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AN INVESTIGATION OF THE FLOW IN THE REGION OF THE RUDDER OF A FREE-TURNING MODEL OF A MULTIPLE-SCREW SHIP

by

W. G. Surber, Jr

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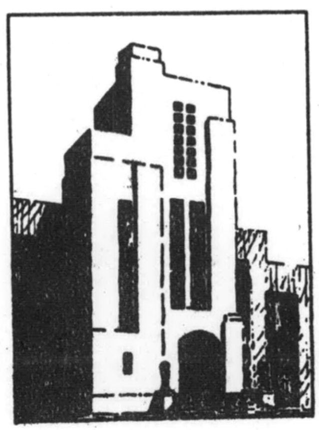

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ABSTRACT

An investigation to determine the velocity and direction of flow in the vicinity of a centerline rudder of a free-turning model of a multiple-screw ship is presented. The investigation includes a flow survey in region of the rudder during a free turn, and a wake survey in a transverse plane at the centerline of the rudder stock while moving on a straight course.

INTRODUCTION

To estimate the forces and moments acting on a rudder it is necessary to know something of the flow conditions in the region in which it is operating. The objective of this study is to determine the velocities and directions of flow in the vicinity of a centerline rudder on a model of a typical multiple-screw ship, and to bring further light into previous studies made for the purpose of predicting the torque of rudders (1)*.

The investigation was divided into two parts; the measurement of flow direction in the region of the rudder during a free turn, and a wake survey while moving on a straight course. The results of the tests and recommended procedures for future tests of this type are presented in this report.

MODEL AND APPARATUS

A 20-foot model of a typical multiple-screw cruiser-type ship having a centerline semi-balanced rudder was selected for these tests. The stern of the model and the relative location of the propellers and rudder are shown in Figures 1 and 2.

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* References will be found on page 9 of this report.

Measurement of the flow direction in the vicinity of the rudder during the free turns required the design and manufacture of a special type of flow-angle instrument. Five such instruments were designed and built at the Taylor Model Basin. Each instrument consisted of a small metal flag attached to a shaft which projected from the hull of the model into the region where the flow direction was to be measured. A microtorque potentiometer was attached to the upper end of the flag-shaft to measure the shaft angle or flag direction. When the model was in motion the flag assumed the same direction as the flow and the output of the potentiometer was recorded using a string oscillograph. The flow-direction flags were located to take a traverse in each of two positions as shown in Figures 1 and 2. In the upper position the flags were located at mid-height of the skeg or fixed section of the rudder. The five openings in the hull for the flag shafts were located on an arc drawn from the centerline of the rudder stock. This was done to situate each flag an equal distance from the stock, and not have the outboard Flags 1 and 5 too near the inboard propellers.

The wake survey was made using an existing 13-hole pitot tube and manometer as described in Reference 2.

TEST PROCEDURE

A series of turns with the model self-propelled, and free turning, were made at speed-length ratios of 0.89, 1.13, 1.24, and 1.34 with 25 and 35 degrees rudder angle. The model was allowed to turn through 120 degrees change of heading to insure steady turning conditions, and oscillograph data were obtained for each turn. The power to each propeller shaft during the turn remained at the same setting as used for the approach speed.

The wake survey was conducted to determine the magnitude and direction of the flow into the rudder while in a straight course approaching a turn. The model was self-propelled but held on a straight course by the towing carriage. The rudder was removed and the 13-hole spherical pitot tube installed with the center pressure orifice initially located at the vertical centerline of the rudder stock. A grid of survey locations was established to cover an area determined by the projection of the trailing edge of the rudder at ± 35 degrees on a transverse plane through the rudder stock. A number of runs were made at each location on the grid until steady

