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ON THE INTERACTION OF PROPELLERS ON MULTISCREW SHIPS

(O Vzaimnom Vlianii Grebnykh Vintov na Mnogovalnykh Korablakh)

by

Dr. L.A. Epstein

Translated by B.V. Nakonechny, Naval Architect

September 1959

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ABSTRACT

The author discusses in this paper a problem of interaction of propellers on multiscrew ships. Both theoretical and experimental approaches are used in this investigation. An approximate method of calculations that takes into account the influence of forward (outboard) propellers on the after (inboard) ones is presented. The recommendations as to the direction of rotation of propellers on multiscrew ships are given.

INTRODUCTION

The problem of the interaction of propellers operating on multiscrew ships is not discussed sufficiently in the literature.

Usually it is supposed that the interaction does not exist when the screw discs, projected on a transverse plane, do not overlap. In addition, proceeding from an idea of contraction of flow of the ideal propeller, it is considered that the after screw always will be outside of the slipstream of the forward screw.

In reality, for ships of normal types the after screws, for practical purposes, do not affect the forward screws; opposite influence, however, can be very material. As will be shown below, this influence depends not only on the distance between the shafts and on the diameter of the propellers, but also on mutual location of the screws with respect to the length of the ship, contours of hull, loading coefficient, and direction of rotation of the propellers.

The test results of the 4-screw ship model showed that the performance of the rear screws substantially depends on their direction of rotation. In this paper an approximated method of calculation is given that takes into account only the influence of forward (outboard) screws on the after (inboard) ones.

THE INFLUENCE OF TURBULENCE ON THE STREAMFLOW OF A PROPELLER

In an ideal fluid at the boundary of a fluidstream there is a rapid drop of velocity from the value of $v_0 + v_x$ inside of the stream to the value v_0 outside. By the presence of as small viscosity as possible, this rapid change of velocity must lead to the appearance of infinitely larger viscous pressures as a result of a frictional drag action of fluid in the stream, and to an increase of velocity of the outer stream, also to the change of velocity profile. Particularly intensive change of velocity in an outer streamflow arises at large Reynolds numbers on account of turbulent mixing. In a case when tangential stresses that originate on account of viscous forces are small as compared with the tangential turbulent stresses, a cylindrical flow (in an ideal fluid) is changing to a conical one with a constant angle opening 2α.

The cases of a thin three-dimensional streamflow and a boundary case of a two-dimensional (plane) streamflow have been theoretically invesitgated, as a result of which a

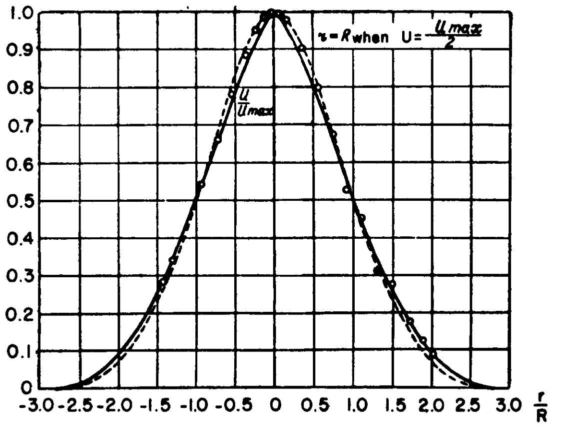

Figure 1 – Velocity Distribution at Cross Section of a Circular Streamflow

—— Theoretical Calculation of Tollmien

--- Experiment of Ruden

○ Experiment of Quito

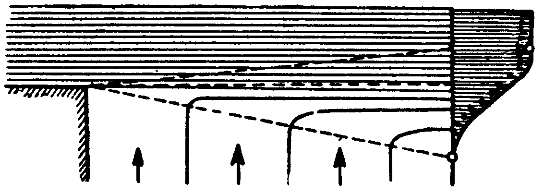

Figure 2 – Edge Washing of a Parallel Streamflow

law of velocity change in a streamflow and a characteristic of its widening are established (Figures 1 and 2).

