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UNITED STATES
EXPERIMENTAL MODEL BASIN

NAVY YARD, WASHINGTON, D.C.

U. S. S. FARRAGUT COMPARATIVE RUDDER TESTS
MODEL AND FULL SCALE

BY LIEUT. COMDR. A. S. PITRE, (CC), U. S. N. AND J. G. THEWS

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BUREAU OF
CONSTRUCTION AND REPAIR
NAVY DEPARTMENT

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U.S.S. FARRAGUT
COMPARATIVE RUDDER TESTS
MODEL AND FULL SCALE

By

Lt. Comdr. A. S. Pitre, (CC), U.S.N.
and
J. G. Thews

U.S. Experimental Model Basin
Navy Yard, Washington, D.C.
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U.S.S. FARRAGUT
COMPARATIVE RUDDER TESTS
MODEL AND FULL SCALE

INTRODUCTION.

As the U. S. Experimental Model Basin possesses no turning basin, model tests for determining tactical characteristics of different rudders are confined to an area limited by the width of the basin - 40 feet. This limitation on space likewise imposes a limitation on the size of model that can be tested. The combination of these restrictions has surrounded these types of tests with many difficulties and disadvantages, the chief disadvantage being the small portion of turning circle - on the average, about one sixth - that can be obtained for study and analysis.

The selection of a suitable rudder for destroyers Nos. 348 to 358 (to which class the U.S.S. FARRAGUT belonged) required a great number of model tests. Since the choice of a suitable rudder from these model tests was not clear cut, it was considered essential to conduct full scale turning trials for determining a final choice of those rudders considered suitable from model tests. Accordingly, at the request of the Bureau of Construction and Repair, and with the cooperation of the Bureau of Engineering, and the approval of the Chief of Naval Operations, the U.S. Experimental Model Basin undertook full scale turning trials on the U.S.S. FARRAGUT; the vessel equipped, in turn, with rudder C and then rudder A - those rudders selected from model tests.

OBJECTIVES OF TESTS.

In addition to the fundamental objective of correlating model and full scale turning tests, the broad objectives of these tests were

(a) The comparison of tactical characteristics of rudders A and C.
(b) The comparison of angle of heel produced in turning with rudders A and C.
(c) The comparison of effects of rudders A and C on propulsive performance.
(d) The comparison of maneuverability characteristics of rudders A and C, the vessel starting from at rest.
(e) The comparison of maneuverability characteristics of rudders A and C, the vessel underway.

PROCEDURE.

The subject matter of this report is presented under the following sections:

Section I – Model Tests.
Section II – Full Scale Trials – Rudder C.
Section III – Full Scale Trials – Rudder A.
Section IV – Comparison of Full Scale Trials – Rudders A and C.
Section V – Model – Trial Comparison.
Section VI – Conclusions.
Section VII – Appendices.

SECTION I
MODEL TESTS

INTRODUCTION.

During the design of destroyers DD348 to 358, the Portsmouth Navy Yard submitted several suggestions relative to destroyer rudder design. These suggestions along with the original rudder and twin rudders proposed by the Bureau were tested on a 20 foot model. Because of the size of model and the limitations in space, the results from these tests were inconclusive.

Coincident therewith, the Commanding Officer of the U.S.S. HOPKINS reported excessive angles of heel while operating at 25 knots speed with 22.5 degrees rudder angle. These facts led to an inquiry and check of stability conditions not only of the HOPKINS class but also the FARRAGUT (DD348 to 358) class. As the calculations for the latter - necessary for the determination of angle of heel in turning - had to be based on assumptions, the Bureau requested typical model tests to determine angles of heel on the FARRAGUT class.

PROCEDURE.

A series of tests was planned, the chief features of which were as follows.

Test A. Tests were to be made with a twenty foot model fitted with struts and all appendages. Displacements were to be fixed corresponding to 1352, 1622, and 1771 tons with GMs of 1.99, 2.36, and 2.44 feet respectively. The rudder was to be placed as close to the hull as possible and then lowered as far as possible, approximately two and one half inches.

Test B. A similar range of tests was then to be made with a twenty foot model identical to that used in Test A except that bossings were to be substituted for struts. For these tests displacements were to be fixed at 1622 and 1771 tons, the corresponding metacentric heights similar to those for test A.

Test C. Finally a twelve foot model, similar in characteristics to that of test A, was to be tested at a displacement corresponding to 1771 tons with a G.M. of 2.44 feet.

As noted, it was originally planned to use models 20 and 12 feet in length. Because of the limiting basin width, it was found that the twenty-foot model described too small a turning path for analysis. This condition, combined with a desire to extend the tests to a speed corresponding to 35 knots ship speed, led to the adoption of a ten foot model for all tests. Unless otherwise specified, each of the following tests have been made with a 10 foot model, displacement 104 lbs. (corresponding to 1771 tons) and a GM of 0.876 inches (corresponding to 2.44 feet).

EXTENSION OF SCOPE OF TESTS.

The original purpose of these tests was the determination of the angle through which the ship heels in calm water when making a turn with "hard over" rudder. In the course of the preliminary tests it was observed that the designed rudder cavitated badly at speeds well below the maximum – thereby causing considerable loss in effectiveness. As a result, the scope of these tests was broadened to include also an investigation of the effect of rudder shape, aspect ratio, and submergence on the angle of heel and the radius of turning path.

This extension of purpose led to the selection of three rudder types to be tested in addition to the original rudder, designated as number 1. The three new types, designated as numbers 2, 3, and 4 were then in turn modified by progressive reductions in area. Fig. 1 gives the outlines of these rudders together with their areas and corresponding aspect ratios.

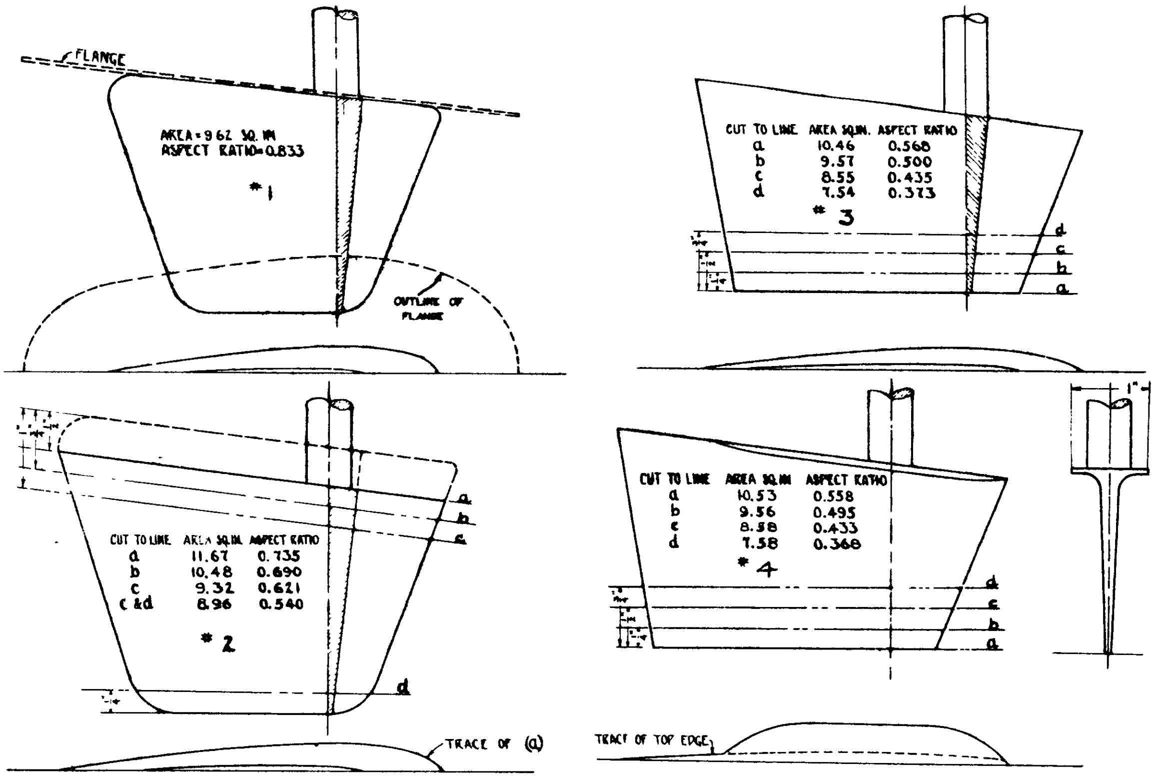


FIG. 1 OUTLINES OF RUDDERS USED IN TESTS WITH MODEL 3174

METHOD OF TEST.

The model with the rudder held on the center line was towed in a straight path near one side of the basin for a distance sufficient to reach steady speed. At a given instant the model was released and an electric motor was started which turned the rudder through a worm gear arrangement to the desired angle, at which angle the gear became locked. The time to lay the rudder from amidships to thirty-five degrees approximated one and one-half seconds. The path of the model and the heeling angle were recorded photographically by means of two cameras located twenty-six feet above the model. Synchronized revolving shutters exposed the photographic plates on half-second intervals. Small electric lights fixed on the model near the bow, the stern, and on top of a short mast left clearly defined marks on the photographic plates, thus fixing the position and inclination of the model every half second. The turning path was determined from the position of the forward light which was located about one-third model length from the bow.

RESULTS OF TEST.

Fig. 2 gives the maximum angle of heel for rudder 1 as a function of the model speed. The inward heel at the beginning of the turn path is shown on the lower part of the figure, while the outward heel on the subsequent part of the turning path is shown in the upper part.

The variation of the maximum angle of heel with the vertical position of the other three rudders at constant speed and rudder angle is shown in Figs. 3, 4, and 5. In these figures also, the inward heel is shown in the lower part, the outward heel in the upper part of each figure.

Fig. 6 shows a typical set of turning paths as determined for rudder 3 C.

From the results obtained (Fig. 6 being typical) Fig. 7 has been plotted as a measure of rudder effectiveness. This figure has been prepared by plotting the transfer for a given advance - this latter being taken as 9 units, one unit equaling 169 feet in full scale, see Fig. 6.

DISCUSSION.

The chief feature of this series of tests was the lengthening of the radius of turning path above 4.5 knots model speed with all rudders when located in the normal position. For this reason the angle of heel, which would normally increase with increase in speed, remained nearly constant at speeds above this critical speed as shown in Fig. 2. Furthermore, at 4.50 knots, it was found that when the rudder was lowered from its normal position by equal amounts the maximum angle of outward heel decreased immediately, while at 6.50 knots model speed, it remained constant or even increased for the first inch of drop and then decreased. This is shown in Figs. 2, 3, 4, and 5. This peculiarity indicates that breakdown of the

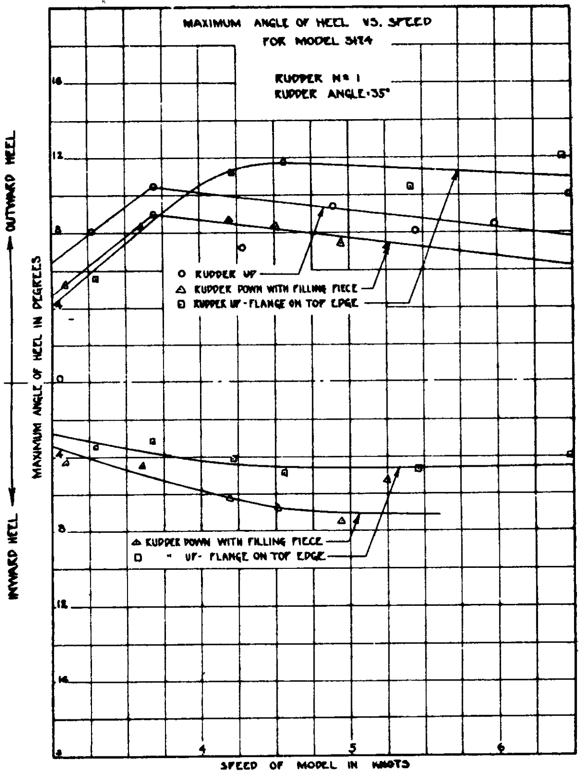


FIG. 2

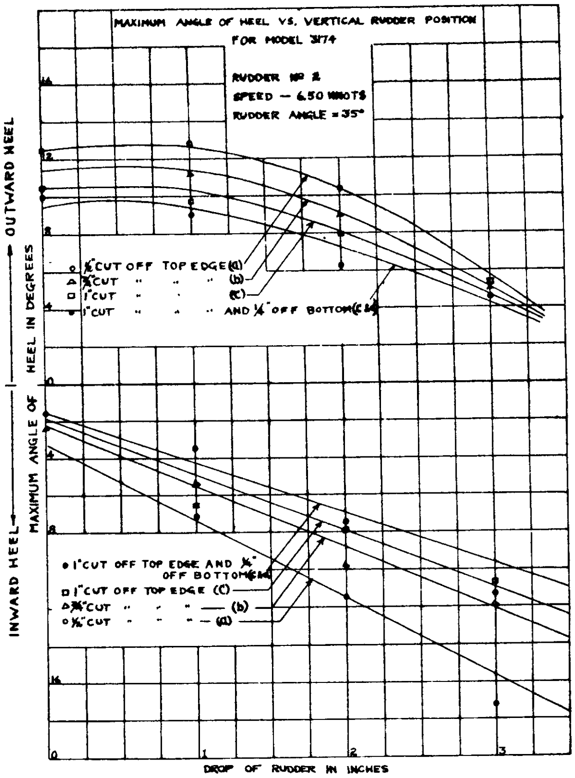


FIG. 3

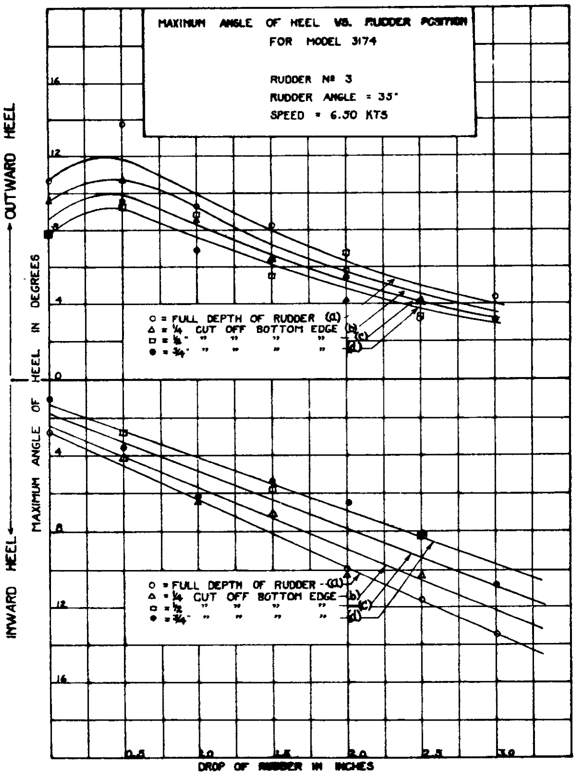


FIG. 4

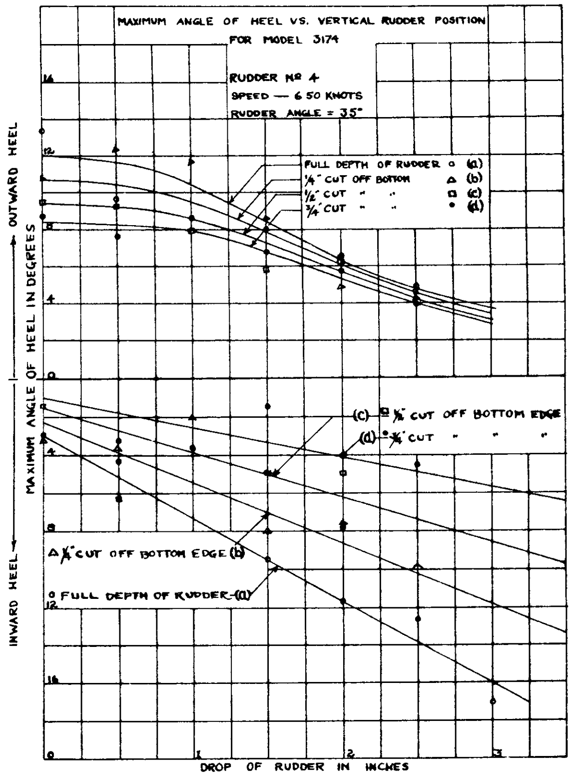


FIG. 5

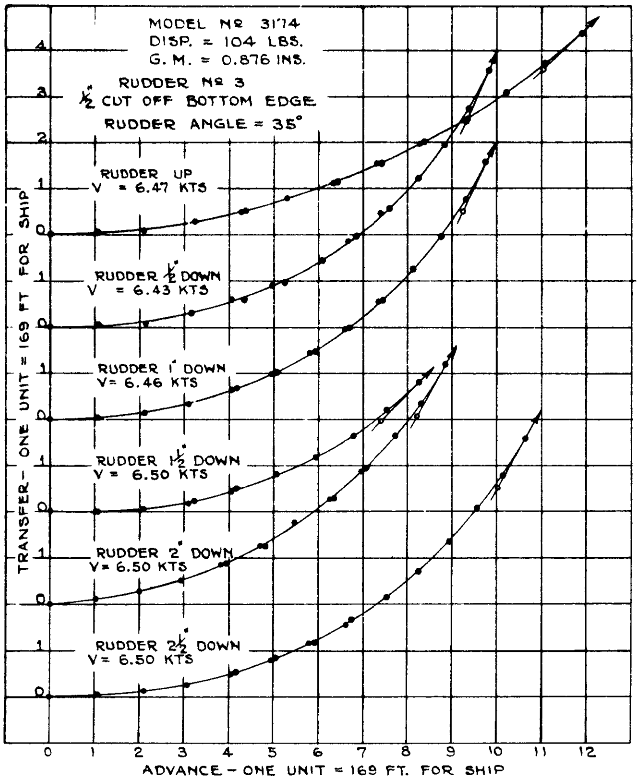


FIG. 6 TURNING PATHS FOR RUDDER 3c
CONSTANT SPEED AND RUDDER ANGLE
VARYING THE VERTICAL DROP

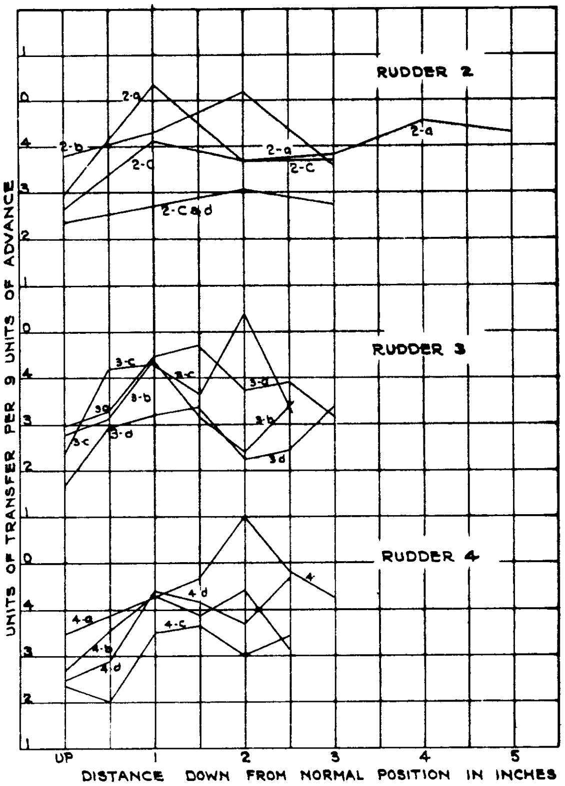


FIG. 7 EFFECTIVENESS OF RUDDERS 2, 3 AND 4
BASED ON UNITS OF TRANSFER PER
9 UNITS OF ADVANCE

rudders was due to cavitation. Dropping the rudder from its normal position to increase the initial depth over the top edge was adopted as a means of correction.

From Fig. 7 the effectiveness for each rudder is found to increase as the rudder is lowered up to one inch from its normal position. Beyond this point, the effectiveness decreases in practically all cases.

Considering that the steering equipment had been designed on a rudder area corresponding to 9.62 square inches in the case of the model, Fig. 8 was prepared to evaluate the results of Fig. 7 in terms of rudder area versus rudder effectiveness at constant submergence. In the normal position the three rudders are equal in effectiveness based on an area of 9.62 square inches. When lowered one inch below its normal position, all three rudders are definitely superior, the gain in effectiveness from normal position being of the order of approximately 75 per cent. When lowered two inches from normal position, rudders 2 and 4 have shown a very slight gain while rudder 3 lost considerably. All things considered, the position of rudder when lowered one inch from normal represented the maximum gain.

Of the several rudders the choice seems to lie between rudders 3 and 4. Since the range of effectiveness was sensibly equivalent in the case of rudders 3a, b, and c, when lowered one inch from normal position, it was believed that these combinations held greater promise than any other. Further, the cross sectional shape of rudder 3 was more favorable in comparison to that of rudder 4.

ADDITIONAL MODEL TEST.

Since these tests indicate a favorable influence by dropping the rudder, consideration was given to a change in horizontal position of the rudder to obtain the same relative advantage without causing so great an area of rudder stock to be exposed. Hence, the rudder was moved 3 3/8 inches forward from its designed position. This movement caused the rudder to drop down 3/8 inches. Tests made with the rudder in this position as normal and then lowered did not show any gain. As a result, no further consideration was given to changing the horizontal position of the rudder from that selected in the original design.

SELECTION OF RUDDER.

Since the shape of the curve between 3a and 3c in Fig. 8, rudder lowered one inch from normal, gave indications of promise, it was decided to select one of this combination for further test. Of these 3c represented the least in area and the smallest aspect ratio. Further, since this combination was favorable with rudder angles of 45 degrees, additional tests were planned with this rudder.

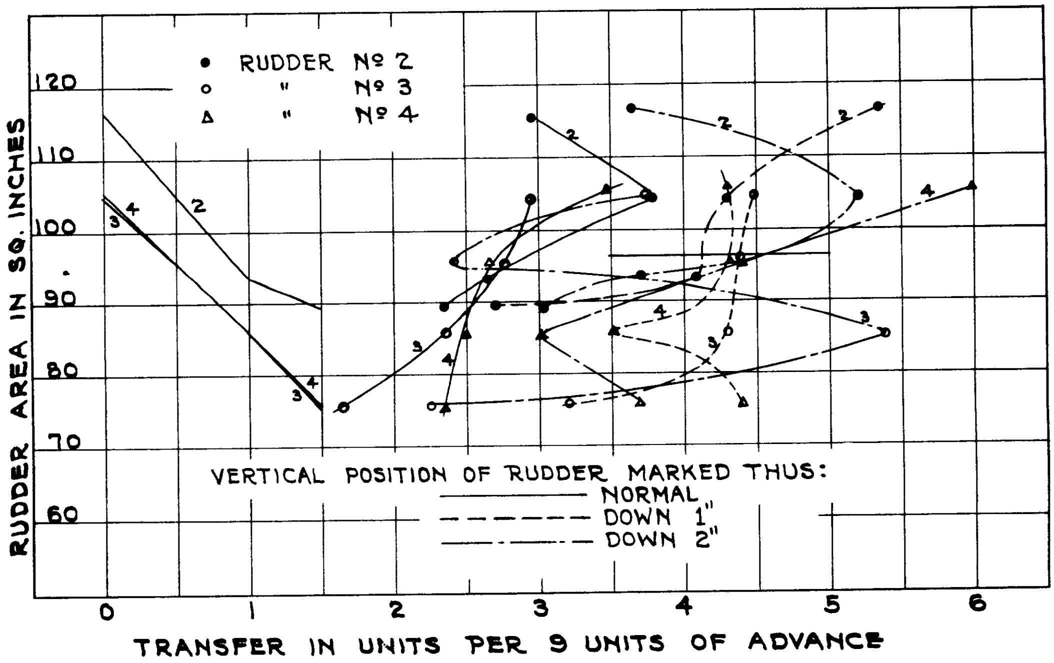


FIG. 8 EFFECT OF AREA WITH RUDDER SUBMERGENCE. UNITS OF TRANSFER PER 9 UNITS OF ADVANCE - MODEL SCALE

TEST WITH RUDDER 3c.

In these tests the rudder was placed one inch below its normal position. Then at 4.50 knots speed and with 45 degrees rudder angle, the corresponding radius of curvature for the ship was found to be 991 feet. At 6.50 knots speed, other conditions the same, the radius was 1465 feet.

In the next series of test, the edges of the rudder - which had been square - were rounded. With conditions similar to those above, the corresponding radii of curvature were found to be 1025 and 1513 feet respectively. Since no beneficial effect had been found by rounding the edges, this practice was discontinued.

Though the results attained so far were an improvement over those determined in the case of the original rudder, the turning path was still considered too large. As a further step rudder 3c was enlarged to approximately 20 per cent increase in area. The results of these tests, expressed as radii of curvature, are given in Table 1.

TABLE 1.

RADII OF CURVATURE FOR RUDDER 5

Vertical Position of Rudder lowered from normal	Model Speed Knots	Radii in feet for rudder angles of	
		35 degrees	45 degrees
1"	4.50		980
1"	6.50	1284	997
1".5	4.50	1115	777
1".5	6.50	1437	1048
2"	4.50	1187	946
2"	6.50	1673	1082

TEST WITH RUDDERS UD-A, UD-C.

As the contractors for the U.S.S. FARRAGUT were reluctant to accept a rudder whose stock would be exposed for a length of 33.4 inches - corresponding to a drop of one inch from normal position in model scale - tests were conducted on two designs, UD-A and UD-C, originated by the contractors. The chief aim in these designs was a shape embodying the essential features developed from the earlier tests but which did not require an exposed stock.

Figs. 9, 10, and 11 give the results of turning and heeling tests. As noted, both rudders cavitated, rudder UD-A at 30 and 35 degree rudder angle, and UD-C at 35 degree rudder angle.

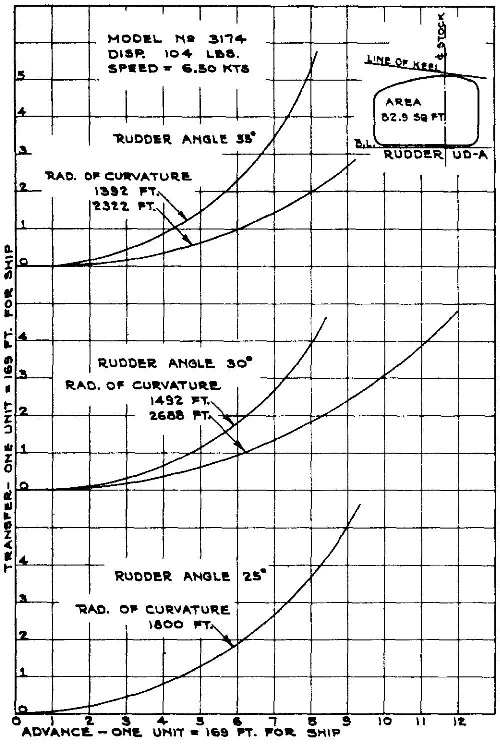


FIG. 9 TURNING PATHS FOR RUDDER UD-A FOR CONSTANT SPEED AND RUDDER ANGLE

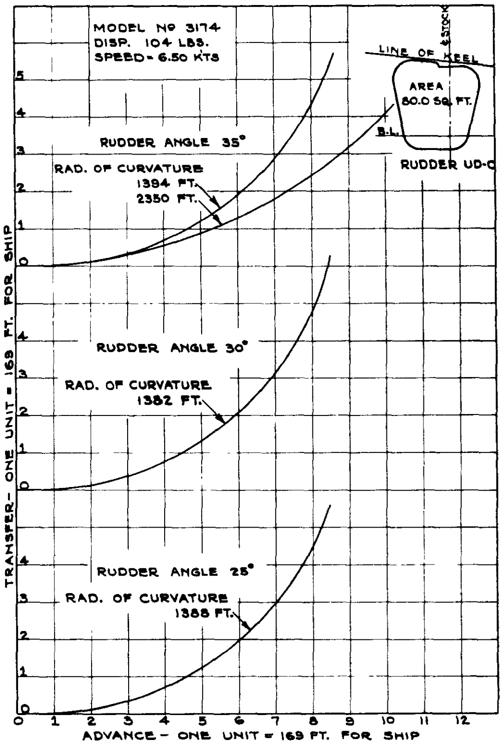


FIG. 10 TURNING PATHS FOR RUDDER UD-C FOR CONSTANT SPEED AND RUDDER ANGLE

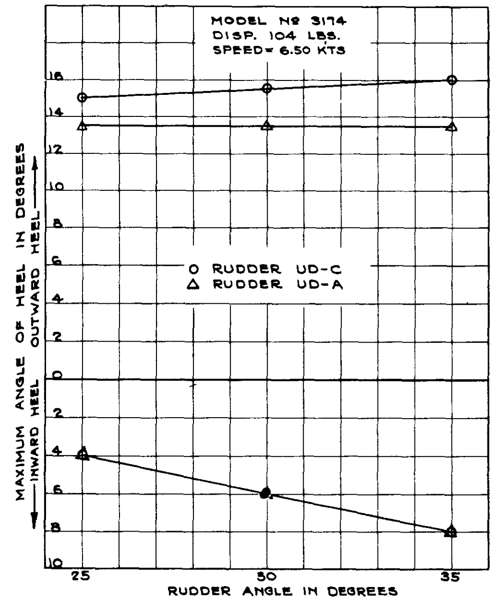


FIG. 11 COMPARISON OF ANGLES OF HEEL MAXIMUM, INWARD AND OUTWARD, RUDDERS UD-A, UD-C

FINAL TESTS.

Of the tests conducted to this point, one fact was definite. To avoid cavitation it was essential to drop the rudder from its normal position. As a one inch drop in model position corresponded to a drop of 33.4 inches in full scale this condition seemed a radical departure. In order to retain some of this advantage, the maximum drop acceptable was limited to 24 inches in full scale which corresponded to a drop of 0.72 inches in model scale. This decision required a new series of tests. As a result, the following rudders were selected for these tests.

Rudder A – Similar in characteristics to rudder 3b. Aspect ratio 0.44.

Rudder B – Essentially equivalent to rudder A except that an additional area was added to fair rudder and avoid an exposed stock.

Rudder C – Area equivalent to that of rudder A except aspect ratio changed to 1.38. No exposed rudder stock.

Rudder D – A modified variation of rudder B.

Fig. 12 gives the outlines of these rudders.

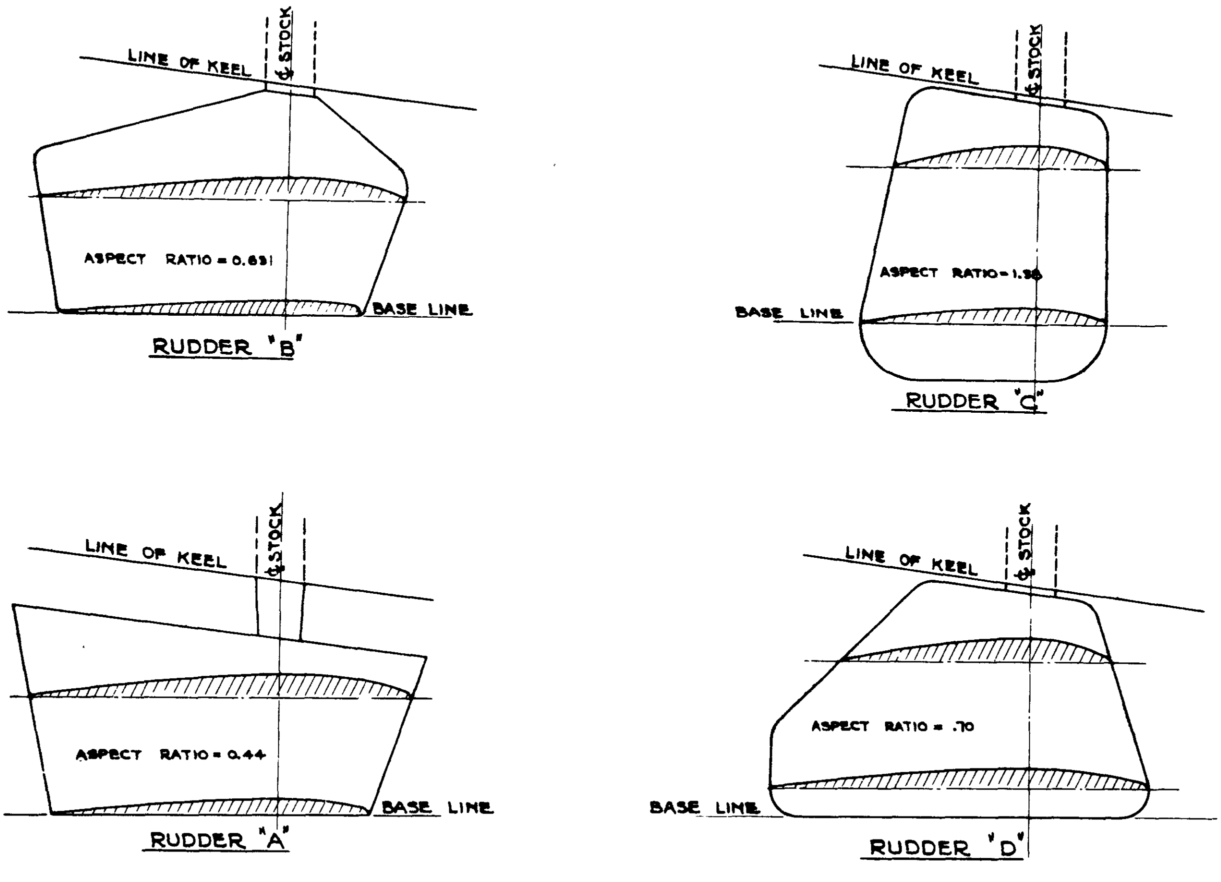


FIG. 12 OUTLINES OF RUDDERS A, B, C, AND D USED IN FINAL TESTS

RESULTS OF TEST.

Fig. 13 gives the results of test of rudders A, B, C, and D. From these curves it is seen that rudders A and C are definitely superior to rudders B and D. As between rudders A and C, the choice, if any, would seem to lie with A, since at designed maximum speed there was no indication of breakdown as noted with C. On the other hand, as C possessed no exposed area of rudder stock, it was believed that this advantage compensated for any slight loss in effectiveness occasioned by cavitation. The maximum angles of heel determined from this same group of tests are given in Fig. 14. From these results, the advantage would seem to lie with rudder A.

ADDITIONAL COMPARISON, RUDDERS A AND C.

The above tests were made at constant model speed of 6.50 knots. To determine the effect of varying speed, additional tests were made.

Fig. 15 gives the radius of curvature for rudder C with constant rudder angles and at different speeds. The corresponding angles of heel are given in Figs. 16 to 19. From Fig. 15 the rudder cavitates at speeds above 33 knots. The angles of heel given in Figs. 16 to 19 are consistent with this indication.

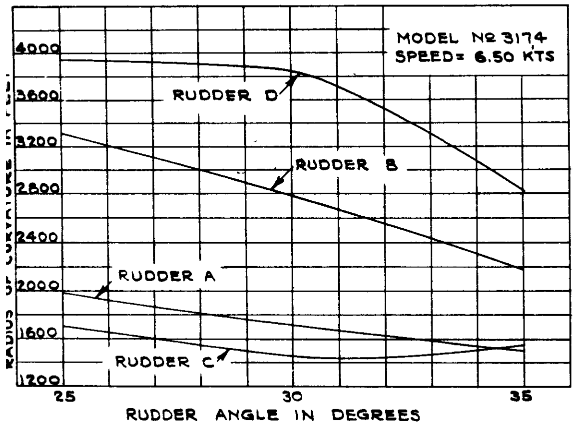


FIG. 13 COMPARISON OF RADIUS OF CURVATURE WITH RUDDER ANGLE FOR RUDDERS A, B, C, AND D

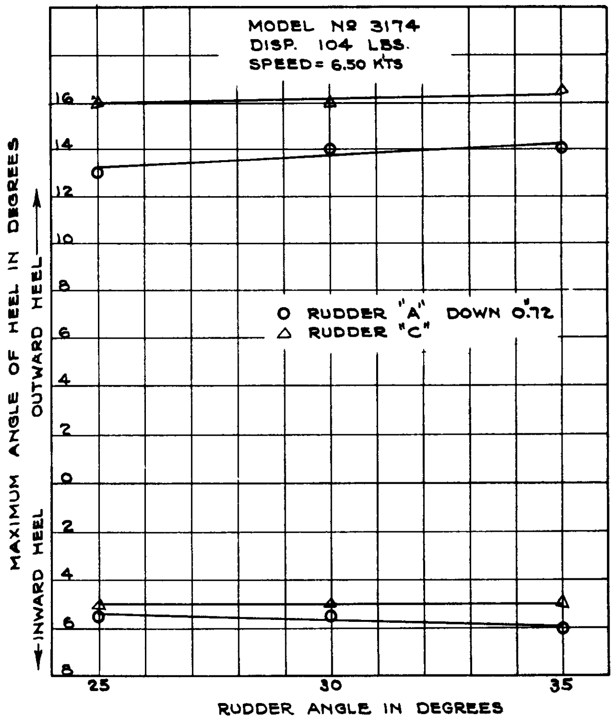


FIG. 14 COMPARISON OF MAXIMUM INWARD AND OUTWARD ANGLES OF HEEL. RUDDERS A AND C. MODEL EQUIPPED WITH STRUTS

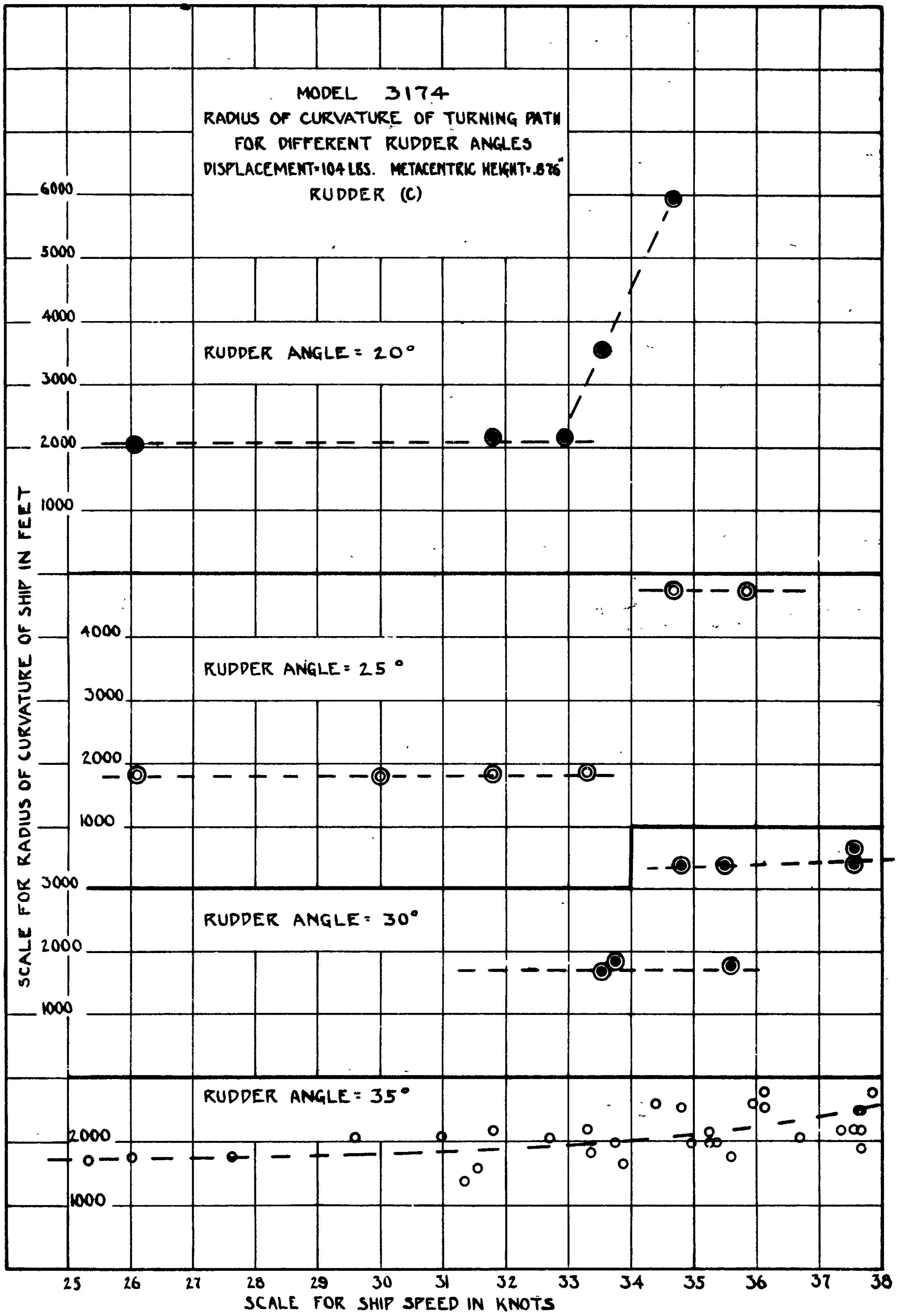

MODEL 3174
RADIUS OF CURVATURE OF TURNING PATH
FOR DIFFERENT RUDDER ANGLES
DISPLACEMENT=104 LBS. METACENTRIC HEIGHT=.876"
RUDDER (C)
RUDDER ANGLE = 20°
RUDDER ANGLE = 25°
RUDDER ANGLE = 30°
RUDDER ANGLE = 35°
6000
5000
4000
3000
2000
1000
4000
3000
2000
1000
3000
2000
1000
2000
1000
SCALE FOR RADIUS OF CURVATURE OF SHIP IN FEET
25
26
27
28
29
30
31
32
33
34
35
36
37
38
SCALE FOR SHIP SPEED IN KNOTS

FIG. 15

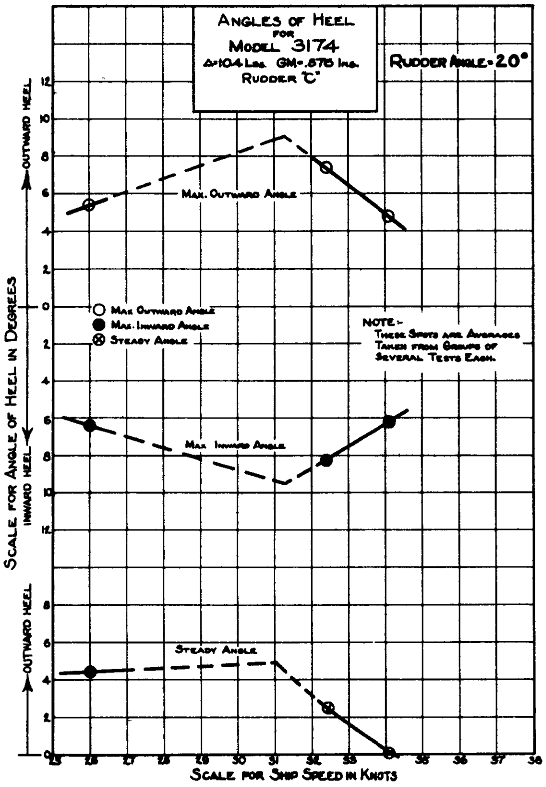


FIG. 16

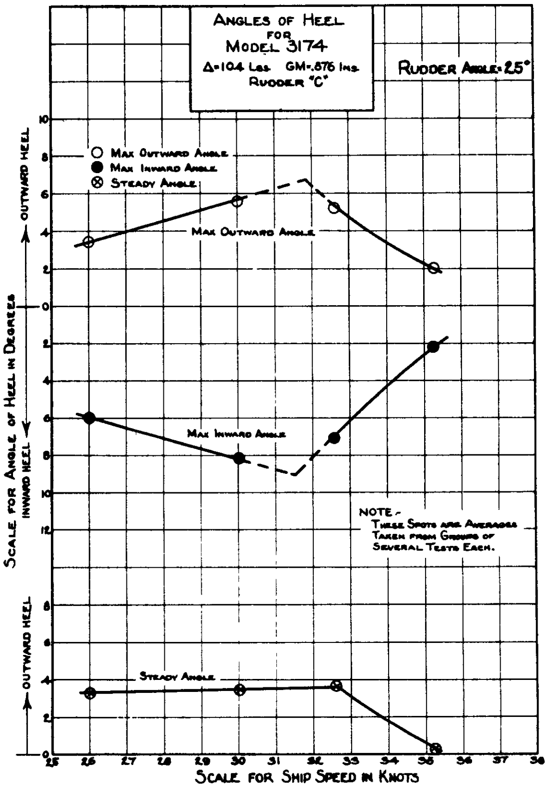


FIG. 17

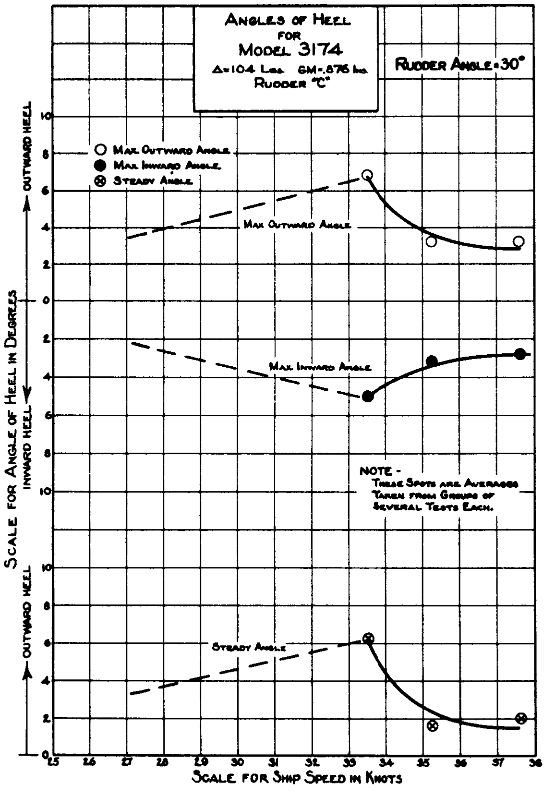


FIG. 18

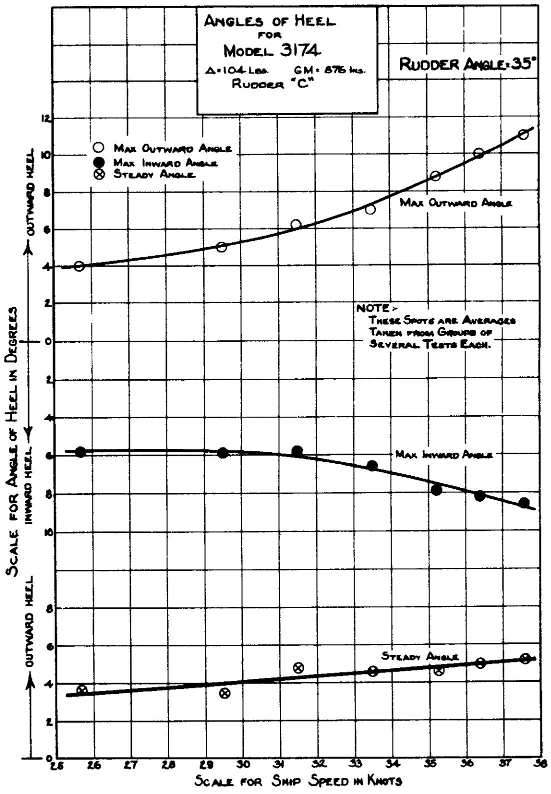


FIG. 19

Fig. 20 gives the radius of curvature for rudder A at a constant rudder angle of 35 degrees at various speeds. For purposes of comparison the curve of rudder C has been included. Fig. 21 gives the angle of heel for rudder A compared to that of rudder C.

