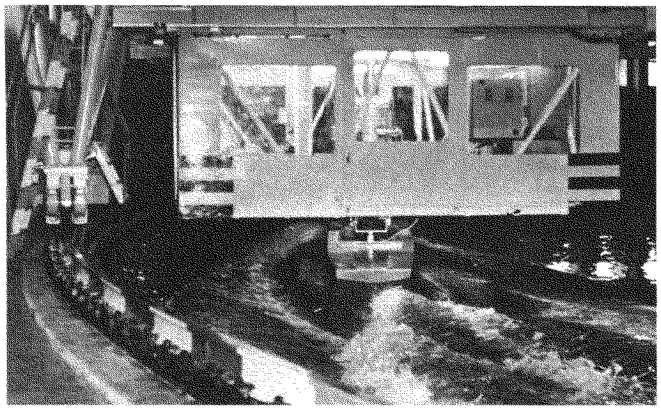


Fig. 3.

necessary data for solving the manoeuvrability problems of ships are obtained by measuring hydrodynamic forces during the towage.

The tank is also widely used for studying the problems related to the simulation of straightline motion. Experiments are carried out to study the forces developing on the hydrofoils and the hull-propeller-rudder interaction. The tank enables permanent circular towing, but this possibility is limited because of the gradual development of wake flow in the basin water. To prevent wake formation, the walls both around the basin and island are furnished with vertical fins (in Figs. 1 and 2 these fins are seen through the water, their upper edge covered with the latticed screens of the breakwater).

The fins as well as the excessive power of the drive enabling the maximum velocity of the arm within a quarter of the first revolution make it possible to eliminate the wake as a factor in most experiments performed at moderate velocities with models of 2.5~4 m in length.

3. Correlation of Test Data

When studying the manoeuvrability of the ships, the experimental data in the circulating tank are used together with the data obtained in the straightline towing tank or in the wind tunnel. Fig. 4 shows the experimental data of the trimming moments which influence the submerged body of revolution in the vertical plane at different combinations of the angle of incidence and non-dimensional curvature. Fig. 4 shows satisfactory agreement between the experimental data obtained in the wind tunnel at the Reynolds number 2 x 10^7 and those obtained in the circulating tank at the Reynolds number 8.5 x 10^7 (the beam) and 5.5 x 10^7 (the arm).

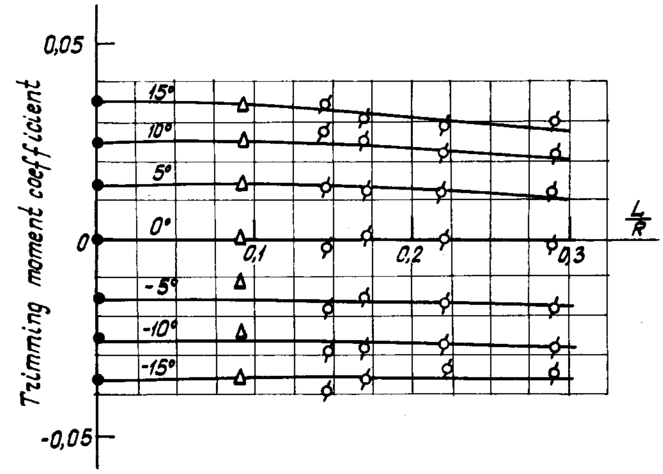


Fig. 4. Agreement between the experimental data obtained for the submerged body of revolution in wind tunnel and in circulating tank

●	wind tunnel
Δ	beam of the circulating tank
ϕ	arm of the circulating tank

$$\frac{L}{R} = \frac{\text{model length}}{\text{radius of the trajectory at the mean point on the model length}}$$

ON THE MODIFIED ZIG-ZAG MANOEUVRE TO OBTAIN THE COURSE-KEEPING QUALITIES OF LESS STABLE SHIPS

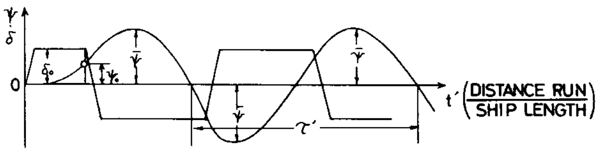
by S. Motora (*Univ. of Tokyo*) and M. Fujino

1. Difficulties in Conducting Z Manoeuvre on Less Stable or Unstable Ships

The Z manoeuvre test which was initiated by Kempf[1] has been a powerful weapon in studying the manoeuvrability of ships. Nomoto's K-T analysis[2,3] has also given a powerful theoretical background to this method.