According to the completed studies, a survey of which is presented in References 1, 2, and 3,* it follows that for a plane (two-dimensional) case $\alpha \approx 6$ deg to 8 deg, and for a three-dimensional case $\alpha \approx 12$ deg.

For a propeller stream having a finite thickness, we can assume a mean value of half an angle of opening $\alpha \approx 9$ deg, since for small distances from the propeller disc the stream is closer to a plane one and only at a considerable distance from the disc is it approaching three-dimensional. Thus, for small loadings the streamflow of a screw propeller will not have a constant diameter $D_1 \approx D$ but a variable one

$$D_1 = D + 2\alpha x \qquad [1]$$

where x is the distance from a propeller disc and $\alpha \approx 9$ deg.

From Expression [1] it follows that at a distance $x \approx 3D$ the diameter of the streamflow will be equal to twice the diameter of a propeller. We note that a mean velocity of the stream is inversely proportional to the radius of the cross section since, because of turbulence, the stream entrains a mass of fluid from the outer flow.

For a propeller working at a high loading coefficient, the jet flow in an ideal fluid cannot be considered cylindrical. The shape of a jet flow is determined by the known relationship of the axial resultant of induced velocity v_x to the distance to a propeller disc x

$$v_x = v_1 \left(1 + \frac{x}{\sqrt{R^2 + x^2}}\right) \qquad [2]$$

where induced velocity in plane of a disc

$$v_1 = v_0 \frac{\sqrt{1 + C_T} - 1}{2} \qquad [3]$$

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*References are listed on page 7.

and loading coefficient

$$C_T = \frac{T}{\rho/2\, F_0 v_0^2} \qquad [4]$$

The loading coefficient is determined on the basis of thrust T, density ρ, disc area of screw $F_0 = \pi R^2$, and speed of incoming flow v_0.

The relationship of a diameter of an ideal jet flow D_{1id} to a distance x is obtained easily from the equation of continuity

$$D^2\,(v_0 + v_1) = D^2_{1id}\,(v_0 + v_x), \qquad [5]$$

$$D_{1id} = D\sqrt{\frac{v_0 + v_1}{v_0 + v_x}} = D\sqrt{\frac{1}{1 + \frac{x}{\sqrt{R^2 + x^2}} \cdot \frac{\sqrt{1 + C_T} - 1}{\sqrt{1 + C_T} + 1}}} \qquad [6]$$

Considering that, even for the larger loadings, the tangent to the jet flow of an ideal propeller makes small angles with its axis, we therefore, introduce a hypothesis, according to which the angle between the boundaries of an ideal and a turbulent jet flow has the same value as in the case of an ideal cylindrical jet flow.

With this assumption it can be readily seen that a diameter of a turbulent jet flow will be

$$D_1 = D_{1id} + 2\alpha x \qquad [7]$$

where D_{1id} is determined by Expression [6] for a given loading coefficient C_T in relation to x. In Figure 3 the calculations (solid line) are compared with the results of tests by Voigt[4] (dotted line).

From Figure 3 it follows that the calculation gives substantially exaggerated dimensions of a jet flow; it is necessary, however, to take into account that in the test of Voigt with model propellers the Reynolds numbers were very small. Besides this, the velocity was so small along a considerable portion of the streamflow boundaries that it could not be measured.

If we neglect, in Figure 1, the region with second-order effects, where the velocity is less than 0.1 v_{max}, then the angle α can be taken as 6 deg.

The streamflow boundaries determined in this way are shown in Figures 3 and 4; they are calculated according to Equations [6] and [7].

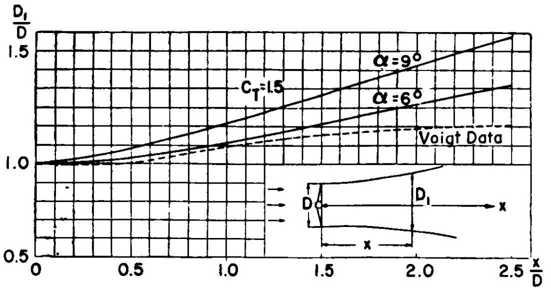

Figure 3 – Comparison of the Calculated Data of Stream Widening of a Propeller with Experimental Data of Voigt

