SHIP MOTION AND VIBRATION

SOME NOTES ON INTERACTION EFFECTS BETWEEN SHIPS CLOSE ABOARD IN DEEP WATER*

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Experiments with Constrained Models

MODELS of the *King George V.*, designated Ship "A", and the *Olna*, designated Ship "B," were made to $\frac{1}{50}$ scale. Ship particulars represented by the models are given in Table I.

The models were towed on parallel courses at different positions relative to each other longitudinally, over a range of corresponding speeds from 10 to 20 knots, and at two separations, 50 and 100ft., beam-to-beam transversely. The models were allowed complete freedom vertically and were fitted with rudders set amidships, but without propellers.

The forces and turning moments determined are plotted non-dimensionally for 50-ft. and 100-ft. separation in Figs. 1 and 2, respectively, to a base of longitudinal separation between the amidship points as "A" overtakes "B" from 600ft. astern to 600ft. ahead.

It is shown later that it is impossible to keep the ships' heads on course as in the model experiments by applying correcting rudder, and that to achieve simultaneous balance of interaction force and couple, the ships must yaw slightly.

Realisation that these constrained model tests, while providing good indication of interaction during approach and break-away, should be accepted with some reserve, since the results apply strictly to ships at equal speed on parallel courses, led to the second series of tests with identical but freely-propelled and remotely-controlled models.

Experiments with Self-propelled Models

The two models were controlled by the well-known "fishing line" technique.

The models were complete with true-to-scale propellers and rudders. The propellers were driven by motors in the models, the speed of the motors being controlled by rheostats on the experiment carriage. The rudders were actuated by M-motors controlled from the carriage, and the controls were so arranged that the maximum speed of putting the rudder over was approximately true to scale for the ships.

The following manœuvres were investigated for approach, "fuelling" and breakaway, for transverse separations when fuelling at 50ft. and 100ft.

(*a*) "A" overtaking "B" from stern to bow on a straight course.

(*b*) "A" approaching "B" fine-on-the-quarter and taking up fuelling position close aboard.

(*c*) "A" breaking away from the close-aboard position on a divergent course and maintaining speed.

(*d*) "A" on a parallel course well away from "B", easing in to close aboard.

(*e*) Runs with the models maintained in various relative positions, as in the constrained model experiments.

Considering the relatively short length of run available in the confines of the tank, and the fact that the rudder operators had only $\frac{1}{7}$ the time in which to anticipate and correct yaw compared with the helmsman in the full-scale ship (the models were made to $\frac{1}{50}$ scale to minimise tank-wall interference), the large fluctuations in rudder movement were not surprising.

In spite of these difficulties, however, the feasibility of the operations (*a*) to (*d*) was demonstrated conclusively and it was decided to carry out full-scale trials of the same type.

Sea Trials

The ships engaged in these trials were the replenishment ship *Bulawayo*, battleship *Duke of York*, aircraft-carrier *Illustrious*, cruiser *Superb*, and destroyer *Dunkirk*. For the purpose of this paper, we are particularly interested in the interaction effects between the *Bulawayo* and *Duke of York*.

Each warship in turn was to approach the replenishment ship by the astern method (overtaking on a close parallel course), by the abeam method (overtaking on a parallel course far out until abeam and then closing-in while maintaining station abeam) and fine on the quarter (overtaking from far out on a convergent course). After maintaining station abeam for about 20 minutes at speeds of 12, 15, 18 and 20 knots, the warship was to break-away either by reducing speed and dropping astern on the same course or by turning away on a divergent course while maintaining or reducing speed.

In each ship, the rudder angle was recorded autographically and the compass bearing, distance apart, r.p.m. and speed by log noted at regular intervals. The depth of water in the trials area averaged 30 fathoms and the weather and sea conditions were generally moderate.