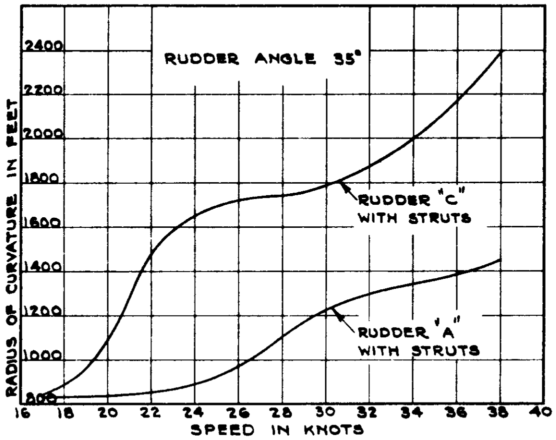


FIG. 20 COMPARISON OF RADIUS OF CURVATURE AT 35 DEGREES RUDDER ANGLE WITH DIFFERENT SPEEDS FOR RUDDERS A AND C. MODEL EQUIPPED WITH STRUTS

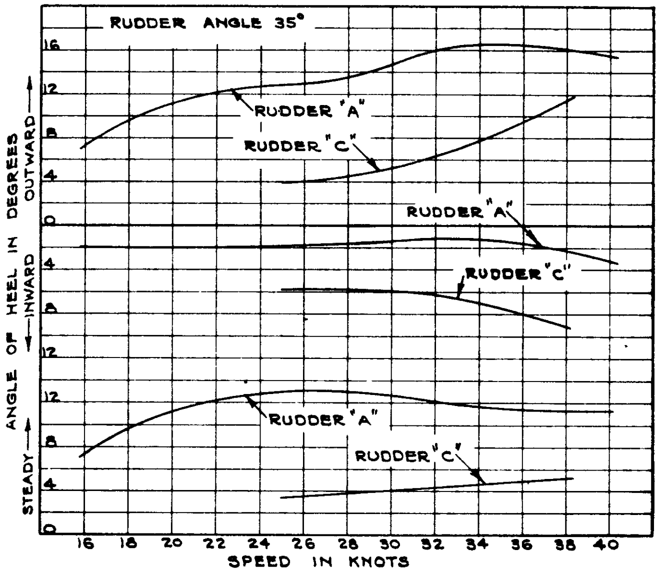


FIG. 21 COMPARISON OF ANGLES OF HEEL AT 35 DEGREES RUDDER ANGLE WITH DIFFERENT SPEEDS FOR RUDDERS A AND C. MODEL EQUIPPED WITH STRUTS

TEST B.
STRUTS VERSUS BOSSINGS. EFFECT ON TURNING.

To evaluate the relative effects of struts and bossings on tactical characteristics, tests were made as originally planned. Fig. 22 gives the comparison of radius of curvature for rudders A and C at 35 degree rudder angle, the model equipped in turn with struts and bossings. The differences disclosed are quite marked not only between the two rudders, but also for the same rudder with struts and bossings.

Fig. 23 gives the comparison of maximum inward and outward heel developed with the use of rudders A and C. A comparison with the results given in Fig. 21 indicates that the maximum angle of heel is produced when equipped with struts. As between the two rudders, however, rudder A produces a greater maximum in the case of struts whereas C produces a greater maximum in the case of bossings.

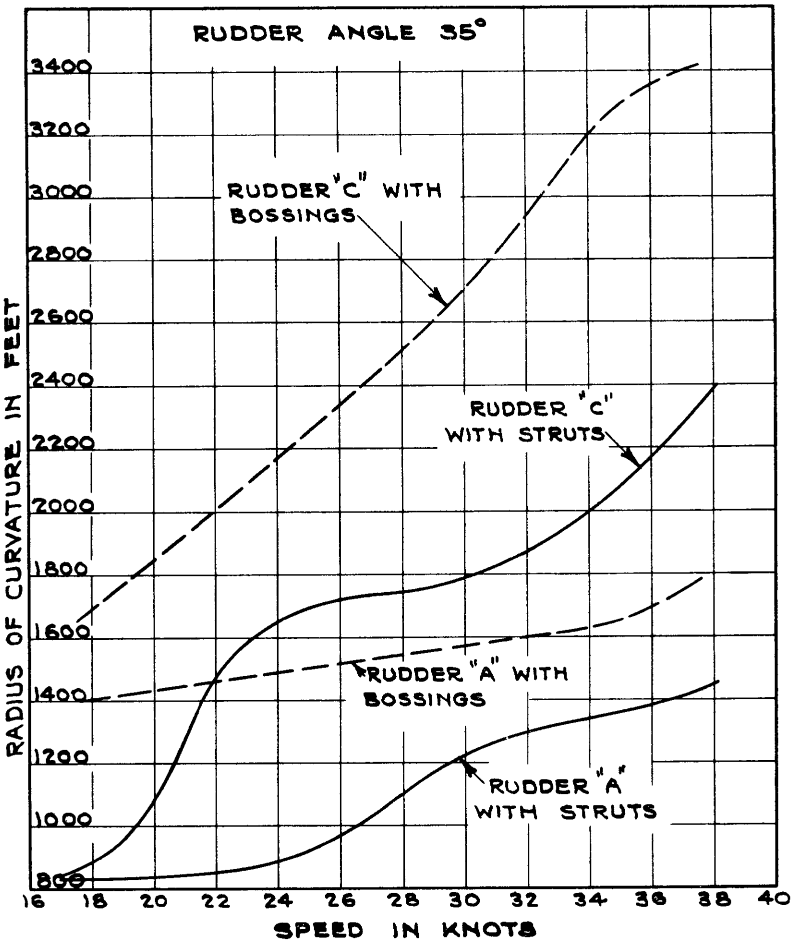


FIG. 22 COMPARISON OF RADIUS OF CURVATURE AT 35 DEGREES RUDDER ANGLE WITH DIFFERENT SPEEDS FOR RUDDERS A AND C. MODEL EQUIPPED IN TURN WITH STRUTS AND BOSSINGS

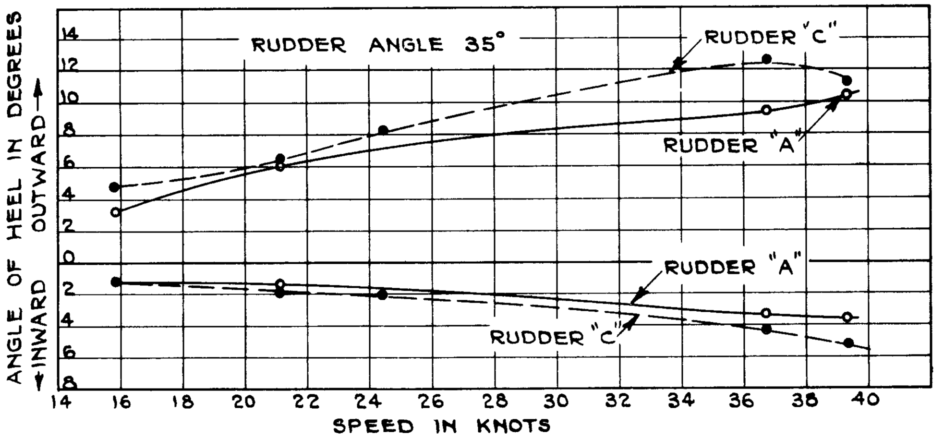


FIG. 23 COMPARISON OF ANGLES OF HEEL AT 35 DEGREES RUDDER ANGLE WITH DIFFERENT SPEEDS FOR RUDDERS A AND C. MODEL EQUIPPED WITH BOSSINGS

FINAL SELECTION.

As regards a definite choice between rudders A and C, the indications as to effectiveness, as measured by radius of curvature, were contradictory. Up to 35 knots, roughly, rudder C (based solely on the conditions of a given angle and speed) was superior. At 35 knots rudder A was superior. The chief distinction was that rudder C did cavitate in the higher regions of rudder angle and speed whereas A did not. Since the superiority of A depended on dropping the rudder from its usual normal position, the question of an exposed stock was believed a disadvantage.

The tests did disclose, however, that rudder C produced a less maximum angle of heel than did A. In this respect rudder C was superior. Though the difference in effectiveness at high speeds and rudder angles was small, the reduction in angle of heel in the case of rudder C caused this rudder to be favored.

As there was no concrete evidence as to the reliability of model turning tests, nor to the extent to which dependence might be placed on the results, it was decided to test rudders A and C in full scale. Accordingly, the U.S.S. FARRAGUT was made available for these tests.

SECTION II
FULL SCALE TRIALS - RUDDER C

INTRODUCTION

A fundamental essential in any test is accurate data - for, if the data are lacking in accuracy, then the comparisons and conclusions flowing from an analysis of such data are proportionately meaningless.

Since the recognition of this objective is a major consideration of every test undertaken at the U. S. Experimental Model Basin, efforts are continuously directed toward checking the character and accuracy of each observation. Because of the facilities and methods available, a procedure has been developed at the Model Basin to assure data indicative of fact.

The translation of this objective in the case of full scale tests, however, has not been subjected to the same treatment and development as in the case of model experiments. This is due to the greater and more complex difficulties associated with full scale measurements, and to the introduction of various influences not subject to the same degree of control and regulation as in model experiments.

METHOD OF FULL SCALE TRIALS.

As regards standardization trials, some progress has been made in developing both methods and procedure for observing and comparing the accuracy of full scale measurements. On the other hand, no such procedure has been developed in the case of turning trials. Generally speaking, full scale turning trial observations have revolved around simultaneous ranges and bearings recorded from one observing point, or simultaneous bearings observed from two fixed shore stations at periodic time intervals. In neither of these cases has the procedure been standardized to a point of assuring a coordination of observations so essential to the final result.

Accordingly, when the proposal for full scale turning trials was submitted, initial consideration was given to the method of measurement. The steps leading to a decision were somewhat as follows:

Prior to the time of the acceptance trials of the U.S.S. FARRAGUT, the Bureau of Construction and Repair requested information and comment as to the method of measuring heeling angles in full scale. Since the usual visual methods of observing the displacement of the horizon against a vertical batten was neither accurate nor satisfactory, consideration was given to the adoption of a photographic method. As a result, a method was developed as given in Appendix 1. Meanwhile, it occurred that a photographic procedure was adaptable and could be developed for observing turning circles. Accordingly, a number of experiments were made with the result that a method was developed as given in Appendix 2.

To demonstrate their practicability, these photographic methods for the measurement of heeling angle and turning circles were employed during the acceptance trials of the U.S.S. FARRAGUT. So as not to interfere with the trial, observations were made as the vessel was turned in making her approach to the mile course. This procedure prohibited observations by some other full scale method to check the photographic observations. However, the results attained during these preliminary experiments were extremely promising when compared to observed model results. When, then, full scale turning trials were proposed, the Model Basin was able to utilize and develop further the basic methods that had been demonstrated in full scale.

TYPES OF TRIALS.

Since the proposed full scale trials were to be taken as a measure of the operating characteristics of rudders A and C, the following types of trials were considered essential as a means for comparison.

A. Standardization trials.

Standardization trials were made to determine the effect of each rudder on propulsion. Rudder A possessed an exposed length of rudder stock of 24 inches whereas rudder C, being of the normal conventional design, had no exposed rudder stock.

B. Turning trials.

The usual practice in turning trials is to have the vessel turn a complete circle. Considering the number of turns contemplated in the proposed trials, this procedure did not appear necessary nor satisfactory. Upon reflection it will be seen that measurements made in the first and second quadrants give a full measure of the rudder's characteristics in turning. Observations continued in the third and fourth quadrant are of no importance - they provide redundant data that have no usefulness or direct bearing on observations made in the first or second quadrants. On the other hand, a greater number of observations confined to the first and second quadrants are more important for an accurate determination of the vessel's path. Because of these considerations, each turn of the vessel was to be limited to a total change of course of 200 degrees.

Observations of heeling angles were to be made simultaneously with turning circle observations.

C. Maneuverability trials.

Maneuverability trials were made for determining the ability of the vessel to answer helm promptly (from a standing start as well as underway), to make varied changes of course, and to be steadied on a new course.

D. Directional stability trials.

Directional stability trials were made for determining the directional stability or the stability of route of the vessel when pushed through the water by propellers without regard to the rudder.

TRIAL PROCEDURE.

The following procedure was developed and utilized in the conduct of the various trials.

A. Standardization trials.

The two-run method was adopted for the standardization trial. Seven spots were selected, making a total of 14 runs, the RPM for each spot being 191, 241, 294, 316, 338, 358, and 375. These spots corresponded, roughly, to 20, 24, 28, 30, 32, 34 and 36 knots. The vessel was without trim or heel, loaded to a displacement of 1725 tons.

B. Turning trials.

The displacement, trim and heel of the vessel during the turning trials was similar to that during the standardization trials.

Runs were made at 15, 20, 25, 30 and 36 knots with rudder angles of 20, 25, 30 and 35 degrees. All turns were made using right rudder. Two turns were made at each speed and rudder angle.

With the vessel steering 270 degrees true, the approach course was first set so as to range on Breakwater Light and the south edge of the Eastern Steamship Dock. When Owls Head Light was abeam – distance approximately 1500 yards – the rudder was to be brought to the desired angle at the normal rate.

When the vessel had changed heading by 200 degrees, the rudder was shifted to bring the vessel on course 90 degrees true. A run of two miles was then made on this course after which the rudder was shifted to bring the vessel on the approach course of 270 degrees true so as to pass Owls Head Light at approximately 1500 yards. During the approach, the vessel was steadied on the specified RPM.

After several turns had been made in accordance with the above, it was observed that a change of the approach course from 270 to 246 degrees true would be preferable. The range marks for this latter course – Breakwater Light and two large stacks approximately five miles inland – were more visible. When Owls Head Light bore 180 degrees true, the rudder was shifted. After the turn was completed, a long figure eight was made for returning the vessel to its approach course. The differences in the two methods are indicated in Fig. 24.

Outside of the advantage of greater visibility of the range points, the latter method provided a more adequate means for piloting so as to make a correct approach after each turn. As a result this procedure was adopted as standard.

The methods of making visual and photographic observation of the vessel's path during the turns are given in Appendix 3. The longitudinal method of making heeling observations was employed as detailed in Appendix 1.

After the vessel had been steadied on its approach course, the turbine throttles were not disturbed until the turn had been completed. Movement of the throttle during turning would have destroyed the comparative value of the results.

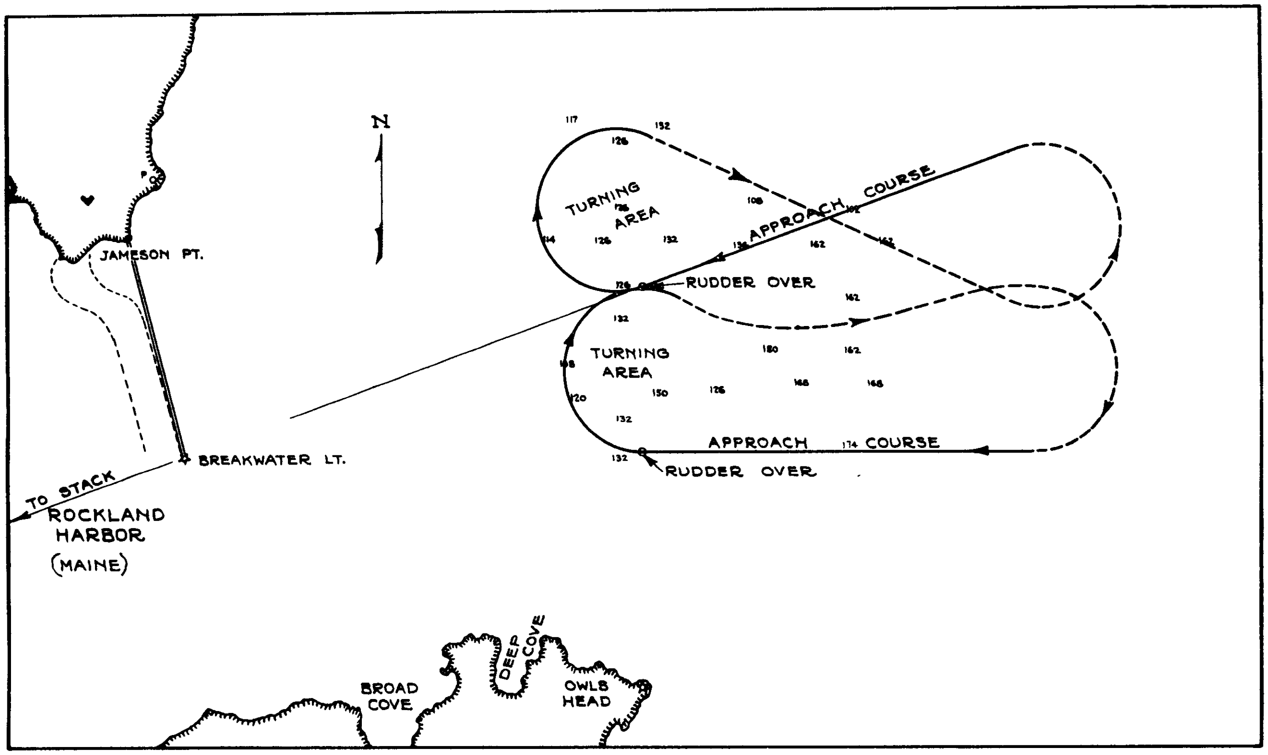


FIG. 24 COURSES AND AREA FOR TURNING TRIALS, HARBOR OF ROCKLAND, MAINE

Furthermore, this procedure provided a means for analyzing the variations in RPM for both shafts while turning.

C. Maneuverability trials.

The maneuverability trials underway were conducted as follows:

A base course was selected by steaming directly into the wind, the vessel being steadied on this course. When the swing of the vessel had been reduced practically to zero, the revolutions in both shafts being the same, the rudder was shifted (at the normal rate) 10 degrees to the right and held there. When the vessel had changed course 10 degrees to the right, the rudder was shifted (at the normal rate) to 10 degrees left and held there. When the vessel had changed course 10 degrees to the left of the base course, the rudder was shifted back to 10 degrees right and held there until the ship reached the base course. At this point the trial was considered completed and the rudder was maneuvered to bring the vessel on the base course.

The cycle of operation for the following run was of the same order except that the rudder was placed 10 degrees left initially.

In like manner runs with 15 degrees rudder, left and right initially, were made. In these runs, the vessel was allowed to swing until a deviation of 30 degrees from the base course was reached.

The above series of runs was made at speeds of 20, 25, and 30 knots. The displacement, trim, and heel of the vessel being similar to that given for the standardization trials.

The maneuverability trials from at rest were conducted as follows:

The vessel was placed at rest, heading approximately 70 degrees true, from 500 to 1000 yards eastward of the breakwater off Rockland Harbor. The rudder was placed 25 and 35 degrees right and left initially. With each of these initial rudder positions the starboard engine was brought to two-thirds speed ahead (operating pressure of 135 lbs.) which corresponded to approximately 10 knots. Similarly, the port engine and then both engines were maneuvered in the same manner. This procedure was employed in the case of Rudder C.

For rudder A, since the rudder presented a greater area to the propeller slip stream than that of rudder C, rudder angles of 20, 25, and 30 degrees right and left were employed. In these tests both engines were maneuvered at one-third and two-third speed ahead with all combinations of rudder angle.

Two large stanchions were erected on the breakwater 500 and 1000 feet from the center of the lighthouse. These three points served as a grid in making photographic exposures for determining the vessel's position.

D. Directional Stability trials.

A base course was selected by steaming directly into the wind, the vessel being steadied on this course. When the swing of the vessel had reduced practically to zero and with the revolutions on both shafts the same, the vessel was allowed to make its own changes in course, the rudder being held fixed in its mid position. When the vessel's heading had changed a total of twenty five degrees, the run was considered completed.

HISTORY OF OPERATIONS.

18 July 1934

Left Boston at 0600 for Rockland, Me. Directional stability and maneuverability trials were conducted enroute. On arrival at Rockland, Me., working parties were sent ashore to prepare and erect shore observing station equipment.

19 July 1934

Underway at 0630. Dragged shafts for torsionmeter zeros. Commenced standardization at 0708. Thirteen runs were made and completed at 1041. Sky overcast, sea smooth. True wind, south, force 2 Beaufort Scale.

Vessel stopped to land shore observing parties. At 1254 started turning trials. Eight circles at 15 knots were made, completed at 1503, and nine circles at 20 knots, completed at 1659. Vessel then returned to anchorage.

20 July 1934

Because of lack of adequate light, no turning trials were attempted. The vessel was brought to rest about 800 yards off Rockland Breakwater. From this position maneuverability trials from at rest were made. Starting at 0804, thirteen runs were made completing at 1013. Because of an increase in haze, further trials were discontinued and the vessel returned to its anchorage.

21 July 1934

Underway at 0645. Proceeded to area for turning trials. Eight circles at 25 knots, beginning at 0709 and completing at 0846, and eight circles at 30 knots, completing at 1012, were made. While working up to 36 knots, a casualty to the main feed pump caused the suspension of further trials and the vessel returned to anchorage.

22 July 1934

As this was Sunday, the vessel remained at anchor.

23 July 1934

Underway at 0600. Proceeded to area for turning trials. Four circles at 25 knots, four at 30 knots, and eight at 36 knots were made starting at 0630 and completing at 0939. Stopped to take shore observing parties on board. Underway for Boston. While enroute repeated maneuverability trials underway at speeds of 20, 25, and 30 knots, starting at 1336 and completing at 1513. Arrived at Boston at 1910.

RESULTS AND DISCUSSION.

A. Standardization Trials.

A-1. Results.

The results of the standardization trials of 19 July corrected to a basis of standard conditions are given in Table 2. These values have been used for plotting the curves of Fig. 25. Table 3 gives a comparison of trial and model results. From this table it is found that the trial RPMs are on the average 3.1 per cent low and the trial SHPs 2.5 per cent low in comparison to corresponding model predictions.

A-2. Propeller Performance Analysis.

Fig. 26 gives for each propeller curves of torque coefficient, corrected for wind effect, plotted against apparent slip ratio. Similar curves, for comparative purposes, obtained from data during the acceptance trials of the vessel, held during

TABLE 2

U.S.S. FARRAGUT

RESULTS OF STANDARDIZATION TRIALS OF 19 JULY 1934

CORRECTED TO A BASIS OF STANDARD CONDITIONS

RUN	STARBOARD		PORT		TOTAL		
NO.	RPM	SHP	RPM	SHP	SPEED	RPM	SHP
1N	190.86	2,370	190.91	2,906	20.35	190.89	5,276
2S	190.88	2,370	191.09	2,914	20.45	190.99	5,284
3N	242.63	5,460	243.62	6,419	24.89	243.19	11,879
4S	241.12	5,480	241.94	6,286	24.69	241.53	11,766
5N	295.96	10,660	295.18	11,842	28.88	295.57	22,502
6S	294.86	10,540	296.38	11,987	29.00	295.62	22,527
7N	315.52	12,640	316.58	14,573	31.08	316.05	27,213
8S	317.40	12,850	317.21	14,662	31.26	317.31	27,512
9N	339.23	15,320	336.68	17,278	33.38	337.96	32,598
10S	340.88	15,540	339.00	17,637	33.63	339.94	33,179
11N	362.79	18,680	363.02	21,134	35.74	362.91	39,814
12S	361.24	18,440	360.27	20,654	35.49	360.76	39,094
13N	360.07	18,270	359.98	20,606	35.43	360.03	38,876

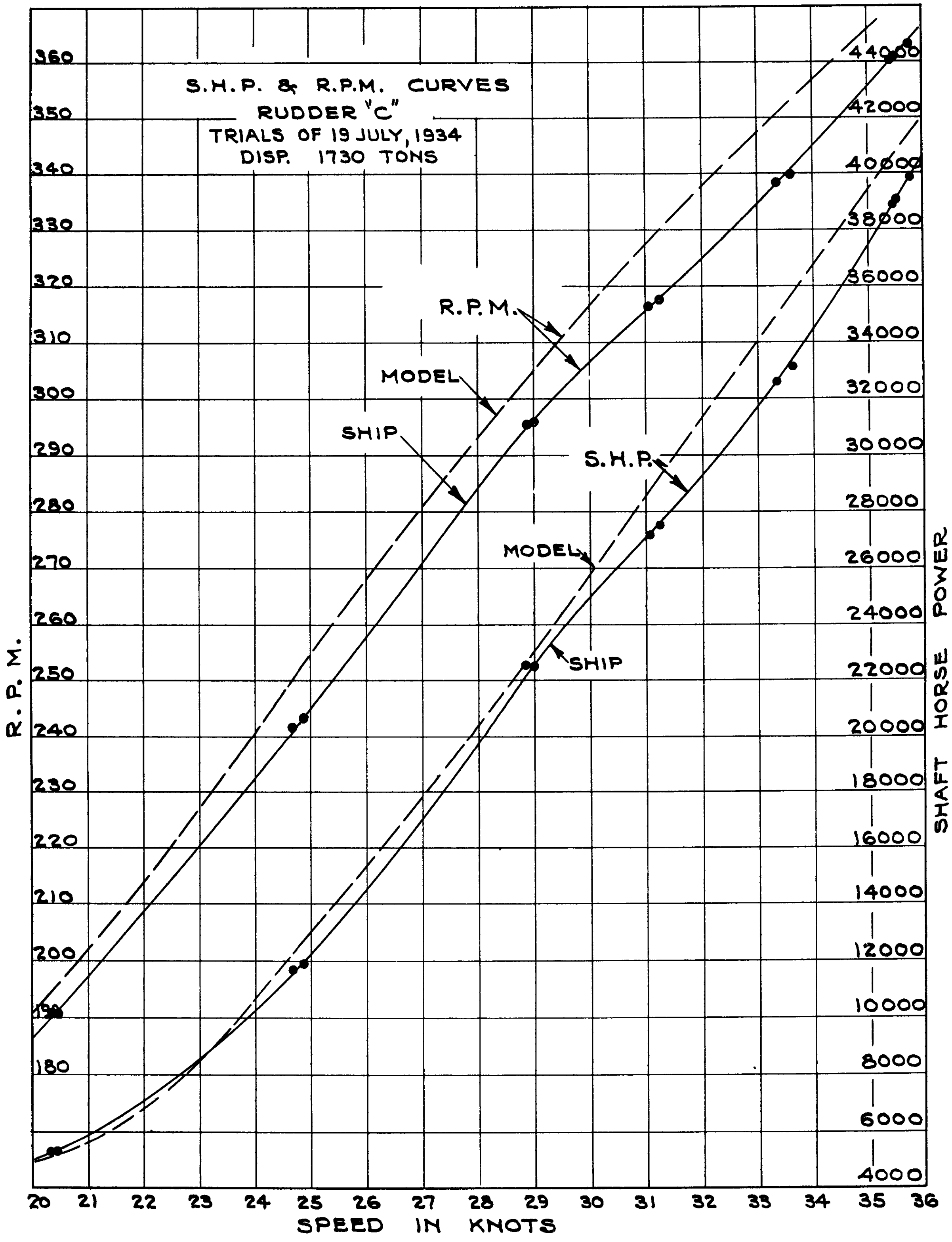


FIG. 25 MODEL – TRIAL COMPARISON. U.S.S. FARRAGUT. STANDARDIZATION TRIALS OF 19 JULY 1934

TABLE 3

MODEL TRIAL COMPARISON, 19 JULY 1934
DIFFERENCES EXPRESSED AS PERCENTAGE OF ACTUAL TO PREDICTED VALUES

SPEED KNOTS	RPM MODEL	RPM TRIAL	RPM PER-CENT	SHP MODEL	SHP TRIAL	SHP PER-CENT
20	191	186.5	-2.3	4,700	4,900	+4.2
21	202	197.5	-2.2	5,500	5,900	+7.3
22	213.5	209	-2.1	6,000	7,100	+4.4
23	226.5	220.5	-2.6	8,500	8,600	+1.2
24	240.5	232.5	-3.3	10,600	10,300	-2.8
25	255	245	-3.9	13,000	12,200	-6.1
26	268	258	-3.8	15,300	14,500	-5.2
27	281	271	-3.6	17,800	17,000	-4.5
28	293	284	-3.1	20,400	19,700	-3.4
29	305	296.5	-2.8	23,000	22,600	-1.7
30	317	306.5	-3.3	25,800	25,000	-3.1
31	328	315.5	-3.8	28,500	27,000	-5.3
32	338	325	-3.8	31,200	29,300	-6.1
33	348	335	-3.7	34,000	31,700	-6.8
34	358	345	-3.6	36,700	34,400	-6.3
35	366	356	-3.0	39,400	37,400	-5.1
36	375	366.5	-2.3	42,200	40,900	-3.1

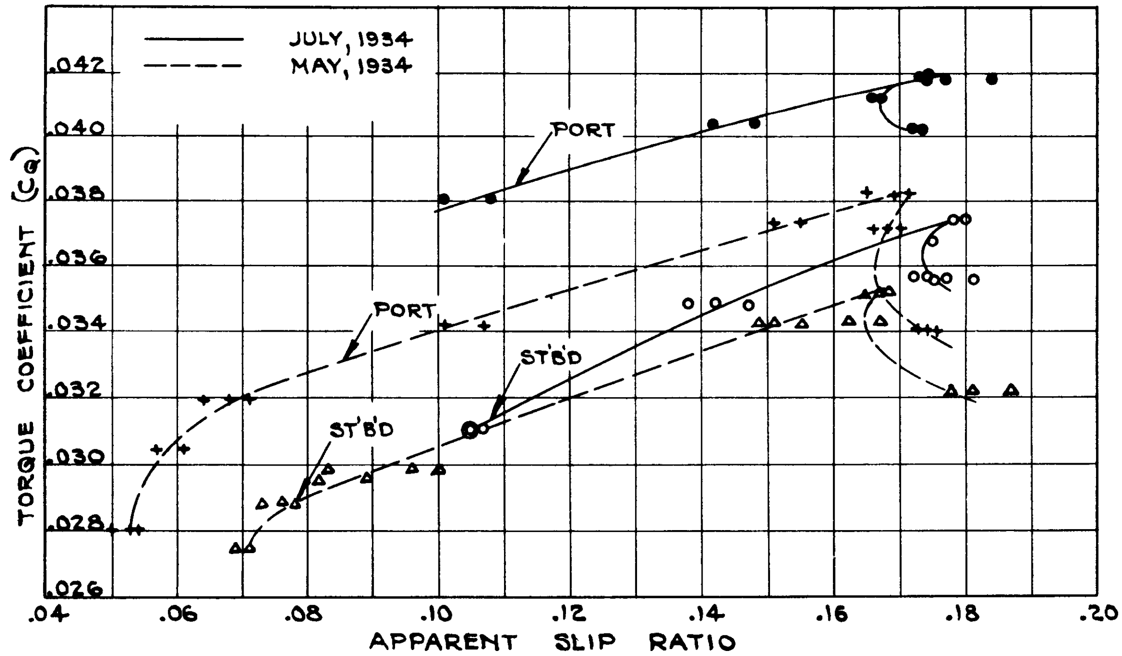


FIG. 26 CURVES OF CORRECTED TORQUE COEFFICIENTS VERSUS APPARENT SLIP RATIO.
U.S.S. FARRAGUT. STANDARDIZATION TRIALS OF MAY AND JULY 1934

18 May 1934, have been included. The shape of these curves at the point of breakdown is unusual. The curves of the starboard propeller for May and July trials seem consistent. Those of the port propeller are consistent as regards trend but inconsistent as regards relative position. The conclusion, provided the data are accurate, is that the port propeller has suffered a progressive loss in efficiency.

Prior to the trials of 19 July 1934, while the vessel was on the marine railway, the attention of the Model Basin's representative was directed to the erosion existing on the backs and in some cases, the roots of each blade. Considering the short interval of time prior to undocking, the importance of holding the trials as planned, and the opinion that the observed propeller conditions were not serious, no interference with the trial schedule was recommended. Photographic exposures of the eroded areas on the backs of each blade, made just prior to undocking, produced exceedingly poor pictures. Consequently, upon return from trials, the vessel was placed on the marine railway at the Boston Navy Yard for another set of photographs of the propeller blades. Figs. 27 – 33 give the conditions on the backs of the starboard propeller. In these photographs the arrows, where appearing, indicate the direction of the water relative to the blade. Figs. 28, 31, and 33 give detailed views of the eroded areas. Figs. 34–41 give the conditions on the backs of the port propeller. Figs. 36, 38 and 40 give detailed views of the eroded areas. Fig. 41 indicates how the trailing edge of each blade was "dished" in the wake of the eroded areas. This condition was found on each blade of the port propeller and very slightly in two blades of the starboard propeller. Since the photographs made prior to the trials were poor, it was impossible to determine whether the propeller conditions had suffered further damage during the trials just concluded. Opinions were divided amongst those who had actually observed the blades before and after the trials.

Since vibrations of the ship's structure were perceptible with these propellers and not perceptible when experimental propellers of another type had been installed, it was believed that vibration and evidence of erosion on the back of the blades indicated cavitation as the cause. This did not appear entirely logical as these designs were based on water tunnel tests and results which promised avoidance of cavitation conditions. Tests repeated in the tunnel confirmed this view. Accordingly templates were made from the full scale propeller showing the shape of the leading edge. These, then, were compared to the designed conditions as determined from the model propellers. This comparison is given in Fig. 42. Since the shapes of the leading edges of each blade vary widely from the designed conditions, it is apparent that the bluntness and thickness of the edges caused cavitation, this, in turn, causing erosion of definite areas.

As the time available prior to the next series of trials was too short, the blades of each propeller were repaired by removing the eroded areas, welding, followed by annealing.

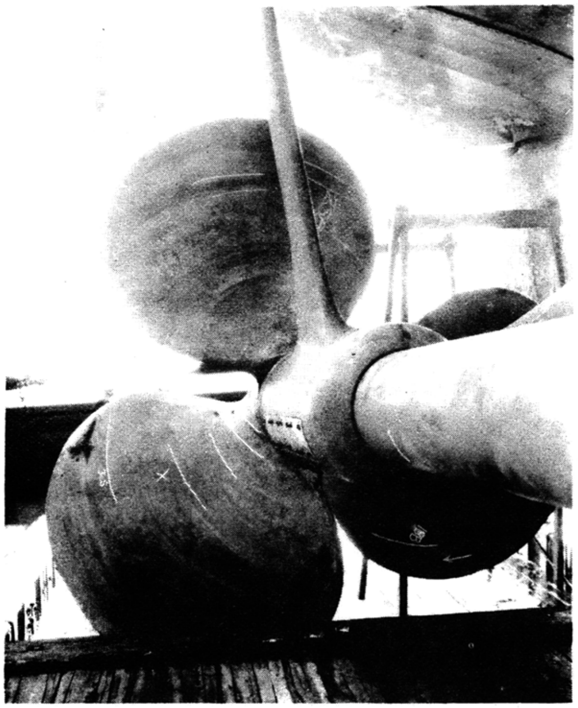


FIG. 27 STARBOARD PROPELLER.
GENERAL VIEW OF BACK.

