

# MANOEUVRABILITY

## INTRODUCTORY REMARKS

by

Rear Admiral J. Dieudonné

The Standing Committee of the I.T.T.C. has asked me to introduce to this Conference the subject of the manoeuvring ability of ships. It has defined the limits as follows:

“Technique of model tests to enable the evaluation and prediction of the ability to manoeuvre and the conditions of steering of ships.”

This introduction is voluntarily limited to a summary examination of the points on which the I.T.T.C. can usefully open discussion or plan programmes of experiments.

The first question is the choice of the qualities which allow one to evaluate objectively the manoeuvring ability of a given ship. These are the quantities which one must necessarily determine in the course of model tests or calculate from first principles if this should ever be found possible.

It would appear to be of value to introduce here, a distinction between two types of elements both of which are connected with the general idea of the manoeuvring ability of a ship, but which refer to two distinct aspects of this idea.

The first aspect which one describes, in French, under the heading “manoeuvrabilité”, concerns the steady states of movement and is characterised by the range of the steady state which the ship can adopt. The data relating to these steady states is usually described, in English, as “turning ability” whereas the English term “manoeuvrability” is used to describe the combination of all qualities which contribute to the ability to manoeuvre.

The second aspect described in French by the word “maniabilité” is characterised by the speed and ability with which the ship can pass from one steady state to another; i.e. in English, handling quality, control lability, or response to rudder. Turning ability can evidently be characterised by the values of the radii of turning (in the steady state) for different rudder angles and different speeds, a secondary element being the reduction of speed produced for constant power by the turn.

The handling qualities are more difficult to characterise. One can seek to define them by elements previously mentioned, and others such as “advance and transfer”, which are traditionally evaluated in circle trials, but these would not seem to be sufficient for the purpose. It seems necessary to obtain a complete evaluation of the curve of headings as a function of time, from the moment when the ship is steaming ahead at the start of the trial and the rudder is turned to a given angle, and this in particular for the small helm angles.

The nature of the stability on the straight course is connected at the same time with the two aspects considered above, and one can characterise it by the result of the spiral test which the author defined in 1949, and which is nowadays current practice, particular in America.

The first task of the new Committee should therefore be, the development of the above considerations with a view to settling on a list of the quantities or qualities defining the ability of manoeuvring of a given ship.

The naval architect who is designing a ship, desires that it should be endowed with suitable qualities of manoeuvring, but equally he needs to know what will be, for the different conditions of use, the forces developed at the rudder stock, so as to allow him to design the rudder stock correctly and to choose suitable characteristics of the steering gear. It therefore appears necessary for the complete study of the manoeuvring qualities of a ship design, that one should add the measurement of the forces and moments on the rudder stock to the determination of the qualities considered in the previous paragraph.

The next question is that of the processes to be adopted in order to determine, by model test, the values of the quantities which will have to be chosen to characterise the manoeuvring ability. This question is aimed on the one hand at the experimental arrangements which are employed in the different tanks in the study of the manoeuvring qualities of the model, and, on the other hand, at the comparisons between the model and full scale which are essential in order to allow the results obtained on the model to be relative to the full scale with a minimum of error.

In this sphere the work of the new Committee could usefully include:

- a) A survey of existing arrangements in the different tanks.
- b) The examination and comparison of the different experimental methods used by these tanks.
- c) Further investigation of the comparisons that have already been established between model and full scale in the sphere of manoeuvring tests.

The next stage of the studies on manoeuvring will be to determine the elements which will allow one to predict, to some degree, what will be the manoeuvring qualities of a hull, from its lines. The object here is to enable the designer to take account of the qualities concerned with manoeuvring in the choice of the essential elements of the design (relative proportions, lines of the hull).

For such studies it is not sufficient just to determine the characteristic quantities for the manoeuvring ability as a solid mass. It is necessary, in order to advance the subject, to proceed analytically and to evaluate for a given model hydrodynamic forces and couples connecting on the model while it is constrained in a circular path with an imposed drift and velocity of rotation.

Such experiments will have to be carried out covering a range extending, for example, for angles of drift from 10 degrees port to 10 degrees starboard and for ratios of length to turning radius from 0 to the maximum permitted by the apparatus.

These tests, having been performed on a model for which one has already made the complete evaluation of the characteristics of manoeuvring ability, will enable one to verify the theoretical studies which have been already carried out on the mechanism of turning, and to verify how the knowledge of the hydrodynamic forces and moments allows one to predict the manoeuvring characteristics.

Taking the study further a comparison between the results obtained for models of different vessels should corroborate to some extent the validity of the assumptions in the pure hydrodynamic sphere for the calculation from first principles of forces and moments acting on a turning ship. From this point of view, it appears desirable to divide the programme of research to be undertaken into two parts, the first being a comparison between similar, but not geometrically similar, models i.e. a series of models expanded from a basic form, in each of the three principal dimensions, length, beam and draught, taken separately, the proportional expansion in the direction of any axis being not necessarily the same as in the others.

This investigation, on similar models, carried out on two or three similar forms, will give indication of the influence of the choice of the principal dimensions in the manoeuvring characteristics. It is probable that this choice and this of the shape of under water projected area are actually more important than that of the usual form coefficients themselves, given the general dimensions.

The second aspect of the problem, to find out the influence of the lines of the forms (rather than the proportions of the ships), could be studied later.

It seems that the I.T.T.C. would have a useful role to play in co-ordinating the researches undertaken by the different tanks on the lines suggested above.

The foregoing remarks have been directed strictly to the problem of manoeuvring in calm water, in great depth on an infinite surface of water.

The conditions governing manoeuvring in shallow water or in a canal can differ considerably from those in unlimited deep water. Reserving, in principle, the complete study of this problem for a second stage, it would be perhaps interesting to survey briefly, at

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the present time, the methods employed by the various tanks for investigations into navigation in a canal and the results obtained.

As for the problem of manoeuvring in a rough sea, it seems that, without underestimating its importance, one must postpone this examination until the case of navigation in calm water is better understood and the necessary facilities for conducting realistic model experiments are available.

### *Conclusions.*

Summarising, it is considered that on the subject of the manoeuvring of ships, the effort of the Committee could be usefully expended on the following points:

*a)* Choice of quantities and qualities considered defining the ability of manoeuvring of a ship.

*b)* A survey of existing resources in the various tanks for the investigation of manoeuvring.

*c)* Examination of experimental methods used and comparison of these methods.

*d)* Review of comparisons carried out between model experiments and the full scale.

*e)* Establishing a programme of tests with the object of making possible the prediction of manoeuvring qualities of a ship design, if possible starting a co-operation between the different tanks concerned.

Paris, le 4 avril 1960.

**J. Dieudonné.**

## FORMAL DISCUSSION

Prof. G. Kempf.

1. For assessing the Manoeuvrability of ships, turning-circles are not so important as the effect of small rudder angles.

To enable such a judgment a *serpentine-test* with models and ships has proved as appropriate. It is easy to manage and affords characteristic results.

2. The Serpentine-test runs as follows: when the ship is running at constant speed with a course-angle ( $k$ ) the helm is turned to a certain small angle ( $w$ ) to starboard at the time zero (f.i.  $w = 5^\circ$  or  $10^\circ$ ). As soon as the ship or the model has reached the course ( $k + w$ ), the helm is reversed to port to the same angle ( $w$ ) and the time is noted for that instant.

At first the ship or model is turning still further to starboard to the so called "overswinging angle" ( $u$ ). The ship will reach the greatest angle to starboard ( $k + w + u$ ) before she turns to port. The time has to be noted for this instant as well as for the instants when the ship swings through the course ( $k$ ) and when she reaches the course ( $k - w$ ). At this last instant the helm has to be reversed again to starboard to the angle ( $w$ ). The ship is turning still further to port up to the angle ( $k - w - u$ ), which instant has to be noted again, before she takes her turn to starboard. This manoeuvre can be continued at will and will deliver the overswinging-angles ( $u_1$ ) for starboard and ( $u_2$ ) for port.

3. The overswinging-angle has proved from numerous serpentine-tests as a marking criterium of manoeuvrability. A larger angle ( $u$ ) means a worse manoeuvrability. The angle ( $u$ ) depends on the form of the hull, the shape of stem and stern, the longitudinal inertia, the shape and area of the rudder and the position of the rudder to the propeller.

4. Serpentine-tests can be easily performed for different conditions of loading and speed as well with selfpropelled models in the tank as with ships at sea. The results can furnish valuable information for naval architects, shipowners and shipmasters. The coordination of the results from various tanks would probably render it possible to find gradually a measure of suitable or admissible limit for manoeuvrability. This will be of special importance for navigation on rivers and canals.

5. Modeltesting can often and easily help to insure a safe manoeuvrability by slight alteration of the construction, the effect of which can be proved by a serpentine-test.

This method reveals under equal conditions with the same angle of helm the properties of the ship by the *overswinging-angle* as a dimensionless value.

With an angle of helm of f. i.  $10^\circ$  the overswinging-angle amounts normally no more than  $3^\circ$ .

Seizo Motora.

PROPOSED MANOEUVRABILITY INDICES AS A MEASURE OF THE STEERING QUALITIES OF SHIPS

Introduction.

As a factor to indicate the manoeuvrability of ships, the radius or diameter of the turning circle, tactical diameter, advance, transfer, etc. have been used. On the other hand, a proposal has been made by Kempf to adopt zigzag test (serpentine test) to evaluate the manoeuvrability of ships in a comprehensive sense.

The present situation is accordingly such that there have been proposed quite a number of qualities of different kinds and characteristics, and their correlation with each other has not yet been clarified. If, therefore, an index of a character which is common to all these qualities and is considered to represent them is obtained, it will be needless to mention here its usefulness.

Nomoto [2], [3], etc., commenced their study on the application of frequency response approach to the steering motion of ships, and then attempted to express the manoeuvrability of ships as a whole in terms of two indices—the one indicating the turning ability and the other indicating the course stability or quick responsibility.

Using these two indices, they succeeded to clarify various characteristics of manoeuvrability of ships had been uncertain so far. This subject has been further studied and developed by Nomoto [5], [6], Takahashi, Kawashima [4] Motora [7], etc.

One of the important subjects to be discussed at the present subcommittee meetings of the 9th I.T.T.C. is the determination of the manoeuvrability indices of ships. Under these circumstances, the author would like to introduce the outline of investigations undertaken and developed in Japan on the manoeuvrability of ships, which, he proposes, could be taken up at the meeting for discussion.

1. The possibility of developing a first order approximation on the steering motion.

When the Davidson's notations [1] are used, the equation of motion is expressed by:

$$\left. \begin{aligned} \left(\frac{l}{V}\right) m_2 \frac{d\psi}{dt} + C_e \psi - \left(\frac{l}{V}\right) m \dot{\theta} &= C_\lambda \cdot \delta \\ \left(\frac{l}{V}\right)^2 n \frac{d\dot{\theta}}{dt} + \left(\frac{l}{V}\right) C_x \dot{\theta} - C_m \psi &= C_\mu \cdot \delta \end{aligned} \right\} (1)$$

- Where:  $\dot{\theta}$  = Angular velocity of turning motion.
- $\delta$  = Helm angle.
- $\psi$  = Drift angle.
- $V$  = Ship's speed.
- $l$  = Length of ship.

Eliminating  $\psi$  from equation (1), then:

$$T_1 T_2 \frac{d^2 \dot{\theta}}{dt^2} + (T_1 + T_2) \frac{d\dot{\theta}}{dt} + \dot{\theta} = K\delta + KT_3 \frac{d\delta}{dt} \quad (2)$$

Where :

$$\left. \begin{aligned} K &= \left(\frac{V}{l}\right) \frac{C_m C_\lambda - C_l C_\mu}{C_l C_x - m C_m} \\ T_1 \cdot T_2 &= \left(\frac{l}{V}\right)^2 \frac{m_2 n}{C_l C_x - m C_m} \\ T_1 + T_2 &= \left(\frac{l}{V}\right) \frac{m_2 C_x + n C_l}{C_l C_x - m C_m} \\ T_3 &= \left(\frac{l}{V}\right) \frac{m_2 C_\mu}{C_m C_\lambda + C_l C_u} \end{aligned} \right\} (2')$$

$T_1$  and  $T_2$  mentioned above have close connection with the course stability of ships, and have the following relation with the Davidson's course stability index.

$$\left. \begin{aligned} T_1 &= -\frac{1}{p_1} \left(\frac{l}{V}\right) \\ T_2 &= -\frac{1}{p_2} \left(\frac{l}{V}\right) \end{aligned} \right\} (3)$$

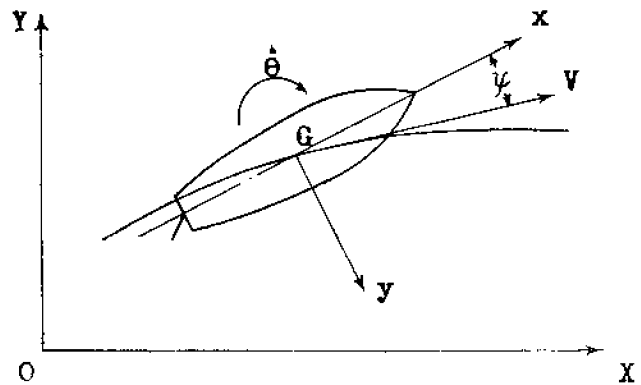


FIG. 1.

Nomoto, etc. [3] have disclosed that, of the coefficients  $T_1, T_2, T_3$  and  $K, T_1$  and  $K$  are predominant factors contributing to the manoeuvrability, and that equation (2) can be expressed fundamentally by the following differential equation of the first order regarding  $\dot{\theta}$ .

$$T \frac{d\theta}{dt} + \theta = K \cdot \delta \quad (4)$$

This theory is based upon the following analysis. When obtained from the exact solution of equation (2) is compared with the solution of equation (4), the difference between these solutions becomes zero after sufficient lapse of time, if:

$$T = T_1 + T_2 - T_3 \quad (5)$$

They have disclosed that the value of  $T$  is very close to  $T_1$  in any ship, ( $T = 0.8 - 0.9 T_1$ ) and that the difference between equation (2) and (4) is not so great even when the lapse of times is not sufficient.

The comparison between the solutions of equations (2) and (4) as two examples is as shown in Fig. 2, which indicates that it would be possible to develop a first order approximation on the steering motion.

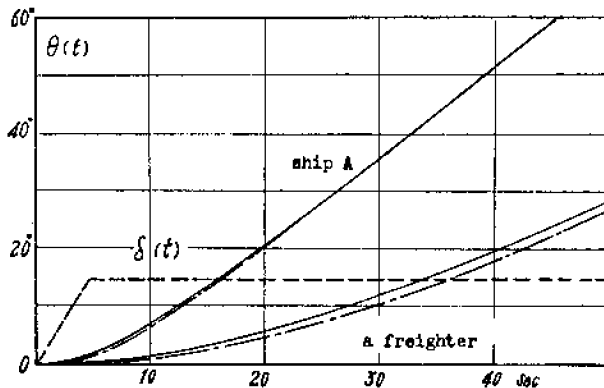


FIG. 2.

If the fundamental motion due to steering can be approximated by a first order system as shown in Fig. 2, any steering motion must likewise be approximated by equation (4) except at very early stage, inasmuch as any motion is the superposition of these fundamental motions. Nomoto paid attention to this fact, and attempted to develop a first approximation from the results of Kempf's zigzag test (standard test).

Fig. 3 shows the values of  $T$  and  $K$  so determined as to give the closest approximation, which have been

obtained from the analysis of the results of zigzag test on a cargo ship in trial condition (Fig. 3-a) and a tanker in full load condition (Fig. 3-b).

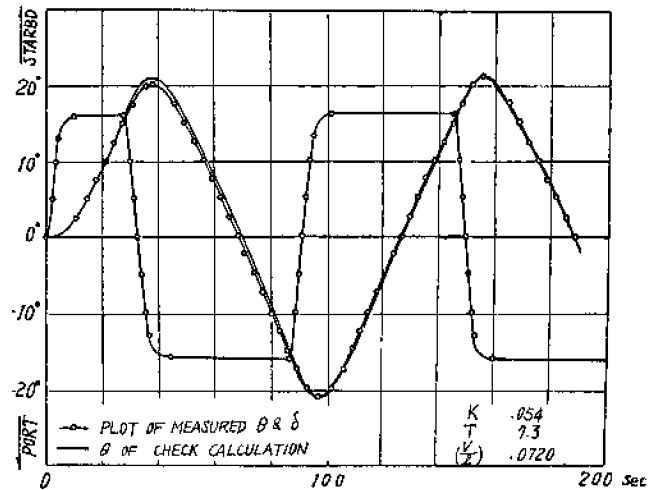


FIG. 3 a.

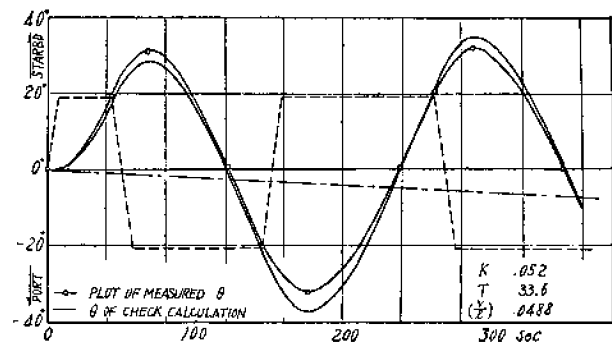


FIG. 3 b.

Standard Manoeuvre Test for a full-loaded Tanker.

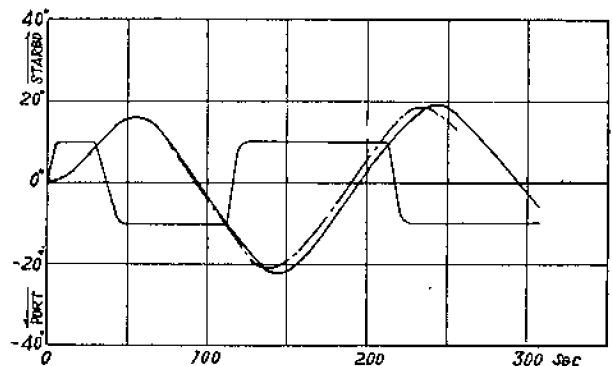


FIG. 3 c.

Standard Manoeuvre Test for a full-loaded Cargo Boat.

It may be noted from Fig. 3 that in case of a cargo ship, which is comparatively directionally stable, almost perfect approximation can be made, and further that in case of a tanker, which is rather directionally less stable, an approximation, though not so close as in case of a cargo ship but sufficiently applicable for practical purpose, can also be made.

On the other hand, an attempt has been made by Motora [7] to explain, from a different standpoint, that the steering motion can be fundamentally approximated by an equation of motion in a first order system. It has been well known that the motion of ships can be resolved into a rotating motion about an axis of instantaneous rotation of ships, which is so called the pivoting point, and a progressive motion along the longitudinal axis of the ship. The ship appears to move along the tangent to the turning path at the pivoting point. When the rudder is suddenly put over, this pivoting point coincides with the centre of percussion when the rudder is subjected to an impact normal to the rudder plane [8]. Then the centre of pressure gradually moves forward as the ship turns, but the shift of this point is not so big. Accordingly the drift angle  $\psi$  in equation (1) does not take an arbitrary value, but changes with the change of  $\theta$ , keeping the relation of:

$$l_p \dot{\theta} = V \psi \tag{6}$$

Where :  $l_p$  = Distance from the centre of gravity of ship to the pivoting point.

Substituting equation (6) for equation (1) (the second equation), we obtain:

$$\left(\frac{l}{V}\right)^2 n \frac{d\dot{\theta}}{dt} + \left(\frac{l}{V}\right) \left(C_k - \frac{l_p}{l} C_m\right) \dot{\theta} = C_{\mu} \cdot \delta \tag{7}$$

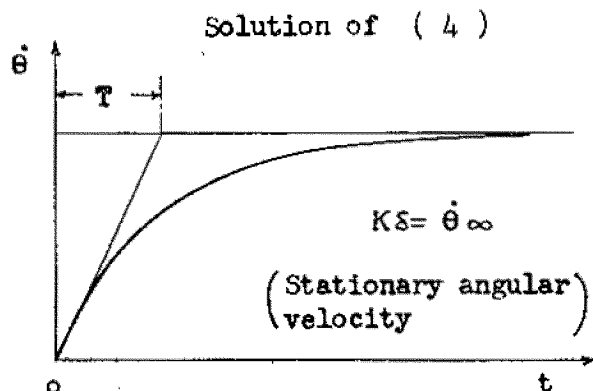


FIG. 4a.

$$\left(\frac{l}{V}\right) \frac{n}{C_k - \frac{l_p}{l} C_m} \frac{d\dot{\theta}}{dt} + \dot{\theta} = \left(\frac{l}{V}\right) \frac{C_{\mu}}{C_k - \frac{l_p}{l} C_m} \cdot \delta \tag{8}$$

In equation (8), put

$$\left. \begin{aligned} \left(\frac{l}{V}\right) \frac{n}{C_k - \frac{l_p}{l} C_m} &= T \\ \left(\frac{l}{V}\right) \frac{C_{\mu}}{C_k - \frac{l_p}{l} C_m} &= K \end{aligned} \right\} \tag{9}$$

then equation (8) coincides with equation (4), and the following relation exists between T and K.

$$\frac{T}{K} = \frac{C_{\mu}}{n} \left(\frac{V}{l}\right)^2 \tag{10}$$

Since in the actual steering motion the pivoting point moves forward with the increase of the angular velocity of turning motion, T and K in equation (9) gradually change keeping the relation as given by equation (10). Accordingly, equation (8) is not exactly equivalent to equation (4), but may serve to understand that the steering motion can be fundamentally approximated by a differential equation of the first order.

2. Manoeuvrability indices.

As mentioned in § 1, the steering motion of ships can be approximated by a first order system, such as equation (4). This equation very much resembles the equation for the transient current when a circuit is closed.

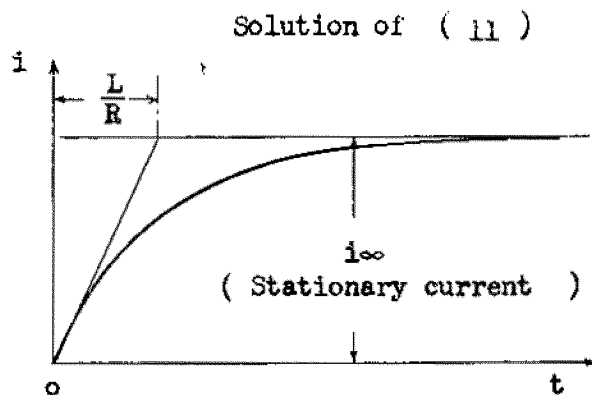


FIG. 4b.

When a circuit, having inductance  $L$ , electromotive power  $E$  and resistance  $R$ , is closed, the electric current  $i$  is given by:

$$\frac{L}{R} \frac{di}{dt} + i = \frac{E}{R} \quad (11)$$

When this equation is compared with equation (4), it may be noted that  $L$  corresponds to  $L/R$  and  $K$  to  $E/R$ . Accordingly it is considered that  $K$  indicates the angular velocity eventually reached, and therefore the turning ability, and  $T$  indicates the quickness to move from one stationary state of another stationary state, i. e. quick responsibility, since  $T$  corresponds to the time lag till the ship reaches the stationary state, i.e. time constant.

On the other hand,  $T$  is nearly equal to the index of course stability as shown in equation (5), so that  $T$  is also considered to be an index indicating the course stability of ships.

The comparison between the solutions of equation (4) and (11) is as shown in Figure 4, which may sufficiently explain the aforementioned relationship.

Figure 5 indicates the angle  $\theta$  obtained by integrating the curve in Figure 4-a, where the helm angles have been taken stepwise for the sake of simplicity.

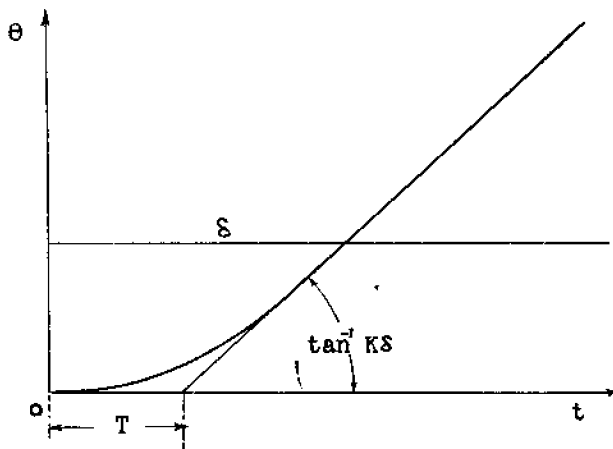


FIG. 5.

When the rudder is suddenly put to the mid-position, the angular velocity changes in a similar manner as the electric current decreases when the electro motive force is made zero. The angular displacement from the direction of the ship's course when the rudder is put to the mid-position to the direction that the ship eventually proceeds becomes  $K\delta T$ . (See Fig. 6).

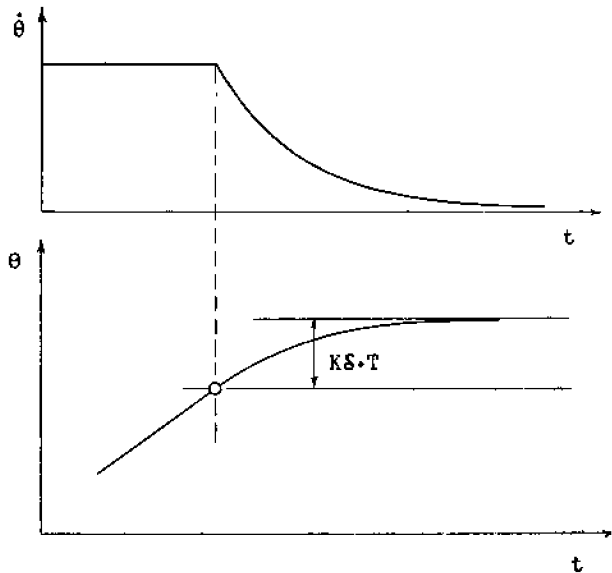


FIG. 6.

The angular displacement from the direction of the ship's course when the rudder is put over to the direction when the angular velocity becomes zero (over swinging angle) obtained from the zigzag test, which has been proposed by Kempf as a measure of manoeuvrability, corresponds to  $K\delta T/2$ . Accordingly the manoeuvrability of ships as a whole can not be sufficiently represented by this over swinging angle only, but it is necessary to couple this angle with another index, for instance,  $K$  which represents the stationary turning.

In summary, the manoeuvrability of ships can be indicated almost perfectly by two indices,  $T$  and  $K$ .

$T$ : represents Quick responsibility or Course stability.

$T$	↑ greater	Quick responsibility and Course stability	} ↑ worse ↓ better
	↓ smaller		

$K$ : represents Turning ability, having the relation  $K\delta = \dot{\theta} \infty$  (stationary).

$K$	↑ greater	Turning ability	} ↑ better ↓ worse
	↓ smaller		

### 3. Relation of $T$ and $K$ with the turning path.

To show the relation of  $T$  and  $K$  with the turning path, the locus of the C. G. of a ship in turning for various combinations of  $T$  and  $K$  are computed. Ship

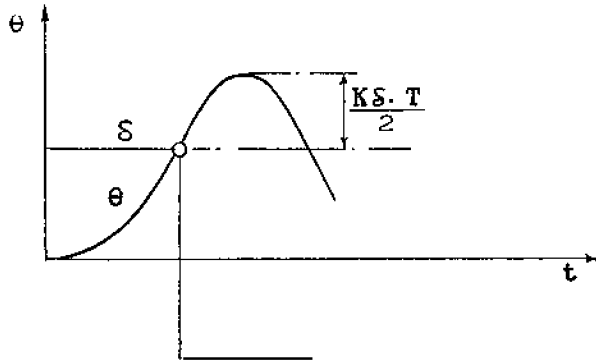


FIG. 7.

speed in that computation is assumed to be 10 m/sec and the rudder is assumed to be put over to  $35^\circ$  suddenly when the ship is running straight. (fig. 8, 9 and 10.)

Advance, transfer, tactical diameter, etc. must be expressed by a function of T and K with regard to the expression of this function in a simple form, investigation are being made by Nomoto and Motora.

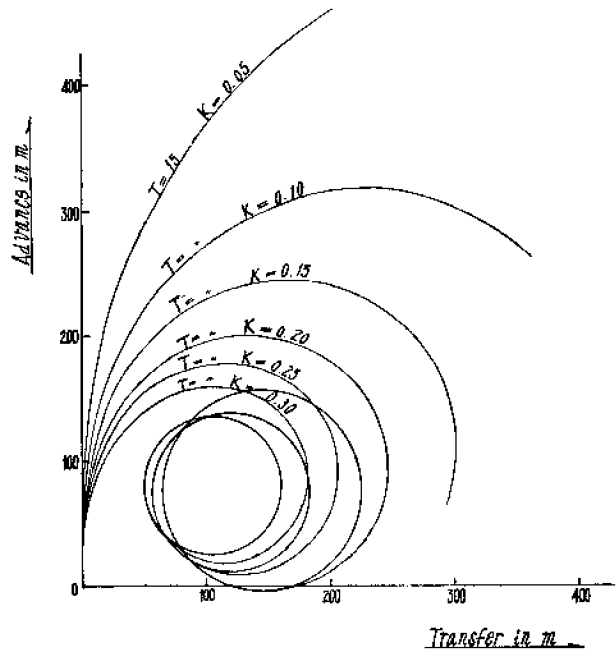


FIG. 9.

T is constant, K is varied.

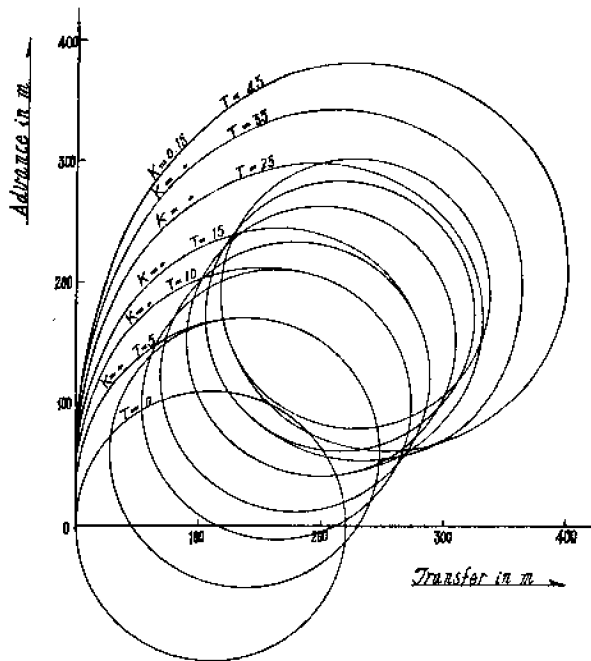


FIG. 8.