However, in the case of less stable ships or unstable ships such as full super-tankers, there are difficulties in conducting a Z manoeuvre at a small rudder angle, say 5 degrees. In most cases, at 5°/5° tests, results tend to show remarkable asymmetry or divergent nature. Figs. 1 a, b show the relation between the rudder angle to the amplitude of course change angle as well as the period of one cycle in terms of distance run/ship length for a Z manoeuvre of a stable ship (ship B), and an unstable ship (ship C). The rudder angle and the course change angle at which the rudder reversed (let as call it the switching angle) are kept equal as usual. These curves were obtained by an analogue simulation as shown in the Appendix. The ships' manoeuvrability characteristics are also shown in the Appendix. As seen in Figs. 1 a, b, the amplitude as well as the period of the Z manoeuvre shows a divergent nature at small rudder angles for the unstable ship.

This will be rather an extreme case, but it is true that it is almost impracticable to conduct a Z manoeuvre of less than 5 degrees for full super-tankers to get course keeping ability of ships.



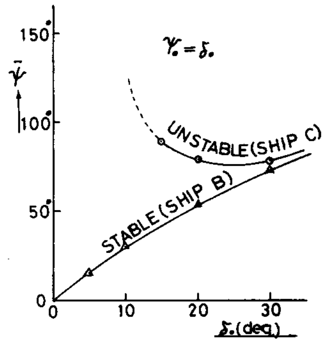


Fig. 1.a

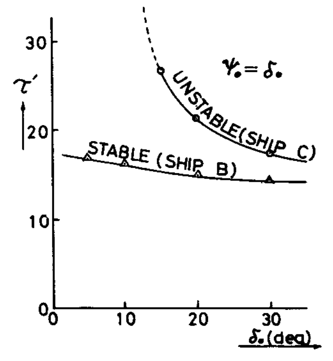


Fig. 1.b.

2. PROPOSED "MODIFIED" Z MANOEUVRE TESTS TO EXAMINE THE COURSE KEEPING QUALITIES OF SHIPS

Such an unstable ship (ship C) as shown in Fig. 1, however, can be steered on a straight course without difficulty in the case of a full-scale super-tanker. The reason will be this, that in a case of course keeping, the switching angle at which the rudder is reversed will be less than 1 degree in the case of manual steering, and will be in the order of 1/10 degree in the case of automatic steering in a calm sea; therefore the angular velocity as well as the drifting velocity do not develop to create an unstable hydrodynamic moment to overcome the rudder moment. Therefore, the ship responds to a small rudder angle such as 5 degrees at these small switching angles.

As an example, results of Z manoeuvre tests on the prescribed unstable ship at which the rudder angle is kept to 5° while the switching angle is varied from 5° (normal Z test) to 0.2° are shown in Fig. 2. As shown here, steady results are obtained at very small switching angles. The results obtained by these Z manoeuvres at a small switching angle will be more similar to the ship motions at course keeping manoeuvres than the normal Z manoeuvre of smaller rudder angles. Therefore, the discussers propose to use such "modified" Z manoeuvres to examine the course keeping qualities of ships.

