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MANEUVERABILITY CHARACTERISTICS OF VARIOUS TYPES
OF REPLENISHMENT SHIPS

by

W. G. Surber, Jr and S. C. Gover

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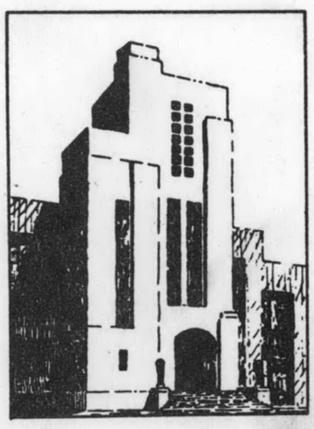

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ABSTRACT

Full-scale maneuvering trials and correlative model tests have been conducted on various types of replenishment vessels to evaluate their control characteristics. Quantitative data are given for the following types of vessels: AO105 and AO143 Class Fleet Oilers, AE12 and AE21 Class Ammunition Ships, and the AF58 Class Store Ships.

INTRODUCTION

The forces afloat have expressed a need for better controllability of replenishment type vessels[1]. Before attempting to improve the control of these vessels the Bureau of Ships requested the David Taylor Model Basin to conduct full-scale maneuvering trials and correlative model tests on various types of replenishment ships to establish their present control characteristics[2].

Accordingly, a program was initiated to evaluate the performance of such vessels on the basis of definitive maneuvers. The characteristics of these maneuvers, in most cases can be expressed numerically and when sufficient data are accumulated will provide a set of objective standards which can be applied toward the development of vessels with improved controllability[3]. Two types of maneuvers were used for this program; the spiral maneuver which provides a measure of directional stability or ability of the vessel to maintain course with a minimum of rudder action and the zig-zag maneuver which primarily provides data on the effectiveness of the rudder in initiating and checking turns.

Data for the following ships are presented and analyzed in this report; AO105 and AO143 Class Fleet Oilers, AE12 and AE21 Class Ammunition Ships, and the AF58 Class Store Ships.

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[1] References are listed on page 39

DESCRIPTION OF SHIPS AND MODELS

The principal dimensions and test conditions of each of the vessels are given in Table 1. A sketch of the stern of each ship is shown in Figures 1 through 5. It will be noted that though two of the vessels have two propellers, and three have a single propeller, all are equipped with a single rudder.

The USS PAWCATUCK (AO108) is representative of the AO105 Class Fleet Oilers. This class is equipped with an unbalanced rudder and propeller bossings whereas the AO22 class has a semi-balanced rudder and propeller struts. The model rudder was arranged to permit its conversion from the normal unbalanced rudder to a flap rudder to enable a comparison of the control effectiveness of the two rudder types. A sketch of the rudder is shown in Figure 6.

The USS NEOSHO (AO143) represents the latest class of fleet oilers and is 18 percent longer than the AO105 class. The ship is driven by two propellers whose shafts are supported by struts. The single semi-balanced rudder has 31 percent more area than the AO105 class. The trial displacement was so light and the trim by the stern so large, that an additional model test was made at a corresponding displacement of 31,600 tons and a trim of 9 inches by the stern. The effect of displacement on the submergence of the rudder may be noted by the waterlines shown in Figure 2.

The USS DIAMOND HEAD (AE19) is representative of the AE12 class. This class of vessel is driven by a single-screw behind a contra-stern and is steered by a single contra-rudder.

The USS SURIBACHI (AE21) which represents a new class was just completed recently and consequently only model test data are available at this time. The model has a single propeller and a semi-balanced rudder. An additional test was made with a section of the skeg removed as shown in Figure 4 to determine the effect on control.

The USS RIGEL (AF58) is the first of a new class of Store Ships, and is equipped with a single-propeller and a single contra-rudder.

TRIAL AND TEST PROCEDURES

A list of the dates and locations of the full-scale trials and model tests is given in Table 2.

TABLE 1
Ship and Model Data

	A0108	A0143	AE19	AE21	AF58
Model No.	3840	4582	4622	4521	4442
Linear Ratio	26.25	30.82	21.75	25.00	25.00
Length between Perpendiculars, ft	525.0	640.0	435.0	486.0	475.0
Beam, ft	75.3	86.0	63.0	72.0	72.0
Draft, Mean, ft	26.25	18.88	22.75	26.50	18.63
Trim by Stern, ft	1.0	8.75	3.5	0.0	6.08
Displacement, tons	18,845	19,000	12,100	15,520	10,230
Length-Beam Ratio, L/B	6.97	7.44	6.90	6.75	6.60
Beam-Draft Ratio, B/H	2.87	4.56	2.77	2.72	3.85
Draft-Length Ratio, H/L	0.0500	0.0290	0.0523	0.0545	0.0394
Displacement-Length Ratio, $\Delta/(L/100)^3$	130.23	72.48	147.00	135.20	95.92
Prismatic Coefficient	0.670	0.717	0.696	0.611	0.621
Number of Propellers	2	2	1	1	1
Propeller Diameter, ft	17.5	18.0	19.0	21.5	22.0
Number of Rudders	1	1	1	1	1
Rudder Area, sq ft	270.0	392.0	170.0	292.0	245.0
Rudder Balance, percent	0.0	24.0	0.0	26.0	0.0
Rudder Aspect Ratio, $(\text{span})^2$/area	1.45	1.18	2.27	2.23	2.36
Rudder Area/Length x Draft	0.0196	0.0325	0.0172	0.0227	0.0276
Rudder Area/Length^2	0.00098	0.00096	0.00090	0.00124	0.00108
Rudder Rate, Average, deg/sec	2.7	3.0	3.5	2.8	3.4