K is constant, T is varied.

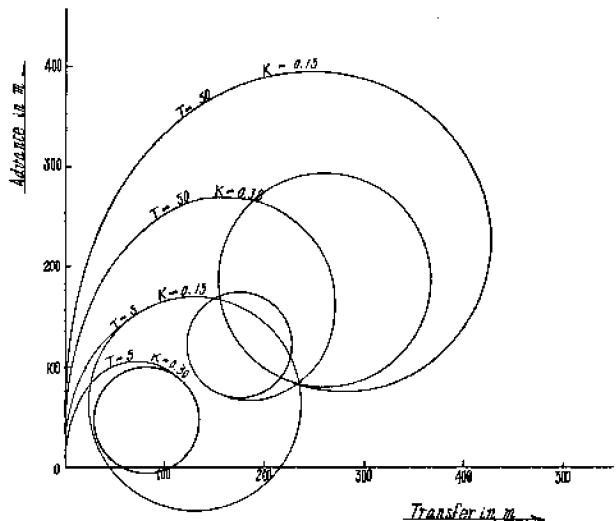


FIG. 10.

K and T are varied.

4. A method to obtain T and K by experiments and their actual values.

1. Method to obtain T and K by zigzag test.

The indices T and K can be calculated from equation (2') and (5) using the fundamental resistance derivatives of ships, but the advantage of these indices is rather such that they can easily be derived from the results of manoeuvre test with actual or model ships.

Nomoto developed a method to obtain T and K as a result of analysing the Kempf's zigzag test, which is published in his paper [3], but this method was rather complicated.

Then he succeeded to simplify the above method, and proposed a simple and very practical method [5] which is considered at present to be the most appropriate method to obtain these indices. In the following is described the outline of this method.

The equation of motion is rewritten as:

$$T \frac{d\theta}{dt} + \theta = K \delta + K \delta_r \quad (12)$$

where  $\delta r$  is the error of the helm angle, which is substituted for the effect of initial velocity, slight unbalanced moment, etc. This term has been defined by Nomoto as residual helm.

Integrating equation (12), then:

$$T\theta + \theta = K \int_0^t \delta dt + K \delta_r \cdot t \quad (13)$$

On the other hand, the time-turning angle diagram is recorded, where the angle and time are denoted as shown in Fig. 11.

i)  $\theta = \theta_0$  and  $\dot{\theta} = 0$  at  $t = t_0$ , then equation (13) becomes:

$$\theta_0 = K \int_0^{t_0} \delta dt + K \delta_r \cdot t_0 \quad (14)$$

$\theta = \theta'_0$  and  $\dot{\theta}' = 0$  at  $t = t'_0$ , then

$$\theta'_0 = K \int_0^{t'_0} \delta dt + K \delta_r \cdot t'_0 \quad (15)$$

From equations (14) and (15), K and  $\delta r$  can be obtained.

ii)  $\theta = 0$  and  $\dot{\theta} = \dot{\theta}_0$  (obtained from the slope of the curve recorded at  $t = t_0$ ), then:

$$T\dot{\theta}_0 = K \int_0^{t_0} \delta dt + K \delta_r \cdot t_0 \quad (16)$$

T can be calculated from equation (16), and thus all of K, T and  $\delta r$  can be obtained.

In the actual calculation, an arrangement has been made in such a way that the foregoing process is made with the former-half and latter-half periods of the test separately, and two sets of K, T and  $\delta r$  thus obtained are averaged.

T has the dimension of time and K of 1/time, so that it may be more convenient, for comparison purpose, to express these values in dimensionless forms, namely:

$$\left. \begin{aligned} T' &= T \times \frac{V}{l} \\ K' &= K \times \frac{l}{V} \end{aligned} \right\} \quad (17)$$

The values of T and K obtained by Nomoto according to the above method as to many ships are as shown in Table 1 (from ref. [9]).

2) Method to obtain T and K by turning test.

This method is to obtain T and K using the relations as given in Figure 5 and Figure 6. This is a direct and appropriate method to obtain T, but the previous method by the zigzag test may be more suitable for obtaining T, since it is an index indicating the transient state.

The method of test is to put over the rudder as quickly as possible when the ship is advancing on a straight course, and then hold the rudder at a fixed angle. After the turning of the ship becomes to the stationary state, the rudder is put to the mid-position as quickly as possible.

From the record of the turning angle  $\theta$  and the time during the above test, T and K can be obtained as shown in Figure 12.

The problem of this method is that, due to the drop of ship's speed, the  $t - \theta$  curve does not become to a straight line at large values of  $t$ , but becomes to a curve convex to the upper side, which causes the error of the measured value of T.

To overcome the above shortcoming, a modification as shown in Figure 13 has been proposed by Motora.

The solid line in Figure 13 indicates the angular displacement of the direction of ship's motion actually measured. On the other hand, the progressive speed of the ship gradually decreases as shown in Figure 13-b.

When the time base is changed from  $dt$  to  $dt_1 = \frac{V}{V_0} dt$ ,

then it can be easily proved that the ship's motion corresponds to the speed  $V_0$ . Accordingly when the

MANOEUVRABILITY FORMAL DISCUSSION

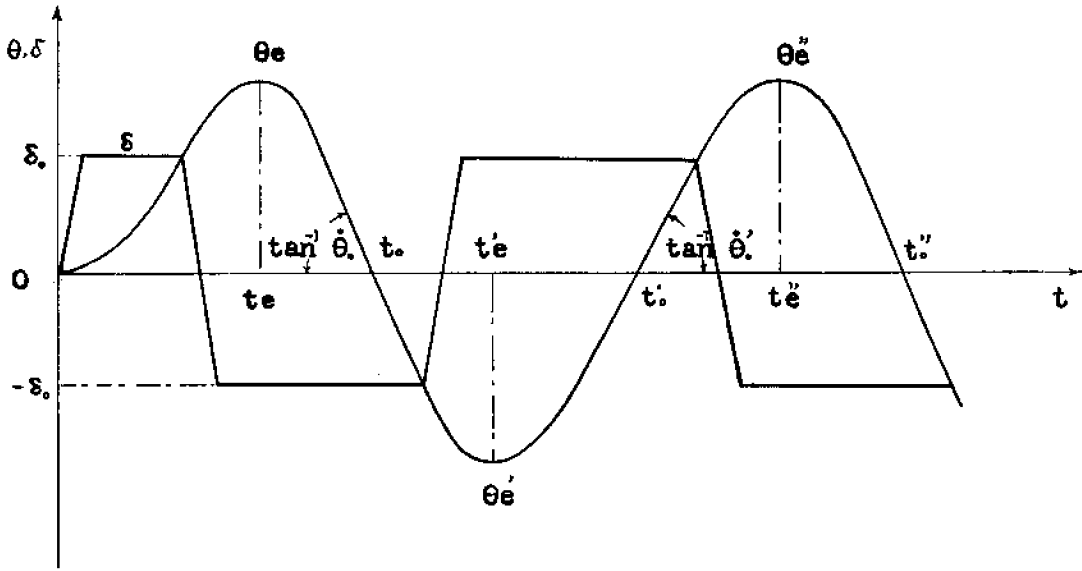


FIG. 11.

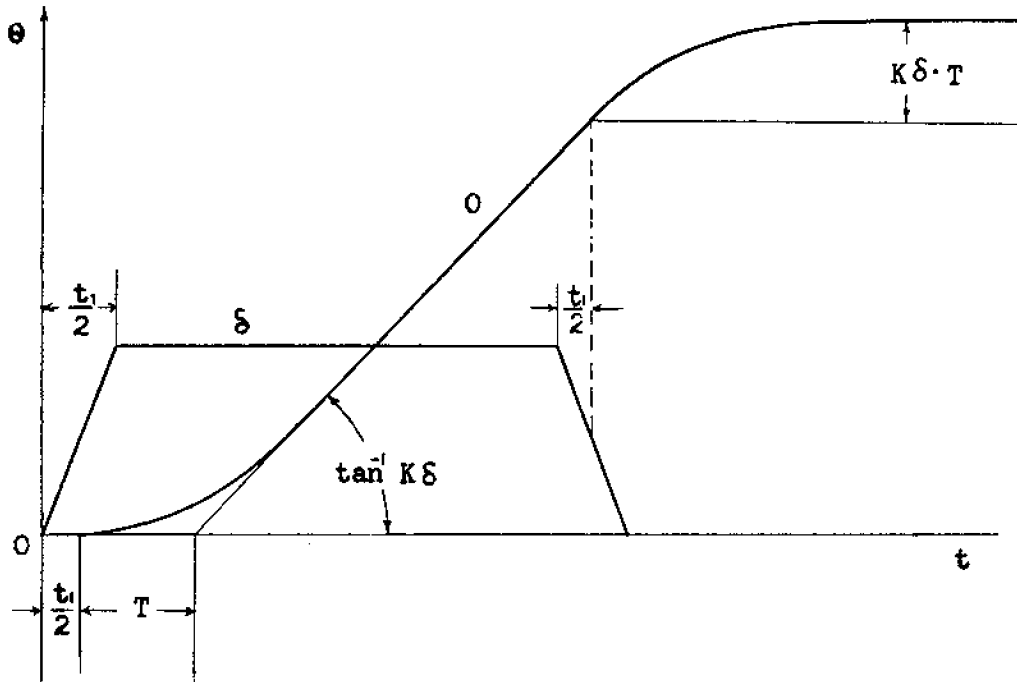


FIG. 12.

TABLE 1 — Standard manoeuvre test results

KIND OF SHIP	COND.	L × B × D	d <sub>a</sub>	d <sub>t</sub>	d	Δ	V <sub>kt</sub>	∇/L <sup>2</sup> d	R/Ld	δ <sub>0</sub>	K	T	K'	T'
C	B	152 × 20.6 × 12.7	5.61	2.44	4.02	8,828	17.2	.093	1/36.3	15	.043	11.0	.74	.64
C	B	114 × 16.4 × 9.3	4.58	1.96	3.27	4,180	15.7	.096	1/30.2	20	.041	10.0	.70	.58
C	F	157 × 19.6 × 12.5	8.60	7.90	8.25	16,000	17.1	.077	1/69.6	10	.071	26.2	1.27	1.47
C	H	121 × 16.2	6.36	3.94	5.15	6,750	10.0	.087		-10	.073	26.7	1.30	1.50
C	F	133 × 18.6 × 10.4	8.62	7.58	8.10	15,160	14.3	.103	1/65.2	15	.040	18.0	.94	.76
C	F	140 × 19.0 × 10.5	8.70	8.00	8.35	16,050	15.0	.096	1/59.9	-15	.035	17.0	.82	.72
C	H	94 × 13.7 × 7.6	5.26	3.04	4.15	3,800	10.3	.101	1/34.2	10	.102	53.2	1.84	2.94
C	F	112 × 16.2 × 9.0	7.84	7.00	7.42	9,980	11.5	.105	1/64.2	-10	.085	46.9	1.54	2.59
T	F	185 × 25.2 × 13.4	10.50	10.10	10.30	37,695	15.5	.104	1/75.4	10	.094	35.0	1.70	1.93
O.T	B	216 × 30.6 × 15.4	7.47	3.07	5.27	26,900	18.0	.107	1/37.5	10	.086	95.0	2.00	4.09
O.T	F	216 × 30.6 × 15.4	10.29	10.21	10.25	56,250	17.6	.115	1/71.1	-10	.063	42.4	1.46	1.83
T	F	192 × 26.5 × 13.87	10.61	10.60	10.60	44,090	16.1	.110		15	.027	11.4	.63	.49
T	2/3 F	106 × 16.2 × 8.0	5.45	5.10	5.27	6,928	14.0	.114	1/51.5	20	.056	61.3	1.33	2.57
T	F	154 × 20.0 × 11.5	8.85	9.18	9.02	20,583	12.3	.094	1/71.8	10	.171	21.5	4.08	9.01
T	F	192 × 26.8 × 13.7	10.60	10.20	10.40	43,000	15.0	.109	1/74.2	20	.050	68.7	1.22	2.82
W	Arrival	57 × 9.7 × 5.1	5.12	3.62	4.37	1,304	16.0	.109	1/72.1	35	.040	58.1	.97	2.38
W	Trial	57 × 9.7 × 5.1	4.56	2.34	3.45	935	17.4	.081	1/29.6	10	.073	80.5	1.70	3.44
Emigrant ship	1/2 F	145 × 20.4 × 11.9	7.20	5.50	6.35	12,070	19.0	.018	1/27.7	15	.060	56.5	1.39	2.44
C	F	75 × 11.9 × 5.5	4.80	4.78	4.79	3,222	10.0	.118	1/21.8	-10	.044	10.6	1.02	.45
Train Ferry	H	111 × 17.4 × 6.8	4.92	4.64	4.78	5,370	14.4	.089	1/49.7	-15	.155	4.1	.99	.64
Coastguard Cutter	H	51.5 × 7.7 × 4.5	2.89	2.58	2.73	534	13.0	.072		15	.053	11.8	.78	.80
										10	.077	25.4	1.10	1.75
										-10	.093	22.9	1.40	1.58
										15	.096	22.6	1.44	1.51
										10	.206	13.1	1.66	1.62
										20	.162	12.2	1.42	1.39
										30	.155	13.8	1.55	1.38

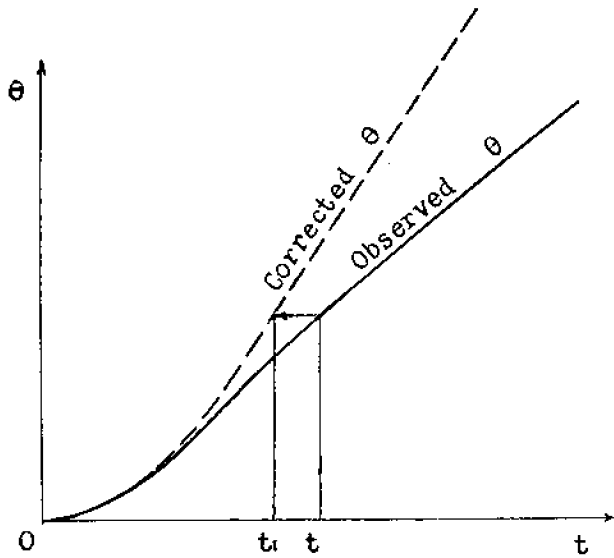


FIG. 13a.

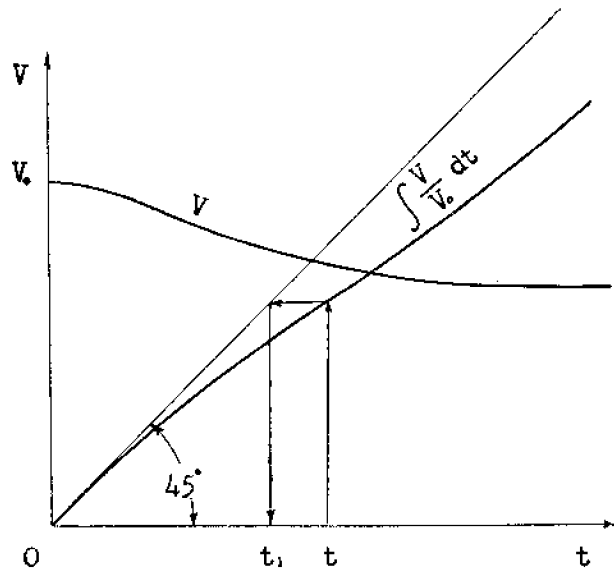


FIG. 13b.

time base is changed from  $t$  to  $t_1 = \int \frac{V}{V_0} dt$  by integrating  $\frac{V}{V_0} dt$ , or, in other words, when  $\int \frac{V}{V_0} dt$  curve is drawn as shown in Figure 13b, then  $t$  can easily be reduced to  $t_1$ . If, therefore, the measured value of  $\theta$  in Figure 13a corresponding to the time  $t$  is shifted to the value corresponding to  $t_1$ ,  $\theta$ -time curve corresponding to the constant speed  $V$  can be drawn.

This modification is applicable not only to turning motion, but also to any steering motion.

5. Relation between  $T$  and  $K$  (Relation between the course stability and the turning ability).

While several kinds of turning path under many combinations of  $T$  and  $K$  are shown in § 3, in actual case, it will be noticed from experimental values of  $T$  &  $K$  shown in Table 1 that there is certain narrow range for the combination of  $T$  and  $K$  values.

Figure 14a shows the relation between  $1/T'$ , and  $1/K'$ , the former represents the course stability and the latter represents the turning ability of ships.

In Figure 14a plotted values are scattered within a range limited by two radial lines through origin.

Though the range bounded by two radial lines in Figure 14a is not narrow, it will be easily found that ships plotted on the upper part of Figure 14a have smaller rudder area ratios  $AR/L \cdot d$ , and ships plotted on lower part have larger rudder area ratios. This

fact indicates that if we choose  $1/K', \frac{AR}{l \cdot d}$  for the ordinate instead of  $1/K'$ , the scattered plots will gather around a radial line through origin.

Figure 14b shows the result.

Addingly, Nomoto [9] modified the ordinate as :

$$\frac{1}{K'} \frac{AR}{L \cdot d} \times \frac{l^2 d}{\nabla} = \frac{AR \cdot l}{K' \nabla} \tag{17}$$

Where  $\nabla$  = volume of displacement. thinking  $l^2 d / \nabla$  as an important factor which will give an effect upon  $K'$  value. The result is shown in Figure 14(c), in which concentration of plots into a radial line is acknowledged.

Therefore, relation between  $T'$  and  $K'$  may be expressed in the following formula;

$$K = \left( \begin{array}{l} \text{almost invariable constant} \\ \text{for all kinds of usual ships} \end{array} \right) \times \frac{AR \cdot l^2 d}{l \cdot d \cdot \nabla} \times T' \tag{18}$$

On the other hand, the above relation between  $K$  and  $T$  can also be presumed from equation (10), namely :

$$\frac{K}{T} = \frac{C_{\mu}}{n} \left( \frac{V}{l} \right)^2 \tag{10}$$

This equation may not represent the ratio  $K/T$  having the significance as given in Figure 5, when the shift of pivoting point according to the lapse of time for turning motion is taken into account. It is, however, considered that this difference can be substan-

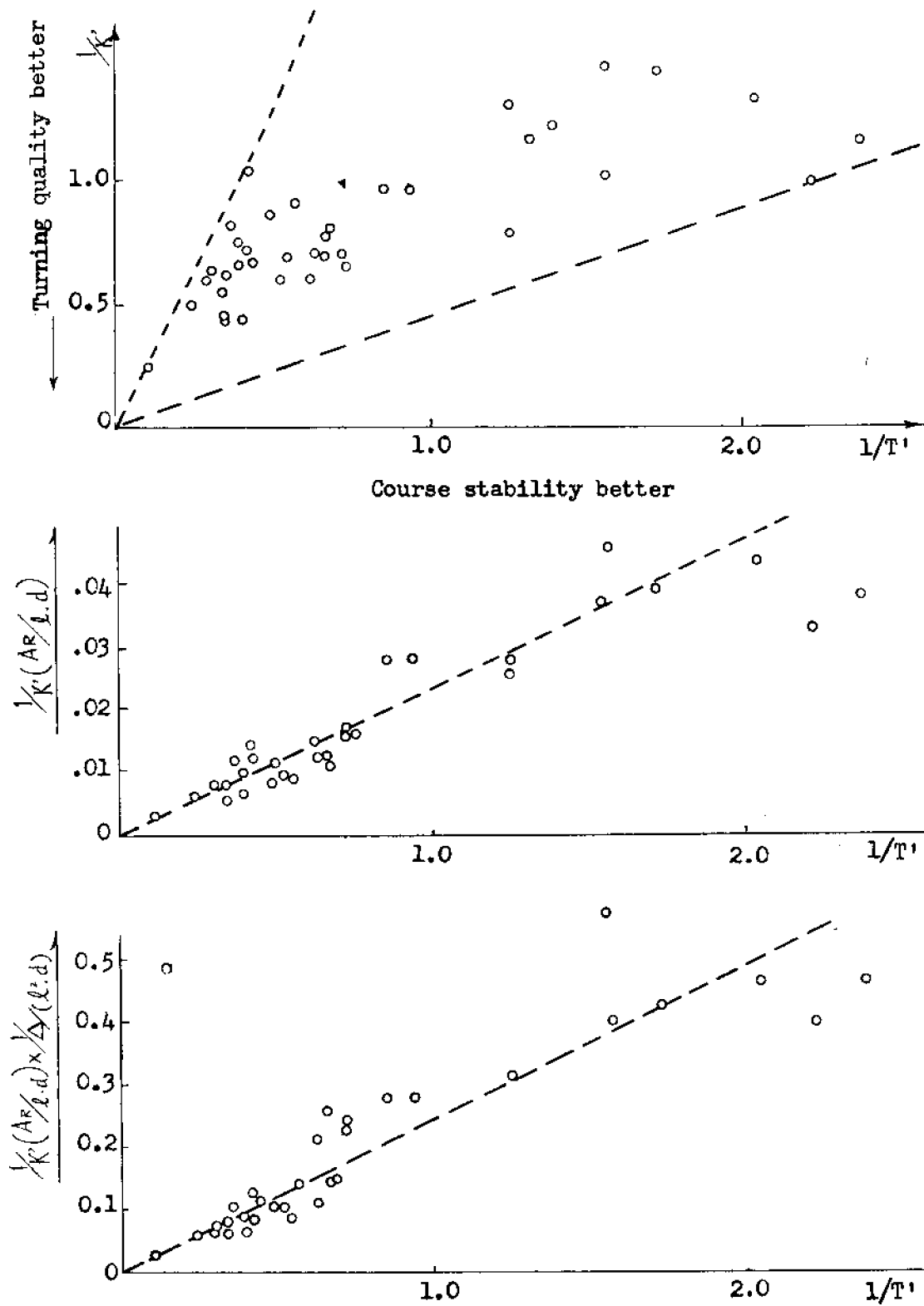
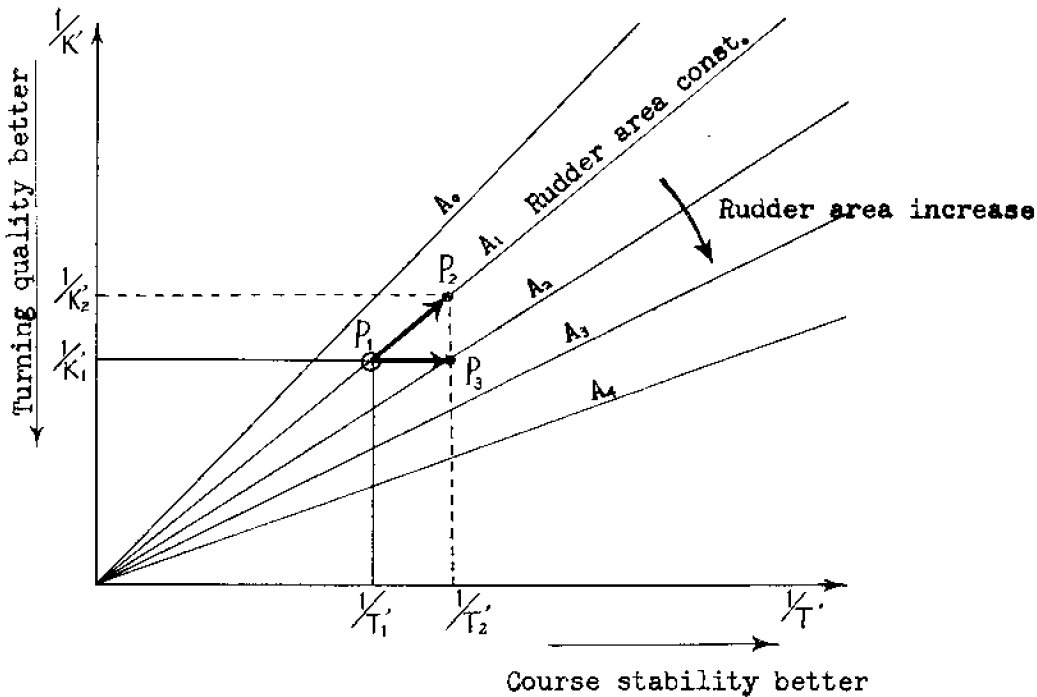


FIG. 14a, 14b, 14c.



tially eliminated by multiplying a coefficient  $k$  which is constant irrespective of the ship's form (\*).

$$\frac{K}{T} = k \frac{C_n}{n} \left(\frac{V}{l}\right)^2 \quad (19)$$

In conclusion the factor which governs the ratio  $K/T$  is the ratio of the rudder moment to the moment of inertia of ships, and accordingly equation (19) can be rewritten as :

$$\frac{K}{T} = \frac{\frac{1}{2} \rho g C_n \cos \delta}{(W/l^2 d) \delta} \frac{A \overline{GR}/l}{Ld (k/l)^2} \left(\frac{V}{l}\right)^2 \quad (20)$$

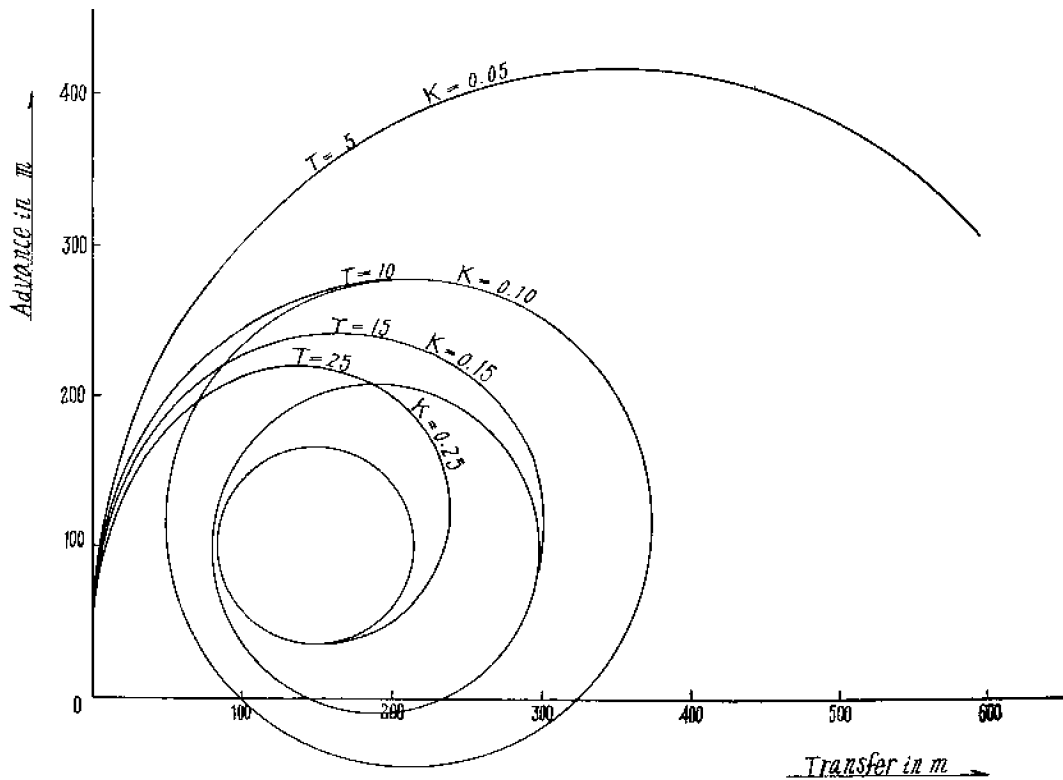
- Where :
- $\rho$  = density of water;
  - $W$  = displacement of ship;
  - $d$  = draught;
  - $C$  = coefficient of normal component of rudder force;
  - $A$  = rudder area;
  - $GR$  = distance from the centre of gravity of ship to the centre of pressure of rudder plate;
  - $k$  = virtual radius of gyration of ship about  $x$ -axis).

(\*) Whilst no assurance has been given to the fact that  $k$  does not change according to the ship's form, the comparison with the results of measurements indicates that this assumption is not ill-advised in general. The value of  $k$  is approximately 1.25.

Of the above factors governing the ratio  $K/T$ , the rudder area ratio  $A/l \cdot d$  is the predominant factor, and the effect of other factors, such as  $W/l^2 d$ ,  $k/l$ , etc. which are dependent upon the ship's form, are not so great as compared with that of the rudder area ratio. Accordingly it can be deduced that  $K/T$  is approximately kept constant unless the rudder area is changed.

The above relation is illustrated in Fig. 15, in which  $1/T'$  which represents the course stability or quick responsibility is taken in the abscissa and  $1/K'$  which represents the turning ability is taken in the ordinate.

In this figure, the relation given by equation (20) is represented by radial lines intersecting the origin of the coordinate. When the rudder area is varied, these lines shift to radial lines nearer to the base as the rudder area increases. Let us now assume that a ship having a steering quality corresponding to the point  $P_1$  in the figure, that is, a ship having the course stability  $1/T_1'$  and turning ability  $1/K_1'$ , is renovated so as to improve the course stability (for instance, by fitting dead wood in the stern). When this renovation is made without changing the rudder area  $A_1$ , then the ratio  $K/T$  does not change, and the point  $P_1$  shifts to  $P_2$  on the same radial line. In this case, therefore, the course stability becomes inevitably worse. If the improvement of the course stability without adversely



affecting the turning ability is desired, it is necessary to increase the rudder area, since such improvement should be made so as to shift the point  $P_1$  to  $P_3$  as shown in the figure.

As explained above, the course stability and turning ability have the character which is contradictory to each other, and therefore, in actual ships, the ratio  $K/T$  can change only within a comparatively small range. Accordingly the combination of  $K$  and  $T$  as extreme as given in Fig. 10 cannot exist in actual ships.

Figure 16 shows the turning paths corresponding to various combinations of  $K$  and  $T$  when the ratio  $K/T$  is kept constant. This figure demonstrates that the greater the value of  $K$ , that is, the better the turning ability, the better the results for the steering quality as a whole.

