XIX. *On the Amount and Changes of the Polar Magnetism at certain positions in Her Majesty's Iron-built and Armour-plated Ship 'Northumberland.'* By Frederick John Evans, *Staff Captain, R.N., F.R.S., Chief Naval Assistant, Hydrographic Department, Admiralty.*

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In the year 1860 an official report made by me on the Deviations of the Compass observed in all the Iron-built Ships, and in a selection of Wood-built Ships in Her Majesty's Navy, and in the Iron Steam-ship 'Great Eastern,' was communicated by Captain Washington, R.N., F.R.S., the Hydrographer of the Admiralty, to the Royal Society, and was published in the Philosophical Transactions for 1860, p. 337.

In the year 1865, with the sanction of the Lords Commissioners of the Admiralty, and in conjunction with Archibald Smith, Esq., F.R S., I presented to the Society a paper on the Magnetic Character of the Armour-plated Ships of the Royal Navy, which was published in the Philosophical Transactions for 1865, p. 263.

These papers contained a reduction and discussion of observations of the deviations of the compass, and of the horizontal and vertical magnetic force made on board a large number of iron-built ships at different positions in the ship, at different times, and in different geographical positions; and comprised almost all the results of any value or importance regarding the deviations of the compass which up to the time of that publication had been obtained in the classes of ships to which they related.

The system pursued in the Compass Department of the Royal Navy of making careful observations whenever the occasion offers, of the deviations and horizontal and vertical force in the ships of the Royal Navy, and of reducing such observations so as to obtain the magnetic coefficients $\mathfrak{A}$, $\mathfrak{B}$, $\mathfrak{C}$, $\mathfrak{D}$, $\mathfrak{E}$, λ, μ, will, I hope, enable me hereafter to lay before the Society a continuation of the former papers, in which I trust one of the deficiencies, viz. the want of a variety of observations made in the same ship in different geographical positions, will be removed by the zeal of the Navigating Officers now serving in several of Her Majesty's ships on foreign stations.

In the meantime I take the opportunity of an unusually detailed set of observations having been made in the latest and largest of the armour-plated ships, the 'Northumberland*,' to lay before the Society, with the sanction of the Lords Commissioners of the

* The observations discussed in this paper were made, and the coefficients computed, by Staff Commander William Mayes, my successor as Superintendent of Compasses of Her Majesty's Navy; and I am happy to have an opportunity of bearing testimony to the care and zeal with which he has discharged the duties of his office. I

Admiralty, some results as to the amount and changes of the magnetic forces at several positions in that ship.

These results may be thought to have some special interest from the circumstance that the 'Northumberland' was made the subject of an attempt to "depolarize" her, which created some interest and expectation not only in the general public, but even in the Naval profession*.

The 'Northumberland' is an iron-built ship of 6621 tons, 400 feet long, $59\frac{1}{4}$ broad, $26\frac{1}{4}$ feet draught of water, 1350 horse-power, screw engines, armour-plated completely round, with plates of an average of 6 inches in thickness. She has further three complete iron decks supported by iron beams and iron uprights, and a poop-deck of wood, but supported by iron beams and iron uprights. The five lower masts are also of iron. The weight of iron employed in the construction of the hull was about 4250 tons, and in the armour-plating about 1550 tons.

The ship was built at Millwall on the river Thames; the direction of her head in building being N. $39\frac{1}{2}°$ E. magnetic. Contrary to the usual practice with ships built on a slip, the armour-plating was completed previous to launching; the latter operation it may be recollected was performed with great difficulty and occupied several days. The launch was completed on the 17th April, 1866, when the ship was anchored in the river, and allowed to swing with the tide. On the 18th April she was towed to the Victoria Docks, where, on the recommendation of the Compass department, she was placed in a direction as nearly opposite to that of building as could be conveniently arranged (viz. S. 22° W. magnetic).

Unfortunately two large iron-plated ships (one iron-built) lay close alongside, and no doubt affected considerably the magnetic phenomena observed in the 'Northumberland.' This circumstance prevents the observations made during her stay in the Victoria Docks being strictly comparable with those made before and afterwards; and this must be borne in mind in looking at the Tables. It has, as far as possible, been allowed for in the assumed value of λ. Some irregularities were also caused by the introduction and movement of the large masses of iron constituting the steam-boilers and engines.

have also to acknowledge my obligations to Mr. ARCHIBALD SMITH, F.R.S., for the assistance which he has given me in the discussion of the observations, especially in their mathematical and graphical treatment.

* I would refer especially to two papers read before the Royal United Service Institution, London, and the discussions thereon, as published in the Journal of the Institution,—the first paper on "Terrestrial Magnetism with reference to the Compasses of Iron Ships; their Deviation and Remedies," read January 29th, 1866; the second paper on "The Demagnetization of Iron Ships, and of the Iron beams, &c. of Wooden vessels, to prevent the deviation of the Compasses, experimentally shown by means of a model," read May 6th, 1867, both papers by EVAN HOPKINS, C.E., F.G.S. The latter paper was also read at the Salle des Conferences, Champ de Mars, Paris (in connexion with the International Exhibition), on the 22nd June 1867, by Captain F. A. B. CRAUFURD, R.N.

At the end of December 1866, the ship was completed in her equipment for temporary service and steamed to Sheerness, where she remained swinging to the wind and tide till the early part of March 1867; when she steamed to Devonport, at which place, with the exception of two days' trial at sea to test the machinery in the middle of May, she has remained in a dry dock with her head directed S. 84° E. magnetic till the present time.

The positions of the compasses at which observations were made were the following:—

Standard Compass.—The 'Northumberland' having been built with her head nearly N.E., the magnetism principally developed was in the upper part of the stern and starboard quarter, and it was therefore desirable that this compass should be as far forward as possible. It was accordingly placed 172 feet from the stern, and $8\frac{3}{4}$ feet above the iron deck.

Steering Compasses.—The upper deck steering-wheel is 52 feet from the stern, under the fore part of the poop wooden deck; two compasses were placed close in front of it 6 feet apart, each 4 feet above the iron deck, and 3 feet 8 inches below the iron beams supporting the poop-deck.

Poop Compass.—This compass was placed on the fore extreme of the poop-deck, and 9 inches before the line joining the steering compasses, and 4 feet above the poop-deck. In the selection of a place for these latter compasses there was no room for choice; the arrangements of the architect and the requirements of the seaman could be alone consulted.

The results of the observations will be found in the Table appended to this paper, and will include a few made at temporary positions not necessary to describe in detail.

For a complete explanation of the meaning of the quantities tabulated, and the method of obtaining them by observation, I must refer to the last of the two papers mentioned above. Here it may suffice to say, that if

ζ represents the magnetic azimuth of the ship's head,

ζ' the azimuth by disturbed compass, $\delta=\zeta-\zeta'$ the deviation, then

$$\sin\delta=\mathfrak{A}\cos\delta+\mathfrak{B}\sin\zeta'+\mathfrak{C}\cos\zeta'+\mathfrak{D}\sin(2\zeta'+\delta)+\mathfrak{E}\cos(2\zeta'+\delta) \text{ exactly,}$$

or

$$\delta=\mathrm{A}+\mathrm{B}\sin\zeta'+\mathrm{C}\cos\zeta'+\mathrm{D}\sin2\zeta'+\mathrm{E}\cos2\zeta' \text{ approximately.}$$

Of these coefficients $\mathfrak{A}$, $\mathfrak{D}$, $\mathfrak{E}$ (or A, D, E) depend solely on the transient magnetism induced in the soft iron, and therefore cannot be affected by any artificial magnetization, or demagnetization.

$\mathfrak{B}$ (or B) depends partly on the magnetism induced in soft iron by the earth's vertical force, partly on the permanent or subpermanent magnetism of the hard iron. $\mathfrak{C}$ (or C) depends on the last. It is therefore to the changes in $\mathfrak{B}$ and $\mathfrak{C}$ only that we are to look for the effects of polarization or depolarization.

λ is a factor almost always less than unity, representing the mean force, to north, as affected by the soft iron in the ship.

