UNCLASSIFIED

AD NUMBER: AD0496158

CLASSIFICATION CHANGES

TO: Unclassified

FROM: Confidential

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to U.S. Government Agencies and their Contractors; Administrative/Operational Use; 1 Aug 1951. Other requests shall be referred to David W. Taylor Model Basin, Naval Ship Research and Development Center, Bethesda, MD 20817.

AUTHORITY

U per DoDD 5200.1 dtd 31 Dec 1963; ST-A per DWTNSRDC ltr dtd 23 Feb 1983

THIS PAGE IS UNCLASSIFIED

UNANNOUNCED

UNCLASSIFIED

~~CONFIDENTIAL~~

AD 496158

NAVY DEPARTMENT

THE DAVID W. TAYLOR MODEL BASIN

WASHINGTON 7, D.C.

COMPARISON OF RUDDER TORQUES FROM MODEL TESTS AND SHIP TRIALS OF SINGLE RUDDER, MULTIPLE SCREW SHIPS

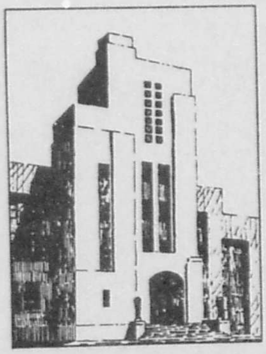
by

Grant R. Hagen

NAVY RESEARCH SECTION
SCIENCE DIVISION
REFERENCE DEPARTMENT
LIBRARY OF CONGRESS

9L89C

2



OCT 22 1951

D D C
RECEIVED
SEP 17 [illegible]
A

8250415

5

August 1951

Report C-373

NS 715-090

DOWNGRADED AT 3 YEAR INTERVALS;
DECLASSIFIED AFTER 12 YEARS
DOD DIR 5200.10

UNCLASSIFIED

~~CONFIDENTIAL~~

UNCLASSIFIED [redacted]

COMPARISON OF RUDDER TORQUES FROM MODEL TESTS AND SHIP TRIALS OF SINGLE RUDDER, MULTIPLE SCREW SHIPS

by

Grant R. Hagen

[redacted]

"Reproduction of this document in any form by other than naval activities is not authorized except by special approval of the Secretary of the Navy or the Chief of Naval Operations as appropriate."

August 1951 Report C-373

UNCLASSIFIED

[redacted]

TABLE OF CONTENTS

INTRODUCTION

To ascertain the type and extent of hydrodynamic loads on rudders and rudder stocks, measurements have been made on ships during full-scale trials, and measurements of the rudder forces have been made on models. Data from these sources are used to aid in solving the design problems. Torque, or twisting moment, on the rudderstock is the load which ordinarily causes the greatest concern and this is the only load which has been amenable to measurement on full-scale trials.

In past years there has been too much disagreement between torques predicted from model tests and torques obtained on full-scale trials to inspire confidence in model tests. Recognition of this fact lead in 1948 to the establishment of a project* which was to be concerned with a reconciliation of rudder-torque data from Joessel's formula, from model tests, and from ship trials, including an improvement of methods of predicting ship performance. Investigations made under this project comprise the material for this report.

More specifically, this report discusses various techniques which have been employed for making model rudder tests, compares full-scale torque measurements with torques predicted from model tests, and presents conclusions based on the investigations. An improved method of conducting rudder tests for the prediction of ship performance is included, but the report does not discuss the prediction of rudder torques without model tests.

TECHNIQUES OF TESTING MODEL RUDDERS

The present method of testing model rudders is the result of continued efforts to obtain model data under conditions similar to those which exist for a turning vessel. There follows a short review of methods which have been used for model testing, and an evaluation of the several methods.

REVIEW OF METHODS

Among the earliest systems for measuring the load on a model rudder was that in which the total transverse restraining force at the stern of the model was measured as the rudder was set at various angles and the model was self-propelled in a straight line. This methdd yielded only a very rough approximation to the side force, or lift, on the rudder.

---

*BuShips ltr S22-(3)(442-440-330) of 17 May 48 to TMB.

The next step was to place at the stern of the model a dynamometer which could support the rudder and also measure the force components. The model was self-propelled in a straight line, and the rudder was set at various angles from zero degrees to thirty-five degrees, the steady-force components being measured at each angular setting of the rudder.

Two new rudder dynamometers have made possible a third technique, to measure the torque on the rudderstock while the rudder is turning and while the model is free to execute a maneuver. One of these dynamometers can also measure the side force and the fore-and-aft force under the same circumstances, if the models are big enough to carry the dynamometer. This can be done for 20-foot models having the rudder on the centerline of the model and for all 30-foot models. The forces are proportional to the strains in cantilever flexures which deflect slightly as the rudder is subjected to load. The strains are measured by wire-resistance strain gages which are connected to a recording oscillograph.

A modification of this last method is to measure the forces as the rudder turns, but with the model constrained to move in a straight line.

EVALUATION OF DIFFERENT METHODS

The first method of testing which was mentioned has long since been discarded at the Taylor Model Basin for it gave very incomplete and unrealistic data. The second method was almost completely abandoned (except for open-water characterization of rudders) in 1948 when the superiority of tests with a turning model became evident. The fourth, and last, method mentioned cannot be relied on to yield results which are comparable with those obtained with the freely maneuvering model.

Figure 1 shows full-scale rudder-torque predictions based on model-test data obtained by the last three methods mentioned. The tests were made on four models, one representing a twin-rudder destroyer, the other three representing cruiser hulls with their rudders on the centerline. For the destroyer no data were obtained with the rudders set at fixed angles. However, tests of that type on this same model when fitted with modified rudders showed that the torque obtained with fixed rudder angles is about midway between the torques obtained for the two methods shown in the figure.

It is clear that the system of conducting a test has a marked influence on the kind of data that are obtained. The freely turning model duplicates most nearly the full-scale-trial conditions, and in preliminary studies it gave promise of yielding data which could be used to predict rather