Since  $K\delta/T$  represents the angular acceleration of turning motion immediately after the steering as indicated by equation (8) and (9),  $K/T = \text{constant}$  means that the initial angular acceleration is constant so long as the helm angle is unchanged. Accordingly, if the steering efficiency of rudder is considered to be proportional to the initial angular acceleration of turning motion, it can be concluded that the *only way*

*to improve the steering efficiency of rudder is to increase the rudder area.*

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Seizo Motora

TANK TEST FACILITIES AND KINDS OF EXPERIMENTS CONCERNING MANOEUVRABILITY  
OF SHIPS NOW IN PRACTICE IN JAPAN

TRANSPORTATION TECHNICAL RESEARCH INSTITUTE

1. *Name and address of organization ;*  
Transportation Technical Research Institute.  
700 Shinkawa, Mitaka, Tokyo, Japan.
2. *Towing basin and other facilities ;*
  - 2.1. Towing Basin  
dimension : 29 m × 8 m × 3.3 m (ref. Fig. 1)  
(Length × Width × Water depth).  
carriage speed : 2.5 m/sec.
  - 2.2. Rotating Arm Basin  
dimension : 6 m × 1.2 m (ref. Fig. 1)  
(Radius × Water depth).
  - 2.3. Manoeuvring Basin  
dimension : 80 m × 80 m × 4.5 m (ref. Fig. 1)  
(Length × Width × Water depth).
3. *Models :*  
length of models for towing basin : 2.5 m ;  
length of models for rotating arm basin : 1.5 m ;  
length of models for manoeuvring basin : 5 m.
4. *Kinds of experiments :*
  - 4.1. Experiments on Manoeuvrability using Free Self-propelled Models.
  - 4.2. Experiments on Rudder Performance.
  - 4.3. Experiments on Derivatives of Ships.
  - 4.4. Experiments on Ship Motion in Waves.
5. *Instrumentation :*

measuring quantity	apparatus
heading angle	free gyro
angular velocity of turning	rate gyro
rudder angle	electric potentiometer
revolution of propeller	electric counter
running path	transit type tracer
rudder force	wire strain gauge type dynamometer

6. *Procedure of analyses and representation of test results.*

- 6.1. Turning abilities and course keeping qualities of the models of different ships with different rudders and appendages are determined from the experimental results of free self-propelled models.
- 6.2. Rudder characteristics are obtained from the experimental results of the rudders and the rudders working behind propellers. The results are sometimes represented as the design chart for practical use.
- 6.3. Derivatives of ship motions are determined from the experiments at the rotating arm basin. From the results it is possible to analyse the steered motion of ships theoretically.
- 6.4. Ship motion in regular and irregular waves are investigated from the stand point of not only oscillation but also course stability. Manoeuvrability of ships affected by strong wind are also investigated experimentally and analytically.

7. *Kinds of full-size manoeuvre test and the procedure of analyses.*

- 7.1. Experiments on Rudder Forces of Ships.  
The characteristics of the rudder performance are investigated from the record of the twisting moment of rudder at ship trial.
- 7.2. Experiments on Manoeuvrability of Ships.  
Manoeuvrabilities of different ships are determined from the record of the turning path, the change of heading angle, the reduction of advance speed, the revolution of the propeller, etc. Comparing the results of actual ships with those of models, correlation of motion of steering between ships and models are investigated.

MEGURO MODEL BASIN

1. *Name and address of organization :*  
First Research and Development Center.  
Research and Development Institute.

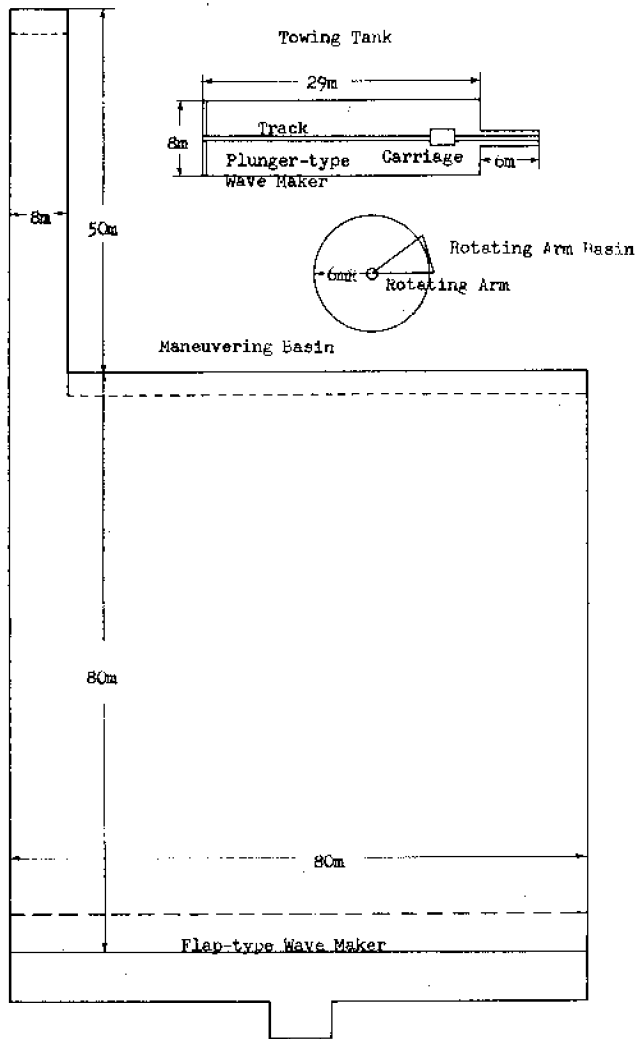


FIG. 1.  
Transportation Technical Research Institute  
Towing Basin.

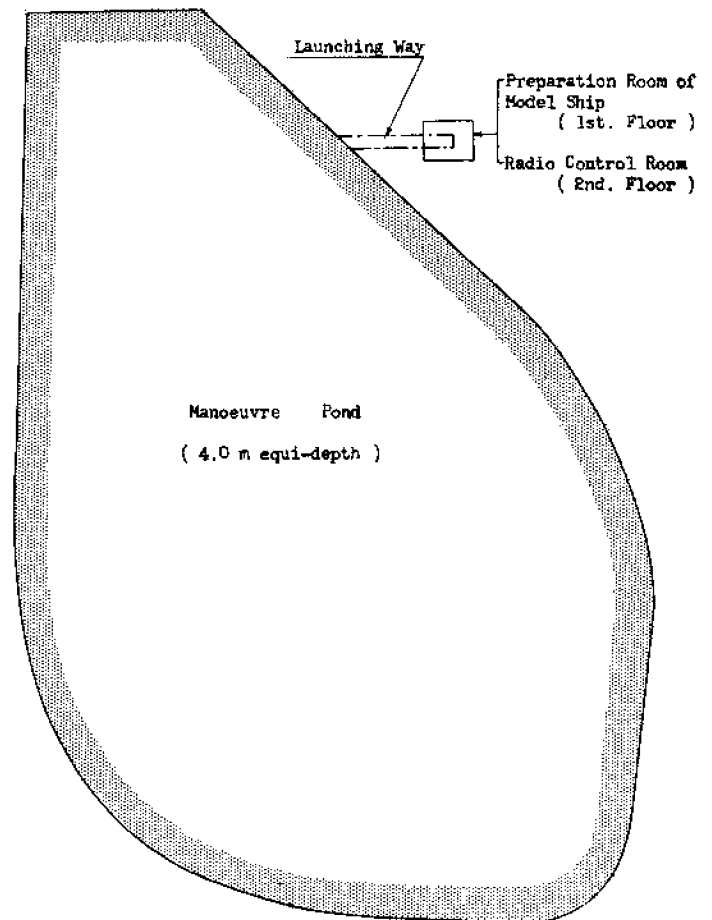


FIG. 2.  
Meguro Model Basin  
Manoeuvre Pond.

**MANOEUVRABILITY      FORMAL DISCUSSION**

**THE LIST OF**

NAME OF ORGANIZATION	TOWING BASIN & OTHER FACILITIES	MODELS (m)
Transportation Technical Research Institute	Towing Basin 29 × 8 × 3.3 m Rotating Arm Basin 6 × 1.2 m Manoeuvrability Basin 80 × 80 × 4.5 m	2.5 1.5 5.0
Meguro Model Basin First Research and Development Center	Towing Basin Large Basin 255.0 × 12.5 × 7.0 m	5.0 — 8.0
Research and Development Institute Japan Defence Agency	Small Basin 102.5 × 3.5 × 2.2 m High Speed Basin 364.5 × 6.0 × 3.0 m, Manoeuvre Pond 21,500 m <sup>3</sup>	1.0 — 2.0 2.0 — 4.0 6.0 & 8.0
Technical Research Laboratory Hitachi Shipbuilding and Engineering Co., Ltd.	Circulating Channel	1.5
Mitsubishi Nagasaki Experimental Laboratory, Mitsubishi Shipbuilding & Engineering Co., Ltd.	Towing Basin Large Basin 165 × 12.5 × 6.5 m Small Basin 120 × 6.1 × 3.65 m	5.0 — 7.0
University of Tokyo, Faculty of Engineering, Department of Naval Architecture	Towing Basin 86 × 3.5 × 2.6 m  Turning Basin 15 × 15 m	2.0 — 3.0  1.7
University of Mercantile Marine of Tokyo	29 m Training-ship	—
Ship Research Laboratory, Mechanical Engineering Dept., Defense Academy	Circulating Tank 1.2 × 1.2 × 6 m	1.2
Osaka University, Faculty of Engineering, Department of Naval Architecture	Towing Basin 52 × 1.8 × 1.0 m Manoeuvre Pond	1.5 — 3.0 4.0 — 6.0
Kyushu University, Faculty of Engineering, Department of Naval Architecture	Towing Basin 80 × 2.5 × 5.3 m  Turning Basin 30 × 5 × 5 m	1.0 — 2.0

TANK FACILITIES IN JAPAN.

KINDS OF EXPERIMENTS	REPRESENTATION OF TEST RESULTS	KINDS OF FULL SIZE MANOEUVRE TEST
Manoeuvrability Rudder performance Derivatives of ships Ship motion in waves	Turning abilities, Course keeping qualities Rudder Characteristics The steered motion of ships Ship motion in regular and irregular waves	Rudder forces of ships Manoeuvrability of ships
Circular turning test Sinusoidal steering test Kempf's standard manoeuvre test	First-order steering quality indices $K_S$ & $T_S$ Systematic formulation of steering quality indices First-order steering quality indices $K$ & $T$	Kempf's standard manoeuvre tests Circular turning trials
Rudder performance Manoeuvre test	The practical formulae for the normal force and the centre of pressure of rudder in the single-screw vessel	The standard zig-zag manoeuvre tests The measurements of rudder torque
Rudder performance Manoeuvre test		
Three components tests & yawing tests Kempf's standard tests Turning tests	Resistance derivatives and virtual moment of inertia around vertical axis The manoeuvrability indices $K$ & $T$ The manoeuvrability indices $K$ & $T$	Turning tests
Standard manoeuvre test Turning tests Manoeuvring (propeller in an astern direction)		
Free yawing test Forced yawing test Frequency response test	The same forme as Tokyo University Tank's	
Manoeuvre test Rudder performance	Steering quality indices $K$ , $T_1$ , $T_2$ & $T_3$ . First-order steering quality indices Resistance derivatives A systematic formulation of steering quality indices. Rudder normal force and rudder torque	Kempf's standard manoeuvre tests Sinusoidal and impulsive steering tests Conventional turning trials and hard-over to hard-hover steering tests and measurements of rudder torque
Oblique sailing test Turning test	The moment and force concerning with ship form The relation between turning and course stability properties	

Japan Defense Agency.  
 Address: No. 13 Mita, Meguro-ku, Tokyo, Japan.  
 Chief: Mitsuo Kanno.  
 Researcher: Seiji Takezawa.

2. Towing basin and other facilities :

2.1. Towing Basin

Large Basin

dimension: 255.0 × 12.5 × 7.0 m;  
 carriage speed: 0.5 — 10.0 m/sec;  
 Instrumentation: a set of usual instrumentation  
 for towing and self-propulsion  
 tests;  
 a set of wave-maker.

Small Basin

dimension: 102.5 × 3.5 × 2.2 m;  
 carriage speed: 0.3 — 7.0 m/sec;  
 instrumentation: a set of usual instrumentation  
 for towing and self-propulsion  
 tests;  
 a set of wave-maker.

High Speed Basin

dimension: 364.5 × 6.0 × 3.0 m;  
 carriage speed: 1.0 — 20.0 m/sec;  
 instrumentation: a set of resistance dynamometer  
 for high speed tests;  
 a set of accelerator for carriage.

2.2. Manoeuvre Pond (Fig. 2)

area about 21,500 m<sup>2</sup>  
 max. length about 215 m  
 max. width about 130 m  
 depth about 4.0 m

3. Models :

for towing basin

large basin: 5.0 — 8.0 m

small basin: 1.0 — 2.0 m

high speed basin: 2.0 — 4.0 m

for manoeuvre pond :

6.0 m (merchant ships);

8.0 m (destroyer, patrol-coaster, etc.).

4. Kinds of experiments :

Manoeuvre test employing free-running, self-propelled models with radio-control.

1. Circular turning test.

2. Sinusoidal steering test.

3. Kempf's standard manoeuvre test.

5. Instrumentation :

5.1. Measuring Item and Method.

See table on the following page.

5.2. Radio Control Equipment of Model Ships (Fig. 3).

This equipment is especially designed for manoeuvre tests of high speed ships as destroyers. Then that is usually used for the experiments of twin-screw and twin-rudder ships.

a) Radio Wave

transmission system	PWM-FM-FM
carrier wave frequency	about 320 MC
carrier wave output	about 10 W

b) Radio Instructions

1st. channel	(1st. propeller)
2nd. channel	(2nd. propeller)

± 150 - ± 3,000 r. p. m. and Stop

3rd. channel	(1st. rudder)
4th. channel	(2nd. rudder)

+ 60° - 0° - - 60°

Instructions of 1st. - 4th. channels are continuously variable. Both 1st., 2nd. channels and 3rd., 4th. channels are possible to operate on linkage and separateness.

5th. channel (Motor-driving camera)  
 on-off control

c) Propulsion System.

See scheme page 629.

\* Engine — Generator

gasoline-engine: 4 cylinders, 21 H.P. at 4,000 r. p. m.  
 D. C. generators

for the use of driving motors (X 2): 4.5 KW, 200 V, 4,000 r. p. m.

for the use of exciter (X 1): 1.0 KW, 100 V, 4,000 r. p. m. for the use of battery charger (X 1): 0.1 KW, 12 V, 4,000 r. p. m.

\* Propeller driving motors (X 2)

4 H.P., D. C. 200 V, 300 - 6,000 r. p. m. (Ward Leonard control system).

Meguro Model Basin — Instrumentation.  
Measuring Item and Method.

	ITEM	METHOD	RECORD
(1)	Propeller Revolution (X 2)	D. C. Generator	Motor Drived 35 mm Camera (inboard)
(2)	Helm Angle (X 2)	400 $\approx$ Synchro	
(3)	Model Speed	Propeller and Pulse Generator	
(4)	Running Path	Tracking Transits	Pen-oscillograph

(1) — (4) are completed in 1960.

(1)*	Propeller Revolution (X 2)	D. C. Generator or Electric Contact	Pen-oscillograph  in Radio Control Room by Wireless Tele-metering  X-Y Recorder
(2)*	Helm Angle (X 3)	400 $\approx$ Synchro	
(3)*	Model Speed	Propeller and Pulse Generator	
(4)*	Course Angle	Gyroscope and Synchro	
(5)*	Heel Angle	Gyroscope and Synchro	
(6)*	Propeller Torque and Thrust (X 2)	Strain Gauge or Differential-Trans	
(7)*	Rudder Forces	Strain Gauge or Differential-Trans	
(8)*	Running Path	Tracking Transit	

(1)\* — (8)\* will be completed in 1961.

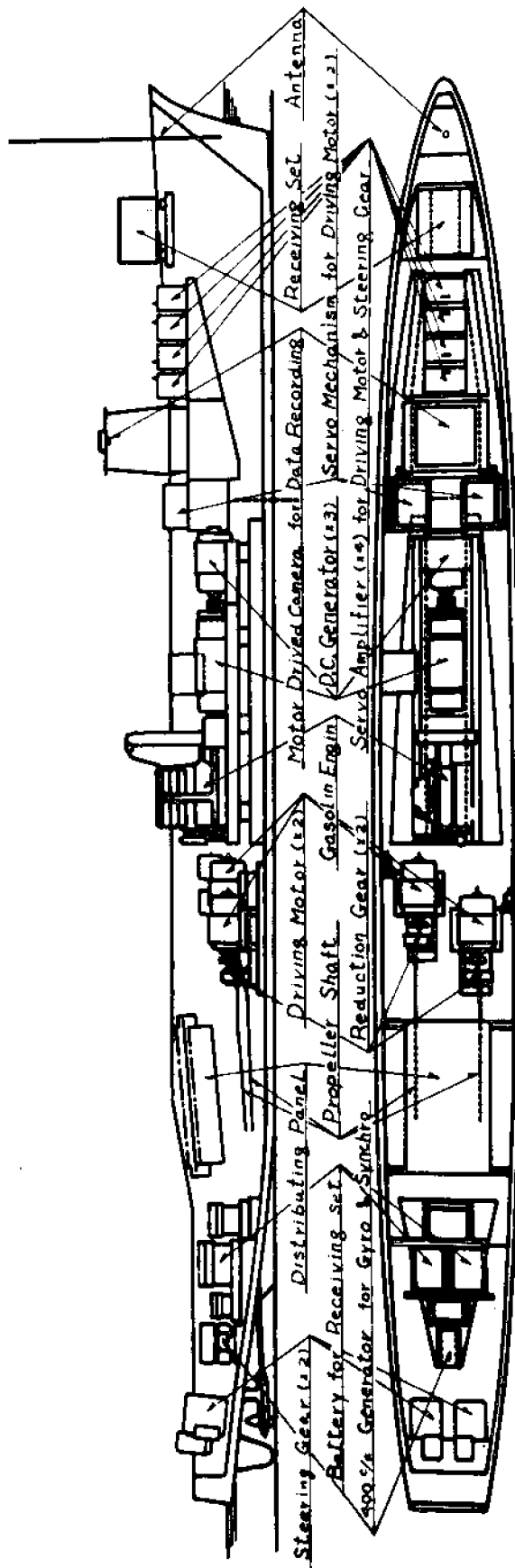
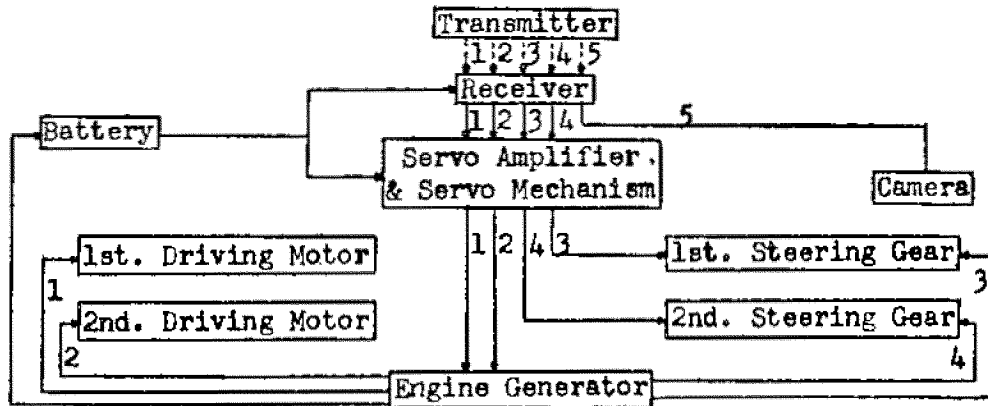


FIG. 3.  
 General Arrangement of the Radio-controlled Model Ship.

c) Propulsion System.



6. Procedure of analyses and representation of test results :

- 6.1. To determine first-order steering quality indices  $K_s$  and  $T_s$  using Kempf's standard manoeuvre tests [4].
- 6.2. To determine first-order steering quality indices  $K_s$  and  $T_s$  using circular turning tests [5].
- 6.3. To construct systematic formulation of steering quality indices as function of relative rudder sizes, slenderness factors, and some other factors.

7. Kinds of full-size manoeuvre tests and the procedure of analyses :

- 7.1. Kempf's standard manoeuvre tests carried out using helm angle of 10, 15 and 20 degrees. The procedure of analysis is similar to one for a free-model test [4].
  - 7.2. Circular turning trials carried out using rudder angle of 10-40 degrees. The procedure of analysis is similar to one for a free-model test [5].
- Note: Full-size tests are executed in cooperation of Maritime Self Defense Force.

TECHNICAL RESEARCH LABORATORY

- 1. Name and address of organization :  
 Technical Research Laboratory,  
 Hitachi Shipb. and Eng. Co., Ltd., Osaka, Japan.  
 Director: Masao Kinoshita.  
 Researcher in charge: Shojiro Okada.

2. Towing basin and other facilities :

- 2.1. Towing Basin.  
 non
- 2.2. Circulating Channel.  
 Dimension and arrangement are given (Fig. 4)

3. Model :

About 1.5 m model for the circulating channel.

4. Kinds of experiments :

- 4.1. Model experiments with reference to the rudder performance (at the circulating channel).  
 Open test for a rudder.  
 Behind test for a rudder with a propeller.  
 Behind test for a rudder with ship and ship's propeller.
- 4.2. Manoeuvre test employing the free-running, self-propelled models.  
 This test will be carried, in future.

5. Instrumentation :

- Quantities to be measured are :  
 Revolution of propeller,  
 Rudder forces and moment  
 Helm angle.

Synopses of detection of each quantity are as follows:

*Revolution of propeller* is detected by an usual electric contact with a reduction gear.

*Rudder forces and moment* : A rudder is supported by a rudder stock isolated mechanically from a gudgeon and shoe piece. A thin circular pipe of

MANOEUVRABILITY FORMAL DISCUSSION

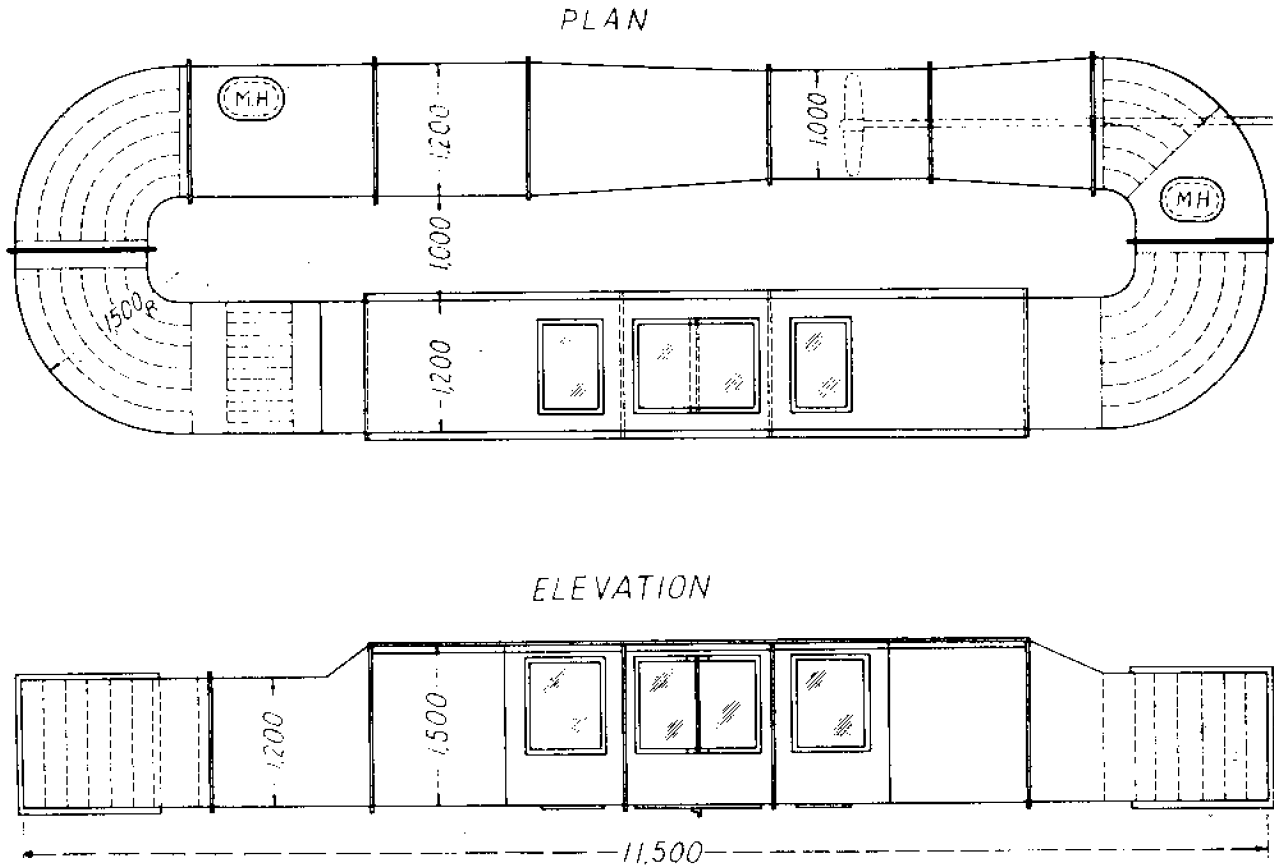


FIG. 4.  
Circulating Channel at Meguro Basin.

steel constitutes an intermediate part of the rudder stock and a number of wire strain gauge are pasted on it so as to detect the normal force, the tangential force and moment acting upon the rudder and rudder stock.

*Helm angle* is detected by a variable electric resistance.

6. Procedure of analyses and representation of test results :

As the results of model experiments of the rudder placed behind the ship and ship's propeller, the practical formulae for the normal force and the centre of pressure of rudder in the single-screw vessel are given, as follows: [6], [10].

FORMULAE

$$N = \frac{1}{2} \rho V_s^A \left\{ 2.41 \left( 1.3 - \frac{1}{2\lambda} \right) (1 - w_a)^2 (1 + k.s^{1.5}) \right\} \sin \alpha'$$

where:

$$k = \begin{cases} 5.8 (0.6 + \text{D.A.R.}) & \text{for the starboard rudder angle.} \\ 6.7 (0.6 + \text{D.A.R.}) & \text{for the port rudder angle.} \end{cases}$$

$$\alpha' = \begin{cases} \alpha_R + (0.6 + 2s) - F(\varphi_R) \text{ (deg.)} & \text{for the starboard.} \\ \alpha_R - (0.6 + 2s) - F(\varphi_R) \text{ (deg.)} & \text{for the port.} \end{cases}$$

- N: Normal force of rudder (kg).
- $\rho$ : Specific gravity of sea water ( $\text{kg.s}^2/\text{m}^4$ ).
- $V_s$ : Ship's speed (m/s).
- A: Area of rudder ( $\text{m}^2$ ).
- $\lambda$ : Aspect ratio of rudder.
- $w_a$ : Mean effective wake fraction of propeller.
- s: Actual slip ratio of the propeller placed behind the vessel.

- D.A.R.: Developed area ratio of the propeller.
- $\alpha_R$ : Rudder angle.

$F(\varphi_R)$ : Modification term due to drift angle for the rudder angle.

The range of  $\left\{ \begin{array}{l} 1.00 \leq \lambda \leq 2.50 \\ 0.2 \leq S \leq 0.6 \\ 15^\circ \leq \alpha \leq 35^\circ \end{array} \right\}$  is the object.

$$\frac{l}{c} = 0.195 + 0.35 \sin \alpha - 0.07s \pm 0.058 w_s + \frac{1}{2} \frac{\Omega}{\sin \alpha}$$

where:

$$\alpha = \alpha_R = F(\varphi_R).$$

$$\Omega = C_j/V_s.$$

$c$ : Chord length of the rudder (m).

$l$ : Distance from the leading edge to the centre of pressure of the rudder (m).

$j$ : Angular velocity of steering (rad/s).

$\pm$ : corresponding to the  $\left\{ \begin{array}{l} \text{starboard} \\ \text{port} \end{array} \right\}$  rudder angle.

In this formulae, the modification term for rudder angle due to the drift angle is not clarified at present.

So that, the studies along this item must be carried out, in future.

#### 7. *Kinds of full-size tests and the procedure of analyses:*

7.1. The standard zig-zag manoeuvre tests are carried out using the helm angle of usually ten degrees.

7.2. The measurements of rudder torque as a function of time are carried out by using the torquemeter and strain gauges.

#### MITSUBISHI NAGASAKI EXPERIMENTAL TANK LABORATORY

##### 1. *Name and address of organization:*

Mitsubishi Nagasaki Experimental Tank Laboratory, Mitsubishi Shipbuilding & Engineering Co., Ltd.

Address: 712 Showa-Machi, Nagasaki, Japan.

Chief: Kaname Taniguchi.

##### 2. *Towing basin and other facilities:*

###### 2.1. Towing Basin

Dimension

large tank: 165<sup>m</sup> (285<sup>m</sup>) × 12.5<sup>m</sup> × 6.5<sup>m</sup>

small tank: 120<sup>m</sup> × 6.1<sup>m</sup> × 3.65<sup>m</sup>

Maximum carriage speed

large tank: 9.0 m/s

small tank: 4.5 m/s

(The towing carriage for the large tank can run 285<sup>m</sup> through both tanks.)

##### 3. *Models;*

Length of ship models 5m to 7m.

#### 4. *Kinds of experiments:*

4.1. Towing experiment with reference to rudder performance (at towing basin).

Open test for rudders.

Behind test with a straight running ship model.

4.2. Manoeuvre test with free-running, self-propelled ship models (at towing basin, in near future).

Serpentine-test.

#### 5. *Instrumentation:*

Quantities to be measured:

ship's heading angle;

helm angle;

number of revolution of propeller;

rudder forces.

#### UNIVERSITY OF TOKYO

##### 1. *Name and address of organization:*

University of Tokyo.

Faculty of Engineering.

Department of Naval Architecture.

Motofuji-cho, Bunkyo-ku, Tokyo, Japan.

(Researcher in charge: Seizo Motora.)

##### 2. *Towing basin and other facilities:*

###### 2.1. Towing Basin (Fig. 5).

dimension: 86 × 3.5 × 2.6 m;

carriage speed: 0.3 - 4.0 m/s.

###### 2.2. Turning Basin (Fig. 6).

##### 3. *Models;*

3.1. For the Towing Basin 2.0 - 3.0 m.

3.2. For the Turning Basin 1.7 m.

#### 4. *Kinds of experiments:*

4.1. Three components tests and yawing tests:

To get resistance derivatives.

4.2. Kempf's standard tests: (in small rudder angles). To get manoeuvrability indices.

4.3. Turning tests:

To get manoeuvrability indices.

#### 5. *Instrumentation:*

5.1. Three components tests and yawing tests:

Resistance, side force, yawing moment arc measured by: magnetostriction dynamometers while running with steady yaw angles and in yawing models being towed.

5.2. Kempf's standard tests:

Ship's heading angle is measured by a free gyro.

5.3. Turning tests:

Ship's heading angle, advance, transfer, tactical

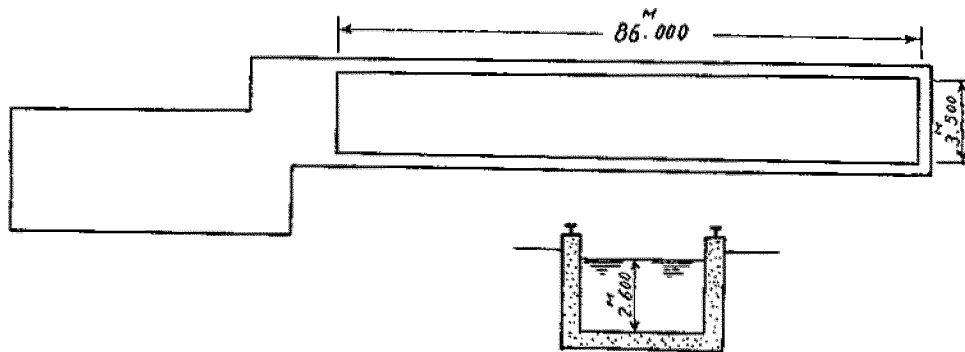


FIG. 5.  
Towing Basin.

diameter, and radius of turning are measured by photographic method.