TABLE 2

Dates and Locations of Trials and Model Tests

Ship and Model	Date	Location
USS PAWCATUCK (AO108)	22 November 1955	Port Everglades, Fla.
Model 3840	16 February 1956	DTMB
USS NEOSHO (AO143)	2 August 1956	Norfolk, Virginia
Model 4582	27 January 1956	DTMB
USS DIAMOND HEAD (AE19)	27 March 1956	Norfolk, Virginia
Model 4622	24 September 1956	DTMB
USS AE21 Class	-	-
Model 4521	15 July 1955	DTMB
USS RIGEL (AF58)	27 February 1956	Guantanamo Bay, Cuba
Model 4442 W	8 June 1956	DTMB

A typical trial agenda is shown in Appendix 1. During some of the trials weather and operating conditions did not permit the completion of all of the tests requested in the agenda. However, in each case it was felt that sufficient data had been obtained to evaluate the control characteristics of each vessel. Spiral and zig-zag tests were used to obtain maneuvering data to determine controllability.

The spiral maneuver is a test adopted from directional stability studies of Dieudonné in which the steady rate of change of heading for various left, right, and zero rudder angles is measured[4]. An analysis of these data provides a measure of directional stability on course as well as the amount of rudder angle necessary to check the swing of the ship.

Full-scale spiral tests are conducted in the following manner. The steersman lays the rudder to 10 or 15 degrees right. After a steady turning rate has been obtained the rudder is shifted to a smaller angle. This procedure is continued through zero to 10 or 15 degrees left and returned. The test is normally conducted at two speeds, and in each case the throttles should remain fixed throughout each test.

When conducting model spiral tests in the narrow confines of the Model Basin, it is necessary to obtain the data by a series of short turns at various rudder settings. The data are recorded on Brown Recorders which receive signals from a rate gyro, heading gyro, and rudder angle indicator.

The zig-zag maneuver, which was extensively used in maneuvering studies by Kempf[5], is employed as a measure of control effectiveness as well as to provide operational data for ship-handling officers. The maneuver consists of steering the ship or model in a zig-zag pattern by alternate use of equal increments of rudder angle in both directions after equal changes of heading from the base course have been reached.

Directions for conducting zig-zag maneuvers during full-scale trials are given in Appendix 1. The conduct of such a test with a model is essentially the same.

For the model tests, ballast was arranged in the models in an attempt to simulate the radii of gyration of the ships. Only an approximation could be made as the gyradii for the ships were not known. It must also be noted that the models were not under the influences of wind and sea conditions as were the full-scale vessels.

PRESENTATION OF RESULTS

The preliminary results of each of the full-scale trials mentioned in this report have been previously reported in References 2, 6, 7 and 8. The preliminary results from model tests of AE21 were reported in Reference 9.

The data from the full-scale spiral maneuvers for each vessel are shown with the corresponding model test data predictions in Figures 7 through 11. Each figure contains data for two speeds except for AE21 where only one speed was used.

Figure 12 compares the results from model spiral tests of AO108 with the rudder flap fixed (to simulate the normal un-balanced rudder), and with the flap working.

Figure 13 contains the results from model tests of AO143 to measure the effect of large differences in displacement and trim on turning rate.

The effect of removal of skeg area upon the turning rate of the model of AE21 is shown in Figure 10.

The principal data derived from the zig-zag maneuver are time to change heading, rate of change of heading, overswing angle of the vessel after the rudder has been reversed, time to return to base heading (referred to in this report as reach) and the period of the maneuver, (defined as time from 2nd execute to 4th execute, or time of one complete cycle).

The data from the zig-zags are summarized in Tables 3 through 7. The turning rates are those obtained at the execute points, and are not necessarily maximum rates which would have been obtained if the rudder had not been reversed. The overswing angle is the difference between the heading at a given execute point and the maximum heading obtained before the ship or model reverses direction. Reach, as defined for these tables, is the elapsed time between the first rudder movement and when the vessel returns to the initial heading following the reversal of the rudder at second execute.

A portion of the data from Tables 3 through 7 is given in the design data sheet for each vessel with the following variations. The times from first to second and third executes are given in terms of ship lengths traveled. The turning rate is given as a turning rate coefficient which is defined as the turning rate in degrees per second times the ratio of ship length in feet to approach speed in feet per second [10]. Reach is also specified in terms of ship lengths traveled. All of the data shown on the design data sheets were obtained from model tests only.

A plot of a zig-zag maneuver using 20 degrees rudder angle after 20 degree changes from base course is given for each vessel in Figures 14 through 18. The plots at the higher approach speeds are shown since they represent the vessels' ability to recover from course changes more adequately than would plots for lower speeds. Model tests of A0108 at 16 knots were not made due to the inability of the model to complete such a maneuver within the small confines of the model basin. However, a plot for both ship and model at 8 knots is given in Figure 19.

Figure 20 presents a comparative plot of the zig-zags from the full-scale trials of the A0108 and A0143.

DISCUSSION OF RESULTS

SPIRAL MANEUVERS

The results from a spiral maneuver give a good indication of the directional stability of the vessel, and demonstrate the amount of rudder angle necessary to check the swing of the vessel when attempting to maintain course.