FIG. 28 STARBOARD PROPELLER. DETAILED
VIEW OF ERODED AREAS NEAR TRAILING
EDGE. BACK #1 BLADE

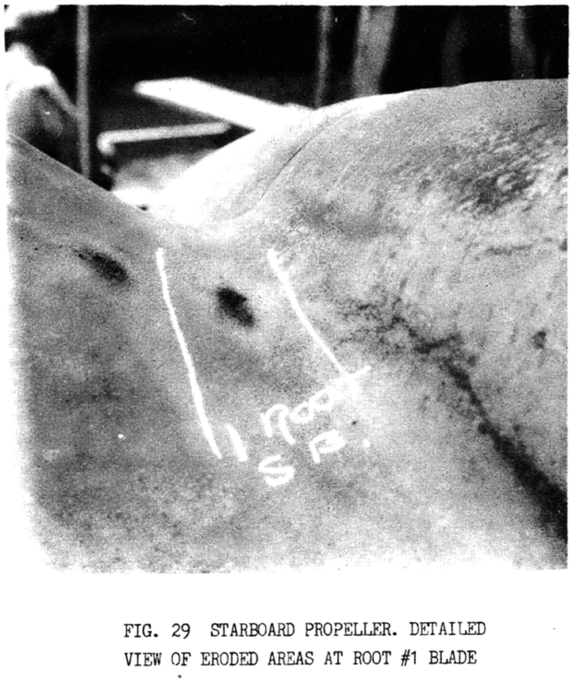


FIG. 29 STARBOARD PROPELLER. DETAILED
VIEW OF ERODED AREAS AT ROOT #1 BLADE

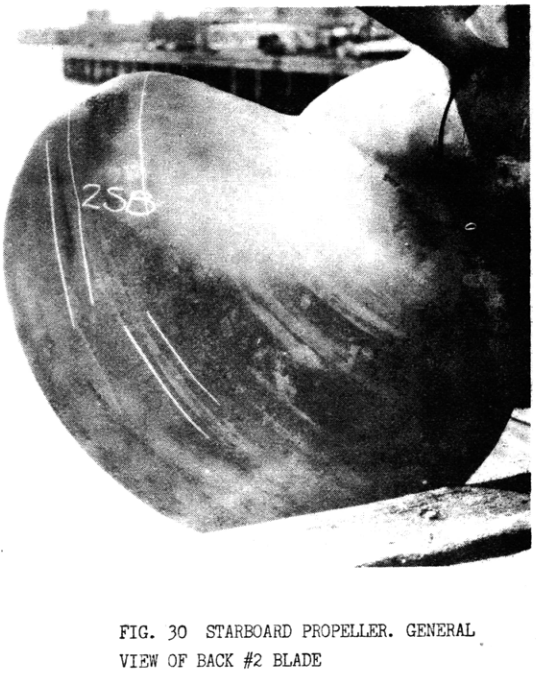


FIG. 30 STARBOARD PROPELLER. GENERAL
VIEW OF BACK #2 BLADE

FIG. 31 STARBOARD PROPELLER. DETAILED VIEW OF ERODED AREA NEAR TRAILING EDGE. BACK #2 BLADE

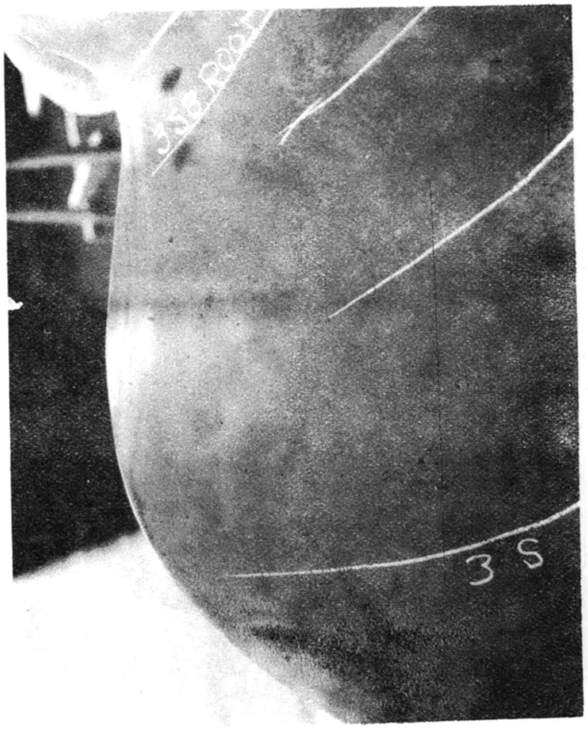


FIG. 33 STARBOARD PROPELLER. DETAILED VIEW OF ERODED AREAS NEAR TRAILING EDGE AND AT ROOT #3 BLADE

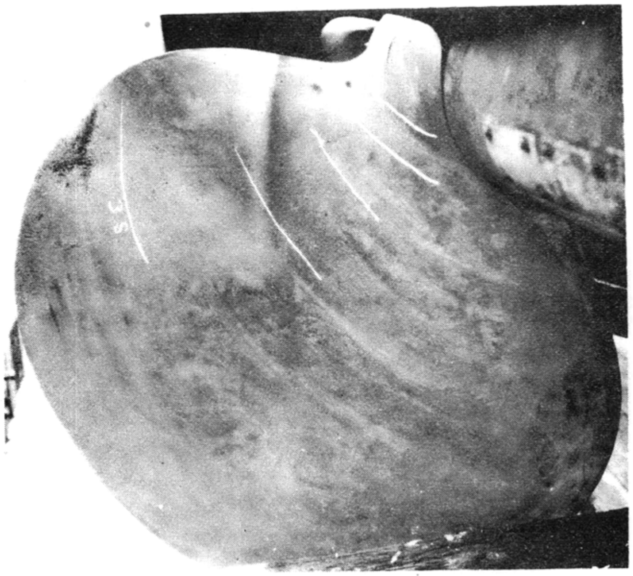


FIG. 32 STARBOARD PROPELLER. GENERAL VIEW OF BACK #3 BLADE

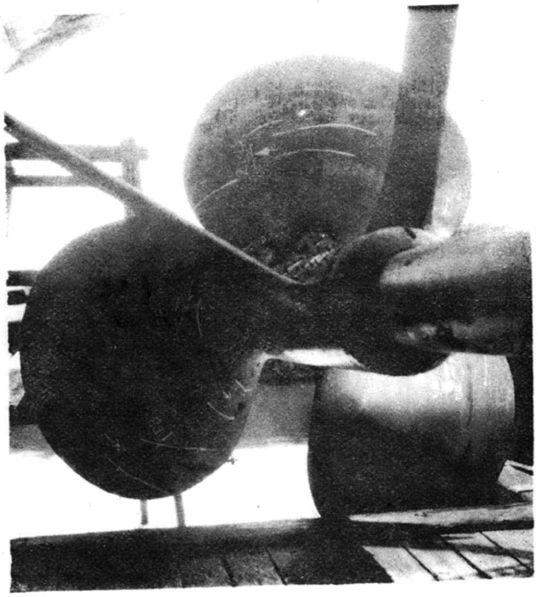


FIG. 34 PORT PROPELLER. GENERAL VIEW OF BACK

FIG. 35 PORT PROPELLER. GENERAL VIEW OF BACK #1 BLADE

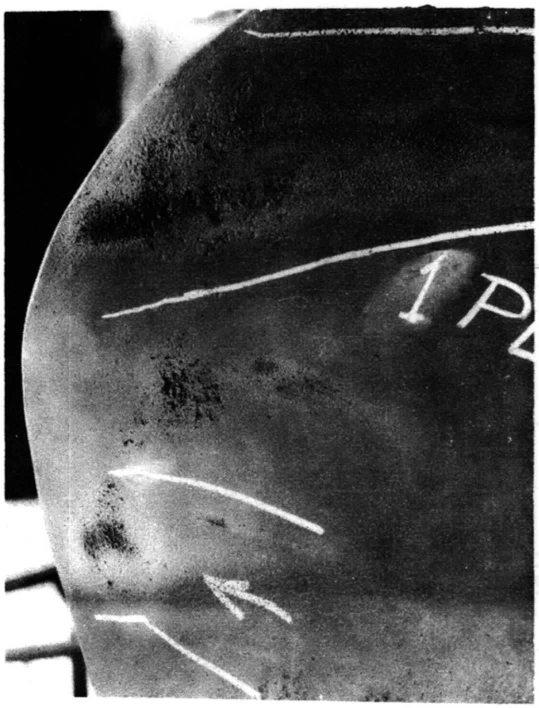


FIG. 36 PORT PROPELLER. DETAILED VIEW OF ERODED AREAS NEAR TRAILING EDGE. BACK #1 BLADE

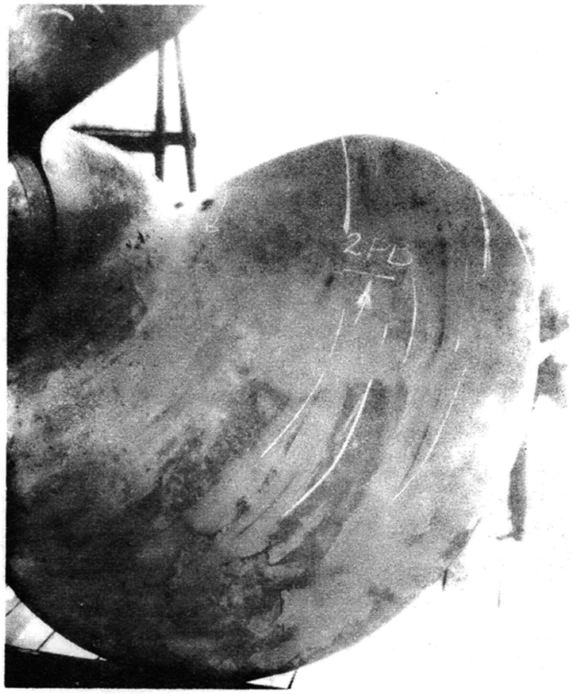


FIG. 37 PORT PROPELLER. GENERAL VIEW OF BACK #2 BLADE

FIG. 38 PORT PROPELLER. DETAILED VIEW OF ERODED AREAS NEAR TRAILING EDGE. BACK #2 BLADE

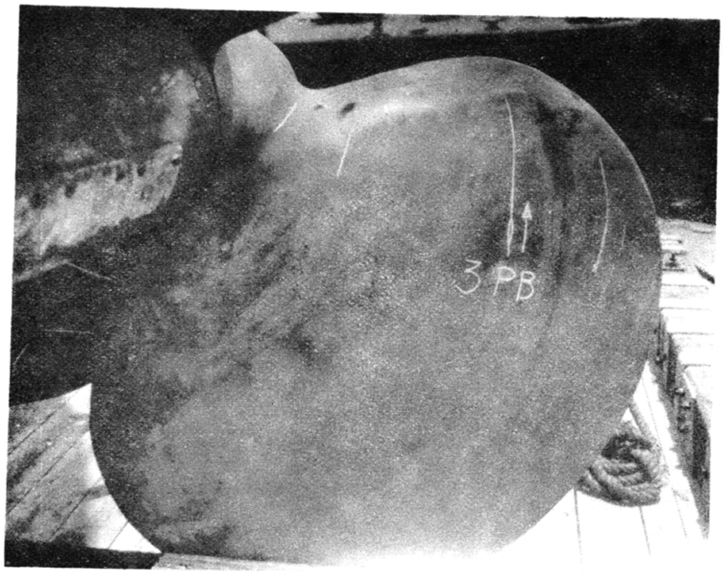
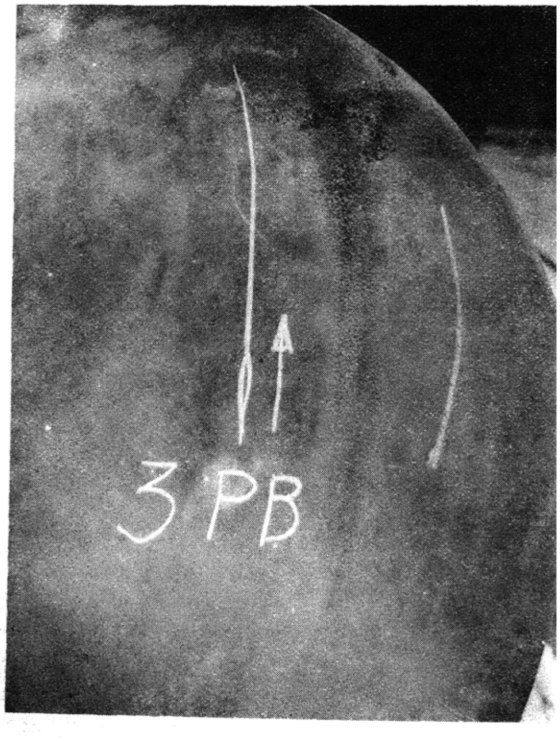


FIG. 39 PORT PROPELLER. GENERAL VIEW OF BACK #3 BLADE

FIG. 40 PORT PROPELLER. DETAILED VIEW OF ERODED AREAS NEAR TRAILING EDGE. BACK #3 BLADE →



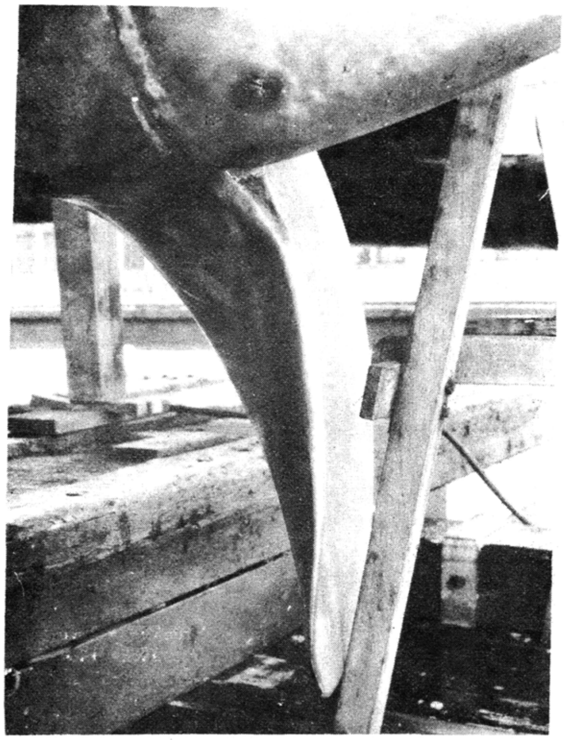


FIG. 41 PORT PROPELLER. VIEW SHOWING "DISH" (SEEN IN LOWER PART OF PHOTOGRAPH) OF TRAILING EDGE IN WAKE OF ERODED AREAS[2]

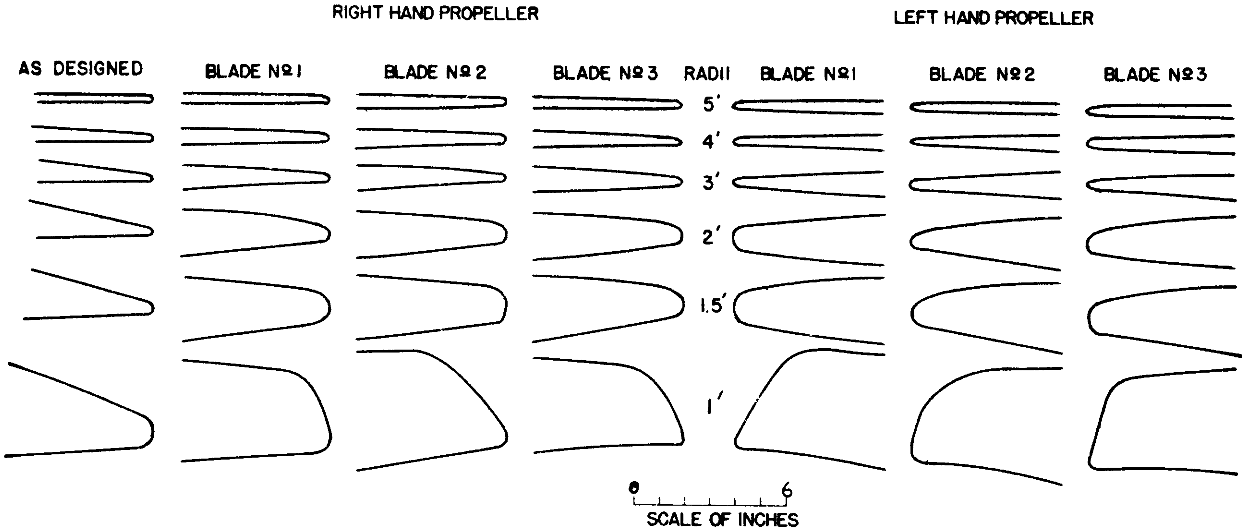


FIG. 42 U.S.S. FARRAGUT PROPELLERS. COMPARISON OF SHAPES, DESIGNED AND ACTUAL, OF LEADING EDGES TAKEN FROM WORK ABOUT AUGUST 10, 1934

Table 4 gives a comparison of the variations in thickness of the leading and trailing edges of each blade. These indicate wide deviations. Table 5 gives a comparison between the actual and designed pitch before annealing and Table 6 gives a similar comparison after annealing. These latter variations do not appear normal.

Reverting to Fig. 26, the above facts are consistent with the indications in that figure.

As noted above, the main objective of this particular design was the avoidance of cavitation. Since it was apparent that changes in the leading edges in full scale were responsible for the existence of cavitation in full scale, there remained the determination, if possible, of the cause or causes of vibration. Hence, when the FARRAGUT arrived at the Norfolk Navy Yard in November 1934, the propellers were removed for rebalancing. Under date of 15 January 1935, the Navy Yard reported the following results upon dynamic balancing.

(a) 1223 ounce inches had to be removed from the forward side of the starboard propeller at a point 19 degrees - 37 minutes to the left of the zero reference plane.

(b) 1027 ounce inches had to be removed from the after side of the starboard propeller at a point 105 degrees to the right of the zero reference plane.

(c) 2441 ounce inches had to be removed from the forward side of the port propeller at a point 11 degrees, 42 minutes to the left of the zero reference plane.

(d) 2188 ounce inches had to be removed from the after side of the port propeller at a point 146 degrees, 57 minutes to the right of the zero reference plane.

These results indicate how seriously unbalanced the propellers were, the port propeller being more out of balance than the starboard propeller. This may, in part, account for the greater power absorbed by the port propeller during the

TABLE 4

U.S.S. FARRAGUT
PROPELLER MEASUREMENTS
VARIATIONS FROM DESIGNED THICKNESS
IN PER CENT

		PORT PROPELLER		STARBOARD PROPELLER	
BLADE	PERCENT RADIUS	MEAN VARIATION TRAILING EDGE TO 1/3 SPAN	MEAN VARIATION LEADING EDGE TO 1/3 SPAN	MEAN VARIATION TRAILING EDGE TO 1/3 SPAN	MEAN VARIATION LEADING EDGE TO 1/3 SPAN
1	55	- 6.13	- 1.55	- 3.40	- 5.21
1	65	-11.29	-10.33	- 8.03	-16.55
1	75	- 9.46	- 5.25	- 4.19	- 2.01
1	85	+ 1.68	- 7.04	+ 5.45	- .85
2	55	- 9.60	- 2.68	- 2.23	- 2.28
2	65	-14.27	- 6.34	- 7.88	-11.92
2	75	-13.54	- 1.68	- 7.12	- .19
2	85	- .01	- 7.33	- 2.74	- 1.46
3	55	- 8.80	- .30	- 8.35	- 3.76
3	65	-14.40	- 9.98	-10.10	-10.93
3	75	-11.12	+ 3.23	- 7.32	- 2.72
3	85	- 2.41	- 1.33	+ .66	- 6.11

U.S.S. FARRAGUT
PROPELLER CHECK MEASUREMENTS AT BOSTON
PITCH MEASUREMENTS TAKEN AT .419R, .55R, .65R, .75R, AND .85R

TABLE 5 – BEFORE ANNEALING

RIGHT HAND

BLADE NO.	PITCH DESIGNED – MEAN	PITCH MEASURED – MEAN	ERROR MEAN – PERCENT	ERROR MAX. – PERCENT
1	12.29	12.74	+3.66	+3.99
2		12.48	+1.55	+2.08
3		12.60	+2.52	+3.26
Average	12.29	12.61	+2.60	

LEFT HAND

BLADE NO.	PITCH DESIGNED – MEAN	PITCH MEASURED – MEAN	ERROR MEAN – PERCENT	ERROR MAX. – PERCENT
1	12.29	12.54	+2.03	+2.58
2		12.59	+2.44	+3.14
3		12.55	+2.11	+3.35
Average	12.29	12.56	+2.20	

TABLE 6 – AFTER ANNEALING

RIGHT HAND

BLADE NO.	PITCH DESIGNED – MEAN	PITCH MEASURED – MEAN	ERROR MEAN – PERCENT	ERROR MAX. – PERCENT
1	12.29	12.72	+3.50	+3.99
2		12.53	+1.95	+2.80
3		12.55	+2.12	+2.83
AVERAGE	12.29	12.60	+2.52	

LEFT HAND

BLADE NO.	PITCH DESIGNED – MEAN	PITCH MEASURED – MEAN	ERROR MEAN – PERCENT	ERROR MAX. – PERCENT
1	12.29	12.60	+2.52	+2.83
2		12.71	+3.42	+4.17
3		12.55	+2.12	+2.39
AVERAGE	12.29	12.62	+2.68	

May and July trials, since it was observed that the port propeller was absorbing approximately 12.5 per cent more power than the starboard propeller at maximum speed.

The sum total effect of this unbalance plus the differences in shape of the blade edge makes a reconciliation of trial and model results difficult and inconclusive.

It is to be regretted that thrust was not observed. An analysis of this coefficient, in light of the above, would have been extremely useful.

B. Turning Trials.

B-1. Results.

Table 7 gives a comparison of the observed tactical diameter by plane table and by photographic method, together with other pertinent data, for the turning trials of 19 July 1934. Similar data are given in Table 8 and Table 9 for observations made on 21 and 23 July 1934 respectively.

Fig. 43 gives the curves of tactical diameter, advance and transfer for rudder C for different rudder angles at various speeds resulting from trial observations. Data from photographic methods paralleling similar data by plane table have not been included in Fig. 43.

Figs. 44-47 give the angles of heel, observed photographically for different rudder angles at various speeds. Figs. 48-55 give the changes in heading in degrees with time for the different rudder angles at various speeds. Figs. 56-60 give the reductions in RPMs in per cent for different rudder angles at various speeds

B-2. Discussion.

A total of 48 circles were made for this series of trials. Of this number, it was impossible to determine the paths of four circles from plane table observations and thirty circles from photographic observations. The chief difficulty in connection with the latter observations was in definitely identifying the different objectives in the negatives. This particular difficulty was caused primarily by a light haze that hung on shore. This, in conjunction with lack of contrast in the background and unfavorable light conditions, made positive identification of the selected landmarks hazardous. Further, since the negatives were small, the size of image was likewise small such that in many cases the combination of factors above produces a blur of the image.

For those runs where a comparison of measurements was possible, Figs. 61-64 are typical. These results taken together with those given in Tables 7, 8 and 9 are favorable. However, as the percentage loss from photographic observations was high, the comparison between the plane table and photographic method is incomplete.

Since the objectives of these trials involved a correlation with model results as well as a full scale comparison of the action of rudders A and C, a more extended discussion of this and succeeding characteristics will be reserved and presented hereinafter.

TABLE 7
U.S.S. FARRAGUT
COMPARISON OF TACTICAL DIAMETER OBSERVATIONS, 19 JULY 1934
BY PLANE TABLE AND PHOTOGRAPHIC METHOD
SHIP EQUIPPED WITH RUDDER C

RUN NO.	RPM AVE	SPEED KNOTS	RUDDER ANGLE DEGREES	RATE OF RUDDER IN SECS.	TACT. DIA. IN YDS. BY PLANE TABLE	TACT. DIA. IN YDS. BY PHOTO.
1			20	12		742
2	139.4	15.5	20	12		
3	140.2	15.6	24 1/2	13	630	
4	137.7	15.2	24	15	634	
5	136.1	15.1	30	16	542	
6	138.3	15.4	30 1/4	17	532	
7	135.2	15.0	35 1/4	18	502	
8	138.4	15.4	35 1/4	18	478	
9	190.6	20.4	20	14	728	
10	189.8	20.2	19 1/2	10	730	
11	191.9	20.5	25	15	578	
12	191.8	20.5	25	15	596	
14	190.7	20.4	30	18	503	
15	191.8	20.5	30	18	498	
16	190.5	20.4	35 1/4	26	486	
17	190.3	20.4	35 1/4	25	506	

TABLE 8

U.S.S. FARRAGUT

COMPARISON OF TACTICAL DIAMETER OBSERVATIONS, 21 JULY 1934 BY PLANE TABLE AND PHOTOGRAPHIC METHODS

SHIP EQUIPPED WITH RUDDER C

RUN NO.	RPM AVE	SPEED KNOTS	RUDDER ANGLE DEGREES	RATE OF RUDDER IN SECS.	TACT. DIA. IN YDS. BY	
					PLANE TABLE	PHOTO.
1			20	11		
2	246.2	25.2	19 1/2	10	828	
3	253.4	25.8	25	15	664	662
4	248.6	25.4	25	14		
5	247.0	25.2	30	16	595	
6	248.8	25.4	30	17	600	
7	248.8	25.4	35 1/4	20	560	
8	247.4	25.3	35 1/4	18	566	556
9	302.7	29.6	20	11	1,011	
10	304.8	30.0	20	12	1,017	
11	306.7	30.1	25	15	866	870
12	304.9	30.0	25	13	869	915
13	305.7	30.0	30	16	778	810
14	305.4	30.0	30	16	788	792
15	307.1	30.1	34	21	714	
16	306.9	30.1	35	20	755	

TABLE 9
U.S.S. FARRAGUT
COMPARISON OF TACTICAL DIAMETER OBSERVATIONS, 23 JULY 1934 BY PLANE TABLE AND PHOTOGRAPHIC METHOD
SHIP EQUIPPED WITH RUDDER C

RUN NO.	RPM AVE	SPEED KNOTS	RUDDER ANGLE DEGREES	RATE OF RUDDER IN SECS.	TACT. DIA. IN YDS. BY	
					PLANE TABLE	PHOTO.
1	245.0	25.0	20	9	840	816
2	247.2	25.3	25	11	711	707
3	245.4	25.0	30	14	588	590
4	246.6	25.2	35 1/4	18	556	556
5	304.9	30	20	11	1,020	972
6	307.5	30.2	24 3/4	12	880	854
7	307.2	30.2	30	15	792	
8	306.0	30.1	35	17	750	
9			20	12	1,134	1,080
10	357.1	35.3	20	12	1,126	
11	355.9	35.2	24 3/4	14	930	
12	357.8	35.4	25	14	968	
13	356.8	35.3	30	21	888	880
14	357.4	35.4	30	16	888	878
15	357.6	35.4	35	17	948	920
16	356.7	35.3	35	18	950	912

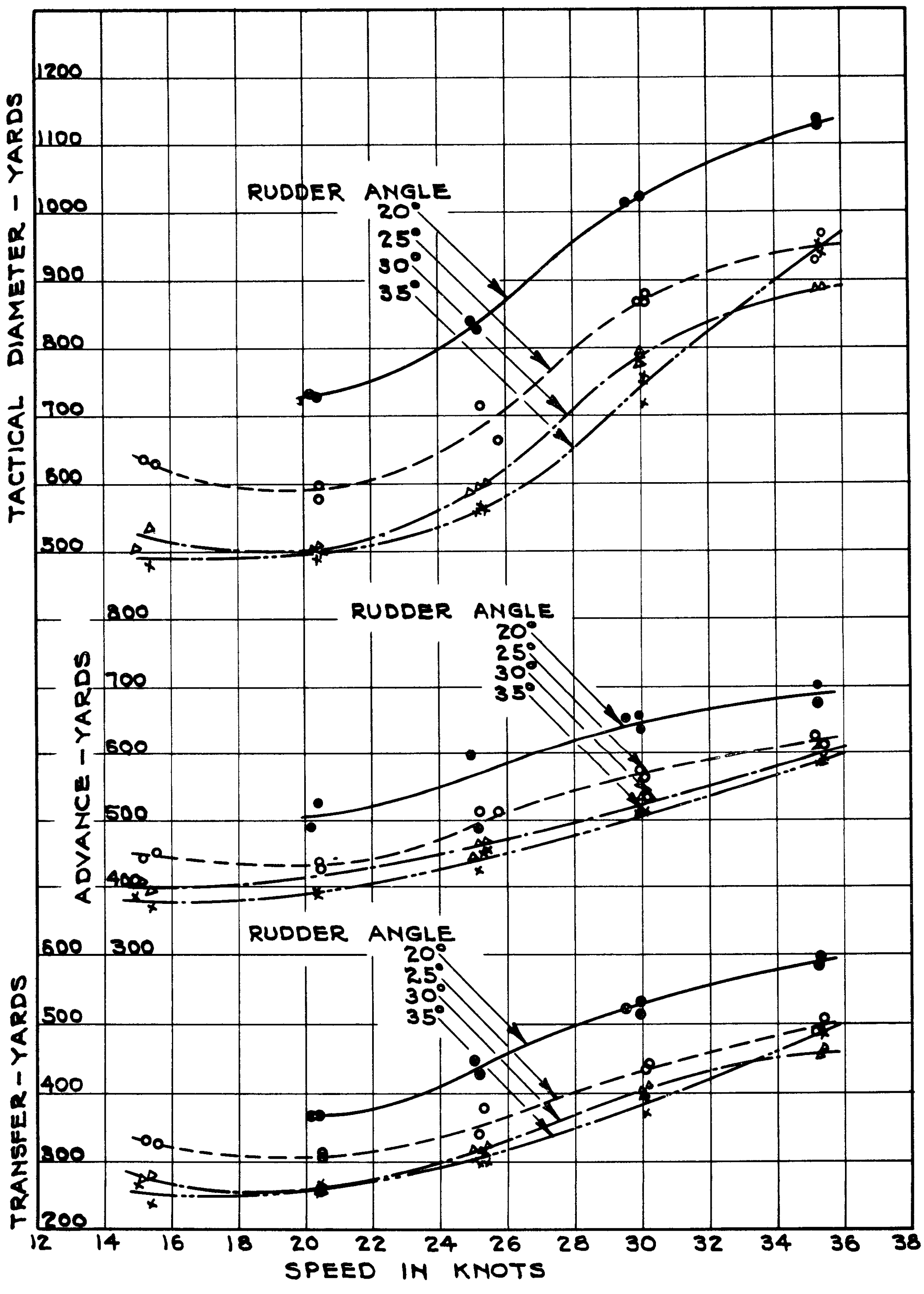


FIG. 43 CURVES FOR TACTICAL DIAMETER, ADVANCE, AND TRANSFER, RUDDER C, FOR DIFFERENT RUDDER ANGLES AND VARIOUS SPEEDS.