Models are controlled by a radio controller.

6. Procedure of analyses and representation of test results;

6.1. Three components tests and yawing tests:

Resistance derivatives and virtual moment of inertia around vertical axis are obtained from measured values of resistance, side force, yawing moment, period of yawing, and the phase difference between yawing moment and yawing motion.

6.2. Kempf's standard tests:

The manoeuvrability indices K and T are obtained by Nomoto's method [14].

6.3. Turning tests :

The manoeuvrability indices K and T are obtained from the recorded locus of ships C.G.

The method of analysis is outlined in Ref. [11].

7. Kinds of full size manoeuvre tests:

Turning tests as usually done.

Items measured and the way of analysis are the same as model tests.

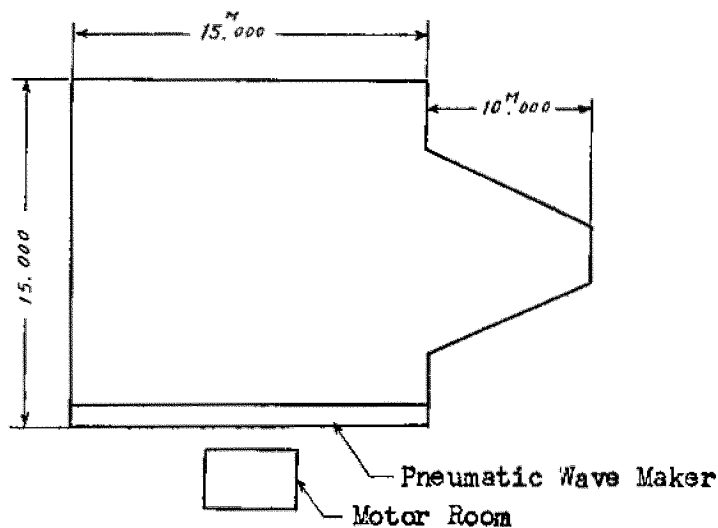


FIG. 6.  
Turning Basin.

UNIVERSITY OF MERCANTILE MARINE OF TOKYO

1. *Name and address of organization:*  
University of Mercantile Marine of Tokyo.  
Fukagawa-Ecchujima, Koto-ku.  
Tokyo, Japan.
2. *Facilities:*  
29 m. Training-ship,  
Length 29.000 m.  
Breadth 6.200 m.  
Depth 3.450 m.  
 $C_b$  0.530  
 $C_w$  0.754  
Draft 2.459 m.  
Displacement 251.7 t.  
Rudder  
Balanced and stream-lined.  
Area 2.277 m<sup>2</sup>.  
 $A/L \times d$  0.0357  
Aspect-ratio 1.2

3. *Kinds of experiments:*  
Standard manoeuver test.  
Turning test.  
Manoeuvring when operating propeller in an astern direction.  
These tests are performed both in smooth sea and in wind sea. The comparison of these tests results with a similar model is now in preparation.
4. *Instrumentation:*  
An electrically-driven gyroscope is used, by which the rate of change of heading is measured.

SHIP RESEARCH LABORATORY  
OF DEFENSE ACADEMY YOKOSUKA

1. *Name and address of organization:*  
Ship Research Laboratory, Mech. Eng. Dept.  
Defense Academy, Yokosuka, Japan.  
Researcher in charge: Masatoshi Bessho.
2. *Towing basin and other facilities:*  
Circulating Tank (see Fig. 7).  
dimension: 1.2 × 1.2 × 6.0 m in open channel;  
velocity: 0 - 1.8 m/s;  
dynamometer for rudder and model ship:  
Three components with strain gauge.
3. *Models:*  
Length 1.2. m or smaller.
4. *Kinds of experiments:*  
Free yawing test for course stability measurement,  
(see Ref. 12).

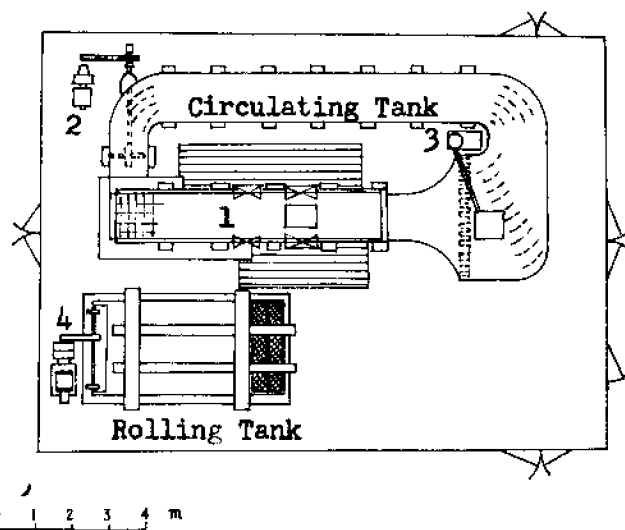


FIG. 7.

1. Open Channel for observation.
2. Motor (40 H.P.).
3. Vacuum pump (2 H.P.).
4. Wave maker (plunger type).

Test plan in near future.

- a) Forced yawing test;
- b) Frequency response test.

5. *Instrumentation:*

Ab.

6. *Procedure of analyses and representation of test results:*

The same form as Tokyo University Tank's.

7. *Kinds of full-size manoeuvre tests and the procedure of analyses:*

No experience.

OSAKA UNIVERSITY

1. *Name and address of organization:*  
Osaka University. Faculty of Engineering.  
Department of Naval Architecture.  
Osaka, Japan.  
(Researcher in charge: Kensaku Nomoto.)
2. *Towing basin and other facilities:*  
2.1. Towing Basin.  
dimension: 52 × 1.8 × 1.0 m;  
carriage speed: 0.1 to 5.0 m/sec;  
instrumentation : a set of usual instrumentation  
for towing and self-propulsion  
tests.  
2.2. Manoeuvre Pond.

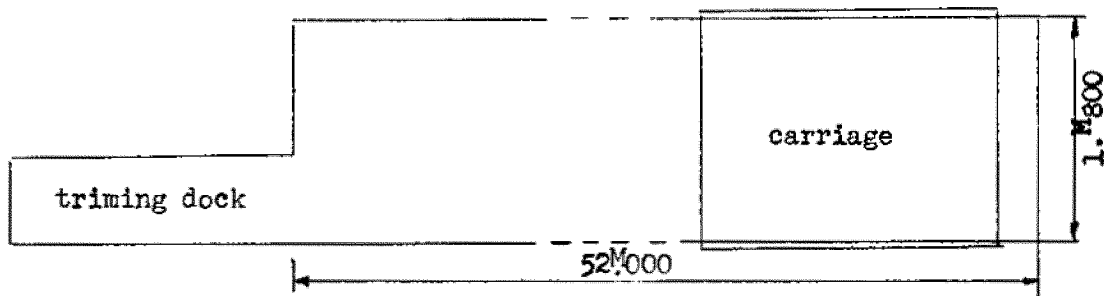
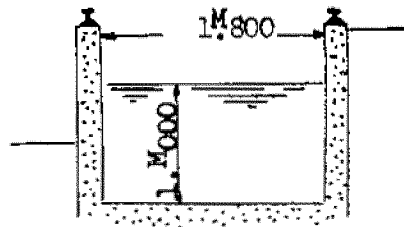


FIG. 8.  
Osaka University.  
Towing Basin.



3. Models:

for towing basin: 1.5 to 3.0 m;  
for manoeuvre pond: 4.0 m usually;  
6.0 m as required.

4. Kinds of experiments:

4.1. Manoeuvre test employing free-running, self-propelled models with radio-control (at manoeuvre pond).

Sinusoidal steering test.

Impulsive steering (transient response) test.

Circular turning test including one with small helm angles Kempf's standard manoeuvre test. Hard-over to hard-over test with particular reference to rudder forces.

These tests are now underway largely for usual merchant ship types.

4.2. Towing experiments with reference to rudder performance (at towing basin).

Open test for a rudder and one accompanied by a propeller.

Behind test with a straight-running model ship.

5. Instrumentation:

Quantities to be measured are:

ship's heading angle as a function of time;  
helm angle as a function of time;  
revolution of propeller;  
running path of a free-model } when necessary.  
rudder forces

These quantities except running path are detected electrically and recorded continuously by a mirror-galvanometer type oscillograph put in a free-model or on the towing carriage.

Synopses of detection of each quantity are as follows:

*Heading angle* (course angle): An electrically-driven free-gyroscope is used. Angle of rotation of the gyro gimbal which indicates immediately a change of heading angle is detected by a photo-electronic means (employing a saw-teeth disk and a photo-transistor) [13].

The accuracy rises to 0.03 to 0.05 degrees for measurements during a short period (less than 20 sec., for example, sinusoidal steering) and for relatively long duration (1 to 5 minutes) it is reduced to 0.2 to 0.5 degrees by reason of a stray drift of the free-gyro.

*Helm angle* is detected and recorded by a similar means as ones for heading angle. A saw-teeth disk attached to a tiller of a steering gear and a photo transistor are used.

*Propeller revolution* is detected by an usual electric contact with a reduction gear.

*Rudder forces*: A rudder is supported by a rudder-stock (rudder shaft) isolated mechanically from a gudgeon and shoe piece. A thin circular pipe of steel constitutes an intermediate part of the rudder-stock and a number of wire-strain-gauges are pasted

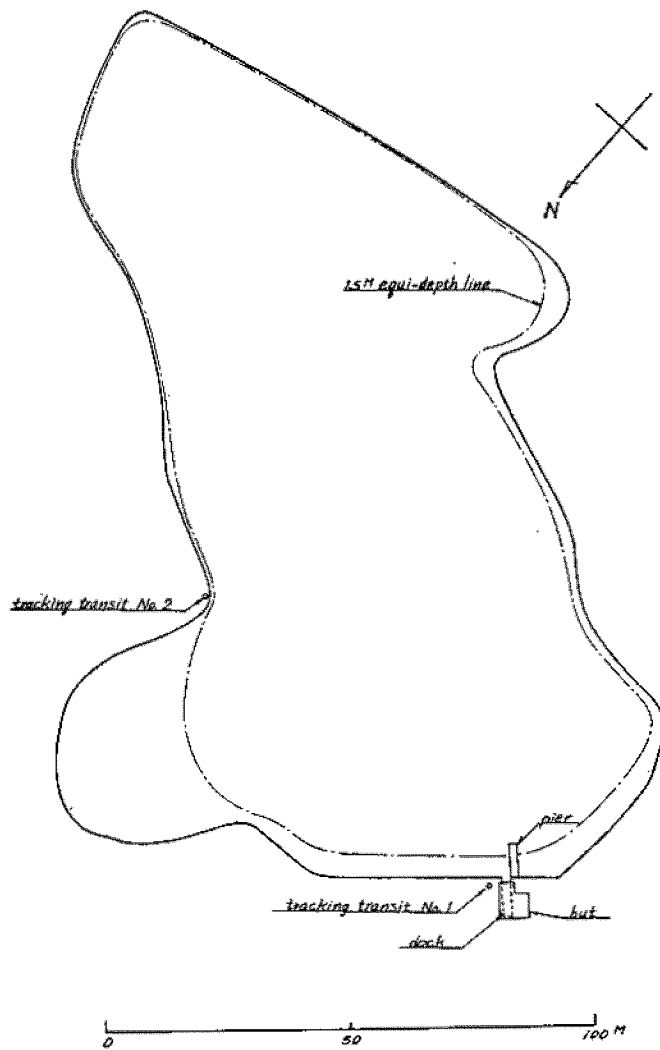


FIG. 9.  
Osaka University, Manoeuvring Pond.

on it so as to detect normal force acting on a rudder and its moment about a rudder-stock. An all-transistorized strain-meter composed of a carrier oscillator and two amplifiers is used.

Running path of a model ship is determined by a pair of tracking transits, each of which yields continuous recording of traverse angle.

6. Procedure of analyses and representation of test results

- 6.1. to determine steering quality indices  $K$ ,  $T_1$ ,  $T_2$  and  $T_3$  through frequency response procedure using sinusoidal steering, impulsive steering and in some cases circular turning test results [4] [14].

- 6.2. to determine first-order steering quality indices  $K$  and  $T$  using Kempf's standard manoeuvre results [13].
- 6.3. sometimes to determine resistance derivatives from the steering quality indices accompanied with results of measuring drift angle in circular turning tests.
- 6.4. to construct a systematic formulation of steering quality indices as functions of relative rudder sizes, slenderness factors, helm angles and some other factors when necessary.
- 6.5. to represent rudder normal force and rudder torque in an usual nondimensional form as functions of helm angle, propeller slip and ship travel in cases of behind tests.

7. Kinds of full-size manoeuvre tests and the procedure of analyses:

- 7.1. Kempf's standard manoeuvre tests are carried out using helm angle of usually 15 degrees and sometimes 10 and 20 degrees. The procedure of analysis is quite similar to one for a free-model test [13].
- 7.2. Sinusoidal and impulsive steering tests are sometimes carried out and the procedure of analysis is similar to one for a model test. These tests for actual ships are, however, usually difficult to practise by reason of their lengthy procedure.
- 7.3. Conventional turning trials and hard-over to hard-over steering tests are carried out and measurements of rudder torque employing wire-strain gauge pasted upon a rudder stock are often accompanied.

Note: Full-size tests are executed in cooperation of shipbuilding companies and shipping ones.

KYUSHU UNIVERSITY

1. Name and address of organization;  
Kyushu University.  
Faculty of Engineering.  
Department of Naval Architecture.  
Fukuoka Japan.  
(Researcher in charge: S. Inoue).

2. Towing basin and other facilities:

- 2.1. Towing Basin  
dimension: 80 × 2.5 × 5.3. m.  
carriage speed: 0.2 - 3 m/s.
- 2.2. Turning Basin  
dimension: 30 × 5 × 5 m.

3. *Models:*

1 - 2 m.

4. *Kinds of experiments:*

4.1. Measurements of force and moment of ships in the case of oblique sailing and turning.

4.2. Measurements of heel and path in the case of turning.

5. *Instrumentation:*

Quantities to be measured are a ships heading angle, heel and running path of a free-model steered by wireless, and force and moment of a obliquely sailing and turning model.

These quantities are mainly determined by spring-type apparatus and cinecamera.

6. *Procedure of analyses and representation:*

6.1. The moment and force are shown experimentally and theoretically by the ship form for example aspect ratio, beam by length, waterplane coef. etc. [16].

The relation between turning and course stability properties is determined. [15].

6.2. The maximum heel is determined comparing with steady turning heel.

7. *Kinds of full size manoeuvre tests:*

None.

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 [16] *On the turning of ships*: Memoirs of the Faculty of Engineering Kyushu University, vol. XVIZ, 1956.

Wieslaw Wenlicki (\*).

MEASUREMENTS OF TURNING QUALITIES OF SHIPS ON SELF-PROPELLED MODELS  
IN CHAIR OF NAVAL ARCHITECTURE OF POLITECHNIKA GDANSKA

1. Introduction.

The investigation of steering qualities of ships are more and more important problem in the naval architecture of last years. Works of many known scientists permit to trace the principal patterns for researches. For many special ships as tugs, icebreakers, warships etc., the manoeuvring qualities are especially important. Chair of Naval Architecture of P.G. is engaged in these investigations since four years. Here is only a little towing tank and no possibility to introduce the manoeuvring tests under the towing carriage. Therefore, all these tests are carried out on the lake.

2. Method of measurements.

Measurements of steady turning of models are based on the equations of motion given by Schoenherr [1], as the most clear for this purpose.

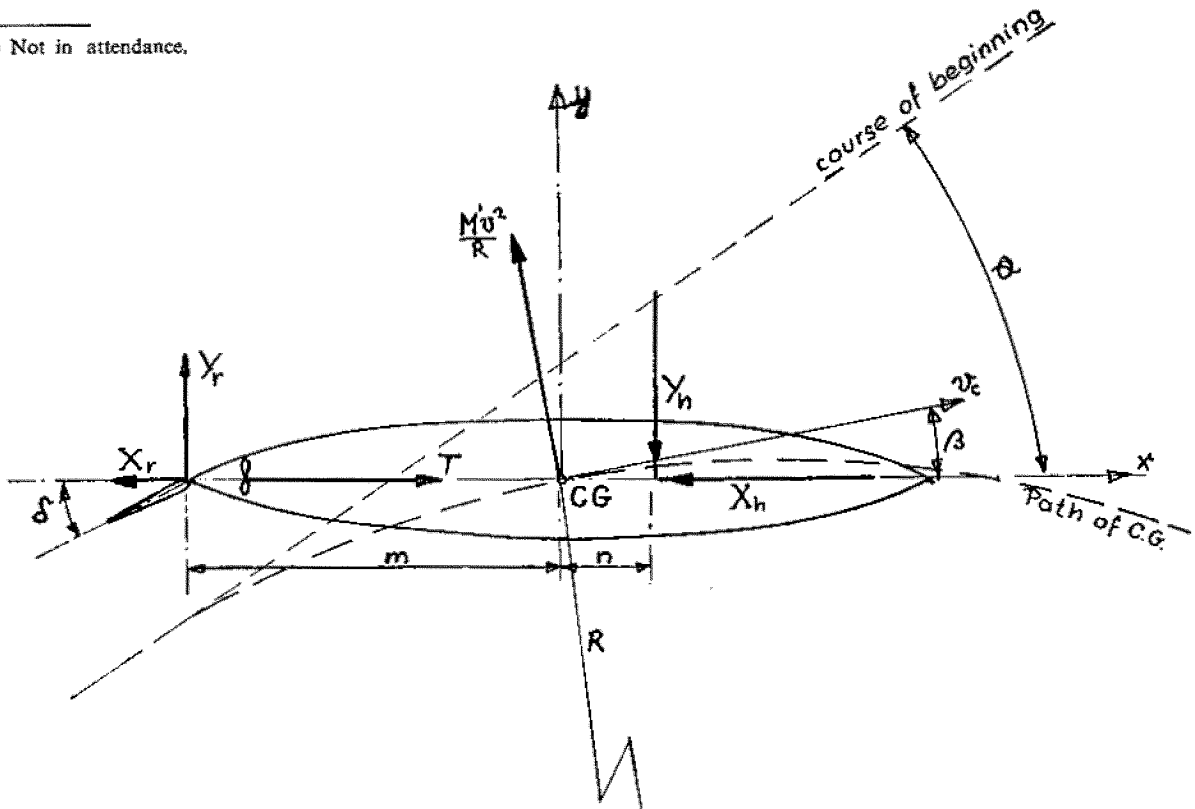
The equations are:

$$\frac{M' v_c^2}{R} \sin \beta + X_h + X_r - T = 0$$

$$\frac{M' v_c^2}{R} \cos \beta - Y_h + Y_r = 0$$

$$Y_r n = Y_r \cdot m + M_p = 0$$

(\* ) Not in attendance.



warships etc., the manoeuvring qualities are especially important. Chair of Naval Architecture of P.G. is

Magnitudes of  $Y_r$ ,  $X_r$ ,  $R$ ,  $v_{cs}$ ,  $\beta$ ,  $T$ ,  $m$  and  $\delta$  are measured directly on the model but  $X_h$ ,  $Y_h$ , and  $n$  are calculated from equations which are seen above (Fig. 1). Magnitude of the torque  $M_p$  following non-axial thrust of propeller is obtained by measurement of the torque  $Y_r$ ,  $m$  on the rudder first in turning on the left side and next on the right one. The virtual mass of ships is obtained with the aid of the coefficients [2]. In this way all characteristics of turning qualities of the ship are known. All tests are conducted on self-propelled wooden models, 4 - 6 m in length. The model propulsion arrangement consists of a constant r.p.m. petrol engine and a Ward-Leonard generator-motor set, geared to the propeller-dynamometer and permitting a multi-step speed and reversing control. Model is steered by a helmsman with the aid of an electrical steering engine or remote controlled by the radio from the shore-station. The magnitudes of  $X_r$ ,  $Y_r$ ,  $M_p$ , measured with the aid of three-component rudder-dynamometer rudder angles  $\delta$ , drift-angles  $\beta$  are recorded together with the indications of a precise second-clock on a film apparatus. There is possible to measure the model speed with the aid of "Otto Flügel" too, but it is obtained commonly from a graph of the path of the model.

The path of the CG of models is obtained from a shore by means of the method of prof. De Santis [4] from a set of records of its successive bearings, observed by two sights. Both theodolites are connected with the same electromagnetic time-recorder, which facilitates simultaneous observations. For every one turning it obtains 20-60 points. After plotting these bearing angles it gets an exact curve of the path of model and change of ships speed. There is possibility to measure on the graph tactical diameter, steady turning diameter, advance, transfer and way of approaching too (Fig. 2). Drift angle was measured previously with the aid of third theodolite connected with the same time-recorder. It gave bearing angles of second mast fastened on the bow of the model. This method of plotting the turning circle and drift angles however is demanding a lot of time, then, a special arrangement named "Pathgrapher", was designed last year. It plots the path of model automatically. The errors of this method depend mainly, on the peoples who serve the sights. But, having some experience, very exact results are obtained. For the little diameters of turning circles and for the great speeds only, these errors can be

notable. The propeller thrust and number of revolutions are measured with the aid of propeller-dynamometer of Kempf and Remmers.

### 3. Some measurement instruments.

#### 3.1. Sights.

Sights used previously in Ch. N.A. P.G. were designed very simply:—on a vertical shaft located on the edge of a special table there was a theodolite to observe the mast of model, and paralalled to it an arm like at compasses. On the end of this arm there was a pen connected with an electromagnetic time-recorder. With rotation of the theodolite, the pen plotted a circuit, marking on it points every three seconds. After every experiment the angles for successive bearings of model have to be read off from these graphs and plotted on the another paper. The points of crossing of left and right sights give the transient position of the CG of model. By joining these points is obtained the path of model and rate of speed (Fig. 2).

#### 3.2. "Pathgrapher".

In the last year a new instrument working on the same principle (Fig. 3) is designed by the author and executed in Ch. N.A.P.G. One of the theodolites is provided with selsyn-sender. Its receiver and the second theodolite are located at a special table. On their shafts there are two stiff arms. In their crossing is a little carriage with a pen, which can move along these arms, but always remains in the crossing point. It gives the momentary position of the CG of models and draws its path. The time-recorder coupled with the pen on the carriage which is tracing marks on the plotted path in equal intervals of time, is starting simultaneously with the clock on the model for synchronisation of the measurements. The relation between the distance of both theodolites and axis of the pathgrapher is the scale of the graph. In our experiments the distance between the theodolites equals 50 m and between the axis—50 cm, then the scale equals 1: 100. The both distances can be changed. Now, the instrument is not yet excellent, but the results are quite good. Its advantage is the possibility of verifying the results of tests directly after they are finished and there is not so much work as in the case of sights too. On the obtained graph have to be plotted the drift angles only,

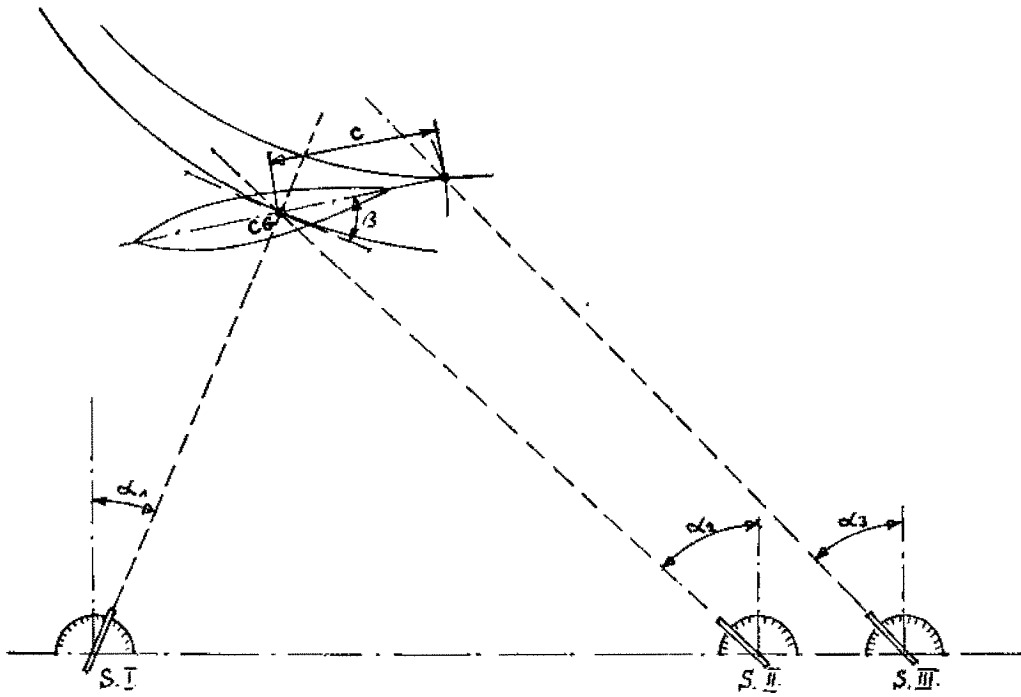


FIG. 2a.

Measurement of path of CG and drift angle with the aid of three sights.

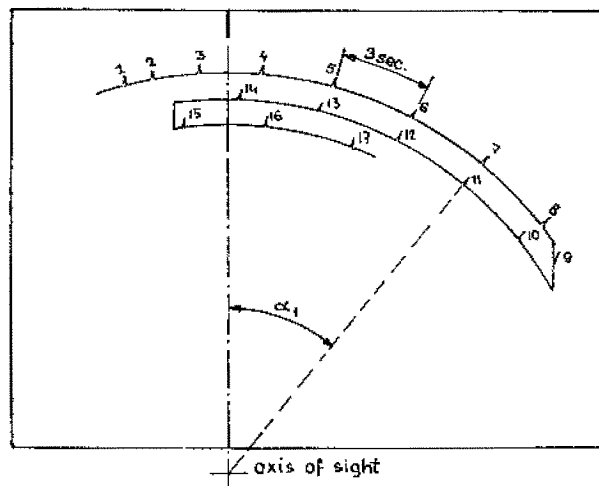


FIG. 2b.

The graph obtained by one of the sights.

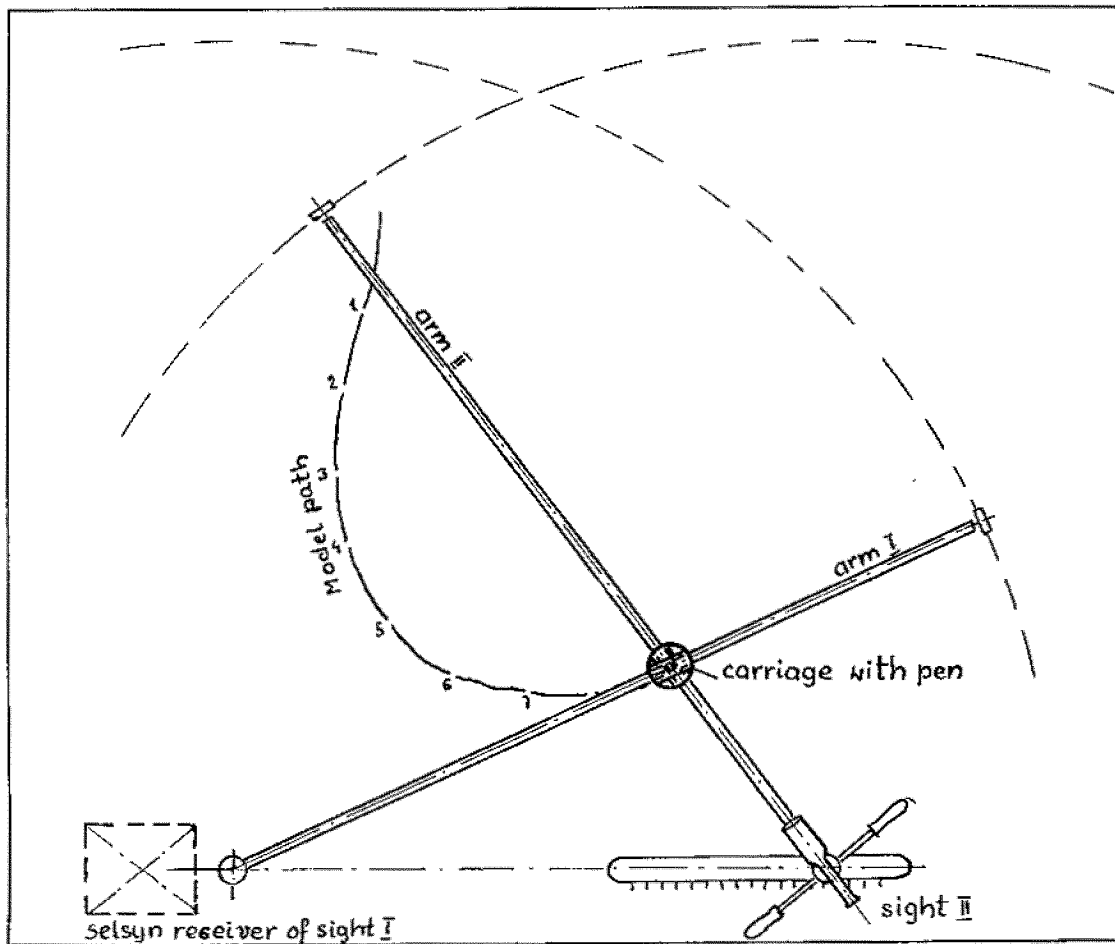


FIG. 3.  
Scheme of the Pathgrapher.

which are measured on the model with the aid of a special instrument called "driftmeter".

3.3. *Driftmeter.*

This instrument is designed on the basis of a weathercock. It consists of a light, hydrodynamical nobalanced fin fixed under the hull of the model. This fin always is parallel to streamlines, then to the velocity vector in given point. On the shaft of the fin there is a potentiometer connected with a pointing instrument. In this matter are obtained the angles between the axis of the model and the velocity vector i.e. the drift angle. Because the driftmeter may be located in any points of the model, it is possible to obtain the distribution of the drift angles or speed along the model.

3.4. *Dynamometer.*

In Ch. N.A.P.G. there is used the three-component rudder-dynamometer. Forces  $X_r$  and  $Y_r$  and torque on the ruddershaft are measured with the aid of elastic elements with electrical tensiometers. It is not very convenient in use, because they are very sensitive on the influence of the humidity and temperature.