Comparison with the model experiments is possible only in the case of the *Duke of York* and *Bulawayo*. The *Duke of York* was a sister ship of the *King George V.* (Ship "A") and the *Bulawayo* (580ft. by 72·5ft. by 25ft. by 20,000 tons) was of similar size and form to the *Olna* (Ship "B"). The comparison is also limited to the correcting rudder required by both ships in the abeam position, as the *Duke of York* used the abeam approach as opposed to the astern approach

Table I.

Item	Ship A	Ship B
Length on W.L., ft	740	567
Beam, ft	103	70
Draft, ft	29.3	30
Displacement, tons	36,890	23,570
Block coefficient	0.611	0.714
Corresponding depth of water	75 fathoms	

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simulated by the model tests. A summary of the four runs carried out is given in Table II.

The minimum and maximum rudder-angles quoted for the ships are the average figures neglecting abnormal values. The rudder-angles for the models were deduced from the constrained model experiments. As the Table shows, correlation between mean rudder-angles estimated from the model experiments and those used by the ships is quite close.

It is interesting to record some other observations during these trials with the *Duke of York* and *Bulawayo* which are pertinent to the subject under discussion.

(i.) Although the battleship approached the replenishment ship by the abeam method only, the *Bulawayo* reported a noticeable effect on steering, even at the lower speeds, as the bow of the *Duke of York* passed the stern of the *Bulawayo* several hundred feet away.

(ii.) The propeller revolutions of the *Bulawayo* were quite steady during each run at the values appropriate to the

