of the speed accordingly.

The *Novgorod* was launched and completed in 1873. From that time her qualities at sea, as proved by her cruising over several thousand miles along the coasts of the Crimea and farther east across the open sea direct to the Circassian shores, have been found to exceed all expectations. She visited all the ports of the Sea of Azov, into which no iron-clad in existence, carrying the same guns, and having the same protection, could enter. Only in her earliest voyages was the *Novgorod* attended by a steamer; since her qualities were ascertained she has been always entrusted alone at sea, as any other ship would be. During that period several alterations have been made in order to make this coast defence vessel able to contend, when necessary, with any seas she may meet. For instance, her natural ventilation has been so improved, that now the ventilating fans are taken out, and when the ship is steaming, even in a heavy sea, with all deck hatches closed, the draught is maintained by the great volumes of air which enter through the big shaft or tube placed in the centre of the vessel, and partly through the perforated bottom of the turret. Her anchors are now worked from the top of the bow superstructure, thus ensuring perfect safety when the vessel is riding at anchor in the open roadsteads. I may state, in passing, that while I was planning under Admiral Popoff's instructions the arrangement of this alteration on board the *Novgorod* the waves swept alternately the low sides of the ship. Yet they produced scarcely any effect upon the vessel. I was able to work comfortably with the drawing instruments, so unnoticeable was the rolling. All boats are now taken up on the davits, instead of being left on the deck, where the sea might injure them. Such are the most important of the many arrangements introduced, since experience has been acquired with this new vessel at sea, to ensure greater comfort of seaworthiness, and this experience leads to the belief that in future such ships need not be designed merely for coast defence purposes. The under-water part of the bow is fuller than that of any other vessel, and consequently it possesses enormous buoyancy. Owing to this buoyancy, increased by the existence of the bow-superstructure above the deck, and owing to other results of her extreme proportions, the ship has a constant tendency to ride over the waves, behaving much in the way that a duck would, and not penetrating through the water like a long and narrow ship. Her stability is immense, and her steadiness as a gun-platform is greater than that of a ship of any other form. Owing to the great beam, low freeboard, and perhaps also to the flatness of the bottom, the rolling of the *Novgorod* is very limited indeed, and it seems to me that in the present state of the subject, instead of entering into the discussion of any theoretical hypothesis on the behaviour of a ship, whose resistance to rolling motion and other conditions are widely different from those of ordinary shaped ships, it would be preferable to state only that the greatest angle of roll which was observed while I had the pleasure of steaming on board the *Novgorod* for several days at sea, during the Equinoctial gales, never was such as to expose her lower edge of the side armour—the instrument for measuring the angle of heel showing at that time that the arc through which she was rolling was 6 or 7 degrees: and this was in waves in which ordinary ships steaming the same course as the *Novgorod* were rolling very heavily, so much so in fact that several objects on board were sliding down and falling in the cabins, whilst some curiously unstable candlesticks on board the *Novgorod* remained unmoved on the tables. The forward sharp edge of the superstructure breaks the tops of the waves when the ship is driven against a head sea, and some of the broken water is precipitated on the deck, but soon disappears from it, because of the great round up of the surface. Both the captain who commanded the *Novgorod*, and the officers who served on board of her, would only be too glad if they were to be sent to the Mediterranean, so confident are they in the sea-going qualities of their circular ship.

Much was said about the *Novgorod* steaming slow, but people compare her propelling power with that of the English ships, forgetting that Penn's engines develop occasionally more than eight times the nominal horse-power, whilst the engines of the *Novgorod* have unfortunately developed at sea as yet only about four-and-a-half times. The *Novgorod's* speed, had the engines been of the same efficiency, would have been nine knots; while there exists no ship in the world so small as the *Novgorod*, and carrying the same armour and guns even on a much greater draught. Therefore had this ship been built for other purposes she might have possessed a greater speed. Owing to the relative power of the engines, there is indeed remarkably little diminution of speed when such a ship is driven against the waves at sea. It has been argued that the screws of the *Novgorod* are left more unprotected than in other ships; but that is of no importance for her purposes, and could be easily altered by arranging them either in special inner tunnels, as I should recommend, similar to Mr. Griffiths' plan, or otherwise, should the purpose for which this vessel is designed be altered.

The improvements in torpedoes, and in their application, lead to the adoption of this formidable weapon in preference to the ram; but a ram can be fitted to a slightly elongated bow, and would be even more than usually effective in such a vessel, because of the advantage that the short ship always has in respect of handiness and manœuvring qualities. The multiplicity of screws affords a most powerful and effective means of governing the course of the popoffka, and of enabling her to be manœuvred really with wonderful ease. Owing to the multiplicity of engines, the *Novgorod* is much safer than any ship having a single or twin propeller, because of the diminished chances of losing entirely her mobility when in action.

The construction of the second popoffka advanced less rapidly, but this was due to the intention of improving her fighting efficiency, and of insuring more perfect armour protection. Accordingly, the diameter and displacement were enlarged to what it is shown in the preceding Table. That was easily done, because very little addition to the then completed double bottom of the hull was required. The very small addition of only 10 feet on each side of the vessel allowed the size of the guns to be increased from 28 tons to 41 tons each, to add to the armour additional 7 inches of solid iron completely round the vessel and the turret, making it now everywhere equivalent to 1 foot 6 inches, and to more than double the power acting upon each of the middle screws on each side. These two screws were consequently made larger, and their shafting lowered nearer to the inner skin of the double bottom; these screws being meant to increase the ship's speed while she is steaming in deep water.

The 41-ton guns in the turret of this ship will be mounted according to Lieut. Raskasoff's plan, which has been skilfully worked out by Messrs. Eastons and Anderson, engineers well-known in professional circles. By this plan the guns will be worked by hydraulic power, and will be lowered down to be loaded and aimed behind the protection of the thick turret armour. On each side of the superstructure, and within it, four smaller guns are placed, able to throw projectiles efficient enough to penetrate the sides of unarmoured vessels or gunboats and destroy them. These guns are above the reach of the sea. Being a bigger ship, the *Admiral Popoff* (such is the name of the second popoffka) is in every respect better than her first consort, and both in seaworthiness and speed she will surpass her. The ventilation of this ship is still more improved as compared with that of the *Novgorod.* The extensive superstructure affords accommodation for an admiral, captain, officers and men, as comfortable and light as on board the best broadside ship.

As we have seen, the service for which the existing two vessels have been designed admitted only a very limited draught. Not only that, but the diameters of these ships, too, were similarly restricted by the means which we possessed in the Black Sea for hauling up vessels in order to examine and make any repairs to their bottoms. The only dock which existed at the time when the building of these vessels was sanctioned, was the patent-slip, with two ways, for hauling up merchant ships of 1,200 tons, on each. This then settled the displacement of the *Novgorod.* The entrance to that dock is 120 feet wide, and that decided the enlarged diameter of the popoffka *Admiral Popoff*, with all allowances. Next year, when the new floating dock, on Clark and Stanfield's principle, is completed, there will be no such limitation to the diameter and size of the Russian popoffkas, as such a dock can be infinitely extended.

Not only the capability of carrying heavy guns and thick armour, or the sea-going qualities, or the speed of these vessels, but even the possibility of their flotation upon water, and their ability of steaming straight, were doubted by the writers to certain Russian newspapers who opposed Admiral Popoff in a most thoughtless manner during nearly a year; but, at the end they only proved the truth of the proverb: "A prophet is "never without honour, save in his own country." English papers have already given some due consideration to the subject, and, speaking now only as a naval architect, it may be hoped that the same thing will not be repeated here, and that Mr. Reed's persistent advocacy of extremely short and extremely broad vessels, the advantages of which he has so ably demonstrated in his lecture "On Circular Iron-clads," above referred to, will be listened to with more confidence and respect. As to Russia, this bold idea of Admiral Popoff's would not have been, perhaps, ever accepted and carried out, but for the great knowledge and remarkable foresight which has always distinguished the Grand Duke Constantine, the Lord High Admiral of Russia, who knew how to appreciate the enormous capabilities of the forces that recent discoveries, such as the introduction of iron and steam propulsion, have placed at the command of men, and the necessity for changes in naval construction consequent upon such changed conditions. Thus, following through the development of the Admiral's idea into the existing ships, we should find the untiring and constant encouragement, and assistance, of his Imperial Highness, and the gracious patronage of his Imperial Majesty himself.

We have seen that the two existing circular iron-clads were designed and built for special purposes. We have also seen that their diameters and draughts were very restricted. Now I will beg you to turn your attention to the great field which the adoption of circular ships of unrestricted dimensions is opening to those who care for the development of the most important quality of fleets, namely, their offensive power.

The constant increase in size of ordinary war ships, as shown by the progress of naval construction for the last seventeen years, has driven us into such dimensions and cost as would have been increditable before armour was introduced. And yet, these great efforts to increase the defensive and offensive qualities have resulted only in reaching 14-inch armour as the maximum thickness attained in a completely protected ship. Increased guns, ready to penetrate any such armour, have given birth to Mr. Reed's now famous design of a citadel ship; and, in my humble admiration of this great idea, as adopted by the distinguished gentleman who at present so ably fills the office of the Director of Naval Construction of England, and as embodied in the *Inflexible*, I feel confident that no bigger guns and no thicker armour can possibly be carried by any future iron-clad of the same displacement, if the same proportions of length to breadth be adhered to. With vessels of such size and proportions, though we are able to measure armour not by inches, but feet, yet such measurement is applicable to the protection of the so-called "*vital*" parts; and in the number of guns, even the *Inflexible*, like all previous heavy-turreted iron-clads, carries only four, mounted in two turrets.

Such, then, is the defensive and offensive power of the very best of all ships of what may be called the ordinary type, yet in existence; and therefore we may regard the armour, varying over the protected surface of a citadel and turrets from 16 inches to 2 feet, and four guns in two turrets, as the limits of the fighting and defensive power of an ordinary ship of 320 feet in length, and about 27 feet draught.

But already we are perfectly sure that the progress of artillery will not end with the completion of an 81-ton gun, and a ship of the same enormous size and proportions would be able to carry on the same draught only two 160-ton guns, and perhaps none of the guns of the future, say, exceeding the weight of 500 tons each. The only course left to get means of carrying on any ordinary long ship, of any ordinary proportions, an additional number of turrets, to enclose a greater number of very heavy guns, would be to enlarge such a ship, and to make her length equal to 400, or 600, or 800, &c., feet, and the draught equal to 35, or 45, or 55, &c., feet, according to the number of guns required. "As to the excessive length," says Mr. Reed, "we know that in the only "great iron-clad action which has been fought at sea, a long and narrow ship, by her "incapability of turning round, brought discredit and disaster on the Italian Navy at "Lissa." Yet the ship referred to here was less than 300 feet long, although she was somewhat less than the ordinary breadth. The importance of smaller draught was remarkably well demonstrated by the passive attitude of the French Navy in the Baltic, during the last war, notwithstanding the superiority in number and power of the French ships as compared with those of the German Navy at the time.