4. *Some contributions to the indices of manoeuvrability.*

The results of turning tests for use by designers and seamen are given on the form of the graphs  $D/L = f(\delta)$  at  $v = \text{const}$  for several speeds and as graphs  $v_o/v = f(D/L)$  and  $t_o = f(D/L)$ . Index  $t_o$  means the time of full turning ( $360^\circ$ ) expressed in non-dimensional form (as unit it applies to the time of passing the way of

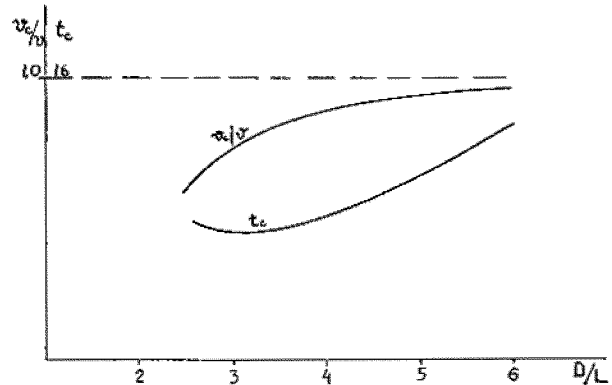
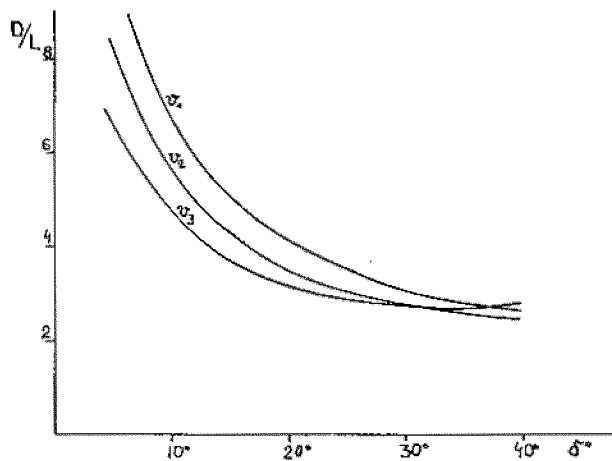


FIG. 4.  
Some results of turning tests of a tug.

length of the ship). Both last graphs are important by estimating the tactical properties of a ship, because the smallest diameter of turning means not always the most speedy turning (Fig. 4).

The course stability and reaction of the ship on the rudder is defined on basis of the Davidson's [3] test and of the "zig zag" test of Kempf [5] as the most comprehensible for majority of constructors and captains.

It seems that the indices K and T proposed by Nomoto [6] can be adopted in the future. Now, there are known few statistical data for comparison and it is difficult to use it in practice. But, it seems that special attention should be paid to the problem of the inertia moment of the mass of the ship. The analysis carried out by the author permits to assume, that for instance the error of the index T, denoted as

$\Delta T = \frac{(\Delta i)^2 + 2\Delta i}{1 + k'}$  where  $\Delta i$  is the relative error of the inertia radius of the model relatively to the ship and  $k'$  coefficient of virtual mass of ship.

It is hoped it will soon be possible to publish some results of the tests with models of a tug and icebreaker conducted by means of these apparatuses and scheduled for fullscale. It is also hoped, the discussion will give many valuable indications for our future work.

Denotes

- CG Center of gravity of ship.
- D 2R.
- L Length of the ship.
- M Virtual mass of ship.
- $M_p$  Turning moment arising from no-coaxial acting of propeller thrust.
- R Radius of steady turning circle.
- T Propeller thrust
- $X_h$  Longitudinal component of hydrodynamical force acting on the hull.
- $X_r$  Longitudinal component of hydrodynamical force acting on the rudder.
- $Y_h$  Transversal component of hydrodynamical force acting on the hull.
- $Y_r$  Transversal component of hydrodynamical force acting on the rudder.
- $m$  Distance between  $Y_r$  and CG.
- $n$  — —  $Y_h$  and CG.
- $v_0$  Velocity of ship in steady turning.
- $\beta$  Drift angle.
- $\delta$  Rudder angle.
- $\varphi$  Heading angle.

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Nils H. Norrbin\* (1)

THE METHODS USED FOR THE TRACKING OF RADIO CONTROLLED MODELS  
IN THE SSPA MANOEUVRING LAKE

## 1. INTRODUCTION

In the introductory remarks on the subject of manoeuvrability [1], Mr. Dieudonné has pointed out five different items, (a-e), which are all suggested for future studies by the ITT Conference. This short paper will be a contribution to items b) and c), i.e. to the survey of existing resources and the examination of experimental methods used for the investigation of model manoeuvring; in particular, it will be confined to a description of the methods used at SSPA for the tracking of free-running ship models, the manoeuvring equipment and instrumentation of which are controlled by radio from a shoreside station.

It is hoped that it will soon be possible to publish the comparative results of some turning circle tests and stopping manoeuvres, carried out with a model of a cargo liner last year and scheduled for full scale repetition this summer, thus contributing to the item d). With regard to the other points noted by Mr. Dieudonné works along different lines are also at hand. SSPA has for some time been engaged in an investigation of the manoeuvring qualities of ships, and a survey report was recently issued, [2]. For many years the measurement of stationary forces on submerged models in oblique towing was been a routine at the tank. Future tests with captive models of merchant ship form are also planned, and SSPA has initiated a close co-operation with the Swedish shipyards on the performance and analysis of manoeuvring trials, [3]. Turning tests with free-running surface models were first begun in 1956, the controls then being operated by a man on board; ratio control was introduced in late 1958.

As there is no proper basin for manoeuvring tests at SSPA, the models are brought by lorry to a temporary station, located at a small lake outside Göteborg. It follows that in the lake there is navigating space enough even for the largest models desirable from considerations of scale effects in flow phenomena.

For ease of handling the length of the models will not exceed 5,5 to 6 m, however, undoubtedly it will be necessary to accept the use of smaller models whenever permanent indoor facilities will be realized.

The model propulsion unit consists of a constant r.p.m. petrol engine and a Ward-Leonard generator-motor set, geared to the propeller shaft and permitting a multistep speed and reversing control. The steering engine is designed for progressive control, also properly scaled to model time; the momentaneous rudder position is displayed to the radio operator on shore by means of a FM telemetering system. As it is in some tests necessary to avoid the scale effects due to time lags in manual operation, there has now been added a mechanical programmer for speed and rudder control, which can be started and stopped by radio, as can also recording equipment on board the model. The r.p.m. of the propeller, the rudder position, the rudder forces and torque, the rate of turning, and the position of a drift angle vane may all be recorded by a SFIM oscillograph. The angle of heel is read from rollfilm shots by a camera, incorporated in the tracking equipment.

The manoeuvring motions of the model are obtained from a set of records of its successive bearings, observed by two theodolites on shore, and from the photographs taken from the model. Although, thus, adhering to well-known principles, the method includes some novel features, which simplify an accurate and rapid plotting of the manoeuvre.

## 2. BASE ANGLE TRIANGULATION

In Fig. 1 is shown how the position and orientation of the model at each instant are defined by the two base angles,  $\varphi_A$  and  $\varphi_B$ , and by the heading deviation from a suitable target table,  $\chi_s$ , simultaneously recorded. The shoreside leg,  $\overline{AB}$ , is measured by a steel yard to the nearest 0.1 m, i.e. usually correct within 0,05 per cent of its length. The fixed positions of the numbered targets are carefully determined by triangulation, too, using the base angle recorders.

To indicate the accuracy of the triangulation method, and the demands on angular resolution, altitude curves

\* Not in attendance.

(1) Principal Scientific Officer at the Swedish State Shipbuilding Experimental Tank, Gothenburg 24.

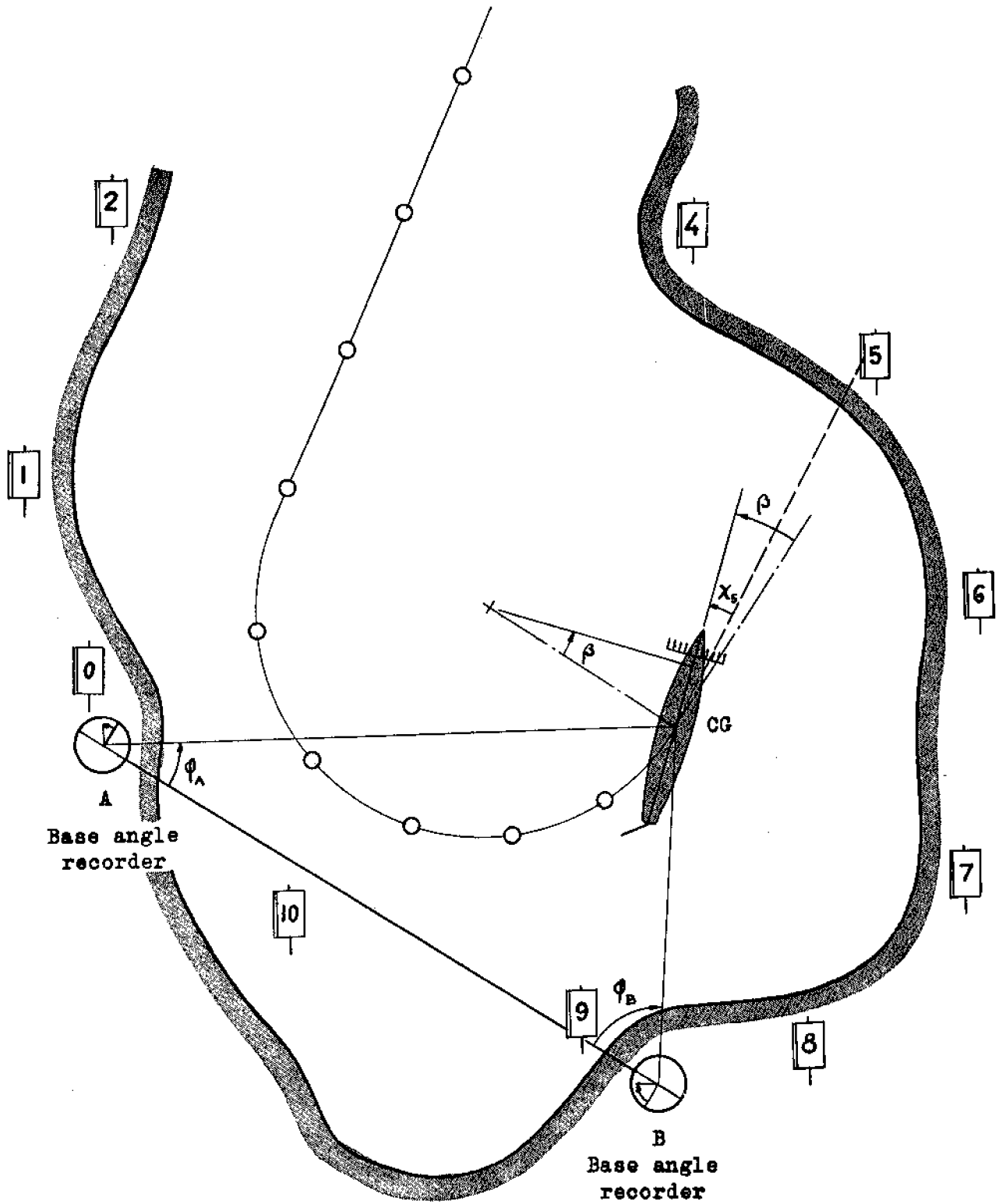


FIG. 1.  
Schematic view of model in lake, illustrating the tracking method.

MANOEUVRABILITY FORMAL DISCUSSION

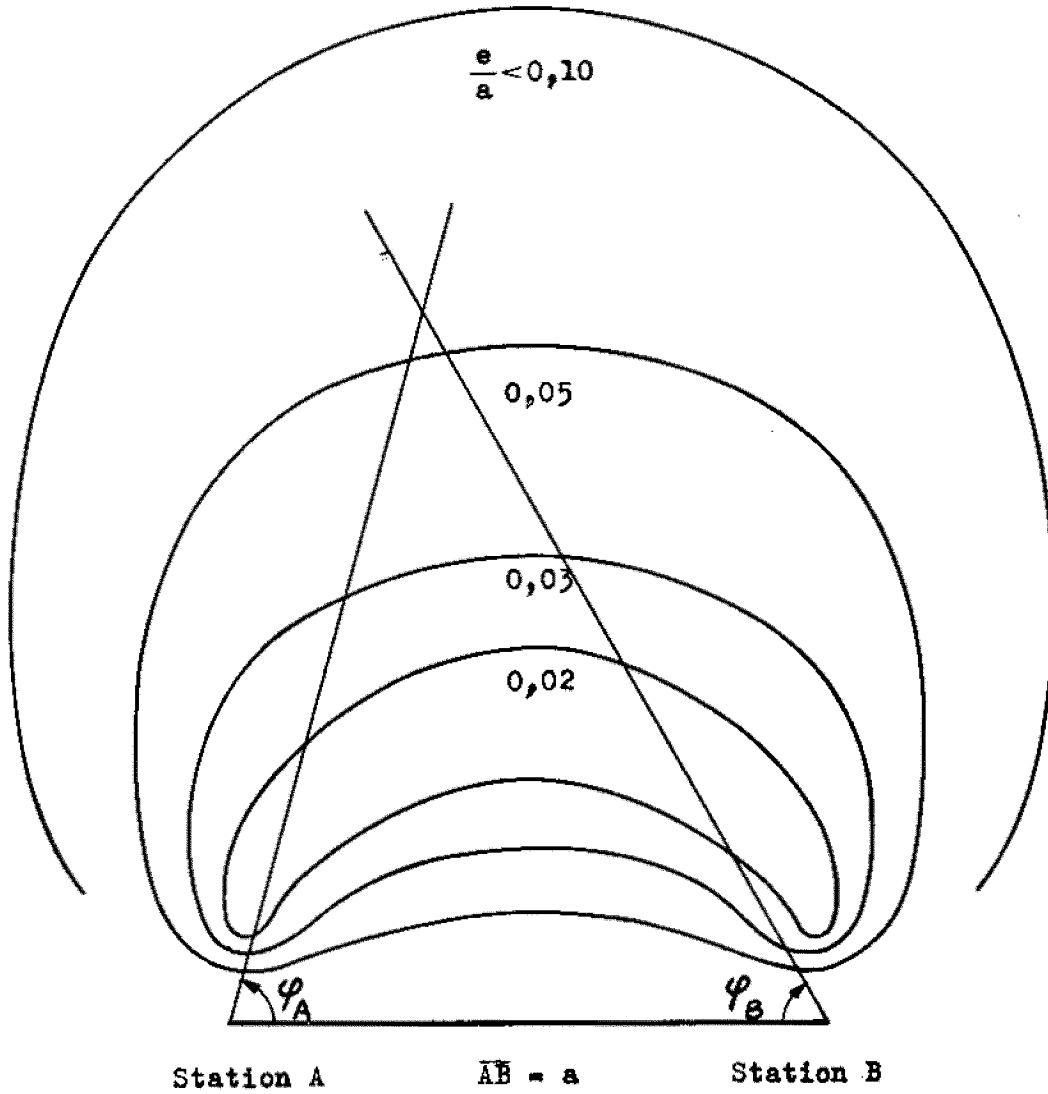


FIG. 2.

Accuracy of triangulation method.  
 Altitude curves of maximum positional errors expected  
 for a one degree base angle error.

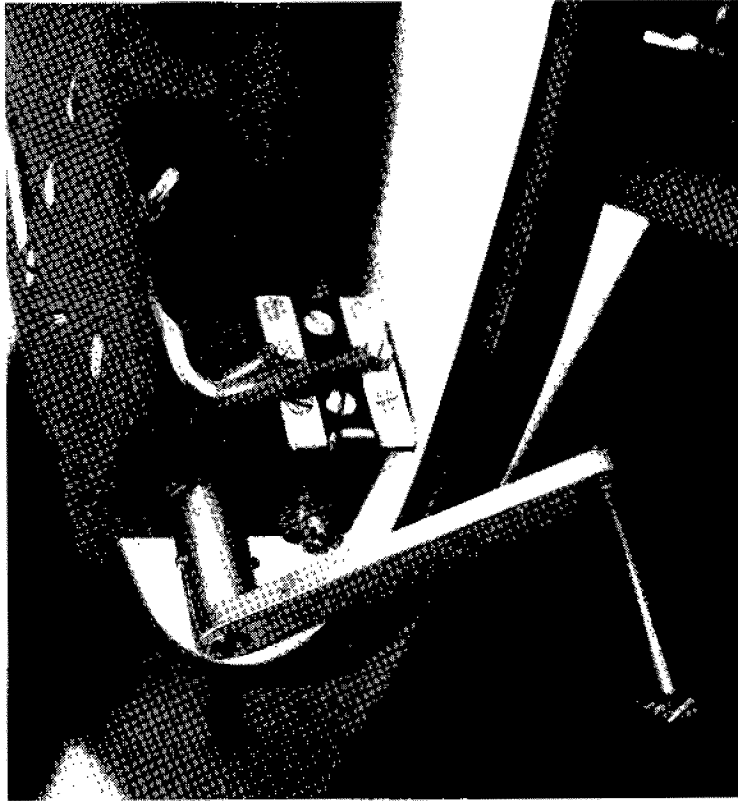


FIG. 4.  
Detail of base angle recorder.

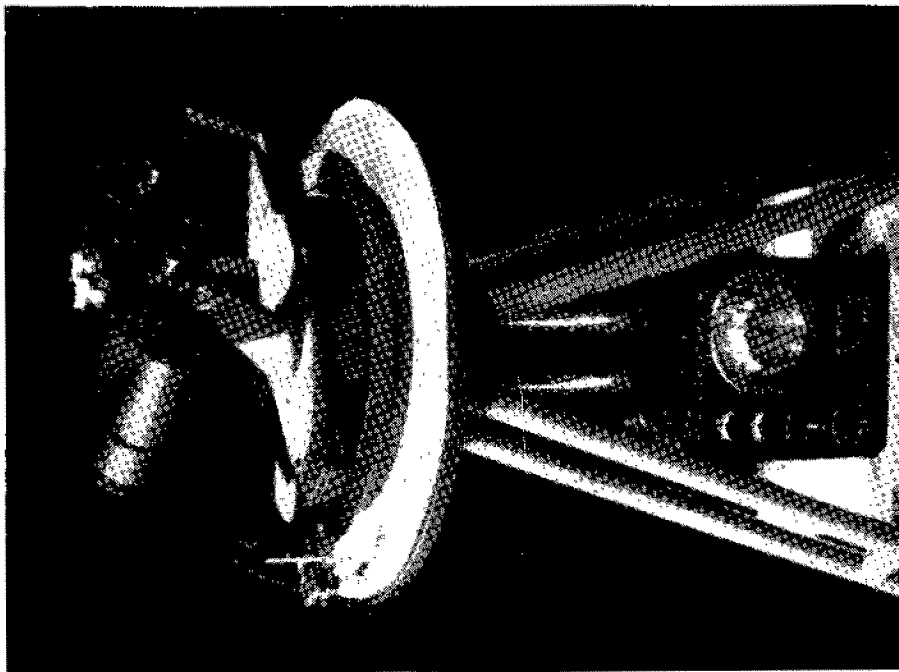


FIG. 3.  
Base angle recorder with timer.

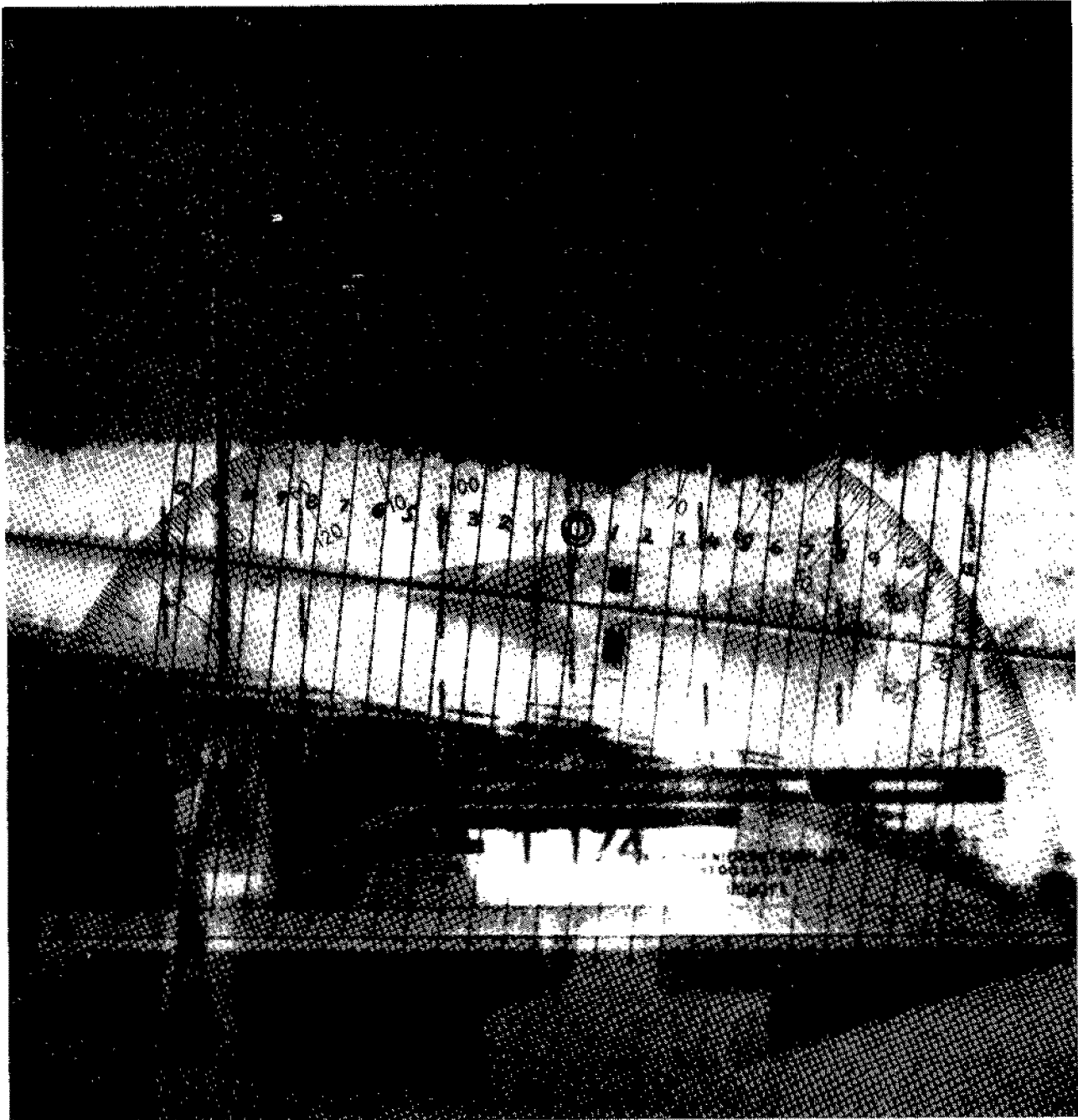


FIG. 6.

Typical scene of camera record.

Photograph shows record as seen in the projector, in which an angular protractor and a graded scale are used for reading off the angles of heel and heading.

of the maximum positional errors expected have been calculated by the formula:

$$\frac{e}{a} = \Delta\varphi \frac{\sin \varphi_B}{\sin(\varphi_A + \varphi_B)} \cdot [1 + \{|\cot \varphi_B| + 2 \cdot |\cot(\varphi_A + \varphi_B)|\}^2]^{1/2}$$

and drawn in Figure 2. It is seen that the absolute value of the error depends on the selection of base distance in relation to manoeuvring area as well. For most tests a base distance equal to 20 times the model length has been found adequate; the relative positional error corresponding to a one degree base angle error then is  $\frac{e}{a} = 0,05$  or less in the area covered. In order to reduce the errors to the order of, say, one model breadth—more or less related to the full scale exactness offered by the Decca Navigator method in fitting areas—it is then necessary to keep base angle errors within a fifth of a degree.

When operating the theodolite (here also named base-angle recorder) the observer just keeps wheeling a handle so as to make the crosshairs of the binoculars always to coincide with the mast of the model, whereas a pen will record the bearing at repeated signals from a timer. It has been found that, by use of suitable gearing and handle size, it is possible to follow the mast within an error usually not exceeding 2 per cent of the model length, or within a tenth of a degree, part of this error being an almost systematic lag or lead. No correction is made for this error, although in some full scale investigations such a correction is achieved by photographic records of the mast, [4]; it would of necessity complicate and delay the evaluation, however. Thus, a resolution of another 0,1 degree is left to be desired in the plotting process. To assure that the smallest possible errors should then be added to the bearings initially recorded, the original pen records are transferred straight on to the plotting table, as will be further described below.

A photograph of one of the base angle recorders is reproduced in Figure 3. Essentially the instrument consists of a tripod platform table with a centre pivot tap, on top of which table rests a frame with a movable lever carrying the binoculars and recording pen. This frame is easily removed when placing the recording paper on to the table, a new paper being used for each run and fixed in its position by the centre tap and a guide pin, and by the weight of the frame.

The frame lever rotates on a centre slide bearing and on special ball bearings in an outer slit in the

frame. In Figure 4 is seen the turning handle with gear box and rubber friction rollers clutching the outer flange of the frame. The pen writes a continuous arc line at a radius of about 160 mm, marking the timer signals in an outward or inward direction from this line; the direction depends on the direction of change of model bearing, and the reversal of the pen relay voltage is accomplished by means of a simple friction conveyer switch, attached to the handle gear box and also seen in the figure. To make it possible to distinguish between two successive sweeps in the same direction and over the same range of angles a thin strip of celluloid is used to change the relay magnet gap and the stroke of the pen. The number of repeated signals simultaneously transmitted to the two recorders and, by radio, to the instrumentation on board the model, usually ranges between 20 and 30 in each run, if an interval of 5 seconds is used; it is recorded by an electromechanical counter in the timer (seen below the base angle recorder in Fig. 3), thus making it possible to check any doubtful records.

Before starting a series of tests the observer at station A adjusts the pen of his instrument on to a base line index, printed on the recording paper. He then turns the platform table until the crosshairs of the binoculars are seen against the recorder at station B, in which position the table then is locked. In the same way the observer at B sets his instrument. The base line bearings are checked between each run. The centre angle from the base line to an individual pen marking is equal to the base angle desired for that model position; it is a characteristic of the method that no figures are read from the records, however.

### 3. PLOTTING OF MODEL PATH AND ORIENTATION

When plotting the manoeuvre the paper records are layed on a special plotting board, on which there are the same centre taps and guide pins fitting the papers. The tap distance is constant, 300 mm, and therefore determines the scale of the graph. The plotting procedure is illustrated in Fig. 5, showing the pivoted rulers for triangulation, using original data only.

After fairing a curve through the plotted spots, the orientation of the model must now be found from the drift angle vane measurements recorded by the SFIM oscillograph, or from the films recorded by the 24 × 24 mm Robot camera on board the model. This camera is also used for the registration of heeling angles. It has a standard relay equipment and a

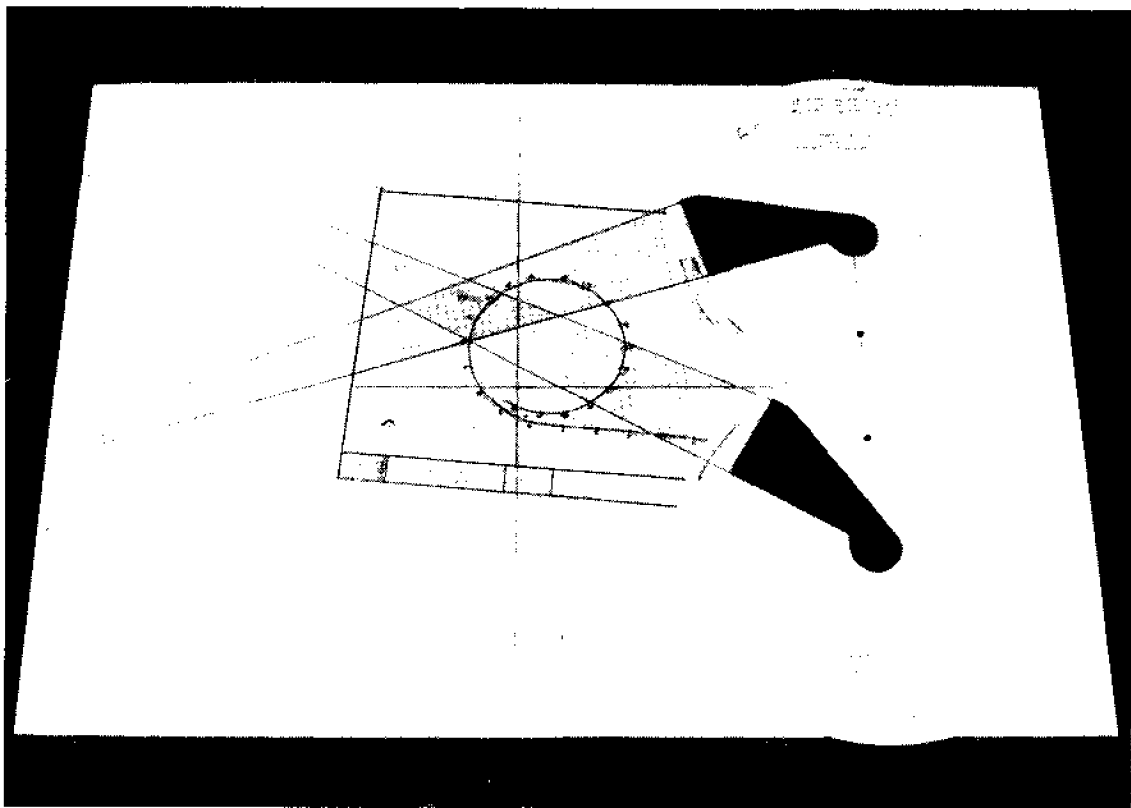


FIG. 5.  
Plotting of triangulation records.