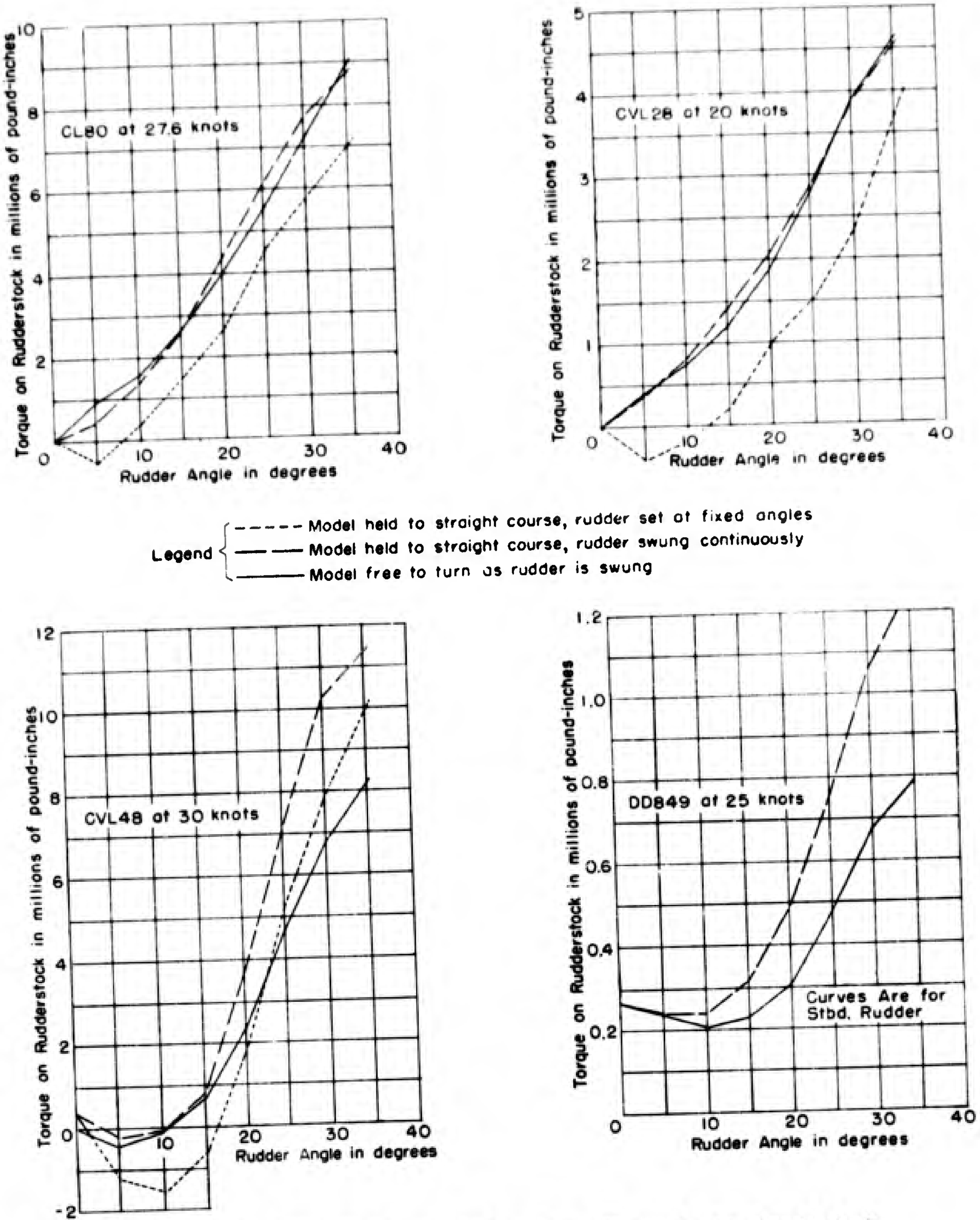


Figure 1 - Rudder Torques for Four Vessels as Predicted from Model Tests in which Three Different Testing Techniques Were Employed

Models were self-propelled in all cases.

closely the full-scale torque. It was therefore employed in all the model tests in which torque was measured for comparison with the results of full-scale trials.

SPECIAL STUDIES

The general method of conducting the rudder tests having been decided upon, it seemed desirable to make several special studies to aid in the evaluation of the data obtained in the later tests. Except in one instance, all of these studies were made with models having single rudders and multiple screws, so the rudders were not in the slipstreams. For all of the tests it was customary to make three runs for each condition, and the average of the results of the three runs is presented as the correct result for the condition studied. In nearly every case the agreement among the three runs was very good.

EFFECT OF RATE OF RUDDER MOVEMENT

The rudder rate ordinarily specified for naval vessels is thirty seconds for hard over to hard over, or an average rate of 2-1/3 degrees per second. To learn what effect the angular rate of rudder movement has on the rudder torque, three rates were tried on a model of CVL48 and on a model of DD849. The tests were made with the models turning freely, and also with the models constrained to a straight course. The results, shown in Figure 2, indicate that torque increases directly with rudder rate. For the range of rates investigated the variation in torque is seen to be of rather small magnitude; but it is enough to show that the rudder rate should be taken into consideration in model tests. Except for these special tests the tests discussed in this report were made with rudder rates comparable to those used on the prototypes.

EFFECT OF PROPELLER SPEED

Rudder-torque measurements were made on a model of CL80, a quadruple-screw vessel with a single rudder, under two conditions of propulsion. The first was with all screws working; the other was with only the inboard screws working. The model was self-propelled at the same speed in both cases. For the two conditions the results are essentially the same, as shown in Figure 3. For rudder angles larger than 25 degrees there is a small increase in torque when only the inboard screws are operating.

It can be concluded that when rudder-torque measurements are made on a model with a centerline rudder which is not in a screw race, variations

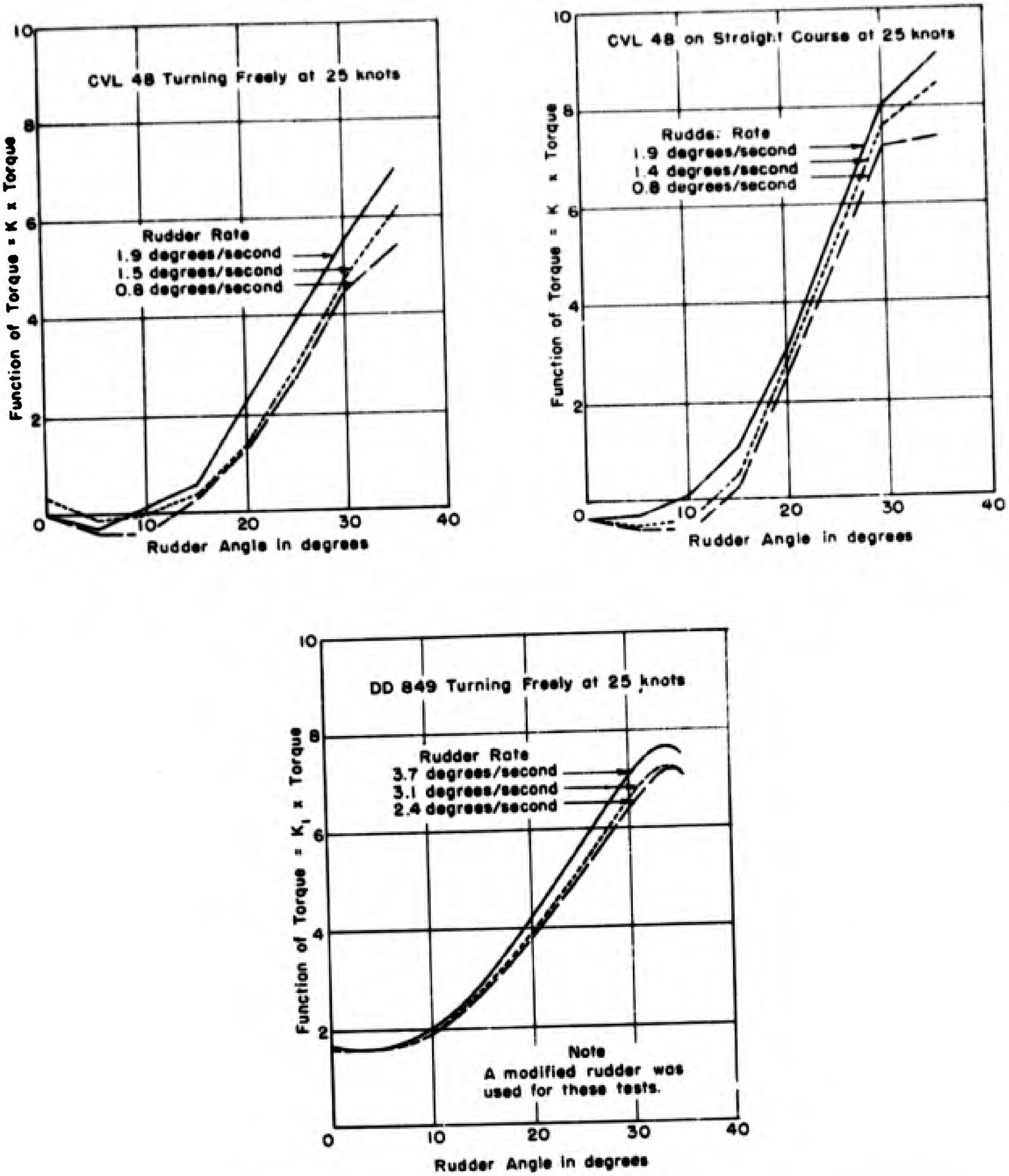


Figure 2 - Comparative Values of Rudder Torque Associated with Three Different Rates of Rudder Movement as Determined by Tests of Models of CVL48 and DD849