$\lambda\mathfrak{B}$ is the mean force, or, in other words, the polar force of the ship, to head.

$\lambda\mathfrak{C}$ is the mean or polar force to starboard, $\lambda\sqrt{\mathfrak{B}^2+\mathfrak{C}^2}$ the mean or polar horizontal force of the ship; each in terms of the earth's horizontal force as unit.

$\frac{\mathfrak{C}}{\mathfrak{B}}$ is the tangent of the angle which the direction of the ship's polar horizontal force makes with the line drawn to the ship's head, or the "starboard angle."

μ is the mean or polar force downwards of earth and ship, in terms of the earth's vertical force as unit; and depends partly on the subpermanent force of the hard iron, partly on vertical induction.

$\left(\mathfrak{D}+\frac{\mu}{\lambda}-1\right)\tan\theta\times1^\circ$ is the heeling coefficient to windward, and represents the deviation to windward caused by an inclination of the ship of 1°, when her head is North or South by compass.

The values of these coefficients, and also of a and e, the coefficients of horizontal induction, headward and to starboard, for the several compasses are given in the General Table appended to this paper.

The character of the deviations of the standard, steering and poop compasses and of their changes, may be thus generally described.

In each, the $\mathfrak{B}$ has originally a large negative value, caused by the ship having been built nearly head North, (N. 39°½ E.). This gradually diminishes as she lies in the Victoria Docks with her head to the South, but, as is usually found, shows a tendency to return to its original value when the ship is allowed to swing. $\mathfrak{C}$, which has originally a large positive value caused by the starboard side having been to the South, decreases, and even changes its sign in Victoria Docks, but returns to its original sign and nearly to its original value when the ship swings at Sheerness.

In the poop and steering compasses down to 1st January 1867, and in the Standard compass throughout,—except for a short period while a magnet was applied to reduce the deviation—there are no changes except what may be considered to be due to the ship's position, and to the other circumstances adverted to; but as regards the poop and steering compasses between 1st and 26th January, the case is different; the causes of the difference, and the inferences to be drawn from it, it is proposed now to consider.

Early in 1866, Mr. EVAN HOPKINS*, C.E. applied for a patent for "An improved method of correcting the Deviation of Compasses in Iron Ships." In the provisional specification, dated 23rd January 1866, the method is described as "destroying the

* Mr. EVAN HOPKINS was the author of a work entitled "On the Connexion of Geology with Terrestrial Magnetism," 1844, 2nd edition, in which many singular opinions are propounded on Astronomy, Magnetism, and general Physics. I regret to have to speak of Mr. HOPKINS in the past tense. He died in the middle of 1867.

polarity acquired while the ship is building, by passing electro-currents through the hull." In the final specification, dated 23rd July 1866, it is described as "moving an electro-magnet from end to end over, and in contact with the main plates of the ship." There is some obscurity in both specifications, from the patentee not distinguishing between electric currents and lines of magnetic force; but whatever may be the meaning of the method described in the provisional specification, it is certain that that method would be utterly inadequate to produce any sensible effect in a large ship.

The method described in the final specification would no doubt produce, wherever applied, some local effect; but the effect produced by the local application of magnetic force of high and rapidly varying intensity must necessarily be wholly different from that which has arisen from the general application of a force of low and uniform intensity, and the former cannot possibly produce any general destruction of the latter. The process is in fact not one of general demagnetization, but of partial counter magnetization. The result will be an irregular distribution of magnetism of very variable intensity, necessarily very unstable, and producing, wherever effective, a rapidly varying field of force. The justice of these remarks will, I think, be shown in the sequel.

In April 1866 Mr. HOPKINS applied to the Admiralty for permission to experiment on the 'Northumberland,' the largest and most heavily armoured ship in the Royal Navy. The application was in the usual course referred to the Magnetic department, and on a report that no injury was to be apprehended, the required permission was granted*.

The first trials were made on the 4th August 1866, and are thus described by Mr. HOPKINS in a report dated 10th August, and received at the Admiralty a few days afterwards. "After having ascertained the actual magnetic condition of the ship, I applied two of GROVE'S batteries of five cells each, with the electro-magnets to the main plates at the stern and bow, and in a few hours the polarity of the hull was destroyed"†.

The results of the observations shown in the General Table, I think entitle me to say that there is no foundation whatever for the statement that the polarity of the hull was destroyed; there is in fact no evidence of its having been affected in even the slightest degree. To facilitate the examination I subjoin the values of the semicircular deviation of the two compasses which were most continuously examined in the period comprising the 4th August, viz. the poop and starboard steering compasses; the position of the Standard compass being at that time occupied by machinery.

* That report, for which I am responsible, was made on the supposition that the process was one to be applied to the hull of the ship generally, according to the specification of the patent. Had I understood that the iron in the immediate vicinity of any compass was to be magnetized to a high degree of intensity, I should certainly have reported differently; and it will be seen in the sequel that from the results of Mr. HOPKINS'S experiments, I was obliged to submit that no such experiments for the future be permitted within 20 feet of any compass placed for the navigation of the ship.

† This statement was subsequently repeated at a Meeting of the British Association for the Advancement of Science held at Nottingham in 1866, in a paper "On the Depolarization of Iron Ships, to prevent the Deviation of the Compass," by Mr. EVAN HOPKINS, C.E. See Athenæum of September 8th, 1866.

1866.	Maximum of Semicircular Deviation. Poop compass.	Starboard Steering compass.
	°	°
May 29th . . .	$48\frac{3}{4}$	$39\frac{1}{2}$
July 12th . . .	$64\frac{1}{2}$	50
August 10th . . .	$55\frac{3}{4}$	$46\frac{1}{2}$

In each case it will be seen there is a slight decrease in the interval comprising the 4th August, but the decrease does not exceed half the increase in the preceeding interval; and seems only the recovery from an anomalous increase in July, probably attributable to some external disturbing cause of the nature before mentioned, viz. the proximity of the two armour-plated ships in the Victoria Docks.

The next and final trial was made between the 1st and 26th January 1867, at Sheerness: ten or twelve days were occupied in passing large electro-magnets along the outside of the ship from the water-line to the top sides. Subsequently, and apparently as an after thought,—as no mention is made in either specification of internal demagnetization on so large a scale,—about five days more were occupied in applying the electro-magnets to the transverse iron beams of the poop and upper deck nearest the poop and steering compasses, and to two adjacent vertical iron stanchions supporting the upper deck. As no appreciable effect was produced on the Standard compass, or on any compasses except those in the immediate vicinity of the beams and stanchions operated on, we may have confidence in attributing the change which took place entirely to the latter operations.

The following Tables, derived from the General Table, furnish the means of deciding this question.

TABLE I.

At position of the undermentioned compasses.	(I.) B Part of semicircular deviation from Headward force.	(II.) C Part of semicircular deviation from Transverse force.	(III.) $\sin^{-1}\sqrt{\mathfrak{B}^2+\mathfrak{C}^2}$ Maximum of semicircular deviation.	(IV.) $\tan^{-1}\frac{\mathfrak{C}}{\mathfrak{B}}$ Starboard angle.	(V.) μ Mean vertical force of earth and ship, in terms of earth's horizontal force as unit.	(VI.) Heeling error to windward for 1° of heel.	(VII.)
	°	°	°	°		° ′	
1st January 1867. Standard	-37	$+\ 4\frac{1}{2}$	$40\frac{1}{2}$	$173\frac{3}{4}$	1·223	+1 18	
1st January 1867. Starboard steering	$-39\frac{3}{4}$	$+15\frac{1}{4}$	$46\frac{1}{2}$	$161\frac{1}{4}$	1·056	+1 4	
1st January 1867. Poop	$-48\frac{3}{4}$	$+15\frac{1}{4}$	$56\frac{1}{2}$	$164\frac{1}{4}$	1·469	+2 1	
1st January 1867. Port steering	-43	$+19\frac{3}{4}$	51	$157\frac{1}{4}$			

TABLE II.