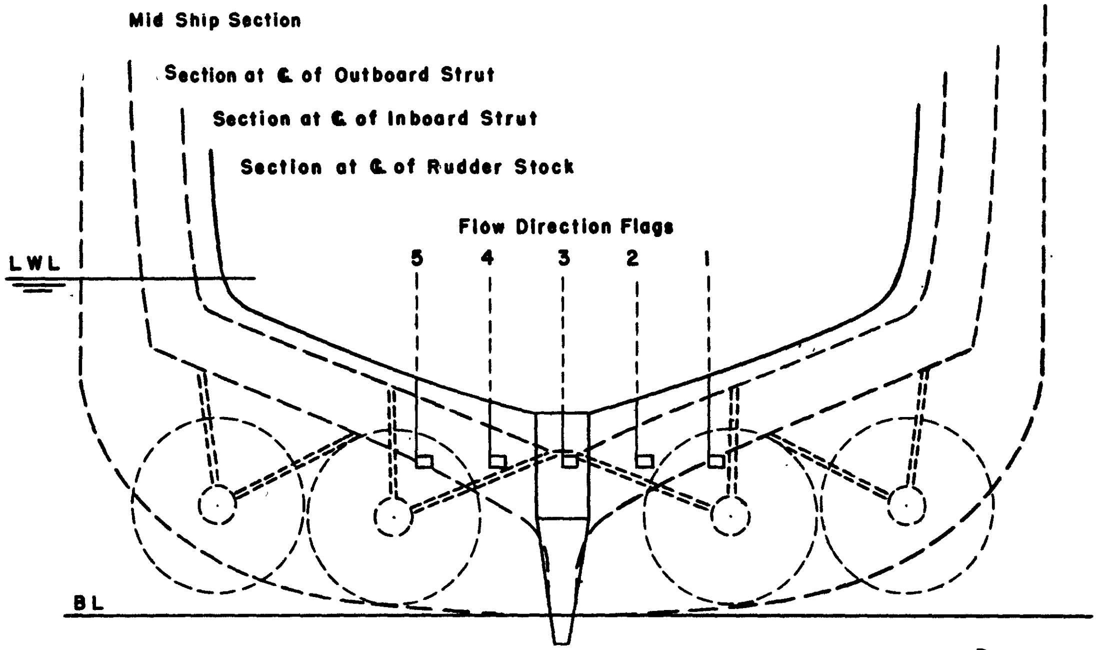


Figure 1 – Transverse Section at Rudder Stock Looking Forward Showing Location of Flow Direction Flags in Upper Position

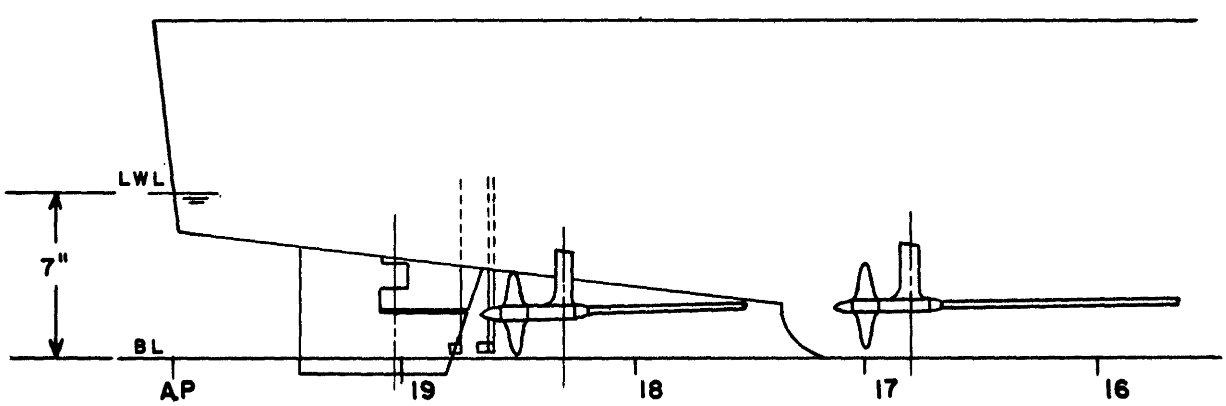


Figure 2 – Stern Profile Showing Location of Flow Direction Flags in Lower Position

values of the manometer were obtained. All data were recorded at a speed-length ratio of 1.24.

DISCUSSION OF RESULTS

The results of the turning test to determine the direction of flow in the vicinity of the rudder are shown in Figure 3, and presented in tabular form in Table 1. Figure 3 shows the rudder, inboard propellers, flow-direction flags and outline of the bottom of the hull as they would be viewed when looking down through a glass-bottom hull. The direction of each flag is indicated by a solid line for the lower position, and by a dashed line for the upper position. The drift angles in Table 1 were measured at the centerline of the rudder stock and were obtained from a previous turning test.