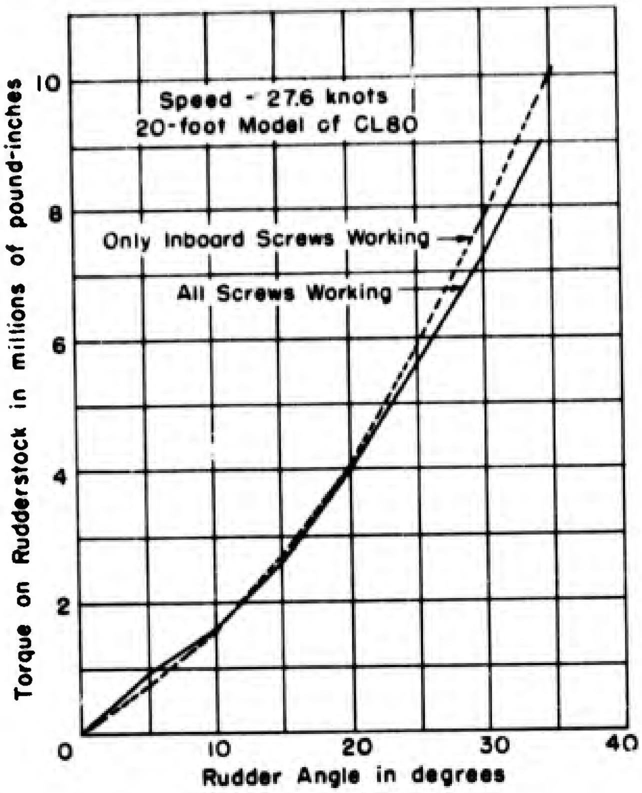


Figure 3 - Comparison of Rudder Torques Obtained with All Screws Working and with Only Inboard Screws Working

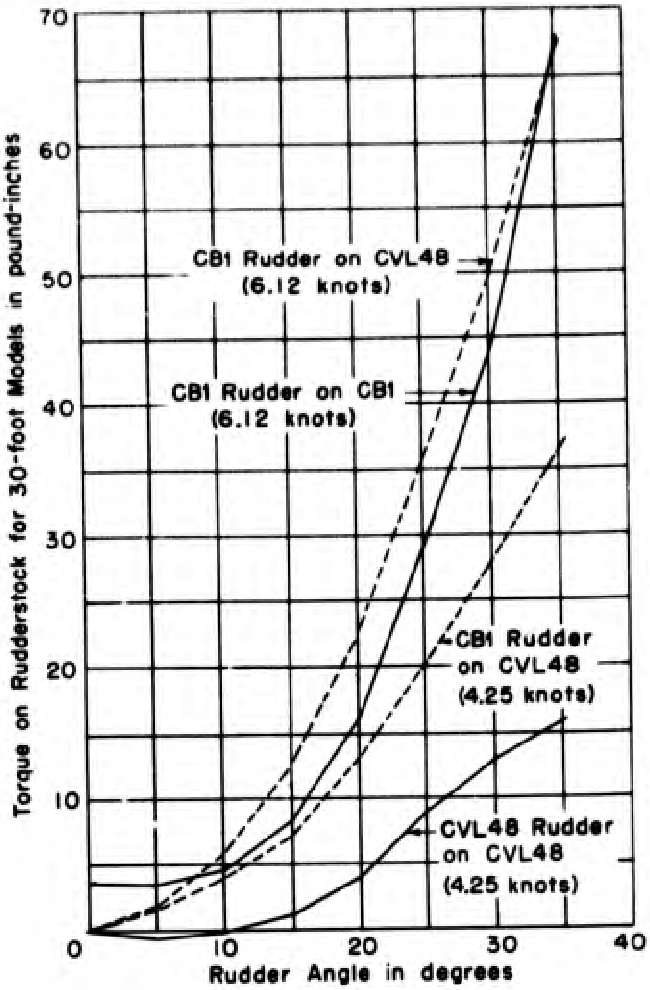


Figure 4 - Comparison of Rudder Torques for CB1 and CVL48 with Those Obtained with CB1 Rudder on CVL48

of propeller speed likely to be encountered are unimportant as long as the model is travelling at the correct speed.

INFLUENCE OF HULL

Tests on 30-foot models of CVL48 and CB1 showed that at nearly equal speeds the maximum rudder torque on the model of CB1 was about twice that for the CVL48 model. The area of the CVL48 model rudder was 87 percent as large as the area of the CB1 rudder. The CVL48 rudder had 24.9 percent balance, the CB1 rudder had 23.0 percent balance. As these differences did not seem large enough to cause so large a difference in the torques it was thought that the hulls themselves might be responsible.

The most evident difference between the hulls was that the skeg on CB1 extended considerably farther aft than did the skeg on CVL48. To learn whether the difference in the torques could be traced to the hulls, the CB1 rudder was installed on the CVL48 hull. Figure 4 shows the results for two speeds. Similar results were obtained at other test speeds. The difference in the torques is very definitely attributable to the differences in the rudders, and such small differences in the hulls as existed in this case are relatively unimportant.

COMPARISONS OF 20-FOOT AND 30-FOOT MODELS

Most of the ship models tested at the Taylor Model Basin are 20 feet in length. For three of the vessels discussed in this report models were available in both 20-foot and 30-foot lengths, and tests were made on both sizes. The models represented CVL28, CVL48, and CB1. Representative comparisons of results of the tests are shown in Figure 5.

The tendency seems to be that torque predictions based on 20-foot models are larger than for 30-foot models. This was true at all speeds for CVL28 and CVL48. For CB1, however, the results were very nearly identical for both sizes at all speeds. A conclusive statement concerning the effect of model size would require many more comparisons. At least this much can be said: If the 30-foot model provides satisfactory predictions, then the predictions based on 20-foot models would, if in disagreement, include a small margin of safety.

TESTS WITH SEMI-BALANCED RUDDERS ON SHIPS' CENTERLINES

Comparison of rudder torques measured during full-scale trials and those predicted from model tests is the only certain way of determining the validity of the model tests. Of course the extent of agreement between ship and model depends upon the acceptability of measurements aboard the ship as well as upon the correctness of the model prediction. In this report twelve ship-model comparisons of rudder torque are discussed, eight of these being for single-rudder vessels with multiple screws.

These eight are CB1, CVL48, CA139, CL145, DD644, CA69, CVL28, and CL80. Figure 6 shows sketches of the sterns of these vessels in profile and also gives the area and balance for each rudder. CA69 is seen to be the same as CVL48, and CL80 is the same as CVL28. After the ship-model comparisons of torque have been made for these vessels, the soundness of the ship results and model results will be discussed. It should be pointed out that the model