26th January 1867. Standard	$-36\frac{1}{4}$	$+\ 7$	$40\frac{1}{4}$	$170\frac{1}{4}$	1·271	+1 27	
26th January 1867. Starboard steering	$-\ 2\frac{1}{2}$	$+38\frac{1}{4}$	$36\frac{3}{4}$	$94\frac{1}{2}$	1·250	+1 45	
26th January 1867. Poop	$-\ 3\frac{1}{4}$	$+12\frac{1}{4}$	$12\frac{1}{4}$	$104\frac{3}{4}$	·986	+0 37	
26th January 1867. Port steering	$-\ 4\frac{1}{4}$	-11	11	246			

TABLE III.—Amount and direction of Magnetic Forces on 1st January 1867.

	$\lambda \mathfrak{B}$ Ship's force to head.	$\lambda \mathfrak{C}$ Ship's force to starboard.	$(\mu-1)\tan\theta$ Ship's force downwards.	$\lambda\sqrt{\mathfrak{B}^2+\mathfrak{C}^2}$ Horizontal force of ship.	$\sqrt{\text{Col. III}^2+\text{IV}^2}$. Total force of ship.	$\tan^{-1}\frac{\mathfrak{C}}{\mathfrak{B}}$ Starboard angle of ship's force.	$\tan^{-1}\frac{\text{Col. III.}}{\text{Col. IV.}}$ Dip of ship's force.
						°	° ′
Standard	−·562	+·062	+ ·553	·566	·791	173¾	+44 24
Starboard steering	−·546	+·186	+ ·139	·578	·595	161¾	+13 32
Poop	−·691	+·196	+1·163	·720	1·368	164¼	+52 46
Port steering.	−·580	+·242	......	·628	......	157½	

TABLE IV.—Amount and direction of Magnetic Forces on 26th January 1867.

Standard	−·554	+·094	+·672	·562	·876	170¼	+50 5
Starboard steering	−·037	+·477	+·620	·478	·783	94½	+52 25
Poop	−·051	+·175	+·035	·181	·184	104¾	−10 57
Port steering	−·062	−·141	......	·153	......	246	

TABLE V.—Amount and direction of additional forces introduced between January 1st and 26th, 1867.

Standard	+·008	+·032	+ ·119				
Starboard steering	+·509	+·291	+ ·481	·586	·758	+30	+38 25
Poop	+·648	−·021	−1·198	·648	1·362	− 2	−61 35
Port steering	+·518	−·383	......	·644	......	−36½	

The values of B and C in Table I. show the remarkable amount of accordance in the deviations of the *four* compasses; a similarity which clearly indicates that the cause of the deviations is to be sought for, not in the iron in the immediate vicinity of those compasses, but in iron at such a distance that the distance between the compasses does not materially affect its action on them.

The values of B and C in Table II. show an important change in *three* of the compasses. The value of B for the starboard steering, poop, and port steering are nearly reduced to zero, showing the introduction of a powerful force attracting to the bow of the ship, or repelling from the stern. With C the case is very different: in the port compass a deviation to port is produced, in the starboard compassa deviation to starboard; indicating the introduction of a repelling force between the two. The same conclusion may be drawn, and perhaps with greater facility, from a comparison of the value of the quantities in columns III. and IV.

The quantities in columns V. and VI. show that the change produced is an upward force on the poop compass, and downward on the starboard steering compass; pointing to a repelling force emanating from a point or region at a height intermediate between the height of the two compasses. These several comparisons show that the change was really caused by a repelling force (a north pole) being introduced in the iron of the poop-deck a little abaft the poop compass.

The precise amount and direction of the force so introduced, and the changes it caused in the previously existing forces, will be seen distinctly by the mathematician from Tables III., IV., V.

The action of the several forces may perhaps be more clearly apprehended when they are represented graphically as in Plate XXXI. In this, fig. 1 represents the projection of lines indicating the amount and direction of the magnetic forces which act on the three compasses on the horizontal plane. Fig. 2 represents the projection of the same lines on the fore and aft vertical plane. The figures are drawn to a scale in which one-fourth of an inch represents one foot, and also one-tenth of the earth's horizontal force. The lightly dotted parts represent iron.

P, Q, R represent the positions of the port, the poop, and the starboard steering compasses respectively; Pp, Qq, Rr represent the projection of lines representing the magnetic forces of the ship at these positions on the 1st January 1867; Pp', Qq', Rr' the same projection on the 26th January 1867; Pp'', Qq'', Rr'' the projection of the additional forces introduced in the interval.

In fig. 1 the near approach to parallelism and equality in Pp, Qq, Rr indicate a distinct cause of magnetic force. The lines Pp'', Qq'', Rr'' produced backwards nearly meet in a point about 5 feet abaft the poop compass; indicating that the additional force is introduced at or near that point. A similar convergence of the line Qq'', Rr'' in fig. 2 indicates that the point lies in or near the poop deck, and suggests that it arose from the magnetization of the central part of the iron beams of the poop deck, modified possibly by some magnetization of the beams of, or stanchions supporting the upper deck.

On the 28th February, and preparatory to the ship being navigated to Devonport, the deviations and magnetic forces were observed. The deviation of the Standard compass being too great for the safe navigation of the ship, and the deviation of the starboard steering compass being so great as to make it practically useless, it was necessary to reduce their semicircular deviations by the application of fixed magnets. The process employed, and which is that generally employed in the Royal Navy, is identical with one of the two methods described by the Astronomer Royal in his well-known paper on the magnetism of iron-built ships (Philosophical Transactions, 1839, see page 196), and may be described as follows.

The coefficients $\mathfrak{B}$, $\mathfrak{C}$, λ being found by observation, or where necessary $\mathfrak{B}$ and $\mathfrak{C}$ being found by observation, and λ being estimated; we have $\lambda\sqrt{\mathfrak{B}^2+\mathfrak{C}^2}$ the tangent of the semicircular deviation when the polar force acts to the east or west of the compass, and $\frac{\mathfrak{C}}{\mathfrak{B}}$ the tangent of the "starboard angle." If we desire to correct the semicircular deviation completely, a magnet of suitable size, adequate power, and proved permanence is selected from those in store at the Compass Observatory at Woolwich. The distance above or below the card at which this magnet, when placed East and West, will produce a deviation of which the tangent is $\lambda\sqrt{\mathfrak{B}^2+\mathfrak{C}^2}$, is ascertained by actual trial. The magnet is then inserted into the pedestal of the Standard compass at the ascertained distance immediately below the centre of the card and in the direction of the starboard angle, the poles being so placed as to counteract the polar magnetism of the ship.

As in newly built ships the polar force is generally undergoing a process of gradual diminution, it is generally considered best not to correct entirely the semicircular devia-

tion, but to under correct it, leaving about 5° uncorrected. This was the object sought in the application of magnets to the 'Northumberland'; and the success with which it was effected, and the certainty of the process, may be seen by the following comparison of the deviations on the 28th February and the 2nd March.

		A	B	C	D	E
Standard compass	February 28, 1867	+0° 01′	−36° 13′	+ 7° 09′	+7° 19′	+0° 59′
	March 2	−0 14	− 4 55	+ 0 14	+7 13	+1 15
Starboard steering-compass ...	February 28	+0 41	− 5 20	+40 41	+6 28	+2 40
	March 2	−0 18	− 4 15	− 1 04	+6 42	+1 44

In general no attempt is made to correct the quadrantal deviation, that deviation and the residual semicircular deviation being the subject of tabular correction. I may observe that in some cases Mr. AIRY's second or tentative mode of correcting, viz. by one or more fore and aft and transverse magnets, is adopted, but only when special circumstances prevent the first method being applicable. In general by the process first described, all that is necessary or desirable in the way of mechanical correction can be effected.