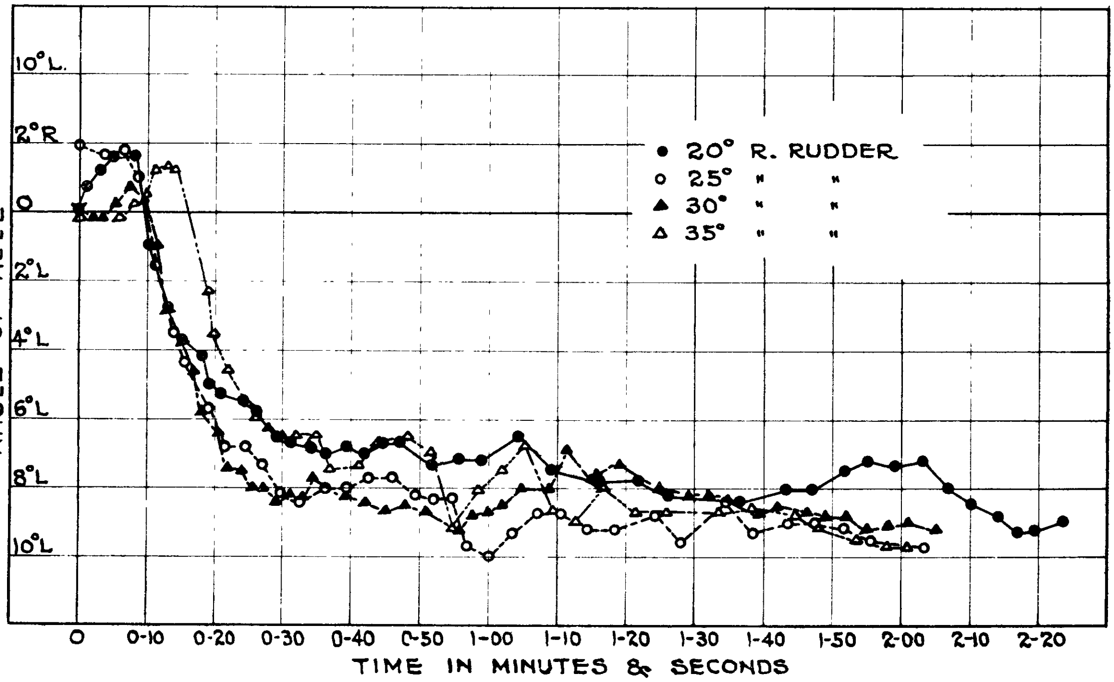


FIG. 44 ANGLES OF HEEL WHILE TURNING, RUDDER C, FOR A SPEED OF 20 KNOTS AND DIFFERENT RUDDER ANGLES

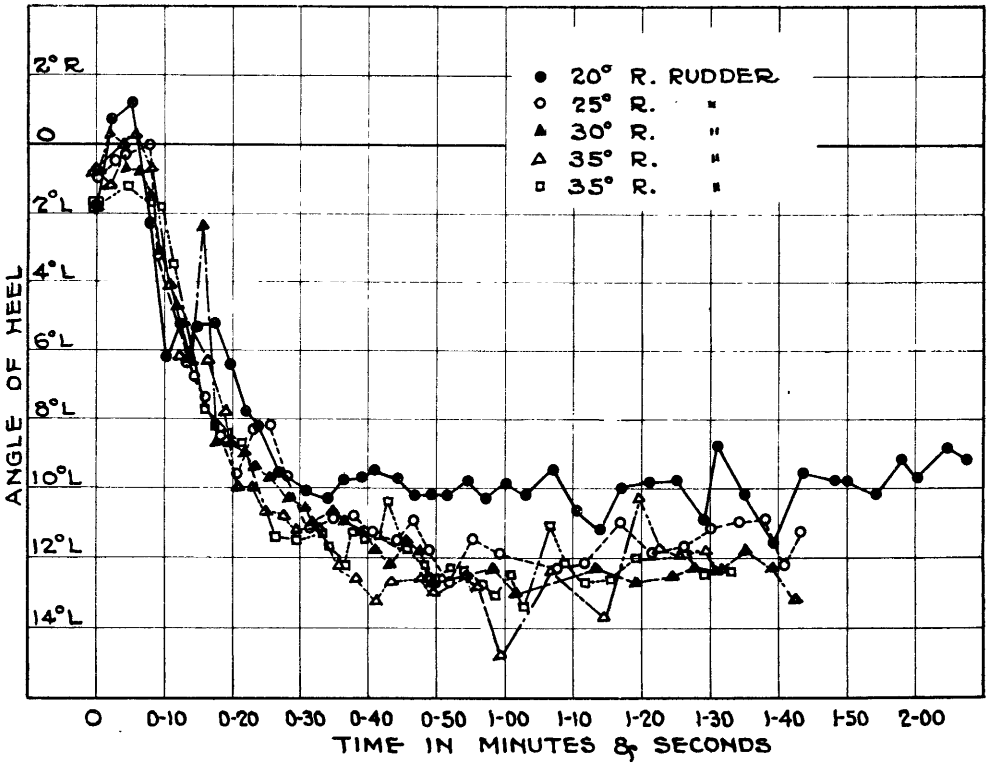


FIG. 45 ANGLES OF HEEL WHILE TURNING, RUDDER C, FOR A SPEED OF 25 KNOTS AND DIFFERENT RUDDER ANGLES

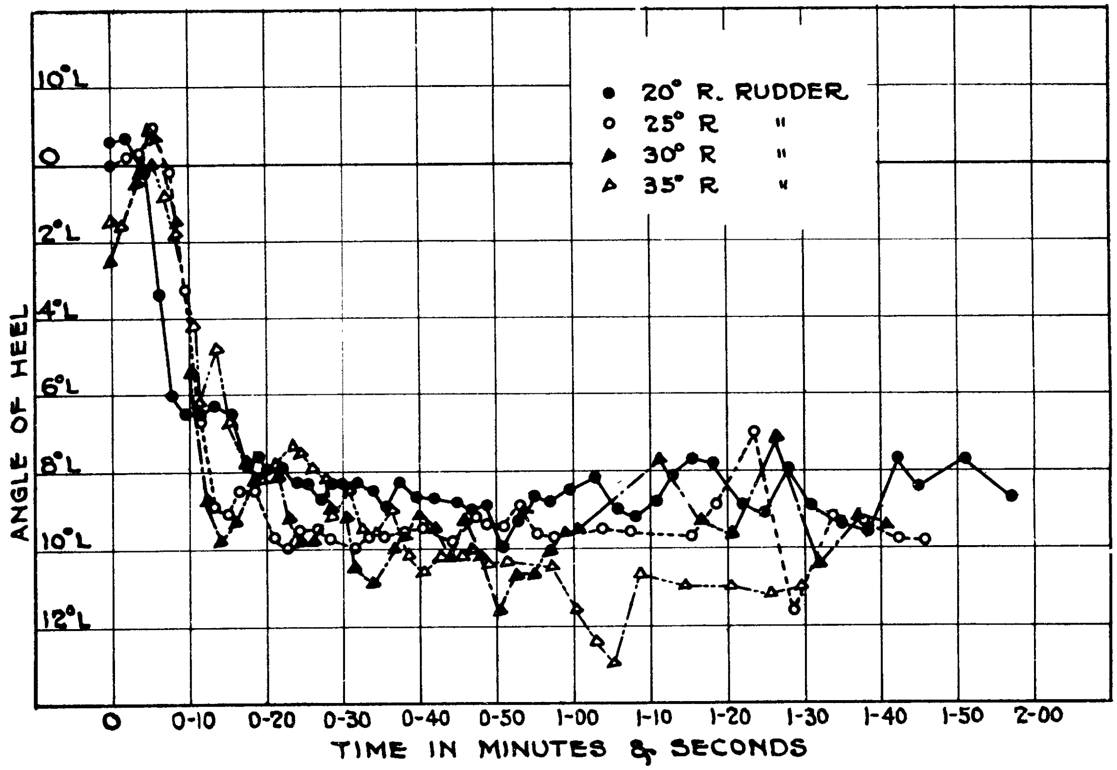


FIG. 46 ANGLES OF HEEL WHILE TURNING, RUDDER C, FOR A SPEED OF 30 KNOTS AND DIFFERENT RUDDER ANGLES

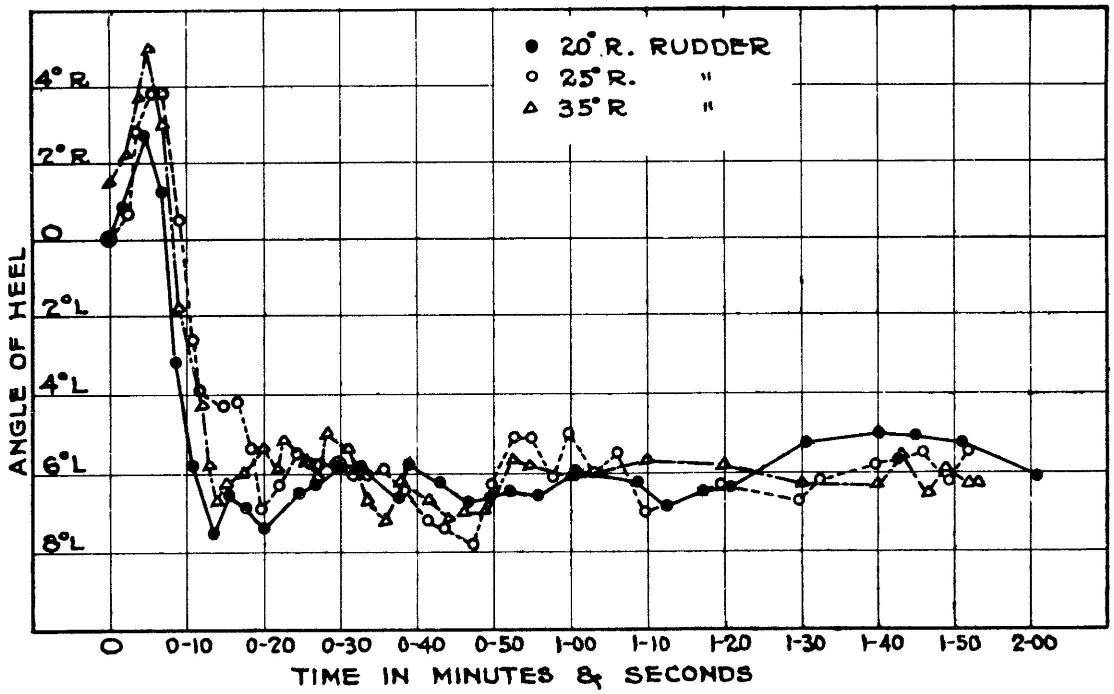


FIG. 47 ANGLES OF HEEL WHILE TURNING, RUDDER C, FOR A SPEED OF 35 KNOTS AND DIFFERENT RUDDER ANGLES

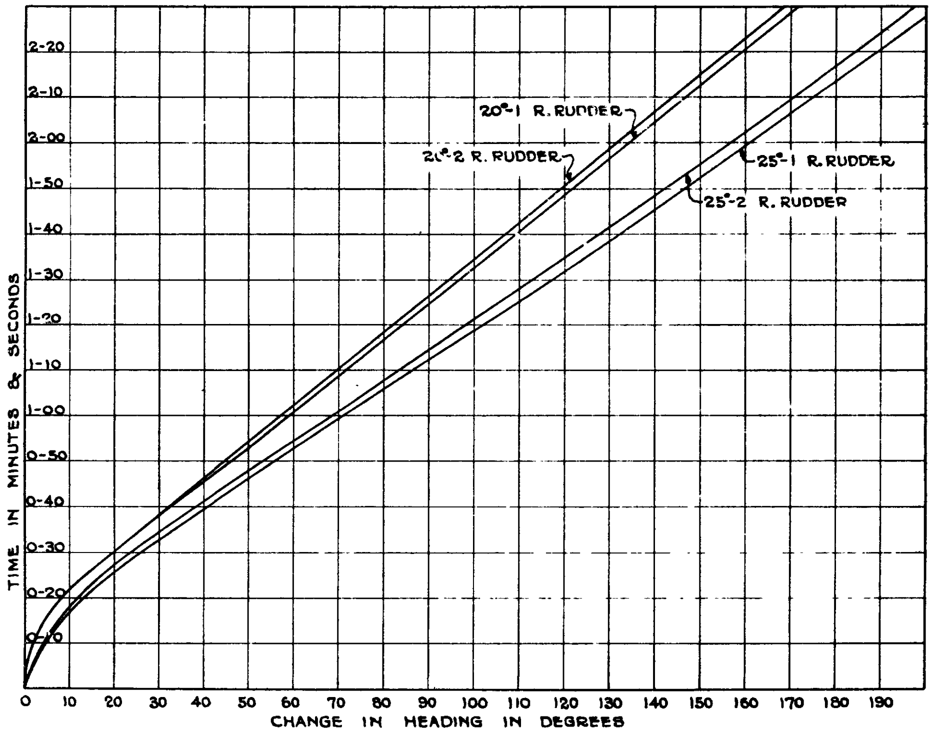


FIG. 48 CHANGE IN HEADING VERSUS TIME, RUDDER C, FOR A SPEED OF 15 KNOTS, RUDDER ANGLES 20 AND 25 DEGREES

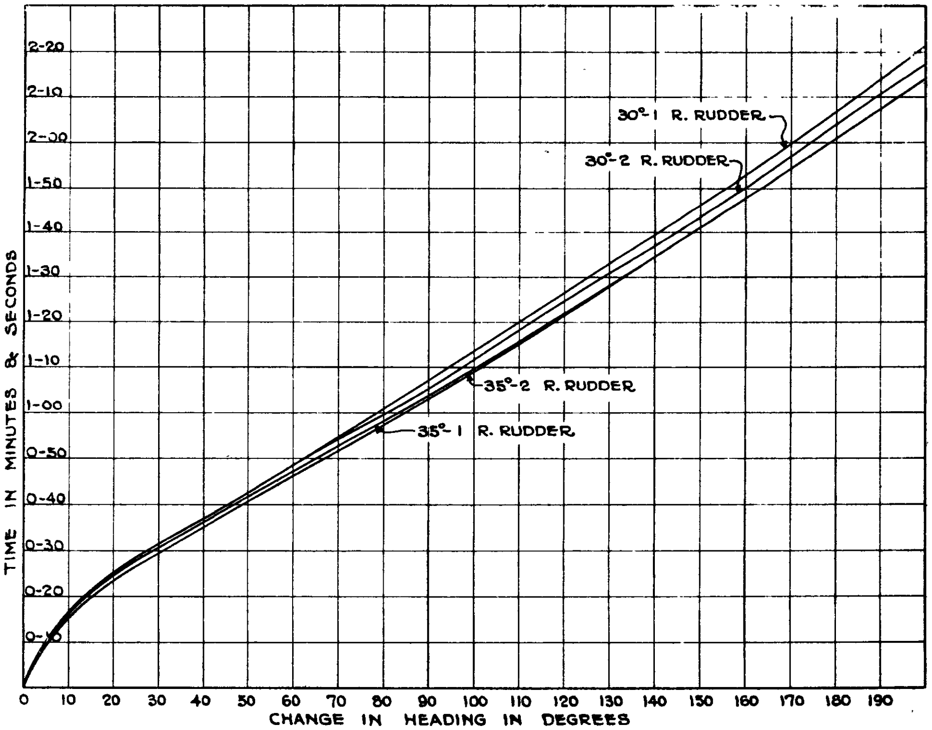


FIG. 49 CHANGE IN HEADING VERSUS TIME, RUDDER C, FOR A SPEED OF 15 KNOTS, RUDDER ANGLES 30 AND 35 DEGREES

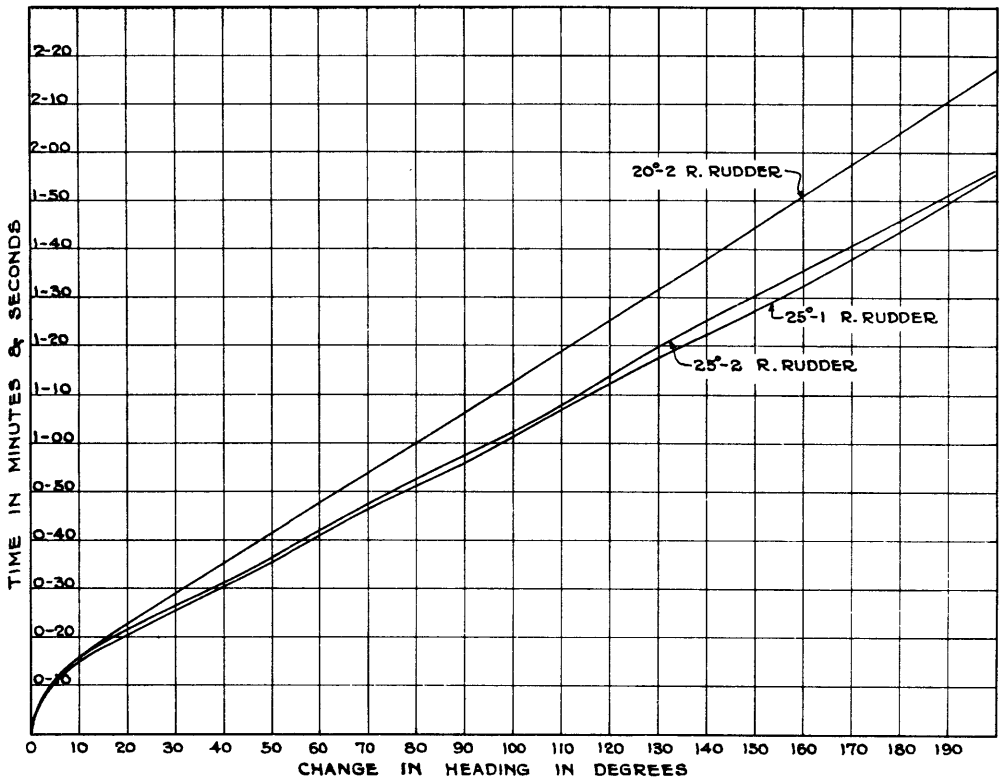


FIG. 50 CHANGE IN HEADING VERSUS TIME, RUDDER C, FOR A SPEED OF 20 KNOTS, RUDDER ANGLES 20 AND 25 DEGREES

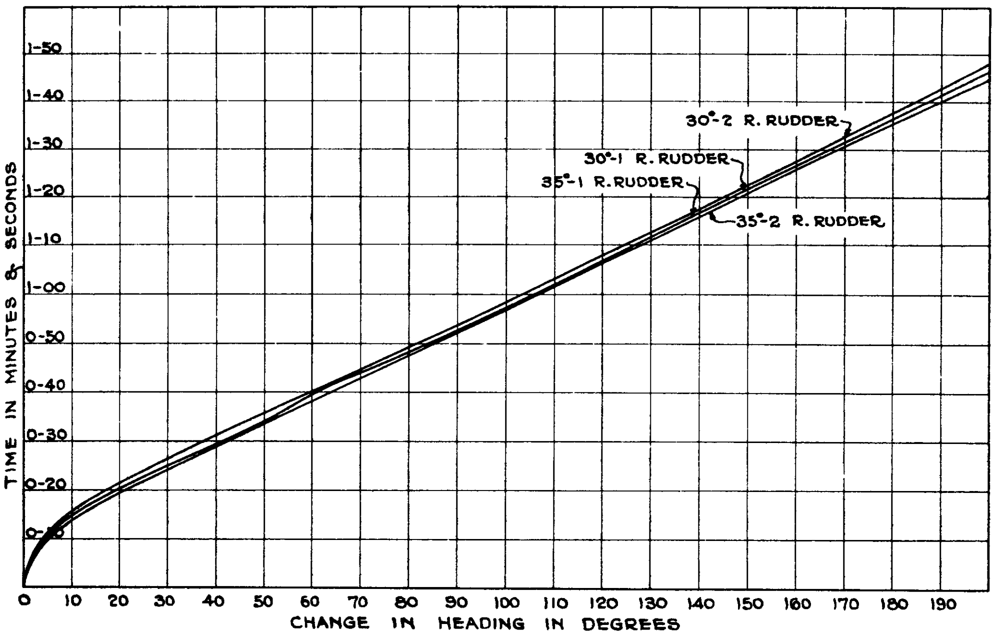


FIG. 51 CHANGE IN HEADING VERSUS TIME, RUDDER C, FOR A SPEED OF 20 KNOTS, RUDDER ANGLES 30 AND 35 DEGREES

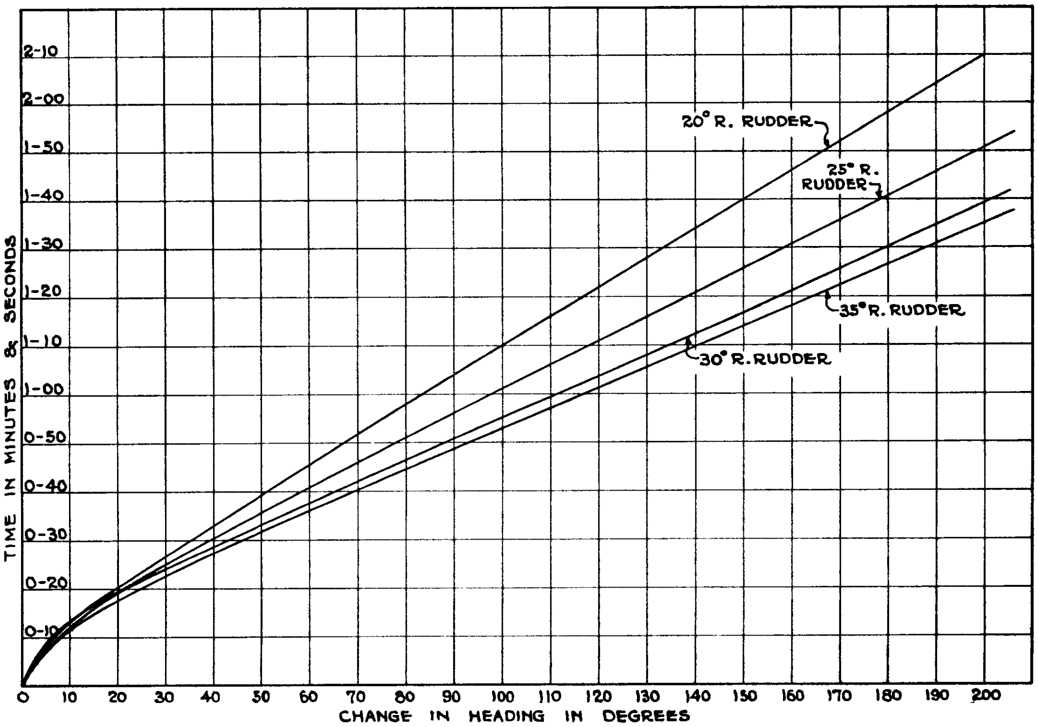


FIG. 52 CHANGE IN HEADING VERSUS TIME, RUDDER C, FOR A SPEED OF 25 KNOTS AND VARIOUS RUDDER ANGLES

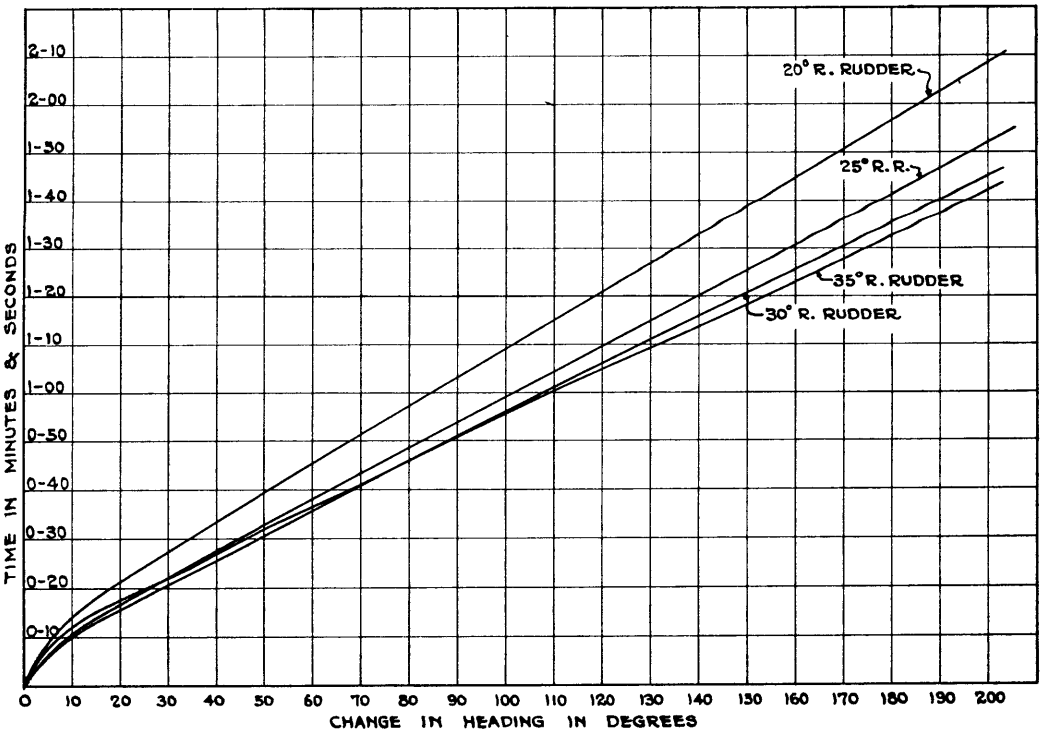


FIG. 53 CHANGE IN HEADING VERSUS TIME, RUDDER C, FOR A SPEED OF 30 KNOTS AND VARIOUS RUDDER ANGLES

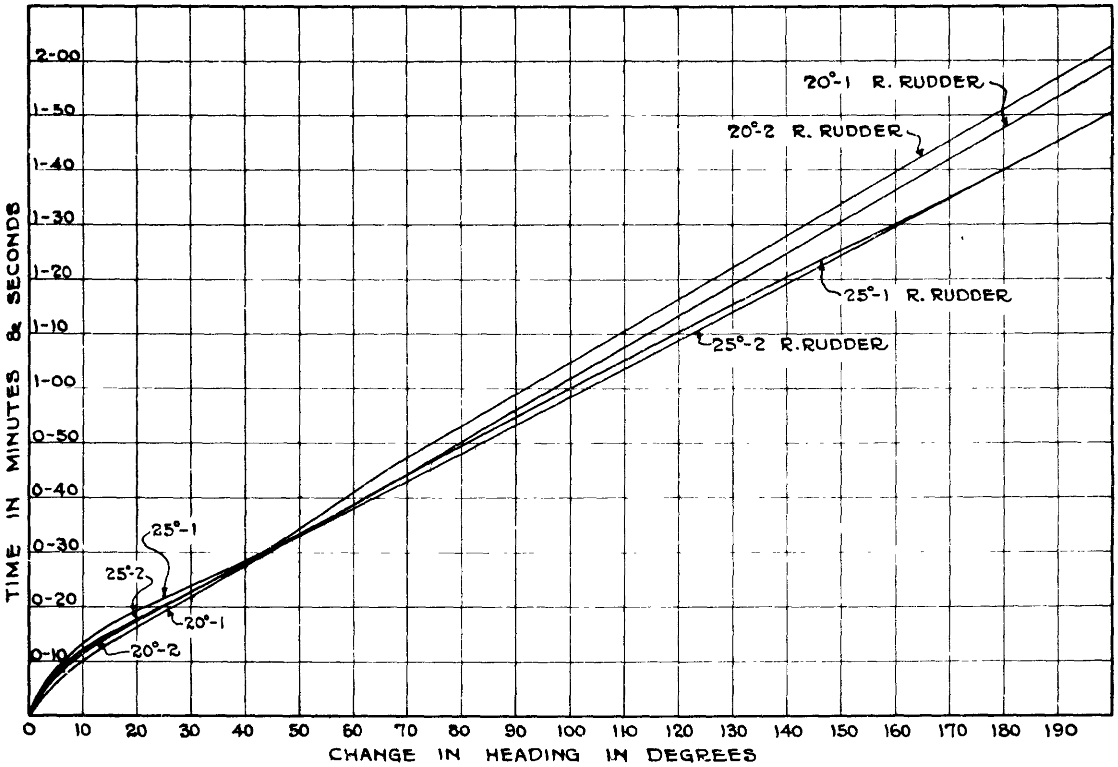


FIG. 54 CHANGE IN HEADING VERSUS TIME, RUDDER C, FOR A SPEED OF 35 KNOTS AND RUDDER ANGLES 20 AND 25 DEGREES

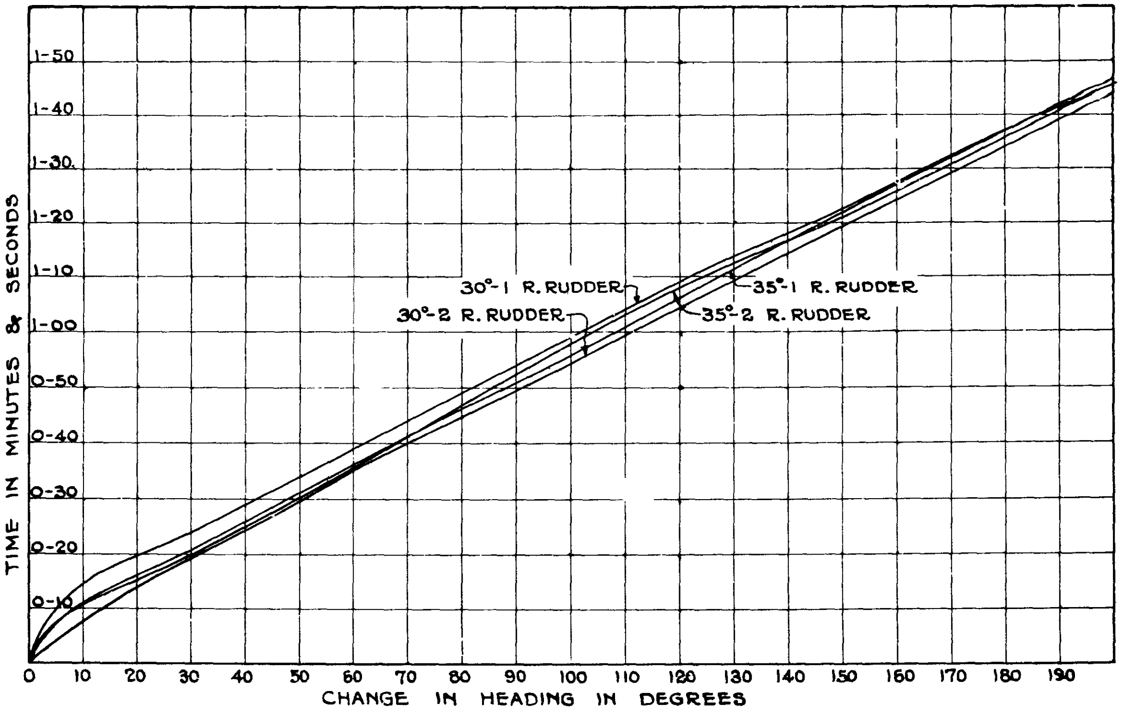


FIG. 55 CHANGE IN HEADING VERSUS TIME, RUDDER C, FOR A SPEED OF 35 KNOTS AND RUDDER ANGLES 30 AND 35 DEGREES

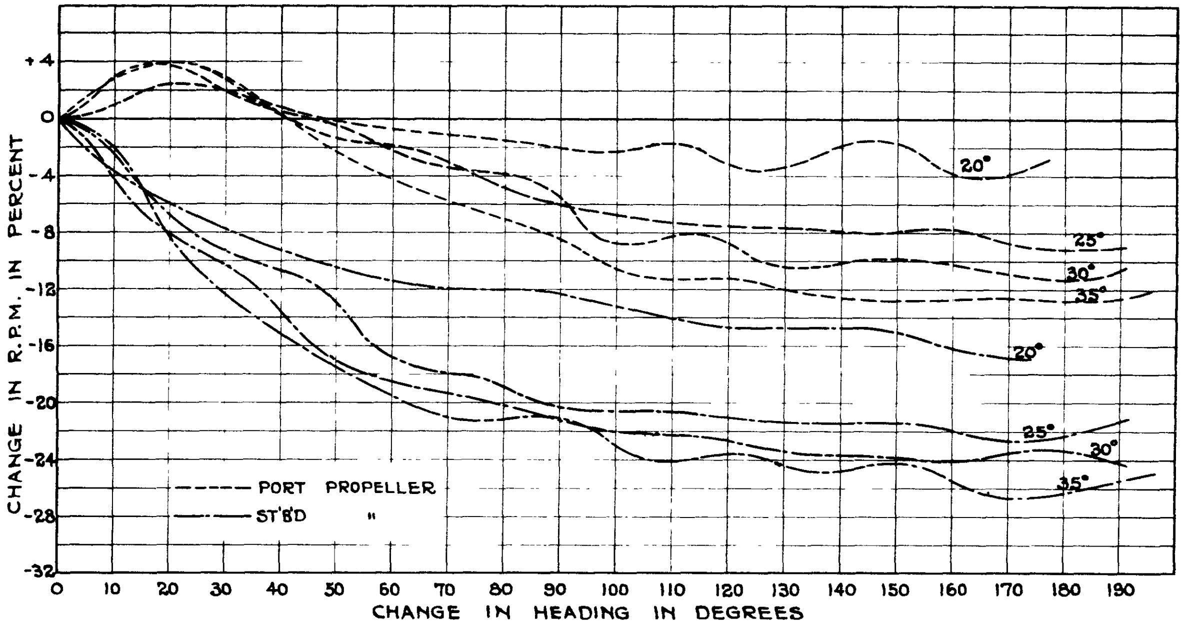


FIG. 56 CHANGE IN RPM IN PER CENT WITH CHANGE IN HEADING, RUDDER C, FOR SPEED 15 KNOTS AND VARIOUS RUDDER ANGLES

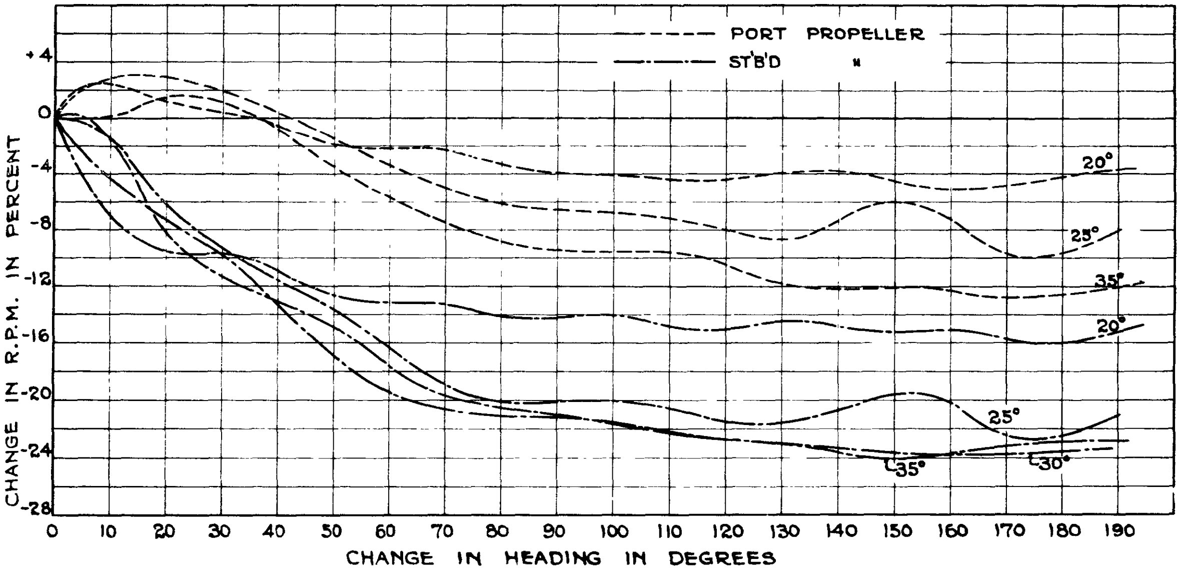


FIG. 57 CHANGE IN RPM IN PER CENT WITH CHANGE IN HEADING, RUDDER C, FOR SPEED 20 KNOTS AND VARIOUS RUDDER ANGLES

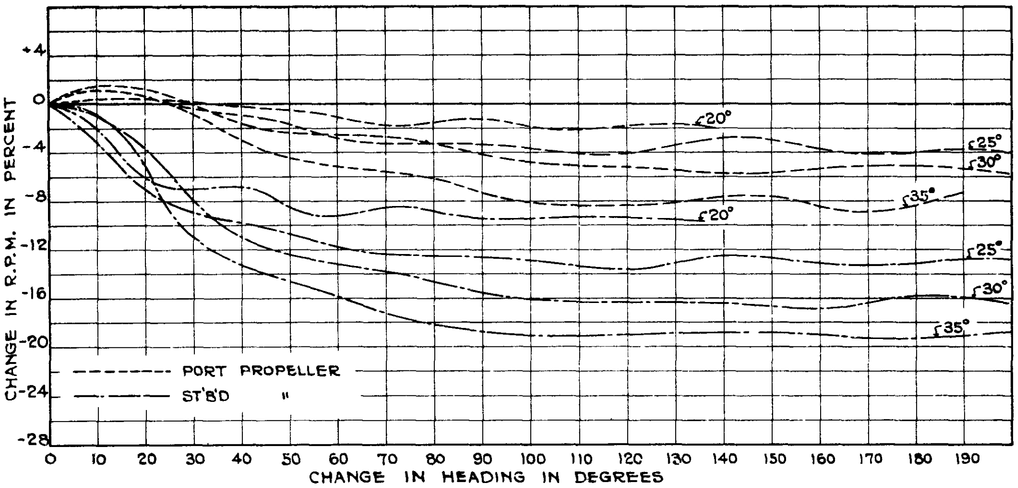


FIG. 58 CHANGE IN RPM IN PER CENT WITH CHANGE IN HEADING, RUDDER C, FOR SPEED 25 KNOTS AND VARIOUS RUDDER ANGLES

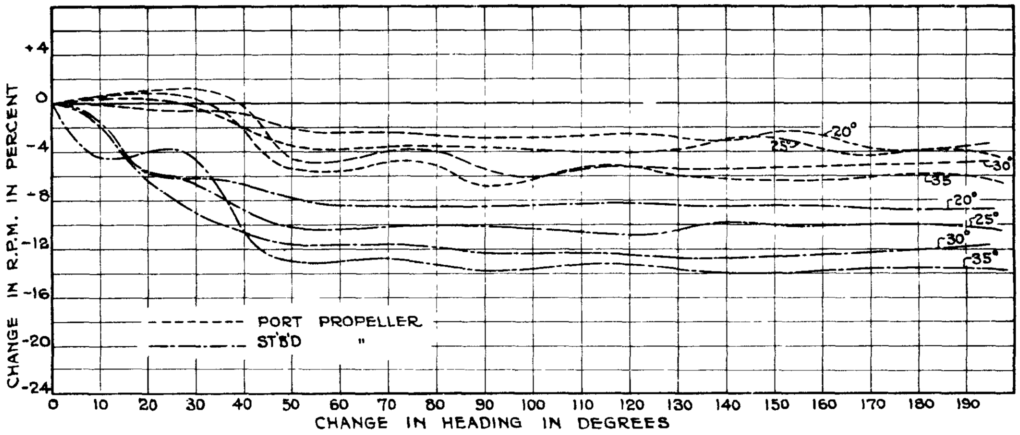


FIG. 59 CHANGE IN RPM IN PER CENT WITH CHANGE IN HEADING, RUDDER C, FOR SPEED 30 KNOTS AND VARIOUS RUDDER ANGLES

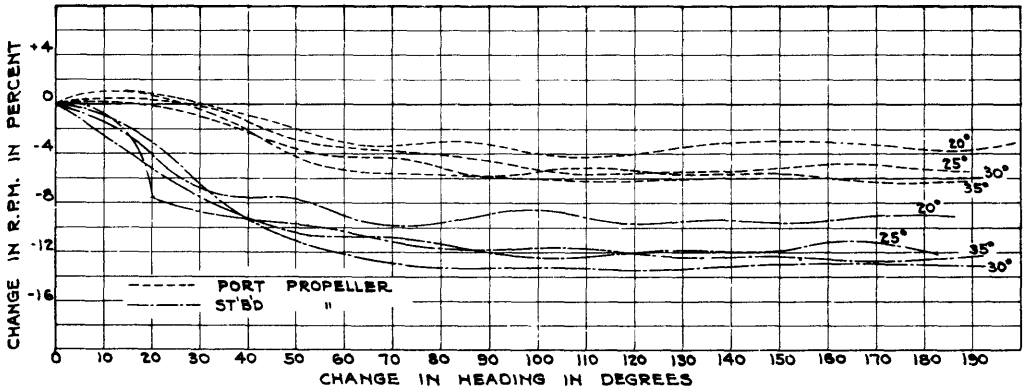


FIG. 60 CHANGE IN RPM IN PER CENT WITH CHANGE IN HEADING, RUDDER C, FOR SPEED 35 KNOTS AND VARIOUS RUDDER ANGLES

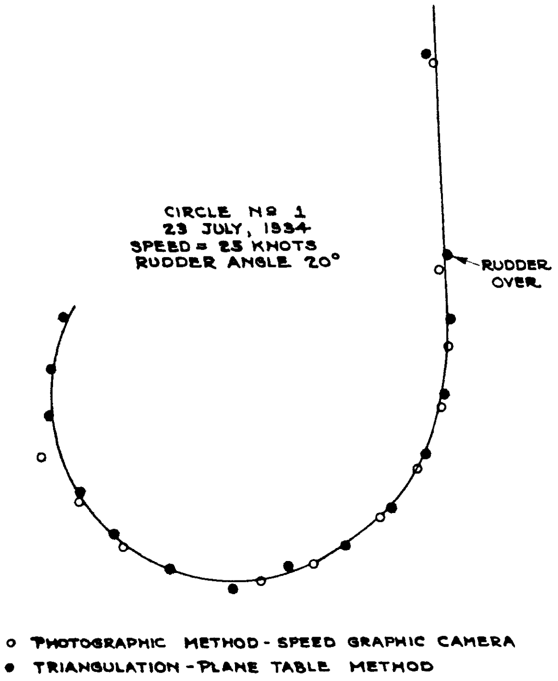


FIG. 61

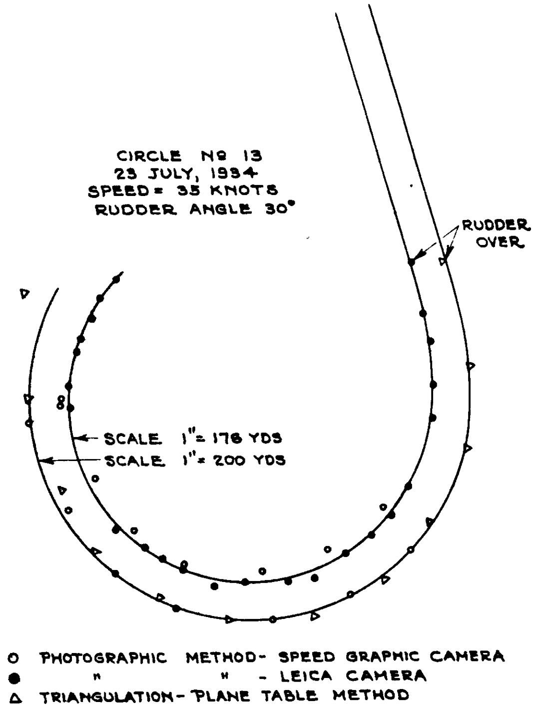


FIG. 62

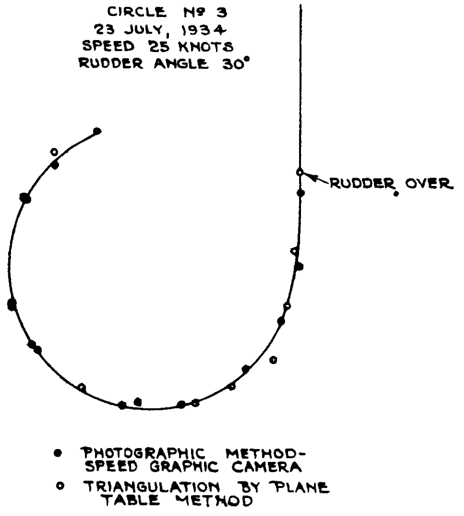


FIG. 63

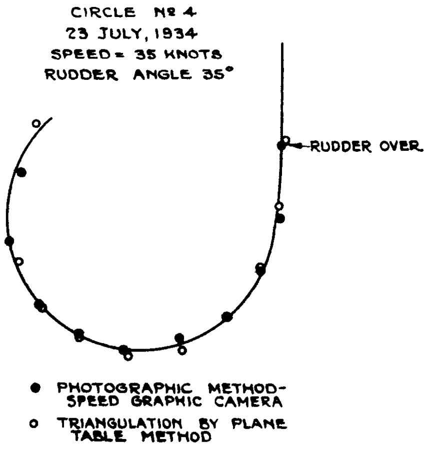


FIG. 64

FIGS. 61–64 TURNING PATHS, RUDDER C, SHOWING COMPARISON OF DATA OBSERVED BY VISUAL AND PHOTOGRAPHIC METHODS

Figs. 44–47 reveal that an inward heel results as soon as the rudder is moved, followed by an outward heel.

Figs. 56–60, which show the percentage changes in RPMs with heading, indicate that the RPM increase for the outboard propeller is confined to a minor percentage for a small fraction of turn following which the RPMs for this propeller decrease for the remainder of the turn. For the inboard propeller, the RPMs decrease. For a given rudder angle, increasing speed causes the percentage change to decrease, while for a given speed, the percentage change increases with rudder angle.

C. Maneuverability Trials.

C–1. Results.

Figs. 65–70 give the results for the maneuverability trials underway.

Figs. 71 and 72 give the results for the maneuverability trials from at rest.

C–2. Discussion.

It had been originally planned to observe the change in heading with time from the record of the course recorder. Because of the slow rate of paper feed on the instrument, the records resulting from the maneuverability trials of 18 July 1934 were found so confused that no analysis was possible. Efforts to make visual

FIGS. 65 AND 66 MANEUVERABILITY TRIALS UNDERWAY, RUDDER C, CHANGE IN HEADING VERSUS TIME

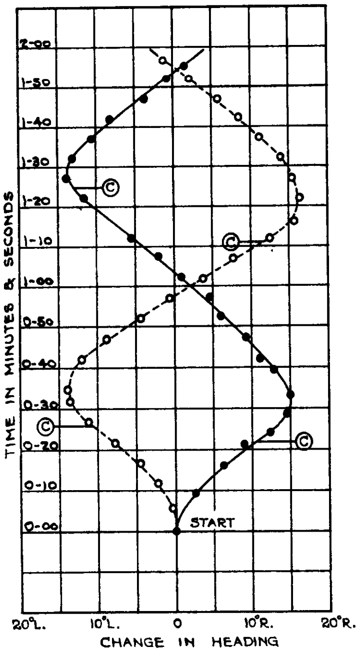


FIG. 65 RUDDER ANGLE 10 DEGREES. SPEED 20 KNOTS

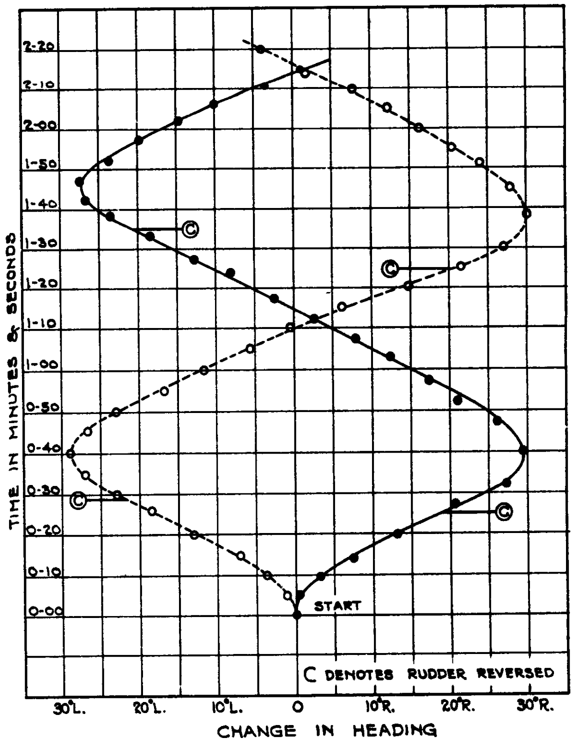


FIG. 66 RUDDER ANGLE 15 DEGREES. SPEED 20 KNOTS

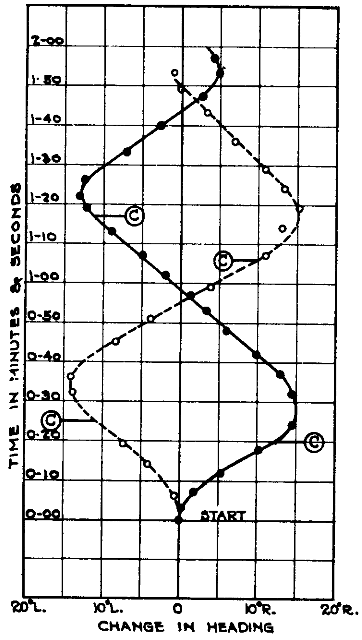


FIG. 67 RUDDER ANGLE 10 DEGREES.
SPEED 24 KNOTS

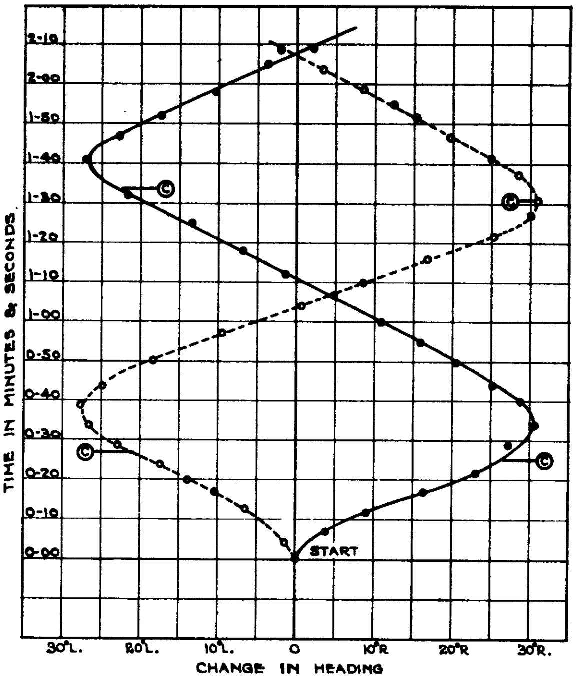


FIG. 68 RUDDER ANGLE 15 DEGREES.
SPEED 24 KNOTS

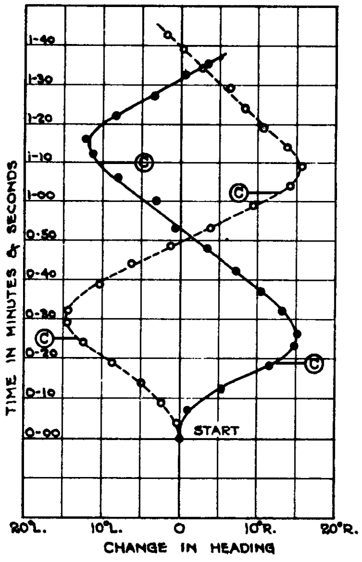


FIG. 69 RUDDER ANGLE 10 DEGREES.
SPEED 28 KNOTS

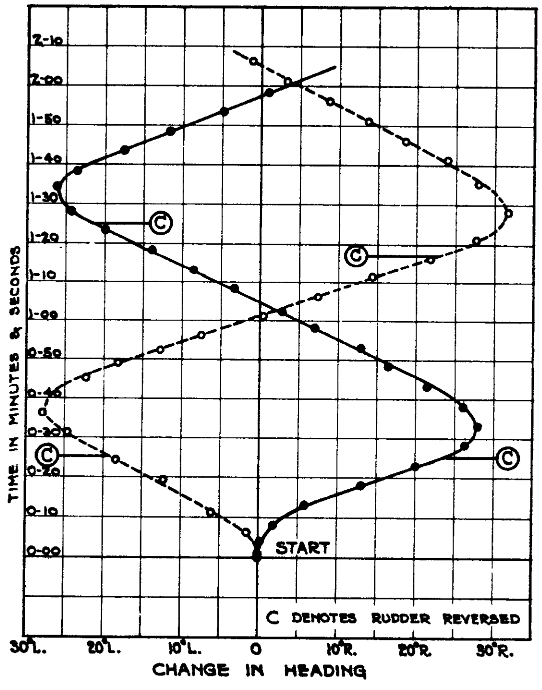


FIG. 70 RUDDER ANGLE 15 DEGREES.
SPEED 28 KNOTS

FIGS. 67-70 MANEUVERABILITY TRIALS UNDERWAY, RUDDER C, CHANGE IN HEADING VERSUS TIME

FIGS. 71 AND 72 MANEUVERABILITY TRIALS FROM AT REST. CHANGE IN HEADING VERSUS TIME

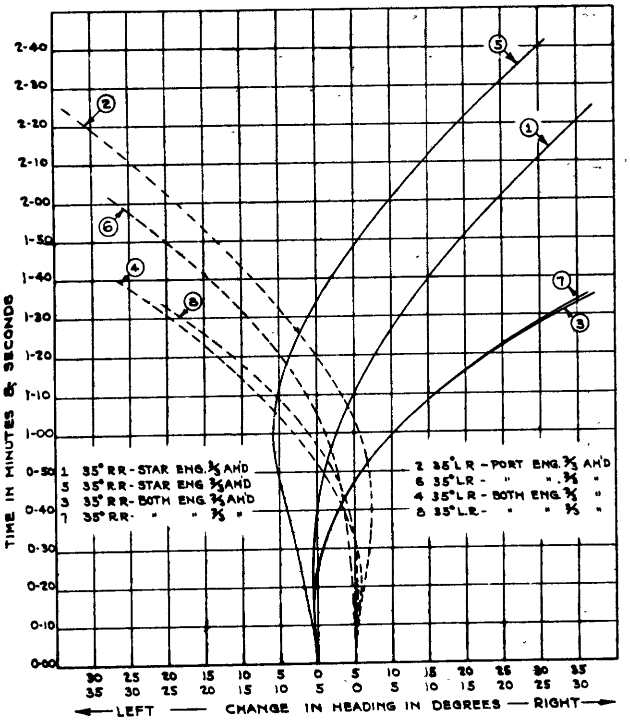


FIG. 71

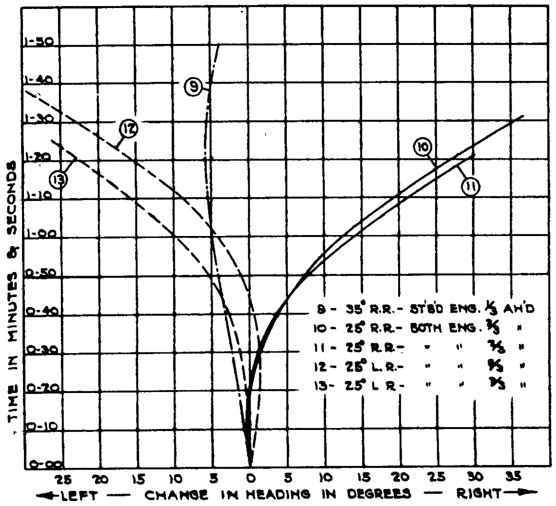


FIG. 72

observations were not successful because of the rapidity of change in heading. Accordingly, a watch was secured to the face of a gyro compass repeater. Then at 5 second intervals of time, photographs were made of the repeater face. In this manner it was possible to correlate time with heading. As the method proved feasible, the maneuverability trials were repeated on 23 July 1934 using the above photographic method.

As regards rudder response while underway, this type of maneuverability trial offers a ready measure for comparing the time necessary to complete a definite maneuver. Hence, further discussion will be deferred pending the results with rudder A.

Passing to the maneuverability trials from at rest, the same difficulty encountered in identifying the chosen landmarks in the turning circle negatives were also experienced in the negatives of these trials. However, visual observations were made of changes in heading with time so that some data resulted.

D. Directional Stability Trials.

D-1. General.

The data for these trials observed during 18 July 1934 could not be utilized for reasons similar to those stated for the maneuverability trials underway held at the same time. As no opportunity was available for repeating this work, these trials were discontinued.

SECTION III
FULL SCALE TRIALS - RUDDER A

CHANGE IN PROCEDURE.

Because of various difficulties experienced during the first set of trials, it was found necessary to effect certain changes in procedure. These changes, together with the reasons therefor, are given herewith.

(a) Considerable difficulty was experienced in matching and correlating the observations made with the two plane tables. Some of this difficulty arose from the indefiniteness in determining the center on the record sheet - this center being essential for fixing the different observed bearings. It also developed that the observers had difficulty in rotating and holding the instrument trained on the vessel during the turn.

Because of these factors, a new type plane table was developed. The chief features of this design were: (a) Offsetting and raising the pivot of the telescope and recording arm such that the record sheet could be secured beneath this point without the necessity of puncturing the sheet. (b) Increasing the possible range of bearings from approximately 110 degrees in the old design to approximately 220 degrees in the new. (c) Improving the mechanical construction for rotating and holding the telescope and recording arm trained on the vessel.

Whereas but two plane tables were used in the first series of trials, three plane tables were provided for this series of trials. These were located at Owls Head Light, Breakwater Light, and point P (north of Jameson Point) as given in Fig. 24.

(b) Though the photographic method had demonstrated its practicability, there were conditions of background, light, and haze that made the complete success of this method doubtful. Because of the manifold advantages of a photographic record, it did not seem wise to discard photography. Since the difficulties encountered resulted solely from conditions relative to the ship, it occurred that placing the small cameras on shore would, in the majority of cases, overcome these difficulties.

Having the cameras located on board provides a greater degrees of control. Placing the cameras on the shore serves to complicate the questions of control and correlation of observations. Despite these disadvantages, it was decided to place two cameras on shore.

When viewed from shore the contrast between ship and background is good. As an objective, the ship is ideal because of its size and contrast against the sky as a background. Lastly, the probability of encountering objectionable haze is more remote when photographing from shore than when photographing from the vessel. Incidentally, by establishing the shore photographic station close and adjacent to the plane table station, a greater degree of coordination between the two methods can be obtained. The disadvantage to this arrangement is lack of instant communication between shore and ship. However, by a simple set of signals much of this disadvantage can be obviated.

Placing cameras on shore presented another advantage. A flash from the ship searchlight was used as a signal for the shore parties to make an observation. If, then, a photograph was made on the flash, this would be shown in the negative. As a watch was in the field of the camera, the interval between flashes, as received, and as recorded could be used for checking against the intervals as sent. This would prove a practical method of correlating the various observations.

A complete description of the method and procedure is given in Appendix 4.

Though complete success had not been attained with the photographic method employed during the trials of rudder C, this method did possess many inherent advantages. For this reason, this same method was reemployed for these trials with the exception that a 5 x 7 Fairchild aerial camera, having an angle of view of about 60 degrees, was used in lieu of the miniature Leica camera. The procedure and details for this method are similar to those given in Appendix 2 and Appendix 3.

Outside of these major changes, the procedure during the trials with the "A" rudder was similar to that employed with the "C" rudder.

HISTORY OF OPERATIONS.

23 August 1934

Departed from Boston at 1030 and proceeded directly to Rockland, Me. arriving at 1830.

24 August 1934

Underway at 0630. Dragged shafts for torsionmeter zeros. Commenced standardization at 0722. Completed nine runs. During the tenth run, a casualty to the steering gear caused the vessel to sheer off the course. Stopped to effect temporary repairs, and then proceeded to anchorage. Partly cloudy, sea smooth. True wind northwest, force 1 Beaufort Scale.

25 August 1934

Underway at 0910. Dragged shafts for torsionmeter zeros. Commenced standardization at 0953. Completed eleven runs. At the start of the twelfth run, casualties to steering gear and main feed pump caused the vessel to return to anchorage for repairs. Sky clear, sea smooth. True wind, northwest, force 2 Beaufort Scale.

26 August 1934

As this was Sunday, the vessel remained at anchor.

27 August 1934

Underway at 0530. Stood out to turning area. At 0640 started turning circles. Eight circles at 15 knots completed at 0849. Continuing made eight circles at 20 knots, completed at 1038, eight circles at 30 knots, completed at 1322, and eight circles at 36 knots, completed at 1458. Proceeded directly to standardization course and made four runs, two at 33 and two at 36 knots, completed at 1544. Dragged shafts for torsionmeter zeros, and then proceeded to anchorage. Sky clear, sea smooth. True wind, northwest, force 2-3 Beaufort Scale.

28 August 1934

Underway at 0530. Proceeded to area 500 yards eastward of Rockland Breakwater for maneuverability trials from at rest. Started at 0556, made twelve runs, six at 1/3 and six at 2/3 speed with various rudder angles. Completed at 0746. Sky overcast, sea smooth. True wind, north, force 2 Beaufort scale. Wind freshening, sea becoming choppy. Stood out to turning area and made eight circles at 25 knots, completed at 0954. Hove to and took aboard shore observing parties. Underway for Boston, Mass. Enroute conducted maneuverability trials. Arrived Boston Navy Yard at 1900.