Returning to the circular vessels, and comparing the *Novgorod* and the *Admiral Popoff* with any of the existing ships of whatever navy, carrying the same guns, and protected by the same armour, it will be evident at once that their size is remarkably small. For instance, in the English Navy we can compare the *Novgorod* only with the *Glatton*, in respect of armament and armour, but drawing more than 19 feet of water; and the *Admiral Popoff*, in size of guns and armour, has no rival afloat; yet the displacement of the *Novgorod* is only 2,500 tons, whilst that of the *Glatton* is 4,915 tons, and the *Admiral Popoff* is but 3,550 tons. Therefore we may regard these existing ships as capable of being enlarged easily to several times their present size before their lengths and draughts would exceed those which are already reached by ships of ordinary proportions. The following diagram is submitted to show the growth of power of the circular ships so enlarged, both in the direction of length and draught.

By the kindness of Mr. Barnaby, I have had the advantage of seeing, at Torquay, several most valuable experiments on the resistance of the circular models, conducted by Mr. Froude with all the precision and wonderful ability which have made him so pre-eminent and well-known, not only in England, but in Russia and elsewhere. In producing my diagram before your notice to-day, I venture to trust that, although the experiments are still incomplete, and, therefore, the results are not yet published, neither Mr. Barnaby nor Mr. Froude will have an objection to my introduction here of only one item chosen out of all those experiments. Upon this item, ascertained with the greatest precision—namely, the true amount of resistance offered to the motion of a model of a circular ship, 160 feet in diameter, and 13·7 feet draught, at a certain speed—I have based the whole construction of this diagram, being able with the help of Mr. Froude's "scale of comparison" to calculate precisely the indicated horse-power of engines necessary to drive each ship at a 12-knots speed, and to ascertain exactly the amount of coals necessary to keep the ship steaming during six days at that speed.

Increasing this 160-feet ship, both in diameter and draught, 1·25, 1·5, 1·75, and 2 times, I have obtained the upper curve No. 1 (Plate II.), representing the rate of increase of the displacement. Then, on corresponding ordinates, I have set downwards from the curve of displacement the number of tons to which the weight of engines and coal supply will amount for each ship, and that has fixed the second curve from the top No. 2. From the base-line I have set upwards, at the corresponding ordinates, the number of tons representing the structural weight: curve No. 4. Further, an approximate number of tons for each ship has been set upwards from the curve No. 4, to represent the weight of crew, provisions, water, anchors, cables, stores, &c., and thus curve No. 3 has been obtained. The remaining part of the displacement of each ship, represented by the parts of ordinates enclosed between the curves No. 2 and No. 3, is available wholly for armour and guns, with their carriages and shot and shell.

The truth of Mr. Froude's "scale of comparison" between the resistances and the corresponding speeds of the geometrically similar bodies moved through water is so well established that I need not refer to the calculations of the parts of the ordinates between the lines No. 1 and No. 2.

The curve of structural weights, No. 4, was drawn on the assumption that 22 per cent. of the displacement of each circular ship is taken up by the weight of her hull. This, at first sight, may seem rather a small per-centage to those who are accustomed to deal with ships of the present proportions. But the fact is that such a per-centage really does represent the structural weight of the existing circular iron-clads. These ships are both afloat, and have shown not the slightest degree of weakness. Their designer, Admiral Popoff, already considers them as heavily built, and is sure to reduce the scantlings of the iron in his next ships. It would have, perhaps, been reasonable for me to diminish this per-centage for the ships under consideration, which have been growing larger; but I feared that such a course might be looked upon as likely to lead to misrepresentation of the real state of the subject. Still, in adopting the method which I have followed, I felt sure that the structural weight would be less than it is shown and not in any case greater.

In speaking of the number of guns which constitute the armament of ordinary iron-clads, we have seen that the best of 320-feet long ships, drawing about 27 feet, is able to float only two 160-ton guns well protected, whilst the figures marked on the diagram in thick black, between the lines No. 2 and No. 3, show the number of 80-ton guns, similarly protected, which the circular ships, of the diameter and draught shown beneath the base-line, are able to carry; each turret capable of holding two such guns, or one 160-ton gun, and the citadels, in which these turrets are enclosed, being completely protected in all cases by armour, 1 foot 9 inches in the smallest ships and 2 feet in bigger ones, spread *uniformly* over the whole extent of the surface of the turrets and citadels, or castles, as we would call them in Russia.

From this diagram it will be seen that when a circular ship is made of such dimensions as to have the weight of hull about equal to that of an ordinary iron-clad, then, with the speed of 12 knots an hour, and with coals for six days' steaming at that speed, her offensive power would be doubled. With the same conditions as to the speed and coal supply, a ship 280 feet long and 24 feet deep will float six times greater number of guns; whilst a ship 320 feet long and 27·4 deep will have ten times greater fighting power as compared with the ordinary ship (the *Inflexible*). In this last, biggest circular ship considered, her forty guns might be mounted in twenty turrets, enclosed in a two-storied castle, protected as well as the turrets completely round by 2 feet of iron; the upper tier of 80 or 160-ton guns, firing at a height of more than 20 feet above water, and at a horizontal distance from the edge of the deck of about 100 feet, so that no sea could reach them. Yet such results are obtained without exceeding the length up to which the existing less powerful iron-clads have already grown. Thus the above-water target presented to the enemy's projectiles would be very nearly the same as that offered by an ordinary iron-clad carrying only two turrets. Owing to the still moderate draught, the under-water target presented by her to the moveable torpedo, or to ram attack, would be the same as the under-water broadside of an ordinary ship. Her handiness would be superior, because she is a short ship.

I will now attempt to show that speeds as high as 14 knots may and will be reached with circular iron-clads, provided only that the size is not too restricted; although even such speeds do not require the ship to be made as long and as deep as ordinary heavy ships are. For that purpose the line No. 2^{A} was drawn and obtained similarly as was the line No. 2, with the only difference that the indicated horse-power and weight of engines were calculated for a 14-knots speed; a similar very large coal supply, as in the case of 12-knots ships, was provided. True, the increased engine-power has taken more from the useful part of the displacement; yet, possessing the means of steaming at 14 knots continually during five days and nights, the circular ship of 240 feet length, and only 20·5 feet draught, will carry one and a half times greater a number of guns as compared with the most powerful vessel in the world. When the weight of the circular hull is about double that of an ordinary ship, she would float four times a greater number of guns; whilst when the weight of hull is about treble that of an ordinary ship, her fighting efficiency will be from seven to eight times the efficiency of an ordinary ship, with, too, a uniform protection by 2-feet armour, without any reduction. Therefore I consider that the highest speeds reached are compatible even with the purely circular form of popoffkas, and do not lessen their advantages in respect of armour and gun-carrying power as compared with long ships.

The above results are due not only to the increase, as the ships grow bigger, of the ratio which the part of the displacement available for armour and guns bears to that part of it which is taken up in shape of hull, engines, coals, &c., but also to the property of the circular ships that their citadels will be built mainly for the efficient protection of the guns, and not to create buoyancy; and to ensure the transverse stability: which both qualities, so extremely important for safety, would not be maintained in ordinary ships, had not the citadels been enlarged so much as not only to protect the battery of guns, but also to protect a good deal of the long narrow body of the vessel. The circular ship, in virtue of her form, already possesses great buoyancy, stability, and therefore safety, thus allowing the vertical armour protection to be limited entirely to the defence of the guns.

As we saw, at 14 knots speed, a large amount of displacement is taken up by engines and coals. Yet all that power may be distributed over a large area covered by the ship, and not confined to one single engine room, as is generally the case with ordinary ships. Dividing the power among many independent engines, similarly to the course adopted by Admiral Popoff in his first ships, the vessel would steam still with a good speed when as many as three, or even four, of those engines would be disabled or injured. Thus, if circular ships must be necessarily provided with powerful engines for reaching high speed, this, when in action, will prove to be one of their greatest advantages, as the ship will continue to hold her own, either in attack or defence, for an incomparably longer time than an ordinary one, which, with a disabled single engine or propeller, might very soon become the prey of the enemy.

I need not enlarge on the evident economy of propulsion, which can be obtained with steaming at reduced speeds, before such ships reach their destination, where battles are to be fought.

I have used in the calculations referred to only one system of protecting the guns, namely, the revolving turrets. I have done so because this system has been favourably looked upon in England, and is very familiar. I have thus been able to compare easily the capacity for carrying such turrets of ordinary and circular ships of the same speed. Such a system, however, would not be likely to be adopted in Russia. Breast-works, open at the top, and guns firing *en barbette*, worked by hydraulic machinery, have met with much favour in that country. With such a system, and with the same number of guns, the protection of 14-knot vessels would be from 2 feet 3 inches in a smaller ship to 4 feet 6 inches of armour in the bigger one, as shown on the diagram (Plate II.) by figures enclosed in circles for distinction. Whether that, or the system of mounting guns adopted in building up the Cronstadt or Spithead armoured forts, be applied, in any case the number of guns which may be mounted on board large circular ships cannot be compared with any of the ships existing, or in course of construction in any country, and may only be paralleled with the ordnance mounted in the fixed forts. But fixed forts require immense foundations, which prove to be extremely costly, and, notwithstanding their cost, sometimes weak. Besides, some points along the coasts, known to be of great strategical importance, have been so far left unfortified, because of the impossibility or difficulty of building such foundations. Finally, fixed forts are disadvantageous, simply because they are fixed. Whilst circular ships may be made not only as efficient for far less expense, but possessing the ability of moving, when necessary, with great speeds for long distances (ships above considered can steam a much greater distance than that between St. Petersburg and London, with their own coal), they may carry their destructive armaments to bear against the shores in the enemy's own waters, against any modern individual ship, or a fleet of such vessels at sea.

I have been increasing, as the ships were growing bigger, only the number of guns. To show how easily such ships can be protected with any thickness of armour, I shall have to quote the following—Admiral Popoff's own words:—" As the bottom is flat, the " increase of the immersion of the ship, by every two additional feet, gives power to " carry three more inches of armour, either over the whole extent of the deck, or over " the surface of the bottom." Therefore it may be seen that no form will lend itself more easily to the protection of the body of the ship against the fire of rifled mortars, or against the attack by fixed torpedoes.

I do not wish the proportions given with reference to the diagram to be accepted as perfectly precise, because in no case have I prepared an accurate design for every individual ship. But, as a large margin was allowed for other weights, I believe that still much greater offensive and defensive power than is shown on the diagram would be got out of each ship upon the dimensions considered.

Consequently, choosing out of an infinite variety of proportions which the diameter of the circular ships can bear to the draught, according to the given conditions, we can obtain ships, carrying any number of the heaviest guns and armour of any thickness within the limits of practical necessity, and yet not exceeding the draught of ordinary ships.