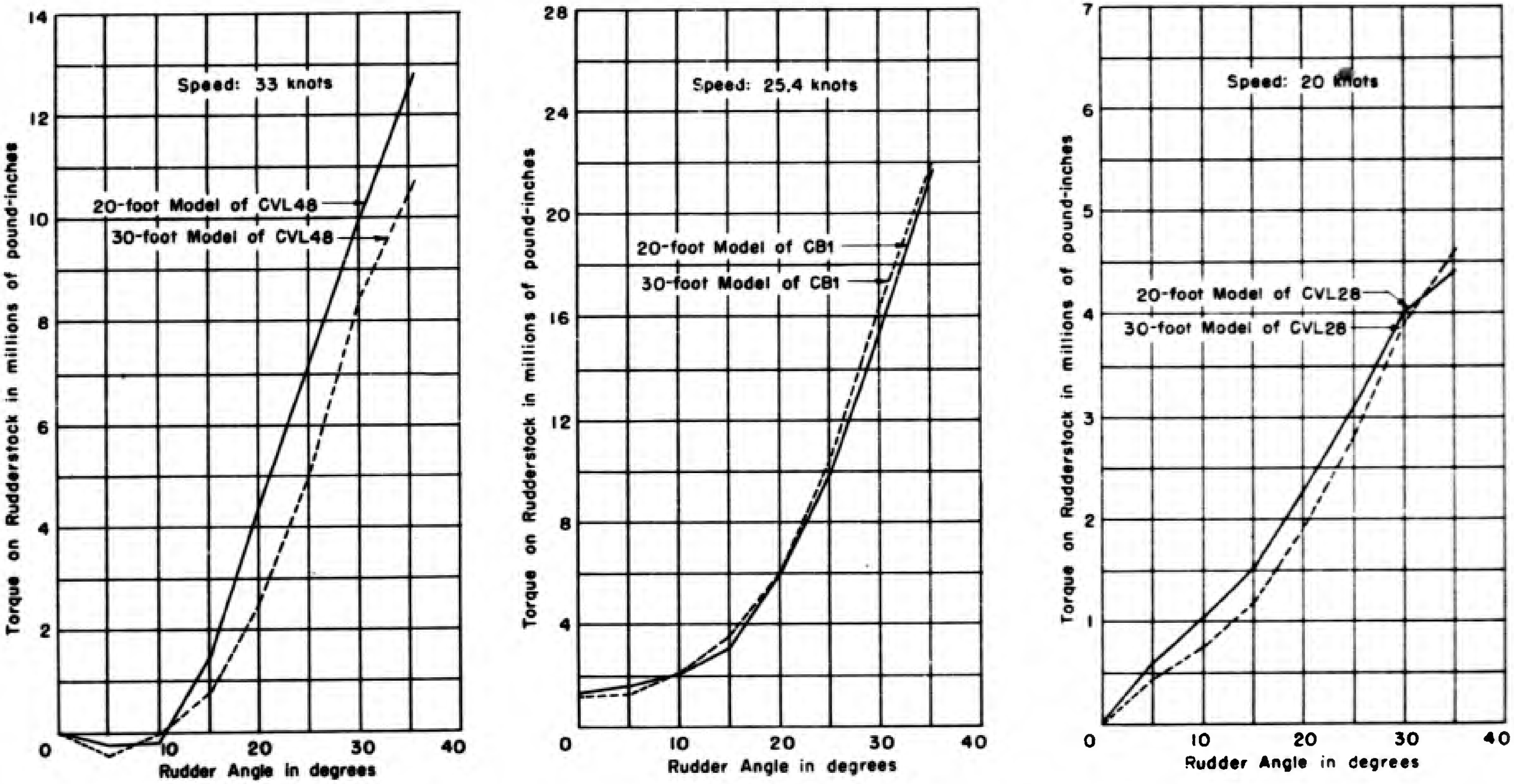


Figure 5 - Comparison of Full-Scale Rudder Torques Predicted from Tests on 20-Foot and 30-Foot Models of Each of Three Classes of Vessels

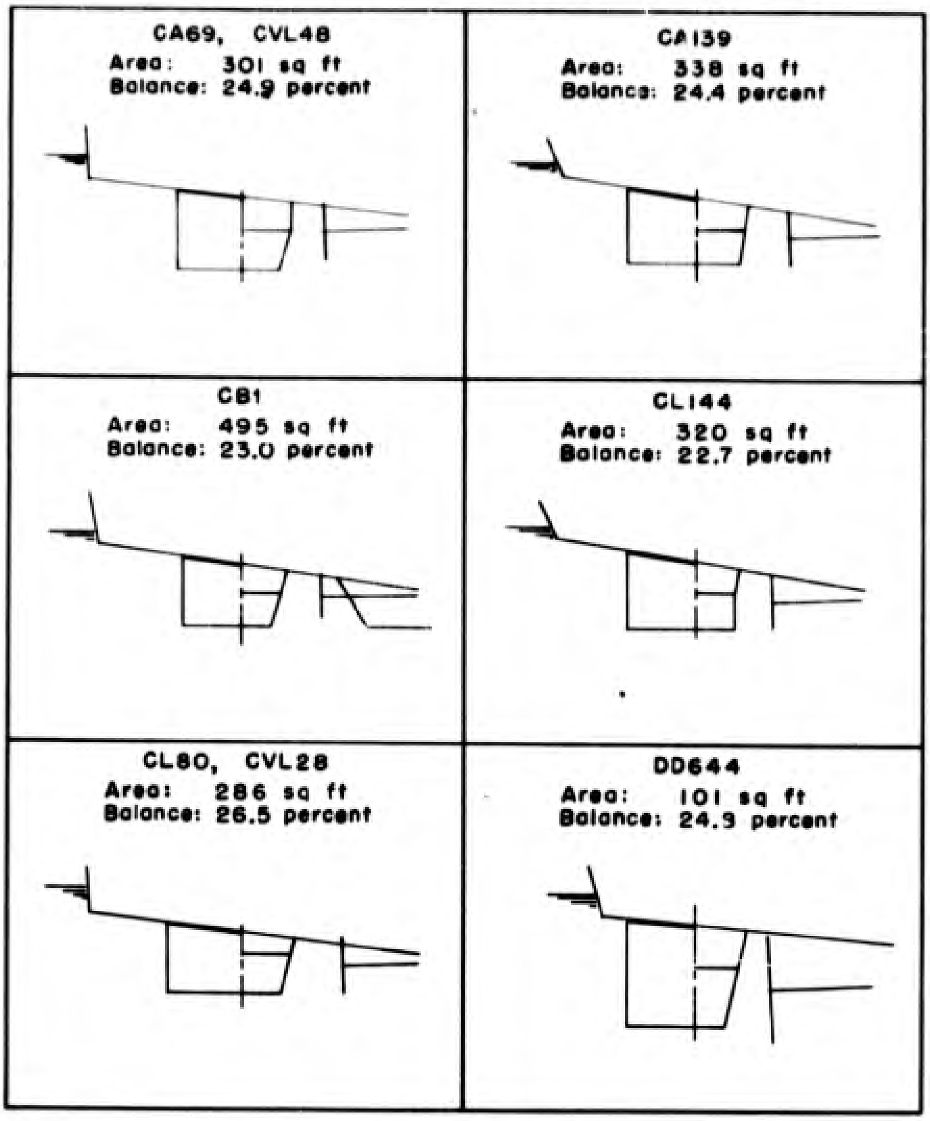


Figure 6 - Sketches Showing Stern Profiles of Single-Rudder Vessels Tested

data were recorded continuously as the rudders turned, and fortuitous fluctuations were faired out to give the plots of model predictions. The full-scale-trial torques were obtained from intermittent recordings of ram pressures as the rudders turned, and the curves for the ships are plots of instantaneous, rather than mean, values of torques.

CB1 - MODELS 3672 AND 3815

In Figure 7 comparisons of rudder torques obtained with ship and model are shown for four speeds. The model was 20 feet long. Similar comparisons are made in Figure 8 for a 30-foot model. The agreement between ship and model is good in both cases.