In each of the eight conditions tested, the flags in the lower position assumed approximately the same angle as the drift angle at the rudder stock and were not affected by the flow from the propellers. The flags which were located near the tip diameter of the propeller apparently were not affected by the propeller flow due to the contraction of the race just aft of the blades (3).

When the flags were located in the upper position the flow angles were less uniform. This possibly may be attributed to the effects of several factors such as drift angle, propeller race, and interaction between hull and rudder.

In virtually every condition, Flag 3 on the centerline of the hull assumed the same direction as the drift angle. Apparently the region midway between the propellers is not influenced by the propeller race.

Force measurements taken on a free-turning model with a rudder divided at the bottom of the skeg showed that when the turn was initiated the lower section contributed a greater lift than the upper section (4). The flag test, however, indicated that during the steady-turning condition the lower portion of the rudder has a very low effective angle of attack and hence contributes little to maintaining the ship in a turn. Therefore, even though the upper part is essentially an unbalanced-flap type and is less efficient than the all-movable lower section, it apparently operates at a large enough angle of attack to maintain the drift angle of the hull.

A more detailed flow exploration would be required to determine why Flags 2 and 4 in the upper position are affected by the slip stream whereas Flags 1 and 5 in the lower position are not.

Table 1

Data from Flag Tests

				Flag Angle in degrees				
Speed-Length Ratio	Rudder Angle, deg.	Flag Position*	Drift Angle, deg.	Flag 5 Port Out'bd	Flag 4 Port In'bd	Flag 3 Center-line of Model	Flag 2 Stbd. In'bd	Flag 1 Stbd. Out'bd
0.89	25	1 2	26.0 26.0	2.0 24.5	6.0 21.6	23.0 26.0	8.5 21.5	10.5 22.5
0.89	35	1 2	27.0 27.0	0.0 27.0	5.5 25.5	27.0 27.0	8.0 25.5	8.5 20.0
1.13	25	1 2	24.5 24.5	2.0 24.5	6.5 21.0	24.5 24.5	9.0 24.5	12.5 21.5
1.13	35	1 2	26.0 26.0	2.0 26.0	6.0 25.5	26.0 26.0	9.0 24.5	8.0 22.0
1.24	25	1 2	22.0 22.0	5.0 22.0	6.0 21.5	22.0 22.5	10.0 19.0	10.0 21.5
1.24	35	1 2	24.5 24.5	2.5 25.0	6.0 24.5	24.5 24.5	10.0 24.5	10.0 24.5
1.34	25	1 2	20.0 20.0	5.0 20.0	- - 20.0	16.0 18.0	10.0 15.5	5.5 20.0
1.34	35	1 2	22.0 22.0	3.0 22.0	4.5 18.5	22.0 22.0	10.0 22.0	5.5 22.0