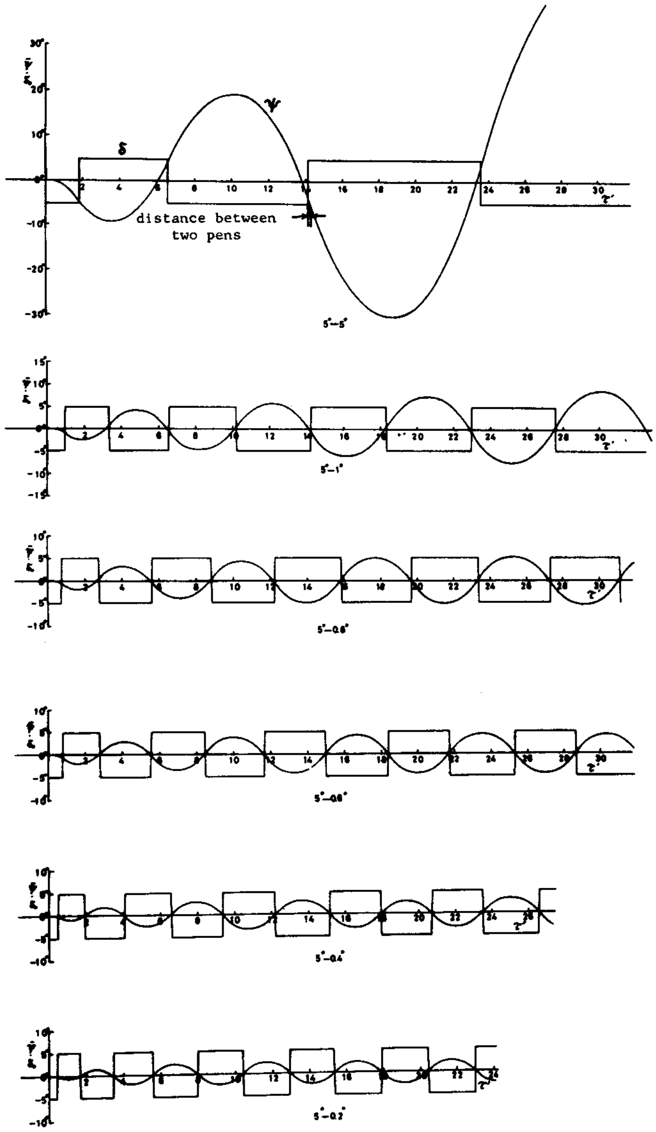


Fig. 2.

In the case of course changing, however, the behaviour of ships is much similar to the normal Z manoeuvre of 15°/15° or 20°/20°. Therefore, a normal Z manoeuvre test is very suitable to examine the course changing qualities of ships. In the case of emergency manoeuvres, the course change angle will be in the same order as the rudder angle. Therefore, a normal Z manoeuvre at a large rudder angle is also very suitable to obtain the emergency manoeuvring ability of ships. Drawing the region of these three kinds of modes of manoeuvre on the $\bar{\psi} - \delta_0$ diagram shown in Fig. 1, we get Fig. 3. Results of analogue simulation of "modified" Z manoeuvres on the prescribed unstable ship are shown in Figs. 4 a, b. $\bar{\psi}$ and τ' shown in Fig. 4 are the steady values.

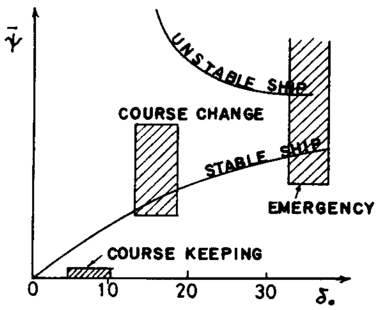


Fig. 3.