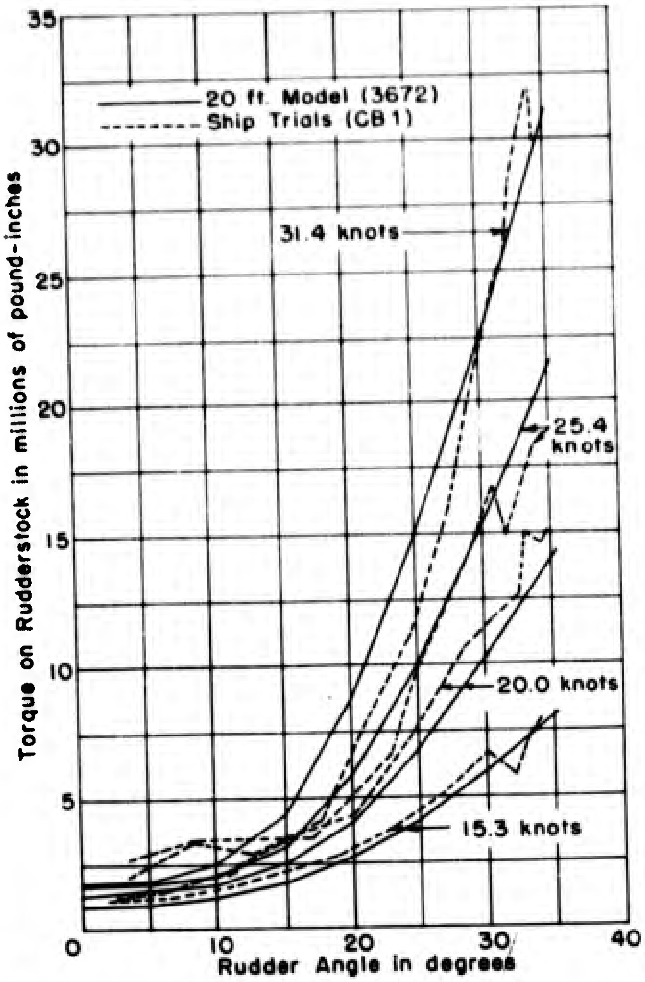


Figure 7 - Rudder Torque on CB1 from Ship Trials and Model Tests

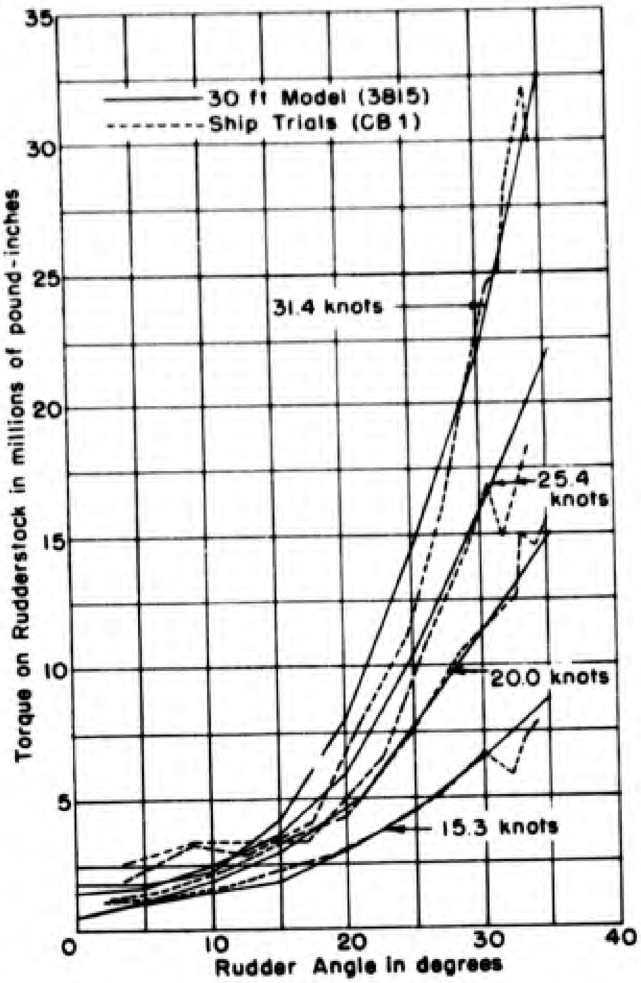


Figure 8 - Rudder Torque on CB1 from Ship Trials and Model Tests

CVL48 - MODEL 3852

A 30-foot model was used to obtain the model data for making the ship-model comparisons of rudder torque for CVL48 as shown in Figure 9. Here again the predictions based on the model test are very good.

CA139 - MODEL 3874

The torque predictions for CA139 are based on tests with a 20-foot model, and the comparisons with results from ship trials are shown in Figure 10. At the two higher speeds the model predictions are somewhat high, although they appear to be quite satisfactory for determining the maximum torque necessary for structural design and for designing the steering machinery.

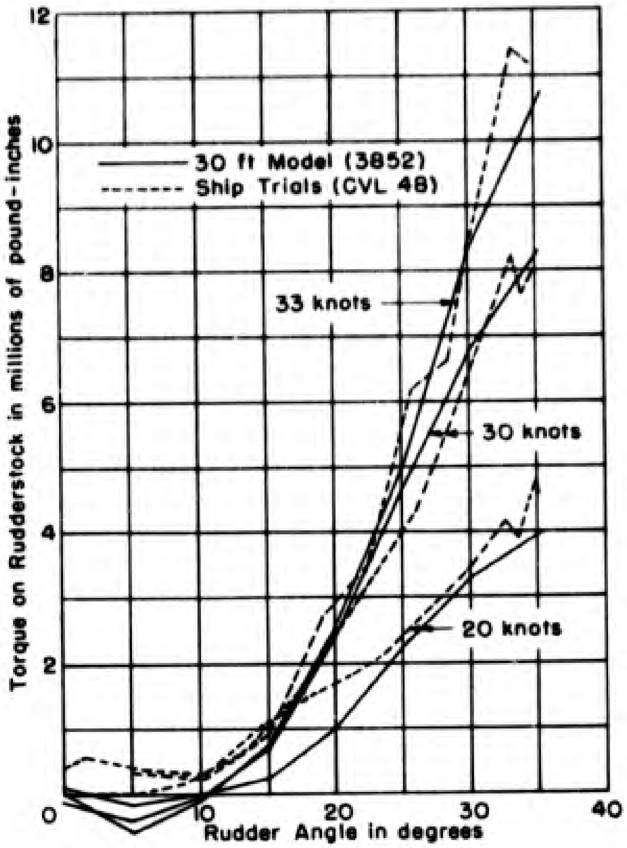


Figure 9 - Rudder Torque on CVL48 from Ship Trials and Model Tests

CL145 - MODEL 3883

A 20-foot model was used to predict the torque for CL145. Figure 11 shows the torque predicted from the model tests and the torque as determined by measurements during full-scale trials. In general the agreement is good, particularly at the maximum rudder angle.