In the middle of March 1867, the 'Northumberland,' as before stated, was placed in a dry dock at Devonport, and the magnets were removed; her head in dock was S. 84° E. magnetic. Such a position would, from all former experience, and especially in a newly launched ship, be expected to increase considerably the force to starboard, or the value of $+\mathfrak{C}$, but without much alteration in the fore and aft force, or the value of $\mathfrak{B}$, in those compasses in which the $\mathfrak{B}$ and $\mathfrak{C}$ were caused by the general magnetism of the hull. We have continuous observations to the end of 1867 strictly comparable as regards the Standard compass; but as regards the other three compasses allowance must be made for the introduction between August and December 1867 of five iron beams* to extend the light poop deck before the poop compass.

The changes in the Standard compass while the ship lay in dock with her head S. 84° E. are shown in the following Table.

	[1867].	$\mathfrak{B}$.	$\mathfrak{C}$.
Swinging at anchors	January 26th	−·637	+·108
	February 28th	−·637	+·110
Head S. 84° E. magnetic from middle of March	June 26th	−·576	+·277
	August 29th	−·569	+·256
	December 10th	−·593	+·329

* The effect of the introduction of the five new poop-deck beams when the ship's head was S. 84° E. magnetic would be to increase $\mathfrak{C}$ and $\mathfrak{D}$ and diminish λ. The exact value of the altered $\mathfrak{C}$ cannot be computed without knowing the altered values of $\mathfrak{D}$ and λ; and these cannot be ascertained till the ship is again swung. I think, however, it is certain that the change in $\mathfrak{D}$ cannot exceed ·017 (or 1° in $\mathfrak{D}$), and the change in λ cannot exceed ·020, and I have accordingly inserted in the General Table, under date 10th December 1867, the values of $\mathfrak{B}$ and $\mathfrak{C}$ computed as well with the original values of $\mathfrak{D}$ and λ, as with values allowing these amounts. It may be safely assumed that the true values lie between the two as limits.

These results are clearly attributable to the change in the general magnetism of the ship due to position; the fore and aft force has been little affected, but there is a decided increase in the transverse force, $=+\cdot 219$.

With respect to the compasses affected by Mr. HOPKINS'S process, the results are widely different:—in seven months (end of January to end of August), as will be seen by the following Table, at the starboard steering $-\mathfrak{B}$ has increased ·183, $\mathfrak{C}$ having scarcely changed in value; at the poop compass $-\mathfrak{B}$ has increased ·281, and $+\mathfrak{C}$ ·162; at the port steering compass $-\mathfrak{B}$ has increased ·098, while the $\mathfrak{C}$ has increased ·320; so that the increase of the $\mathfrak{C}$ in the poop compass is almost exactly the mean of the increase in the port and starboard compasses.

1867.	Port steering compass.		Poop compass.		Starboard steering compass.	
	$\mathfrak{B}$	$\mathfrak{C}$	$\mathfrak{B}$	$\mathfrak{C}$	$\mathfrak{B}$	$\mathfrak{C}$
January 26 ……	−·078	−·176	−·059	+·203	−·046	+·596
February 28 ……	−·071	−·128	−·070	+·230	−·078	+·625
June 26 …………			−·153	+·360		
August 29 ………	−·176	+·150	−·340	+·365	−·229	+·637
December 10……	{−·212 −·218	+·508 +·481}	{−·215 −·221	+·541 +·516}	{−·136 −·141	+·641 +·617}

If we confine ourselves to the practical question of the amount of the semicircular deviation, and also of the direction of the ship's force [starboard angle], or, in other words, the direction of the neutral or zero-points of the semicircular deviation, the comparison is as follows:—

1867.	Standard.		Port steering.		Poop.		Starboard steering.	
	Maximum semi-circular deviation.	Starboard angle.	Maximum semi-circular deviation.	Starboard angle.	Maximum semi-circular deviation.	Starboard angle.	Maximum semi-circular deviation.	Starboard angle.
	°	°	°	°	°	°	°	°
January 1…	37¼	173¾	47½	157	51	164¼	42¾	161¼
" 26…	37	170¼	12	246	12¾	104¾	38½	94½
February 28…	37	170	8¾	241	14½	107	41¾	97
June 26…	39½	155	…	…	23	112		
August 29…	38½	156	13¼	139½	30	133	42¾	110
December 10…	42½	151	33½	112½	35½	111½	40	102

From this comparison it will be seen how short lived is the apparent benefit derived from the process we have been considering.

The nature of the changes in the polar force will perhaps be more clearly apprehended if we represent them graphically, as in Plate XXXII., by taking the position of each compass as origin and laying down the points, of which $\lambda\mathfrak{B}$ and $\lambda\mathfrak{C}$ are the coordinates, as derived from the observations on January 1st and 26th, February 28th, August 29th, and December 10th, 1867.

As regards each compass, a line drawn from the origin to one of these points represents in amount and direction the polar force acting on that compass at that epoch; and a line drawn from one point to the next succeeding in order of date represents, in amount and direction, the additional polar forces acting on that compass introduced in

the interval. To avoid confusion in the figure, the lines from the origin are only drawn for the earliest date. The *joints* added to these lines, therefore, represent the additional forces introduced in each interval.

This Plate shows strikingly the contrast between the comparatively small and regular changes in the polar magnetism of the Standard compass, and the large and irregular changes in the polar magnetism of the other compasses; but at the same time shows strikingly the general analogy in the changes in these three compasses.

An attentive study of it will also show, that while the changes in the polar magnetism of the Standard compass are almost entirely from an increasing attraction to the south side of the ship, in the other compasses this is combined with an increasing attraction to, or rather a diminishing repulsion from, the point abaft the poop compass to which a powerful north pole had been communicated.

In the interval between the 28th August and the 10th December, a general headward force on the three stern compasses is also added. What was the cause of this force I am unable say; it may possibly be connected with the introduction of the five iron beams in front of these compasses, and the general hammering to which that part of the ship was consequently exposed.

The views which I have taken of the effect of the application of the electro-magnets are, I think, strongly confirmed by observations made on the 10th December 1867, at four points surrounding the position of the supposed north pole produced by them.

Of these, the position of the poop compass was one; the second was 18 feet abaft the poop compass; the third, 7 feet 3 inches abaft the poop compass, and 4 feet to port of the midship line; the fourth, 7 feet 3 inches abaft the poop compass, and 4 feet to starboard of the midship line. The values of 𝔅 and ℭ for these compasses were—

	𝔅.	ℭ.
No. 1. Poop compass	−·215	+·541
2. 18 feet abaft Poop compass	−·641	+·482
3. $7\frac{1}{4}$ feet abaft Poop compass, 4 feet to port	−·457	+·260
4. $7\frac{1}{4}$ feet abaft Poop compass, 4 feet to starboard	−·458	+·692

An inspection of these values will show that they indicate a generally attractive force to the stern and starboard sides; but modified by a repulsive force emanating from a point nearly centrically situated with respect to the four compasses. We may, in fact, I think, infer that the mean of these values, or a 𝔅 of −·443, and a ℭ of +·494, is due to the general magnetism of the ship, and as regards ℭ partly to the new iron beams, and that the difference from these values as to each compass arises from local magnetization. These differences—which are also multiplied by λ(·860) to express them in terms of the earth's magnetic force as unit—will be

	𝔅.	ℭ.	λ𝔅.	λℭ.
No. 1. Station (Poop)	+·228	+·047	+·196	+·040
2. ,,	−·198	−·012	−·170	−·010
3. ,,	−·014	−·234	−·012	−·201
4. ,,	−·015	+·198	−·013	+·170

The interpretation of which Table is that, besides the general magnetism of the ship, there is a horizontal force nearly equal to one-fifth of the earth's horizontal force, repelling the north end of each needle from a point situated nearly in the centre of the compasses. This I conceive to be the remains of the strong north pole to which I have referred, which it will be remembered affected the poop compass with a repelling force $=\cdot 648$, and now reduced to $\cdot 200$; so that more than two-thirds of the force introduced in the operations of January 1867 seem to have disappeared in the course of eleven months; and the general result of these operations may be described as the introduction at a point in the poop-deck, a few feet abaft the poop compass, of a north pole acting on the compass with a force of nearly two-thirds of the earth's horizontal force, and which force in the course of eleven months diminished to about one-fifth of the earth's force, or to less than one-third of its original amount.