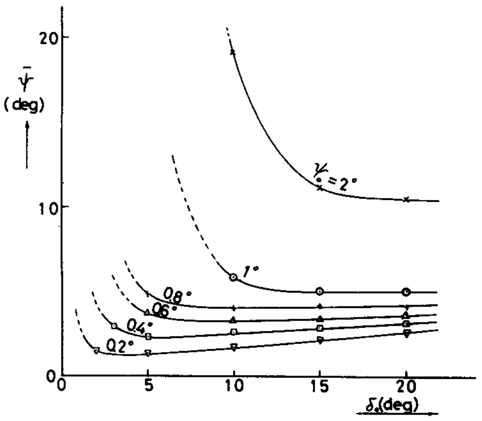


Fig. 4.a

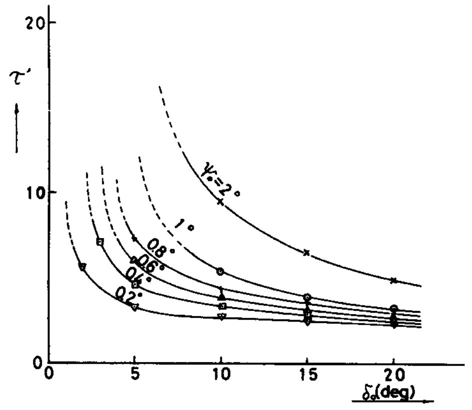


Fig. 4.b

3. APPLICATION OF THE 1ST ORDER SYSTEM ANALYSIS (K-T ANALYSIS) OF Z MANOEUVRE ON LESS STABLE SHIPS

In the previous section, a "modified" Z manoeuvre test at which the switching angle is much smaller than the rudder angle was proposed to be a suitable method for examining the course keeping ability of ships. Then, what would be the results compared to the normal Z manoeuvre results if Nomoto's K-T analysis$^{2)}$ were applied to these modified Z manoeuvre data?

1) *Significance of 1st order system analysis*

For simplicity, let us consider a linear system first. When a linearized equation of motion is written as follows:

$$T_1 T_2 \frac{d^2 r}{d t^2} + (T_1 + T_2) \frac{d r}{d t} + r = K \delta + K T_3 \frac{d \delta}{d t} \qquad (1)$$

where

$r = \dfrac{d\psi}{dt}$

δ is the rudder angle,

T_1, T_2, T_3 and K are coefficients,

then the 1st order approximation of this equation is given by Nomoto as equation (2):

$$T \frac{d r}{d t} + r = K \delta \qquad (2)$$

where

$T = T_1 + T_2 - T_3$.

If the solutions of (1) and (2) are integrated to be ψ and compared, (2) gives smaller ψ at an earlier stage but (1) and (2) finally become equal when considerable time has elapsed, as shown in Fig. 5. This difference is greater in the case of less stable ships.

When a Z manoeuvre is applied to the ship (Eq. (1)), the result will be as shown in Fig. 6 by solid lines. On the other hand, when a Z manoeuvre is applied to the 1st order system (Eq. (2)), the result will be as the broken lines in Fig. 6.

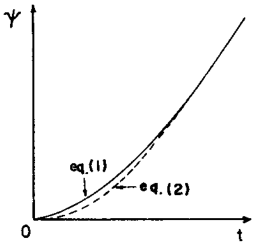


Fig. 5.

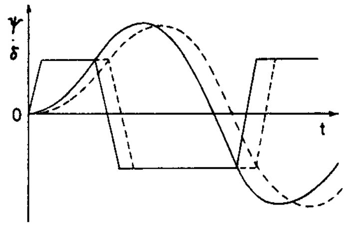


Fig. 6.

Therefore, if K-T analysis were applied to the solid lines of Fig. 6, the K and T obtained would not be equal to the K and T of Eq. (2), but would be such as to give a 1st order solution which fits to the solid line. To avoid confusion, let us denote K and T obtained from the ship data (solid line) as K*, T*. The difference between K*, T* thus obtained and K, T of Eq. (2) must be smaller if the ship is more stable on course. But in the case of less stable ships or unstable ships, the difference could be considerable. To examine this difference, a linearized equation of motion as shown in appendix (ship A) was used for simulation of a Z manoeuvre at different combinations of rudder angle and switching angle, and the 1st order system analysis was applied to obtain K* and T* which best fit the test results. Obtained K* and T* are as shown in Figs. 7 and 8 in non-dimensional forms. A series of tests with different rudder angles with fixed switching angle ($\psi_0 = 15°$) were conducted first. As the system is linear——K* and T* values will be the same when ψ_0/δ_0 (switching angle/rudder angle) is equal——K* and T* values for different ψ_0 can be obtained. (For instance, K* and T* values for $\psi_0 = 30°$, $\delta = 20°$ should be equal to those for $\psi_0 = 15°$, $\delta = 10°$ etc.) Radial lines in Figs. 7 and 8 show ψ_0 = constant line, and horizontal broken lines show ψ_0/δ_0 = constant lines. The thick broken line shows $\psi_0/\delta_0 = 1$ which corresponds to the normal Z manoeuvre tests.