TABLE 3

Summary of Zig-Zag Maneuvers from Full-Scale Trials and Model Test of A0108

Rudder Angle in degrees	Change in Heading in degrees, Port and Starboard	Time from First Execute in seconds to Execute:			Turning Rate in degrees/second, at Execute:			Overswing Angle in degrees after Execute:			Reach* in seconds
		2	3	4	2	3	4	2	3	4	
Full-Scale Trials Approach Speed 8 knots Speed-Length Ratio 0.35											
10	10	96	273	609	0.15	0.28	0.24	4.0	14.0	7.0	238
20	20	100	320	563	0.34	0.41	0.40	9.5	9.5	12.0	275
Full-Scale Trials Approach Speed 16 knots Speed-Length Ratio 0.70											
10	10	60	205	412	0.25	0.50	0.48	7.0	19.0	15.0	185
20R	20	53	183	325	0.58	0.70	0.73	11.5	13.5	15.0	155
20L	20	56	193	342	0.58	0.70	0.73	14.0	16.0	15.0	165
Model Test Approach Speed 8 knots Speed-Length Ratio 0.35											
5	5	101	386	716	0.08	0.16	0.15	4.0	6.5		348
10	5	60	238	433	0.13	0.21	0.21	3.0	5.5	6.5	209
10	10	93	322		0.18	0.25		4.0	8.5		278
15	10	72	248	453	0.25	0.35		5.0	8.5	7.5	215
15	15	90	295		0.26	0.37		5.0			250
15	20	103			0.30			6.5			
20	20	93	299		0.36	0.46		7.0			252
Model Test Approach Speed 16 knots Speed-Length Ratio 0.70											
10	10	53	191		0.37	0.53		7.0			
20	10	35	126		0.55	0.53		8.0	12.5		
20	12	40	137		0.58	0.76		8.0			
20	14	44	146		0.59	0.78		8.0			
20	16	45	157		0.61	0.81		9.0	13.5		

* Time elapsed between first execute and when the ship returns to base course

TABLE 4

Summary of Zig-Zag Maneuvers from Full-Scale Trials and Model Test of A0143

Rudder Angle in degrees	Change in Heading in degrees, Port and Starboard	Time from First Execute in seconds to Execute: 2	3	4	Turning Rate in degrees/second, at Execute: 2	3	4	Overswing Angle in degrees after Execute: 2	3	4	Reach* in seconds
Full-Scale Trials Approach Speed 10 knots Speed-Length Ratio 0.395											
10	10	62	210	368	0.25	0.34	0.35	5.5	7.0	7.0	180
20	20	67	220	393	0.42	0.56	0.47	10.0	9.5	9.0	185
Full-Scale Trials Approach Speed 17 knots Speed-Length Ratio 0.67											
10	10	48	149	273	0.44	0.56	0.56	6.0	9.0	8.0	130
20	20	49	159	281	0.65	0.80	0.72	11.0	12.0	11.0	135
Model Test Approach Speed 10 knots Speed-Length Ratio 0.395											
10	10	70	273	429	0.27	0.27	0.32	5.0	4.0	7.0	227
15	5	54	161	248	0.29	0.29	0.34	4.5	3.5	4.3	144
15	10	67	212	328	0.34	0.34	0.41	5.0	4.3	5.3	179
15	15	77	247	401	0.36	0.36	0.40	5.0	4.5	6.0	207
20	10	53	169	281	0.38	0.40	0.44	4.8	5.3	6.0	142
20	20	85	265	428	0.45	0.41	0.45	6.5	5.5	7.0	214
Model Test Approach Speed 17 knots Speed-Length Ratio 0.67											
10	10	57	179	281	0.38	0.44	0.50	4.3	5.0	6.0	154
15	5	46	117	185	0.42	0.50	0.57	6.0	6.5	7.0	111
15	10	53	150	231	0.50	0.56	0.61	6.0	5.0	7.0	131
15	15	74	193	300	0.56	0.58	0.62	7.5	7.0	10.0	165
20	5	40	106	168	0.52	0.59	0.63	7.3	7.5	8.0	97
20	10	47	139	213	0.61	0.65	0.70	9.0	7.3	8.0	119
20	15	49	149	239	0.67	0.67	0.72	8.0	6.0	7.0	126
20	20	64	188	312	0.72	0.68	0.70	10.0	11.0	11.5	158

* Time elapsed between first execute and when the ship returns to base course

Table 5

Summary of Zig-Zag Maneuvers from Full-Scale Trials and Model Test of AE19

Rudder Angle in degrees	Change in Heading in degrees, Port and Starboard	Time from First Execute in seconds to Execute:			Turning Rate in degrees/second, at Execute:			Overswing Angle in degrees after Execute:			Reach* in seconds
		2	3	4	2	3	4	2	3	4	
Full-Scale Trials Approach Speed 7.5 knots Speed-Length Ratio 0.36											
10R	10	70	205	355	0.22	0.27	0.26	3.0	4.0	3.5	168
10L	10	68	210	358	0.21	0.28	0.28	3.5	4.0	4.0	172
20R	20	75	238	410	0.35	0.40	0.35	5.0	6.0	5.5	185
20L	20	76	240	405	0.35	0.38	0.40	5.5	5.5	6.0	185
Full-Scale Trials Approach Speed 15 knots Speed-Length Ratio 0.72											
10R	10	40	120	200	0.37	0.45	0.47	4.0	4.5	4.0	97
10L	10	40	120	203	0.37	0.43	0.43	4.0	4.0	4.0	98
20R	20	44	138	238	0.65	0.70	0.65	7.5	8.0	7.0	108
20L	20	43	144	245	0.68	0.65	0.60	8.5	7.0	7.0	113
Model Test Approach Speed 7.5 knots Speed-Length Ratio 0.36											
10R	10	71	219	379	0.25	0.30	0.27	4.0	4.0	4.7	183
15R	15	80	232	389	0.35	0.40	0.35	6.0	6.0	6.5	190
20R	20	71	230	402	0.44	0.46	0.42	7.5	7.5	7.0	183
Model Test Approach Speed 15 knots Speed-Length Ratio 0.72											
10R	10	37	124	211	0.43	0.50	0.46	5.0	4.7	5.4	103
15R	15	38	127	216	0.62	0.65	0.60	6.5	5.5	7.0	104
20R	20	39	129	222	0.72	0.75	0.70	9.0	8.5	9.0	103