RESULTS AND DISCUSSION.

A. Standardization Trials.

A-1. Results.

The results of the standardization trials of 24, 25 and 27 August 1934 corrected to a basis of standard conditions are given in Table 10. These values have been used for plotting the curves of Fig. 73. Table 11 gives a comparison of trial and model results. From this table it is found that the trial RPMs are on the average 2.5 per cent low, and the trial SHPs 4.8 per cent low in comparison to corresponding model predictions.

A-2. Discussion.

Fig. 74 gives, for each propeller, curves of torque coefficients, corrected for wind effect, plotted against apparent slip ratio. For sake of reference and comparison, the curves given in Fig. 26 have been included. As regards the starboard propeller, there is fair agreement between the curves of various dates. The July curve is somewhat out of harmony with those of May and August. This may be attributed to the progressive erosion of the propeller blades in July and their repair just prior to the August trials. For the port propeller there is a more pro-

TABLE 10

U.S.S. FARRAGUT
RESULTS OF STANDARDIZATION TRIALS OF 24, 25 AND 27 AUG. 1934
CORRECTED TO A BASIS OF STANDARD CONDITIONS

	STARBOARD		PORT		TOTAL		
RUN NO.	RPM	SHP	RPM	SHP	SPEED	RPM	SHP
1S	192.2	2,380	192.1	2,710	20.33	192.15	5,090
2N	191.1	2,400	190.4	2,500	20.19	190.75	4,900
3S	240.8	4,570	239.2	5,390	24.39	240.0	9,960
4N	241.7	5,150	240.1	5,300	24.48	240.9	10,450
5S	293.3	9,240	293.5	10,520	28.54	293.4	19,760
6N	296.6	10,350	296.6	11,200	28.85	296.6	21,550
7S	317.9	12,800	317.6	11,780	30.89	317.75	24,580
8N	317.1	11,860	317.0	11,980	30.82	317.05	23,840
1S	191.2	2,360	191.3	2,690	20.21	191.25	5,050
2N	190.5	2,340	190.4	2,620	20.16	190.45	4,960
3S	240.0	5,160	237.5	5,500	24.36	238.75	10,660
4N	239.0	5,100	237.3	5,510	24.31	238.15	10,610
5S	297.3	10,340	297.3	11,680	29.00	297.3	22,020
6N	294.3	9,780	295.0	11,230	28.87	294	21,010
8N	317.0	12,200	317.8	14,400	30.64	317.4	26,600
9S	317.5	11,700	317.5	14,500	30.92	317.5	26,200
1S	371.7	19,700	365.7	21,150	35.97	368.7	40,850
2N	364.6	18,200	366.1	21,450	35.73	365.35	39,650
3S	351.2	16,100	351.2	19,400	34.44	351.2	35,500
4N	351.0	15,700	350.8	19,300	34.63	350.9	35,000

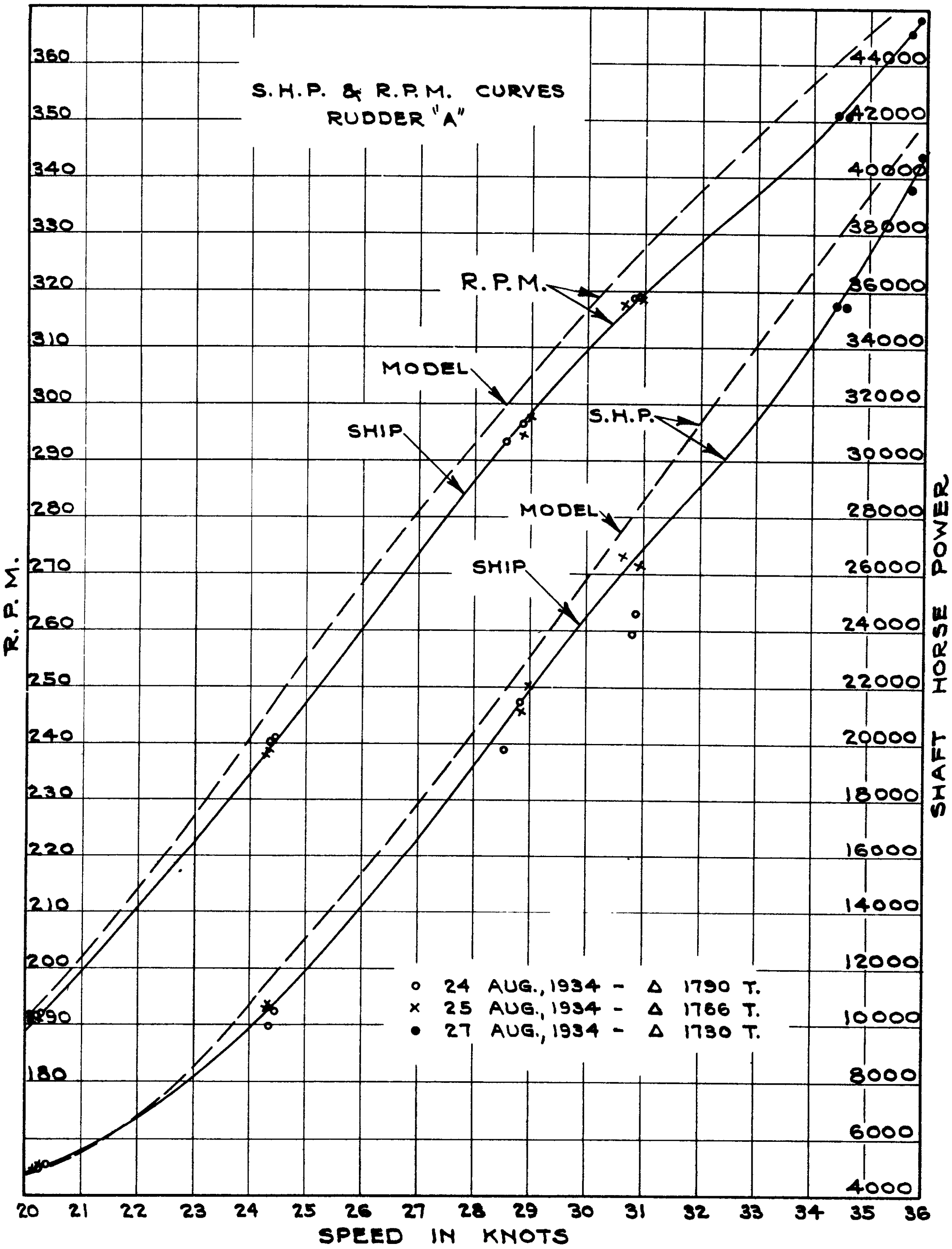


FIG. 73 MODEL - TRIAL COMPARISON, U.S.S. FARRAGUT, STANDARDIZATION TRIALS OF AUGUST 1934

TABLE 11
U.S.S. FARRAGUT
MODEL TRIAL COMPARISON, 24, 25, 27 AUGUST 1934
DIFFERENCES EXPRESSED AS PERCENTAGE OF ACTUAL TO PREDICTED VALUES

SPEED	RPM			SHP		
KNOTS	MODEL	TRIAL	PER-CENT	MODEL	TRIAL	PER-CENT
20	191	189	-1.0	4,700	4,900	+4.3
21	202	199	-1.5	5,500	5,600	+1.8
22	213.5	211	-1.2	6,800	6,800	0
23	226.5	222	-2.0	8,500	8,100	-4.7
24	240.5	234	-2.7	10,600	9,800	-7.5
25	255	247	-3.1	13,000	11,800	-9.2
26	268	260	-3.0	15,300	14,100	-7.8
27	281	273	-2.8	17,800	16,500	-7.3
28	293	286	-2.7	20,400	19,200	-5.9
29	305	298	-2.3	23,000	22,000	-4.4
30	317	309	-2.5	25,800	24,500	-5.0
31	328	319	-2.7	28,500	26,800	-6.0
32	338	328	-3.0	31,200	29,100	-6.7
33	348	337	-3.3	34,000	31,400	-7.6
34	358	346	-3.4	36,700	34,200	-6.8
35	366	357	-2.5	39,400	37,700	-5.6
36	375	368	-1.9	42,200	40,700	-3.6

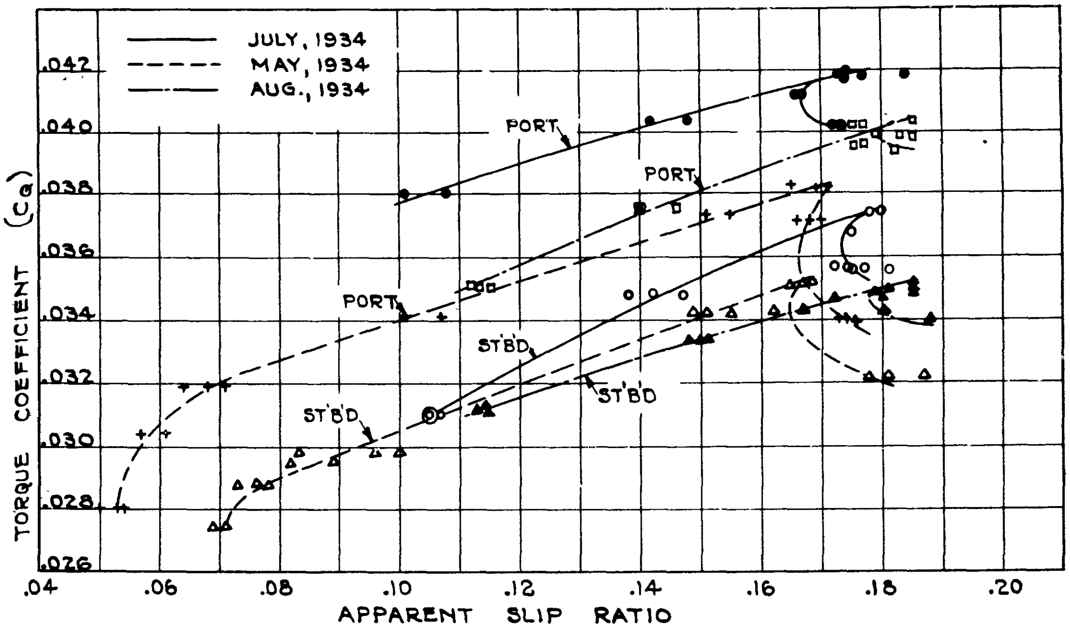


FIG. 74 CURVES OF CORRECTED TORQUE COEFFICIENT VERSUS APPARENT SLIP RATIO. STANDARDIZATION TRIALS OF MAY, JULY, AND AUGUST 1934

nounced lack of agreement in the curves of various dates, the cause being similar to that noted for the starboard propeller.

B. Turning Trials.

B-1. Results.

Table 12 gives a comparison of the observed tactical diameter by plane table and by photographic method, together with other pertinent data for each turn held 27 August 1934. Similar data are given in Table 13 for trials of the same data. Table 14 gives data for trials of 28 August.

Fig. 75 gives the curves of tactical diameter, advance, and transfer for rudder A for different rudder angles at various speeds resulting from photographic and plane table observations.

Figs. 76-80 give the angles of heel observed photographically for different rudder angles at various speeds.

Figs. 81-85 give the changes in heading versus time for the different rudder

TABLE 12

U.S.S. FARRAGUT

COMPARISON OF TACTICAL DIAMETER OBSERVATIONS, 27 AUG. 1934

BY PLANE TABLE AND PHOTOGRAPHIC METHOD

SHIP EQUIPPED WITH RUDDER A

RUN NO.	RPM AVE	SPEED KNOTS	RUDDER ANGLE DEGREES	RATE OF RUDDER IN SECS.	TACT. DIA. IN YDS. BY PLANE TABLE	TACT. DIA. IN YDS. BY PHOTO.
1			20	10		860
2	140.1	15.3	20	11	896	876
3	138.2	15.0	25	17	764	756
4	133.8	14.6	25 1/2	13	760	756
5	136.4	14.8	30 1/2	15	634	638
6	139.5	15.1	30	16	610	606
7	134.0	14.6	34 1/2	19	560	560
8	135.7	14.8	34 1/2	19	570	548
9	186.5	19.7	20	11	920	906
10	190.6	20.2	20	11	928	934
11	186.8	19.7	25	13		734
12	186.1	19.7	24 1/2	14	732	736
13	188.5	20.0	30	17	624	604
14	188.5	20.0	30	14	632	618
15	189.6	20.1	35	20	538	546
16	187.5	19.8	35	20	546	542

TABLE 13
U.S.S. FARRAGUT
COMPARISON OF TACTICAL DIAMETER OBSERVATIONS, 27 AUG. 1934
BY PLANE TABLE AND PHOTOGRAPHIC METHOD
SHIP EQUIPPED WITH RUDDER A

RUN NO.	RPM AVE	SPEED KNOTS	RUDDER ANGLE DEGREES	RATED RUDDER IN SECS.	TACTICAL DIA. IN YDS. BY PLANE TABLE	PHOTO.
17	315	30.6	20	14		1,320
18	315	30.6	20	13	1,320	1,340
19						
20	315.3	30.6	24 1/2	14	1,068	1,074
21	315.4	30.5	24 1/2	13	1,078	1,075
22	314.8	30.5	30	15	903	910
23	315.5	30.6	30	15	910	898
24	316.7	30.7	34 1/2	20	806	800
25	312.2	30.2	34 1/2	19	820	816
26	365.8	35.8	20	13	1,406	1,402
27	366.7	35.9	20	10	1,426	1,415
28	363.8	35.6	25	12	1,142	1,145
29	367.7	36.0	25	11	1,146	1,134
30	365.4	35.8	30	16	976	961
31	370.7	36.2	30	16	1,016	976
32	367.1	36.0	34 1/2	20	880	866
33	366.3	35.9	34 1/2	19	862	880

TABLE 14

U.S.S. FARRAGUT

COMPARISON OF TACTICAL DIAMETER OBSERVATIONS, 28 AUG. 1934 BY PLANE TABLE AND PHOTOGRAPHIC METHODS

SHIP EQUIPPED WITH RUDDER A

RUN NO.	RPM AVE	SPEED KNOTS	RUDDER ANGLE DEGREES	RATE OF RUDDER IN SECS.	TACT. DIA. IN YDS. BY PLANE TABLE	PHOTO.
1	244.5	24.7	20	9	714	702
2	247.1	24.9	20 1/2	10	692	704
3	245.1	24.8	24 1/2	11	604	650
4	247.4	25.0	24 1/2	11	622	632
5	246.5	24.9	29 1/2	14	564	556
6	247.4	25.0	29 3/4	14	570	570
7	245.5	24.8	34 3/4	16	500	508
8	244.1	24.7	34 3/4	16	516	526

angles at various speeds.

Figs. 86-90 give the reductions in RPMs for different rudder angles at various speeds.

B-2. Discussion.

A total of 41 circles were made for this series of trials, one circle being lost because of an interference caused by a small boat, the ship sheering to avoid a collision. Of the remaining number, it was impossible to determine the paths of three circles by plane table observations, whereas the photographic methods did not fail. Of these latter methods, a casualty was experienced with the Fairchild aerial camera. During the 27th circle the shutter jammed and no further exposures could be made. No difficulty was experienced with the Leica cameras on shore.

Of the plane table measurements, it was found that the observations made by No. 3 station could not be properly correlated in all cases. Accordingly the data of this station were disregarded where evidences of error were apparent.

In the total of 40 circles, the measurements of tactical diameter by plane table method and by photographic were equal in two cases. In 22 circles, the measurements by plane table exceeded those by photographic by an average of 1.6 per cent, while in 13 cases, the results by plane table were 1.3 per cent low, no comparison being possible in the remaining three cases. Considering the total number for which comparable data were secured, the plane table measurements were, on the average, 0.4 per cent high.

Figs. 91-94 give a comparison of the circles and spots observed by plane table and the two photographic methods for a speed of 30 knots using rudder angles

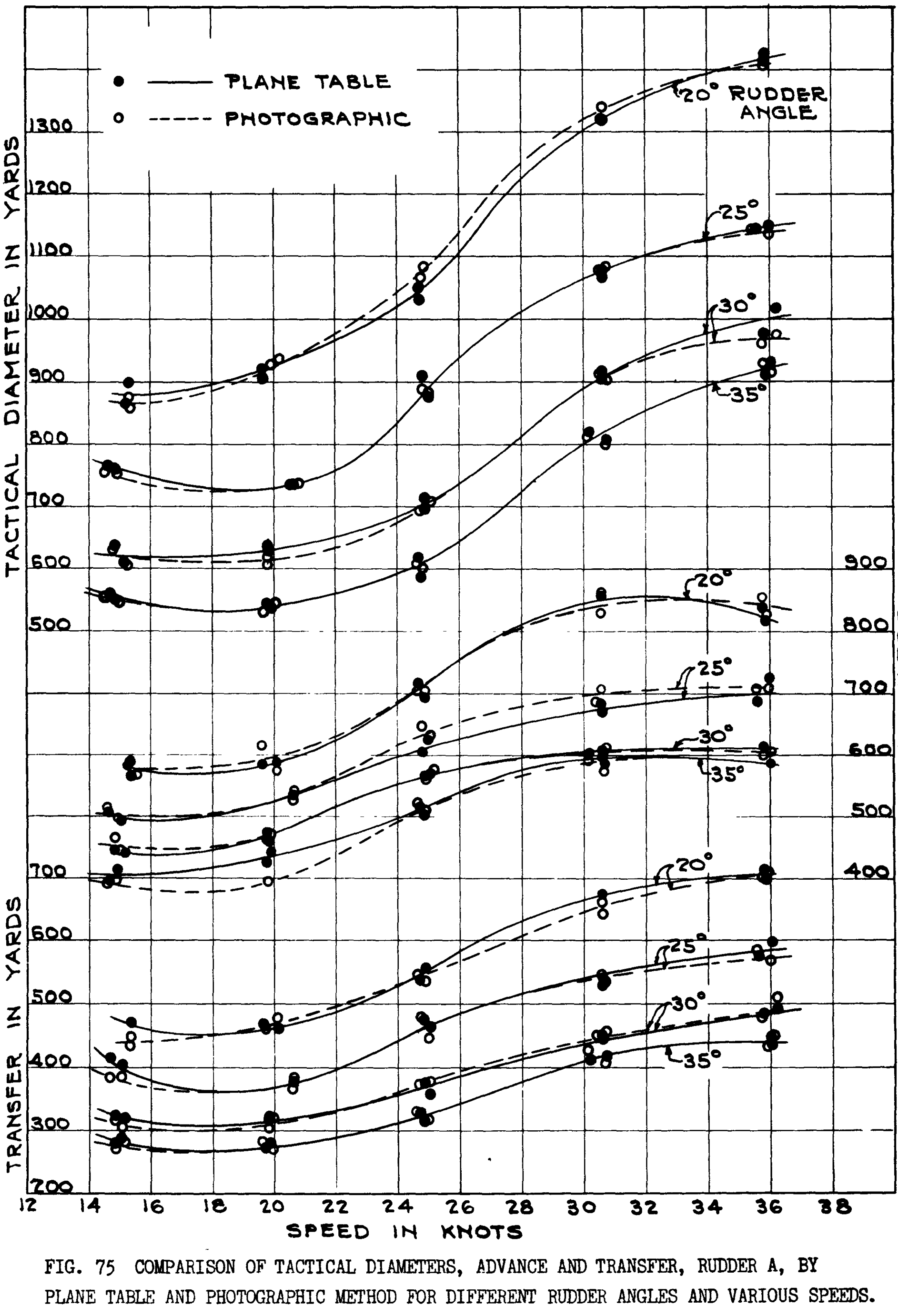


FIG. 75 COMPARISON OF TACTICAL DIAMETERS, ADVANCE AND TRANSFER, RUDDER A, BY PLANE TABLE AND PHOTOGRAPHIC METHOD FOR DIFFERENT RUDDER ANGLES AND VARIOUS SPEEDS. TRIALS OF AUGUST 1934