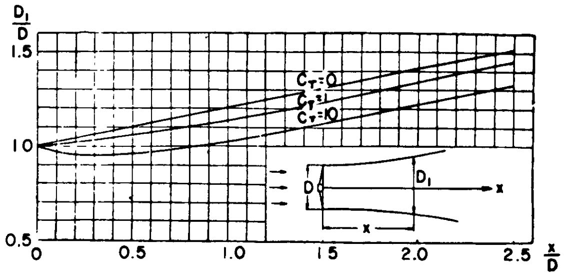

Figure 4 – Widening of Streamflow of a Propeller at Different Load Coefficients (Calculation)

SHAPE OF AN AXIAL LINE OF A JET FLOW OF OUTBOARD PROPELLERS

In addition to the investigated increase in diameter of the slipstream of the forward propellers, it is necessary to take into account the curvature of its axis, connected with the flow pattern around the hull of a ship.

Considering as small (in comparison with draft and breadth) the clearances between the hull and propeller and disregarding the induced velocities, for an approximate estimate we can assume that a centerline of a jet flow coincides with a meridional* section of a plane, equidistant from the hull and passing through the center of a propeller. In view of these remarks, the general scheme of relative position of a stream flow and a propeller (Figure 5a) can be presented in a form as shown in Figure 5b.

This, firstly, explains the appearance of a favorable negative flow for inboard propellers and, secondly, allows us to expect that, when choosing properly the direction of rotation we can obtain substantial counterrotating propeller effect due to recovery of energy lost in the twisting of the streamflow of the forward propeller.

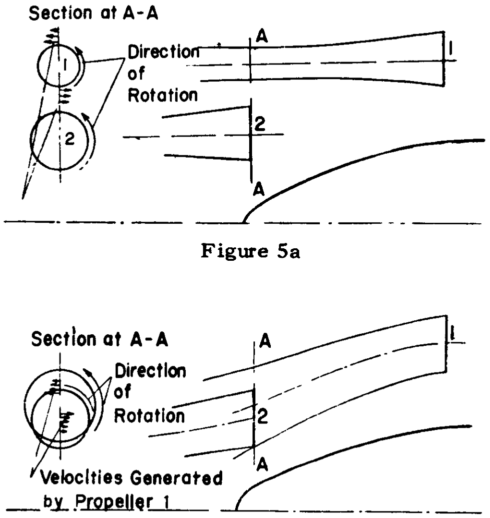

Figure 5a

Figure 5b

Figure 5 – Relative Position of Propeller Streamflows for 4-Screw Ship

(a) Usual Layout (Arrangement)

(b) When Taking into Account the Turbulent Washing of Streamflow Boundaries and the Twist of Its Axis

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*Section by a plane, passing through the centerline of a ship and the center of a propeller.

We note that a judgment as to the correct (from the point of view of utilization of contrapropeller effect) choice of direction of rotation depends on a relative position of the jet flow of the forward propellers and the disc of the rear propellers. Thus, for an arrangement as shown in Figure 5a (when we take into account the diffusion of a fluid), the contrapropeller effect will give the same kind of rotation; for the arrangement shown in Figure 5b, an opposite one.

For a ship model with propellers arranged as shown in Figure 6, the change of direction of rotation of the rear propellers led to a change in their efficiency, reaching 30 percent. Thus, as anticipated in light of the previous discussions, greater efficiency was obtained when the direction of rotation of the rear propellers was opposite to the direction of rotation of the forward propellers.

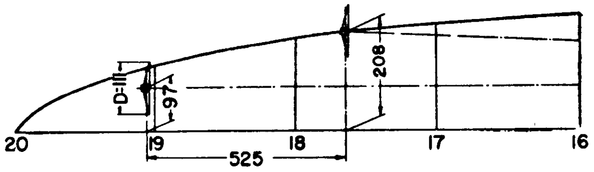


Figure 6 – Scheme of Position of Propellers at the Model

THE EFFECT OF DIRECTION OF ROTATION OF THE FORWARD PROPELLERS ON THE PENETRATION OF AIR INTO THE INBOARD PROPELLERS

These experiments have shown that outboard propellers should have an outward direction of rotation. This is related to the fact that, besides the influence of the velocity field of the forward propellers on the after ones, as investigated before, there is also an effect caused by a penetration of atmospheric air into the inboard propellers. This happens for inward direction of rotation of outboard propellers. The scheme of the air penetration is shown in Figure 7. The appearance of a velocity of flow, directed from free surface to the hull, is connected with the intensive turbulent mixing.