* Time elapsed between first execute and when the ship returns to base course

TABLE 6

Summary of Zig-Zag Maneuvers from Model Test of AE21
with Full Skeg and with Skeg Shortened

Rudder Angle in degrees	Change in Heading in degrees Port and Starboard	Time from First Execute in seconds to Execute:			Turning Rate in degrees/second, at Execute:			Overswing Angle in degrees after Execute:			Reach* in seconds
		2	3	4	2	3	4	2	3	4	
Approach Speed 14 knots Speed-Length Ratio 0.635 Full Skeg											
10	10	35	99	166	0.44	0.60	0.50	3.5	5.0	-	90
10	15	50	148	-	0.46	0.70	-	3.5	6.0	-	111
20	20	48	-	-	0.70	-	-	6.0	-	-	110
Approach Speed 14 knots Speed-Length Ratio 0.635 Shortened Skeg											
10	10	38	114	-	0.56	0.75	-	4.5	9.5	-	98

* Time elapsed between first execute and when the ship returns to base course

TABLE 7

Summary of Zig-Zag Maneuvers from Full-Scale Trials and Model Test of AF58

Rudder Angle in degrees	Change in Heading in degrees, Port and Starboard	Time from First Execute in seconds to Execute: 2	3	4	Turning Rate in degrees/second, at Execute: 2	3	4	Overswing Angle in degrees after Execute: 2	3	4	Reach* in seconds
Full-Scale Trials Approach Speed 10 knots Speed-Length Ratio 0.46											
10R	10	55	146	245	0.40	0.49	0.45	4.5	4.0	4.5	125
10L	10	50	144	249	0.40	0.50	0.45	4.0	5.0	5.0	125
20R	20	50	160	274	0.67	0.63	0.55	7.0	6.0	8.0	128
20L	20	47	160	276	0.70	0.60	0.62	7.0	8.5	7.0	128
Full-Scale Trials Approach Speed 17 knots Speed-Length Ratio 0.78											
10R	10	27	92	157	0.67	0.69	0.70	4.0	6.0	5.5	77
10L	10	27	93	157	0.63	0.68	0.70	5.5	5.0	5.5	79
20R	20	34	110	178	1.25	1.08	1.02	10.0	10.0	9.5	91
20L	20	36	112	189	1.15	1.05	0.98	9.5	9.0	10.0	92
Model Test Approach Speed 10 knots Speed-Length Ratio 0.46											
5R	5	43	142	270	0.18	0.26	0.23	2.0	3.7	3.2	119
10R	10	45	148	263	0.36	0.44	0.38	4.0	5.0	6.0	123
15R	15	47	159	278	0.30	0.55	0.48	6.8	6.2	5.3	130
20R	20	47	160	289	0.61	0.64	0.56	7.5	7.5	7.5	127
Model Test Approach Speed 17 knots Speed-Length Ratio 0.78											
5R	5	26	108	173	0.32	0.32	0.34	3.0	2.0	3.8	91
10R	10	34	111	180	0.52	0.62	0.57	5.0	5.3	6.0	89
15R	15	43	119	197	0.73	0.78	0.73	7.0	7.5	7.0	99
20R	20	38	118	202	0.88	0.95	0.84	8.5	8.0	8.0	97

* Time elapsed between first execute and when the ship returns to base course

The spiral curves for A0108 and A0143, Figures 7 and 8, show hysteresis loops which indicate small amounts of directional instability. The A0108 at 8 knots requires more than 2 or 3 degrees of opposite rudder angle to check the swing of the vessel. The A0143 requires more than 5 degrees rudder to check the swing at 10 knots. An increase in speed reduced the degree of instability in both ships.

It will be noted from Figures 9, 10, and 11 that there is no hysteresis evident in the spirals for AE19, AE21, and AF58 which indicates very good directional stability at both speeds. These ships are single-screw vessels whereas the A0108 and A0143 have twin screws. The fact that the rudder is directly in the slip-stream at zero and small angles might explain the better directional stability characteristic of the single screw vessels. However, this assumption should be explored more fully before this conclusion is drawn. The reduction in skeg area of AE21 increased the turning rate but had no noticeable adverse effect on directional stability.

The model test results of A0108 with a flap rudder indicate higher turning rates although practically no improvement in directional stability on course, as shown in Figure 12. This could be expected since the flap would have very little effective angle at small rudder angles and none at zero angle. It was noted in the heavy displacement test of the A0143 model that the turning rate was increased and directional stability decreased as compared to the light displacement (Figure 13). This is apparently due to the accompanying decrease of 8 feet in trim by the stern which decreases the stabilizing effect of the stern and its resistance to turning. Figure 2 shows that at light displacement the rudder is not completely submerged tending to lessen its turning effectiveness.

It is felt that with all the variables involved in the full-scale trials including weather and sea conditions, and improper adjustment and operation of the ships steering systems, that generally good correlation between ship data and model predictions was obtained.

ZIG-ZAG MANEUVERS

The zig-zag maneuver shows clearly the response of a vessel to rudder action in altering course or checking a change in course. It also serves to compare maneuvering characteristics of different vessels and to assist in determing the effect of hull and appendage alterations on maneuverability of a given vessel.

Figure 20 shows that the turning rate and ability to alter course is much better for the AO143 than the AO108. This does not prove the AO143 to be entirely satisfactory but does show the inadequacy of rudder power for the AO108. The improvement in maneuvering by the alteration of the existing rudder into a flap rudder may be seen in Figure 19.

The reduction in skeg area of AE21 increased both the turning rate and overswing angle, as would be expected, since the reduction of skeg area tends to lessen the directional stability of the vessel.