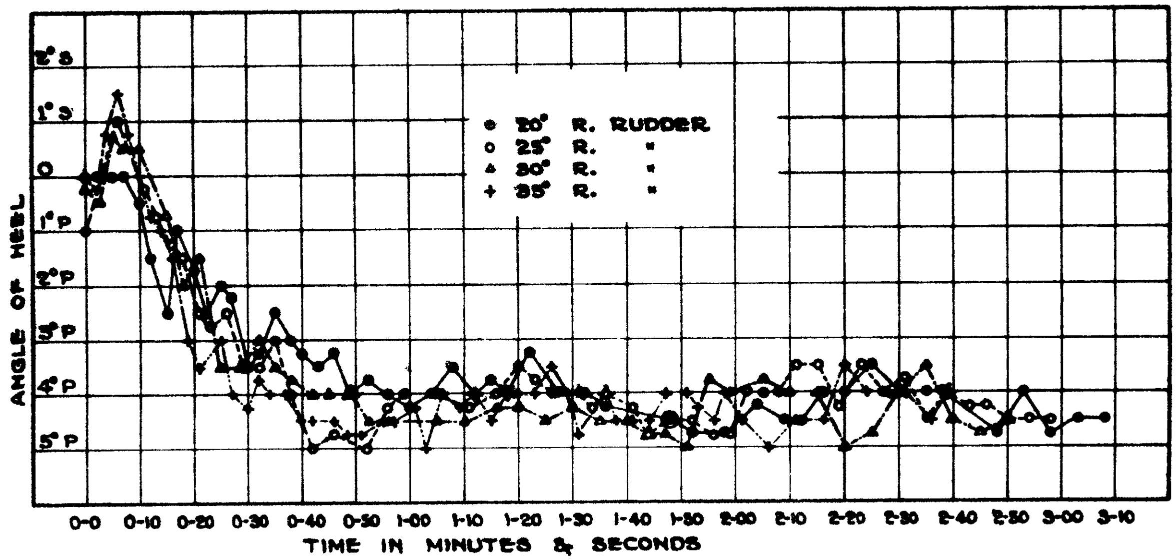


FIG. 76 ANGLES OF HEEL WHILE TURNING, RUDDER A, FOR A SPEED OF 15 KNOTS AND DIFFERENT RUDDER ANGLES

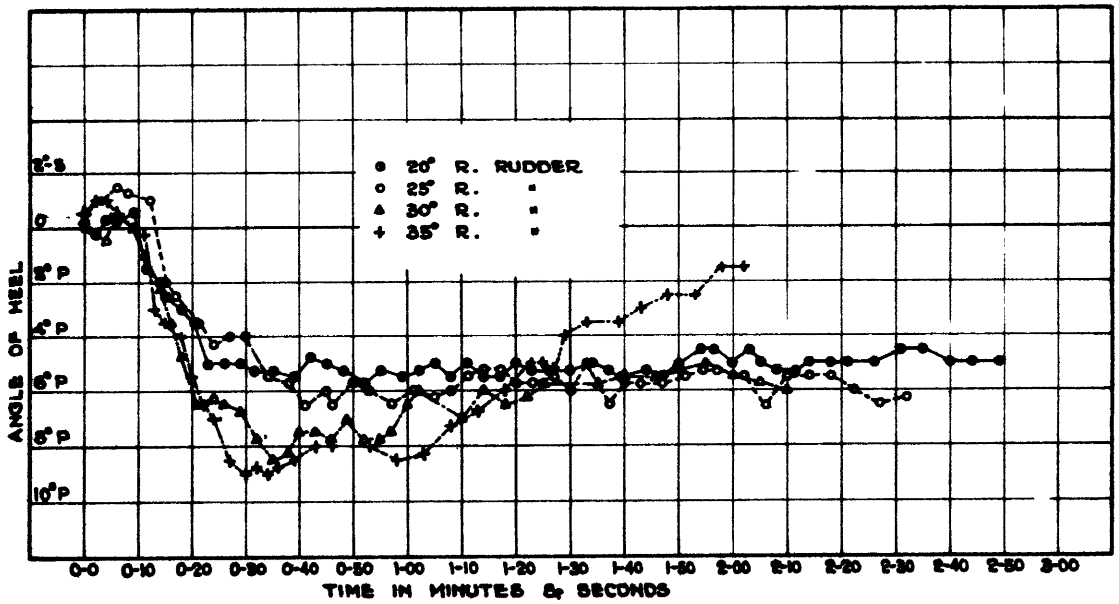


FIG. 77 ANGLES OF HEEL WHILE TURNING, RUDDER A, FOR A SPEED OF 20 KNOTS AND DIFFERENT RUDDER ANGLES

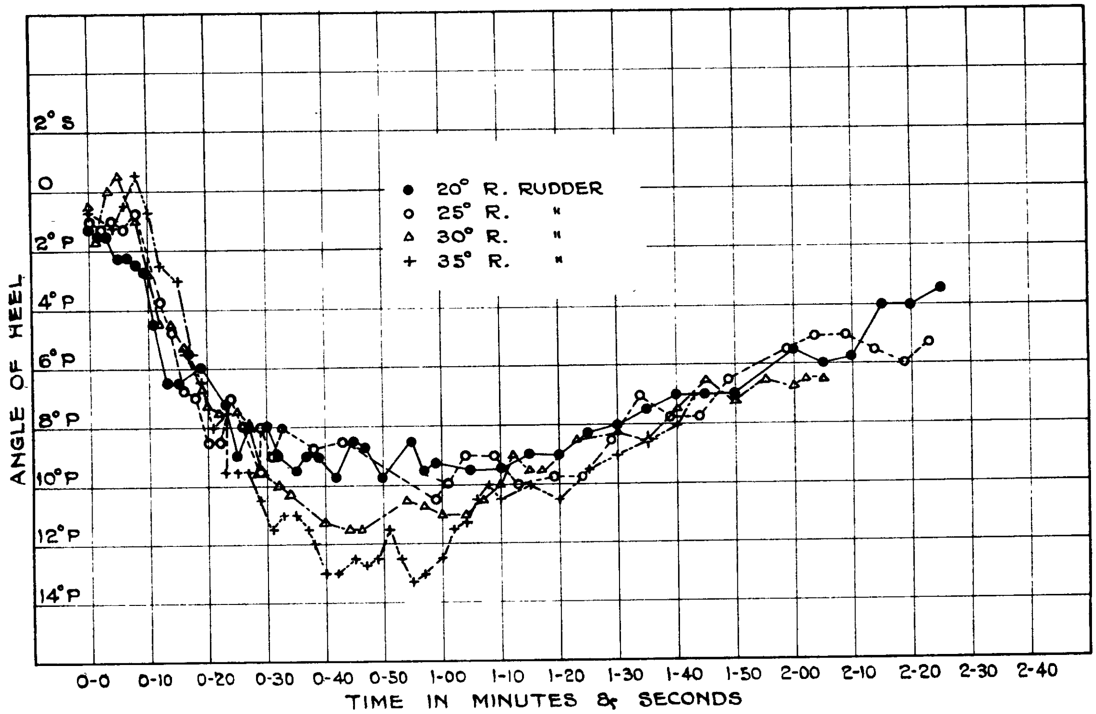


FIG. 78 ANGLES OF HEEL WHILE TURNING, RUDDER A, FOR A SPEED OF 25 KNOTS AND DIFFERENT RUDDER ANGLES

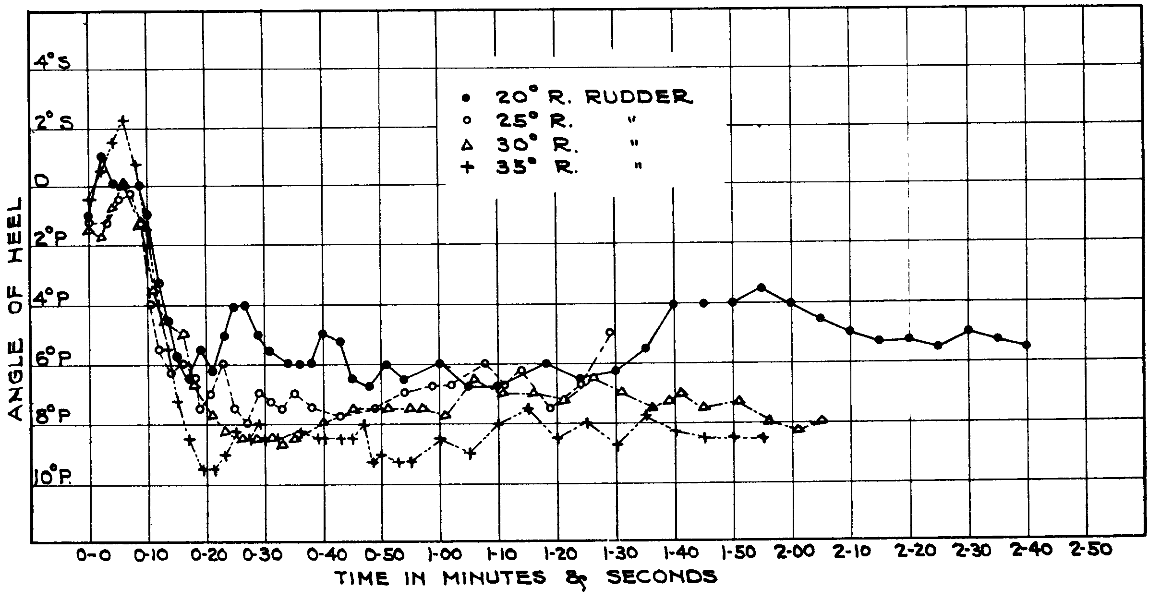


FIG. 79 ANGLES OF HEEL WHILE TURNING, RUDDER A, FOR A SPEED OF 30 KNOTS AND DIFFERENT RUDDER ANGLES

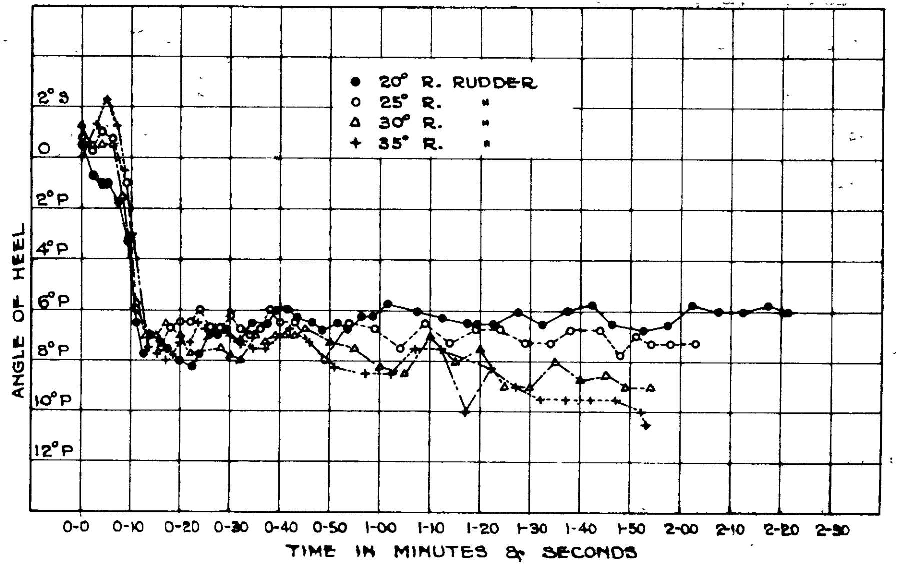


FIG. 80 ANGLES OF HEEL WHILE TURNING, RUDDER A, FOR A SPEED OF 36 KNOTS AND DIFFERENT RUDDER ANGLES

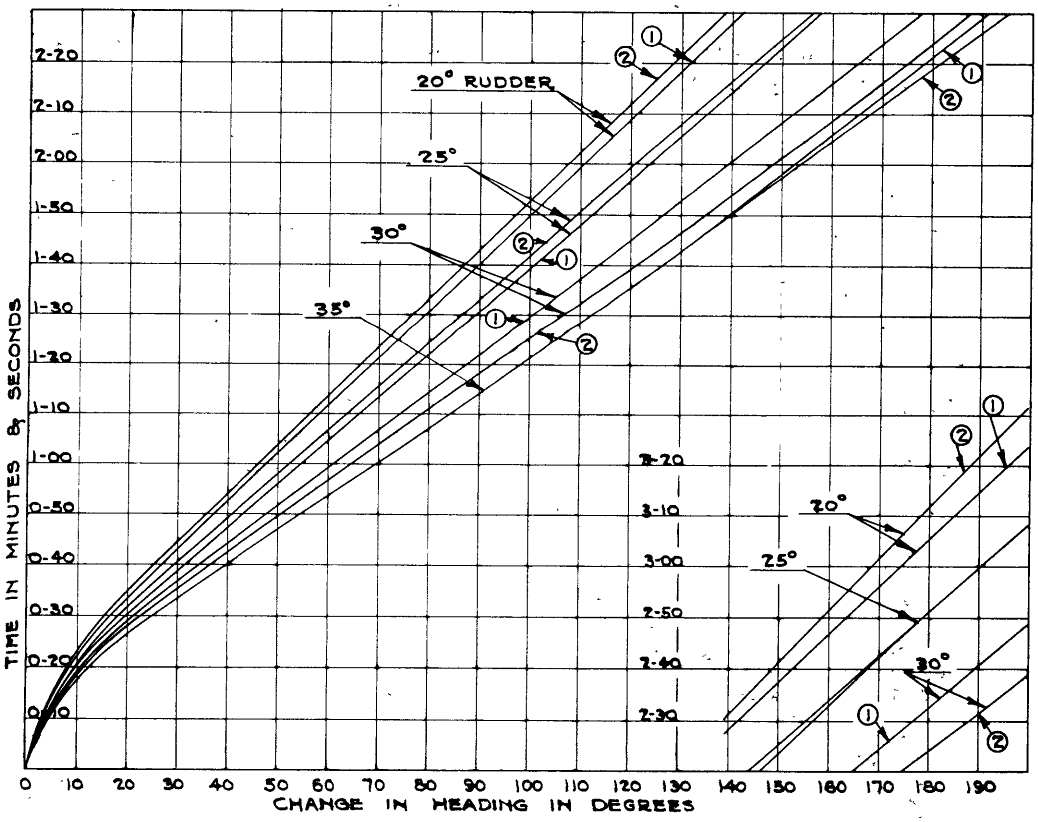


FIG. 81 CHANGE IN HEADING VERSUS TIME, RUDDER A, FOR A SPEED OF 15 KNOTS AND DIFFERENT RUDDER ANGLES

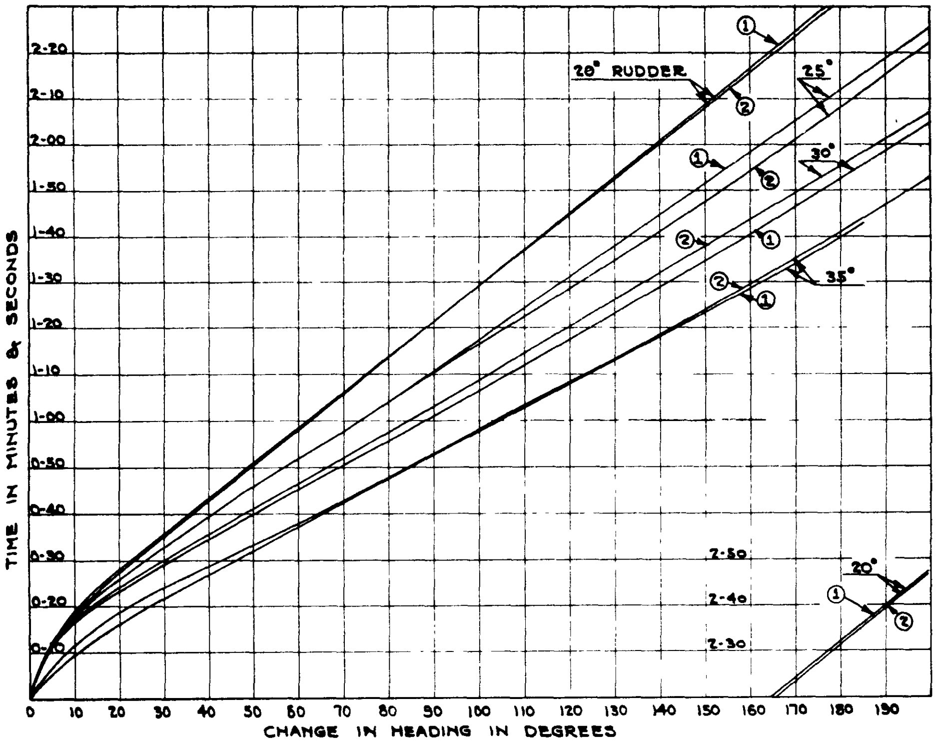


FIG. 82 CHANGE IN HEADING VERSUS TIME, RUDDER A, FOR A SPEED OF 20 KNOTS AND DIFFERENT RUDDER ANGLES

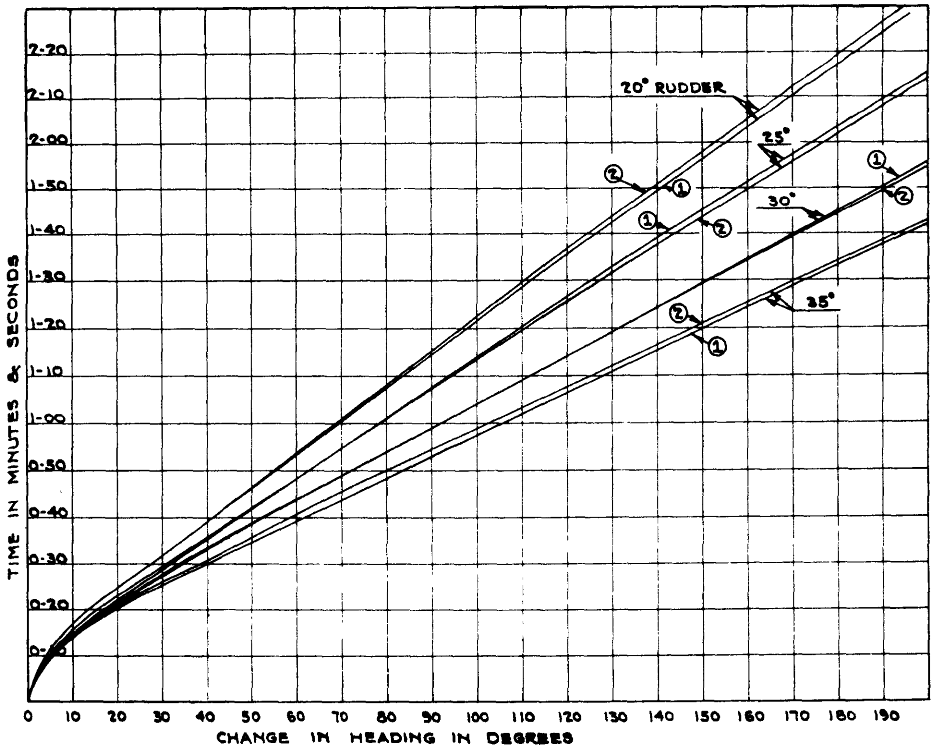


FIG. 83 CHANGE IN HEADING VERSUS TIME, RUDDER A, FOR A SPEED OF 25 KNOTS AND DIFFERENT RUDDER ANGLES

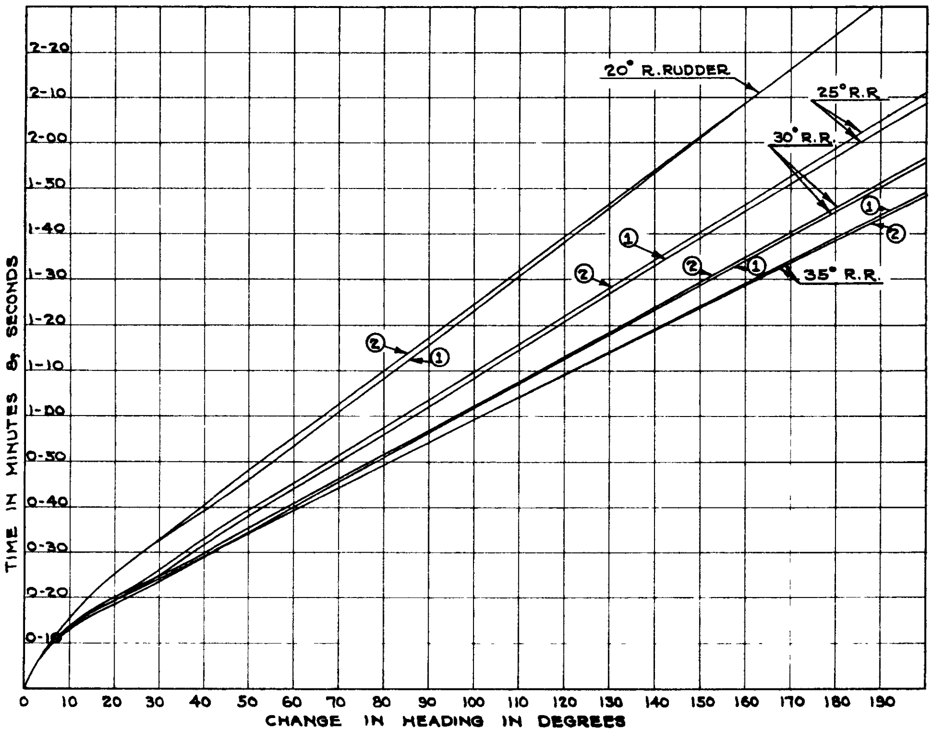


FIG. 84 CHANGE IN HEADING VERSUS TIME, RUDDER A, FOR A SPEED OF 30 KNOTS AND DIFFERENT RUDDER ANGLES

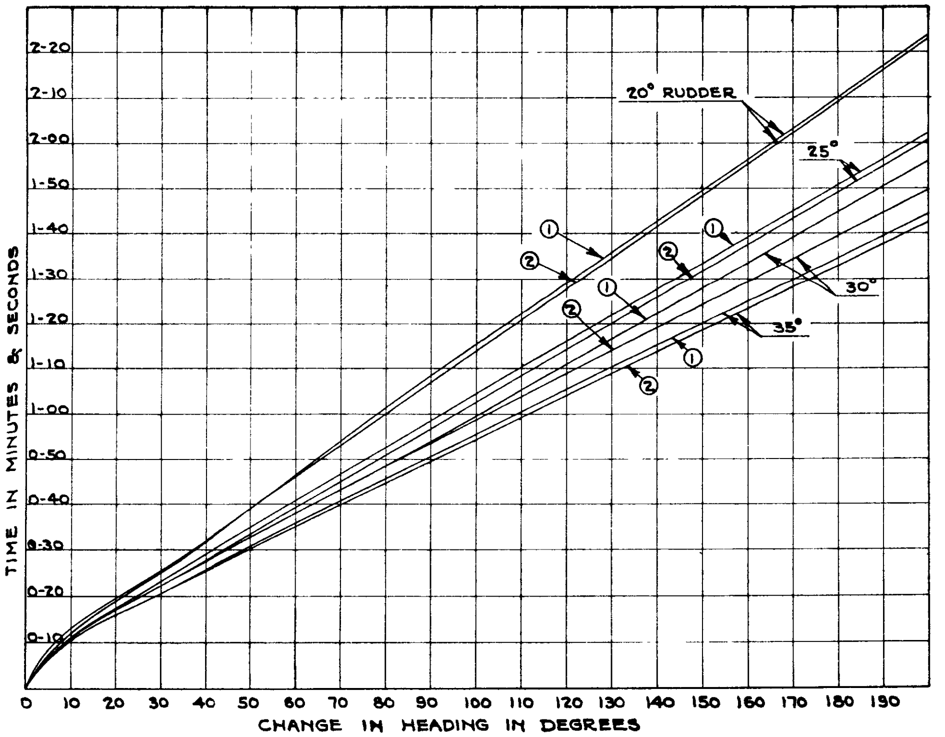


FIG. 85 CHANGE IN HEADING VERSUS TIME, RUDDER A, FOR A SPEED OF 36 KNOTS AND DIFFERENT RUDDER ANGLES

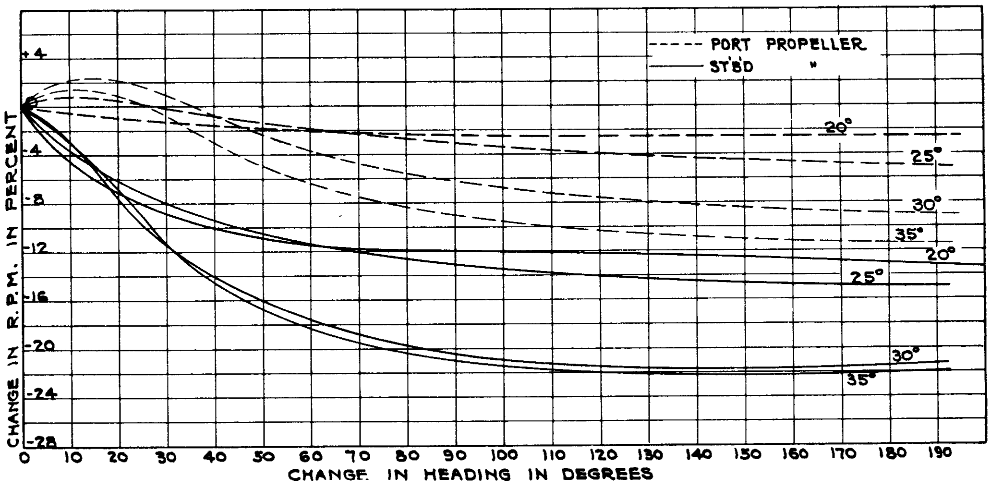


FIG. 86 CHANGE IN RPM IN PER CENT WITH CHANGE IN HEADING, RUDDER A, FOR A SPEED OF 15 KNOTS AND DIFFERENT RUDDER ANGLES

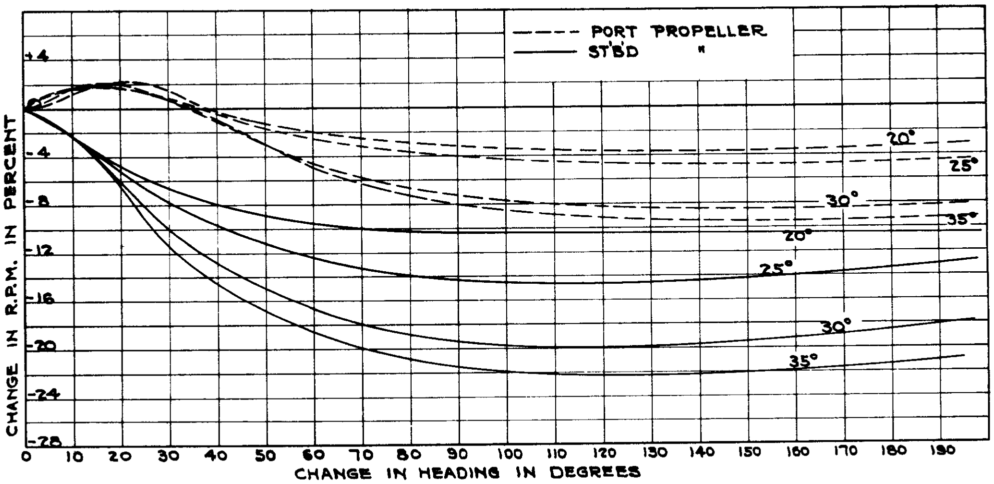


FIG. 87 CHANGE IN RPM IN PER CENT WITH CHANGE IN HEADING, RUDDER A, FOR A SPEED OF 20 KNOTS AND DIFFERENT RUDDER ANGLES

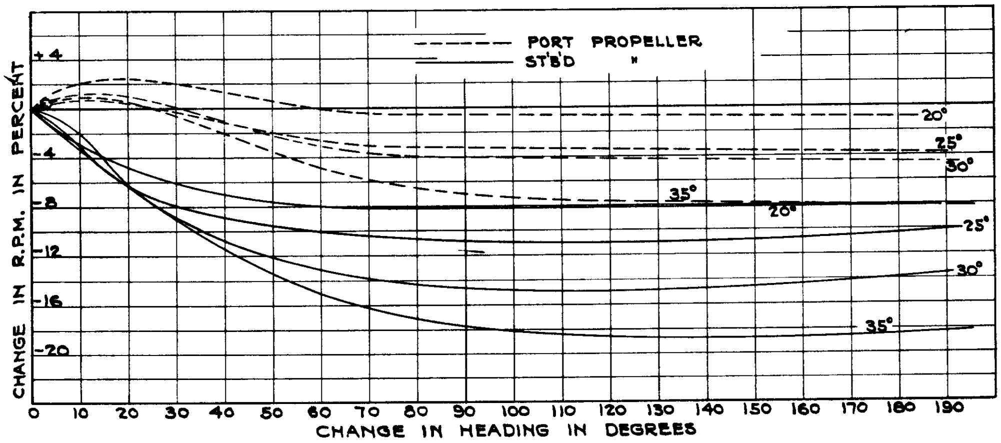


FIG. 88 CHANGE IN RPM IN PER CENT WITH CHANGE IN HEADING, RUDDER A, FOR A SPEED OF 25 KNOTS AND DIFFERENT RUDDER ANGLES

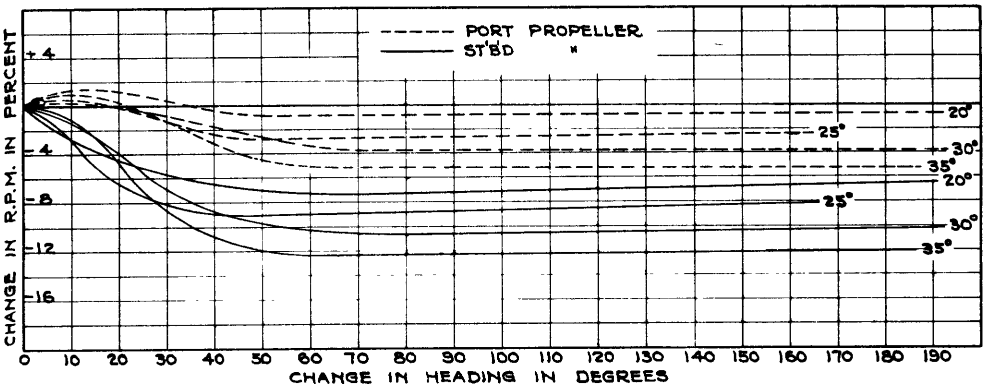


FIG. 89 CHANGE IN RPM IN PER CENT WITH CHANGE IN HEADING, RUDDER A, FOR A SPEED OF 30 KNOTS AND DIFFERENT RUDDER ANGLES

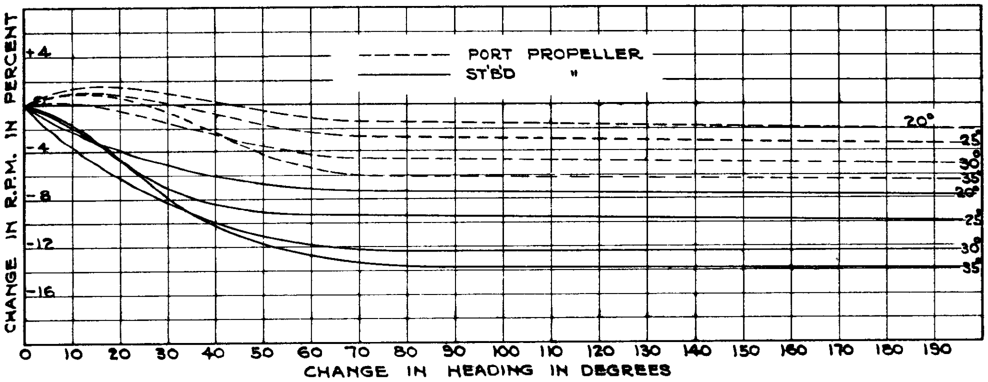


FIG. 90 CHANGE IN RPM IN PER CENT WITH CHANGE IN HEADING, RUDDER A, FOR A SPEED OF 36 KNOTS AND DIFFERENT RUDDER ANGLES

of 20, 25, 30 and 35 degree rudder. The dispersion in observed bearing from No. 3 station by plane table is evident in these cases. These figures are typical.

Figs. 76–80 give, in general, the same type characteristics in heeling as was evidenced in Figs. 44–47.

In like manner, the indication noted in Figs. 86–90 are similar to those noted in Figs. 56–60.

C. Maneuverability Trials.

C–1. Results.

Figs. 95–99 give the results for the maneuverability trials underway.

Figs. 100–105 give the results for the maneuverability trials from at rest.

C–2. Discussion.

Figs. 95–99 give data comparative to those observed for rudder C as shown in Figs. 65–70. A comparison of these results will be given hereinafter.

Since the photographs taken during the maneuverability trials from at rest could not be analyzed, in the case of rudder C, Figs. 71 and 72, showing changes in heading versus time, were the only comparisons possible. With rudder A, however, the photographs could be analyzed in 9 out of the 12 trials. Accordingly, Figs. 100–105 were obtained. These curves show, in addition to the changes in heading, the actual position and path of the vessel in maneuvering from a standing start.

Figs. 100–102 give the results at 1/3 standard speed (about 5 knots) with various rudder angles. During the period of these tests, the luni-solar tidal current was ebbing in a southerly direction at a varying rate from 0.17 to 0.06 knots per hour. A steady wind, of approximately 15 knot strength, was blowing from the north. The effects of these distrubances, especially the latter, are evidenced in every trial.

Fig. 101 shows the vessel's motion with 25 degrees right and left rudder at one-third speed. With right rudder the stern should, normally, move to the left, the motion being reversed with left rudder. Hence, the paths should be similar except to opposite hands. The combined effect of wind and tide, however, have caused the stern to move to the right during both maneuvers. With left rudder the vessel has moved 16 yards south and 133 yards east in 89.5 seconds. With right rudder the vessel has moved 94 yards south and 275 yards east in 123 seconds – the ship's heading, in both maneuvers having changed 15 degrees. These results are, therefore, inconclusive.

As the photographs for the trials with 20 degrees left and 30 degrees right rudder could not be analyzed, comparisons for these conditions are incomplete.

Figs. 103–105 give the results for conditions paralleling those above except for 2/3 speeds – roughly 10 knots – from a standing start. For these trials the luni-solar tide was ebbing and flooding, from 0.06 south to 0.05 north. In other words, the period was one of slack water. Wind direction remained the same, though the force had increased to approximately 18 knots per hour.

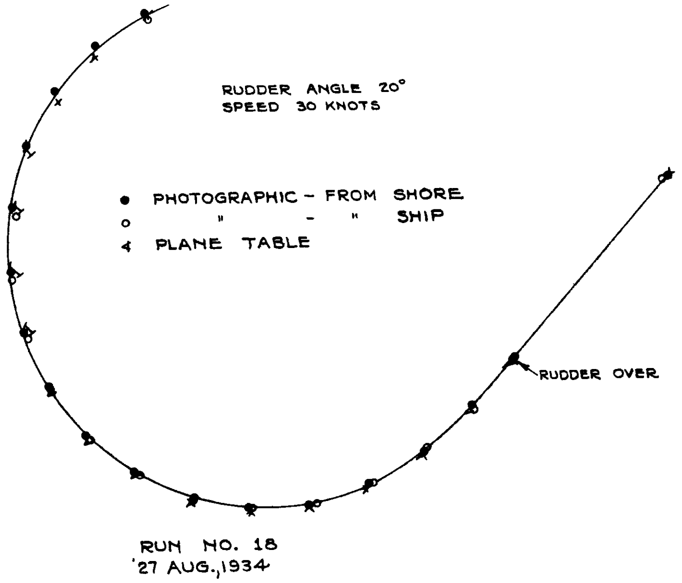


FIG. 91

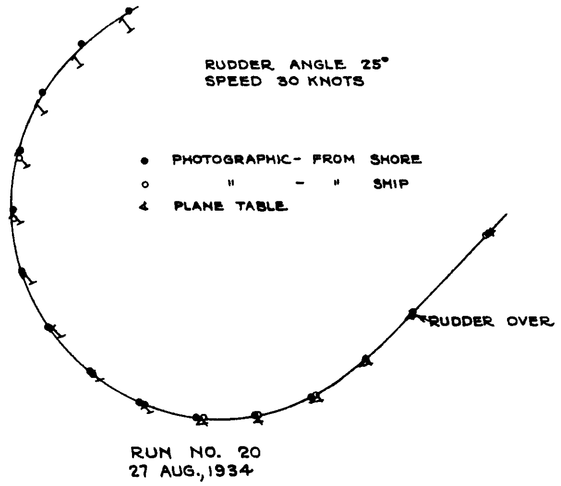


FIG. 92

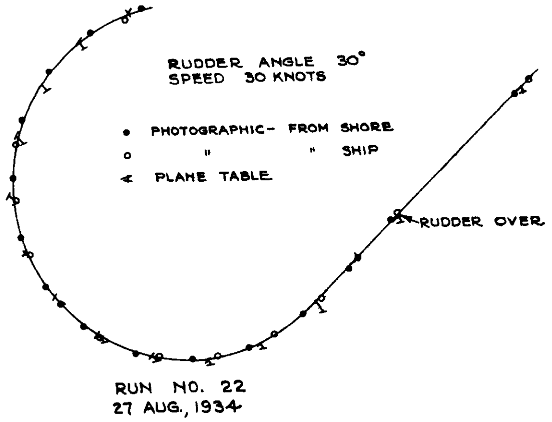


FIG. 93

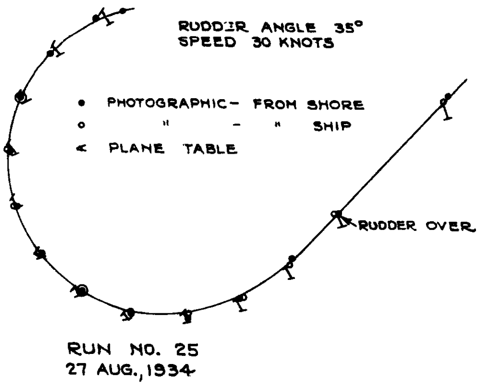


FIG. 94

FIGS. 91–94 TURNING PATHS, RUDDER A, SHOWING COMPARISON OF DATA OBSERVED BY VISUAL AND PHOTOGRAPHIC METHODS

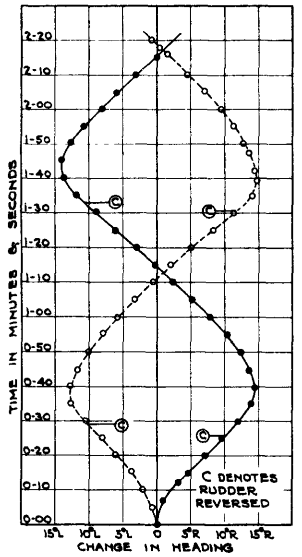


FIG. 95 RUDDER ANGLE 10 DEGREES.
SPEED 20 KNOTS

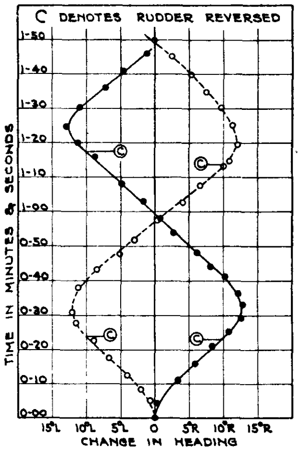


FIG. 96 RUDDER ANGLE 10 DEGREES.
SPEED 24.6 KNOTS

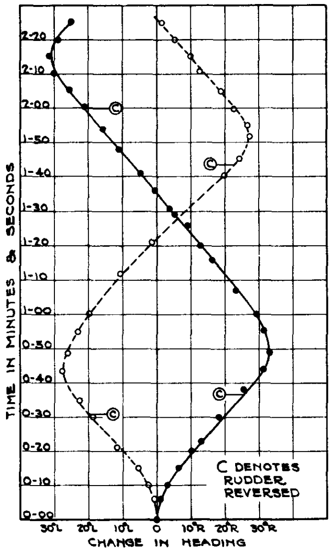


FIG. 97 RUDDER ANGLE 15 DEGREES.
SPEED 24.7 KNOTS

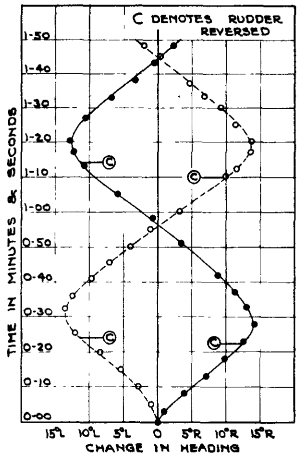


FIG. 98 RUDDER ANGLE 10 DEGREES.
SPEED 30.0 KNOTS

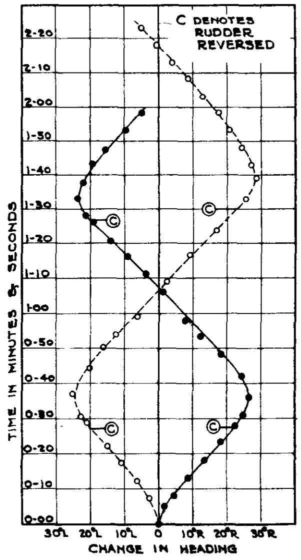


FIG. 99 RUDDER ANGLE 15 DEGREES.
SPEED 29.7 KNOTS

FIGS. 95–99 MANEUVERABILITY TRIALS UNDERWAY, RUDDER A, CHANGE IN HEADING VERSUS TIME

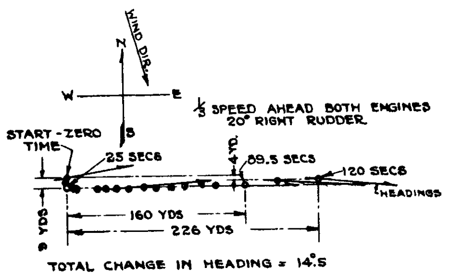


FIG. 100

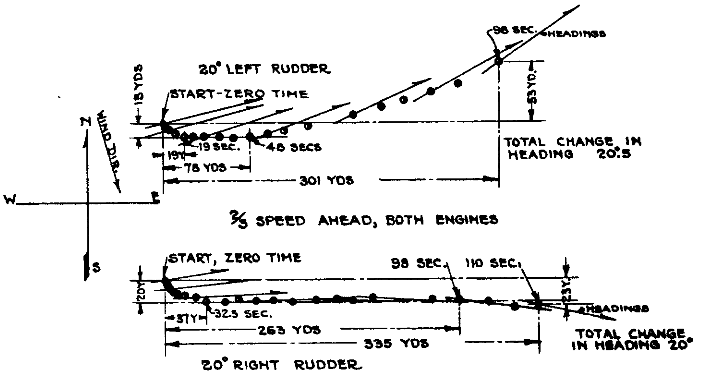


FIG. 103

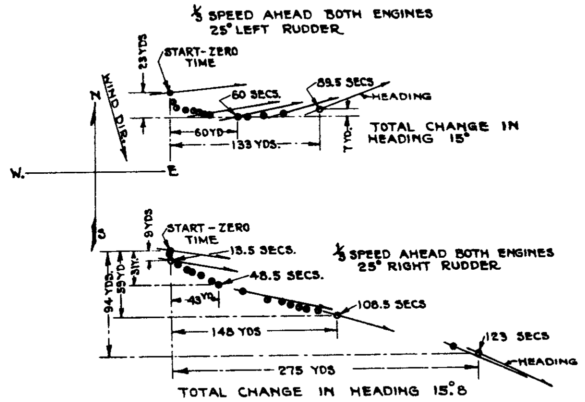


FIG. 101

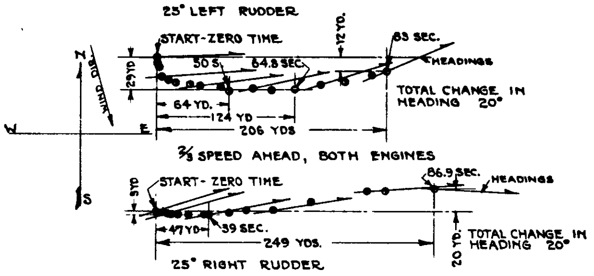


FIG. 104

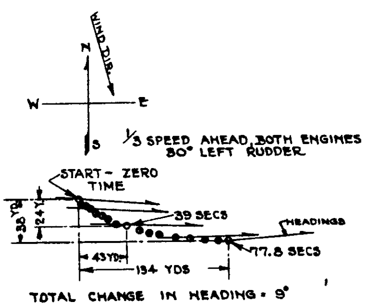


FIG. 102

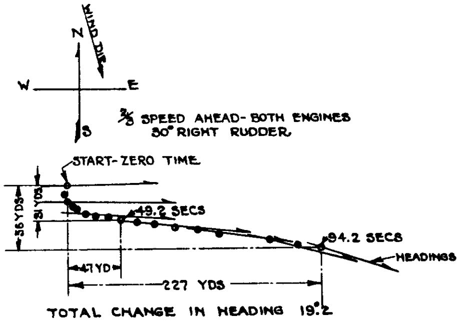


FIG. 105

FIGS. 100–105 MANEUVERABILITY TRIALS FROM AT REST, RUDDER A, CHANGE IN POSITION AND HEADING DETERMINED FROM PHOTOGRAPHIC OBSERVATIONS

In Fig. 103, as in Fig. 101, the trials under right and left rudder are not consistent. Because of the increase in speed and the consequent greater rudder reaction, a greater force is available to combat wind and tide effect for the maneuver using right rudder. Since these forces balance, roughly, the vessel's path is, as shown, practically along a straight line. In Fig. 104, however, the rudder reaction has overbalanced the wind and tide force such that some translation to the left, or north, has been obtained. In Fig. 105, however, conditions have reversed such that the results parallel closely those as given in Fig. 101.

To indicate a method of comparing the above data in terms of advance and transfer from a given point, Figs. 106 and 107 have been prepared. Under this method the translation north or south, east or west, may be evaluated for any degree of rudder at a constant speed. Since the conditions of wind and tide were such as to influence the results, no comparisons are possible. For analyzing a vessel's motion under the influence of any given rudder or rudder angle – the vessel starting from at rest – this method of comparison is far more specific than a mere comparison of the change in heading with time (indicated in Figs. 71 and 72) as this factor gives no information concerning the vessel's relative positions.

FIGS. 106 AND 107 MANEUVERABILITY TRIALS FROM AT REST, RUDDER A, ADVANCE AND TRANSFER IN YARDS PER UNIT OF TIME FOR DIFFERENT RUDDER ANGLES AT DIFFERENT SPEEDS

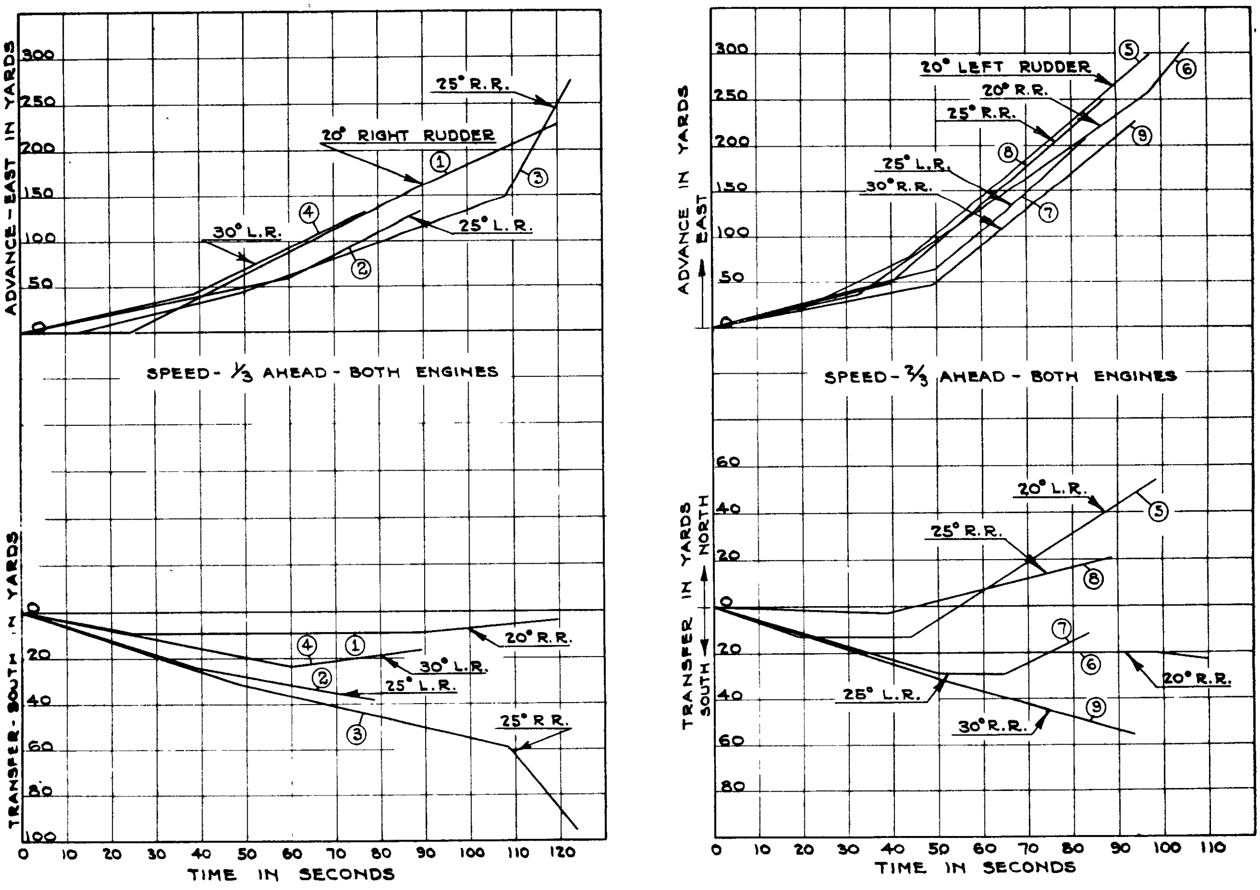


FIG. 106

FIG. 107

SECTION IV
COMPARISON OF FULL SCALE TRIALS
RUDDERS A AND C

The comparative performance, the vessel equipped in turn with rudder C and rudder A, is noted under the following sections.

SPEED AND POWER.

Fig. 108 gives the comparison obtained from standardization as given in Figs. 25 and 73. Considering that the propellers were repaired between the two trials, the slight differences noted may be due to the processes employed (welding and annealing) in effecting repairs.

On the other hand, the differences may result from slight errors and inaccuracies always present in observed data.

The fact that rudder A possessed a length of exposed stock has not proved detrimental insofar as propulsion is concerned. For all practical purposes, then, the performance of the two rudders as regards speed and power characteristics of the vessel may be considered equivalent.

TURNING.

Table 15, 16, 17 and 18 give a tabular comparison of the tactical diameters, advance and transfer for rudder A and C. A similar comparison is given in Figs. 109 and 110 respectively.

From Fig. 109, rudder C, for a given angle is more effective than rudder A. At 35 knot speed, however, rudder C "breaks down" at about 30 degree angle such that at the same speed and at 35 degree rudder angle, rudder A is more effective than rudder C. The advantage in actual distance is slight, though in point of rudder action rudder C has cavitated whereas rudder A has not.

These same general characteristics are found in the advance and transfer as given in Fig. 110.

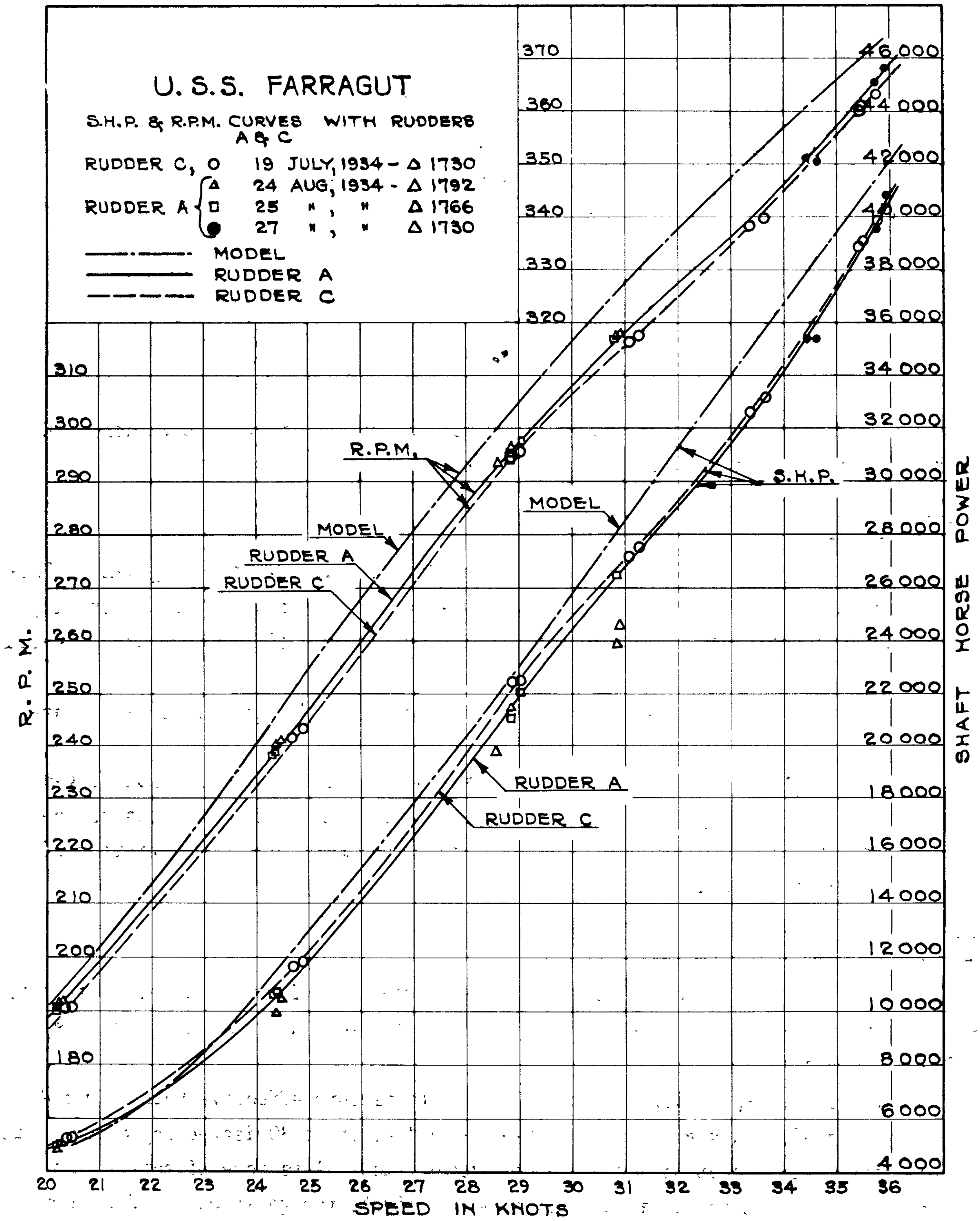


FIG. 108 MODEL – TRIAL COMPARISON, U.S.S. FARRAGUT, STANDARDIZATION TRIALS OF JULY AND AUGUST 1934

U.S.S. FARRAGUT
COMPARISON OF TACTICAL CHARACTERISTICS
RUDDERS A AND C MEASUREMENTS IN YARDS

TABLE 15 - RUDDER ANGLE 20 DEGREES

SPEED	ADVANCE		TRANSFER		TACTICAL DIAMETER	
KNOTS	A	C	A	C	A	C
16	580		460		890	
18	570		450		900	
20	585	505	460	370	930	730
22	620	520	490	380	970	750
24	680	545	530	410	1,020	795
26	755	585	580	460	1,105	870
28	810	620	630	500	1,220	945
30	840	645	665	530	1,300	1,020
31	850	655	680	540	1,330	1,045
32	855	665	685	555	1,355	1,070
33	850	675	695	565	1,375	1,090
34	845	680	700	570	1,390	1,110
35	835	685	705	580	1,415	1,130

TABLE 16 - RUDDER ANGLE 25 DEGREES

SPEED	ADVANCE		TRANSFER		TACTICAL DIAMETER	
KNOTS	A	C	A	C	A	C
16	490	445	380	320	745	620
18	500	435	365	310	730	595
20	525	430	370	305	730	590
22	560	440	395	315	760	605
24	600	470	440	335	830	645
26	630	510	480	365	940	710
28	650	540	510	400	1020	795
30	670	570	540	430	1060	870
31	680	580	550	445	1080	890
32	685	590	560	460	1100	910
33	690	600	565	470	1115	925
34	695	610	570	480	1130	940
35	700	620	575	490	1140	945

U.S.S. FARRAGUT
COMPARISON OF TACTICAL CHARACTERISTICS
RUDDERS A AND C MEASUREMENTS IN YARDS

TABLE 17 - RUDDER ANGLE 30 DEGREES

SPEED	ADVANCE		TRANSFER		TACTICAL DIAMETER	
KNOTS	A	C	A	C	A	C
16	440	400	315	265	620	515
18	445	400	310	255	620	500
20	470	410	315	260	630	500
22	520	430	330	270	650	520
24	550	450	355	300	680	560
26	580	470	385	330	735	620
28	595	495	415	370	810	710
30	605	520	435	405	890	785
31	610	535	445	420	920	815
32	610	550	455	430	945	835
33	615	565	460	440	960	855
34	615	580	470	450	980	870
35	610	595	475	455	990	885

TABLE 18 - RUDDER ANGLE 35 DEGREES

SPEED	ADVANCE		TRANSFER		TACTICAL DIAMETER	
KNOTS	A	C	A	C	A	C
16	405	380	275	250	540	490
18	415	380	270	250	530	490
20	435	390	275	255	540	495
22	465	405	290	270	560	505
24	495	425	310	290	590	535
26	540	450	340	315	640	580
28	575	475	380	345	725	650
30	590	505	410	380	800	740
31	595	520	420	400	830	780
32	600	535	430	420	855	820
33	600	550	435	440	875	860
34	595	565	435	460	895	900
35	590	580	435	480	920	935

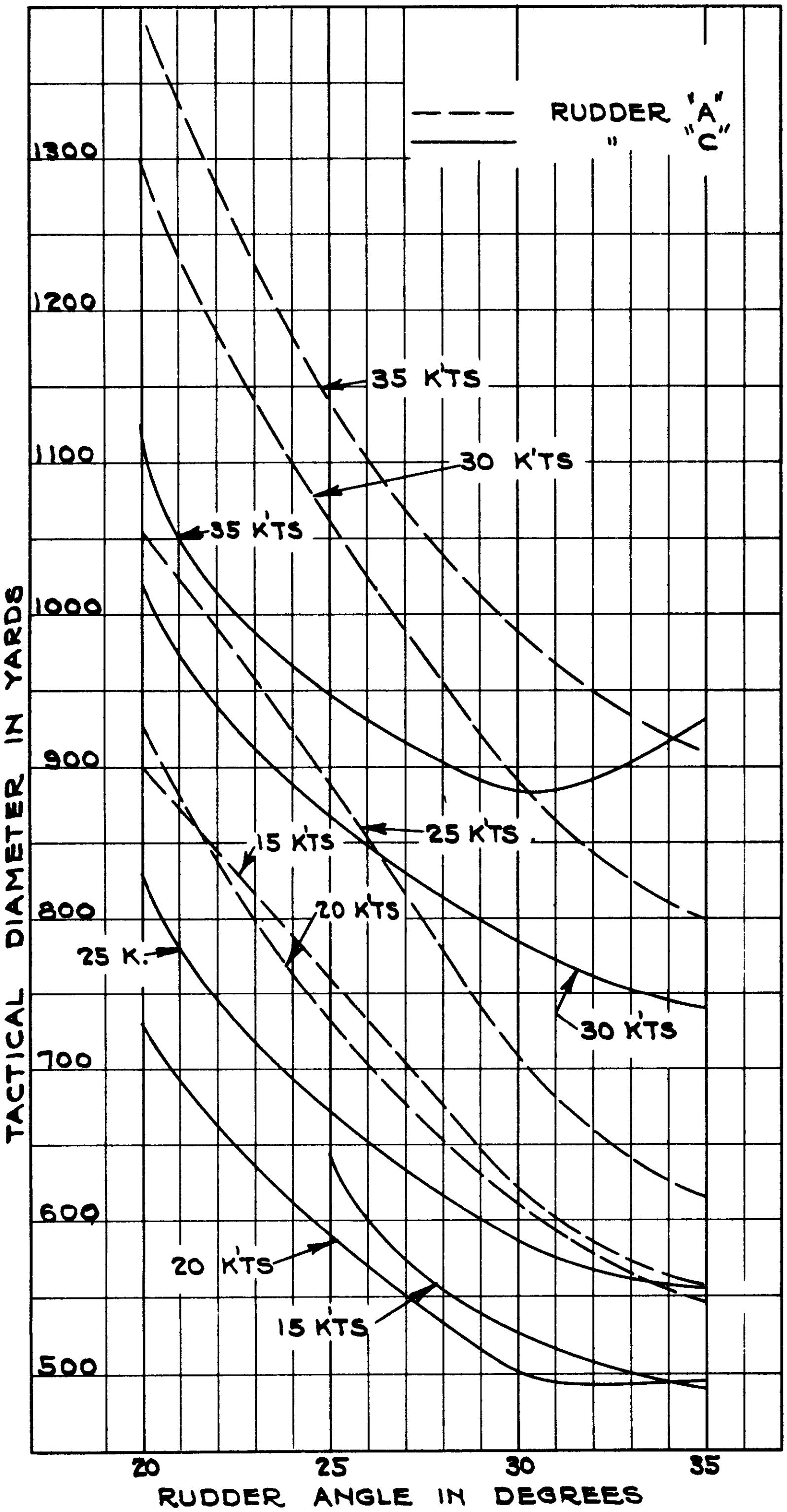


FIG. 109 COMPARISON OF TACTICAL DIAMETER, RUDDERS A AND C, FOR DIFFERENT RUDDER ANGLES AT VARIOUS SPEEDS

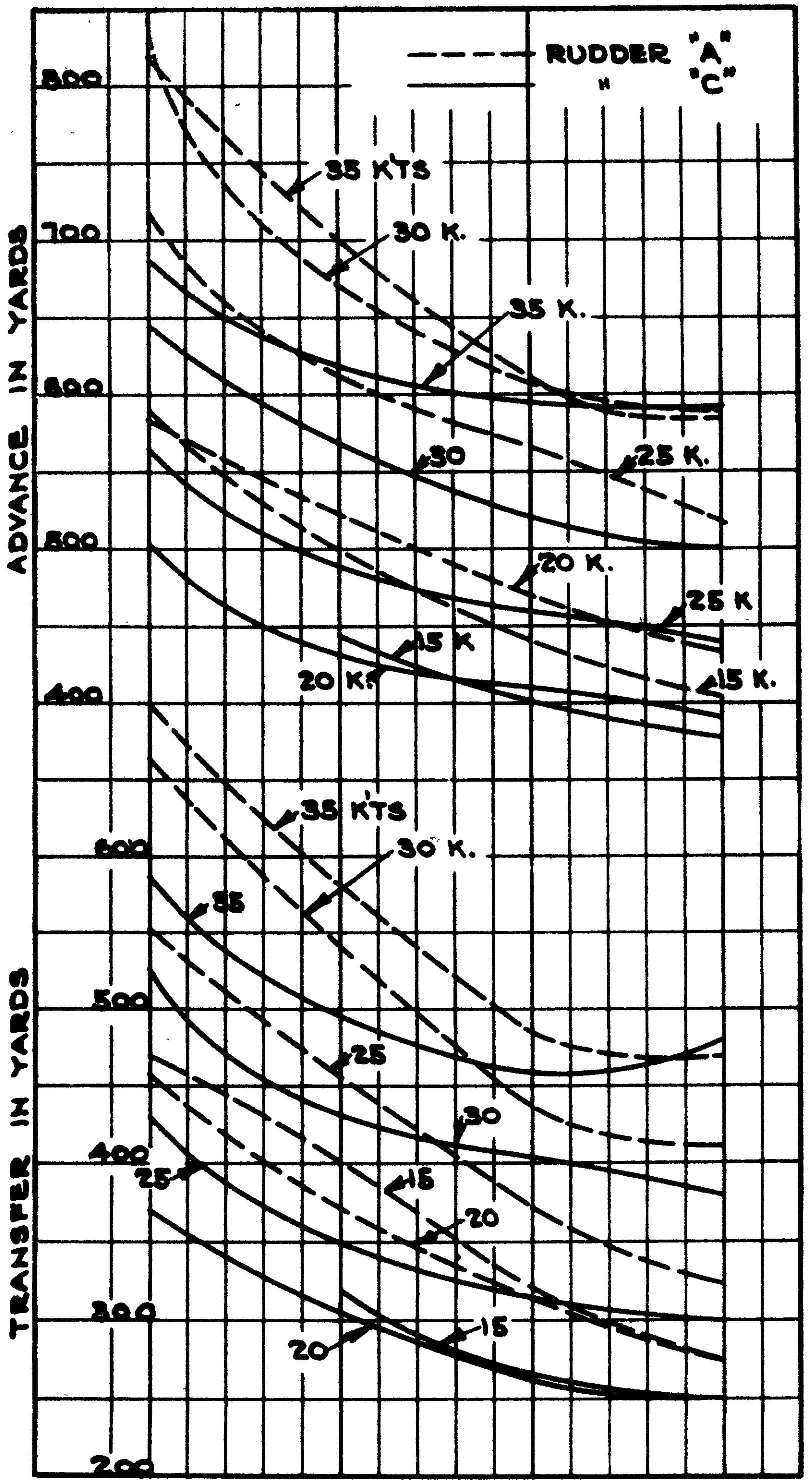


FIG. 110 COMPARISON OF ADVANCE AND TRANSFER, RUDDERS A AND C, FOR DIFFERENT RUDDER ANGLES AT VARIOUS SPEEDS

Fig. 111 gives a comparison of the maximum outward heel, maximum inward heel, and the average steady angle while turning with rudder A and C. As regards the maximum outward and steady outward angle, rudder A produces a comparatively less angle than rudder C. As regards inward angle, there is little difference between the two rudders.