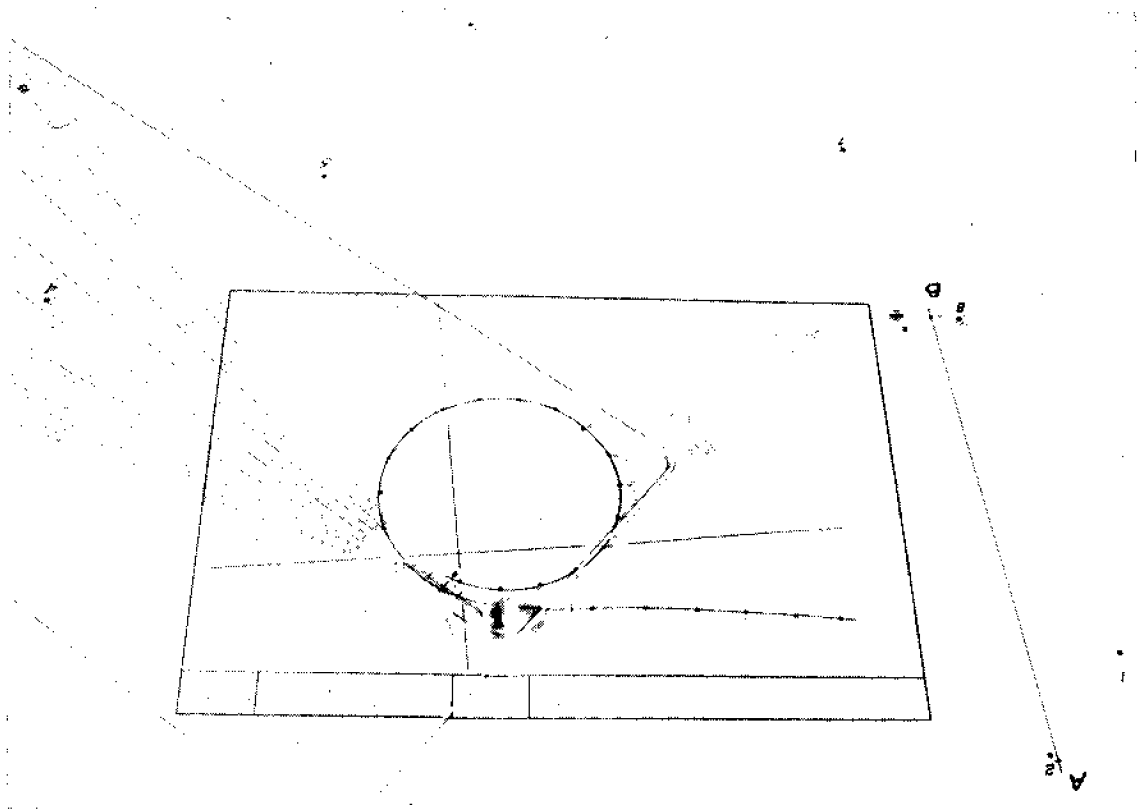


FIG. 7.  
Orientation of model heading as recorded by camera method,

magazine for 55 successive shots, which is usually sufficient for two test runs, after which the model must therefore be brought to shore. The oscillograph paper magazine permits up to six or eight circle tests to be performed in a sequence, however. (All instruments onboard the model are started and stopped by radio control.) As, in general, a fairly good agreement has been found between the drift angles as obtained from direct vane measurements and from camera records, it is not necessary to interrupt the testing unless information of heeling angles is also desired. The camera method only will be described here, however.

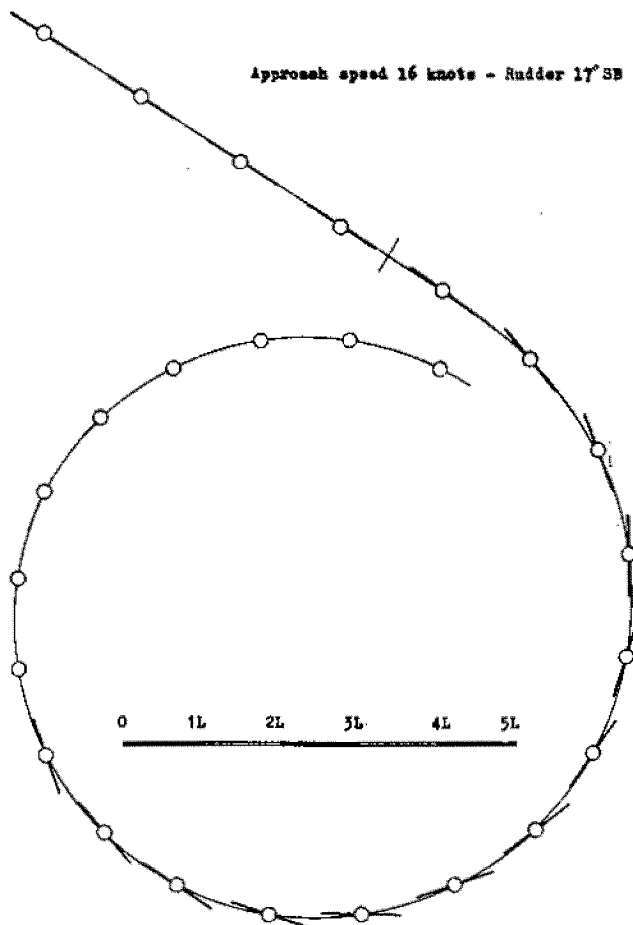


FIG. 8.  
Turning path and drift angles  
of single screw cargo liner model.  
(Example of plotted graph.)

Near the bow and at a known distance in front of the camera is placed a ladder screen, which, together with a test code number, is photographed against the beach line and the numbered targets distributed along the shore. A typical scene is shown in Figure 6. When reading the films in a projector a transparent protractor and a network, copied from the upright screen, both are positioned over the picture and used for reading off the angles of heel and heading respectively, as shown in the figure.

The last step in plotting the model orientation is reproduced in Figure 7. The graph obtained from the plotting board is now adjusted in its correct position on a large table, where the numbered targets are also marked. By means of a special graduated ruler a set of short lines representing the model is easily drawn through the individual spots of CG positions. The completed graph is seen in Fig. 8.

#### 4. SUMMARY

Following a short review of the work at hand at SSPA in the field of ship and model manoeuvrability, here is a description of the methods and equipment used for tracking models in steering tests. The special features of this method, which may also be used in full scale trials, are inherent in the expedient and accurate handling of original triangulation data, achieved by the design of the base angle recorders and simple plotting devices.

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A. Suarez and J. Breslin

COMMENTS CONCERNING ZIG-ZAG AND SPIRAL MANEUVER DATA

INTRODUCTION

The design and development of surface craft in the past has been basically concerned with improvements aimed at obtaining low drag forms. The problems of manoeuvrability and controllability, until the last decade, were never considered as a major design criteria. The trend in most ship designs has been dictated by ship operators who are basically interested in having the greatest cargo carrying capacity for any one vessel with the lowest construction cost. This trend has led to extremely full forms which, in general, have poor handling characteristics. As long as it could be steered by present standards, each vessel was accepted regardless of its ability to maneuver. Only special types of high-speed racing craft have been known to be concerned with stability and maneuverability by utilizing air-stabilization surfaces and special rudders.

In an article published by Lloyds Registry some two years ago, it was ascertained that there are at least 1000 ship accidents per year. Some of these accidents can be associated with poor operating judgement, unusual circumstances, etc. It can also be said that, since little effort has gone into the problems associated with the handling qualities of vessels, some of these accidents could have been avoided if manoeuvrability and controllability qualities were originally considered in the design of vessels. The value of safe handling qualities of ships has never been considered in the establishment of insurance rates.

The Society of Naval Architects and Marine Engineers Controllability Panel (H-10) has undertaken the task of developing the necessary research and classification techniques in order to establish information which can be of use to naval architects and ship operators and thus permit the evaluation of manoeuvrability and controllability of new designs and existing ships. This panel is also concerned with setting forth specifications for acceptable handling qualities. It has tried to interest insurance companies to include some consideration in the determination of premiums based on relative handling qualities of the various vessels insured.

The H-10 Panel is now soliciting various ship operators in order to obtain full-scale data to aid in clarifying acceptable limits of handling qualities. Specifically, the data being requested are that obtained

from the spiral and zig-zag maneuvers suggested by Dieudonné [1] and Kempf [5]. It is expected that the data obtained from these two maneuvers will supply information concerning controllability and manoeuvrability. These data are not expected to provide an understanding of the hydrodynamic nature of the contributing factors, but will help to establish a relative measure from vessel to vessel. It is the intent of this panel that these data can be obtained during the normal operation of the vessels without additional cost to operators.

The tools and techniques for the determination of spiral and zig-zag maneuvers from model studies are at present in existence and can be gainfully employed to aid naval architects in new designs. Free-running self-propelled models equipped with the proper instrumentation, or data obtained with a captive model in which all of the forces and moments are measured, can be used to obtain the various maneuvers. The qualities determined by these methods are not, as yet, in sufficient quantity or reduced to simplified forms so that evaluations can be made in the initial design stages. The present design procedure is somewhat of a "cut-and-try" process and must await refining before requirements for handling qualities can be incorporated in the preliminary stages of design.

SPIRAL AND ZIG-ZAG MANEUVERS

The results of spiral and zig-zag (serpentine trajectory) maneuvers may produce qualitative measures of directional stability and controllability of a vessel. Spiral tests permit the determination of the rates of steady change-of-heading as a function of rudder angle, while zig-zag tests indicate the response of a vessel to corrective rudder action. The results of both of these experimental maneuvers will not contribute to an understanding of detailed hydrodynamic factors which cause satisfactory or unsatisfactory characteristics. These maneuvers can also be evaluated from studies of captive models in which the hydrodynamic forces and moments are measured and applied in representative equations of motion.

Gertler and Gover [3] presented a procedure for obtaining spiral and zig-zag maneuver data. A detailed version of this procedure has been incorporated into a request being made by the S.N.A.M.E. Panel

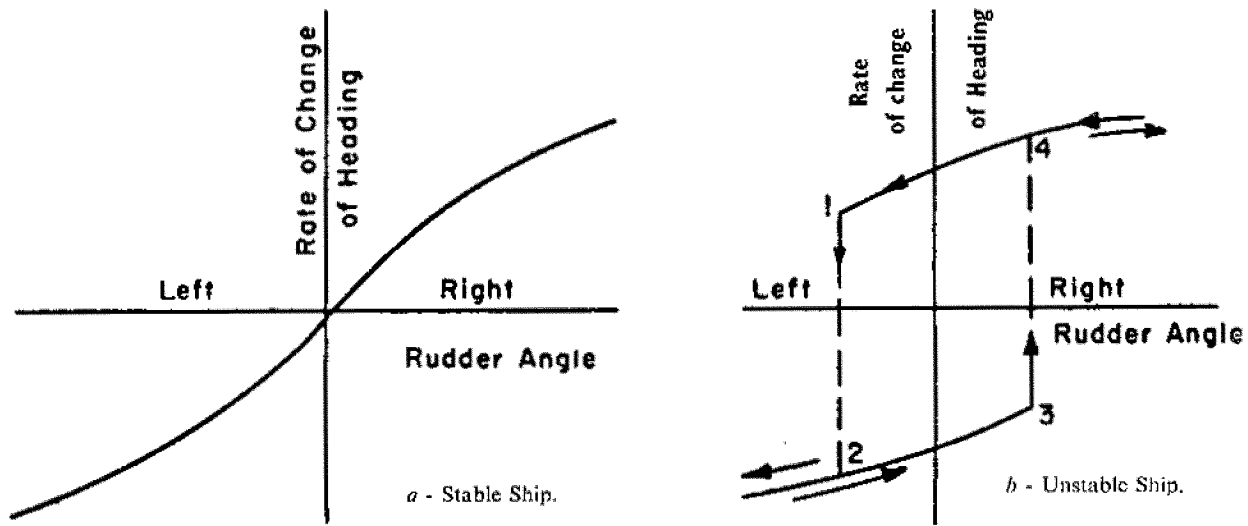


FIG. 1. — Typical Curves from Spiral Maneuvers.

(H-10) in the form of instructions and log sheets to be submitted to ship operators. Gertler and Gover indicated the type of results which can be obtained from these data. For example, for ships that are stable, the results of a spiral maneuver (Fig. 1a) will give a rate of change-of-heading as a continuous function of rudder angle, while, for an unstable ship (Fig. 1b), this function is discontinuous.

This form of investigation does not lead to a determination of the magnitude of stability or instability,  $\sigma_1$ , of a vessel. For example, the slope of the curve in Fig. 1a, which is characteristic of all stable vessels, is directly proportional to the rudder effectiveness, while the height and width of the hysteresis loop in Fig. 1b, which is characteristic of all unstable vessels, is a function of the rudder effectiveness and nonlinearities of the hydrodynamic forces and moments.

The zig-zag maneuver is basically a forced oscillation of a vessel whose space frequency (cycle of heading oscillation per length of ship travel) is a function of the response of the vessel, of the magnitude the vessel is permitted to wander in heading, and of the magnitude of the correcting force (rudder effectiveness). The effects of these items are not separable from the observations of this form of experiment; at best it is possible to obtain the initial departure from a straight course and the amount a vessel will overshoot its heading from the time the corrective rudder action is taken. Fig. 2 is an example of the result that such a maneuver will give.

Gertler and Gover [3] attempted to correlate the results

of such tests for a number of ships based on a vessel length of 500 feet for a 20-20 overshoot maneuver (20-degree rudder correction when the vessel has altered its course 20 degrees from its original heading).

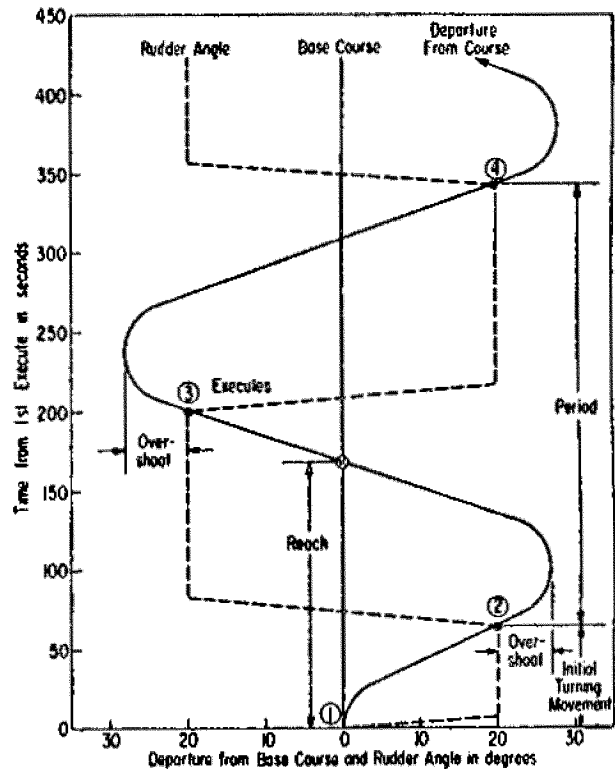


FIG. 2. — Diagram of Overshoot Maneuver.

The time to reach execute-heading-angle in seconds versus speed in knots and overshoot angle in degrees versus speed in knots is shown in Figure 3 which indicates a large scatter as a function of ship speed. It appears that these criteria are not adequate to point out the significant factors contributing to the observed motions.

Both the spiral and zig-zag experiments were devised mainly to obtain, in full scale, with the least amount of test equipment, information of handling qualities which may be useful to ship operators. The results of these tests will certainly establish whether the vessels tested are stable or unstable and the overall response to their rudder action. It is impossible to separate from these results the hydrodynamic contributions that cause satisfactory or unsatisfactory operating conditions. Procedures to obtain full scale data by these experiments, which would lead to hydrodynamic factors representative of any one vessel, would require extensive instrumentation and data reduction techniques. Model studies of spiral and zig-zag maneuvers, which

the necessary measurements is a form of quiescent pool of water with a rotating boom over it to which can be attached a model through a balance system that can be fixed at a number of radii. This form of test facility is commonly known as a rotating-arm basin.

Since rotating-arm techniques are capable of experimental evaluation of the hydrodynamic forces and moments acting on a body, a systematic exploration of hull forms and associated appendages, such as done by Tsakonas (\*), will provide naval architects with the necessary data for considering stability and control in ship designs. This link between hull form, appendages and free or steered motion of a vessel is, at present, lacking so that designers are somewhat at a loss as to the eventual handling characteristics of their designs.

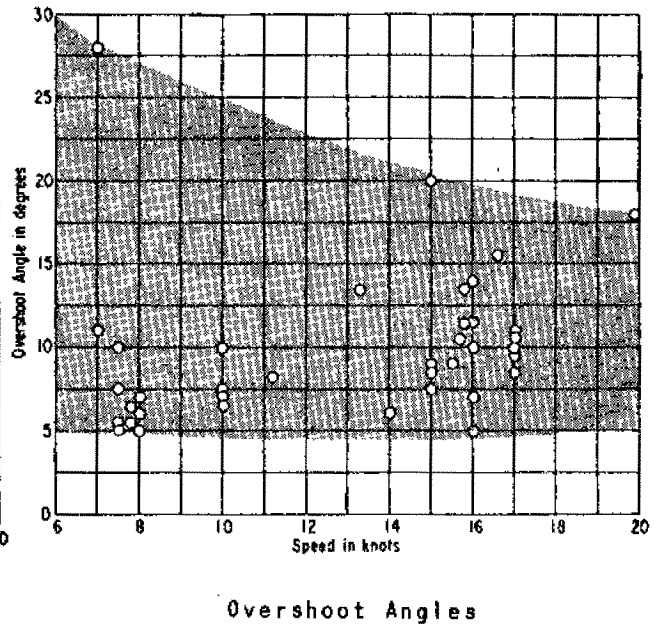
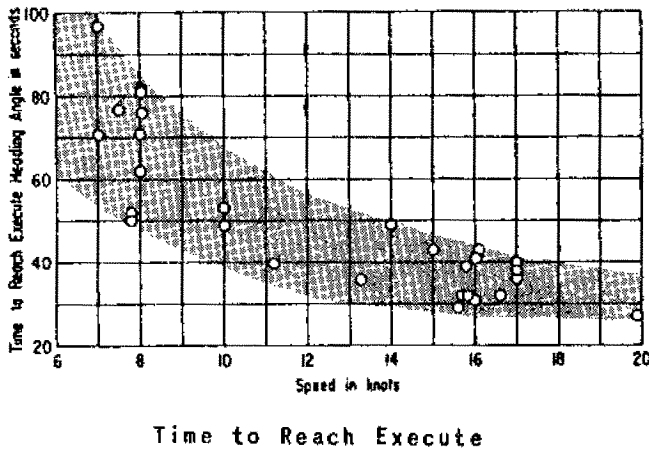


FIG. 3.  
20-20 Overshoot Maneuver.

are, moreover, further complicated by scale effects, would not produce any more knowledge of the hydrodynamic factors but can encompass a greater range of investigation of these maneuvers.

Detail studies of the hydrodynamic factors, from which many forms of trajectories can be calculated, can only be undertaken by captive model studies in curvilinear motion. This form of investigation will supply the various hydrodynamic parameters, both linear and nonlinear, necessary to perform the various calculations. The facility most applicable to obtain

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(\*) See page 664[4].

A. Suarez and J. Breslin.

#### THE DAVIDSON LABORATORY ROTATING-ARM FACILITY

##### *The Davidson Laboratory rotating-arm basin.*

The Davidson Laboratory rotating-arm basin, the first test facility of this form in the United States, has been in operation since 1944 (See Fig. 1). This basin has undertaken hydrodynamic investigations of surface craft, various submerged bodies such as submarines, torpedoes and underwater missiles, and many other forms. The original work performed with this test facility was concerned with naval surface craft. In that connection these investigations supplied the various hydrodynamic parameters from which members of the D.L. staff and Schiff [1] evaluated the dynamic stability, the steady-state turning trajectories, and the initial transients.

Physically, the facility consists of a rectangular tank 75 feet square and 4.5 feet deep with a vertical shaft in the center supported at the bottom by a tripod containing a thrust bearing and at the top by a bearing anchored to the roof trusses. A sleeve is fitted over this shaft and connected to it by a series of keys. To this sleeve is anchored a radial boom and a double rail system 35 feet long supported by a truss to the sleeve. The entire sleeve and supporting truss is vertically positioned by a system of electrically controlled hydraulic jacks. The sleeve has a vertical motion of about three feet with respect to the shaft. This feature permits the raising of the entire model and strut system of a submerged test setup completely out of the water.

The rotating-arm drive shaft is driven by a 20 horsepower, direct current motor through a spur gear reduction system (See Fig. 2). Power to this motor is delivered by a 30 horsepower, direct current generator driven by a 30 horsepower, 60-cycle, alternating current motor. The output of a General Electric "Thymotrol" is applied to the field of the direct current generator to regulate the power output as indicated in Figure 3 which depicts a schematic diagram of the system. Figure 4 shows the various constituents of the D.L. rotating-arm and two test setups, one for surface vessels and one for submerged bodies.

This installation is now capable of driving the rotating-arm boom up to 15 revolutions per minute so that a tangential velocity of 50 feet per second at a

radius of 32 feet is obtained. The drive system has sufficient power to accelerate the boom to its maximum speed (15 revolutions per minute) in about two revolutions. The present testing apparatus (balances and strut systems) for the experimental work performed to date is capable of tangential speeds up to 25 feet per second. The various balance systems in use are capable of resolving three components (longitudinal forces, X, lateral forces, Y, and yaw moments, N—see Fig. 5) and six components (X, Y, N, vertical forces, Z, pitching moments, M, and roll moments, K—see Fig. 6). The carriages to which the balances are attached are mounted on protractors which can be oriented up to  $\pm 45$  degrees in yaw angle (angle with respect to the direction of motion) and locked to the rails at any radius from 8 to 32 feet. There are other auxiliary attachments which will permit positioning the models in pitch and roll.

Experimental determination of the hydrodynamic forces and moments acting on a surface craft are not complicated by unusual tare corrections, while the evaluation of these forces and moments for submerged bodies involve the complexity of eliminating many tare factors due to the necessary model-supporting structure. The forces and moments resulting from the radial acceleration of the actual mass of a surface craft are easily calculable and, with the unique feature of the D.L. rotating-arm, these forces and moments for submerged bodies can be obtained by raising the model with its supporting structure out of water and rotating the entire system in air.

In general, the balance systems at the Davidson Laboratory are of a spring deflection type whose deflections are converted to electrical signals by differential transformers. The maximum deflection of the spring systems will maintain the model within  $\pm 0.1$  degrees of its prescribed attitude about the three  $x$ ,  $y$ ,  $z$ -axes. The maximum motion of the differential transformer cores with respect to their coils is  $\pm .005$  of an inch. Signals generated by the transducers are sent through microphone cables to silver slip-rings and silver graphite bushes and then transmitted "ashore" through microphone cables to recorders.

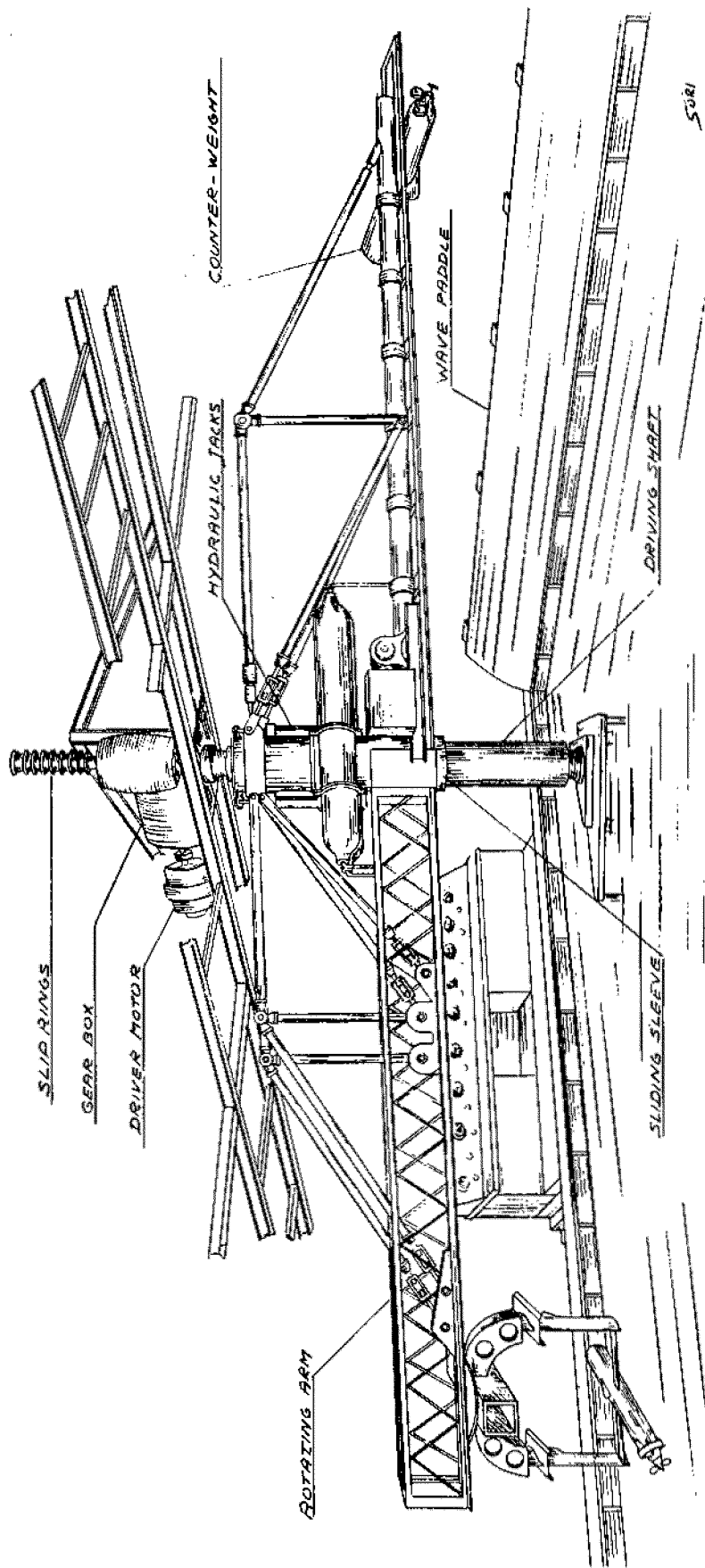
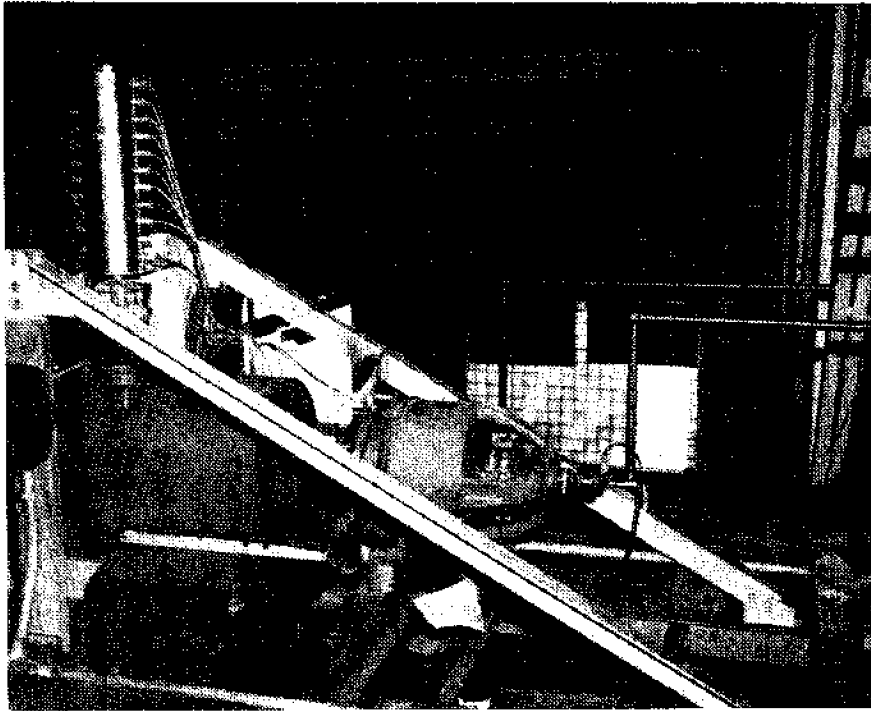
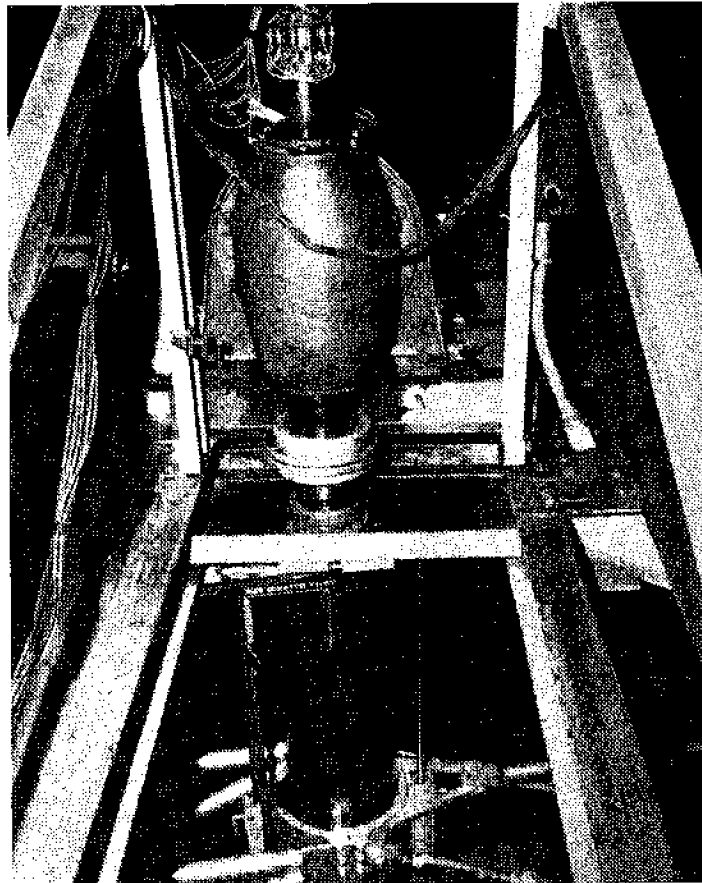


FIG. 1.  
Davidson Laboratory rotating-arm.