Radial lines converge at one point at $\delta_0 = 0$. This point shows the K or T value of Equation (2), because at $\delta_0 = 0$ with finite ψ_0, the period of the Z manoeuvre will be infinity and the difference between Eq. (1) and Eq. (2) becomes zero. On the contrary, if ψ_0/δ_0 is small as in the proposed modified Z manoeuvre, obtained K* and T* will be much different from K and T. Similar results have been obtained by model experiments by Das[5].

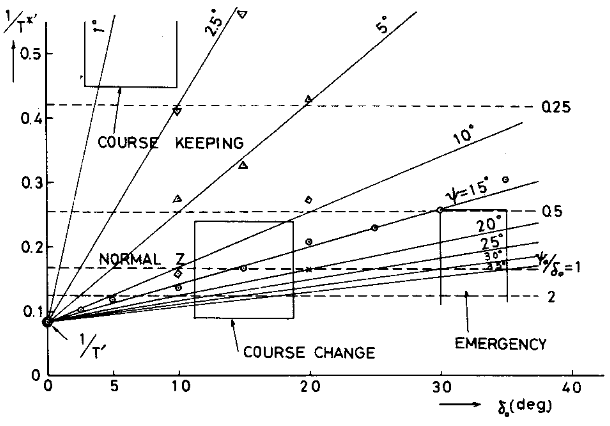


Fig. 7.

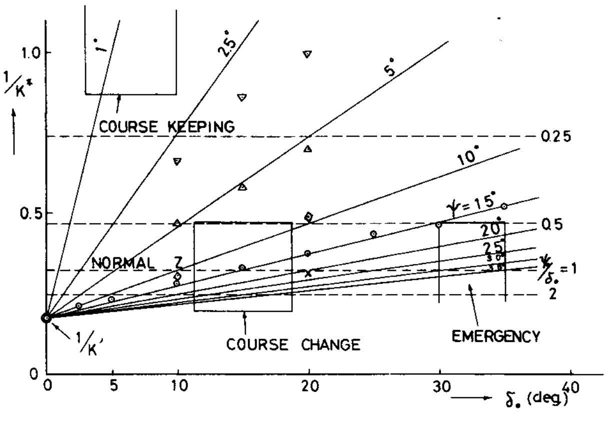


Fig. 8.

(2) *What is the purpose of Z manoeuvre tests?*

If the purpose of Z manoeuvre tests is to obtain the real K and T values of Eq. (2), greater ψ_0/δ_0 (greater switching angle compared to rudder angle) must be chosen. However, such tests are not practicable for less stable ships, as explained in the previous sections.

The purpose of Z manoeuvre tests, the discussers believe, is to obtain information of manoeuvring characteristics by giving a ship such motions as are similar to the practical modes of motion of ships under steerage. Principal modes of steering motion of ships will be classified under the following items:

a) course keeping manoeuvre,
b) course change manoeuvre,
c) emergency manoeuvre.

As was stated in section 1, items b) and c) are well covered by the normal Z manoeuvre of $\delta_0 = 15°$ and 35°, and obtained K*, T* will not be much different from K and T. However, in the case of a), the modified Z manoeuvre with small ψ_0/δ_0 will be much more similar to a practical course keeping manoeuvre, and obtained K*, T* values will be much different from K and T as shown in Figs. 7 and 8. K*, T* thus obtained from the modified Z manoeuvre will give a 1st order system which fits Eq. (1) at an earlier stage of motion, while Eq. (2) fits at a later stage of motion.

Similar results to Figs. 7 and 8 will be obtained for an unstable ship. In this case, since K and T should be negative, radial lines will converge at 1/K' and 1/T' which are both negative values. Radial lines will curve upwards due to non-linearity.

APPENDIX——SIMULATION OF Z MANOEUVRE BY AN ANALOGUE COMPUTER

Let us use a simplified 2nd order non-linear equation such as the following form which has been used by Nomoto,

$$T_1' T_2' \frac{d^2 r'}{d t^2} + (T_1' + T_2') \frac{d r'}{d t} + r' + \alpha' r'^3 =$$