* No. 1 - Flags in upper position
No. 2 - Flags in lower position

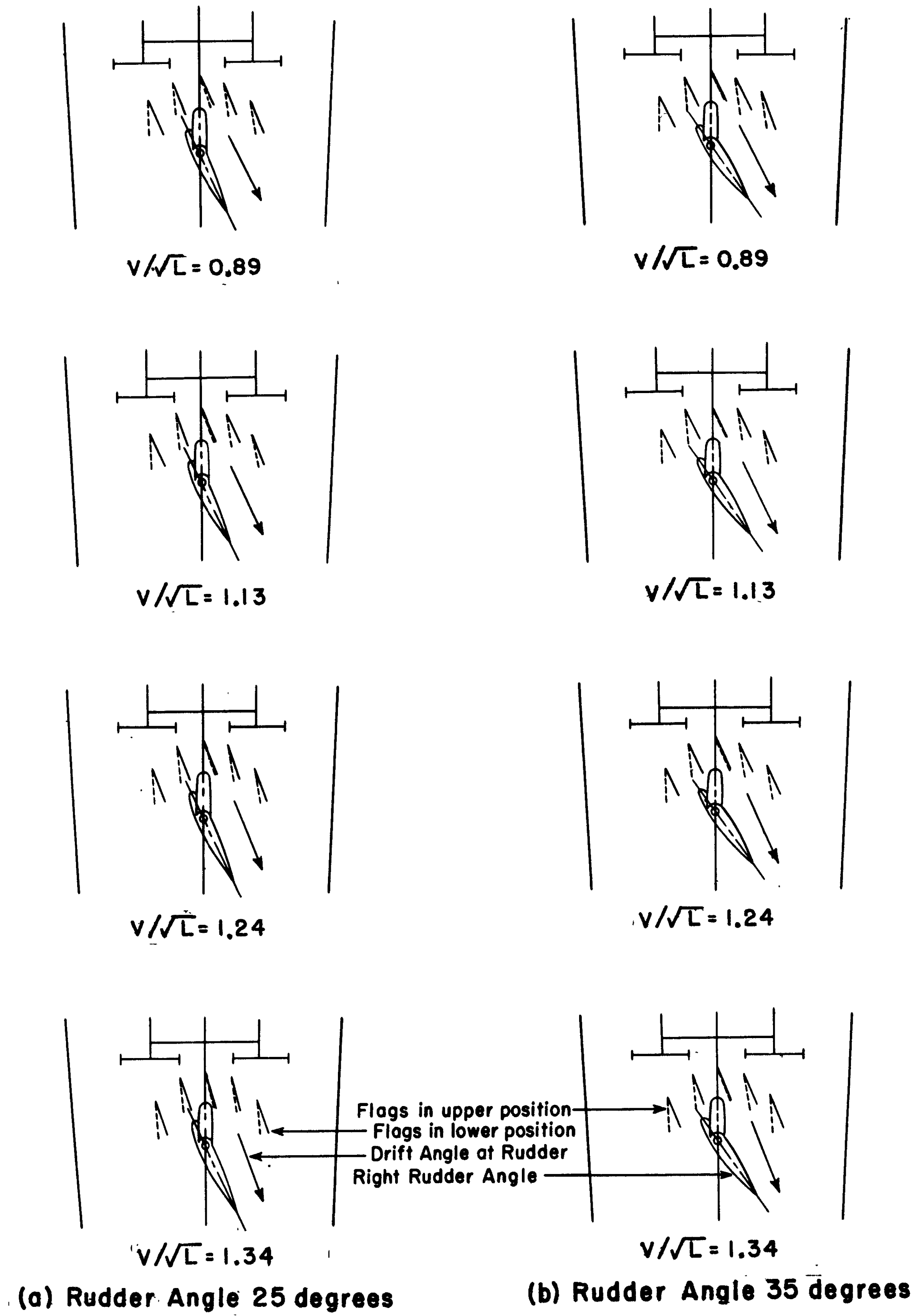


Figure 3 – Plan View of Stern near Rudder showing Directions of Flow Flags

The results of the wake survey are shown in Figure 4. The method of presentation is essentially the same as that conventionally used for propeller wake surveys. A definition of the measurements of wake is given in the appendix.

Outlines of the rudder at zero angle and 35 degrees left rudder are shown to indicate the regions of flow in which the rudder is operating when on a straight course and at the beginning of a turn. While steering a straight course and at the start of a turn the rudder is moving in a region of positive wake velocity which progressively decreases in magnitude with an increase in distance from the hull. It will be noted that the only region where negative wake velocity will be found is in the slip-stream of the propellers, and that a rudder angle of 25 degrees or more is required before the trailing edge of the rudder enters this region.