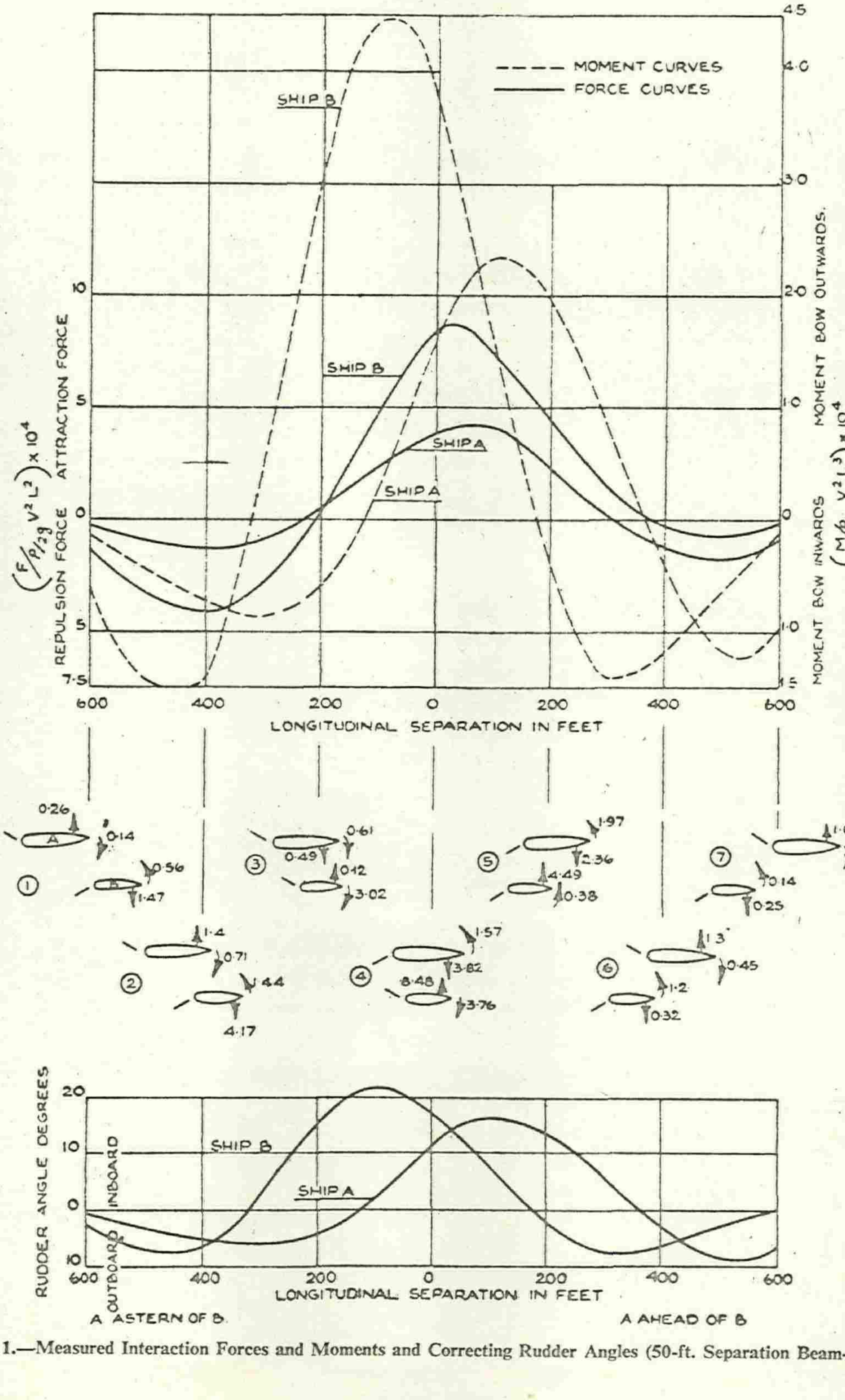

Fig. 1.—Measured Interaction Forces and Moments and Correcting Rudder Angles (50-ft. Separation Beam-to-beam).

nominal speed of the run. Those of the *Duke of York* also were steady, but generally corresponded to slightly higher speeds than the nominal speed.

(iii.) The transverse distances between ships varied during each run, sometimes appreciably. The closest approach occurred during a 20-knot run, when the distance closed to 55ft.

(iv.) The ships maintained station with little fore-and-aft variation at all speeds.

(v.) The mean angles of inboard rudder carried by the *Bulawayo* decreased as the speed increased, from 13 deg. inboard at 12 knots to 8 deg. inboard at 20 knots. The mean angles of rudder carried by the *Duke of York*, however, were approximately constant, *viz.*, 6 deg. inboard, at all speeds.

(vi.) Although the arrangements for measuring relative yaw between the ships in the abeam position were not very satisfactory, it was clear that each ship carried a bow-outward