CONCLUSIONS

As the result of maneuvering tests with both full-scale ships and models the following conclusions concerning the maneuverability of replenishment ships can be drawn:

1. The single screw vessels, AE19, AE21, and AF58 have better directional stability on course than the twin-screw vessels AO108 and AO143.

2. The larger rudder area coefficient of the AO143 produces higher turning rates and better recovery than is obtained with the AO108, but does not improve the course-keeping qualities.

3. The maneuverability characteristics predicted from model tests appears to be somewhat better than those indicated by the full-scale trials of the AE12 Class.

4. Model spiral tests of AO143 indicate the vessel has better directional stability at light displacement with a large trim by the stern than at heavy displacement, with a small trim by the stern.

5. The flap rudder improves the maneuvering characteristics of the AO105 Class.

6. The removal of skeg area of AE21 increases the turning rate and overswing angle, but has no noticeable adverse effect on maintaining straight course.

7. In view of the sea and wind conditions experienced during the full-scale trials it is felt that the correlations between ship and model were generally good.

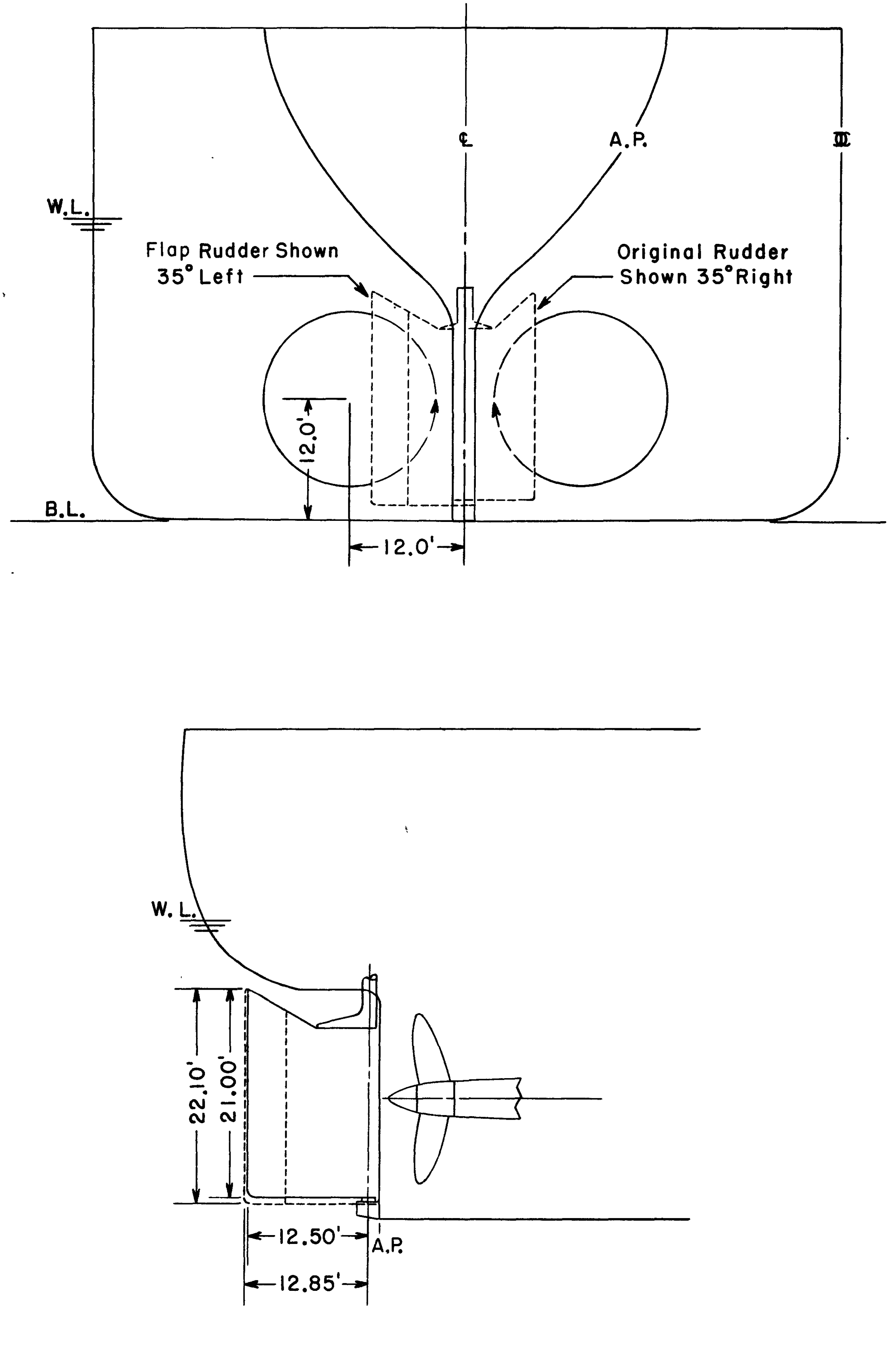


Figure 1 — Stern Arrangement of AO 108

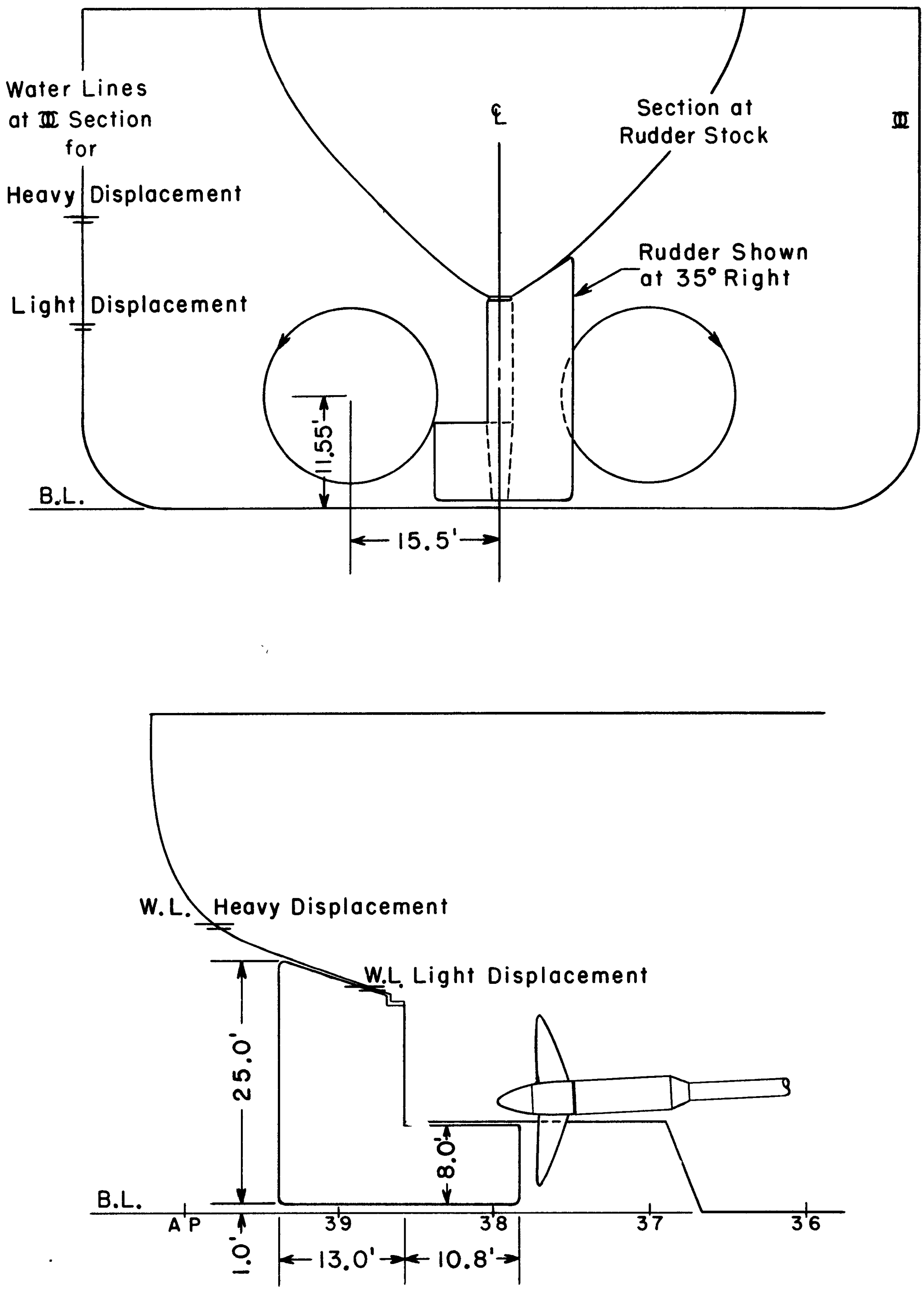


Figure 2 – Stern Arrangement of AO 143

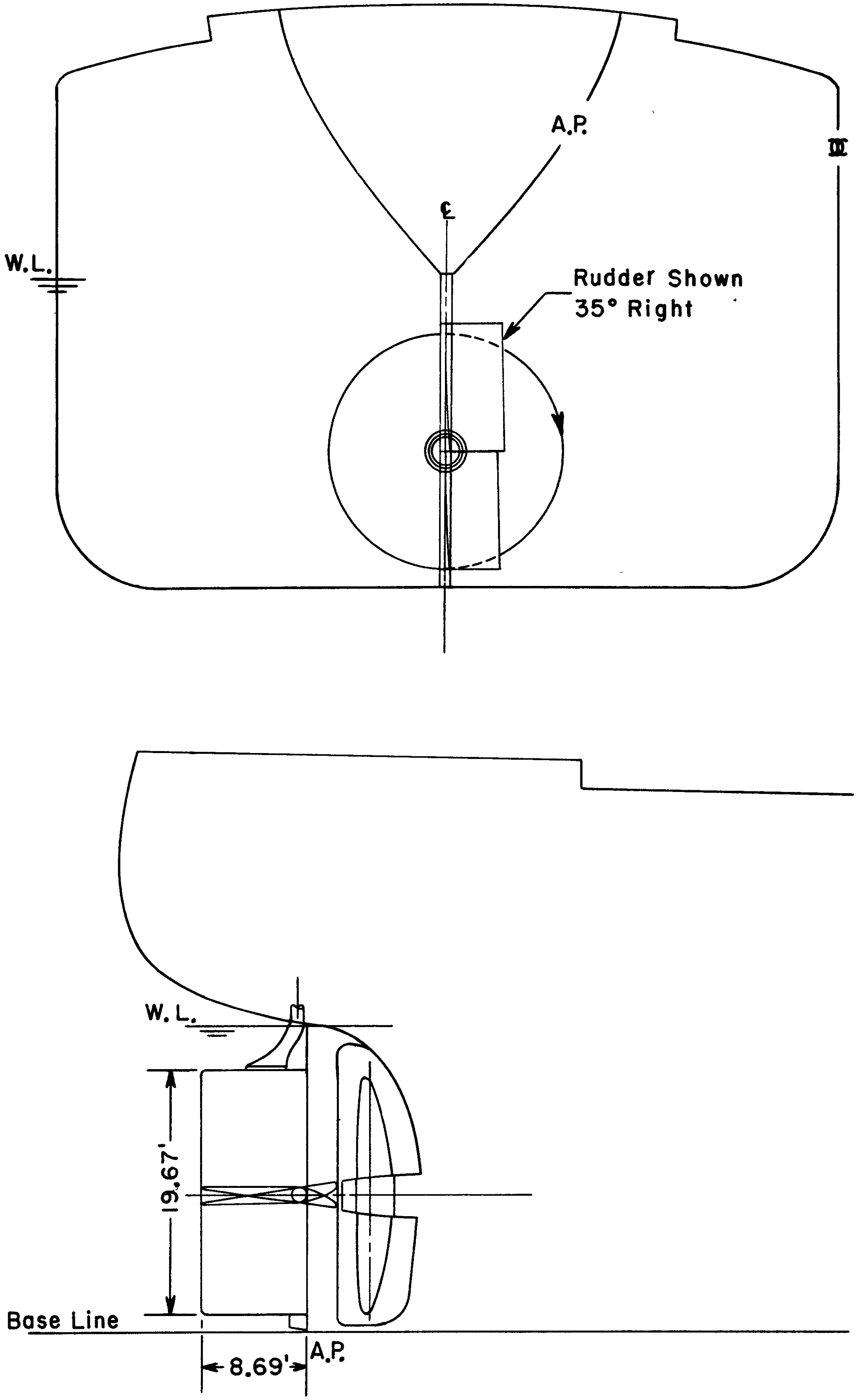
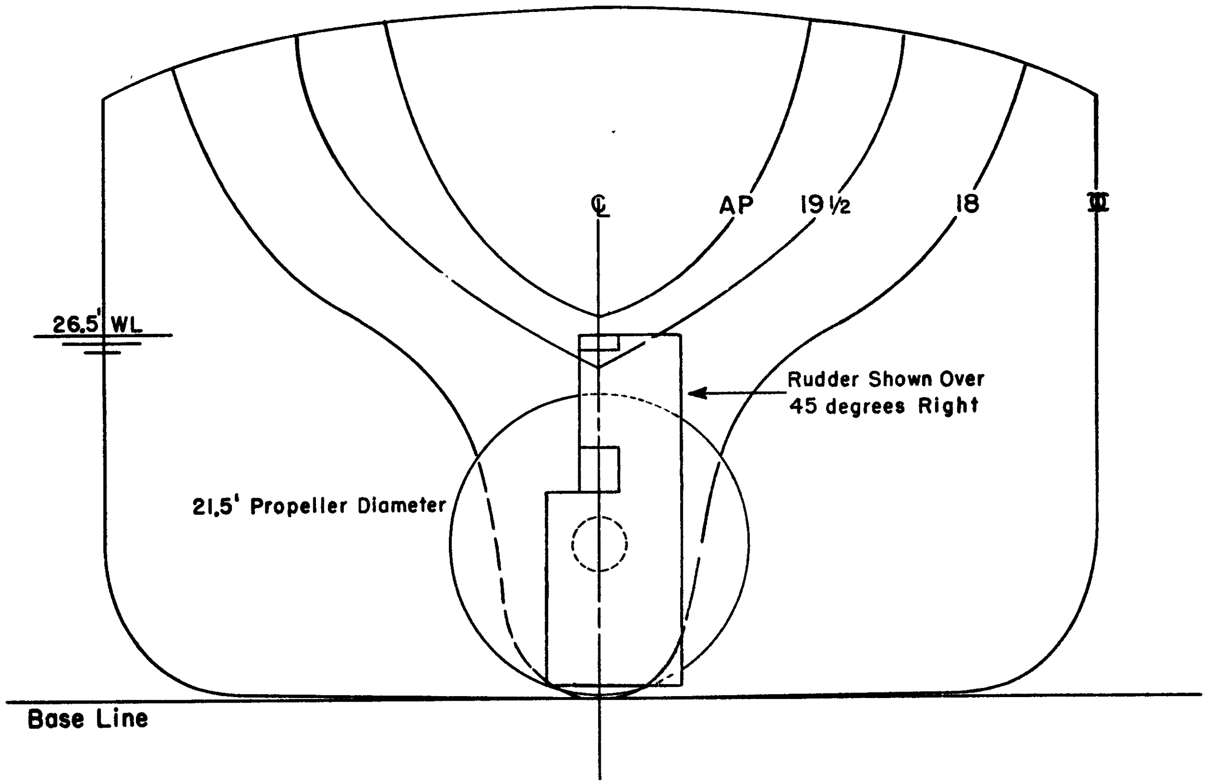