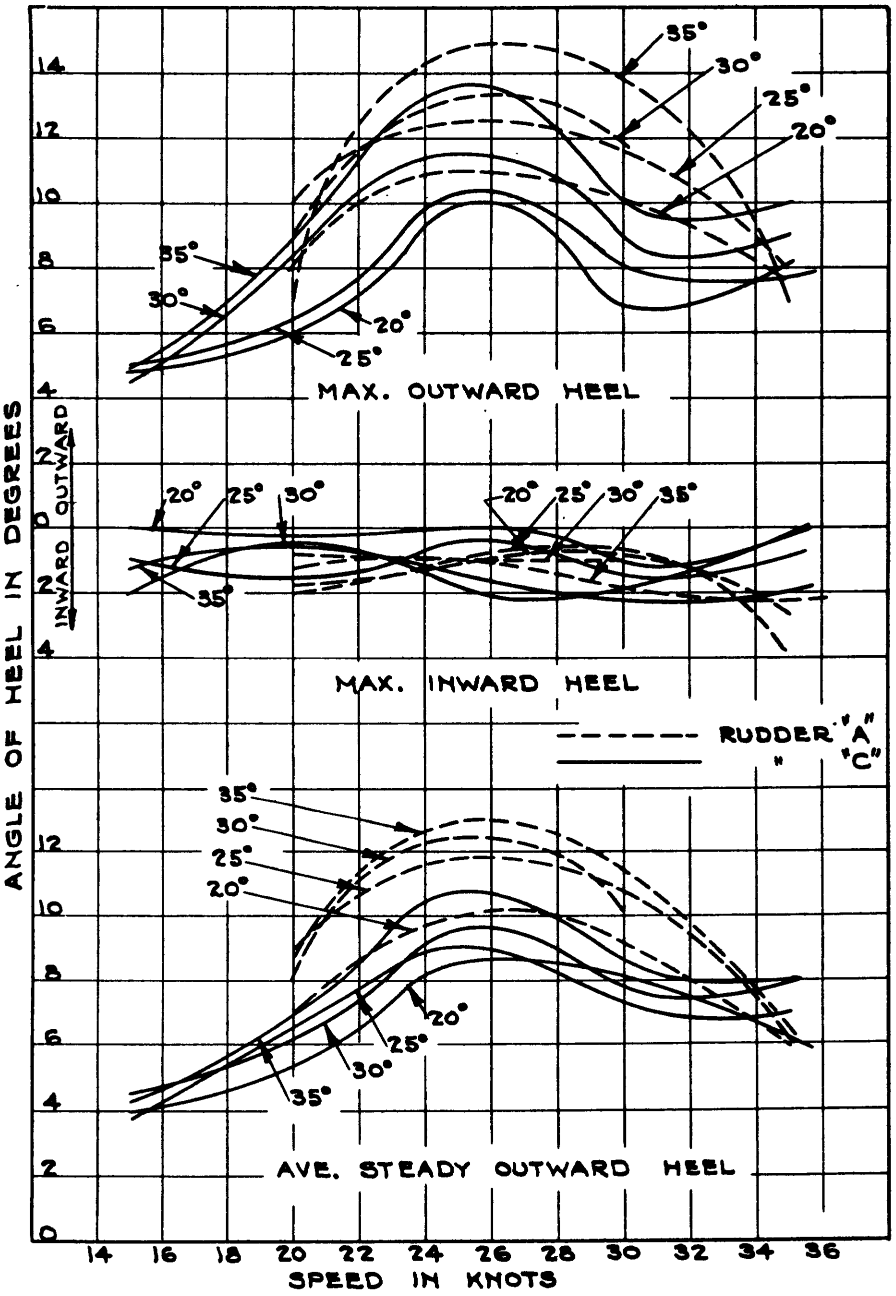


FIG. 111 COMPARISON OF HEELING CHARACTERISTICS, RUDDERS A AND C, FOR DIFFERENT RUDDER ANGLES AT VARIOUS SPEEDS

Fig. 112 gives a comparison of the time required to effect a 45 degree, 90 degree and 180 degree change in course for rudders C and A at 25 and 35 knots respectively. These results are consistent with those noted in Figs. 107.

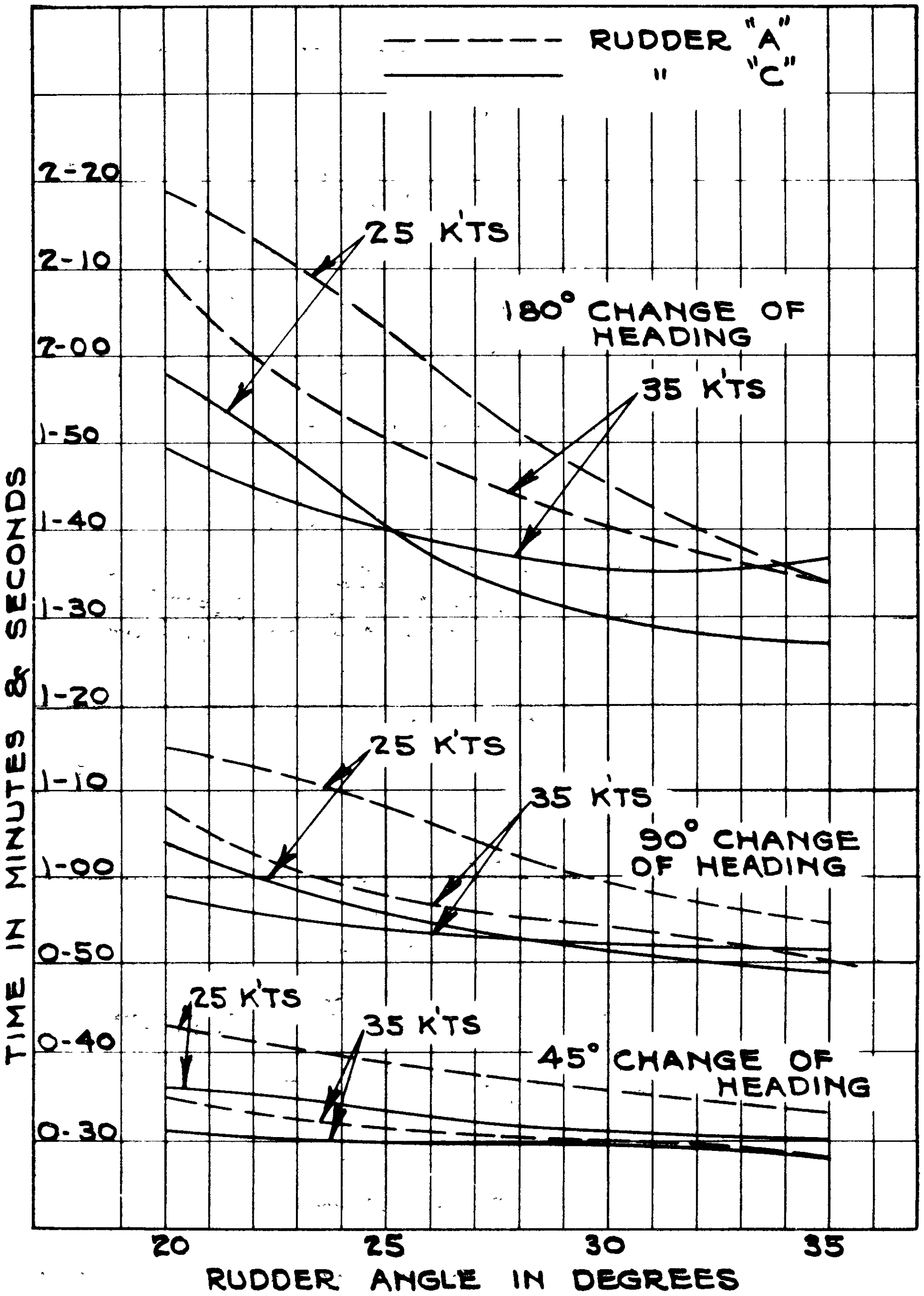


FIG. 112 COMPARISON OF TIME TO EFFECT GIVEN CHANGES IN HEADING, RUDDERS A AND C, FOR DIFFERENT RUDDER ANGLES AT 25 AND 35 KNOT SPEED

Fig. 113 indicates the percentage changes in RPMs for both the inboard and outboard propeller during the turn. Since the throttle controls were undisturbed during the turn, the values are representative.

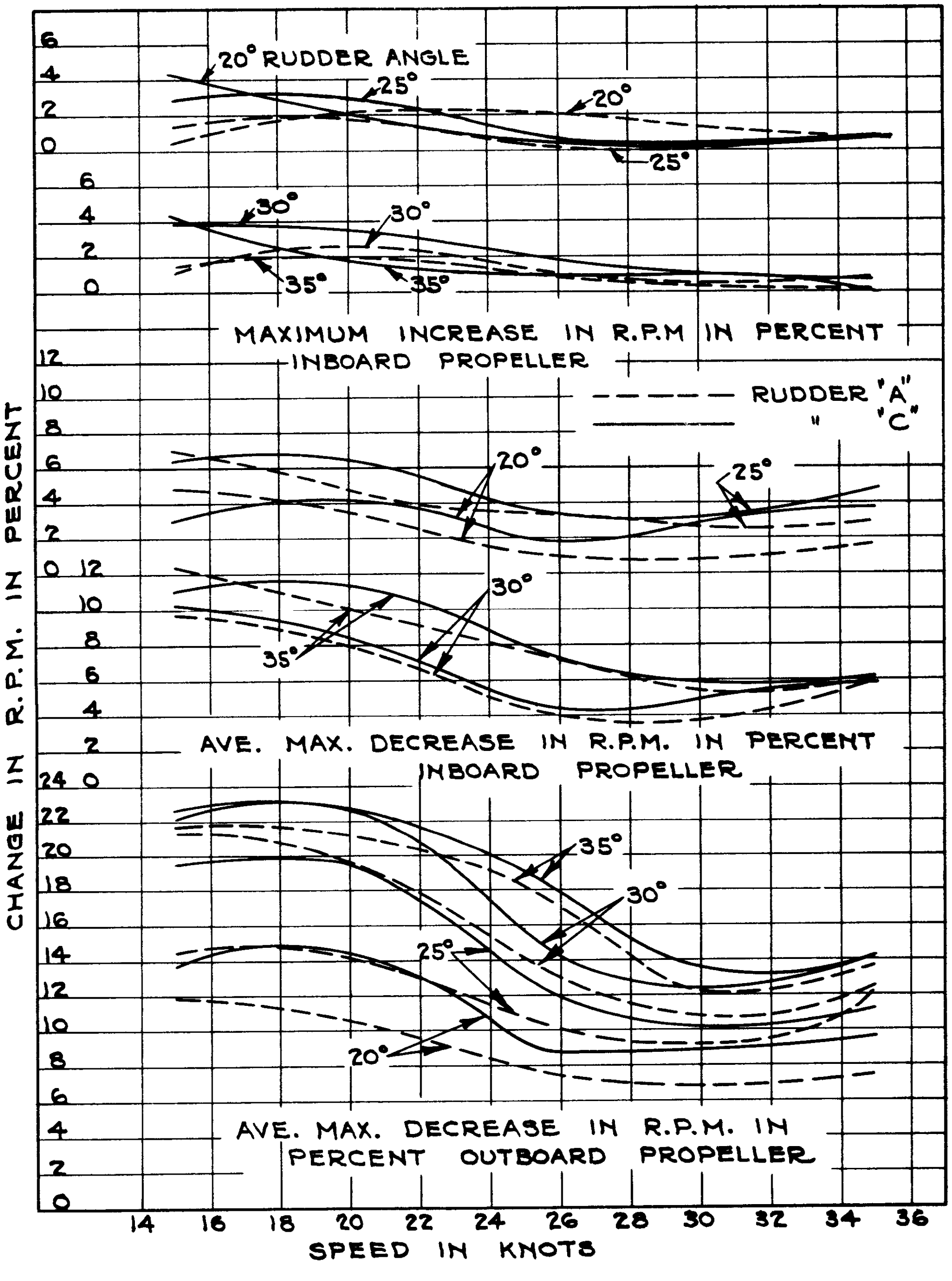


FIG. 113 COMPARISON OF CHANGES IN RPM IN PER CENT, RUDDERS A AND C, FOR DIFFERENT RUDDER ANGLES AT VARIOUS SPEEDS

During the initial stages of the turn, the maximum percentage increase of the inboard propeller is exceedingly small. Even at maximum speed, the maximum increase is of the order of but one per cent. For the latter stages of the turn, the maximum decrease for the inboard propeller varies over a wider range. The variations are, on the average, similar to those experienced for the outward propeller. In both cases, at a given speed, the percentage decrease increases with rudder angle and, for a given angle decreases with increasing speed.

Though the differences are slight, rudder A produces less reduction than rudder C.

MANEUVERABILITY.

(a) Underway.

Fig. 114 indicates the comparison of maneuverability characteristics underway when viewed solely from the point of time required to complete a specific maneuver. In this case rudder C is more effective.

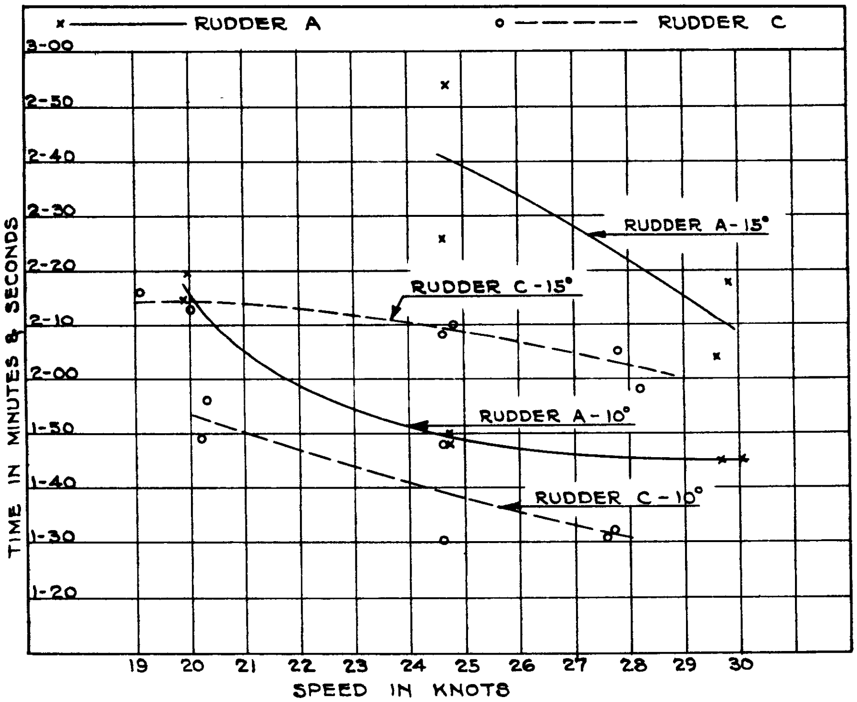


FIG. 114 COMPARISON OF TIMES REQUIRED TO COMPLETE DEFINITE MANEUVER, RUDDERS A AND C, FOR DIFFERENT RUDDER ANGLES AND VARIOUS SPEEDS (SEE FIGS. 65-70 AND 95-99)

(b) From at rest.

Unfortunately no concrete comparison can be obtained for this characteristic. The comparison of change in heading alone, given in Figs. 71 and 72, is not complete in that it is not possible to compare the ship's position - in other words, its advance and transfer from a given point in a given time.

SECTION V

MODEL - TRIAL COMPARISON

STANDARDIZATION.

The comparison of speed and power between model and trial has been indicated hereinbefore. Considering the differences obtained between model and full scale propellers, the results are consistent with the facts noted.

TACTICAL CHARACTERISTICS.

During the full scale trials, measurements were made of the time required to shift the rudder to the desired angle. These measurements indicated that the average rate of swing of the rudder was 0.53 seconds per degree for the trials with rudder A, and 0.55 seconds per degree for the trials with rudder C. The average rate for both trials would then be 0.54 seconds per degree. In terms of model conditions, this rate would require a time of 3.2 seconds for shifting the rudder 35 degrees on the model. Since the rate of swinging the model rudder varied and was less than this given interval, tests were made to evaluate the effect of varying this rate on the radius of curvature. Fig. 115 gives the results. As rudder C

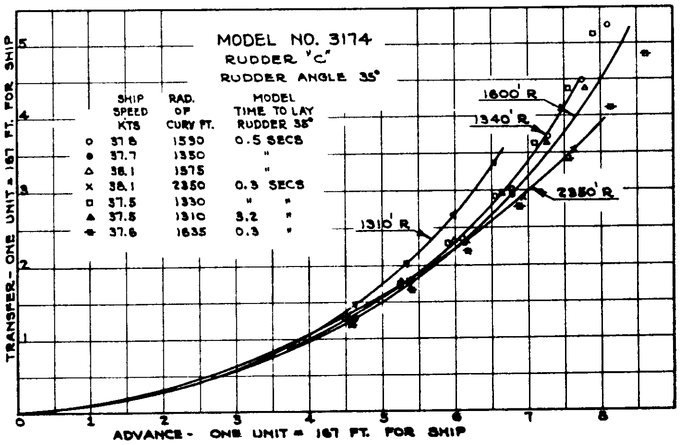


FIG. 115 TURNING PATHS, RUDDER C, SHOWING INFLUENCE OF VARYING TIME TO TURN MODEL RUDDER ON RADIUS OF CURVATURE

cavitates at 35 degrees rudder angle, the effect of this variation is obscured with the result that the comparison is inconclusive.

However, in order to eliminate any influence that this variable may have possessed, model experiments were repeated using the new time rate for shifting the model rudder. From these results Fig. 116 has been prepared giving the model-full scale comparison of tactical diameter for rudder A. In like manner, Fig. 117 indicates a similar comparison for rudder C.

Basing the comparison on model predictions, Fig. 116, rudder A, shows the full scale results to be 1.1 per cent low at 20 knots, 3.2 per cent high at 25 knots, 5.7 per cent high at 30 knots, and 4.3 per cent low at 35 knots. These represent an average deviation of approximately 0.9 per cent.

In like manner, Fig. 117, rudder C, shows the full scale results to be 6.9 per cent low at 20 knots, 1.5 per cent low at 25 knots, 4.6 per cent high at 30 knots, and 4.0 per cent high at 35 knots. These represent an average deviation of zero.

In addition to the above comparisons, the scope of these model experiments were extended to include rudder angles in excess of 35 degrees. From these results, it was found, in the case of rudder A, Fig. 116, that the rudder angles could be carried as high as 45 degrees at 35 knots with no sign of cavitation. With rudder C, Fig. 117, there were signs of cavitation at 25, 30, and 35 knot speeds with rudder angles above 30 degrees - the breakdown point being about 33 degrees.

In general, the full scale results confirmed these broad observations. Rudder A showed no sign of breakdown. For rudder C, Fig. 117, the full scale curve is remarkably similar to that of the model scale at 20 knots except for a displacement of approximately 2½ degrees as regards rudder angle. Continuing for the same rudder at 25 knots, the trend can be considered equivalent. At 30 knots, the full scale rudder was not quite so effective as indicated in model scale. At 35 knots the curves are equivalent up to 35 degree rudder angle. Beyond this point, the full scale rudder cavitates earlier than does the model. Despite these minor deviations the indications noted in model scale have been confirmed in full scale.

HEELING CHARACTERISTICS.

Fig. 118 gives the comparison of angle of heel for 35 degrees rudder angle for model and full scale. Of the two there is far better agreement in the case of rudder A than in rudder C - the latter showing considerable variation especially in outward heels, both maximum and steady average.

In establishing this comparison it should be noted that the model experiments were conducted at a fixed GM. In the case of the full scale, however, this quantity suffered changes due, primarily, to shifts in the loading of the vessel. The model experiments were made at a GM corresponding to 2.44 feet in full scale. A

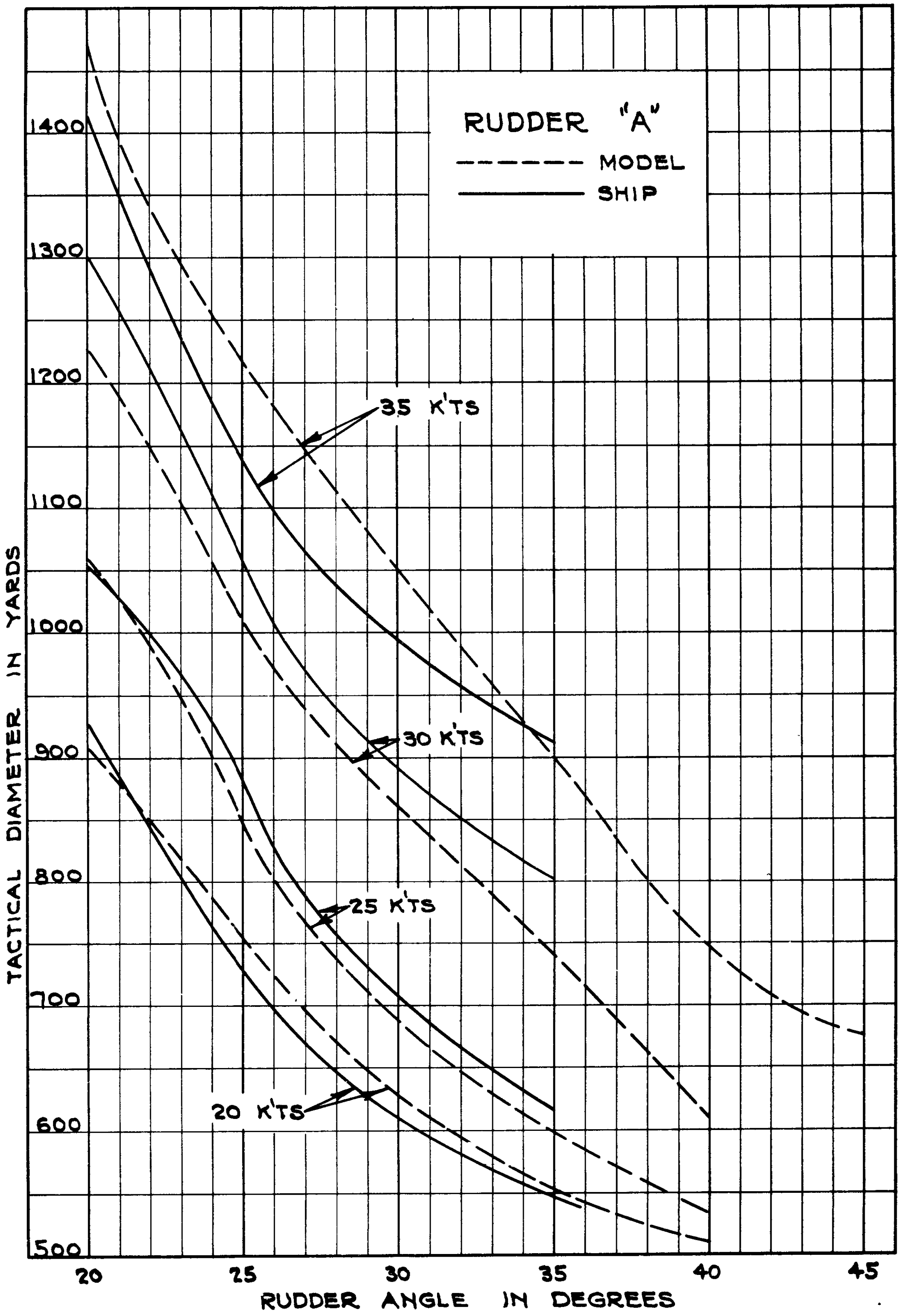


FIG. 116 COMPARISON OF TACTICAL DIAMETER IN YARDS, MODEL - TRIAL, RUDDER A, FOR DIFFERENT RUDDER ANGLES AND VARIOUS SPEEDS

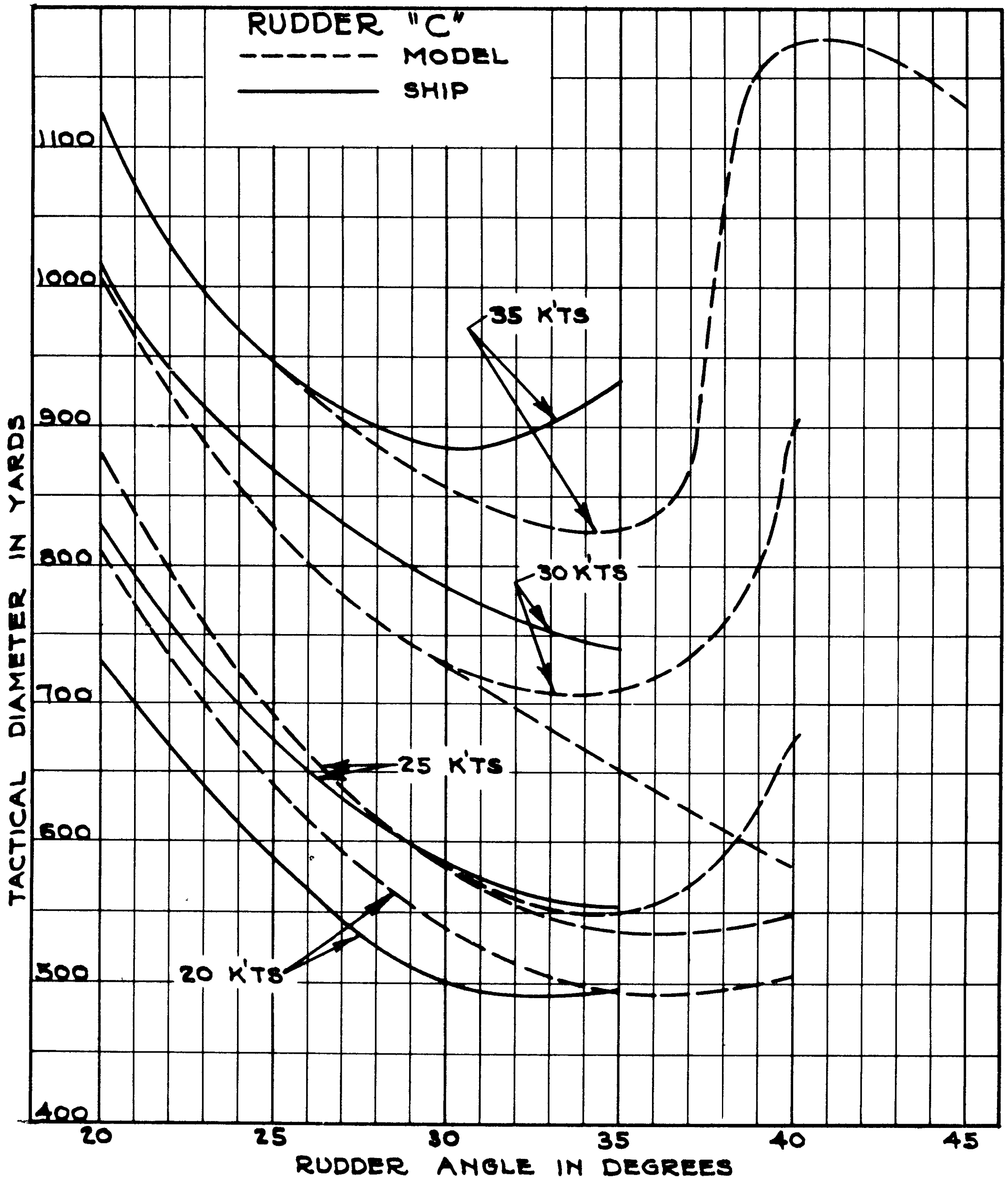


FIG. 117 COMPARISON OF TACTICAL DIAMETER, IN YARDS, MODEL - TRIAL, RUDDER C, FOR DIFFERENT RUDDER ANGLES AND VARIOUS SPEEDS

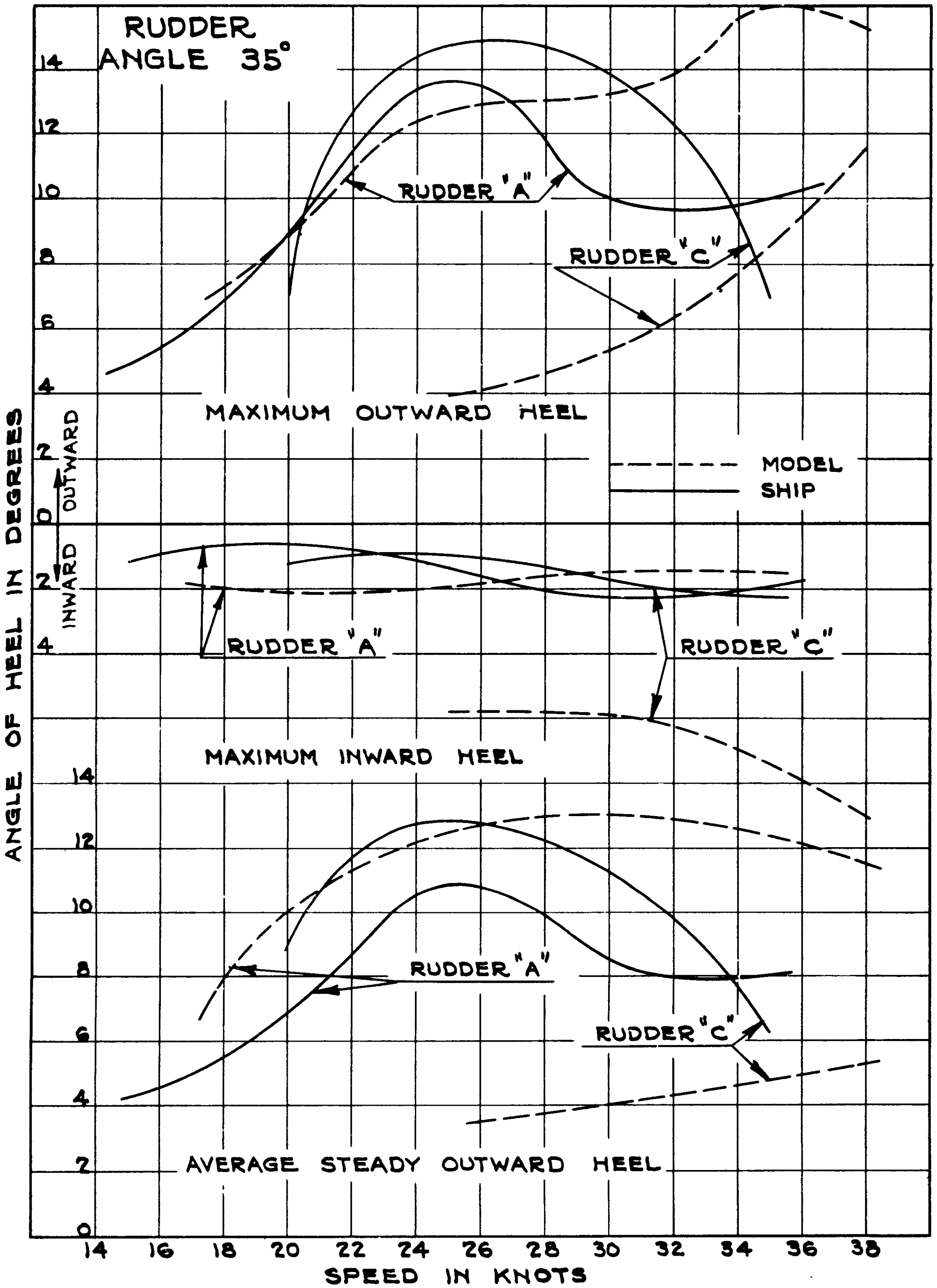


FIG. 118 COMPARISON OF ANGLES OF HEEL, MODEL - TRIAL, RUDDERS A AND C, FOR RUDDER ANGLE OF 35 DEGREES AND VARIOUS SPEEDS

check made prior to the trials indicated that the vessel's GM would be approximately 2.76 feet, an increase of 10 per cent. Since angle of heel is inversely proportional to GM, it would be anticipated that the full scale should show less angle than the model scale.

As regards rudder A, this offers some reconciliation for the deviation in the curves. With respect to rudder C, it is evident that other factors have influenced the result. The heeling predictions for rudder C were obtained when the rate for swinging the model rudder was faster than that determined on trial. The increase in this rate would directly affect the heeling angle. In other words, since the relative model rate was faster than the full scale rate, a greater inboard heel would result after which the energy absorbed in producing this heel was sufficient to reduce the maximum outward heel. However, it is not possible to estimate the actual extent of this influence.

METHODS OF TACTICAL MEASUREMENTS.

As noted in section I, measurement of the vessel's path, in model scale, is obtained by photography, the camera being located well above the model, thus permitting successive positions of the model to be recorded on the same plate. In this procedure the accuracy is limited solely by the direct measurements for replotting the model's successive positions.

Fundamentally the photographic methods developed in full scale are limited in accuracy to the same degree as that of the corresponding method in model scale. Practically, however, other factors influence full scale results over a wider range than that experienced in model scale. An extended discussion of the comparison and accuracy of the several methods used in full scale will be found in Appendix 5.

In comparison to full scale, there is one point of dissimilarity in procedure that should be noted. Since model experiments were conducted on a 10 foot model, it was not possible to drive each of the model propellers by its own motor. Instead the two propellers were driven, through gearing, by a common motor. As a result the model propellers were caused to revolve at the same revolutions while making a turn. In full scale each propeller was able to seek its own revolutions dependent solely on the conditions of slip imposed during the turn. This caused the differences already noted in Fig. 113. Though the divergences between the inboard and outboard propellers in full scale were not excessive, there did result sufficient differences which may have had an influence on the results, thereby accounting for some of the deviations between model prediction and full scale performance.

SECTION VI
CONCLUSIONS

1. Though these trials represent the first series of tests made for correlating model and full scale results as regards tactical characteristics, the following conclusions are warranted.

A. Whereas individual model measurement of tactical diameter may cause resulting predictions to vary as much as ten per cent, the average of such measurements translated to full scale should be within a variation of one per cent.

B. The deviations between model and full scale heeling characteristics show a greater range of deviations than experienced in the case of tactical characteristics. This quantity, however, is sensitive to conditions of the vessel's loading in full scale and therefore is not susceptible to rigorous comparison.

C. Where model experiments indicate rudder cavitation, the same phenomenon will be observed in full scale. A difference in point of inception as regards cavitation, or burbling, may be experienced due to differences in absolute pressure conditions between model and full scale.

D. The results, both in model and full scale, are in agreement with the aspect ratio characteristic of hydrofoils; that is, with an aspect ratio greater than unity, a high lift is evidenced at small angles of attack, but the range of angle of attack before burbling occurs is small. On the other hand, an aspect ratio less than unity usually possesses a relatively smaller lift at small angles of attack, but the range of angles of attack before burbling occurs is relatively great.

E. The time of shifting the rudder has an influence on the tactical and heeling characteristics in model scale.

Considering the present restrictions imposed on model turning tests, it was feared that the model results might not be indicative of full scale performance. These comparisons, however, offer the first definite indications that model turning results can be applied for predicting full scale turning within reasonable limits of accuracy.

Though a reasonable degree of correlation between model and full scale turning has been established, there still remains the necessity for a more extended comparison. As noted, there is available, on the average, but one-sixth of a circle in model scale. Consequently, the resulting model data must be extrapolated to obtain full scale predictions – another factor that may account for the individual deviations noted. With a half circle in model scale, it is possible to analyze the rudder's action in the first and second quadrants of the turn. This is essential and provides a more representative comparison between model and full scale turning.

Finally, the fact that a close correlation of model and full scale turning results is possible lends encouragement to a more extended study of model tests.

2. In comparing the performance of rudders A and C, the following facts have been established.

A. Within a range of from 20 to 35 degrees rudder angle, rudder C, for a given angle and speed is more effective than rudder A. An increase in the angle by 5 degrees in the case of rudder A over that corresponding to rudder C will produce approximately equivalent turning results. As this occurs within that range where the additional rudder angle is available, rudder C does not possess any inherent advantages.

B. At 35 degrees rudder angle and maximum speed, rudder A is more effective than rudder C.

C. By increasing the range of rudder angles to 45 degrees, the tactical diameter at maximum speed can be decreased to approximately 75 per cent of its value at 35 degrees rudder angle. In this respect rudder A possesses an inherent advantage over rudder C, the latter being unable to attain an equivalent result because of its early "burbling".

D. Considering the maneuvering characteristics underway, rudder C, for a given rudder is more effective than rudder A. However this result is modified for the same reason as given in 2 (A).

E. Rudder A produces a smaller maximum angle of heel than rudder C, though the difference is not great.

F. The propulsive characteristic of the vessel is not influenced by the difference in the rudders.

G. The comparison of maneuvering characteristics from at rest is incomplete.

H. The decrease in revolutions – and hence speed – is slightly less with rudder A than rudder C.

3. Based on the above, the selection of either rudder A or C is governed by the following conditions.

A. If the range of rudder angles cannot be increased beyond 35 degrees, then either rudder is satisfactory.

B. If the range of rudder angles can be increased to 45 degrees, then rudder A alone is satisfactory.

C. Irrespective of range, the performance at maximum speed should govern. Accordingly, rudder A is superior to rudder C.

SECTION VII

APPENDICES

APPENDIX 1

PHOTOGRAPHIC METHODS FOR DETERMINING A SHIP'S ANGLE OF HEEL.

INTRODUCTION.

To obtain a measure of a ship's angle of heel, it is essential to provide two reference planes, one of which is fixed, and a time base. Because of the rapidity with which changes of heel occur, observations by visual methods are, at best, subject to large errors. On the other hand, photographic observations are definite, can be made at any desired time intervals, time being also recorded, and they provide records that can be read at any future time.

DESCRIPTION.

Two photographic methods for measuring a ship's angle of heel while either turning or maneuvering were developed. Both of these methods required a camera fixed rigidly to the ship and aimed, when the ship is in its normal upright position in quiet water, on the horizon, i.e., the camera's optical axis horizontal.

For purposes of references the methods will be distinguished by the camera's direction relative to the ship. In one method the camera's axis was in line with the longitudinal axis of the ship. This will be known as the longitudinal method. In the other, the camera's axis was set transversely to the ship's longitudinal axis – that is, the camera was aimed off the beam, either port or starboard. This will be known as the transverse method. Thus, in either method, with the ship at rest in quiet water, the image of the horizon in the camera's field of view is a horizontal line across the center of the plate.

When the ship rolls the aspect of the image of the horizon line changes, and the magnitude of this change, in any particular photograph, determines the heeling position of the ship at the instant at which the photograph was made. In the longitudinal method, when the ship heels, the image of the horizon line rotates approximately about the center of the plate, thus providing a record which may be read directly by means of a straight edge and protractor. In the transverse method, the image of the horizon moves vertically up or down on the photographic plate, depending upon the direction of the ship's heel, whether to port or starboard. To determine an angle of heel by the latter method, the vertical displacement of the horizon line must be measured. The camera's focal length must be accurately known. From these two quantities the tangent of the particular angle of heel is computed and thence the angle.

The accuracy of the two methods is essentially the same, both requiring a single measurement to be made from some reference line, the side of the photographic plate, to another, the horizon line.

Of the two methods, the longitudinal method is superior for the following reasons:

(a) The greater ease and rapidity with which the desired data may be obtained.

(b) Any angle of heel can be recorded regardless of amplitude whereas the transverse method has a limited maximum equal to the half value of the vertical angle of view of the camera.

(c) The transverse method is subject to lens distortion whereas the longitudinal method - as long as the horizon line passes near to or through the center of the plate - is not.

Because of these facts, though both methods were utilized, the longitudinal method was accepted as standard.

EQUIPMENT AND INSTALLATION.

In the first full scale demonstration on the U.S.S. FARRAGUT, two cameras were mounted on a rigid support above the bridge on the director platform. These supports carried marks showing the center line and a frame line of the vessel. With the vessel in normal upright position in quiet water, the cameras were secured to the support, their axes parallel to the water line.

For the longitudinal method a Sept camera, using regular 35 mm movie film, was used. For the transverse method a Leica camera was used. A chronometer stop watch equipped with a center post second hand was placed in the field of view of each camera. A thin two inch lens of twelve inch focal length was placed between each watch and camera in order to bring the watch to a focus on the plate when the camera's lens was set to focus on the horizon.

The Sept camera takes a film charge sufficient for about 250 exposures whereas the Leica is limited to 36. In subsequent trials the Sept camera was used. In operating this latter camera, exposures may be made as frequently as deemed necessary, the maximum speed for single exposures, that is when not operated as a movie camera, being limited only by the speed with which the shutter release can be operated by hand. During the various tests, a maximum speed of one exposure per second was found sufficient for such times when the ship changed her heeling positions rapidly. At times when steady in some heeling position, an exposure every four to five seconds was found satisfactory. This combination of intervals permitted judicious expenditure of film.

The angle of heel and time data as obtained from the developed negative - Fig. 119 being an illustration for the longitudinal method - is plotted to give a graphical record of the heeling behavior of the ship for the particular maneuver executed. All the angles of heel included hereinbefore give the results obtained in this manner.

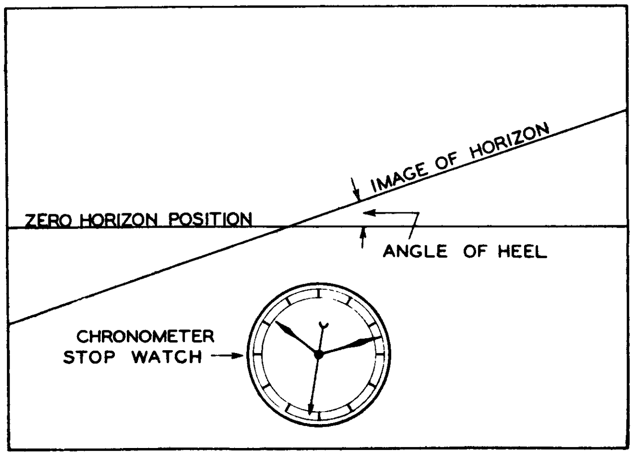


FIG. 119 VIEW OF NEGATIVE, LONGITUDINAL METHOD, SHOWING ELEMENTS FOR MEASURING ANGLE OF HEEL

APPENDIX 2

ONE CAMERA METHOD OF MAKING PHOTOGRAPHIC OBSERVATIONS FROM SHIP FOR DETERMINING TURNING CIRCLES

INTRODUCTION.

As noted hereinbefore, full scale turning trial observations have revolved around simultaneous ranges and bearings observed from one observing point, or simultaneous bearings from two fixed shore stations at periodic time intervals. In addition to the fundamental question of correlation of observed data, most trials have been conducted at such distances from the observing point or points as to involve considerable error by reasons of minor variations in the observed data. Once made, however, observations under this procedure cannot be checked for accuracy. With the development of a satisfactory photographic method, such questions of doubt can be obviated. Accordingly, the following method, designated as method A, was developed.

PRINCIPLE OF METHOD.

The principle of this method is illustrated in Figs. 120 and 121. It is an application of the geometric facts that (a) in a plane two points and an angle including the points determine a circle, and (b) three points and two independent angles with one of the points common to the two angles determine intersecting circles.

In Fig. 120, A and B are the fixed known points and α is the angle. P is the vertex of the angle. When P moves so that α, the angle subtended by the two points, remains constant, the path described by P (A P P' P" B) is a part of a circle.

If, as in Fig. 121, there are three points in a plane, A, B, and C, and two constant angles, α and β, subtending respectively the chords AB and AC, two circles intersecting at points A and P are determined.

Suppose now that a camera were located at some unknown point P and that A, B, and C represent objects in the field of view whose location on the plane is

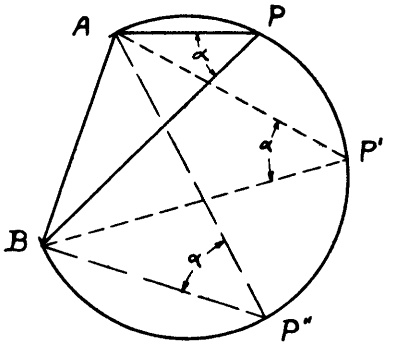


FIG. 120 GEOMETRY OF TWO POINTS AND ANGLE FOR DETERMINING A CIRCLE

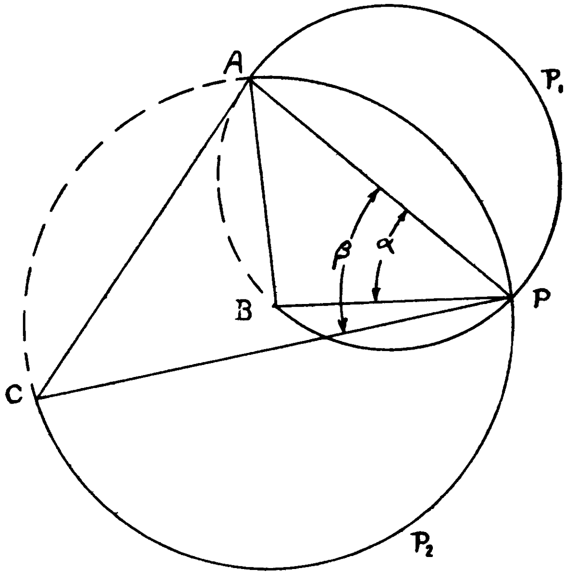


FIG. 121 GEOMETRY OF THREE POINTS AND TWO ANGLES, ONE POINT COMMON TO BOTH ANGLES, FOR DETERMINING INTERSECTING CIRCLES

known. From the photographic plate, knowing the camera's focal length, the angles α and β may be computed. A, B, and angle α determine circle A P B, and likewise A, C, and angle β determine circle A P C. Then the intersection (P) of these two circles is the location of the camera since the camera must be somewhere on each of the two circles and can be in but one place at a given time. It is true that other circles (mirror images of those drawn in Fig. 121) may be drawn and thus the proper point of intersection other than P be ambiguous. However, for any given field problem this ambiguity cannot arise since here the mapped positions of the points A, B, C, and the region relative to these points in which the ship or camera is located will be known.