Such circular ships will be more economical than the existing ones of ordinary shapes, because from the adjoining Table we can see that, even at the great speed, the ratio

	Proportion of Weight of *Hull* to Weight of *Armour* and *Guns*, carried.	Proportion of *Engine-power* to Weight of *Armour* and *Guns* *protected*.
PARTIALLY PROTECTED SHIPS.		
Warrior	2·5 to 1	4·9 to 1.
Defence	3·0 to 1	3·5 to 1.
COMPLETELY PROTECTED SHIPS.		
Prince Consort	2·4 to 1	3·9 to 1.
Circular Ship—		
Novgorod	0·6 to 1	2·8 to 1.
Fast Circular Ships—		
"280 feet long"	0·5 to 1	2·9 to 1.
"320 Ditto"	0·4 to 1	2·2 to 1.

which the *cost of hull* of these vessels bears to the *cost of armour and guns* carried is very much less than in the case of ordinary ships, and also because the proportion of the *engine power* to the *cost of guns and armour* driven is also less. Therefore the circular form ensures the *true* economy. As another instance, I may mention the new design for a small unarmoured circular vessel able to carry two 41-ton guns, having the cost of hull and engines in proportion to each ton of weight of the guns *less* than in the ordinary unarmoured gunboats, carrying one less powerful gun.

But I should be unfaithful to the cause of "popoffkas" if I conclude this Paper without mentioning the following most important considerations:—

It has been proved in practice that Mr. Reed's 300-feet ship can be propelled through water as fast as a less powerful 400-feet vessel, and it has also been proved by careful experiments that a ship whose length is three times the beam can be made to go as easy, even with less expenditure of power, than one having the length equal to four times the breadth; therefore we must conclude that extremely short and broad vessels, approaching much more closely to the circular form than to the form of the present existing long ships—yet not quite circular—will do away with that increased part of the resistance which is due to the increased eddies appearing when a body of so comparatively abrupt an entrance and run as that shaped circular is driven through water. That has induced Admiral Popoff not to restrict his ships by the purely circular water-lines when higher speeds will be contemplated. Such moderate elongations of bow and stern, as were described by Mr. Reed, reducing the size of engines necessary to drive these ships, and consequently reducing their total displacement, and avoiding probably some other difficulties, arising, as Mr. Reed and Mr. Froude have suggested, out of the coincidence of period in ship and wave at high speeds, will promote the most economical propulsion at sea of the very heaviest guns protected by the very thickest armour.

Such ships, then—I mean those with slightly elongated bow and stern—could no longer be called "circular ironclads," nor would the name of "cyclads," or any other such term, be any longer available, but that of "popoffkas," which name was graciously given to this class of vessels by His Majesty the Emperor of Russia.

DISCUSSION.

Mr. J. D'Aguilar Samuda, M.P.: My Lord and Gentlemen, as to the Paper that is before us, I certainly am very glad to have the opportunity of expressing an opinion upon this matter, which has been rendered so interesting by the observations which have already fallen from Mr. Reed with reference to these vessels. But I would beg to say, that, with every disposition (which I am quite sure every Member of the Council and of the Institution has) to give the greatest praise which they possibly can to any subject so interesting and so novel, I think we should be wanting in candour, if we allowed a desire to give that praise to have any precedence over our convictions, when we feel we cannot reasonably or freely give it. With regard to this Paper, it appears to me that it may properly be divided into three distinct subjects:—the first and most interesting one, which gives us a clear description of that which has been done with these vessels; the second, which I venture to think is a purely imaginative one, as to that which may be done, and which draws conclusions as to speeds to be obtained with these vessels—to which conclusions, I must say, I cannot find the smallest clue throughout the whole of the Paper justifying any such results being arrived at; and then the last of the three perfectly distinct matters which are put before us is (and it is a very remarkable one, as the Meeting will observe), that if the conclusions under the second head could be obtained, namely, that you could obtain a vessel to go 14 knots and to carry an unheard-of quantity of guns, and an unknown thickness of armour—something like upwards of 4 feet is that which is named—one might have been content to have rested upon the acquirement of a vessel so totally superior to anything else that had ever been dreamt of. But then the third proposal ignores the second altogether, and goes on to urge that, with all the advantages that are to be got from circular ships, the right thing is to depart from and not produce circular ships, but to produce elongated ships. I really think that, in discussing this matter, as I hope and believe we all desire to discuss it in this Institution—first with regard to its truth, and next with regard to its being the foundation for future consideration in the development of this subject—we must look upon this matter in a less favourable way than that which the author of the Paper would have us deal with it. Now I propose to deal with a few of the subjects that are brought before us, in the order in which I have just now put them. First, with regard to the vessels that have been produced. It is rather a remarkable circumstance that the speed of these vessels has not been stated to us by the author of this Paper; but we have the means of gathering from that which he does tell us, that the speed of his *Novgorod* would in all probability have been 7 knots. The paragraph I refer to, which brings me to that conclusion is this, that "People forget when comparing "the speed of these vessels with the propelling power that was attained in English ships, that with "English engines they occasionally develope more than eight times the nominal horse-power, whilst with "the engines of the *Novgorod* they developed about four and a half times." Then it goes on to say that the *Novgorod's* speed, "had the engines been of the same efficiency as those English engines, would "have been 9 knots." Then, drawing as near a conclusion from that as I can, it comes to this, that if the 9 knots would have been obtained with eight times, the speed of $7\frac{1}{4}$ would have been obtained at the outside with that which was given. I believe, from what I have heard indirectly, that that was about the speed which was obtained. Now giving it the fullest advantage of that which we are able to derive from the statement put before us, what does it come to? It comes to this, that, if you enter upon the figures which are given to us in this Paper as to the resistance which this vessel has to overcome, and of the power which is given to it to overcome it, the mechanical power to overcome and cause this vessel to advance is five times as great as that which it would be in an ordinary ship.

Mr. E. J. Reed, C.B., F.R.S., M.P.: It is nearly that.

Mr. Samuda: I am very glad, indeed, to find that I am confirmed in that by Mr. Reed. Now what does that lead us to? It leads us to this, that if we have got that resistance with a vessel going at 7 knots an hour, and with a form that certainly is ill suited to go at great speed (and 7 knots an hour is probably the speed which would be the fairest and best that you could assume in comparing this vessel with others), what would be the result if you attempted to develope this to something like those useful speeds which have been treated in this Paper subsequently as perfectly easy of attainment? From the experience I have had in connection with steam—which has gone over as long a period, I think, almost as that of any one in this Meeting—my conclusion would be that no conceivable power that you could put in one of these vessels could drive it 14 knots. It could not be done. That is my conclusion. I think that it would be allowing the most complete hallucination to exist if one were not to attempt to elucidate some more correct conclusions from the facts which have been stated than those which are contained in this Paper, and if it were allowed to go forth to the world that there was read at this Institution a Paper which dealt with the possibility and certainty of acquiring these speeds when it is positively certain that it cannot be done. I have got now to the question of speed. This Paper puts before us, not only the statement that you can go 14 knots with these vessels, but that you can carry, when you are going at this speed with these vessels, "a similar very large coal supply as in the case of 12 knots' ships;" that "increased engine-power has taken more from the useful part of the displacement," but that she still possesses "the means of steaming 14 knots continually during five days and nights." Let me just call attention to what that would involve if you were to accept it as a problem capable of being carried out. If I take the *Kaiser* and the *Deutschland*—two iron-clad frigates I have lately built for the German Government, and which are two of the best ships of that peculiar form of construction for which Mr. Reed has had so much and such just praise, for here he carried to the greatest extent the beam of the ship as contradistinguished from the length of the ship—those vessels burnt, when going 14 knots, 10 tons an hour, or 240 tons a day; and therefore would have burnt in five days 1,200 tons of coals. I have already shown to you, and Mr. Reed has confirmed the view, that when going at 7 knots the quantity of coal—that is to say, the resistance of the circular ship in proportion to the engine-power—was nearly five times that of the ordinary ship.

Mr. REED: What ordinary ship?

Mr. SAMUDA: An ordinary sea-going vessel of the English Navy.

Mr. REED: Of what size?

Mr. SAMUDA: If Mr. Reed will let me give the details in my own way, I think he will find he will be answered more satisfactorily. Perhaps he may call his own ship an extraordinary ship, but I was going to compare the circular ship with the result of these very ships themselves—the *Kaiser* and *Deutschland*—and if they possess anything beyond the ordinary qualities, it will be all in favour of the vessel I am going to compare it with; because I am going to show what popoffkas would have to carry if their conditions were similar to those which we have already seen they actually do possess when going 7 knots. When going 7 knots they require five times the quantity of power beyond a ship of ordinary form; when going at 14 knots they certainly would require considerably more than five times the quantity of power. That is a natural conclusion, from the form of the vessel. If you only take them as requiring five times the power, you would require in this case 6,000 tons of coal to carry out the conclusion arrived at in this Paper. I put it to this Meeting whether it is right that we should have to discuss these matters which are purely imaginative to the extent which this Paper has evidently put before us? I am quite content to yield every kind of approval to the ingenuity of the plan where it is suitable; but the only place, to my mind, where these vessels could suitably be adopted would be in a position where a fort is required to be stationed, and is not required to be attached to the land. There they would be extremely useful. The power which is given to them, which is exceedingly minute as to their power of locomotion, might be very usefully applied to take them from one port to another. I am sure I need not offer any apology to this Meeting for putting this problem before them. The science of naval architecture is considered to advance in proportion as you are able to diminish resistance, and to make use of a given power to accelerate speed, and improve the passage of the vessel through the water. This power, far from accomplishing this result, does exactly the reverse—it involves the use of five times the power for a similar speed; and there is not a person of my age but can recollect that at the time when the first suggestion was made with regard to increasing the fineness of the lines of vessels, there was this remarkable result: all those vessels which had been built upon the river, and which were built with bows something approaching to these circular vessels—that is to say, with the full old sailing vessel bows—had those bows elongated, not very considerably so, but so as to make what was then considered fine lines. And with what result? This: that they immediately doubled the mechanical effect produced upon the ship. It is in that direction we have been working ever since, and we have gone on till we have produced something like good ships. Each alteration in that direction was considered an improvement of the ship, and this is doing away with the whole of that acquired experience. I venture to think that this Paper fails altogether to give us any insight into the mode by which any such conclusions as those contended for from the second problem here discussed could be obtained. I am willing to give the greatest possible credit to these vessels, so far as they have gone, when used simply as forts not requiring locomotion to enter into the condition of their floating powers, but I cannot extend my approval beyond.

Mr. William Froude, M.A., F.R.S.: I wish to say a very few words on the subject. My friend Lieut. Goulaeff has referred to the experiments which I made by direction of the Lords of the Admiralty of the resistance of these ships, and perhaps I had better advert to the results so obtained before I attempt to discuss the general question. I must say, however, that I cannot feel so sanguine of extremely favourable results as he seems to be. I do not know where Mr. Samuda got his figure of 5 to-day, but it happens that about 5 to 1 expresses the relative resistances of the *Novgorod* or *Popoffka* and an *Inflexible* of the same displacement. There is another thing worth mentioning, which is to me rather a curious fact in relation to the resistance of these ships, namely, that up to the highest speed at which we drove them through the water their resistance was just as the square of the speed and not more—in fact it was rather less. So that you might infer from that that there would be some gain in pressing these ships to a high speed, because in other ships, generally speaking, as you approach high speed the resistances grow faster than the square of the speed.

Mr. J. Scott Russell, F.R.S.: Not always.

Mr. Froude: In all that I have ever tried that is the case.

Mr. J. Scott Russell: And in those I have tried it is the contrary.