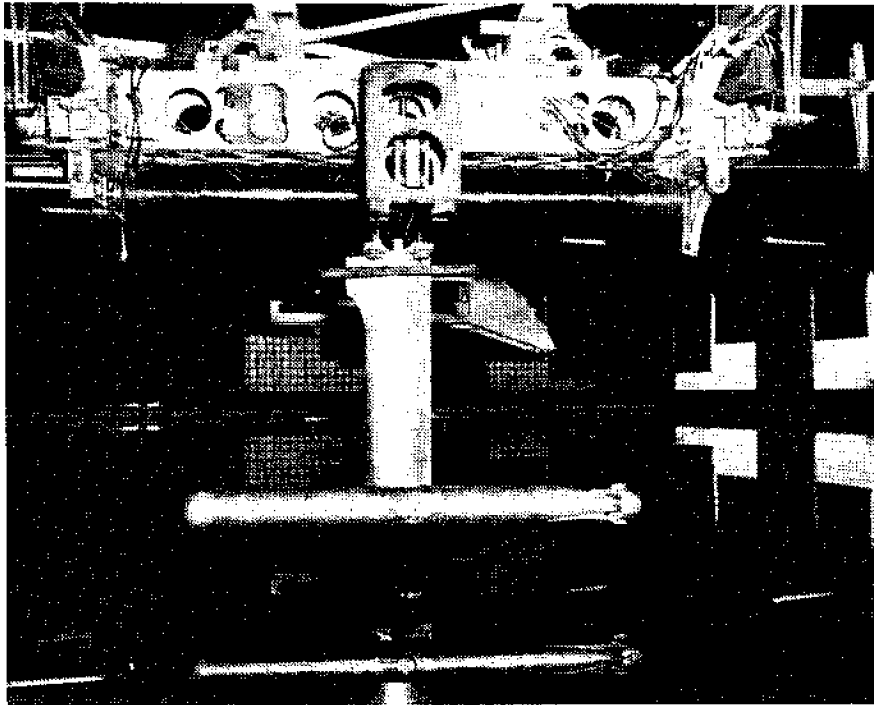


Rotating-arm drive motor

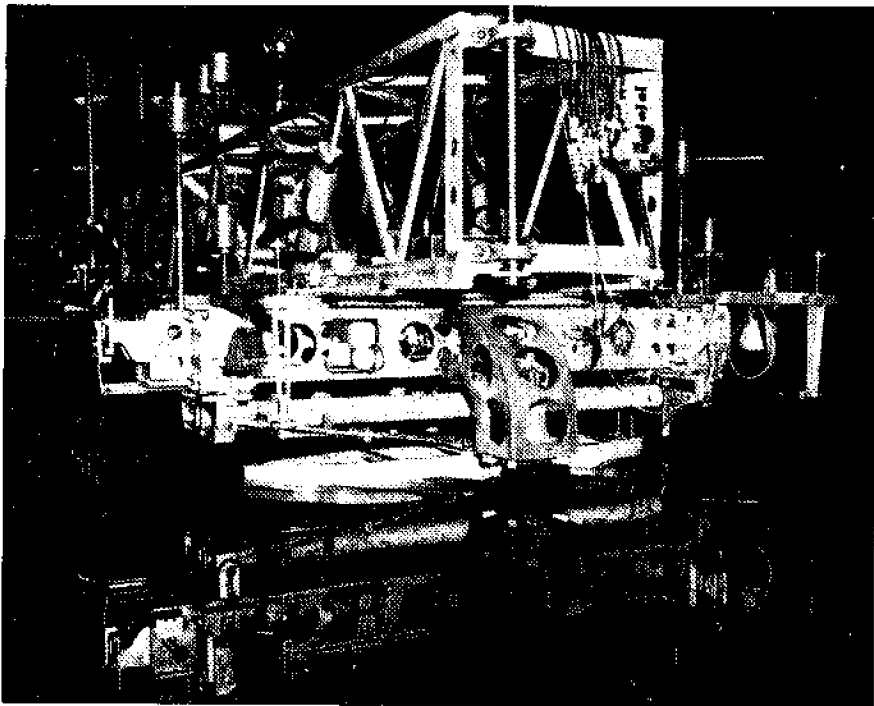


Rotating-arm drive gear box

FIG. 2.  
Photographs of rotating-arm driving elements.



Submerged body setup.



Surface craft setup.

FIG. 4.  
Photographs of rotating-arm test setup.

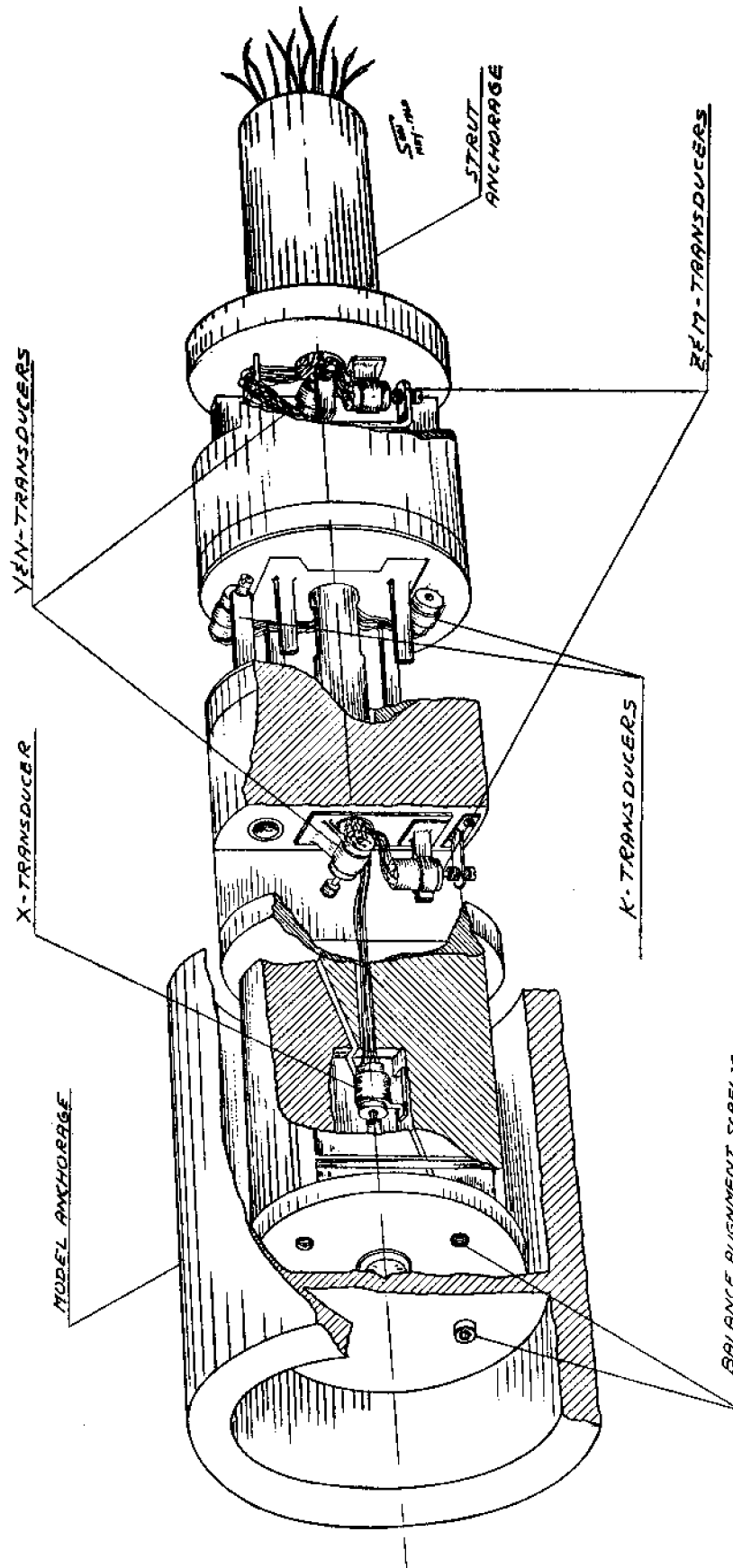


FIG. 5.  
Internal 6-component rotating-arm balance.

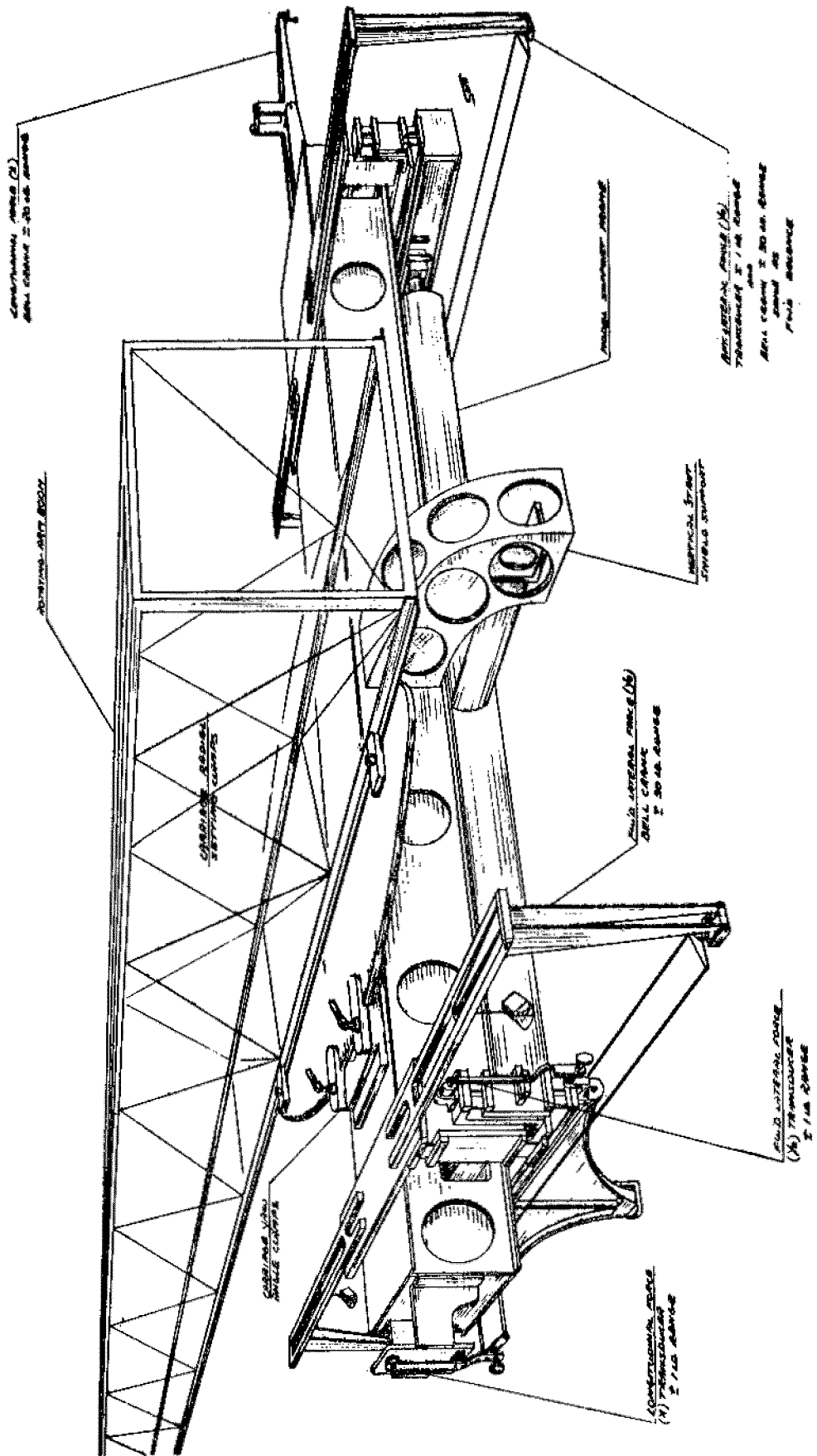


Fig. 6.  
External rotating-arm balance.

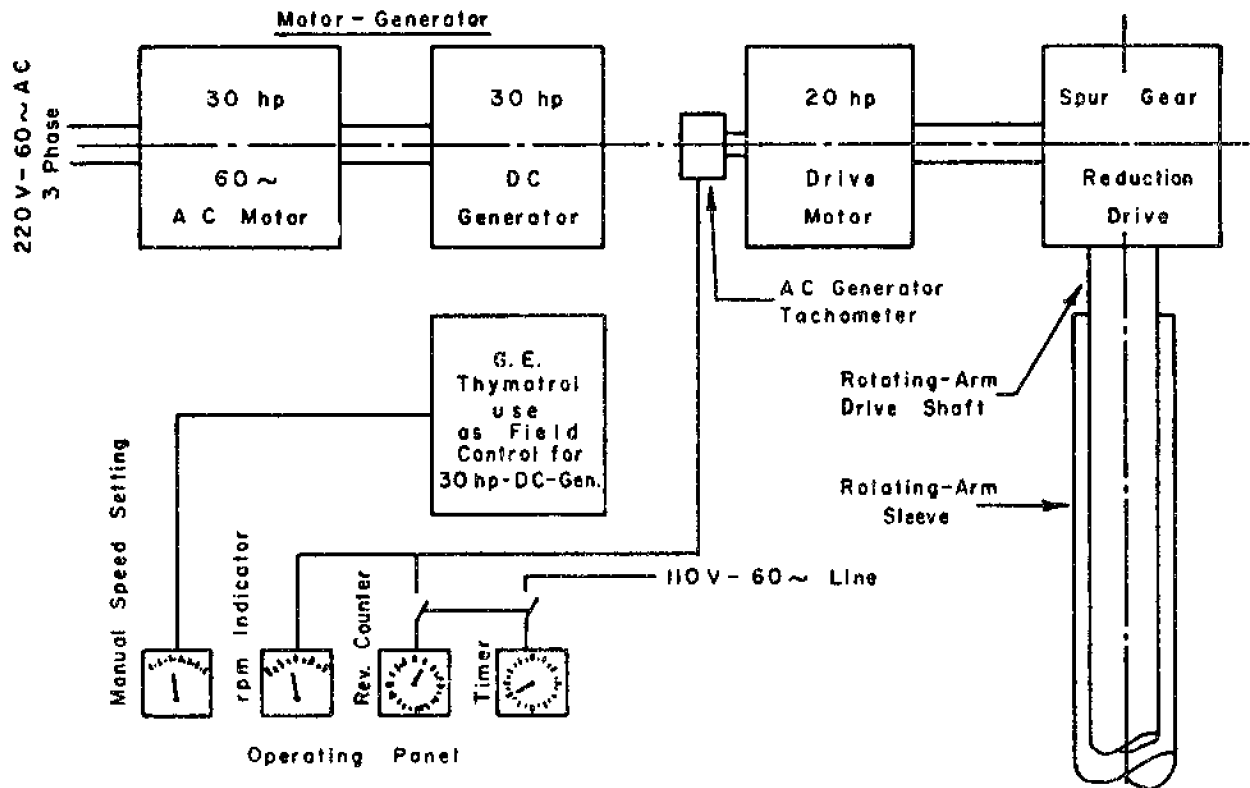


FIG. 3.

Schematic diagram of rotating-arm drive system.

The slip-ring assembly contains three heavy duty power supply rings and 18 signal rings for a total of 21 rings. Each slip-ring has three silver graphite collector brushes bearing on them and are completely electrostatically and magnetically shielded. The entire ring assembly is easily removable as one entire unit for quick servicing. To date there has been no need for more than the present 21 channels. In the event that additional channels are required, it will be possible to use multi-carrier, modulated signals which can permit many more signals to be transmitted to the shore recorders by the proper electronic devices.

(This system has been utilized by telephone companies in the transmission of many signals on single channels.)

The Davidson Laboratory has adopted model sizes of the order of five feet in length in most of its surface craft experimental studies. The submerged bodies have been limited to a maximum length of 5.5 feet and a diameter of eight inches. Within these model size limitations, the surface crafts, in order to maintain their Froude-scale relationship, require force and moment balance systems which will resolve forces to a precision of  $\pm 0.02$  of a pound and moments to  $\pm 0.10$  of a foot-pound. Submerged bodies for deep water

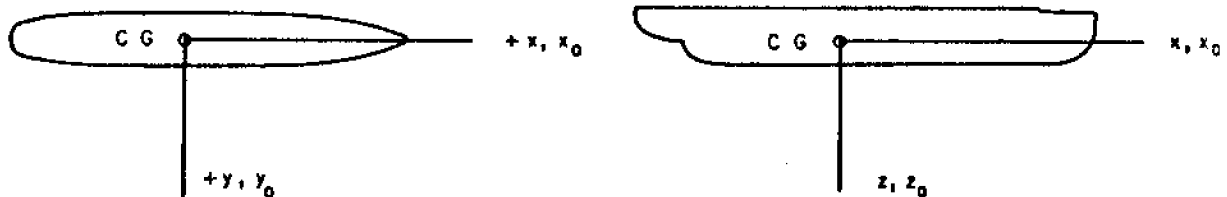


FIG. 7.

Fixed coordinate axes.

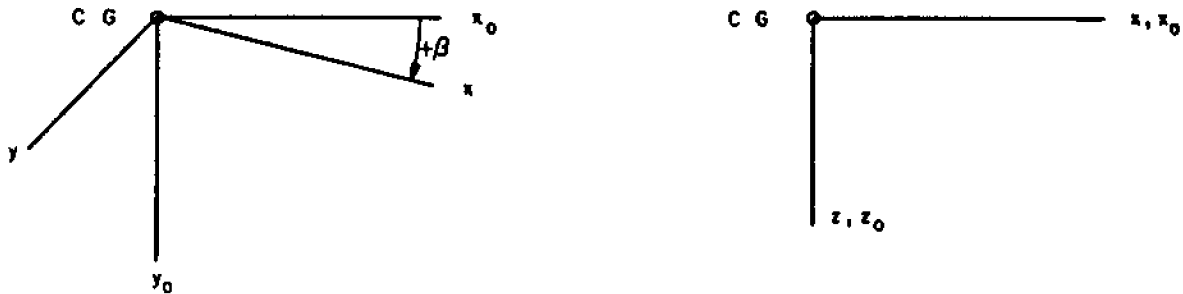


FIG. 8.  
Displacement of body axes.

evaluation are tested at depths of two feet and at speeds above ten feet per second. These conditions are sufficient to avoid major effects due to the free surface and bottom. The external and internal balances used for testing these bodies are capable of resolving forces to  $\pm 0.05$  pounds and moments to  $\pm 0.05$  foot-pounds. Figure 6 shows the external balance systems which have been in use since 1947, and Figure 5 one of many internal balances developed and in use since 1956.

*Typical rotating-arm data for surface craft.*

The following relationships of body orientation with its displacements and forces and moments are

established in order to permit the interpretation of the experimental results.

Assume, as shown in Figure 7, the following reference axes ( $x_0, y_0, z_0$ ) orientation and the  $x, y, z$ -axes locked in the body (Eulerian axes) at the center of gravity; and the following positive displacements of the  $x, y, z$ -axes, as shown in Figure 8:

In addition, assume an angular rotation of the body about the  $z_0, z$ -axes with a velocity,  $U$ , along the  $x_0$ -axis. The  $x_0$ -axis will be considered as being perpendicular to the rotating-arm boom and the  $y_0$ -axis will be regarded as being parallel to the rotating-arm boom located at some radius  $R$ . And finally, assume that the vertical position of the C.G. is unchanged and the body remains level ( $z = \varnothing = \theta = 0$ ).

Now let the yaw angle,  $\beta$ , vary in steps; and then vary  $R$ , and repeat the same step changes to  $\beta$ , as shown in Figure 9. At every one of these fixed conditions make observations of the forces along the  $x$  and  $y$ -axes and the moments about the  $z$ -axis, designated as  $X, Y$ , and  $N$  at the C.G. of the body in Figure 10. For convenience of handling these results, it is advantageous to nondimensionalize  $X, Y$ , and  $N$  in the following forms:

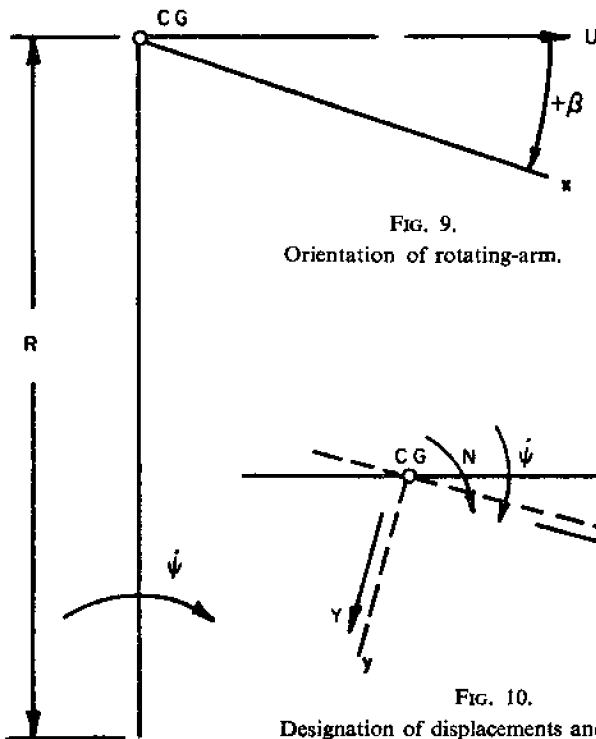


FIG. 9.  
Orientation of rotating-arm.

FIG. 10.  
Designation of displacements and velocities.

$$X' = \frac{X}{l^2 \frac{\rho}{2} U^2},$$

$$Y' = \frac{Y}{l^2 \frac{\rho}{2} U^2},$$

$$N' = \frac{N}{l^2 \frac{\rho}{2} U^2},$$

$$r' = \frac{l}{R},$$

where, as indicated in the basic S.N.A.M.E. nomenclature [2]

- $x_0, y_0$  are the reference axes.
- $x, y$  are the axes along and perpendicular to the ship centerline, respectively.
- $U$  is the instantaneous velocity vector (tangent to the path of the vessel), fps.
- $u, v$  are the velocity components along the  $x$  and  $y$ -axes, respectively, fps.
- $\beta$  is the yaw angle.
- $\theta$  is the pitch angle.
- $\varphi$  is the roll angle.
- $\psi$  is the angle between the fixed axis,  $x_0$ , and the body axis  $x$ .
- $\dot{\psi}$  is the angular velocity of the body about the  $z$ -axis.
- $X, Y$  are the force components along the  $x$  and  $z$ -axes, respectively, lb.
- $N$  is the yaw moment, ft.-lb.
- $X', Y', N'$  are dimensionless coefficients.
- $r'$  is the dimensionless angular velocity.
- $R$  is the turning radius of the CG, ft.
- $l$  is the waterline length of the vessel, ft.
- $\rho$  is the mass density of the fluid in which the tests were made, slugs per cubic ft.

Fig. 11 shows a typical graphical representation of the data obtained for a surface vessel by the above procedure using a rotating-arm.

For a symmetrical body such as a surface vessel, since both  $Y$  and  $N$  are odd functions [ $Y(\beta, r') = -Y(-\beta, -r')$  and  $N(\beta, r') = -N(-\beta, -r')$ ] and  $X$  is an even function [ $X(\beta, r') = X(-\beta, -r')$ ], it is only necessary to perform rotating-arm experiments in one direction of rotation over the same intervals of yaw angle,  $\beta$ , in the positive and negative attitudes. This procedure will permit the fairing of the data through the infinite radius (rectilinear motion,  $R = \infty, r' = 0$ ) region. A cross fairing of the intercepts versus  $\beta$  will result in the equivalent results obtained from similar tests in towing tanks, water tunnels, circulating water channels, etc. The Davidson Laboratory verified the justification of this interpolation procedure with actual experimental data at  $r' = 0$  in its rectilinear basin for a submerged body test (see Ref. 3) and for surface vessels (see Ref. 4). Since the agreement between the interpolated results from the rotating-arm data and the rectilinear basin results were in excellent agreement, the rectilinear testing has been discontinued. It is a standard practice at the Davidson Laboratory to obtain the rectilinear results by interpolation of its rotating-arm data.

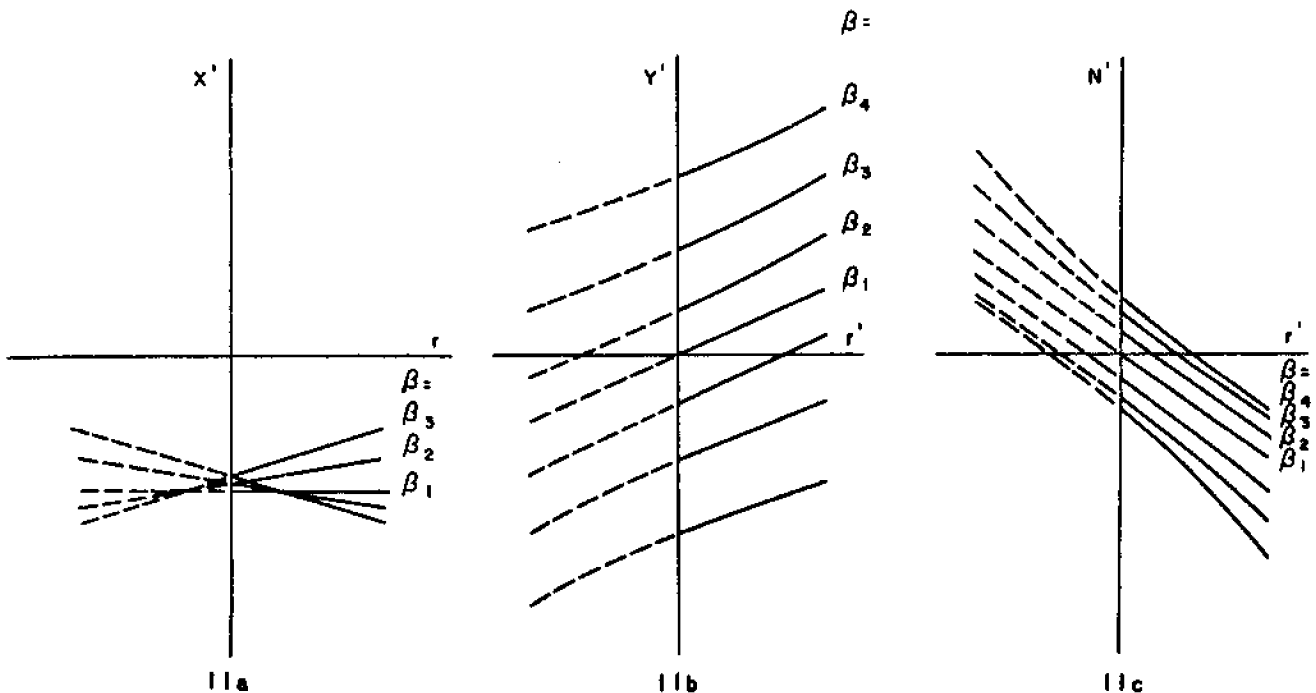


FIG. 11. — Typical form of rotating-arm results.

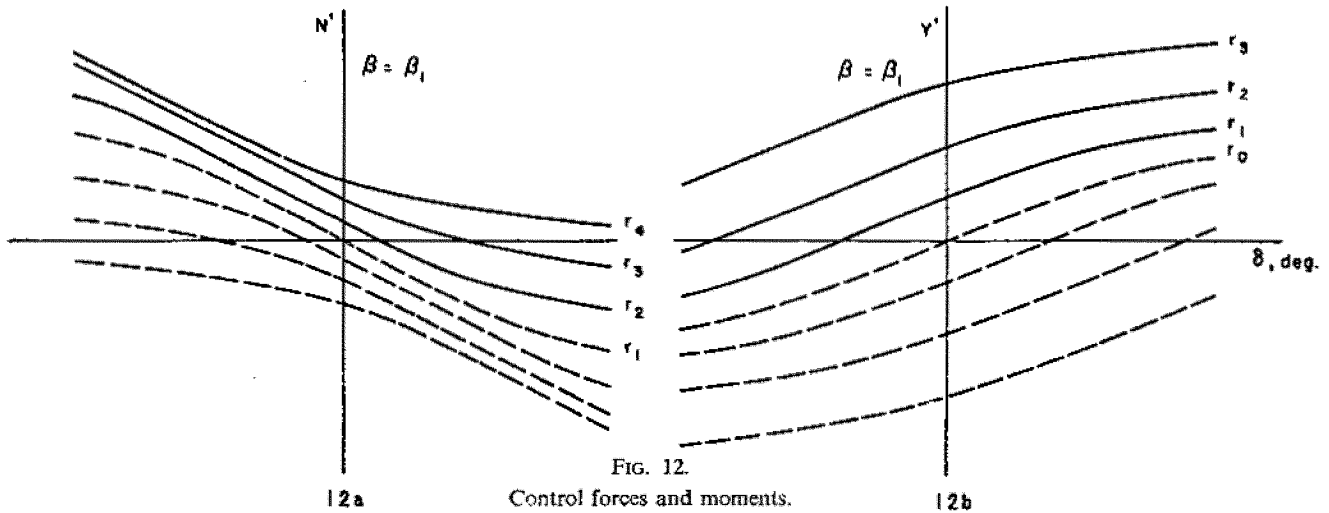


FIG. 12.

Control forces and moments.

From rotating-arm data indicated in Fig. 11b, c, the following derivatives can be readily obtained:

$$\frac{\partial Y'}{\partial \beta} = Y'_\beta, \frac{\partial N'}{\partial \beta} = N'_\beta, \frac{\partial Y'}{\partial r'} = Y'_r, \frac{\partial N'}{\partial r'} = N'_r \quad (2)$$

If, during the experimental investigation of the nature just described, the vessel under consideration is equipped with control surfaces, the contributions to the forces and moments due to angular deflections,  $\delta$ , of the control surfaces are also obtained. Fig. 12 is a graphical representation of the form of the experimental results obtained with a rotating-arm facility for such an investigation. From results of this form, utilizing the reflection technique as previously indicated for  $Y'$  versus  $r'$ , the force and moment control surface coefficients can be obtained, i. e.;

$$\frac{\partial Y'}{\partial \delta} = Y'_\delta \text{ and } \frac{\partial N'}{\partial \delta} = N'_\delta \quad (3)$$

Many additional force and moment coefficients and derivatives can be obtained with a rotating-arm

facility, but, for the present, those necessary to study the motions of a surface craft in a horizontal plane are the only ones considered. In general, it has been found that, for most surface vessels, the various derivatives indicated above are linear over a sufficient range of  $\beta$ ,  $r'$  and  $\delta$  so that a stability analysis, zig-zag maneuver and a spiral maneuver can be calculated from a fairly simple mathematical representation of the equations of motion.