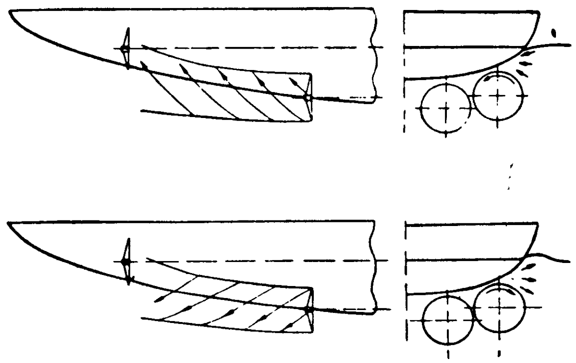
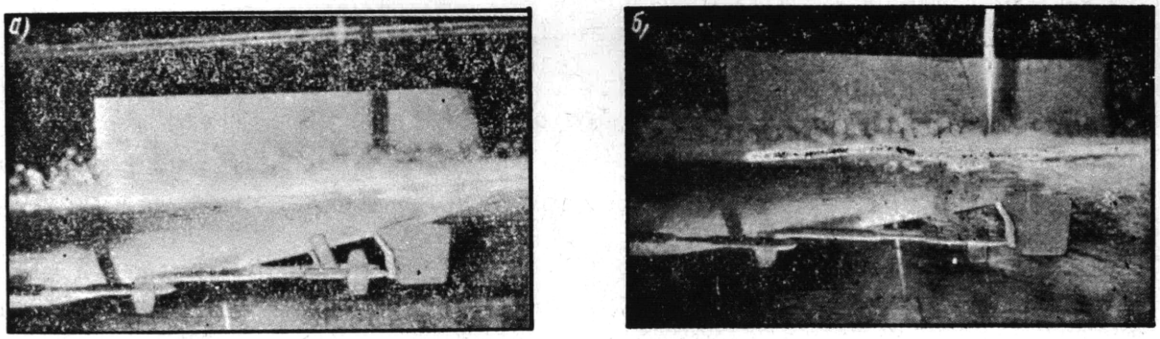


Figure 7 – Scheme of Air Penetration toward Inboard Propellers for a Different Direction of Rotation of Outboard Propellers

In Figures 8a and 8b, the shape of a flow pattern is schematically represented for corresponding outward and inward rotation of the outboard propellers. In the latter case, we see clearly that air is getting into the inboard screws. The intensity of air suction increases with the increase of the loading coefficient, and even for normal pitch values shows appreciable effect on action of inboard propellers. According to investigations performed (for the scheme of propeller arrangement shown in Figure 6), this influence leads to a decrease in



(a) Outward Rotation (b) Inward Rotation

Figure 8 – Flow Pattern for Different Direction of Rotation of Outboard Propeller

thrust coefficient of 7 to 8 percent when the efficiency drops insignificantly (by 3 to 4 percent).

CONCLUSIONS

The physical effects discussed in this article, which determine the influence of the forward (outboard) propellers on the rear (inboard) ones, are correct for any multiscrew ship, from a qualitative point of view. Therefore, the following conclusions can be made as to the choice of direction of rotation of propellers of a multiscrew ship.

1. Outboard propellers, to eliminate the risk of air suction into inboard propellers, should be outward turning.

2. Inboard propellers, to utilize the contrapropeller effect from the slipstream of the outboard propellers, should be inward turning. When, during an analysis in line with the aforementioned indications, it is found that the flow of the forward propellers passes outside of the disc of the after propellers, then the direction of rotation of the after propellers has no serious effect. Even in this case it is desired that the outboard propellers have the outward direction of rotation. For the triple-screw ship, it is obvious that the direction of rotation of the middle screw is immaterial in all cases.

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