The effect of the forces introduced by the operations of January 1867, and of the gradual decay of these forces in the interval between January and December, is no less obvious in the heeling-errors of the different compasses. This error, it may be remembered, is expressed by the deviation to windward produced by an inclination of the ship of 1°, when its head is North or South by the disturbed compass.

In the interval between the 1st and 26th January 1867, there is a diminution of the heeling-error of the poop compass from 2° 1′ to 0° 37′, but an increase of the heeling-error of the starboard compass from 1° 4′ to 1° 45′. The diminution is caused by the upward force on the poop compass; the increase by the downward force on the starboard steering compass introduced in the interval.

The changes so introduced in both compasses diminish as time passes. By the 10th December that of the poop compass had risen to 1° 14′, that of the starboard steering diminished to 0° 56′. During the whole of this period the heeling-error of the Standard compass is hardly altered; the slight apparent changes being not greater than can be accounted for by unavoidable errors of observation.

We are now in a position to form an opinion as to the real nature of the changes effected by the operations of January 1867, and the advantages and disadvantages of these changes.

The process was in no sense of the word one of "depolarization," either of the whole ship or of any part of it. It was, on the contrary, the "polarization" to a high degree of intensity of a particular portion of the iron in the neighbourhood of three of the compasses. The iron so magnetized was iron capable of receiving only subpermanent magnetism, and which from its forming part of the structure of the vessel was subject to strains and concussions from which detached magnets are wholly free. The magnetism so communicated was therefore necessarily unstable and transient, and from its liability to change suddenly and unexpectedly, was a source of danger to the vessel. So strongly was I impressed with the danger that in an official report to the Admiralty of 31st January 1867, after a careful reduction of the observations the results of which are already given, I expressed the hope that, should further experiments be permitted in

Her Majesty's ships for depolarizing their hulls, the so-called "depolarization" should not be allowed "within 20 feet of any compass that may be placed for the navigation of the ship."

Nor could the effect produced, even if it had been much more permanent than it proved to be, be considered an advantage. In two out of the three compasses to which it was applied the semicircular deviation was reduced within the limits which make tabular corrections possible, not within those which allow it to be dispensed with. In the third—the starboard steering compass—the effect, though considerable, was rather a change in the direction, than a reduction of the amount, of the semicircular deviation; for it exceeded 36°, and a reduction by a magnet was still necessary. In the two compasses in which the process was effective to the extent we have mentioned, the requisite reduction might have been effected with infinitely greater ease and certainty, as well as permanency, by the application of a single magnet to each compass.

In dismissing this subject it may seem that some apology is necessary for occupying the time of the Society with the details of a process which had so little to recommend it, and which has proved injurious, not beneficial; it is, however, a process to which many persons looked with hope, and from which no one apprehended danger; both were mistaken, and in both respects it is desirable that the results of the trials should be known.

The Tables and the discussion will also I hope be accepted as an interesting example of the method now constantly practised in the Royal Navy of supplementing the observations made in "swinging" a ship, by observations of deviation and horizontal and vertical force made on one azimuth.

As regards the observations generally, the conclusions to be drawn from them, or rather which, having been already drawn from numerous other observations, are supported by those made in the 'Northumberland,' seem to be—

1. That in an iron-built ship, and in that part of her within which the Standard compass is generally placed, the polar force is that from the magnetism of the whole body of the ship, and is nearly uniform.

2. That we cannot escape from the action of that force by any care in the selection of a place for the compass.

3. That though positions may be found where from the magnetism of particular masses of iron counteracting that of the ship, the deviation will be small, yet that such positions are in general to be avoided, as the change of magnetic force in such positions will probably be larger and less regular than when the compass is only acted on by the general magnetism of the whole ship:—any attempt to produce this counteraction by magnetizing artificially masses of iron in the vicinity of a compass is to be deprecated.

4. That in iron-built ships, as at present constructed, the ship's polar force is generally so great as to make it necessary to employ magnets to equalize the directive force on different azimuths of the ship's head, even at the most carefully selected position; but that the use of correcting magnets does not dispense with the necessity of ascertaining from time to time by observations, the amount of the remaining deviations.

General Table.—Her Majesty's Ship Northumberland.

Ship.	Compass.	Place.	Date.	Approximate coefficients. A	B	C	D	E	Exact coefficients. 𝔄	𝔅	ℭ	𝔇	𝔈
				° ′	° ′	° ′	° ′	° ′					
NORTHUMBERLAND.	Standard.	On Stocks	Mar. and Apr. 1866	By deviation, horizontal and vertical forces on one point						−·157	+·427	+·133a	......
(6621 tons),		Off Deptford	Apr. 19, 1866							−·004	+·416	+·133a	......
26 guns,		Sheerness	Jan. 1, 1867	+0 50	−36 53	+ 4 35	+7 02	−0 24	+·015	−·646	+·071	+·122	−·007
1350 horse-power,		Sheerness	Jan. 26, 1867	+1 12	−36 13	+ 7 02	+7 22	−0 35	+·021	−·637	+·108	+·128	−·010
Iron hull, iron-plated.		Sheerness	Feb. 28, 1867	+0 01	−36 13	+ 7 09	+7 19	+0 59	+·001	−·637	+·110	+·127	+·017
		Sheerness	**March 2, 1867**	**−0 14**	**−4 55**	**+ 0 14**	**+7 13**	**+1 15**	**−·004**	**−·091**	**+·004**	**+·126**	**+·022**
Armour bulk-heads.		Devonport	June 26, 1867	By deviation, horizontal and vertical forces on one point. Ship in dock, head S. 84° E. magnetic						−·576	+·277	+·123a	......
Rifle-tower on quarter-deck.		Devonport	Aug. 29, 1867							−·569	+·256	+·120a	......
		Devonport	Dec. 10, 1867							−·593	+·329	+·120a	......
Built at Millwall, River Thames; head N. 39½° E. magnetic.	Poop.	On Stocks	Mar. and Apr. 1866	By deviation and forces on one point						−·788 −·801	+·358 +·361	+·090a +·104a	....
Plated on Stocks.		Off Deptford	Apr. 19, 1866	From swinging through a Quadrant						−·877 −·890	+·296 +·291	+·090a +·104a	....
Launched April 17, 1866.		In Victoria Docks.	Apr. 21, 1866	By deviation and forces on one point (head S. 22° W. magnetic). Two iron-plated ships alongside. Steam machinery, iron masts, &c., placed on board during this interval						−·800	+·135	+·090a	......
			May 29, 1866							−·742	+·129	,,	......
			July 12, 1866							−·900	+·075	,,	......
			Aug. 10, 1866							−·821	+·099	,,	......
			Sept. 1, 1866							−·842	+·076	,,	......
			Oct. 24, 1866							−·814	+·003	,,	......
			Dec. 17, 1866							−·825	+·025	,,	......
		Sheerness	Jan. 1, 1867	+1 15	−48 43	+15 13	+5 55	−0 35	+·022	−·803	+·228	+·103	−·010
		Sheerness	*Jan.* 26, 1867	+2 14	− 3 16	+12 20	+5 39	−0 48	+·039	−·059	+·203	+·098	−·014
		Sheerness	*Feb.* 28, 1867	+0 35	− 3 51	+13 59	+6 07	+0 29	+·010	−·070	+·230	+·107	+·008
		Devonport	*June* 26, 1867	By deviation, horizontal and vertical forces on one point. Ship in dock, S. 84° E. magnetic						−·153	+·360	+·100a	......
		Devonport	*Aug.* 29, 1867							−·340	+·365	,,	......
		Devonport	*Dec.* 10, 1867							−·215	+·541	,,	......
		Devonport	*Dec.* 10, 1867							−·221	+·516	+·117a	......

Note.—The coefficients marked (a) are assumed values.

General Table (continued).—Her Majesty's Ship Northumberland.