*Equations of motion for uniplanar motion of a surface craft.*

Utilizing the basic S.N.A.M.E. [2] nomenclature, as shown in Fig. 13, the lateral force and moment equations presented by Davidson and Schiff [5] become:

$$\begin{aligned} Y'_v v' + (X'_u - Y'_r) r' - Y'_v v' - Y'_\delta \delta &= 0 \\ N'_r r' - N'_r r' - N'_v v' - N'_\delta \delta &= 0, \end{aligned} \quad (4)$$

and the stability criterion will be:

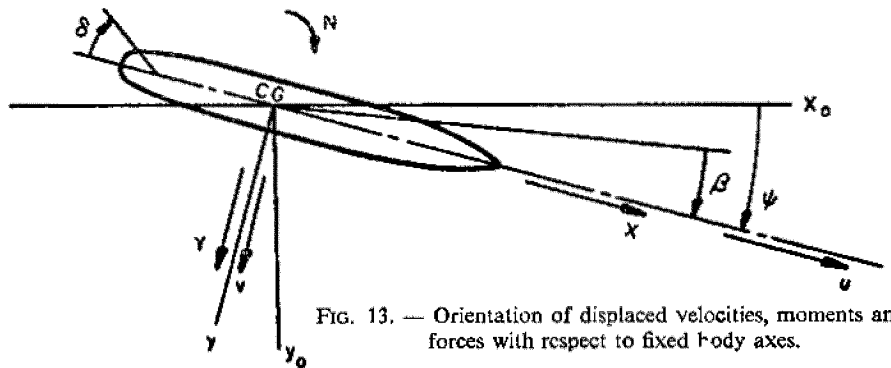


FIG. 13. — Orientation of displaced velocities, moments and forces with respect to fixed body axes.

$$\sigma_{1,2} = \frac{-(N'_r Y'_v - Y'_v N'_r) \pm \{ (N'_r Y'_v - Y'_v N'_r)^2 + 4 Y'_v N'_r [Y'_v N'_r + (X'_u - Y'_r) N'_\delta] \}^{1/2}}{2 Y'_v N'_r} \quad (5)$$

This expression will establish the magnitude of the dynamic stability or instability for the case of a vessel with its rudder held amidships in a calm sea. Since  $\sigma_{1,2}$  are the exponents which will satisfy the original differential equations which have solutions of the form:

$$A = A_1 e^{\sigma_1 s} + A_2 e^{\sigma_2 s} \left( s = \frac{Vt}{l} \right) \quad (e = 2.714), \quad (6)$$

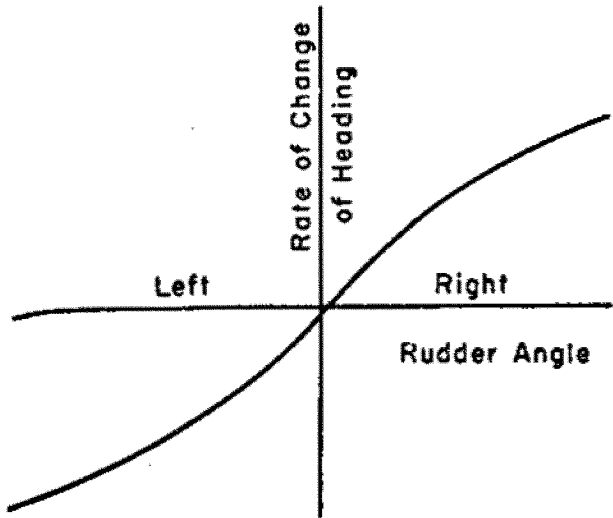
it can be seen that a vessel will be dynamical stable only when both  $\sigma_1$  and  $\sigma_2$  have negative values. In general,  $\sigma_2$  is always a comparatively large negative quantity, while  $\sigma_1$  may be positive or negative. As can be seen from the form of the above solution, an initial disturbance will damp to 1/e of its initial value in  $1/\sigma_1$  lengths if the vessel is stable. The solution also indicates that an unstable vessel, when disturbed, will diverge more and more with each ship length traveled. Since the hydrodynamic coefficients are, in general, linear to rudder angles up to about 15 degrees, the steady-turning radius for a dynamically stable vessel can be expressed as follows:

$$r'_\delta = - \frac{Y'_v N'_\delta - N'_v Y'_\delta}{Y'_v N'_r - N'_v (Y'_r - X'_u)} \delta, \quad (7)$$

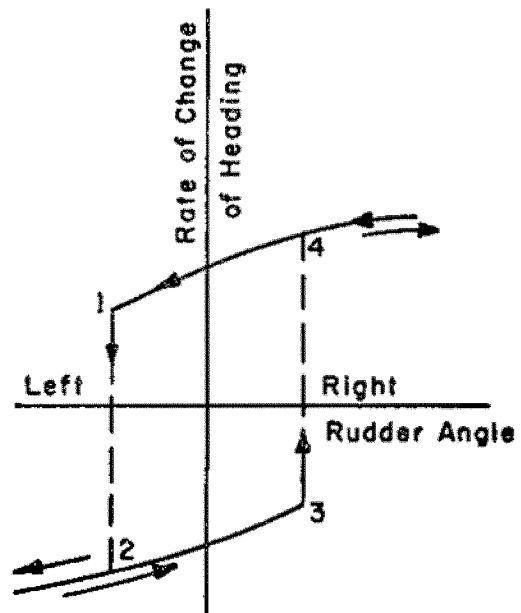
The space angular,  $r'$ , as shown in this expression, is not only proportional to the rudder angle but also is a function of the rudder coefficients  $Y'_\delta$  and  $N'_\delta$  and is inversely proportional to the controlling factor of the discriminant of Eq. 5. The derivative of  $r'$  with respect to  $\delta$  of Eq. 7,

$$r'_\delta = \frac{\partial r'}{\partial \delta} = - \frac{Y'_v N'_\delta - N'_v Y'_\delta}{Y'_v N'_r - N'_v (Y'_r - X'_u)}, \quad (8)$$

shows that  $r'_\delta$  is dependent on the rudder coefficients  $Y'_\delta$  and  $N'_\delta$ . This result is contrary to the statement of Gertler and Gover [6] that "the spiral is a definitive maneuver which is intended to provide quantitative measures of the inherent directional stability characteristics of a ship". From Eq. 8 for  $r'_\delta$  it is evident that the slope of the rate-of-heading-change of a ship,  $\dot{\psi}$ , with rudder angle,  $\delta$ , (Note:  $r' = \dot{\psi}/U$  so that  $r'$  is proportional to  $\dot{\psi}$ ) is directly proportional to the rudder effectiveness,  $Y_\delta, N_\delta$ . The stability of a vessel could remain the same, but the rudder effectiveness can be increased or decreased by changing the size of the rudder and by making corresponding changes in the deadwood aft so that many values of  $r'_\delta$  can be



14a - Stable Ship



14b - Unstable Ship

FIG. 14.

Typical curves from spiral maneuvers.

obtained with the same vessel, i. e., holding the four other parameters in Eq. 8 fixed. Therefore, the results of a spiral maneuver, as suggested by Gertler and Gover [6] do not indicate the dynamic stability of a vessel since the information obtained is insufficient to determine  $\sigma_1$  or  $\sigma_2$ .

The linear treatment of the equations of motion as shown in Eq. 4 through 8 are limited and must be expanded to include higher order terms in order to explore maneuvers for rudder angles greater than 15 degrees for stable vessels. Since unstable vessels will not stay on a straight course with their rudder amidships, in order to explore their turning ability with rudder angle, it is necessary to formulate their representative equations with higher order terms. The results to date from rotating-arm experiments indicate that the hydrodynamic coefficients can be fitted with cubic expressions so that the equations become:

$$\begin{aligned}
 & Y'_v \dot{v} + (X'_u - Y'_r) r' - Y'_\delta v' - Y'_{v\delta} v'^2 - Y'_{rrr} r'^3 - \\
 & - Y'_{vrr} v'^2 r' - Y'_{rrv} v' r'^2 - Y'_\delta \delta - Y'_{\delta\delta\delta} \delta^3 = 0 \\
 & N'_r \dot{r}' - N'_r r' - N'_\delta v' - N'_{rrr} r'^3 - N'_{vrr} v'^2 r' - \\
 & - N'_{vrr} v'^2 r' - N'_{rrv} r'^2 v' - N'_{\delta\delta} \delta - N'_{\delta\delta\delta} \delta^3 = 0 \quad (9)
 \end{aligned}$$

There are no theories at present from which the higher order derivatives can be evaluated so that it is necessary to resort to curve fitting of rotating-arm data.

Since these equations are nonlinear and of the third order, it can be expected that  $\dot{\psi}$ , as a function of  $\delta$ , is of a cubic form, as has been oft verified by both model and full-scale tests. This relationship for a stable vessel will go through the origin, as in Fig. 14a, while for an unstable vessel there will be a double branch to

this function (a hysteresis loop) in the vicinity of  $\delta = 0$ , as in Figure. 14b. The height and width of this loop bears no relation to the magnitude of the instability in the region  $\psi = \delta = v' = 0$ .

With the form of relationship shown in Eq. 9 and with data derived from a rotating-arm facility, it is possible to calculate virtually any form of maneuver prescribed. In the future it may be possible to associate the various hull parameters with the hydrodynamic coefficients and to develop improved theoretical methods as more rotating-arm data become available.

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## INFORMAL DISCUSSION

**The Chairman, Prof. C. W. Prohaska.**

It is for me a great pleasure and a great honour to preside over the proceedings of this first technical meeting. We have before us a written introduction by M. Dieudonné and six written contributions on this subject; they are all regarded as formal contributions and therefore to be taken as read. I find it a proper procedure to ask M. Dieudonné to introduce this subject, which is a new one for the Conference, and it is up to the audience today to decide whether this subject shall continue to be on our programme at our future Conferences. It depends on the decision of the Conference; personally I have no doubt it will be adopted. I would ask M. Dieudonné to make his introductory remarks.

**R. Adm. J. Dieudonné.**

*R. Adm. Dieudonné presents his Introductory Remarks.*

**The Chairman.**

I think M. Dieudonné has given us an excellent introduction to this fascinating subject. It is very comforting to find that so many valuable contributions have been circulated to the members, and I think this promises success for this particular subject which is on the programme for the first time. We have about 70 minutes at our disposal. There are three speakers on our list but I hope there will be more. I will ask Mr. Newton to make his contribution.

**Mr. R. N. Newton.**

M. Dieudonné in his introductory statements on this new subject has covered the general field and has suggested in his conclusions those aspects of the subject on which the Committee might well concentrate their initial attention.

A.E.W. is in full agreement with steps (a), (b), (c) and (d) recommended by M. Dieudonné for it is obvious that a collation of data on facilities and techniques employed is a very necessary requisite for a good start to co-operative work in the field. The

importance of doing this, and perhaps arriving at more or less standard techniques, has been made only too clear by the reports of other Committees which we have yet to discuss.

No formal contribution was made by A.E.W. for the reason given by the Chairman that it was understood to be the intention of the Conference on this occasion to discuss the subject in general terms with the express purpose of formulating the terms of reference of the new Committee. A.E.W. will, of course, make available to the Committee full details of our facilities and of our experimental and analysis methods. We also have available comparative ship and model data for the standard turning circle manoeuvre for a variety of warship forms. Conclusion (e) of M. Dieudonné's statement, however, is considered to warrant some discussion, on general lines, at this stage of the proceedings.

It is suggested that there are two ways of studying manoeuvrability and that these should be pursued in parallel:

- (a) A study can be made of the coefficients in the equations of motion. It is to be hoped that eventually it may be possible to calculate these, but at present they must be measured experimentally. For the present purpose it is immaterial whether the coefficients are studied in their own right, whether the equations are normalised to reduce the number of independent coefficients or whether the results are expressed in terms of "stability indices".
- (b) A study can be made of certain manoeuvres designed to bring out certain aspects of ship control. The technique of these manoeuvres should fulfil the following requirements:
  - (i) They should correspond as closely as possible to realistic ship manoeuvres.
  - (ii) They should be readily and reliably carried out both on model scale and full size and be readily simulated on a computer.
  - (iii) They should reflect clearly changes in performance due to those changes in ship characteristics which are known to be important to ship handling.

- (iv) They should avoid the human element, particularly in the model work. This will mean in general some form of automatic or programmed control.

In common with many other Establishments, A.E.W. have so far concentrated their attention on the turning circle manoeuvre with some zig-zag and spiral manoeuvres in recent years. Whilst agreeing that these manoeuvres can be readily interpreted by a ship operator, they can hardly be said to lead to a better fundamental understanding of the problem. Even assuming that a set of manoeuvres meeting all the requirements given above could be specified, and assuming that in a few years a great deal of information has been amassed on these manoeuvres, the question would almost certainly remain "why is one design superior to another"? This point is made by M. Dieudonné on page 3 of his statement where he states:

"... it is not sufficient just to determine the characteristic quantities for the manoeuvring ability as a solid mass. It is necessary, in order to advance the subject, to proceed analytically and to evaluate for a given model hydrodynamic forces and couples connecting on the model while it is constrained in a circular path with an imposed drift and velocity of rotation."

A.E.W. is, therefore, strongly of the opinion that the terms of reference of the new Committee should include a study of methods of measuring these forces and couples including a comparison of results from various facilities capable of making such measurements. Coupled with this should be the specifying of desirable degrees of directional stability. Last, but not least, there is another need, with which I am sure all delegates will agree, viz: the establishing of an agreed nomenclature and terminology in this rapidly expanding field.

**Mr. H. Lackenby.**

In the first place, I should like to say that, like Mr. Newton, I agree generally with the proposals made in Admiral Dieudonné's introductory remarks subject to a qualification I shall make later.

As he clearly states, two different but doubtless inter-related qualities are involved in this work:

- (a) the turning ability;
- (b) handling or controllability.

I would agree, therefore, that the first task of the Committee is to consider appropriate techniques

which will help to elucidate these qualities and, in this connection, careful consideration will doubtless be given to the spiral test referred to by Admiral Dieudonné and also the zig-zag manoeuvre referred to in Professor Kempf's contribution. It is interesting to see from Mr. Motora's contribution that it should be possible to deduce from the zig-zag manoeuvre criteria for both turning ability and controllability. Perhaps similar information can also be derived from the spiral manoeuvre.

I should just like to raise one point of detail in connection with the zig-zag manoeuvre and that is the apparent arbitrary correspondence between the rudder angle and the course angle at which the rudder movement is made. As far as I can see, there would appear to be no particular reason why these two angles should be the same although in developing a standard manoeuvre we must come to some agreement on these angles. I only mention this in case detailed consideration of the matter shows that there might be some advantage in maintaining freedom of choice as regards the rudder and course angles.

Having decided on the appropriate techniques for elucidating turning and handling qualities, the next step of course is to obtain reliable full scale data on actual ships for comparison with corresponding tests on the model scale to prove the model technique or at least to determine the scale factors which would enable model results to be interpreted correctly.

I would certainly support the inclusion of the measurement of the rudder force and moments in this work and agree that, in the first place, attention should be confined to the problem of manoeuvring in deep calm water. On the other hand, there would appear to be no objection to making a survey of the methods employed by the various tanks for investigating the steering of ships in canals and waters of restricted depth.

Finally, I should like to say that I agree generally with points made by Admiral Dieudonné in his conclusions, except perhaps the final point (e) which refers to the establishment of a programme of tests with the object of predicting the manoeuvring qualities of particular ship designs. This appears to go beyond model techniques and their interpretation which I understand is the essential function of this Conference. I must admit however, that it is difficult at times to draw the dividing line between what can be regarded as techniques and interpretation on the one hand and the subject itself on the other.

Just one further point: I would like to suggest that adequate attention should also be given to course stability i. e. the tendency for a ship to yaw when under way and which has to be corrected by rudder action. This has been briefly mentioned by Admiral Dieudonné and is also referred to in Dr. Kempf's remarks on model techniques to be discussed to-morrow under the heading of Resistance.

There is little doubt that this question of yawing or course stability may well prove to be an important matter in the correlation of ship and model results as regards the work of the Resistance and Propulsion Committees.

#### R. Adm. Brard (translated from French).

1. In his introductory remarks, R. Adm. Dieudonné has very well pointed out the matters about which the Conference could organize a useful collaboration between the various tanks.

This is not surprising. R. Adm. Dieudonné's contribution to the investigation of turning and steering of ships is well known. That is the reason why the Standing Committee asked him to present the Introductory Report on the subject. On behalf of the Standing Committee, I thank him for having agreed to perform this task.

I should like now to say a few words about the first point of his conclusions, namely:

Point a: Choice of quantities and qualities allowing to evaluate the manoeuvring ability of a given ship.

2. This choice is of an urgent need. Several proofs could be produced; I would emphasize only that sometimes, confusion is made by some people between two categories of tests whose aims are nevertheless very different and which I will deal with in a moment (Dieudonné's tests and Kempf's tests).

3. The origin of this confusion is most probably due to the fact that the distinction between the characteristics of steady and transitory states of motion is not clearly enough made.

As reported by R. Adm. Dieudonné the first ones are, in French, described by the word "manoeuvrabilité", the others by the word "maniabilité". These two words are possibly not the most suitable ones, because they do not immediately call to mind the two groups of qualities involved. Nevertheless these two groups are distinct. One can imagine a ship with a small turning radius for large rudder angles compared with her length who nevertheless steers

badly owing to either a too slow response to rudder, either a lack of directional stability making it impossible to keep constant head.

4. Some authors are of the opinion that ship motion can be defined by only one equation. So it would be, if there was, under every circumstances, only one relation between the drift angle and the falling aback angular velocity but it is not so. The ship is often subjected to disturbances (wind, rough sea, and so on...) resulting in variations independent of these two parameters.

On the other hand, I don't think that we can consider the two equations as linear. Numerical values of radii of turning in steady state of motion are closely bound to non-linear terms.

5. A rather intuitive idea is that a ship steers badly if her straight course is stable. However, at least for small rudder angles, it is quite the contrary which occurs. When we are saying that a ship is stable it means that both characteristic exponents  $s_1$ , and  $s_2$  governing transitory motions are negative. If a ship is accidentally pushed away from her stable state of motion, the larger are  $s_1$  and  $s_2$  in absolute value, the more quickly the ship comes back to her previous state, as soon as the disturbance vanishes. For instance, let us assume that when the ship is beginning to turn, we set quickly the rudder amidships. Then, the ship is in a disturbed state as compared with the state of motion corresponding to the new rudder angle. The larger in absolute value will be  $s_1$  and  $s_2$  assumed negative, the more quickly the angular velocity of the ship will reach zero.

$s_1$  and  $s_2$  depend on the steady state of motion associated. They are always negative if this one corresponds to sufficiently a large rudder angle; turning at large rudder angles is always stable. It is not necessarily the same thing at small rudder angles, especially with rudder amidships.

6. R. Adm. Dieudonné has clearly explained from both geometrical and mechanical point of view the stability criterion with rudder amidships (point "D" between points "G" and "T").

It is perhaps worthy of note that this criterion was obtained, assuming that the hydrodynamic forces acting on the ship with rudder amidships depend only on instantaneous drift angle and turning velocity. This assumption is not correct; in transitory conditions, the hydrodynamic forces depend on the "previous history" of the motion (hence the correct equations are

integral equations with variable limits). In fact the latter are such that the found condition remains true. The previous history of motion has only the effect of increasing the quickness of the ship for coming back to a constant heading (if stable) or for taking a steady turning (if unstable); it may sometimes occur that (in the case of a stable ship) few oscillations will take place before the ship will come back to the straight course with rudder amidships.

7. I should like now to compare Kempf's tests with Dieudonné's tests.

The values of angle chosen by Kempf are too high for the corresponding steady states to be unstable. These tests, for the chosen angles, give an idea of how quickly the ship responds to rudder and how high is her inertia. They are, from this point of view very interesting.

On the contrary they do not give any information regarding ship ability to keep constant heading. This quality is connected with the stability on the straight course. Dieudonné's tests enable us to determine if this stability is positive or negative. They do not give indeed the numerical value of the stability; they give only its sign.

Some authors, noticing that one of the two exponents is negative have proposed to define the stability by the product  $s_1, s_2$ . It would be interesting to investigate thoroughly this point.

Some of our colleagues emphasize the interest of forced turning. I believe they are right. Only such tests can provide the characteristic coefficients of hull and rudder—hull interaction for the steady state of motion. I need hardly to point out that such tests can only be carried out in tanks fitted with a rotating arm.

**Prof. W. Weinblum.**

*Prof. Weinblum reads the following remarks by H. Thieme "On selection of suitable indices for qualities of rudders, steering and manoeuvring".*

Within the contributions made to the Conference significant qualities of rudders are not mentioned hitherto. Yet in my opinion such qualities are connected as essential fundamentals with the steering qualities of ships in a broad sense. Within the limits of the state "free running rudder" one should consider the following derivativa.

"Initial effectiveness of the rudder"

"Initial rudder-torque"

and the following maximal values

"Maximum of rudder-effectiveness"

"Maximum of rudder-torque".

These four indices mentioned are increased to about seventeen if the performance and properties of the rudder are considered for typical ahead-manoeuving conditions.

*Steering and Manoeuvring.*

From the report *Indices for Steering Qualities (Kennzahlen von Steuereigenschaften, Schiff und Hafen 1957, S. 81-100)* three indices shall be emphasized here, which separately or combined with each other mark the most essential steering qualities. These indices shall fulfil the following obvious conditions:

They shall

a) cover a well known concept in a complete and unmistakable way;

b) be physically clearly defined;

c) be derived from well known theoretical procedures in the simplest way;

d) be derived from model tests in such a way that they can be performed and evaluated in the easiest possible way;

e) be derived from full scale trials in such a way that they can be performed and evaluated in the easiest possible way;

f) deliver a nondimensional value suitable to compare the qualities and quantities of ships with different properties;

g) have a sufficient degree of technical evidence without any strained theoretical considerations.

These three indices are as follows:

1. *The steadiness on course* or mostly called *course stability* as originally noted in recommended ITTC notation:

This value has to be calculated from equation (15) of the above mentioned report or to be taken from results of whirling-arm tests as presented in yawing-moment-diagrams Figures 2 to 4 (of the mentioned report). By use of equation (131) the value is connected with the result of Z-manoevres or spiral-tests (Fig. 16).

2. *The maximum-turning-moment.*

originally noted: ITTC recommendation.

As stated in equation (28) the value is to be calculated from the derivativa of ship and rudder, also to be taken from a whirling-arm test and finally by a formula similar to equation (130) connected with the results of unsteady model-tests or full scale trials.

### 3. *The maximum-turning.*

originally noted: ITTC recommendation.

This value is stated in equation (39). Its determination presents much more difficulties but it can be derived from results of whirling-arm tests and unsteady tests with free running models or ships.

The importance of these indices becomes evident from the diagram of yawing moments (yawing moment dependent on rate of turning for constant values of rudder-angle and zero-cross-force condition for the drift-angle). A highly negative value of  $i$ ) means a high degree of *steadiness in course*. A highly positive value of  $j$ ) means a good possibility of *turning*, and a high relation of  $2$ ) to  $3$ ) represents a good ability to *steady the ship*.

#### Pr. G. Kempf (translated from German).

About 30 years ago. In the Hamburg tank, I started this ziz-zagging method and for the following reason. We are limited, for this purpose to a canal, and can therefore only investigate small rudder angles. We cannot do any turning or spiral tests at all. Furthermore, the work we do in Hamburg is different in so far as we make tests for the merchant navy; whereas in the other towing tanks, very largely, you make your tests for the Navy, and of course their methods are different.

The Navy has the time to carry out large-scale tests and also they have bigger services and they can have these turning tests.

The merchant navy, for particular purposes, can deal with the serpentine type of tests. I have been most happy to read the Japanese contributions, by Mr. Nomoto and Mr. Motora and I was very happy to note the Japanese have found indices K and T which enable them to get really significant comparison from the serpentine tests or the zig-zag tests, and as far as manoeuvrability of ships is concerned, to be able to determine the difference between manoeuvring ability and manoeuvrability in general.

I really would suggest, like Admiral Dieudonné has suggested, that these terms be defined and then kept to. As far as I am concerned, all I wanted to do really was to stress this difference of testing methods. It is much easier for practical purposes to make serpentine tests rather than have these turning tests. I have done it myself with several merchant ships, you need no more than half an hour to get a very nice serpen-

tine curve and with the Japanese formula, you can then establish your measurements, which does not mean to say by any means that the turning circle method has become redundant. But when we come to cooperation between towing tanks, I can imagine easily that the serpentine method is simpler. And I really see no reason why one should not carry out these tests if they be as simple as they are, and if they are really meritorious.

#### Mr. E. V. Lewis.

We are all aware of the necessity of close cooperation among the different Committees. In this case, I should like to call attention to the need for cooperation between this new Committee and another comparatively new Committee of the I.T.T.C. family—the Committee on Seagoing Qualities of Ships. Model tests in oblique waves cannot be carried out without rudder control on the model, and this brings us into problems of steering or course-keeping (French "Manoeuvrabilite"). These involve not only the hydrodynamic characteristics of the hull and rudder combination but the characteristics of the automatic control system for the rudder.

Although the fields of Manoeuvring and Seagoing Qualities are thus closely related, they need not actually overlap. I suggest that the distinction here is that manoeuvring studies can establish criteria of stability and course-keeping qualities, and methods of evaluating them in calm water. It is hoped that studies of model behaviour in oblique waves can, on the other hand, provide more precise information regarding the required values of these criteria for satisfactory control of ships at sea. Excessive course stability may be undesirable from the viewpoint of good turning ability, and it is hoped that model tests in oblique seas can clarify the minimum requirements for good performance.

#### Prof. Schuster.

The confusion mentioned by some delegates is in my opinion based on the different definitions of the respective terms in the various languages. In German we distinguish between course steadiness and turning ability when engaged in manoeuvrability. The steps to be made for any improvement of these two properties are opposed to each other as is well known. Likewise model tests should be analyzed with the aim at these two different meanings. For free running

models for instance when running a zig-zag course, this will be difficult for nonsteady phenomena are coupled with steady ones. Therefore I should like to remind you of the reverse method as proposed by Prof. Horn, an old member of this Conference, where the fixed model is performing guided motions and where the forces occurring in the tie-rods are measured continuously.

The test program is divided into four parts. First the transverse force and the moment of rotation about the vertical axis of the model with fixed yawing angles is measured. Hereafter the same is done for yawing angles periodically changing according to a sinus law, with the centre of gravity running a straight course. Then measurements of the model in parallel transverse oscillation will follow and finally a winding course is run with the centre of gravity on an sine-shaped path. Thus result the coefficients of the equations of motion and course stability and turning ability can be judged.

This procedure was used repeatedly in the Berlin tank. It may be somewhat complicated for routine tests. Mostly we are therefore limiting ourselves to two steady motion tests. First the model with different rudder angles is towed straight on and the transversal forces acting at two points are measured out of which relative conclusions can be made as to the readiness for commencing a turning circle. The next time the model with the rudder amidships is towed diagonally under different yawing angles, so that a measurement of the steady course stability results. Each time transverse force and rudder shaft moment can be measured. The whole procedure can be made as well with the propeller running.

**Dr. Graff.**

I should like accent, that in carrying out manoeuvring tests, it will be necessary, to choose two different ways. For tests for commercial purposes for shipyards or shipowners I might recommend simple tests, which can be carried out with moderate expenses of costs and time. For these purposes I believe, that spiral or zig-zag tests will give sufficient values of manoeuvring qualities. But for scientific work and analysing the single factors influencing these qualities as shipform, deadwood, rudderform and arrangement it's necessary to carry out more detailed researches and to choose other methods. For these purposes I believe that detailed and extensive test with a rotative

arm would be the most successful method of research. I hope the new Committee will find way to coordinate both requirements.

**Mr. A. B. Murray.**

As the Davidson Laboratory has been engaged in model manoeuvrability tests for almost two decades some informal comments might be of interest. They supplement the more detailed paper of Dr. Breslin and Mr. Suarez.

The Stevens Manoeuvring Tank was built in 1942 for the specific purpose of obtaining by means of free self-propelled models navigation information for ships unable at that time to make shake down cruises. It was engaged at that time primarily with spiral manoeuvres.

When it became expedient to determine the reasons for varied reactions to the rudder it was found that the spiral manoeuvre was inadequate. A rotating arm was designed and built to enable the measurement of forces and moments on the hull and rudder with the model in a captive circular path. These measurements made it possible to solve many problems and to complete useful equations of motion.

Subsequently interest in ship manoeuvrability waned and the apparatus was converted for use of underwater bodies with balances for measuring all six components. This work has continued unabated.

Only recently has there been increased interest in the problem of surface ship directional stability and steering. The rotating arm has been useful in improving designs in this respect.

The Davidson Laboratory feels that for complete answers on manoeuvrability problems the captive model technique with the rotating arm is desirable.

**Dr. Breslin.**

I wish to make only two brief comments. Although our contributions to this subject stress the need for the use of a rotating arm to study manoeuvrability, I do not want to give the impression that we are opposed to the use of zig-zag, spiral or any other simple manoeuvre which will assist in obtaining a ship's response.

The ultimate goal of research in this area must be the understanding of the phenomenon so that the basic physical features of the ship and rudder which play

important roles in turning and manoeuvring can be revealed. While we advocate the use of a rotating arm for such scientific studies, it is not sufficient merely to measure the total force and moment for various total ships and rudder geometries. In order to understand how the hull and rudder contribute, it is necessary to measure the forces and moments on the hull and on the rudder separately and also while the rudder is operating on the model. I would therefore like to suggest that the new Committee encourage research on:

- a) forces and moments arising from hull form alone;
- b) forces and moments arising from rudders alone;
- c) interaction of rudder on the hull;
- d) interaction of hull on the rudder.

Some experiments at the Davidson Laboratory, and, I am sure, at other Tanks, have indicated that the forces and moments developed by hulls are considerably different than with the rudder. Thus the interaction effects must be studied so that the influence of afterbody shape, rudder clearance, influence of propeller slip-stream and other factors may be properly assessed.

#### Mr. M. Gertler.

The introduction of the subject of manoeuvrability at the ninth International Towing Tank Conference is particularly timely for the David Taylor Model Basin since we hope to start operating our new manoeuvring and Seakeeping Facilities by early this winter. The rotating arm facility should be available for operation by the end of November and the manoeuvring Basin should be available for tests with radio controlled models by the end of January.

Personally, I am very sorry that I was unable to prepare a formal contribution in time for presentation at the Manoeuvrability Session of the I.T.T.C. This was due, for most part, to the duties required of me as chairman of the First Symposium on Ship Manoeuvrability held at the David Taylor Model Basin in May 1960. As a brighter note, I am pleased to announce that the transactions of this symposium will go to print about the 15th of September and should be distributed at the end of October. Furthermore, all of the delegates of the I.T.T.C. are on the mailing list and should receive their copies as soon

as practicable thereafter. I would like to make the comment that I consider the Symposium as complementary to the I.T.T.C. The papers were restricted to the subject of manoeuvrability independent of the technique used to acquire the results presented in contrast to dealing with technique or "Tankery" which was considered to be primarily the province of the I.T.T.C.

Tests pertaining to the field of ships manoeuvrability have been carried out at the Taylor Model Basin and its predecessor the U.S. Experimental Model Basin since about 1920. However, we have been very active in this field during the last 5 or 6 years, particularly with regard to submarines. With the acquisition of the new facilities we hope to treat the surface ship problem with equal thoroughness both experimentally and analytically. Our experimental approach, in general, has been twofold: the acquisition of hydrodynamic coefficients by use of "captive" model techniques (D.T.M.B. Planar-Motion Mechanism System) and their analysis in the equations of motion and the determination of handling qualities of ships based on definitive manoeuvres with free-running models. The latter includes the well-known Dieudonné spiral manoeuvre and the zig-zag manoeuvre proposed by Kempf. It is beyond the scope of this commentary to argue which of these approaches is best. Suffice it to say at this time that each has its merits.

Since the subject has just been introduced I will not go into further detail. I will close by saying that the new Manoeuvrability Committee is faced with a most interesting and challenging task. The Taylor Model Basin has already circulated inquiries to determine whether the various rotating arm facilities of the world would be interested in participating in a correlative test program with standard models. The response has been gratifying and I hope that the new Committee will see fit to place this item high on their agenda.

#### The Chairman.

Now, Gentlemen, I think you will allow me to express our gratitude to Mr. Gertler for having put all the Delegates on the mailing list of the American Conference. We certainly look forward to these papers with the greatest interest. Thank you, Mr. Gertler.