only sufficient to examine the side-force generated by a lateral-thrust unit when the centre of action of the force is known and stationary, i.e. at zero speed. When the centre of action varies then the turning effect is no longer directly proportional to side force and must be assessed in terms of both side force and turning moment. The surprising result is that the centre of action moves so far aft, the suction force being far from an effect localized in the region just aft of the tunnel exit, but more nearly acting over the complete length of the hull.

A perusal of relevant test results from other establishments in the light of this interpretation yields a certain amount of corroborative information.

Wind tunnel experiments made by Jordinson[6)], in connection with vertical take-off aircraft using jets to provide the necessary thrust, consisted principally of pressure measurements to define the mixing process of a jet issuing perpendicularly from a flat wall into a main-stream flow parallel to the wall. These results show that after having been deflected almost parallel with the main stream, the jet has a fairly stable character, and that a region of low pressure exists between the jet and the wall, extending far downstream of the jet exit. The region of low pressure might, in very rough terms, be described as a plane slab, of thickness equal to 2 to 3 tunnel diameters, joining the deflected jet and the wall (or ship side) and although the measurements only extend for 18 diameters (or a little less than $L_{pp}/3$) downstream, the pressure field appears to extend considerably further.

English used the same model[1)], for measurements of turning rate in response to bow thruster action in the free-sailing state, and for side force measurements while constrained on a straight path. His side force measurements show exactly the same trend as Fig. 3, the fall-off occurring at progressively higher speeds as propeller revolutions and jet velocity increase, levelling off to approximately constant values for further increases of speed. The measured rate of turn values for the free-sailing model, however, have the same character as the moment curves in Fig. 3. At the lower propeller revolutions, turning rate first falls and then rises against as speed is increased. As propeller revolutions are raised, the minimum point is reached at progressively higher speeds.

On the basis of a limited number of tests made with the HyA model, it was found that superimposed results of turning effects due to lateral thruster action, and drift angle of sign corresponding to a turn in response to the thruster, were considerably less than values measured for simultaneous thruster action and drift angle. That is to say, drift angle had a marked beneficial influence. This is probably explained by the jet being swept into the neighbourhood of the hull more quickly when the hull assumes a drift angle, the advantageous effects due to interaction between jet and main-stream flow past the hull being augmented.

The very small speed effect on side force reported by Stuntz and Taylor[4)], would appear to be due to their having made tests on a partial model representing only the forward three stations of the hull. Similarly in the discussion pertaining to Ref. 1), English mentions that on the basis of a limited number of measurements, the fall in side force when going astern was less than when going ahead. In both cases, the reduced pressure regions associated with the deflected jet would have been largely clear of the hull.

MANOEUVRABILITY AT SLOW SPEED

by S. MOTORA (*Univ. of Tokyo*)

INTRODUCTION

Recently, serious accidents of ships in harbours have been increasing with the growth of ships in number and in size. For the purpose of preventing these accidents, it will be necessary to know the characteristics of motion of ships at slow speed and transient conditions, and to improve the effectiveness of the rudder in these conditions. Moreover, it will not be premature to discuss on the possibility of braking ships.

Such improvement of manoeuvrability at slow speed will be useful not only for the prevention of accidents but also for the increase of the port speed.

1. INVESTIGATIONS INTO THE MOTION OF SHIPS AT SLOW SPEED AND IN TRANSIENT CONDITIONS

Generally speaking, a ship will experience the following four stages when she enters a harbour and slows down until she stops at a berth:

a) going ahead at slow speed with propeller rotating ahead, b) going ahead by inertia with propeller stopped, c) going ahead by inertia with propeller rotating astern, d) going astern with propeller rotating astern.

In such cases, the effect of a rudder naturally varies at each stages. At stage a), though the effectiveness of the rudder decreases with the decrease of revolution of the propeller, a normal ship will still maintain considerable manoeuvrability. However, at stage b), the effectiveness of the rudder drops suddenly when the propeller stops. This phenomenon has been explained by sheltering effect of the propeller. The same trend will also appear at stage c) with strong turning moment to starboard when the ship is single screw with single rudder. At stage d), a ship almost loses its controllability and will turn to either starboard or port depending upon the initial conditions.

The following researches will be necessary to investigate the motion of ship in such conditions.

1) *Observations by self propelled models, especially observations of the influence of ship form, propeller and kinds of rudder on the effectiveness of the rudder.*

Usually, a ship behaves quite capriciously at her transient condition from going ahead to going astern. However, this capriciousness is naturally of apparent nature. Therefore, the motion should be always unique for a specified ship, if a specified initial condition was given. Accordingly, it will be necessary to conduct experiments varying initial conditions for different combination of the stern configuration, the propeller and the rudder.

It will be quite useful to employ a testing technique which was used by Yamanouchi and others[2)]. They attached an air-propeller to a ship model which was self-propelled by an ordinary screw propeller. By virtue of air-propeller, the model can maintain an arbitrary stationary speed which may be quite different from that to be derived from the revolution of the screw-propeller. For instance, the model can stationarily go ahead with screw-propeller rotating astern. This method enables us to observe ship's behaviour at each stage as stated before more precisely.