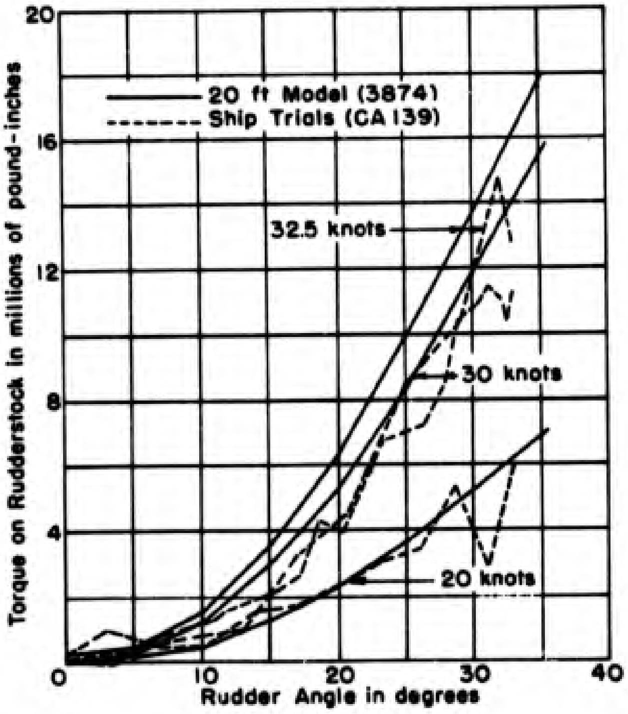


Figure 10 - Rudder Torque on CA139 from Ship Trials and Model Tests

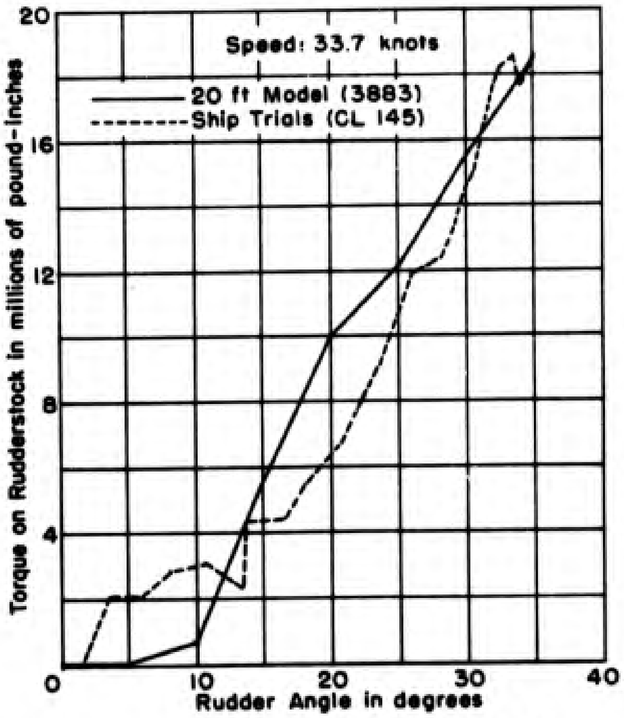


Figure 11 - Rudder Torque on CL145 from Ship Trials and Model Tests

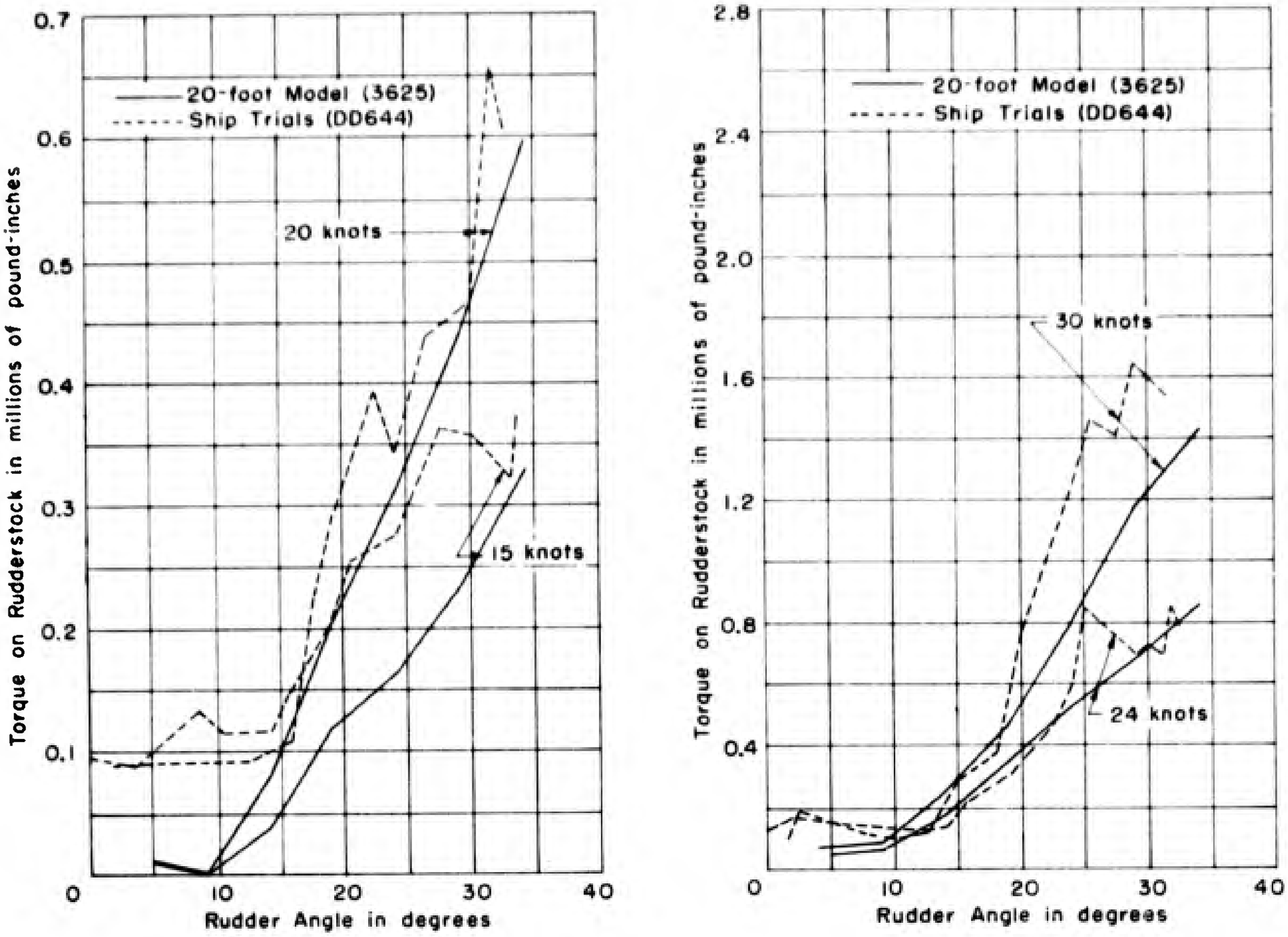


Figure 12 - Rudder Torques on DD644
from Ship Trials and Model Tests

DD644 - MODEL 3625

Figure 12 presents the ship-model comparison of rudder torque for DD445 and for a 20-foot model. The rudder angle indicator was known to be working improperly on the ship trials, so the ship curves (except the 30-knot curve) were corrected somewhat arbitrarily. Torque versus time was known for the ship, so a reasonable curve of rudder angle against time was assumed in order to obtain the plots of torque versus rudder angle. The results are not especially satisfactory, but it does appear that the model predicted the maximum torques reasonably well.

CA69 - MODEL 3649

An unsatisfactory comparison of ship and model torques is shown for CA69 and a 20-foot model in Figure 13. It is likely that a large part of the discrepancy in the comparison can be attributed to unsatisfactory data on the ship trials. Actually CA69 and CVL48 have similar hulls and rudders; yet it can be seen from Figures 9 and 13 that the torque obtained on CVL48 was considerably larger than that obtained on CA69. Furthermore, CA69 did not show an increase in torque as the speed increased beyond 30 knots. That such a situation should exist is unreasonable. Nevertheless, it is likely that the model predictions also err by being somewhat too large, because the predictions are larger than the torques determined from ship trials of CVL48, and these torques were in good agreement with torques predicted by a 30-foot model.