Maximum of semicircular deviation. Mean horizontal force of ship $\sqrt{\mathfrak{B}^2+\mathfrak{C}^2}$†. Amount.		Direction.	Mean force to North, λ ‡	$\frac{1}{\lambda}$	Coefficients of horizontal induction. Headward. a ‡	To starboard. e ‡	Part of $\mathfrak{D}$ from Fore and aft induction.	Transverse induction.	Mean Vertical force, μ §	Heeling coefficient to *windward*.	Heeling coefficient for Vertical induction in transverse iron.	Vertical force and induction in vertical iron.	Variable part of Vertical force. $\frac{g}{\tan\theta}$ §	g ‡
°		°					° ′	° ′		° ′	° ′	° ′		
27½	·461	110	·860a	......	......	......	......	......	1·241	+1 25	......	......	+·007a	
24½	·416	90½	·860a	......	......	......	......	......	1·164	+1 11				
40½	·650	173¾	·869	1·151	−·025	−·237	−0 48	+7 50	1·223	+1 18	+0 40	+0 38	+·007	+·017
40¼	·646	170¼	·870	1·149	−·019	−·241	−0 34	+7 56	1·271	+1 27	+0 41	+0 46		
40¼	·646	170												
5¼	·091	177½	·878	1·139	−·012	−·232	−0 21	+7 34	1·168	+1 07	+0 39	+0 28	+·013	+·032
39¾	·639	154½	·885a	......	......	......	......	......	1·272	+1 24	......	......	+·010a	
38½	·623	156	·885a	......	......	......	......	......	1·232	+1 17	......	......	”	
42¾	·678	151	·885a	......	......	......	......	......	1·266	+1 22	......	......		
59¾	......	155½	·800	......	......	......	......	......	1·637	+2 50	......	......	+·070a	
61¾	·880	155½	·840	......	......	......	......	......	1·691	+2 48	......	......	·000	
67¼	......	161½	·800	......	......	......	......	......	1·646	+2 52	......	......	+·070a	
69½	·936	161¾	·840	......	......	......	......	......	1·596	+2 30	......	......	·000	
54¼	·811	170½	·800a	......	......	......	......	......	1·529	+2 30	......	......	+·070a	
48¾	·753	170	”	......	......	......	......	......	1·531	+2 06	......	......	”	
64½	·902	175½	”	......	......	......	......	......	1·383	+2 03	......	......	”	
55¾	·827	173½	”	......	......	......	......	......	1·411	+2 08	......	......	”	
57¾	·847	174½	”	......	......	......	......	......	1·449	+2 15	......	......	”	
54½	·814	180	”	......	......	......	......	......	1·442	+2 14	......	......	”	
55½	·825	178	”	......	......	......	......	......	1·355	+1 58	......	......	”	
56½	·834	164¼	·860	1·163	−·052	−·228	−1 44	+7 30	1·469	+2 01	+0 39	+1 22	−·001	−·003
12¼	·211	104¾	·854	1·171	−·062	−·230	−2 04	+7 43	·986	+0 37	+0 40	−0 03		
14	·240	107	·894	1·118	−·010	−·202	−0 21	+6 28	·929	+0 22	+0 34	−0 12	+·033	+·082
23	·391	112	·880a	......	......	......	......	......	·996	+0 35	......	......	+·030a	
30	·499	133	”	......	......	......	......	......	1·044	+0 43	......	......	”	
35½	·580	111½	”	......	......	......	......	......	1·230	+1 14	......	......	”	
34	·561	113	·860a											

$$a=\lambda\mathfrak{D}-(1-\lambda).$$
$$e=-\lambda\mathfrak{D}-(1-\lambda).$$

Part of $\mathfrak{D}$ from
- Fore and aft induction $=\frac{a}{2\lambda}=\frac{\mathfrak{D}}{2}-\left(\frac{1}{\lambda}-1\right).$
- Transverse induction $=-\frac{e}{2\lambda}=\frac{\mathfrak{D}}{2}+\left(\frac{1}{\lambda}-1\right).$

Heeling coefficient to *windward* $=\left(\mathfrak{D}+\frac{\mu}{\lambda}-1\right)\tan\theta.$

Part of heeling coefficient.
- from Vertical induction in transverse iron .... $=\left(\mathfrak{D}+\frac{1}{\lambda}-1\right)\tan\theta.$
- from Vertical force and Vertical induction in Vertical iron...... $=\left(\frac{\mu}{\lambda}-\frac{1}{\lambda}\right)\tan\theta.$

† Mean force to North (λH) being unit. ‡ Earth's Horizontal force (H) being unit. § Earth's Vertical force (Z) being unit.

General Table (continued).—Her Majesty's Ship Northumberland.

Ship.	Compass.	Place.	Date.	Approximate coefficients.					Exact coefficients.				
				A	B	C	D	E	𝔄	𝔅	ℭ	𝔇	𝔈
				° ′	° ′	° ′	° ′	° ′					
Northumberland (*continued*).	Starboard steering.	On stocks	Mar. and Apr. 1866	......	......	......	......	......		−·846	+·499	+·105a	......
										−·855	+·491	+·117a	......
		Off Deptford	April 19, 1866	*By deviation and forces on one point*						−·882	+·455	+·105a	......
										−·874	+·447	+·117a	......
		In Victoria Docks.	April 21, 1866	......					......	−·761	+·150	+·105a	......
			May 29, 1866	*By deviation and force on one point* (*head* S. 22° W. *magnetic*). *Two iron-plated ships alongside steam machinery, iron masts, &c. placed on board during this interval.*						−·635	+·018	,,	......
			July 12, 1866							−·760	−·108	,,	......
			Aug. 10, 1866							−·726	+·022	,,	......
			Sept. 1, 1866							−·740	−·071	,,	......
			Oct. 24, 1866							−·668	−·107	,,	......
			Dec. 17, 1866							−·651	−·089	,,	......
		Sheerness	Jan. 1, 1867	+0 09	−39 50	+15 18	+ 6 39	+ 0 42	+·003	−·683	+·232	+·116	+·012
		Sheerness	*Jan.* 26, 1867	−0 24	− 2 37	+38 19	+ 6 24	− 0 20	−·007	−·046	+·596	+·112	−·006
		Sheerness	*Feb.* 28, 1867	+0 41	− 5 20	+40 41	+ 6 28	+ 2 40	+·012	−·098	+·625	+·113	+·046
			Mar. 2, 1867	**−0 18**	**−4 15**	**−1 04**	**+6 42**	**+1 44**	**−·005**	**−·078**	**−·018**	**+·117**	**+·030**
		Devonport	*Aug.* 29, 1867	*By deviation and forces on one point*					...	−·229	+·637	+·110a	......
		Devonport	*Dec.* 10, 1867	*Ship in dock* (*head* S. 84° E. *magnetic*)					...	−·136	+·641	+·110a	......
		Devonport	*Dec.* 10, 1867	......	......	......	......	......	...	−·141	+·617	+·127a	......
	Port steering.	Sheerness	Jan. 1, 1867	+1 13	+43 0	+19 48	+ 6 18	− 0 28	+·021	−·725	+·302	+·110	−·008
		Sheerness	*Jan.* 26, 1867	−0 39	− 4 13	−10 52	+ 7 40	− 2 11	−·011	−·078	−·176	+·133	−·038
		Sheerness	*Feb.* 28, 1867	+0 53	− 3 55	− 7 50	+ 6 54	− 0 12	+0·15	−·071	−·128	+·120	−·003
		Devonport	*Aug.* 29, 1867	*By deviation and forces on one point*					...	−·176	+·150	+·110a	
		Devonport	*Dec.* 10, 1867	*Ship in dock* (*head* S. 84° E. *magnetic*)					...	−·212	+·508	......	
		Devonport	*Dec.* 10, 1867	......	......	......	......	......	...	−·218	+·481	+·127	
	Lower deck.	Sheerness	Feb. 28, 1867	−0 11	− 3 23	+11 05	+13 02	+ 0 32	−·003	−·065	+·170	+·228	+·009
		Devonport	Aug. 29, 1867	*By deviation and forces on one point*					......	−·025	+·333	+·220	
		Devonport	Dec. 10, 1867	*Ship in dock* (*head* S. 84° E. *magnetic*)					......	−·082	+·412	+ 220	

Note.—The coefficients marked (a) are assumed values.