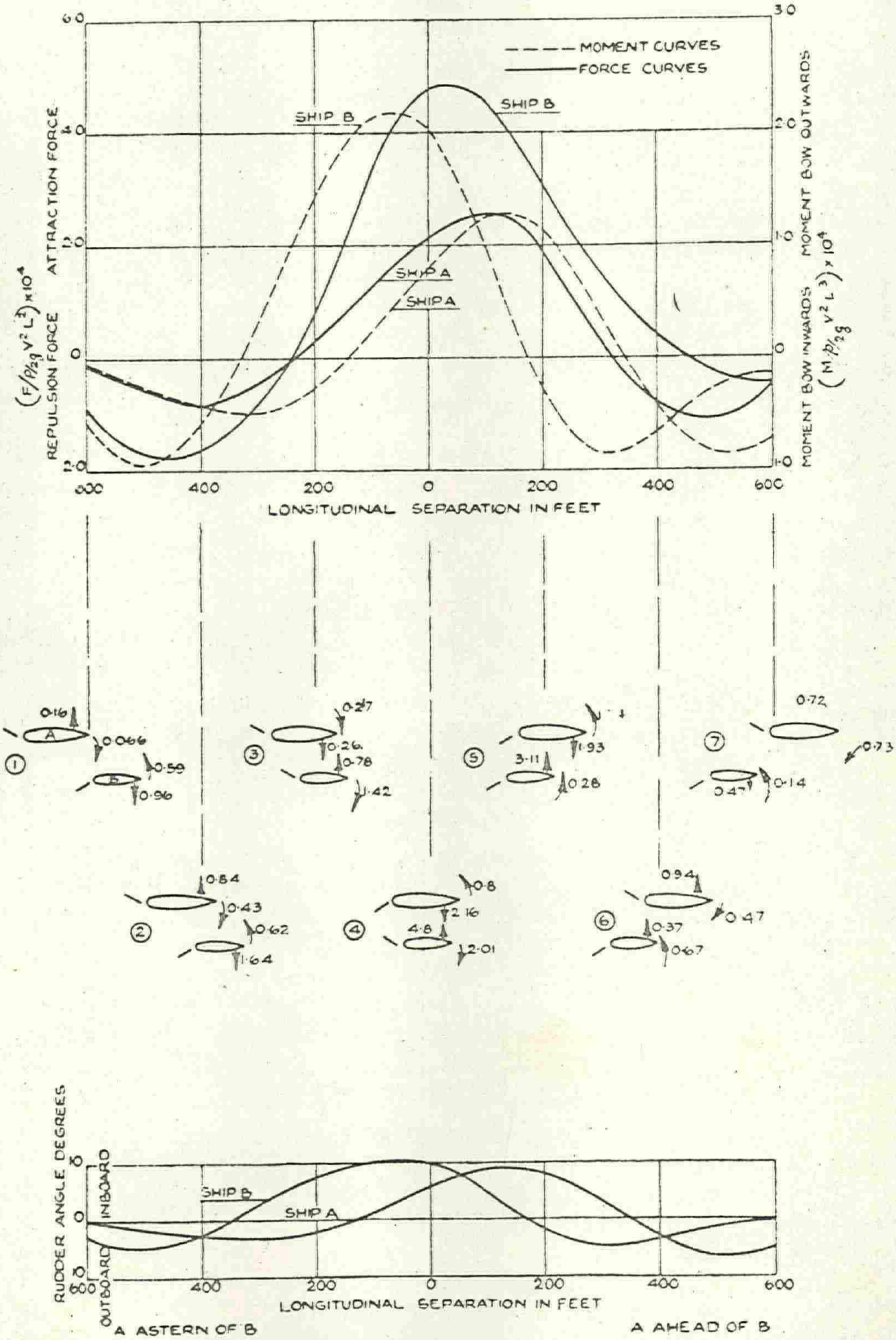

Fig. 2.—Measured Interaction Forces and Moments and Correcting Rudder Angles (100-ft. Separation Beam-to-beam).

TABLE II.

Run	1		2		3		4	
Mean separation, beam to beam, ft	125		110		105		115	
	A	B	A	B	A	B	A	B
Speed deduced from rpm, knots	12.3	12.0	15.5	15.0	18.2	18.0	19.7	20.0
Inboard rudder angle, deg Min.	0.0	9.0	0.0	7.5	0.0	4.5	0.0	1.0
Mean	5.0	13.0	6.0	12.0	6.5	10.0	6.0	8.0
Max.	13.5	17.5	16.0	15.5	15.5	14.0	15.0	14.5
Rudder angles deduced from model experiments, deg	4.5	8.0	5.0	9.0	5.5	9.0	5.0	8.5

yaw of small magnitude, thus again bearing out the conclusion reached from the constrained model experiments.