Mr. Froude: That may rest for the present. With the *Inflexible* it appears that her resistance is pretty nearly as the square of the speed up to 14 knots—the highest speed taken account of—so that those two ships are capable of a tolerably easy comparison throughout. No doubt, as Mr. Samuda has said, the 5 to 1 resistance is a most formidable proportion to start with. Then I may say that the *Novgorod* of her natural size, 100 feet in round numbers—I think it is 101—will go up to 8 knots without encountering any of the formidable difficulties which she seems to encounter at the higher speeds. According to the correct scale of comparison, and indeed according to the old-fashioned mode of estimating —which is here equally applicable since the resistance is as the square of the speed is—the 320-foot ship would go 14 knots, making the same disturbance in the water as the *Novgorod* makes at 8 knots; but that ship, as I calculate it—I have only done it roughly—would come to 80,000 tons, and the reason why the 80,000-ton ship seems to do comparatively well is that, as we all know, as ships are enlarged their propulsive efficiency, that is their economy of propulsion, is greater and greater. The larger the ship the less power per ton is required to drive her at a given speed. I will not say I shudder, but I own that I am amazed, when I think of an 80,000-ton ship of that form driven through the water in that way. No doubt it would go if you put the power into it. I cannot say that I have calculated them carefully at all, but in the cases in which I have made some rough guesses, it seemed the weight of the hull and machinery and armour required by these round ships must be considerably greater in proportion than that required for an ordinary shaped ship if you went at the same ordinary speed. The substitution of a very small relative speed will tell somewhat in favour of the circular form; the result will not be so much against the circular ship and in favour of the other ship as at the high speed. I think the idea which has led to the adoption of the circular ship is rather a dogma than a practical truth. The view has been suggested that if you regard the thing to be sent to sea as a fortress—that if you wish to send thus a certain offensive power to sea, with some means of locomotion, and a certain means of carrying men and ammunition, and you wish to do that with the least weight, and the least cost, no doubt the circular ship seems to promise that the weight of armour, and indeed of the ship herself, will be less than for any other for a given form. Yet so far as I can see, if the proposition is fairly followed out, you will never rest at a circular ship, but you will be immediately driven to adopt some greater relative length in view of the necessity of greater speed, and the absolute length that you select must be decided by what you settle is the speed you wish to go at. I give great credit to Lieut. Goulaeff for the pains he has taken in working this question out, but I cannot believe that the ultimate result will be as favourable to the purely round ship as he has conceived it to be. Very much shorter ships for certain purposes may prove efficient, but I do not think we shall ever come to circular ships; we shall stop far short of that if we are guided by practical considerations.

Mr. Nathaniel Barnaby, C.B.: I think that the first observation which I make in public on circular ships ought to be that I feel a great deal of admiration for the boldness of Admiral Popoff. I always admire boldness in anybody, and when one sees it in a man who is working in one's own profession, and who does something out of which you must learn a great deal, one's admiration is apt to become great, and mine is. I have great pleasure also in seeing that we have a description of Admiral Popoff's ship from a gentleman whose training was received in England, and I think the manner in which he has put it before the Institution does credit to his training. There are one or two points which are somewhat inaccurate in the Paper which I would like to remark upon :—One is a slight matter, but still it is an inaccuracy. He credits the *Inflexible* with 27 feet draught of water. I think that is some $2\frac{1}{2}$ feet too much—I hope it is. In the Paper he has read to us, giving the dimensions and other particulars as to the *Novgorod*, Lieut. Goulaeff has not done himself justice, because he has not given the indicated power of the engines and the speed. Now he must know perfectly well that although he does not give them we know them, and it would have been better for him if they had been stated and not concealed, because it would appear that he wished to conceal them, which I presume he does not wish to do. He will probably tell us what his reason was for not giving the indicated power and the speed, which we have had to guess at. Mr. Samuda has guessed at it, and I daresay he is not very far wrong, and Mr. Froude has told us roughly and generally what it is interesting for us all to know with regard to the great question of the resistance which the ships have to meet in being propelled through the water; but as Mr. Reed has said many times, and which is quite true, that is not the only question we have to consider in a ship of war. I quite agree with that, but then I observe that Mr. Reed's view of this question is not the same as has been put before us this morning. We have been told that they were designed strictly for coast defence purposes, and for use in shallow waters. I am not the person to stand up and say they are not perfectly fitted for the purpose for which they were designed, because so far as I know they may be. But Lieut. Goulaeff goes beyond that, and treats them and puts them before us as ships capable of going to such a speed as ships should; and there, as he has already found, we are not able to follow him. Mr. Reed has very wisely called them points of departure, and I quite agree that as ships they are to be regarded only as points of departure. As coast defence batteries they may be as successful as you please, but as ships the sooner we depart from them the better. We have been told that it may be desirable to elongate them, and that after they are elongated the results which probably will be obtained from them may be great; and that we shall be able to call the vessels so elongated "popoffkas." I am sure for one I shall not have the least objection to calling them popoffkas; and if they should only have a small elongation of bow and stern they would turn out far better forms for propulsion, looking at all the advantages they get from their fulness, than the ships we are accustomed to use. But it must be borne in mind that we in England have been going down and down in the length of the ship. Mr. Reed came down considerably, and we have been going down since, shortening ships in proportion to their breadths; and everybody who knows Mr. Froude and Mr. Froude's labours, must know how hard he has been at work in proving for us what advantages are to be got by an increase in beam. I will before I sit down place on record one fact, which I owe to Mr. Froude's investigation—a point of considerable interest, in the matter of proportion affecting some little boats which we are now building. There were some gunboats designed for river defence, with 5 feet 10 inches draught of water, and it was a question what the proportions of those boats should be in order that they might go 9 knots. Mr. Froude was good enough to subject to experiment two forms, one of them having these proportions, 110 feet long and 26 feet broad, and he told us that for a displacement of 349 tons 330 horses would be required for 9 knots speed. But we had another form 110 feet long—that is the same length—and 34 feet broad; and he told us that if the displacement was 369—that is, 20 tons more—we should only require 220 horses instead of 330 to go at the same speed, the difference being due apparently partly to the proportions, and partly to the great fineness of entrance and run obtained by the increased breadth. The model of the boat to which I refer is lying on the table, and is the model of the boats which are now being built by Mr. Palmer for river service; and as I have spoken of them, it is right for me to say, that while I think the form an exceedingly good one—and I liked it before it was submitted to Mr. Froude for examination—the form is not due to me, but to one of the Foreign Members of this Institution, Mr. Carvalho, the Brazilian Constructor, who in fact had proposed to his own Government a boat of that form at the time we were considering it; and it was his form and our own we compared. I think that after what I have said you will see that we in England are ready to accept from any one, it does not matter to what country he belongs (for "science is of no country"), anything which seems to us to add to the efficiency of our Navy.

Mr. Reed: I think it will almost be expected of me to say a word or two on this question, looking to the fact that I am afraid I am partly responsible for the attention given to it. My friend, Mr. Samuda, has met with a well-merited answer, and I would almost say rebuke, in the facts just stated by Mr. Barnaby. For what do those facts amount to? Mr. Samuda having in the roundest manner condemned this plan, because it was for a very short vessel in proportion to its length, and upon the ground that all his experience, and everybody else's experience, goes to the point of greatly lengthening ships, if you want to get speed—almost immediately afterwards, a gentleman of official responsibility, and whose knowledge on the subject cannot be questioned, rises and tells us that in undertaking to build some vessels for the service of the Government—not armoured vessels at all—it was found by that most distinguished investigator, Mr. Froude, that if you increased the beam from 26 feet to 34 feet, with the same length, you reduced the horse-power requisite for propelling the vessel from 330 to 220.

Mr. Samuda: Would you allow me to rise to explain? Mr. Reed is quite in error in imagining that that is a rebuke, because it is an entire confirmation of my own statement, for Mr. Barnaby stated that the great reduction in the horse-power with the greater beam arose from the fact that you were able to give finer lines from carrying practically the same displacement in a wider vessel with finer ends.

Mr. Reed: Well, my Lord, if that is a satisfactory answer to the state of things, then I think we may certainly find in it a corroboration of this view, that the circular ship has only to have given to it very fine lines at the bow and stern, in order to become quite right. If that be so, it is the most ample confirmation of the one view which I have always held about these vessels, and that view is this: I have never stated, although it has often been imputed to me, that I thought the circular form was the most desirable form for a fast ship. The furthest statement in that direction that I ever used has been that I did not believe it impossible, as my friend, Mr. Samuda, does, but I believed it possible to drive them fast; and on that point I must say I think in this scientific Institution that when Lieut. Goulaeff has placed before us to-day a scientific investigation of the grounds of his belief in its being possible to drive them at a high speed, it is much to be regretted that no one should in the least degree have touched his scientific argument and investigation, and that no allusion has been made to his diagram up to this moment, but that he should be condemned by *à priori* references, and on that oft-abused ground of "authority" which was invoked. Nothing as yet has been said, and it remains to be seen whether anything will be said, in disproof of the grounds on which Lieut. Goulaeff has proceeded in his Paper with reference to that diagram. For myself, I may say that I have not given that diagram sufficient consideration to be able to express any opinion upon it, and I do not claim for my original remark anything more than that, seeing the extraordinary and unexpected behaviour and steaming power of the *Novgorod*, in which I travelled many hundreds of miles in the Black Sea, I did, I confess, express the opinion given without minute inquiry, that, if it were necessary or desirable, you might drive a circular ship very fast. My view is that there was not a single reference in the speech of my friend, Mr. Samuda, that touched at all the merits or demerits of this form; and for this simple reason, that to my mind it is the idlest thing in the world to talk about resistance, in total disregard of the thing you have to carry about. What you have to carry about in an armour-plated ship is armour and guns; and you, my Lord, took a lively interest in the *Warrior*, and my friend, Mr. Scott Russell, also took an active part, no doubt, in her design, and all of us have been for years proud of the *Warrior;* but I believe there is not a single soul in this Institution at the present moment who would say that, in order to send guns and armour to sea you would dispose of them after the fashion of the *Warrior*, because there you employ no less than 5,400 indicated horse-power to send 4½-inch armour about the seas to cover very light guns. This question must be considered from that point of view, if it is to be considered with any scientific result; and I should like to ask those gentlemen who spoke so strongly against this class of vessel, if they will be good enough to refer me and this Institution to any vessel whatever in the whole world, except the *Novgorod*, which carries at from 7 to 8 knots armour 11 inches thick, and two 28-ton guns. There is no other vessel in the world that does it.

Mr. Barnaby: Nine inches.