General Table (continued).—Her Majesty's Ship Northumberland.

Maximum of semicircular deviation. Mean Horizontal force of ship $\sqrt{\mathfrak{B}^2+\mathfrak{C}^2}$†. Amount.		Direction.	Mean force to North, λ ‡	$\frac{1}{\lambda}$	Coefficients of horizontal induction. Headward. a ‡	To starboard. e ‡	Part of $\mathfrak{D}$ from Fore-and-aft induction.	Transverse induction.	Mean vertical force, μ §	Heeling coefficient to *windward*.	Heeling coefficient for Vertical induction in transverse iron.	Vertical force and induction in vertical iron.	Variable part of vertical force. $\frac{g}{\tan\theta}$ §	g ‡
°		°					° ′	° ′		° ′	° ′	° ′		
77½	·976	149¾	·800a	......	......	......	......	......	1·186	+1 28	......	......	+·100a	
79¾	·984	150¼							1·259	+1 43	......	......	−·005a	
84¼	·995	152½	·800a	......	......	......	......	......	1·296	+1 49	......	......	+·100a	
78¾	·984	153							1·221	+1 36	......	......	−·005a	
51	·777	168½	·800a	......	......	......	......	......	1·126	+1 17	......	......	+·100a	
39½	·635	178½	”	......	......	......	......	......	1·163	+1 24	......	......	”	
50	·767	188¼	”	......	......	......	......	......	·996	+0 58	......	......	”	
46½	·726	178½	”	......	......	......	......	......	·821	+0 37	......	......	”	
48¼	·744	185½	”	......	......	......	......	......	·935	+0 40	......	......	”	
42½	·676	189	”	......	......	......	......	......	·949	+0 43	......	......	”	
41	·657	188	”	......	......	......	......	......	·924	+0 39	......	......	”	
46¼	·721	161¼	·802	1·247	−·105	−·291	−3 45	+10 24	1·056	+1 04	+0 54	+0 10	−·005	−·012
36¾	·598	94½	·783	1·277	−·105	−·304	−4 43	+11 12	1·250	+1 45	+0 57	+0 47		
39¼	·630	97												
4½	·080	193	·841	1·189	−·064	−·254	−2 11	+ 8 39	1·285	+1 35	+0 45	+0 50	+·041	+·102
42¾	·678	110	·820a	......	......	......	......	......	1·114	+1 10	......	......	”	
40	·655	102	”		......	......	......	......	1·036	+0 56	......	......	”	
39¼	·633	103	·800a											
51	·786	157¼												
11	·193	246												
8¼	·146	241												
13¼	·231	139½	·820a	......	......	......	......	......	1·255	+1 36	......	......	”	
33½	·550	112½	”	......	......	......	......	......	1·102	+1 08	......	......	”	
31¾	·527	114	·800a											
10½	·182	111	·729	1·371	−·105	−·437	−4 05	+17 24						
19½	·334	94	·740a											
24¾	·420	101	”											

$$a=\lambda\mathfrak{D}-(1-\lambda).$$
$$e=-\lambda\mathfrak{D}-(1-\lambda).$$

Part of $\mathfrak{D}$ from:
- Fore-and-aft induction $=\frac{a}{2\lambda}=\frac{\mathfrak{D}}{2}-\left(\frac{1}{\lambda}-1\right)$.
- Transverse induction $=-\frac{e}{2\lambda}=\frac{\mathfrak{D}}{2}+\left(\frac{1}{\lambda}-1\right)$.

Heeling coefficient to *windward* $=\left(\mathfrak{D}+\frac{\mu}{\lambda}-1\right)\tan\theta$.

Part of heeling coefficient:
- from Vertical induction in transverse iron .... $=\left(\mathfrak{D}+\frac{1}{\lambda}-1\right)\tan\theta$.
- from Vertical force and Vertical induction in Vertical iron...... $=\left(\frac{\mu}{\lambda}-\frac{1}{\lambda}\right)\tan\theta$.

† Mean force to North (λH) being unit. ‡ Earth's Horizontal force (H being unit). § Earth's Vertical force (Z) being unit.

H.M.S. NORTHUMBERLAND.

Figure 1.

Plan.