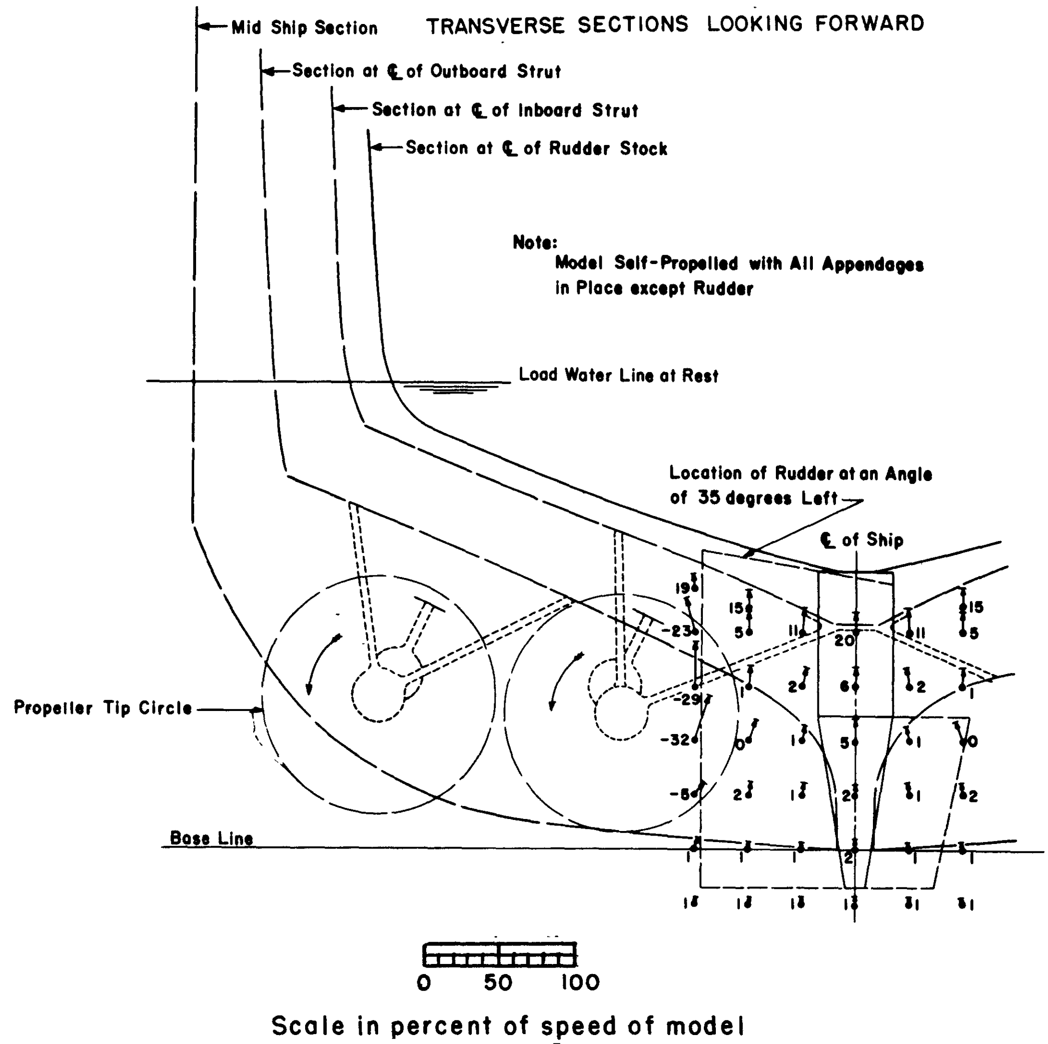
It is not possible with existing equipment to conduct a wake survey such as this on a free-turning model. However, the results of such a test would be of great value in design and research, and the development of such an instrument has been started.

CONCLUSIONS

The results of an investigation made to determine the flow angularity and velocities in the vicinity of the rudder on a free-turning model of a typical multiple-screw ship indicate that:

1. The flags in the lower position assume approximately the same direction as the drift angle and are not affected by the flow from the propellers. This suggests that the lower portion of the rudder has a very low effective angle of attack while in a steady turn and contributes very little to maintaining the ship in a turn.

2. In the upper position, the flow angles are less uniform. This possibly may be attributed to the effects of several factors such as drift angle, propeller race, and interaction between hull and rudder. However, the upper portion of the rudder apparently has a large enough angle of attack to maintain the drift angle of the hull.



Note: The vectors show the transverse components of wake. The magnitude of these vectors is scaled as a percentage of the speed of the model. The numerals indicate the longitudinal components of wake in percent of model speed. Numerals of a negative value designate negative wake where the flow is traveling faster than the speed of the model.

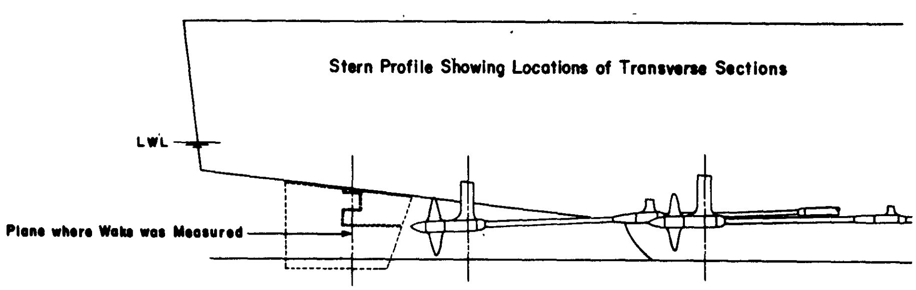


Figure 4 - Wake in Transverse Plane in Way of Rudder of a Typical Multiple-Screw Ship Model at a Speed-Length Ratio of 1.24

3. In a straight course approaching a turn, the rudder is operating in a region of positive wake, which decreases with an increase in distance from the hull.