Figs. 122 and 123 indicate the method of determining the angles subtended by the chosen objectives. Fig. 122 shows the desired elements on the negative. A, B, and C are the selected objects, as for example: a water tower, a chimney, and a church spire. The horizon (H H') is across the center horizontally and (M M') is the vertical centerline of the plate. The watch indicates the time when the particular exposure was made, the third hand being a center post second hand. Point O is the pierce point of the camera's optical axis on the photograph. A deviation of the horizon from O by a few degrees does not affect the results appreciably since, from the geometry of the camera, the correction factor for a given deviation is the cosine of this angle and for small angles, one or two degrees, this is negligible.

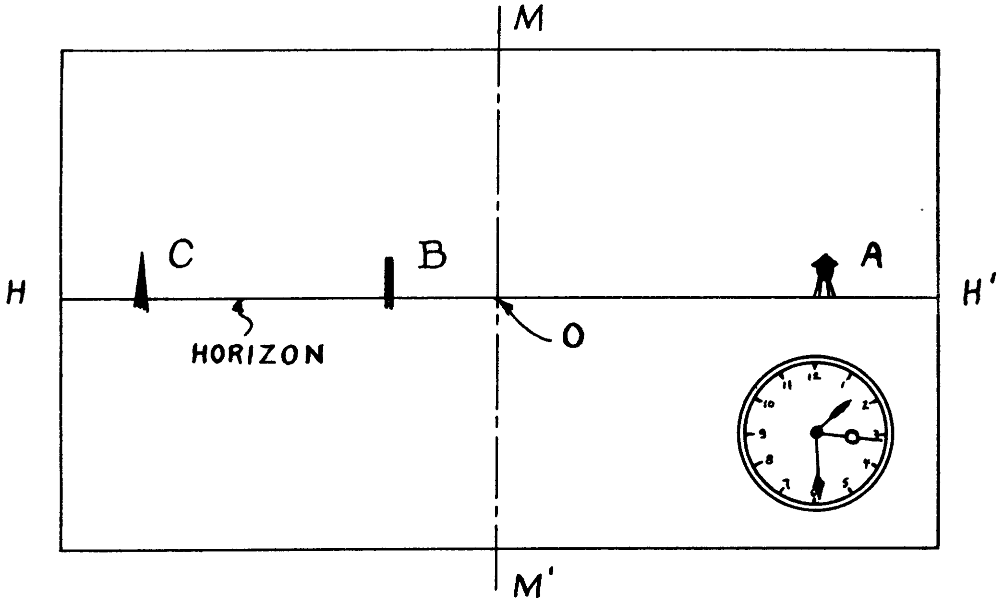


FIG. 122 VIEW OF NEGATIVE SHOWING ELEMENTS TO BE MEASURED FOR DETERMINING ANGLES BETWEEN ELEMENTS

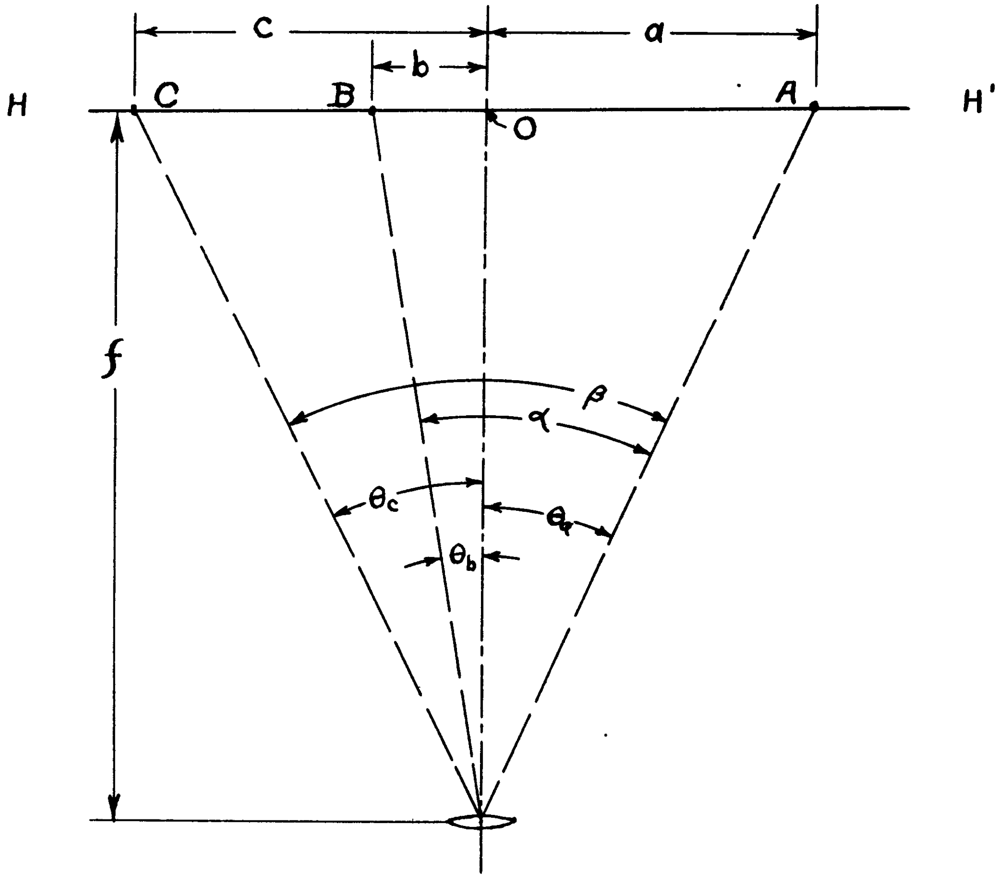


FIG. 123 GEOMETRY OF MEASUREMENTS TAKEN FROM FIG. 122

Fig. 123 shows a horizontal section through the camera on the optical axis. f is the focal length of the camera. After locating the point O, the distances AO, BO, and CO, or a, b, and c respectively, are measured.

Let $a/f = \tan \theta_a$

$b/f = \tan \theta_b$

$c/f = \tan \theta_c$

Then the desired angles (α and β) for this photograph are respectively $(\theta_a + \theta_b)$ and $(\theta_a + \theta_c)$. This process is carried out for all of the plates and the results tabulated.

APPLICATION OF METHOD.

To determine the feasibility of this method a special box camera with a wide angle lens was constructed using 8 by 10 plates. From an inspection of the area surrounding the trial course at Rockland, it was evident that sufficient distinguishable land marks were available for photographing. Accordingly, as the vessel made its turn at the northern end of the course, photographs were made at the instant the rudder was put over and at each 45 degree change of course thereafter. Only four photographs were possible under this procedure since the rudder was generally eased after effecting a 135 degree change of heading in order to make a correct approach to the standardization course. Fig. 124 shows the results attained.

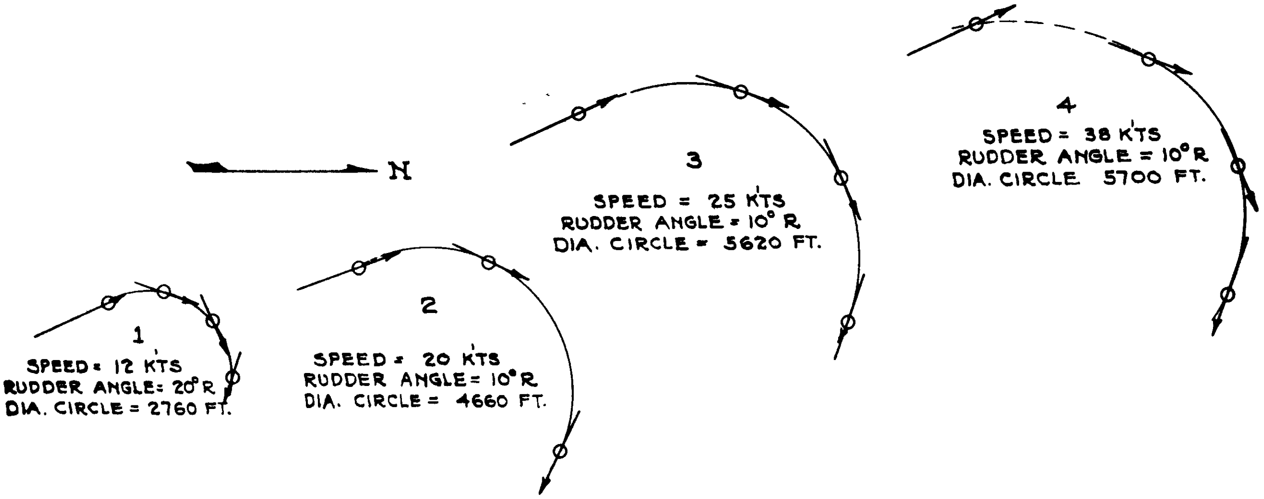


FIG. 124 U.S.S. FARRAGUT. TURNING PATHS DETERMINED BY PHOTOGRAPHIC OBSERVATIONS DURING ACCEPTANCE TRIALS – MAY 1934

APPENDIX 3

U.S.S. FARRAGUT

METHOD OF VISUAL AND PHOTOGRAPHIC OBSERVATIONS FOR DETERMINING TURNING CIRCLES FOR TRIALS OF JULY 1934

VISUAL METHOD.

PRINCIPLE.

This method - designated as method B - is based upon the principle that the position of a third point on a plane is known when the bearings of this point from two mapped points in the same plane are known, the three points not being in a straight line.

Fig. 125 indicates the geometry of this method. The two mapped points are selected shore stations whose positions are accurately determined. The instantaneous position of the ship is represented by the third point. Simultaneous cross bearings from the shore stations will determine the ship's position for the time at which the bearings are taken.

The path of the ship relative to the stations may be determined from successive pairs of bearings taken as the ship moves. In Fig. 125, let points A, B, 0, 1, 2, - - - 14, 15 represent successive ship positions at the times at which simultaneous bearings are recorded by the stations. These points are then the graphical intersections of the bearings from the stations. A smooth curve drawn through these points gives the path of the ship.

METHOD OF RECORDING DATA.

To take the data, that is to record bearings, each station has a plane table, pivoted telescopic alidade, binoculars, and sheets of paper to fit the table. On each sheet of paper, one at each station for each turn of the ship, the bearing line joining the two stations is drawn. During the time that the ship approaches the turning area and while it makes the turn a member of each shore party keeps the telescope of the alidade trained on the ship's foremast. Another observes the ship through the binoculars and watches for the signals - flashes from ship's search-

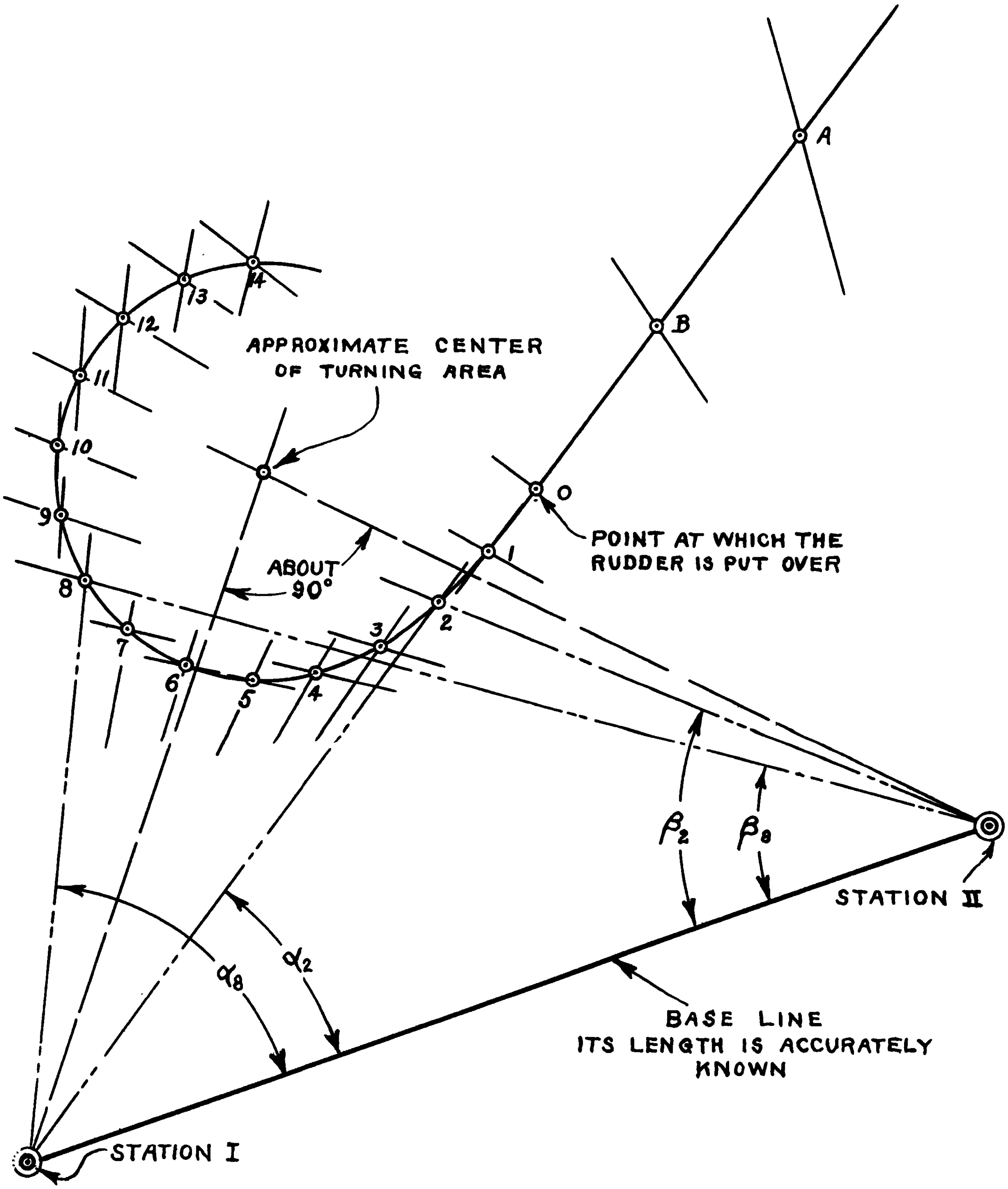


FIG. 125 GEOMETRY FOR DETERMINING TURNING PATH FROM VISUAL OBSERVATIONS

light or other means - that are sent out by the ship at the times bearings are to be recorded. As the proper signals are observed, the observer calls 'mark' for each such signal and the third member of the party records the bearing by drawing a straight line along the ruling edge of the alidade. Each bearing line as it is drawn is numbered according to some scheme as indicated in Fig. 125.

METHOD OF DETERMINING TURNING CIRCLE.

To plot a turning circle from these data corresponding plane table record sheets are oriented on a convenient base line. Corresponding bearing lines are extended until they intersect. As noted above, the smooth curve drawn through these points of intersection gives the ship's turning circle. The scale of the plot is determined by the ratio of the length of the drawn base line to the physical distance between the shore stations.

METHOD OF OBSERVING DATA.

During these particular trials, signals for observing and recording data were controlled by the vessel. After steadying on the approach course three flashes from the signal searchlights - each trained continuously on its station - were sent out when the object, Owls Head Light (on which the rudder was to be shifted when true bearing was 180 degrees) bore approximately 210 degrees true. Two flashes were signaled when Owls Head bore approximately 190 degrees true. When Owls Head bore 180 degrees true, one flash was signaled coincident with the shift of the rudder. These points, corresponding to A, B, O, in Fig. 125 determined the ship's approach and also provided means for measuring RPM and speed. From point O onward, one signal was flashed every 10 seconds during the turn. When the ship's heading had changed by 200 degrees, a five flash signal was given signifying the end of the run.

In the application of this method the choice of shore stations is usually limited. In order to later locate the stations on the map it is convenient to place them near known, mapped points as light houses, chimneys, or watertowers. In this case the stations were located at Owls Head and Breakwater Light - see Fig. 24.

The positions of the stations should also be such that the center of the ship's turning area lies near the perpendicular bisector of the line joining the two stations. Evidently the best condition is obtained when the difference in the simultaneous bearings of the ship from the stations is in the neighborhood of ninety degrees.

Assuming that the best available sites have been chosen for shore stations, the accuracy of this method is determined by the accuracy with which the bearing lines can be drawn and drawn simultaneously. With careful and alert cooperation between ship and shore parties this method is capable of fair and immediate results.

The chief objections to the method are: (a) considerable difficulty is experienced in keeping the telescopes trained on the ship and in drawing the bearing lines on signal, and (b) if a single signal from the ship is unknowingly missed by either station, and this is surprisingly easy to occur, it may later be particularly difficult if not impossible to correctly correlate the data from the stations and plot the particular ship's circle.

PHOTOGRAPHIC METHOD.

INTRODUCTION.

During the preliminary trials in May 1934, no auxiliary method was available for checking the photographic observations while turning. In the proposed trials, photographic observations were to be made coincident with the visual observations. It was evident that the equipment devised for the May 1934 trials would prove unwieldy - firstly because of the number of plates involved, and secondly because of the lack of time for shifting plates in the proposed interval of time between exposures. Accordingly new equipment was considered and devised for the July 1934 trials.

EQUIPMENT.

Because of the number of exposures required per turn, the miniature Leica camera, possessing a maximum of 36 exposures before reloading, presented a feasible solution. As the maximum angle of view of this camera was less than required (approximately 40 degrees whereas 60 degrees were required), it was essential in certain parts of the turn to secure two exposures - one immediately following the other - to cover adequately the contemplated number of shore objectives. To facilitate ease of handling, the camera, chronometer stop watch, and focusing lens were mounted on an arm fashioned like a gun. This provided means for handling and operating the combination expeditiously. Thus, the only time lost between exposures was that necessary to load and reset the shutter. Again, it left the operator free to move about in some restricted area of the ship; that is, within about 10 feet of some specified point on the ship to avoid having the camera's view masked by some part of the ship in making the turn. The error introduced by this movement of the camera is negligible since the tactical diameters range from 1500 to about 3000 feet.

To avoid possible loss of exposures, a 4 x 5 Speed Graphic using film packs, 12 films per pack, was mounted similarly to the Leica and operated from the ship.

Exposures were made at simultaneous intervals corresponding to those given above for visual observation by plane table.

WORKING UP THE DATA.

The photographic films were developed, classified, and measured. Rather than determine and lay down the two circles each time as determined from each photograph in order to fix a point on the ship's path, a general set of circular coordinates was made covering the region in which the ship maneuvered. Fig. 126 shows a simple set of such coordinates indicating the method of their construction. Points A, B, and C represent selected shore objects and M N Q R the general area in which the ship turns.

In order to locate the ship at the time of any exposure it is only necessary to know the corresponding values of the angular coordinates, α and β, as determined from measurements on the photograph. For example if $\alpha = 23^\circ$ and $\beta = 27^\circ$, the position of the ship for this photograph is P, Fig. 126, the intersection of these angular coordinates.

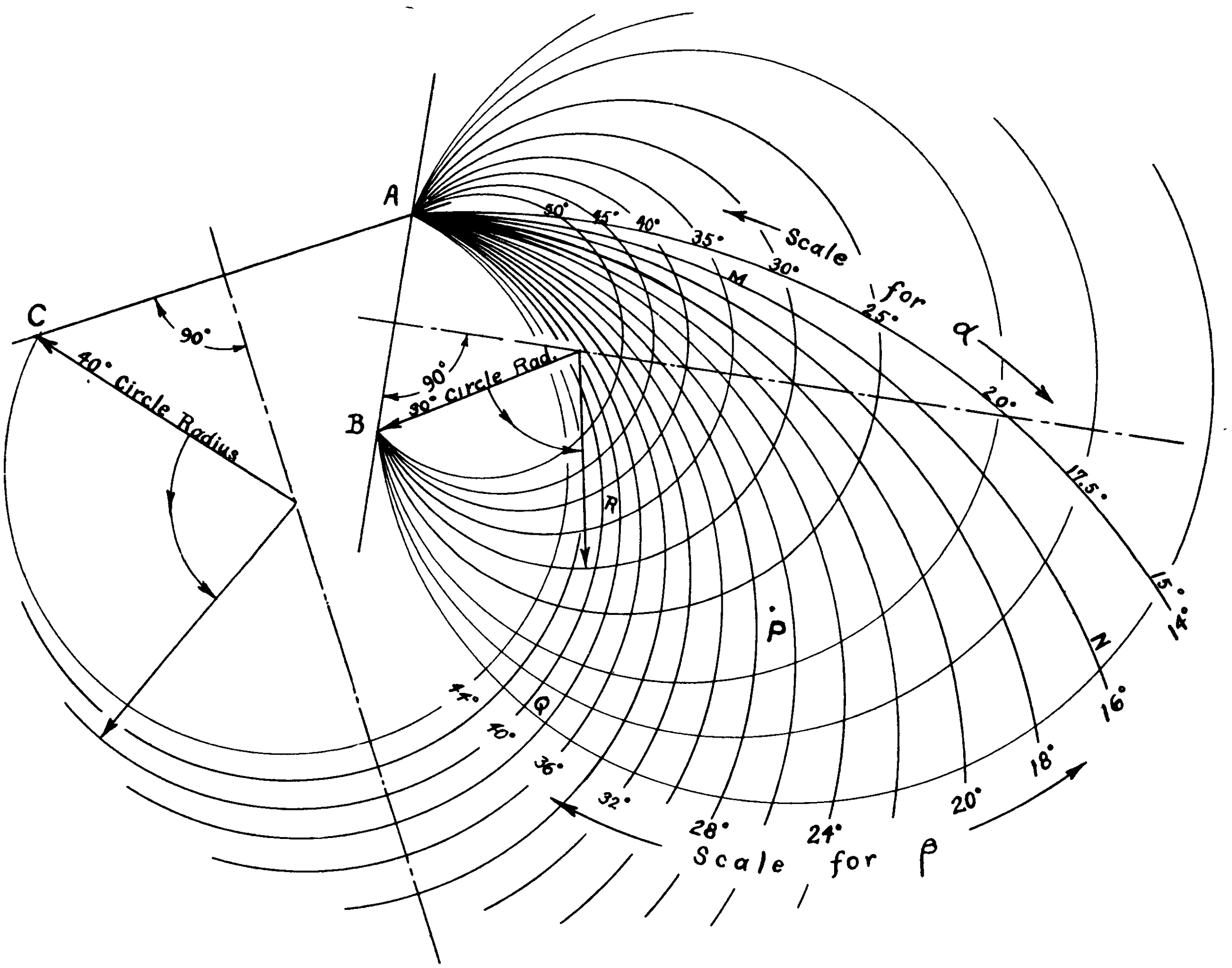


FIG. 126 METHOD OF CONSTRUCTING CIRCULAR COORDINATES FOR PLOTTING ANGULAR COORDINATES RESULTING FROM PHOTOGRAPHIC OBSERVATIONS, ONE CAMERA METHOD, TO DETERMINE TURNING PATH

Fig. 127 shows the set of coordinates laid out in 20 minute intervals on mapped points as actually used in plotting the turning circles. For each circle a tracing cloth is placed over these coordinates, the successive positions of the ship plotted and a curve faired through them. Knowing the scale of the coordinates, any desired dimensions may be taken from the circle.

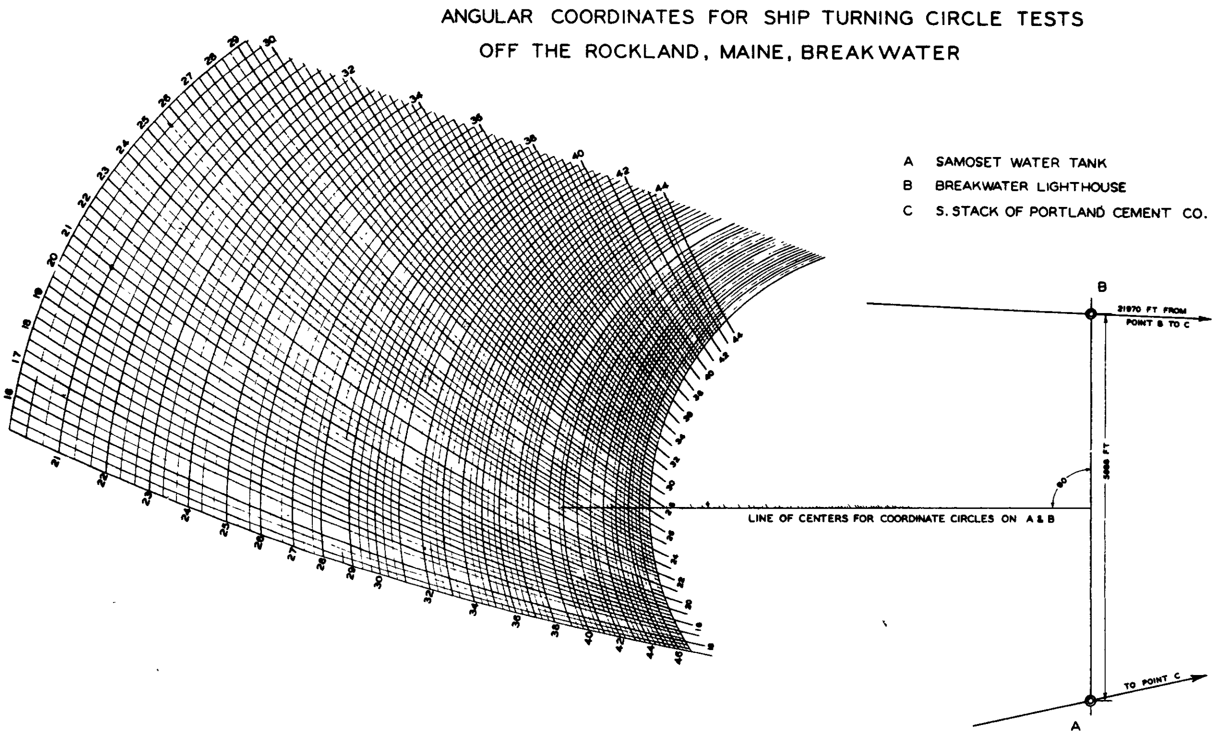


FIG. 127 CIRCULAR COORDINATES FOR TURNING AREA IN ROCKLAND HARBOR, MAINE, FOR PLOTTING ANGULAR COORDINATES FROM PHOTOGRAPHIC OBSERVATIONS, ONE CAMERA, TO DETERMINE TURNING PATH

APPENDIX 4

U.S.S. FARRAGUT
TWO CAMERA METHOD OF MAKING PHOTOGRAPHIC OBSERVATIONS FROM SHORE FOR DETERMINING TURNING CIRCLES

INTRODUCTION.

In view of the difficulties associated with the miniature cameras when used from aboard ship, consideration was given to the use of these miniature cameras from shore.

PRINCIPLE.

The principle of this method, known as method C, is essentially that of method B, Appendix 3. The data, however, are recorded photographically. Successive pictures are taken more or less simultaneously from two shore stations. In each picture appear the images of: the ship, a fixed reference point in the foreground, and a chronometer stop-watch. The watch has a center-post second hand to permit the reading of time to a fifth of a second.

The time at which a picture is taken is indicated by the image of the watch. The general composition of the picture identifies the station from which it is taken. Knowing the focal length of the camera at each station, the respective bearings of the ship relative to the fore ground reference points may be computed from measurements from the photographs.

Fig. 128 shows the geometric essentials of this method. The relative desirable positions of shore stations and ship's turning area are the same as for Method B. The foreground reference points are convenient photographic targets located about fifteen feet from the cameras. They should appear in the pictures just below the horizon line. If placed so as to appear above the horizon there is the possibility that at some time or another they may obscure the ship. The bearing of the reference point from the camera at each station should be about on the center of the ship's turning area.

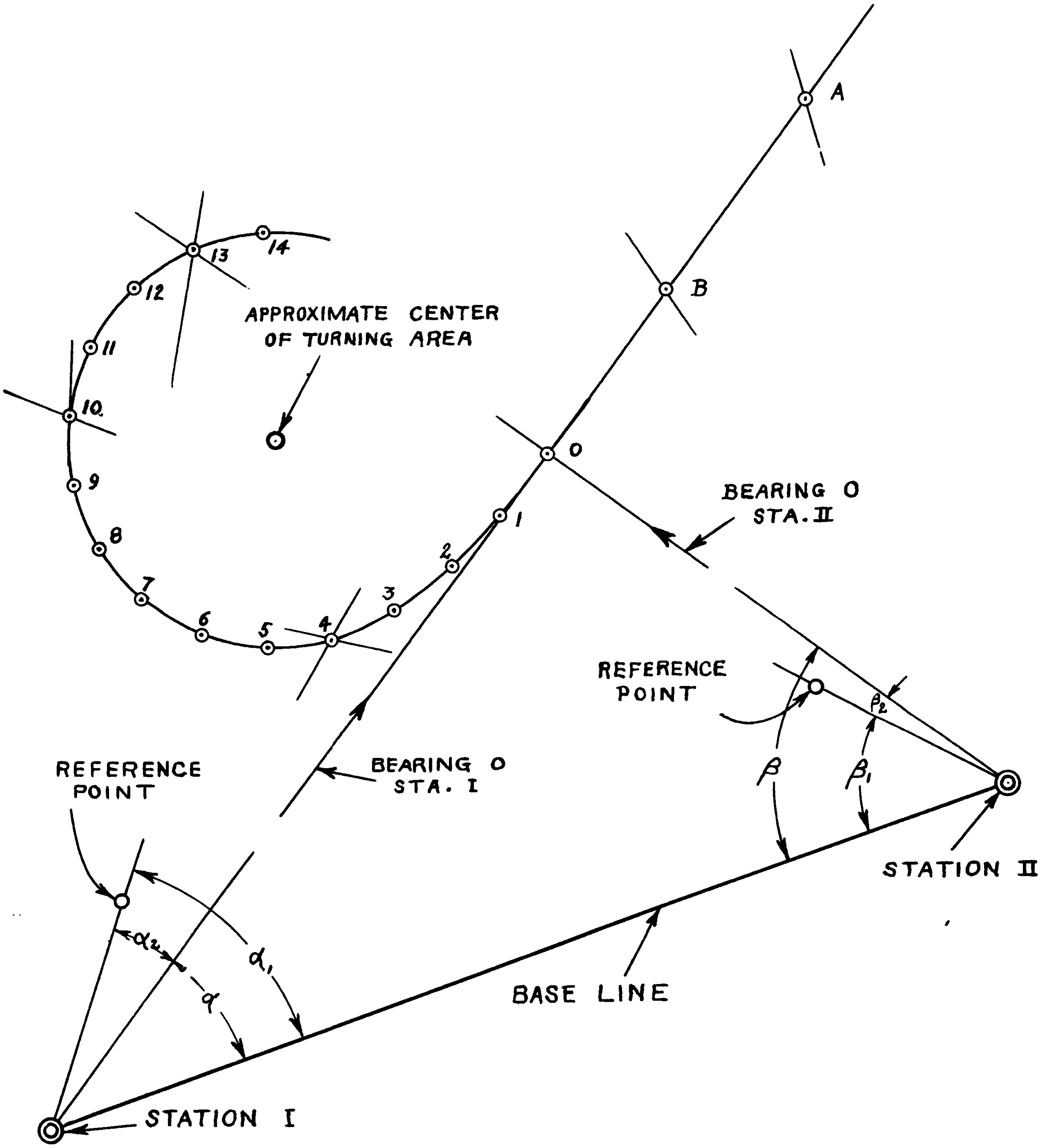


FIG. 128 GEOMETRY OF METHOD FOR DETERMINING TURNING PATH FROM PHOTOGRAPHIC OBSERVATIONS, TWO CAMERAS, FROM SHORE

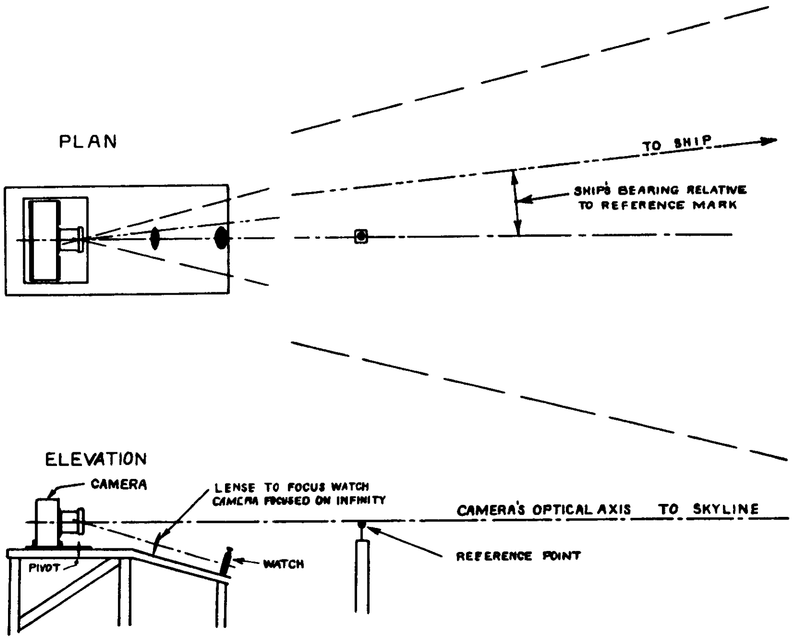


FIG. 129 DETAILS OF ARRANGEMENT OF CAMERA LOCATION FOR OBTAINING TURNING PATH BY PHOTOGRAPHIC OBSERVATIONS FROM SHORE

Fig. 129 shows details of a camera's position. The camera at each station is mounted on a level, rigidly fixed table with the camera's optical axis horizontal. The camera is pivoted about a vertical axis which passes through the center of its lens system. This makes it possible to rotate the instrument without introducing a parallax error between it and the target.

For a given field problem the base line and reference angles α_1, and β_1, (Fig. 128) must be accurately determined. The base line obviously is the line joining the pivots of the two cameras. If the stations are set up near known mapped points, as in Method B, the length of the base line may readily be determined from a few short local measurements. The easiest way in which to determine the reference angle at each station is by the alidade–plane table method, the alidade being pivoted on the camera's pivot. Another method is to make a photographic traverse or panorama (successive overlapping pictures) over this angle from reference point to base line. The angle may then be computed from measurements made on these photographs, the camera's focal length being known. Knowing then, the bearings of the ship relative to the reference points respectively at the two stations and also the bearings of the reference points relative to the base line, cross bearings to the ship are known.

To determine a turning circle of the ship the successive bearings of the ship from the reference points are first obtained from measurements from the photographs. These bearings are next plotted against time as in Fig. 130, and smooth curves are drawn through the points. There are two curves for each run, one for each station. The zero on the time scale is taken as the time at which the rudder is put over for the turn.

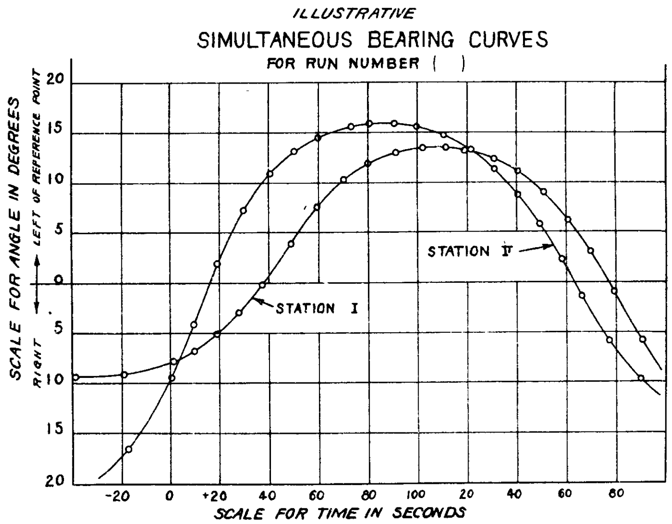


FIG. 130 METHOD OF PLOTTING INDIVIDUAL BEARINGS TO OBTAIN SIMULTANEOUS CROSS BEARINGS FROM PHOTOGRAPHIC OBSERVATIONS, TWO CAMERA METHOD, TO DETERMINE TURNING PATH

Simultaneous cross bearings at desired time intervals are taken from the faired curves. These are then used as in Method B to locate points on the path, the smooth curve drawn through the points then being the path or desired circle. If the time of occurrence of any particular event is known, for example: the time at which the rudder is put over for the turn, the location of this point on the path is readily determined by plotting the simultaneous cross bearings to the ship for this time as obtained from Fig. 130.

This method has a number of advantages over Method B. Simultaneous cross bearings are obtained without the necessity of recording them exactly simultaneously in the field. The record is permanent and may be referred to later as often as necessary for initial and check readings. The possibility of losing the identity of successive bearings for correlating data from two or more stations is eliminated. There is no necessity for keeping an instrument aimed exactly on a point on a moving ship.

Possibly the most important factor in this method, apart from the fact that the cameras must be precision instruments, is the time scale. The stop watches, images of which appear on each picture indicating the time of the exposure, must be synchronized at the beginning of a day's work with the ship's chronometer and checked with it again at the end of the day. Knowing the time at which the watches were set together and their relative time rates, all exposures can be determined in terms of ship's chronometer time.

Errors due to film distortion were found to be negligible. The film used was Eastman Panatomic Movie Film, thirty exposures per roll. The cameras were miniature Leica Cameras each equipped with 50 mm, F/3.5 lenses, K2 yellow filters, and sun shades. The size of negative produced by these cameras is 0.96 inches by 1.44 inches.

APPENDIX 5

COMPARISON AND ACCURACY OF METHODS FOR MEASURING SHIP'S TURNING CIRCLES

As detailed in Appendices 2-4, three basic methods for determining turning circle measurements were developed. These, briefly, are

Method A	Photographic observations from the ship of the successive relative position of three or more known shore objects.
Method B	Simultaneous cross bearings observed visually from known land stations.
Method C	Simultaneous cross bearings observed photographically from known land stations.

The selection of one of the above methods is dictated largely by external conditions of visibility, topography of the shore line in the immediate vicinity of the turning area, and the normal idiosyncrasies of weather surrounding the particular area selected for trials.

Under ideal conditions of background, visibility of shore objects, and lack of haze, method A is more accurate and practical than method C. Method A requires but one camera, this located on the ship. There is but one watch to be set with the ship's chronometer. The adoption of a scheme for identifying one negative or picture of each set of exposures, as for example, by making the third exposure coincide with the instant that the rudder is shifted in making the turn, then, the exact setting of the watch with the ship's chronometer is not essential. The time scale is useful in identifying pictures of a set and their order. It would also prove useful for determining the speed of the ship in any part of the turn.

Lastly, method A requires the services of but one camera operator to take all of the required data for determining turning circles, the need for co-ordinating several ship and shore parties, as in methods B and C, being absent.

The objections to method A are several. Firstly, suitable shore targets, as a rule, do not exist where near shore conditions (depth of water and traffic) permit turning. Secondly, suitable shore targets, such as spires, towers, chimneys, etc. are not always visible, photographically - that is against the usual background-to ensure uniform success. Thirdly, the angular spacing between objects, as viewed on the camera, does not approach the ideal as indicated in Fig. 122.

As against this, method C possesses none of the disadvantages as regards shore conditions. The only requirement for this method is that the reference angles for each station and the base line between the two stations (its length) be accurately known. Because of the size of the vessel, it is normally visible photographically.

In so far as photographic equipment is concerned, method A requires a camera equipped with a wide angle, long focal length lens. Because of the number of exposures required in one turn, the types of cameras available are limited. Of the cameras used for this method, the Fairchild Aerial Camera gave the best results. This camera was equipped with a wide angle lens, F/4.5 and of 7.35 inch focal length. The Eastman non-shrink aero film, 18 foot roll giving 36 exposures per roll was found satisfactory.

The miniature Leica camera was also used in this method. Other things being equal, a smaller camera is best because of the ease with which it may be handled and operated. Due to the lack of appropriate shore objects for its short focus lens, and because of its small angle of view (forty degrees, whereas at least fifty or sixty are required) this camera proved impractical for method A. However, in those cases where the images of the shore targets were visible, the accuracy with which the ship's position could be computed from its small negative was comparable with that for the larger Fairchild camera.

Because of the relative ease with which exposures could be made with the miniature Leica, this camera was ideal for method C. No other type was considered or employed for this method.

Lastly, the visual method of observing simultaneous bearings was employed in all trials mainly to give a rapid means for determining the results - both photographic methods involved the necessity of developing the films, measuring each negative, and then calculating the necessary data before any results could be plotted.

The above discussion of choice has been guided largely by external factors and conditions. It is now necessary to consider the accuracy of the three methods.

Comparative accuracy may be considered from several points of view: the theoretical, the practical under ideal conditions, and the practical as applied.

Theoretically all three of the described methods are capable of equally high accuracy. They all depend upon measuring angles of the same magnitude and determining simultaneous reference bearings.

Practically, under ideal conditions, method A would give the greatest accuracy followed in order by C and B. Method A is independent of the human or personal element except for establishing one zero or reference mark for each turn on the scale of events as noted above. In this method recorded simultaneous bearings are absolutely simultaneous since both bearings of a pair are obtained from a single photographic exposure. Also in working up the data it is most direct, the process being only a matter of measuring the photographs and plotting the turning circles. It is assumed that the chart of angular coordinates may be drawn with any desired degree of accuracy.

Method C should be capable of not more than one fourth of the accuracy of method A because it requires two camera's operated by two independent people and in addition requires the cooperation of three ship parties with two shore parties, thus more than doubly doubling the human element. It also requires absolute synchronization of watches or some means of obtaining simultaneous bearings. Thus, where as in method A simultaneous bearings are obtained in fact, in method C their simultaneousness is determined indirectly and is never exact. It is, however, determined mechanically. Method C is less direct from photographic record to the plotted turning circle by two steps. It has two films to be measured instead of one and the bearings for plotting are determined from faired curves.

Method B should be capable of fair accuracy but considerably less than that of method C. The human element is fully doubled in its application and once a bearing is recorded it cannot be checked. The simultaneous feature of cross bearings is obtained entirely from human cooperation by a double relay of separate signals from ship to bearing recorder. A partially compensating feature of this method may be: that of the three methods it is the most direct from recorded data to plotted turning circle.

In making these comparisons it is assumed that triangulation data is equally accurate for them all. Thus the positions of the shore targets for method A are known as accurately as are those of the shore stations in methods C and B.

In comparing these methods for actual use reliability as well as accuracy must be considered. Methods B and C hold their comparative positions as noted above. Method A, however, is likely to pass from the extreme of greatest accuracy to the other of complete uselessness. This is due to the fact that it must make use of available shore targets, both in regard to their form, their relative position, and their visibility. Photographic visibility of these objects determines the accuracy with which measurements may be taken from the films.

In general then method A may be eliminated. Method C is far the better of the remaining two in degree of accuracy but it is the more complicated from the standpoint of working up the results. Method B is capable of giving immediate results but is subject to a large number of errors.