INTERPRETATION OF DATA

In the first place, it is necessary to explain the method of presentation of the force and moment curves in Figs. 1 and 2. As already noted, for each position of one model relative to the other, two forces on each were measured at the positions of the guides, *i.e.*, F_1 and F_2 in Fig. 3. These two forces can be represented by a single force $F_I = F_1 + F_2$ and a couple M_I, the magnitude of which depends upon the position about which moments are taken. It is convenient to choose a position for F_I coinciding with this position and which is related to the action of the corrective rudder which must be applied to keep the ship on course, and which is also associated with the force and couple set up as a result of any small yaw which the ship may take up. Such a point is the "neutral point" N, at which, neglecting transient effects, any lateral force applied will not cause a change in heading, although it will cause a change of course. The neutral point has been shown by experiments at the British Admiralty Experiment Works (A.E.W.) and from data given by Rydill to lie well-forward of the centre of gravity, and has been taken at $\frac{1}{5}$ the length of ship from the bow. The position of the neutral point is assumed constant for small angles of yaw but varies with the type of ship. It should be pointed out, however, that if a different position were chosen for this neutral point, say, 0·25 to 0·15L from the bow, this would make no difference in principle to the discussion on use of corrective rudder which follows later.

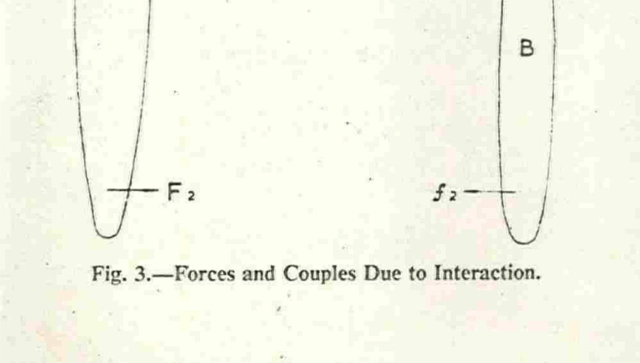

Fig. 3.—Forces and Couples Due to Interaction.

Referring to Fig. 3, it will be seen that, if no corrective rudder action is applied, the interaction moment will cause the ship to yaw outwards, bringing its stern towards the other ship. As the ship yaws, a hydrodynamic force due to it will come into action at the point N. If, now, correcting rudder is applied, this will counteract the interaction moment and bring the ship back to a position of equilibrium at a small angle of yaw to the direction of advance. In this position, assuming a steady-state motion, we have for equilibrium:—

$$F_R + F_Y = F_I$$

$$F_R \times \lambda L = M_I$$

where λL is the distance of the centre of pressure of the rudder from the neutral point.

It follows that, although the moment of the force from the rudder can counteract the interaction moment, there may be occasions when the rudder force will be insufficient to balance the interaction force unless the ship yaws slightly to produce a lateral force opposing the interaction force.

For moderate rudder angles, the transverse force produced by the rudder can be expressed as

$$F_R = 0{\cdot}03\ AV^2\theta$$

where A is the rudder area in square feet,

V is the ship speed in feet per second and

θ is the rudder angle in degrees.

Substituting for F_R gives the relation

$$\theta = \frac{M_I}{0{\cdot}03\,\lambda A V^2 L}$$

and for Ship "A" $\quad \theta = 74{,}300\left[\frac{M_I}{\rho/2V^2L^3}\right]$

TABLE III.

Item	Ship "A"	Ship "B"
Interaction force F_I, tons	60	78
Rudder angle θ, deg.	5·5	9·8
Rudder force F_R, tons	30	36
Yaw force $F_Y = F_I - F_R$, tons	30	42
Yaw angle (estimated), deg.	1	1·5

Ship "B" $\theta = 50{,}400 \left[\frac{M_I}{\rho/2 V^2 L^3} \right]$

Using the moment curves, the values of correcting rudder θ have been calculated from these formulæ and are plotted in Figs. 1 and 2.

It is then found, however, that the estimated rudder force is not always large enough to balance the interaction force, and to effect a complete balance each ship must yaw slightly to produce an opposing interaction force. For instance, when the ships are abeam, there is a force of attraction between them and couples tending to swing their bows apart. The rudders will therefore be required to be turned inward, but the ships will settle down at a small outward angle of yaw. The yaw angles for both ships have been estimated approximately, using the results of some recent experiments at A.E.W., in which lateral forces and moments were measured at different speeds and angles of yaw on a mathematically shaped model. The results are tabulated in Table III., for a speed of 10 knots at 100-ft. separation.