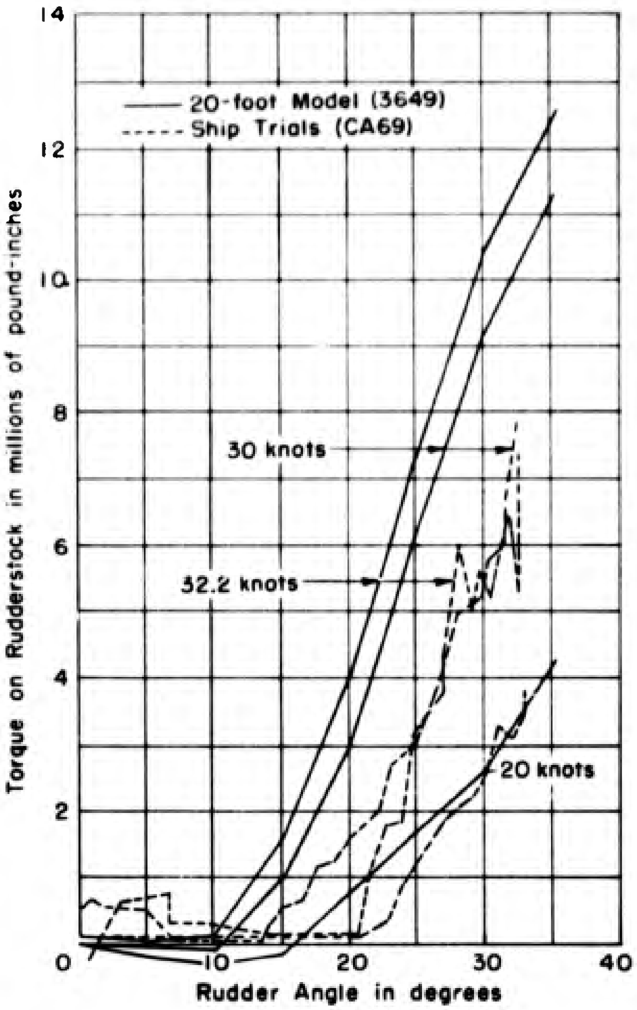


Figure 13 - Rudder Torque on CA69 from Ship Trials and Model Tests

CL80 - MODEL 3641, CVL28 - MODEL 3744

CL80 and CVL28 also have similar hulls and rudders. A 20-foot model was used for the torque comparison with CL80, and a 30-foot model was used for CVL28. In each case the model predictions were much larger than torques determined from ship trials as is shown in Figures 14 and 15. Again there is reason for believing that the ship-trial data are not good, and this will be discussed in the following section. The shape of the model curve for CVL28 at 29.2 knots seems a bit unusual, although it was obtained on more than one run.

EVALUATION OF MODEL PREDICTIONS AND FULL-SCALE DATA

It is apparent that the agreement between the torque predictions from model tests and the values obtained from full-scale trials is not consistent, and this naturally raises the question as to which are more reliable.

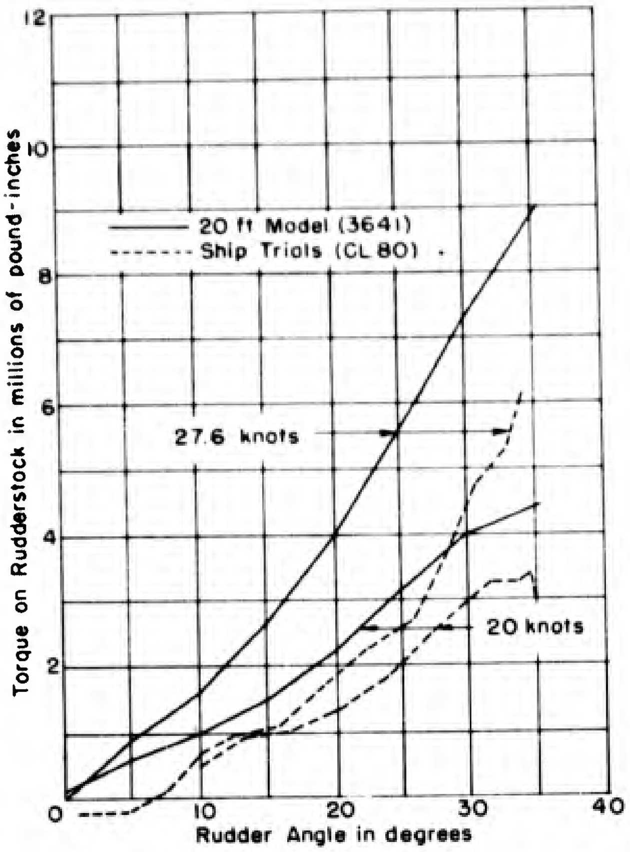


Figure 14 - Rudder Torque on CL80 from Ship Trials and Model Tests

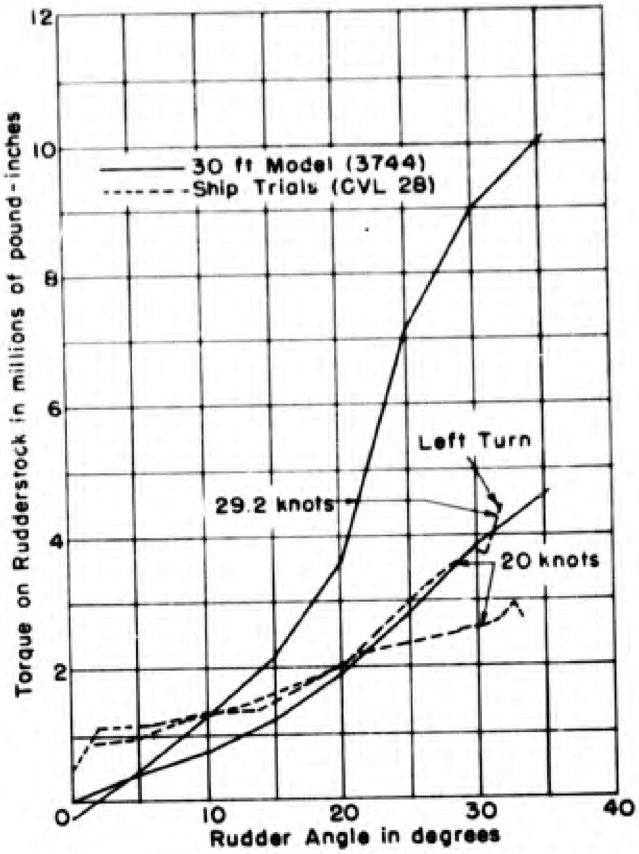


Figure 15 - Rudder Torque on CVL28 from Ship Trials and Model Tests

Evaluation of the reliability requires that consideration be given to (1) the accuracy of the model data, (2) the accuracy of the full-scale data, and (3) scale effects.

On the average it is to be expected that more precise measurements can be obtained in model scale because more careful procedures and more sensitive instruments can be utilized under the conditions obtainable in the laboratory. In particular, in the model work regular calibrations are made, tests are repeated as a check, and parasitic friction is substantially eliminated, whereas on full-scale trials over-all calibration has never been accomplished, there is seldom time for an adequate number of tests, and the magnitude of friction in rams and in bearings is unknown. Nevertheless, conclusions cannot be drawn from this argument with respect to individual comparisons of model and full-scale data. Another means of evaluation is needed, and theoretical formulations seem most likely to show up individual inconsistencies in results obtained from tests.

Unfortunately, there is at present no sound theoretical basis for the calculation of rudder torque for configurations of the type involved here. On the other hand, all the rudders are of the semi-balanced type and

TABLE 1

Coefficients of Reduction K for Joessel's Formula at 30-degree Rudder Angle

Ship	$V/\sqrt{L}$	Aspect Ratio	K Ship	K Model	$\frac{\text{K Model}}{\text{K Ship}}$
CL80	1.13	0.61	0.415	0.660(20' Model)	1.59
CVL28	1.19	0.61	0.320	0.763(30' Model)	2.38
CA139	1.23	0.67	0.614	0.715(20' Model)	1.16
CL145	1.31	0.76	0.552	0.584(20' Model)	1.06
CB1	1.12	0.77	0.580	0.586(20' Model) 0.554(30' Model)	1.01 0.96
CA69	1.24	0.83	0.364	0.625(20' Model)	1.72
CVL48	1.28	0.83	0.557	0.554(30' Model)	0.98
DD644	1.25	1.12	0.467	0.467(20' Model)	1.00

it can be expected that the application of Joessel's formula, through comparison of the derived coefficients of reduction,* will show up gross errors. In Table 1, therefore, there are shown these coefficients of reduction for both model and ship and the ratio of model to ship coefficients, together with the speed-length ratio and the aspect ratios of the rudders. These values are given for 30-degree rudder angles because full-scale data were not available for all ships at 35 degrees.