Mr. Reed: Mr. Barnaby says 9 inches. The explanation of that is simply this, that the Russian authorities have introduced a heavy backing in the form of channel rails, which takes the same place as armour, and which it seems to me most desirable should be reckoned if we are to consider the weight of armour which is carried about. What I think is this—we started, when we began armour-clads, with the *Warrior*, and I say that the *Warrior* is already out of consideration as an armour-plated construction. The Russian Government have begun their efforts, at least with regard to this class of vessel, with the adoption of an exceedingly short vessel, no doubt, and we have heard to-day of vessels building by the

Government which are slightly over three times their beam, without any armour at all. Now the inference that I draw from all that is this, that if we, as Mr. Barnaby candidly and fairly put it, take the circular form as a point of departure, and put to it such bows and such sterns as we can afford to put, with gain in the point of economy of fuel all the time we are extending them, and without incurring other and serious disadvantages as regards the sacrifice of fighting qualities, then I say that we are bound by every scientific consideration to depart from the circular form to that extent, whatever the speed may be that we have to aim at. But if, on the other hand, it be true that with an unarmoured vessel you can come down to three beams to the length of her with advantage, surely that is a striking suggestion at any rate that in heavy armour-clad vessels it may be desirable to put but very short bows and sterns upon them; and I showed in a Paper which I read elsewhere a little time ago, that by putting very short elongations at the bow and stern you can probably get rid of a very large part of those causes of resistance, which, as Mr. Froude so well knows, attend this circular form of vessel, and is the occasion of that four or five times the ordinary power which is required. I wish to be clearly understood in the matter. I am not able to affirm all the investigations of my friend Lieut. Goualeff: that is because I have not studied them sufficiently to do so; but they have not been contravened, and they will certainly form a worthy subject of consideration to Members of this Institution. But I do believe myself that very short iron-clads will become the order of the day, and that the inducement to make them so will increase more and more as the thickness of armour is increased also. After the debates of to-day I think we may feel that one thing is quite certain, and particularly after the speech of Mr. Barnaby, which he has just delivered, and that is, that however anomalous, and unusual, and extraordinary this circular form of vessel may seem, it will be considered with thorough impartiality, and with that propriety of view which it ought to receive in this country. I must say also for Admiral Popoff, and for his friends in Russia, that they are most anxious, as Mr. Barnaby knows, to have all the results of experiments published as soon as possible, so as to get the question brought within the view of scientific investigation. I will conclude by saying that having made several passages in this *Novgorod* over the Black Sea, one of them in eminently rough weather, I was gratified to find that I made those passages with the greatest possible comfort; and that when the sea was rolling freely over the deck of the vessel, and when the waves were running to considerable height, indeed so high that you could not stand on an elevated bridge at a very great height above the water because of the lash of the sea, you sat in the cabin in the deck-house with the ship in a state of almost absolute tranquillity—no rolling worth mentioning to trouble you, and scarcely any pitching. It is due to Mr. Froude to say that he was the original suggestor of the defect which I believe is the strongest of all reasons for not hastily adopting the circular form in the fast vessels. And he has shown that you may easily, when the ship is steaming fast in this form, establish a synchronism, as it were, between the period of the ship and the period of the wave, and that would result in great plunging. I am sorry to have trespassed upon the Institution, but I thought it hardly proper that I should not make these remarks. I do hope that, from this Institution at any rate, while we shall have listened I trust with interest and benefit to the Paper of Lieut. Goulaeff, and while we study it afterwards in the same way, it will not go further that I am a maintainer of the circular form under all conditions, and without any modification. I believe that for speed it must be modified, but that the modifications will be very much more limited than some friends of mine seem disposed to think. My Lord, perhaps I may relieve your mind and mine by saying that I think my Paper, which comes last, might very well be withdrawn. It is simply a Paper for record in the *Transactions*, and is not intended to invoke any discussion at all.

The PRESIDENT: I must, of course, be in the hands of the Meeting. We have come to the difficulty which I feared this morning, and I am afraid it is absolutely impossible, having regard to the fact of an Evening Meeting, to finish the Papers put down for to-day. I understand Mr. Reed to say that he will not press the Paper in his name; but there is a Paper on the subject of "Cellular Ships"—an interesting question at all times, and especially so at this present moment; and unless this Discussion on Lieut. Goulaeff's Paper is to close, I am afraid we must give up "Cellular Ships," and that will be a very great loss. Therefore I must leave it to the Meeting to say what course they would like to take. Mr. Scott Russell naturally wishes to speak on Lieut. Goulaeff's Paper, and I should be most happy, as I am sure everyone here would be, to hear him; but, if we are to continue this Discussion, it must be on the understanding that Mr. Boold's Paper is to be given up.

Mr. J. SCOTT RUSSELL: My friends around me say I had better go on.

The PRESIDENT: If that is the opinion of the Meeting, I have no objection.

Mr. J. SCOTT RUSSELL: Allow me to say that my strong wish to go on is to do justice to Admiral Popoff's circular ship; and I think I shall do the greatest justice to his circular ship if I try to direct our minds to what its real advantages are, and if I try also to divert the minds of my friends away from what I think the fictitious advantages which have been asserted for it. I believe that Admiral Popoff's invention is, for some purposes for which he made it, an extremely admirable application of the circular form. I believe, on the contrary, that whenever you claim for that the advantages which it has not, you do great harm to Admiral Popoff and injustice to the inventor. Permit me then to say what I think, most unquestionably, is the great advantage of the circular form as here applied to ships of war. It is simply this, with a given quantity of material the circular form will give the greatest cubic contents. With the circular form you will carry, with a given quantity of ship material, the greatest quantity of dead weight; and with the circular form, and its large dimensions equally all round, you will do the most a ship can do to obtain a steady platform with equal command all round. If, therefore, you will, with this form, carry the greatest amount and greatest thickness of armour, and carry the most powerful of armaments, have I not said enough to recommend this to your careful attention? And now I go to the second point. The second point is this:—When you have got circular floating fortresses, with the greatest possible amount of armour, and the greatest possible amount of armament, then comes the question, Is it desirable to move these floating fortresses from one place to another? The answer to that is, that there are many cases in which they ought not to be moved, and ought not to have facilities for moving; and there may be other most important cases in which it is desirable to move them. Then comes the question, Will you remove them by towing them by other vessels around them, or will you furnish these floating batteries with engines and engine-power and fuel to move themselves? There the question becomes a critical one—there it becomes a question that is answerable in a different way, according to different circumstances. Allow me to tell you, that, having served on a Defence Commission, I know there are many cases in which it was desired that such batteries should not have the power within themselves of moving themselves. I now come to the next point. The vessels having great qualities as floating batteries, and having great qualities also which enable them to be moved from place to place, I consider that, in the circumstances for which Admiral Popoff built these vessels, they were very wise vessels; and I do not think that economy of mechanical power, or their fitness for long voyages, or their being very seaworthy ships, had anything material to do with the purpose for which Admiral Popoff immediately designed them. Therefore to him and to the Grand Duke Constantine, the head of the Admiralty, I think belongs great credit for having first had the courage to introduce so economical and so powerful a machine into the naval service; and I know several situations in England in which a circular battery of enormous power, on this principle, would be a fortress of very great value. I know such places. And now, leaving that, I go to the next point. In regard to the construction of ships meant for a given speed—meant to carry given weights—meant to accomplish given purposes—meant, for example, for given lengths of voyage, Does the circular form give us any information we did not possess before? Does it give us the power of making a ship in any way better or different from what we have already been in the habit of doing? I answer, none whatever. I answer, no new information of any kind is obtained; no additional knowledge is communicated to us of any kind. This circular form has none of the advantages that we want for a sea-going ship, and everything that it can tell us we have long known. I wish that it should go forth from this Meeting, and be thoroughly understood, that we shipbuilders and engineers, who know our business, do not build ships out of our own heads, and do not build them of our own whims; but we do build them for distinct, clear, specific purposes, and we allow the purposes to create the ship. Allow me, then, to show you why I should at once deviate from the circle, if I had got, not a floating battery to build, but a ship or a ship of war. If I had to build a ship or a ship of war, and you told me that this circular form was the form in which—although it would carry all you wanted—you wanted me to make a ship, which should have the same beam, but go faster, What should I, at once, have to do? You know what I should have to do; you know that I would lengthen the circle that way [*describing*]; and I know exactly how much to lengthen it if I want a given speed. Tell me the speed, and then the quantity I have to lengthen it is all contained in printed Tables. Having lengthened this line, mathematically, both ways, say to each an additional diameter, what do I do next? I take the well-known curve of sines, on which all we shipbuilders make the lines of our fast ships, and I take simply the ordinary mathematical form of the curve of sines in the water-line—I am not drawing the ship out of the water, I am drawing the water-line of the ship—and I do that at both ends; and what have I got? Do you mean to call this, now, a circular ship? This is the old-fashioned boat, three beams to her length; and when I was a young man, and was first sent to sea, those were the lines of the fishing boats of the North Sea, in which I first learnt what a sea was made of, and what waves meant, and how boats behaved themselves, and how waves behaved themselves to boats. I have now changed the form and transformed your circle, and what have I made it? I have made it a modern wave-line ship. And what have I done? I have done the very thing Mr. Reed was praising in these boats. Mr. Reed was delighted to see that a boat, with a very broad beam and very short ends, could be made to go wonderfully quicker and with wonderfully less resistance than a boat with much less beam and fuller ends. Of course it could. That was the discovery we made in the present century, that, by sharpening the ends of a ship, and by making her very much wider, the sharp ends would go a great deal more to diminish her resistance than the beam did to increase it. I remember one of the first of those new classes of ships was built under the following circumstances. This new form was made to beat the old form by a new man coming and building a boat with 6 feet more beam than the old boat with the same length as the old boat, and with engines two-thirds of the engines of the old boat, and the new boat beat the old one. There is nothing, therefore, in this matter that we do not already know. What is the next step? The next step is this: If you tell me that you want this boat to go so much faster, I then add another beam, and another beam, and then I continue *this* line in this manner, and *this* line in this manner, and *this* line in this manner, and *this* line in this manner [*describing*], and what have I now done? These are the curves of sines, and what are the sines? The sines are only, after all, ordinates of a circle. What have I done? I have merely manipulated the circle. I have taken the circle; I have introduced no new element, I have taken the sines of the circle—its own progeny—and I have merely put these sines of the circle in the right place, and they have brought out the right shape of ship, and I am sure you will agree with me that that is the right shape of ship, and this other is the tub shape of ship. Allow me to say that there is no whim, fancy, or caprice in anything I have laid down there. These are the mathematical inevitable lines of a ship. And now I have only to say that when the ship's speed is given, this length is given without leaving us any choice. This is a minimum length; and if we do not take that we know that we waste power, or do not get the speed we ought. What is the next thing to do? The next thing to do to this ship is this. At present this ship that I have shown you will go at the speed you want, but she will not go a long voyage at that speed. What is the reason of that? She will not go a long voyage at that speed, because for that amount of beam she must have a given horse-power; and for that speed she must expend her fuel and her horse-power at a given rate, and therefore this vessel is not a vessel that can remain at sea—she cannot keep the sea long enough; and, therefore, though I am a great advocate, as I have told you, of very broad ships with sharp ends, though I am a great advocate—and every man who has owned ships must be an advocate—for making a ship not a foot longer than she requires to be made, and must be made for her speed, yet if I want this ship now to be a ship able to keep the sea, and if I want her to go a certain length of voyage and back again without coaling, which as a good ship doing our ocean service, or our sea service, she must do, I have no choice but to lengthen the ship. Perhaps Mr. Reed will tell me that I have the choice of making the ship broader. Yes, I have. But as I have already given her that breadth, and as I have already given these fine lines at the ends, as before I say I have no choice. What have I to do now? I will tell you what I have to do. I have to stick in the middle of this ship, what? I will tell you. For every fifty miles I want that ship to steam I have to stick on an additional foot of length of body, whether I like it or not. If, therefore, I want this ship to steam 1,000 miles, I have to put (I will not calculate it exactly just now) about 25 feet into her length, and then this portion I have added will carry fuel enough to take her 1,000 miles. But suppose you tell me I must have fuel to take her 2,000 miles, I have no choice. I go back again, and put 25 feet more into the middle of her, so that she may go another 1,000 miles, and if you take 3,000 miles, I have to repeat the process each time; so observe that I do not make the ship, you make the ship—the work she has to do makes the ship—the conditions make the ship. But you say, Could not I do all this by merely increasing the beam? I answer Mr. Reed, No. I think myself a clever fellow, and I tell you, "No." When I have already fined the ship as much as she ought to be, and when I have already given her the right length proportioned to her speed, I tell you I cannot make her go a longer voyage upon that given length—I have no choice. Widening her will not do; filling her up will not do; nothing will do except lengthening the body of the ship. I have now shown to you, I hope, that when you talk of making short ships do the work of long ones, it is out of the question; that when you talk of making a ship do a given speed and a given length of voyage, the length of your ship is found for you, and when you say you will make a circular ship of this kind do anything of this nature, I answer, "Yes you can," and you can make her do it by making her shape to be a circular shape, and by making her a ship with the water lines which transform the circle out of what we call the shape of a tub, into what we have always called a ship-shaped vessel.