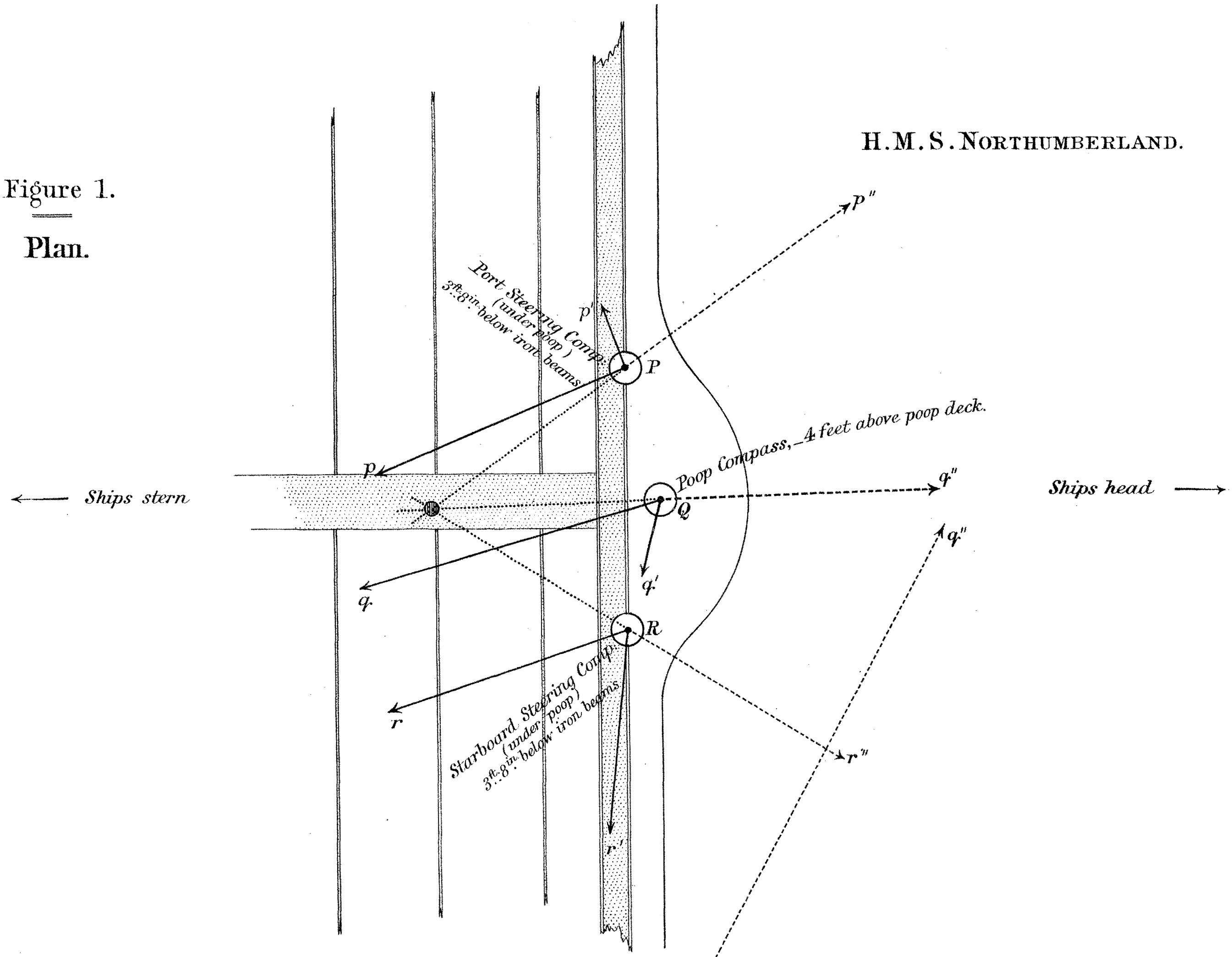
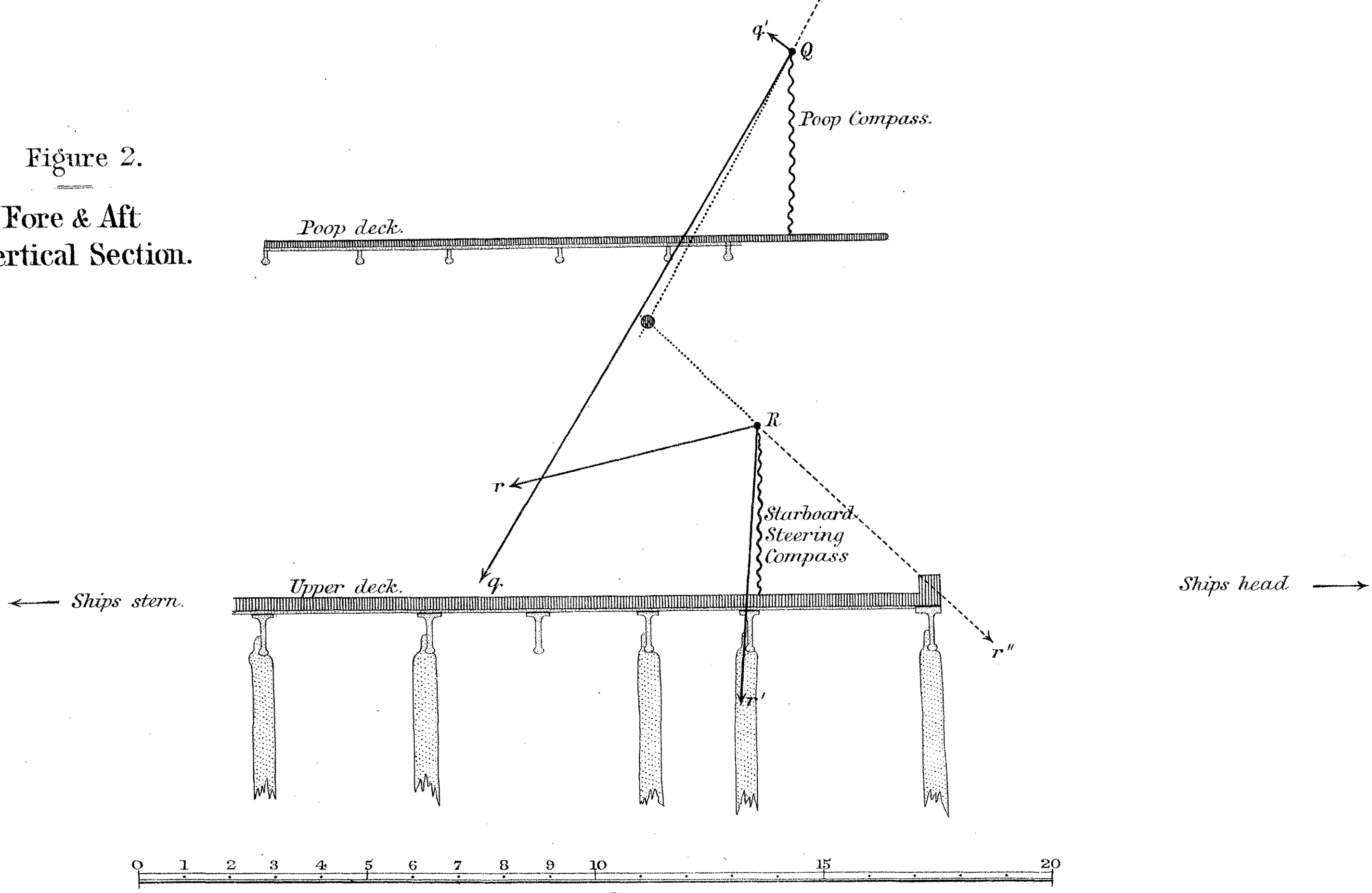


Figure 2.

Fore & Aft Vertical Section.

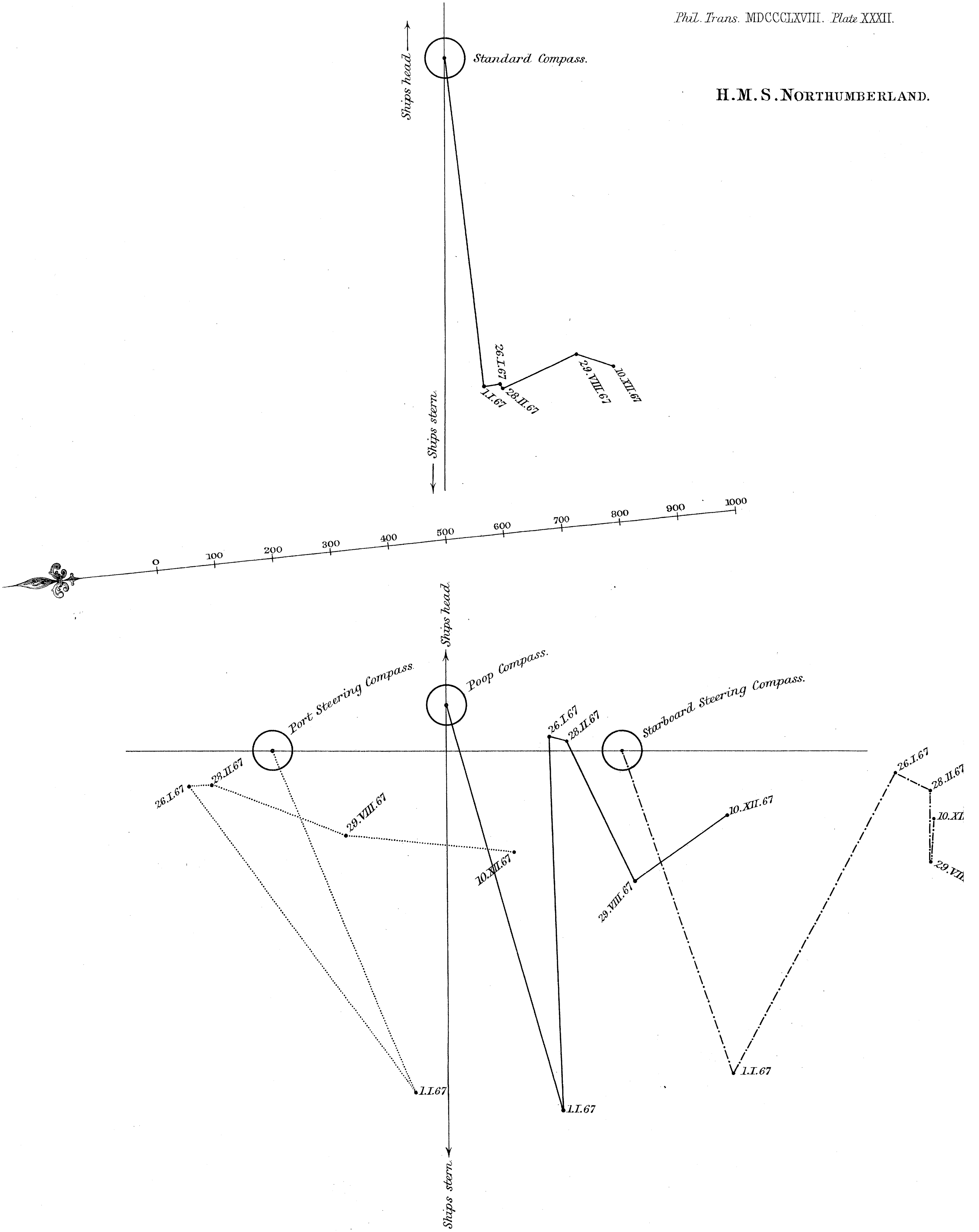


Scale of Feet, and also of 10ths of Earth's horizontal force.

F. J. Evans, Del.

Malby & Sons, Lith.

H.M.S. Northumberland.



F. J. Evans, Del. Malby & Sons, Lith.