2) *Measurement of the rudder force by captive models.*

By captive models the rudder force, as well as the force and the moment on the whole ship are to be measured with different combinations of the propeller r.p.m., ship speed and the helm angle. Information on the exciting force and moment will be obtained by this series of experiments. These experiments can be conducted in circulating channels as well as towing tanks.

3) *Measurements of stability derivatives.*

The hydrodynamic side force and the yawing moment can be measured with a captive model at slow speed, especially in conditions where advance speed, drifting speed and turning rate are comparable. Derivatives (up to higher order) will be obtained by this series of experiments. In non-dimensionalizing the derivatives, it will be necessary to consider which speed is to be taken out of the advance speed, the drifting speed and the turning rate. If the advance speed is used as usual, some difficulty may arise in the condition where the ship turns at zero advance speed.

4) *Equation of motion and it's solution.*

Naturally, the equation of motion in this case will be non-linear, and the effect of change of the speed of advance should be taken into account.

2. ESTABLISHMENT OF TRIAL CODE FOR STOPPING AND ASTERN TRIALS

Trial code for stopping and astern trials should be established in order to accumulate data of ships with higher accuracy, and to compare the results with each other.

3. MEANS FOR IMPROVEMENT OF MANOEUVRABILITY AT SLOW SPEED

1) *In case of ordinary propeller and rudder*

The best combination of propeller, stern configuration, and shape of rudder which makes the rudder most effective at slow speed can be obtained by the experiments stated in chapter 1.

2) *Special equipments.*

There are many contributions on the effect of side-thruster, Voith-Schneider propeller and Kort rudder[3,4)].

Though they have been reported to be very effective, it will be desirable to conduct series of comparative experiments in view of their effectiveness at slow speed by the method stated in chapter 1.

4. BRAKE

According to the data on modern tankers, the thrust increases approximately proportional to the square of ship length, while the increase of the displacement is almost proportional to the fourth power of ship length. Accordingly, the stopping distance at crash astern of ships has been increasing. This problem has grown so important that development of means to brake a ship is seriously expected.

Jaeger[5)] showed that the stopping distance could be decreased considerably by extending flaps on both sides of the shoulder of a ship.

Motora[6)] showed effectiveness of a special type of rudder which opens up around a hinge at the trailing edge of the rudder to brake a ship. It was also shown that the rudder opened up with helm angle worked as a side-thruster.

5. PREDICTOR FOR MANUAL STEERING

A prediction suggested by Norrbin[4] will be also useful to avoid accidents in harbours.

A predictor is a small analogue computer carried on the bridge, by which the future motion of the ship is displayed on a screen in front of the helmsman. For normal steering the coefficients of the equations of motion may be selected beforehand, from theory and trials. For slow speed manoeuvring an instrument which calculates the rudder force may be included.

A simple example to display the use of the predictor given in his paper. The helmsman can readily see what will happen if he does not give a new rudder, or if he makes a certain manoeuvre.

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THE DETERMINATION OF TRANSVERSE HYDRODYNAMIC NONLINEAR FORCES BY MEANS OF STEADY TURNING

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1. GENERAL REMARKS

For turning of large helm angle, of a ship with insufficient course stability or of large tankers, nonlinear term of force acting upon ship hull is indispensable. It is empirically possible to deal with the problem by analyzing it as a polynomial of drift angle β and nondimensional angular velocity r', but for the present, to consider it theoretically, we depend on the cross flow theory.

The author[1] also found, when he researched the same problem before, that it is the term of $\beta r'$ that is the most important at turning of ship, and induced the calculation method on the drag coefficient 2. He has modified the drag coefficient 2 in accordance with more accurate calculation of rudder force and the data from model experiments ready for the purpose in order to make calculation of ship's turning feasible.

2. METHOD OF ANALYSIS AND RESULTS

If we consider the term $\beta r'$ of the force and the moment acting upon ship hull at steady turning, we can put

$$r'=\frac{C_R\,\dfrac{A_R}{S}\left(N'_\beta+\dfrac{l_R}{L}Y'_\beta\right)}{N'_{r'}Y'_\beta-N'_\beta(m'_x-Y'_{r'})+C_R\,\dfrac{A_R}{S}\left(h_M-\dfrac{l_R}{L}h_Y\right)+r'\{h_M(m'_x-Y'_{r'})+h_YN'_{r'}\}}\qquad\cdots\cdot(1)$$

where

Y'_β, N'_β, $Y'_{r'}$, $N'_{r'}$ = nondimensional derivatives
C_R = rudder force coefficient
A_R = rudder area
S = centre vertical plane area, nearly equal L (length) $\times$ d (draft)
l_R = distance between centre of gravity G and rudder stock
h_Y, h_M = force and moment coefficient of nonlinear term
m'_x = virtual mass coefficient of longitudinal direction

Derivatives and h_Y, h_M are calculated as, from low aspect ratio wing theory and cross flow theory, assuming τ as trim

$$Y'_\beta=K_1\pi\lambda\left(1\pm\frac{\tau}{4d}\right)$$

$$Y'_r=K_1\pi\lambda\left(0.367+0.21\lambda\pm\frac{\tau}{16d}\right)$$