Sir R. Spencer Robinson, K.C.B., F.R.S., Admiral: I do not rise to prolong this Discussion, as I consider that it cannot be terminated without a great deal more explanation than has yet been given to it, but I wish to ask whether it is not possible that some arrangement may be made by which many gentlemen who wish for further information upon the facts with regard to this circular ship should be enabled to obtain them, and to bring their understanding and comprehension to bear upon what I think the not only very difficult problem, but the most interesting problem that is set before us. Unfortunately the worthy gentleman who read the Paper to us is not so conversant with the English language as I wish he had been; and it was to me, and I have no doubt to many gentlemen here, a very great source of loss and difficulty that we could not follow him in his demonstrations. When Mr. Froude—than whom a more scientific analyst of all the questions that affect naval architecture there is not—rose, I did anticipate that he would have enabled us to understand these diagrams which are before us by a brief explanation, because there is no man more capable of showing in a few words what is meant by those figures than Mr. Froude, and I had hoped he would have told us a little of the exact effect of those lines, and of the effect of multiplying resistance or deepening vessels in the water; and of the various reasons, experimental and scientific, which prove, or do not prove, the utter impossibility of such a ship ever being converted to the ordinary purposes of a ship. I confess I was very much struck with the decided condemnation that my friend Mr. Samuda gave of so interesting a design, and I listened with the attention that every word which falls from him rightly commands, to hear the grounds on which that condemnation was so unreservedly pronounced. I was not fortunate enough to follow Mr. Samuda, or to be convinced by him, neither have I been convinced by the able speech of Mr. Scott Russell. There is no doubt that whenever Mr. Scott Russell takes the trouble to tell us anything, he tells it in such charming language that I almost feel myself in the position of Eve and the old serpent. I cannot find it in myself to resist those eloquent periods, that magnificent declamation, and those very sound and sensible points which Mr. Scott Russell puts before me—although sometimes I cannot help thinking it is my imagination, and not my reason, which gives way to his arguments. What I really wish to say is this, that no subject of more importance I will venture to say has often been brought before this Institution than the subject of these circular ships. What I contend for, without having any fixed opinion upon the subject as a naval officer deeply interested in the right construction of our ships, and in the due adaptation of them to the work they have to perform, is that we should have some more scientific and complete exposition of all the points which constitute this circular ship, as shown in those diagrams, as derived from Mr. Froude's experiments, and that if possible by some adjournment, or by some other arrangement which I am not called upon to suggest, we should have some further explanation if Mr. Froude will give it.

Mr. Froude: I shall be very happy to do so.

Sir R. Spencer Robinson: If Mr. Reed, who has not as he has told us to-day thoroughly investigated this matter, and Mr. Froude, and the talented author of this Paper, would specify the points to which more attention should be given, and give us more explanation and information upon them, I think that this Institution would stand in a better position than that in which it now stands after the very unreserved but apparently very unsatisfactory condemnation of something so great, so novel, and so powerful as the circular ship that we have just had described. I think it would not be to the credit of this Institution to pass the thing over *per saltum*, and with a great deal of laughter and fun, simply to laugh the thing out of Court. The matter is too important and serious to be dealt with in that way, and I think if possible more time should be devoted to the subject.

The PRESIDENT: I must say that I most entirely agree with what has fallen from Sir Spencer Robinson, that it is most desirable so important and so novel a question as this should be fully discussed; and I hope no one will suppose from what has fallen from me that I desired to shorten this Discussion. I am sure everybody will allow that in this chair my duty is simply to carry out our Regulations. I agree with Sir Spencer Robinson entirely. I think it is almost due to Lieut. Goulaeff, who has given us a Paper of great ability, and has contended very successfully with the difficulties that every foreigner has in dealing with a great subject in a foreign language. I think also we are very much indebted to him for having read that English Paper with a rapidity that very few Englishmen could have done—at all events it had that merit, and his Paper is entitled to full discussion. I do not know what to suggest, as the time is now twenty minutes past four. If Mr. Boolds is disposed to withdraw his Paper, which it would be very difficult now to do justice to, we might sit and continue this Discussion until five. I do not see how we can sit after five, with due regard to the Evening Sitting. Another suggestion I might offer would be to renew this Discussion at eleven o'clock instead of twelve to-morrow morning, so as to have an hour before the regular Papers of the day began, but still I very much doubt whether that will be sufficient. I am the more disposed to throw out the suggestion whether the difficulty we are now in does not bear very closely on the suggestion that I threw out for consideration this morning, whether this subject is not of so much importance as to be well worthy of a distinct sitting of this Institution. I think on the whole that is the most practical suggestion that I can offer; and, as that seems to find favour with the gentlemen who are now here, I will venture to suggest that we should now pass to Mr. Boold's Paper, and that at the Council Meeting, which is always held at the end of these Annual Sessions, the Council shall take into consideration what is the most practical and best mode of reviving this question at some subsequent period.

Mr. THOMAS BRASSEY, M.P.: If it were possible for the Council to take into consideration the propriety of a sitting on Monday morning, with the view of completing the Discussion, I should be very glad.

Mr. J. SCOTT RUSSELL: On Saturday evening.

The PRESIDENT: We had better not begin now the discussion we shall have in the Council. I think the practical point is whether we shall in the Council consider it wise to revive this Discussion. I think that suggestion seems to find favour with the gentlemen here. I cannot even now close this present Discussion without expressing my acknowledgment to Lieut. Goulaeff for his able Paper, and for the clear mode in which he read it to us considering his disadvantages.

On Saturday, the 8th April, the Morning Meeting was presided over by the President, Lord HAMPTON, who commenced the proceedings by saying:—The time has now come for commencing our proceedings, but before I call on the author of the first Paper, I wish to mention that this morning, at a meeting of the Council, the question has been considered which was raised on Thursday last, whether under all the circumstances it is desirable to appoint another day with a view to a renewed Discussion of Lieut. Goulaeff's Paper with regard to Circular Iron-clads, and on the whole the Council are of opinion, although we feel much regret that the circumstances in which we were placed prevented the continuation of the Discussion on that day, that appointing another day for a revived Discussion is a very different question. Some gentleman the other day suggested that we might revive it on Monday next, but I am sorry to say it is found upon consideration that from want of notice and other reasons that would be impossible. On the whole, although much regretting the necessity of coming to that decision, we are of opinion that for the present, at least, it would be very difficult, if not impossible, to revive that Discussion. But I cannot make this announcement without repeating to some extent what I said on the first day of this Session, that it is a serious question whether or not the present Rules and Regulations under which we act, do not tend upon some occasions (and this would be a remarkable instance of it) to curtail our Discussions of these Papers to an extent that is disadvantageous to the public interest. Of course, I, sitting here as Chairman, have no option excepting to the extent to which I am supported by the Meeting. All I can do is to carry out our Regulations; and, above all, to carry out those Regulations so far as I possibly can with the strictest fairness to all those gentlemen to whom we are so greatly indebted for devoting their talents and time to the preparation of the Papers, and also for coming here to read those Papers which lead to discussion. That is a practice we must not abandon; and it must, of course, be carried out with fairness and strictest regard to the claims of the gentlemen who give us that valuable assistance; but it is deeply to be regretted that under the existing Rules it does operate sometimes in a manner that we must all regret, and as I have said, I think this is one of those cases. Therefore, I announce that as the decision at which the Council have arrived.

Mr. JAMIESON (of John Elder & Co.): My Lord, I regret very much this decision of the Council. I came to hear the Paper by Lieut. Goulaeff, "On Circular Iron-clads," read, and state my views respecting it; but, as the decision of the Council has limited the Discussion to the gentlemen who have already spoken, I trust that I may be permitted to make a short statement respecting the claim of the late Mr. John Elder, of Glasgow, to be the inventor of the circular iron-clad ships of war which Admiral Popoff assumes to be, through Lieut. Goulaeff, in the Paper just read at this Institution. The facts of the matter are pretty much these:—For a number of years Mr. Elder's private friends were aware that he was engaged in considering the subject of circular iron-clads, previous to giving his views to the public in September 1867, and reading his Paper, at the United Service Institution, in May, 1868, and that he discussed them with the officers of various Governments—Admiral Popoff included—and Mr. Elder thought the chief object of Admiral Popoff's visit to Glasgow, in 1868, was to get full information regarding the details of his circular ship, respecting which Admiral Popoff was quite enthusiastic. Mr. Elder became unwell in the winter of 1868-9, and, but for his death in September, 1869, would, no doubt, have carried out his intention to build an experimental vessel, at his own expense, to cost about £10,000. Lieut. Goulaeff now says it was in the beginning of 1869 that Admiral Popoff conceived the idea of his circular ships, *i.e.*, after Mr. Elder had published his specification and account of them more than a year, and two years after his first interview with Admiral Popoff. In his Paper, just read to this Institution, Lieut. Goulaeff describes the curvature of the bilge as being the arc of a circle, and the bottom flat, whereas, in his original description, he describes the bilge as ascending in the quadrant of a circle from the bottom to the deck. Mr. Elder's description of his vessel—made eight years before—was, if for light draught, the bottom would be flat, with the side rising or radiating to the deck; and, if for high speeds, the form of the bottom would be spherical. It is, therefore, apparent Mr. Elder's plans are being adopted, the terms employed in describing them only being somewhat varied. It is on these grounds, as a personal friend of Mr. Elder's of long standing, and as due to the memory of a great man, I protest against his being robbed of the fame of the invention of circular iron-clads, which involved so much of novelty in conception and construction; a task for which his other inventions and improvements—particularly the compound engine, which has conferred such immense advantages on the country and the world—proved him to be eminently capable; and I do trust these remarks will be put on the records of this Institution, as giving an account of the origin of the circular type for vessels of war being the conception of Mr. Elder.