The figures in Table III. are necessarily approximate, but they serve to indicate that, in spite of the large forces involved, both rudder angle and yaw angle are small, provided the ships are not allowed to approach one another too closely.

Referring to the small diagrammatic figures in Figs. 1 and 2, it will be seen, however, that there are positions when both the interaction force and couple are tending to draw one ship into the other. Such positions are three for Ship "A" and five for Ship "B." If now-correcting rudder is applied to counterbalance the interaction moment, the rudder force adds further to the force of attraction. In these positions it is necessary to apply sufficient outboard rudder to overbalance the interaction moment and produce an outward yaw, so that a yaw force is again introduced which will counteract both the interaction force and the rudder force. These conditions persist, of course, over an appreciable length of travel and are not merely momentary.

It will be seen that these positions three and five are quite close to the fully abeam position when opposite rudder has to be applied to keep the ships on course. In a short space of time, therefore, the rudder has to be swung from outboard to inboard, and the moment when this has to be done is obviously not easy to choose, so that in these positions there is considerable navigational difficulty and risk.

If, when approaching positions three and five, the lateral separation of the ships is so small that there is insufficient rudder available to counteract the interaction moment or insufficient time for it to take effect, it would seem that a collision is unavoidable except that any reduction of speed on the part of the astern vessel, thereby reducing the interaction effects, must reduce the risk. In brief, the onus for avoiding action would appear to rest upon the astern ship, except that the ahead ship can probably ease the situation by breaking-away on a divergent course.

In the absence of similar investigations into the case of ships passing in opposite directions, one can only conjecture as to the degree of risk. From first prinicples, the same type of interaction occurs, but the interaction forces act for a shorter time and are therefore less likely to bring about a collision.

These observations assume calm weather conditions. In inclement weather, as indicated by the sea trials carried out with a cruiser and replenishment ship, the risks involved would be increased. The larger variation in rudder angle alone must make control more difficult and the direction of wind and sea probably more so.

AXIAL VIBRATION IN A SINGLE-SCREW CARGO SHIP

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UNTIL recent times, it appeared that the problem of axial vibration of shafting systems was largely confined to multiple-screw ships and, in particular, highly-powered naval vessels. In 1955, when the British Shipbuilding Research Association was invited to participate in an investigation of axial vibration in a single-screw ship, no documented evidence of similar problems was available and it is only in more recent times that the matter has received a measure of publicity. The ship concerned in the investigation is a turbine-propelled cargo liner with the main machinery installed amidships; and it is of some interest to note that, within a short space of time, the Association had occasion to investigate a similar problem on a single-screw motorship with an after-end installation.

Particulars of Ship

The ship is a single-screw cargo liner having the principal particulars given in Table I.

The main machinery consists of a set of three-casing steam turbines, in which the h.-p. turbine drives through double-reduction gears and the i.-p. and l.-p. turbines drive through single-reduction gears.

The machinery develops 10,250 S.H.P. at 116 r.p.m. through a four-blade propeller, which gives the ship a service speed of 16·5 knots. The propeller-aperture clearances are shown in Fig. 1.

Measurements of Vibration

Measurements were made with Cambridge Universal Vibrographs mounted either as seismic instruments or deflection-measuring instruments.

Two typical records taken on the thrust block and at the tailshaft are analysed in Fig. 2. The principal vibration occurs at propeller-blade frequency, that is, at four times the propeller shaft r.p.m., and is caused by thrust variations consequent upon the propeller blades operating in a varying wake.

Fig. 3 illustrates diagrammatically the breakdown of the measured deflections on the shafting and thrust block for a

Table I.

Length overall	514 ft.
Length BP	480 ft.
Breadth moulded	67 ft.
Depth to shelter deck	42 ft.
Deadweight	10,270 tons
Draught	28 ft. 0¼ in.