4. A rudder angle of 25 degrees or more is required before the trailing edge of the rudder will enter the region of negative wake created by the propeller.

RECOMMENDATIONS

It is believed that considerably more knowledge could be obtained on the flow conditions in the vicinity of the rudder by the addition of two more types of tests:

1. Measurements of the distribution of forces on a segmented rudder for the transient and steady turning conditions with the flags in place. Additional vertical settings for the flags would be desirable.

2. The adaptation of an existing pitot-static yaw head rake to measure the magnitude as well as the direction of the wake in the vicinity of the rudder during free turns. Steering to be accomplished by mounting an auxiliary rudder on an outboard rigging.

REFERENCES

1. DTMB Report 915 "A Method of Predicting the Torque of Semi-balanced Centerline Rudders on Multiple Screw Ships", S. C. Gover and C. R. Olson, November, 1954.

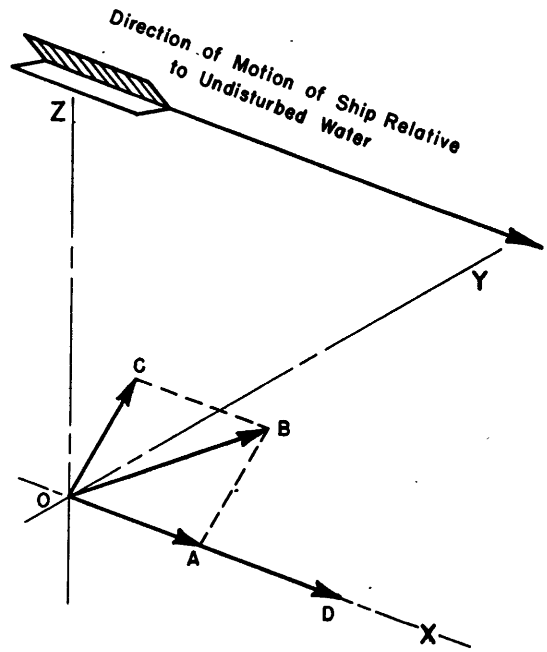
2. DTMB Report 487 "Instruments and Methods for Measuring the Flow of Water Around Ships and Ship Models", C. E. Janes, March 1948.

3. Rossell and Chapman, "Principles of Naval Architecture", Societv of Naval Architects and Marine Engineers, Vol. 2, page 128 (1939).

4. Unpublished TMB data.

APPENDIX

When a ship passes through the water, it imparts motion to the neighboring fluid particles. The motion of these particles, at any point, relative to the water which is not disturbed by the ship is designated as the wake. Unless otherwise indicated, all velocities are considered as relative to the undisturbed water. The resultant wake velocity at a given point can be divided into two components as shown in the accompanying diagram.



The Y-Z plane which belongs to the system of rectangular coordinates shown is a plane through the point at which the wake is being measured perpendicular to the centerline of the ship.

Vector OD represents the velocity of the ship, vector OB represents the resultant wake velocity, vector OA represents the longitudinal component of the wake velocity along a line parallel to the centerline of the ship, and vector OC represents a component of the wake velocity in the transverse plane Y-Z.

The longitudinal component of the wake velocity is considered as positive when it is in the same direction as the ship velocity and negative when in the opposite direction. The longitudinal component of the wake velocity expressed as a ratio to the ship velocity is called the longitudinal wake fraction.

The longitudinal wake fraction is related to the longitudinal velocity of flow which is measured by a pitot tube mounted on the ship as follows:

$$W = 1 - \frac{V_m}{V_s}$$

where W is the longitudinal wake fraction,

V_s is the ship velocity, and

V_m is the longitudinal component of the flow velocity measured by the pitot tube and is, therefore, the water velocity relative to the ship.

On the diagrams which present the results of wake tests in this report, the numerals indicate the longitudinal wake fraction ×100. The transverse component is shown as a vector and is drawn to scale as a percentage of ship velocity.

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