The PRESIDENT: I merely wish to say, that I think Mr. Jamieson has expressed himself in a most moderate and considerate tone; and for myself, and I am sure that when I speak for myself I speak for the whole of this Meeting, I do very deeply regret that the want of time on Thursday last deprived Mr. Jamieson or any other gentleman—I believe there were other gentlemen—of the opportunity of making any statement they desired to make. Under the circumstances, as it comes so near the nature of an explanation, I apprehend the reporters have taken down the explanation offered by Mr. Jamieson; and I certainly, for one, should offer no objection to that explanation appearing in our *Transactions;* but I would also add this:—Mr. Jamieson must be perfectly aware that the press is open to him to make any explanation he may think it right, for the reasons he has mentioned, to set before the public.

Mr. NATHANIEL BARNABY: Perhaps I may also be allowed to offer one word of explanation with regard to a matter to which I gave Mr. Reed notice that if there was an opportunity I should refer. It is to a statement which Lieut. Goulaeff made in his Paper. He spoke of the *Inflexible* as the embodiment of Mr. Reed's favourite design of a citadel ship. This is likely to leave on record in our *Transactions* a statement open to some misapprehension. The *Inflexible* does not embody any design of Mr. Reed's any more than other ships now building—the *Nelson* and *Northampton*, for example, which are cruising broadside ships, with only a belt of armour—can be said to do. Mr. Reed does not himself, as I understand him, claim more than the idea of omitting vertical armour from the ends of ships, and substituting horizontal armour for it.

The PRESIDENT: I hope that there will be no misunderstanding or misconception with regard to the course taken to-day. I think it quite right that Mr. Barnaby should have had the opportunity of making this explanation; and I think it right that Mr. Jamieson should also have had the opportunity of making the explanation which has fallen from him; but I trust the Meeting will understand, and I feel it to be my duty not to object to the course so taken by those two gentlemen, on the ground that it was clearly understood on Thursday last that the Discussion on Lieut. Goulaeff's Paper was not concluded—it was still an unfinished Discussion, and therefore explanations may now be fairly admitted.

Lieut. E. E. GOULAEFF, F.R.S.N.A.: I should like to offer some explanation in reply to what Mr. Jamieson has said on a subject which has not been brought up by my Paper, and which only to-day he has brought under your notice.

Mr. J. SCOTT RUSSELL, F.R.S.: I rise to order. I ask Lieut. Goulaeff just to make the motion he was going to make, that the additional information he has got, and the additional calculations he has made, should be laid on the table and placed at the disposal of the Council for the purpose of being printed. Would you move, Lieut. Goulaeff, that your Paper and calculations be laid on the table?

The PRESIDENT: We should all wish to do the fullest justice, Lieut. Goulaeff, to the part which you have taken so ably in these Discussions.

Mr. J. SCOTT RUSSELL: I am afraid I must also ask your permission to lay on the table three documents which have been sent to me, which are of great importance to this subject. I have been sent documents containing, first, an accurate drawing of the circular merchant vessels at present in use in Asia Minor, and on the Euphrates, taken from a photograph; second, the description of round ships as given by Herodotus; thirdly, a photograph of round merchant vessels as now in use in Eastern waters. These documents I beg to lay on the table.

The PRESIDENT: I had no idea this Institution, valuable as it is, was likely to become an institution for the promotion of classical literature.

APPENDIX.

The following is the Paper laid on the table by Lieut. GOULAEFF:—

Since the Discussion which followed the reading of my Paper on Thursday, I have certainly had no direct reference to the subject which I have brought under your notice in the Paper—at least in the second part of it; I should therefore consider it as a great favour if you, my Lord and Gentlemen, will allow me to submit to you the following short description of the diagram, by means of which *I proved* the capability of circular ships of moderate length and draught for carrying enormous guns and armour with a speed of 12 and 14 knots.

The questions before us are:—(1.) Whether the circular ships, when made sufficiently large, *have or have not* the displacement to afford them the power to carry engines necessary to drive them through water at 12 or 14 knots. (2.) Whether carrying such engines, the circular ships *can or cannot* carry guns and armour, and whether the capacity of lifting these guns and armour increases or decreases as the ships grow bigger.

To answer these questions I will take the largest ship which I have considered. She is 320 feet in diameter, 27·4 feet draught, and has a displacement of 53,920 tons. In reply to the first question: The bases of my calculations of indicated horse-power, as was explained in the Paper, were certain *definite* results obtained by Mr. Froude, relating to the resistance of a model of a circular ship 160 feet in diameter and 13·7 feet draught.

If, having certain definite results derived from the experiments with the model, you accept these results, and infer from them the resistance of an actual ship, say 100 times the dimensions of the model, the same faith must be given to the application of the results derived from a model for ascertaining the resistance of a ship 200 times the dimensions of the model.

I trusted that Mr. Froude's valuable contribution to science—his "law of comparison"—was generally known, but from the Discussion it appeared to me that such was not the case, or else the possibility of moving large circular ships at great speed would not have been denied. Therefore, I will state it briefly: If the bigger ship be D times the dimensions of the smaller ship and if at the speed V the ascertained resistance of the smaller ship is R, then for the speed $\sqrt{D}\,V$ of the bigger ship, the resistance will be $D^3 R$. Therefore in order to obtain the indicated horse-power necessary to drive at 14 knots the 320-feet circular vessel, 27·4 feet draught (which is the 160-feet vessel 13·7 feet draught, increased *twice*) it would be necessary to find the speed of the 160-feet ship which corresponds with 14 knots for the 320-feet ship; to take the resistance of the 160-feet ship at that speed, and to multiply it by the cubed ratio of the dimensions, namely 8.

Calling V the speed of 160 feet, corresponding to the 14-knot speed of the larger ship we obtain—

$$\sqrt{2} : \sqrt{1} :: 14 : V; \text{ or, } V = \frac{14}{\sqrt{2}} = 9{\cdot}9.$$

Resistance of 160-feet vessel at that speed is 355 tons.

$\therefore$ Resistance of 320-feet ship at 14 knots will be $= 35{\cdot}5 \times 8 = 284$ tons.

According to Mr. Froude's formula—

$$\text{I.H.P.} = 2{\cdot}3 \times 284 + \tfrac{1}{6}\, 2{\cdot}3.\ 284 \text{ at 14 knots} = 73{,}404.$$

So far the calculations were checked by Mr. Purvis, of Mr. Froude's professional staff, and he wrote to me, "On "account of arithmetical difference between your work and mine, I should bring the indicated horse-power figures "out about 1 per cent. lower than you do, which I think we needn't squabble over."

The weight of engines, boilers and water in the *Devastation*, the last of the twin-engine ships, amounts to 1,000 tons. The indicated horse-power developed was 6,600, therefore each ton of engines developed 6·6 horse-power.

I might have submitted to you the names of the new actual ships having a smaller proportion of weight of engines in proportion to the horse-power developed, but I can be liberal in dealing with circular ships.

According to the *Devastation* data—weight of engines $= \frac{73{,}404}{6{\cdot}6} = 11{,}211$ tons. Such weight would be necessary to drive the ship under consideration at 14 knots.

I have taken the coal consumption per indicated horse-power per hour as $2\frac{1}{4}$ pounds. I might have submitted the names of certain ships provided with compound engines in which the coal consumption is less. However, using the figure $2\frac{1}{4}$, we shall have $\frac{73{,}404 \times 2\frac{1}{4} \times 24}{2{,}240}\ 5 = 8{,}845$ tons of coal supply necessary to keep the ship steaming during five days continually at 14 knots.

It would be evident to everybody that as the weight of engines + the weight of coal, corresponding to 14 knots for five days is equal to 19,966 tons, and as the displacement of such a vessel is 53,920, therefore such a vessel *is able* to float the machinery necessary to drive her at 14 knots.

That answers my first question.

In reply to the second question—Assuming that in such a ship the crew, provisions, stores, &c., amount to 800 tons, no less than 33,920 is left for hull, armour and guns.

Weight of Hull.—The weight of the *Novgorod's* hull, including half of the skin and the deck plating beneath the deck armour, is 22 per cent. of the displacement. Adopting the same per centage in a 320-feet vessel we shall have the weight of hull equal in that ship to 11,862 tons.

I may here mention that the *Transactions* for the year 1874 contain a record of an attempt to generalize the question of the useful displacement as limited by the weight of structure and propulsive power. In this Paper, read by Mr. Froude, he says (page 150):—"From this follows the remarkable result that alike whether we enlarge

" a ship by increasing her three dimensions throughout in the same given ratio, so as to enlarge her total displacement " in the cube of that ratio, or whether we enlarge her by increasing her length alone, the ratio, in which the " structural weight should be increased is the fourth power of the ratio in which the dimension is enlarged." When asked by Mr. Merrifield, " whether his theoretical notion of elongation meant the same kind of proportionate " elongation which takes place when we convert a circle into an ellipse ?" Mr. Froude answered, " I meant the last."

Therefore, from this we may infer that part of the hull which is meant to resist the general strains would be the same whether we elongate a circular ship 160 feet in diameter and 27·4 feet deep, twice only in direction of her length, or enlarge it twice in all directions so as to obtain a circular ship 320 feet in diameter and 54·8 feet deep. If the larger ship of these two would have the weight of hull of 4,000 tons (approximately true), the weight of hull which I have adopted in my calculation for a circular ship, namely 11,862, is certainly sufficient, if it is not too great to resist local and general strains.

Again, it is evident that if each linear foot of a circumference of a circle corresponds to 80 square feet of the area enclosed, each linear foot of a total perimeter of four long water lines inserted in this circle corresponds only to 25 square feet (co-efficient of fineness supposed to be 0·7) of the total area enclosed. The ratio $\frac{80}{25}$ being $= 3{\cdot}2$; also gives a certain indication of the proportion in which the surface of the circular ship is less as compared with that of four long ships, having their *length* equal to the diameter.

The weight left for armour and guns, out of the whole displacement will be 21,292 tons. The system of mounting guns was explained in the Paper, the armour was supposed to be arranged according to one of the systems described in Mr. Reed's United Service Institution Paper. Thus, the weight of 21,292 tons I have distributed in the following way :—

Vertical armour, 4 feet 6 inches thick, protecting guns, with backing and ($\frac{1}{2}$) skin	11,888
Horizontal armour, 2 inches thick, protecting the outer circle of thin iron and laid over the $\frac{3}{4}$-inch deck plating	1,112
Thirty 80-ton guns, their carriages, shot and shell	8,160
	21,160
Spare weight ...	132 tons.

Thus, so far as overcoming the resistance of such vessels is concerned, they are able to carry enormous ordnance and extremely thick armour at 14 knots speed. The diagram, Plate II., representing the graphic illustration of similar calculations made for ships of different sizes, shows that the capacity of carrying guns and armour increases as the ships grow larger.

That answers my second question.

Neither of the ships referred to in the diagram exceeds the length of the *Inflexible*, carrying only four guns, and the draught of the largest ships considered does not surpass several existing ships, carrying incomparably less powerful guns and very thin armour. With respect to the steadiness of platform and the sea-keeping capabilities of such armoured fortresses, these can be judged of by the performance of the *Novgorod.*

In answer to Mr. Jamieson, I have laid particular stress in my Paper on the considerations which induced us in our Navy to adopt the circular form, namely, the principle of broadening and shortening ships. Also, I referred particularly to the plans of broadening ships, cutting them longitudinally. That I hoped would show in what way Admiral Popoff's labours were directed.