The apparent spread of the coefficients of reduction in Table 1 may be reduced by plotting them against the aspect ratio of the rudders as in Figure 17. The ship coefficients for CA69, CL80, and CVL28 are so low in comparison with the others that there is little doubt that these trial results are in error. Another circumstance casts doubt on these values: the three ships were among a series of seven vessels on which hurried trials were conducted at Rockland, Maine, during World War II and were tested in succession with no known recalibration of the test instruments between the trials. The only other ship (of the seven mentioned above) used in this study is the DD644. This was the first ship tested, so the instruments were well calibrated.

The model-to-ship ratios of the coefficients of reduction in Table 1 point up even more emphatically the large deviation of the three from the

---

*The coefficient of reduction is defined here as the ratio of the actual torque on the rudderstock to the torque calculated by Joessel's formula which assumes that the rudder is advancing into open water at the speed of the ship and at an angle of attack equal to the rudder angle on the ship.

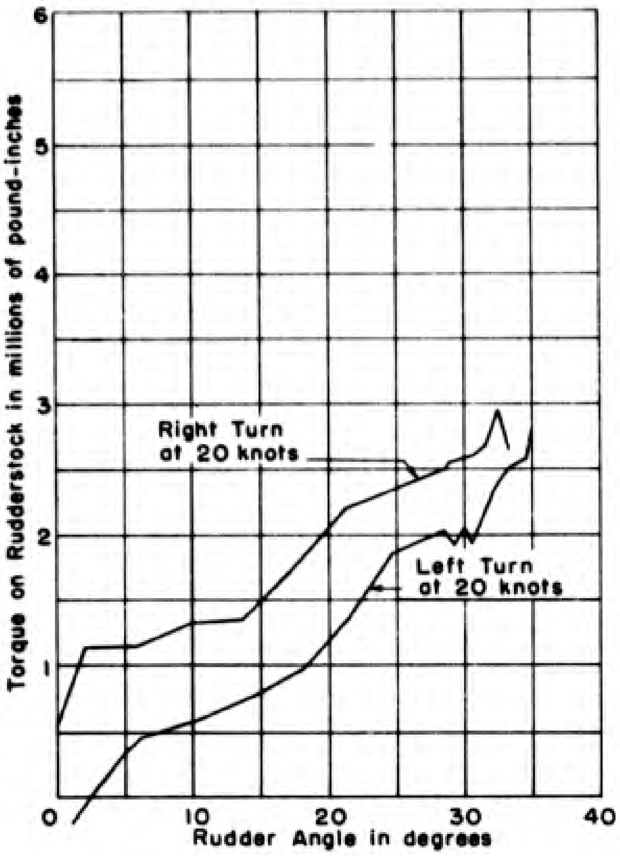


Figure 16 - Rudder Torque for Right and Left Turns from Full-Scale Trials on CVL28

other ships. Figures 14, 15 and 16 show torque curves which give additional reasons for doubting the accuracy of the full-scale trial data for CL80 and CVL28. As these ships were built to the same lines, the data should be comparable. Nevertheless, Figures 14 and 15 show that the torque for CL80 at 27.6 knots was greater than the torque for CVL28 at 29.2 knots. These results are unreasonable, as are those in Figure 16 where it is shown that right and left turns for CVL28 at 20 knots yielded different torques.

Disregarding the three ships in question, it is shown in Figure 17 that the coefficients of reduction for the remaining five ships fall very nearly on a fair curve. This indicates that where trials are conducted carefully the torque data obtained from ram pressure measurements, although including unknown friction losses, are consistent.

In Table 1 two pairs of ships are grouped together. The ships in each pair were built to identical lines but the models representing them were of different lengths: 20 feet and 30 feet. In one case the coefficient for the 20-foot model is larger than for the 30-foot model and in the other case vice versa. For the CB1, where 20- and 30-foot models were built to represent the same ship, the differences are very small. Thus, there seems to be no consistent scale effect between the 20-foot and 30-foot model results. Where there are differences between ship and model, the model results are higher. However, no consistent scale effect is evident.

TESTS WITH RUDDERS IN SLIPSTREAM

In recent years there has been a marked increase in the use of twin rudders on naval vessels to take advantage of the improved turning to be derived from the location of the rudders in the slipstreams of the propellers.

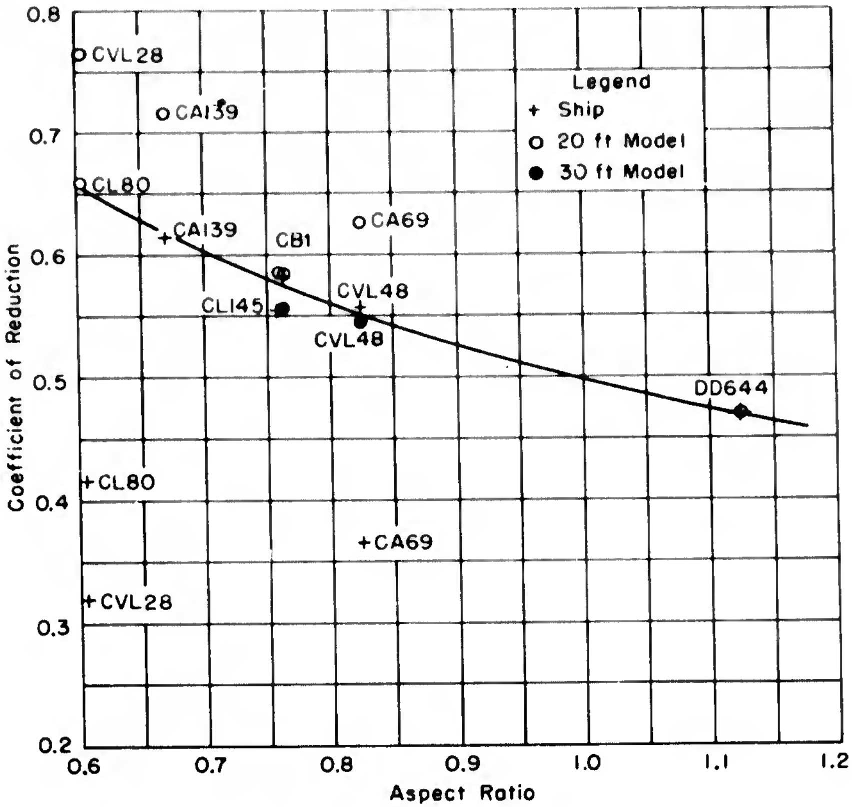


Figure 17 - Coefficients of Reduction for Correlating Rudder Torque Calculated from Joessel's Formula with Experimental Data at 30-degree Rudder Angle

There has been considerable skepticism concerning the validity of model predictions of the rudder torque for such installations due to the lack of agreement between model-test and full-scale results. Unfortunately, there have been relatively few turning trials of twin-rudder vessels, and in most of these cases the rudder-torque data have been rather meager or unsatisfactory.

The reason for the lack of agreement between model predictions and full-scale trial measurements of rudder torque for twin-rudder vessels has not been determined. The influence of the propeller slipstream on scale effect and the location of the center of pressure, the occurrence of air-drawing in model tests, and the relative proportion of steering-gear friction to torque in twin-rudder and single-rudder installations is being investigated and will be discussed in a subsequent report.

CONCLUSIONS

1. Full-scale rudder torques for single-rudder, multiple-screw vessels can be predicted satisfactorily from tests on 20-foot models in which the torques are measured as the rudders are swung and the models execute turns.

2. Rudder torque is affected by large variations in rate of rudder movement. Experimental variations of the order of 10 to 15 percent cause barely perceptible variations in rudder torque.

3. There seems to be no consistent scale effect between 20- and 30-foot model results, nor between ship and model values of the rudder torque.