$$= K'\delta + K' T_3' \frac{d\delta}{d t}. \qquad (1)$$

Integrate Eq. (1) with respect to time and set into an analogue

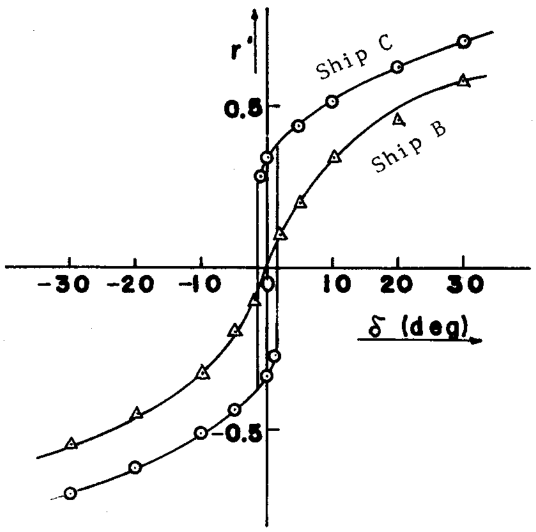


Fig. A.1

computer. δ, r, and $\psi = \int_0^t r\,dt$ are taken out of the computer as outputs. Three kinds of sets of coefficients were used as shown below:

	Ship A	Ship B	Ship C
Stability	Stable	Stable	Unstable
Linearity	Linear	Non-linear	Non-linear
T_1'	12.68	12.68	−17.75
T_2'	0.420	0.420	0.485
T_3'	0.893	0.893	0.895
K'	5.82	5.82	−9.15
α'	0	1.33	−2.52

Results of simulated spiral tests are as shown in Fig. A.1.

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ON THE POSSIBILITY TO SIMULATE HIGHER REYNOLDS NUMBER CONDITION FOR RUDDER MODEL BY INCREASING ITS SURFACE TEMPERATURE

by M. RAKAMARIC (*Brodarski Inst.*) and J. KORLEVIĆ

The possibility of using heated rudder models in performing model manoeuvrability experiments is shown. Measurements of rudder model characteristics have been carried out to investigate the influence of the increased model wall temperature at different Reynolds numbers.

INTRODUCTION

In performing manoeuvrability experiments with ship or submarine models it is not usually possible to achieve sufficiently high values of Reynolds numbers for rudder or plane. This may cause significant scale effect when rudder angles in the vicinity of or over stall angle are used. Trying to find the way to diminish that problem, the idea to change the flow around the rudder model by heating its surface has occurred.

The theory shows in some way an analogy between dynamic and temperature boundary layers. The influence of the wall temperature will be practically confined within the thickness of the dynamic boundary layer. The wall temperature being kept higher than the water temperature will result in a water viscosity decrease within the boundary layer. According to the law of temperature distribution the viscosity will change along the boundary layer thickness with higher gradients near the wall. That will cause a fuller velocity profile in the boundary layer. The flow within the boundary layer with fuller velocity profile is more capable to overcome the positive pressure gradients, i.e., the separation will be postponed.

The matter becomes more complicated when the question of laminar-turbulent transition arises. A fuller velocity profile due to viscosity decrease in laminar boundary layer tends to stabilize that regime of flow. At the same time viscosity decrease will weaken the damping influence of viscosity on the velocity pulsations in the boundary layer, i.e., it will destabilize laminar flow. The final effect depends on quantitative relations. It is supposed that with Reynolds numbers in question and with a normal free turbulence present in the tank water it will be possible to promote a turbulent flow with a sufficiently great difference between wall and water temperature. To verify the idea a short experimental programme has been performed and its results are to be found in this Report.

DESCRIPTION OF EXPERIMENTS

The rudder model was made of steel plates with a height of 333 mm, chord length 250 mm (aspect ratio 1,33) and NACA 0015 profile. A three-component dynamometer with electronic pickups of inductive type was used for measurements of lift, drag and moment about the rudder-stock placed at midchord. The model was attached without gap to the dynamometer circular plate, which was inserted with a clearance of about 1 mm in the larger circular plate fixed to the dynamometer housing (Fig. 1). The circular plate was used to avoid the free surface interference.

The heating of the model was performed by circulating a hot glycerin from the thermostat device through the hollow rudder-stock to the model inside (Fig. 2). The wall temperature was measured by two thermistors built-in flat to the model surface at one side. The thermistors were located at the model midheight, chordwise at one quarter and three quarters of chord length. The thermostat device was able to keep the