Admiral Popoff, after the design of the first small circular boats were got out, saw Mr. Elder's sketch in

Engineering, but neither then nor ever considered that such a ship could be of any use for our purpose; because from that sketch it was at once evident that such ships had not enough displacement, and would draw too much water.

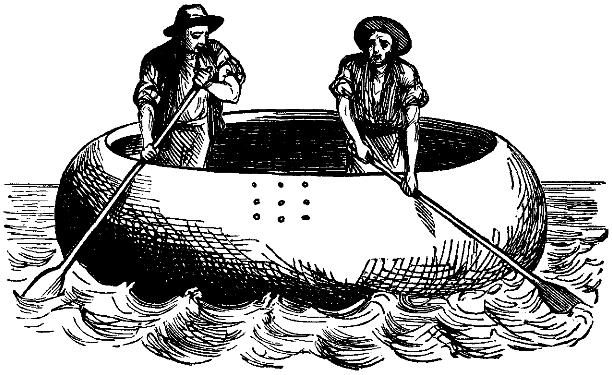
Admiral Popoff never knew of Mr. Elder's idea as to the flat-bottomed ships, and has never known about his specification, drawn for a patent, before it was published in the *Times* a few weeks ago, by Messrs. Elder and Co. If Mr. John Elder really had entertained any idea of building such ships for Russia, as stated in the *Times*, then surely he would have shown the model of her to Admiral Popoff. As it is, we never could have wanted a ship of 16,000 tons, because the largest then existing Black Sea dock could only have lifted a vessel of 2,400 tons, with a width of 120 feet.

The following is the translation from *Herodotus*, Book I., chap. 194, laid on the table by Mr. J. Scott Russell:—

" The boats which come down the river to Babylon are circular and made of skins. The frames, which are " of willow, are cut in the country of the Armenians, above Assyria, and on these which serve for hulls, a " covering of skins is stretched outside, and thus the boats are made, without either stem or stern, quite round " like a shield. They are then entirely filled with straw, and their cargo is put on board, after which they " are suffered to float down the stream. Their chief freight is wine, stored in casks made of the wood of the " palm tree. They are managed by two men, who stand upright in them, each plying an oar, one pulling and the " other pushing. The boats are of various sizes. . . . Each vessel has a live ass on board; those of the " larger size have more than one. When they reach Babylon, the cargo is landed and offered for sale, after which " the men break up their boats, sell the straw and the frames, and, loading their asses with the skins, set off on " their way back to Armenia. The current is too strong to allow a boat to return up stream, for which reason they " make their boats of skins rather than wood. On their return to Armenia they build fresh boats for the next " voyage."

The date of Herodotus' visit would be about B.C. 450 or 460, *i.e.*, not less than 2,300 years ago.

NOTE.—*See* various annotations in Rawlinson's edition of *Herodotus* translated. The modern boats of this description are navigated in the same way, but are said to be coated with bitumen instead of skin. They are called "kufa." The accompanying sketch shows the shape of the kufa, and the attitude of men in her.



Trans, Inst. Naval Architects Vol. XVII. 1876.
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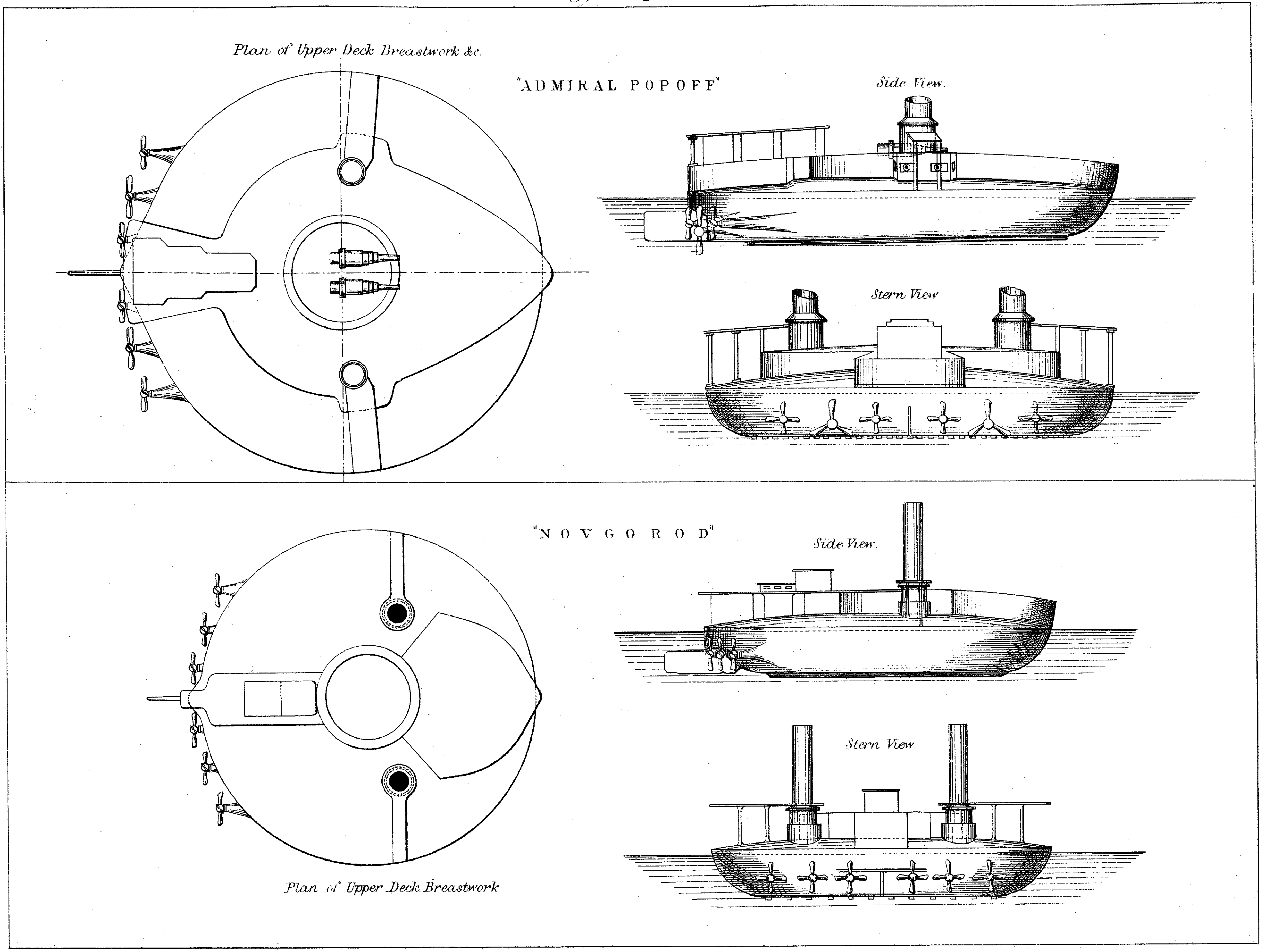
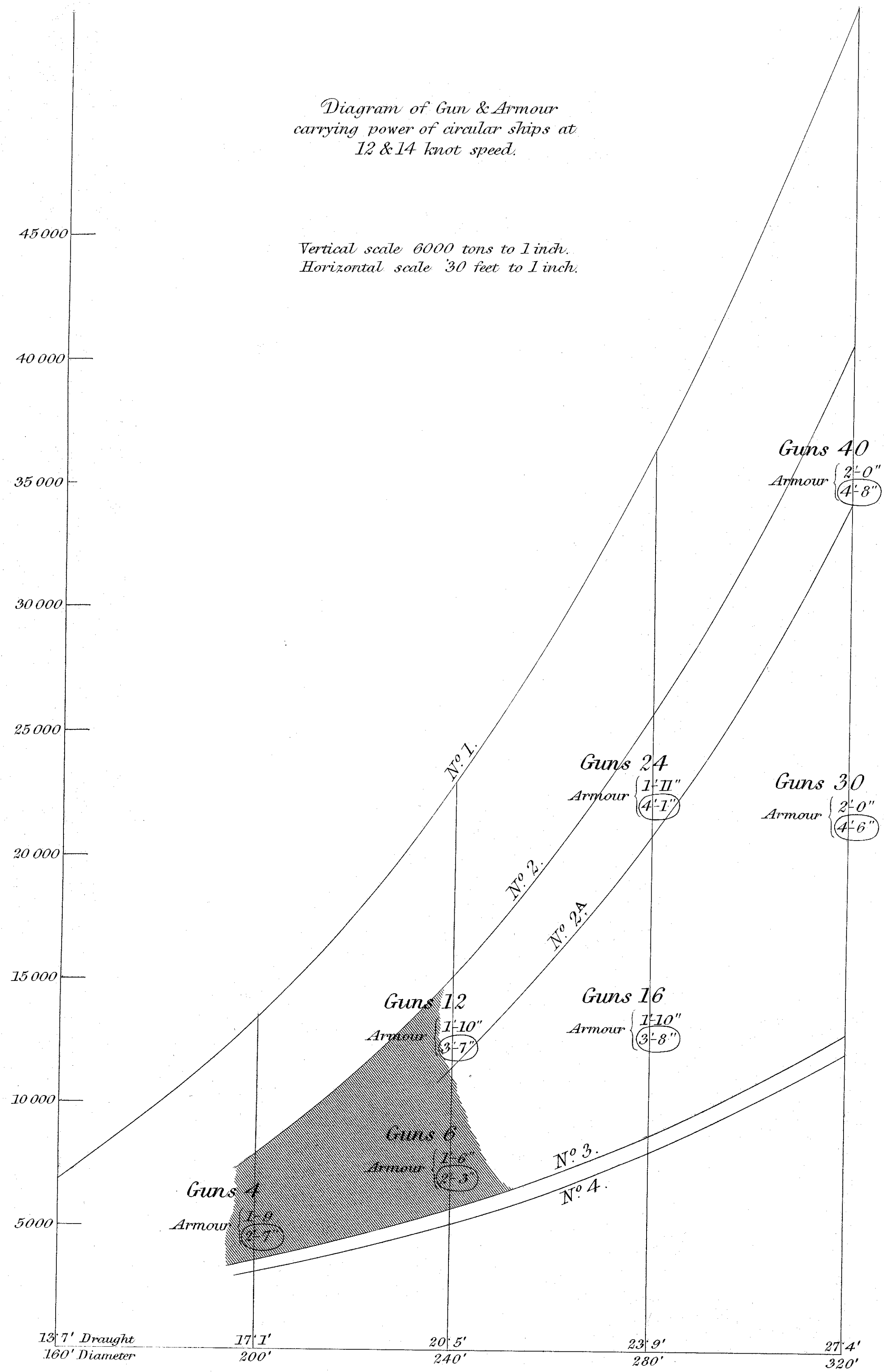
To illustrate Mr Goulaeff's Paper on Circular Ironclads.

Plate. I.



To illustrate Mr. Goulaeff's Paper on Circular Ironclads.



Engraved by W. Fawn orn.