Figure 3 – Stern Arrangement of AE 19



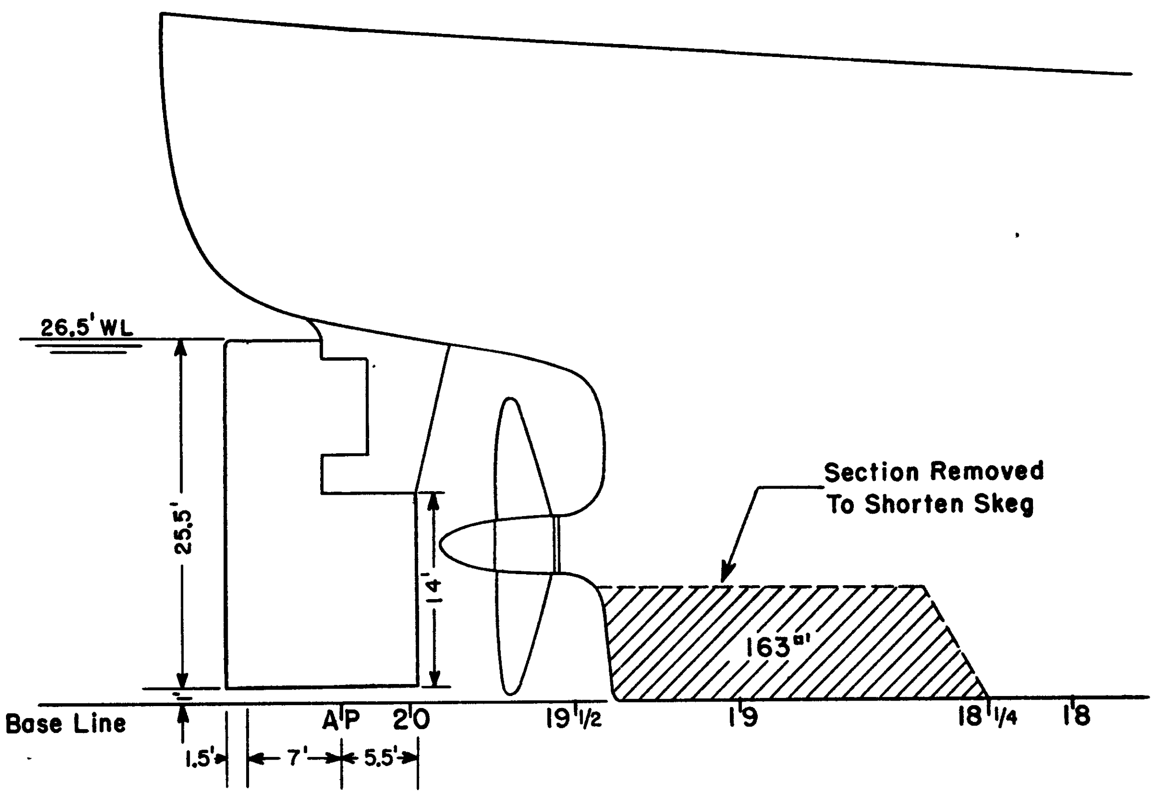


Figure 4 — Stern Arrangement of AE 21

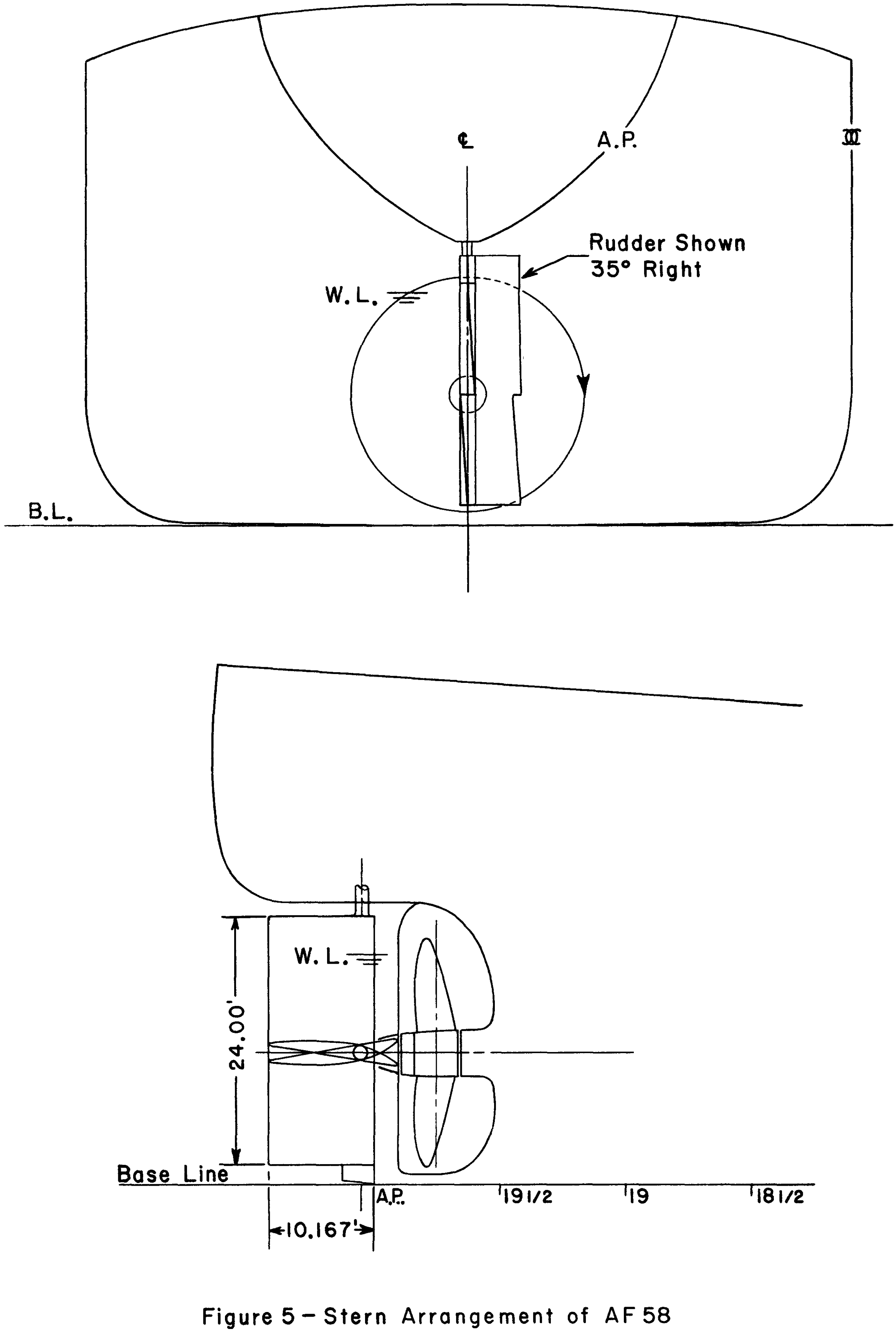


Figure 5 – Stern Arrangement of AF 58

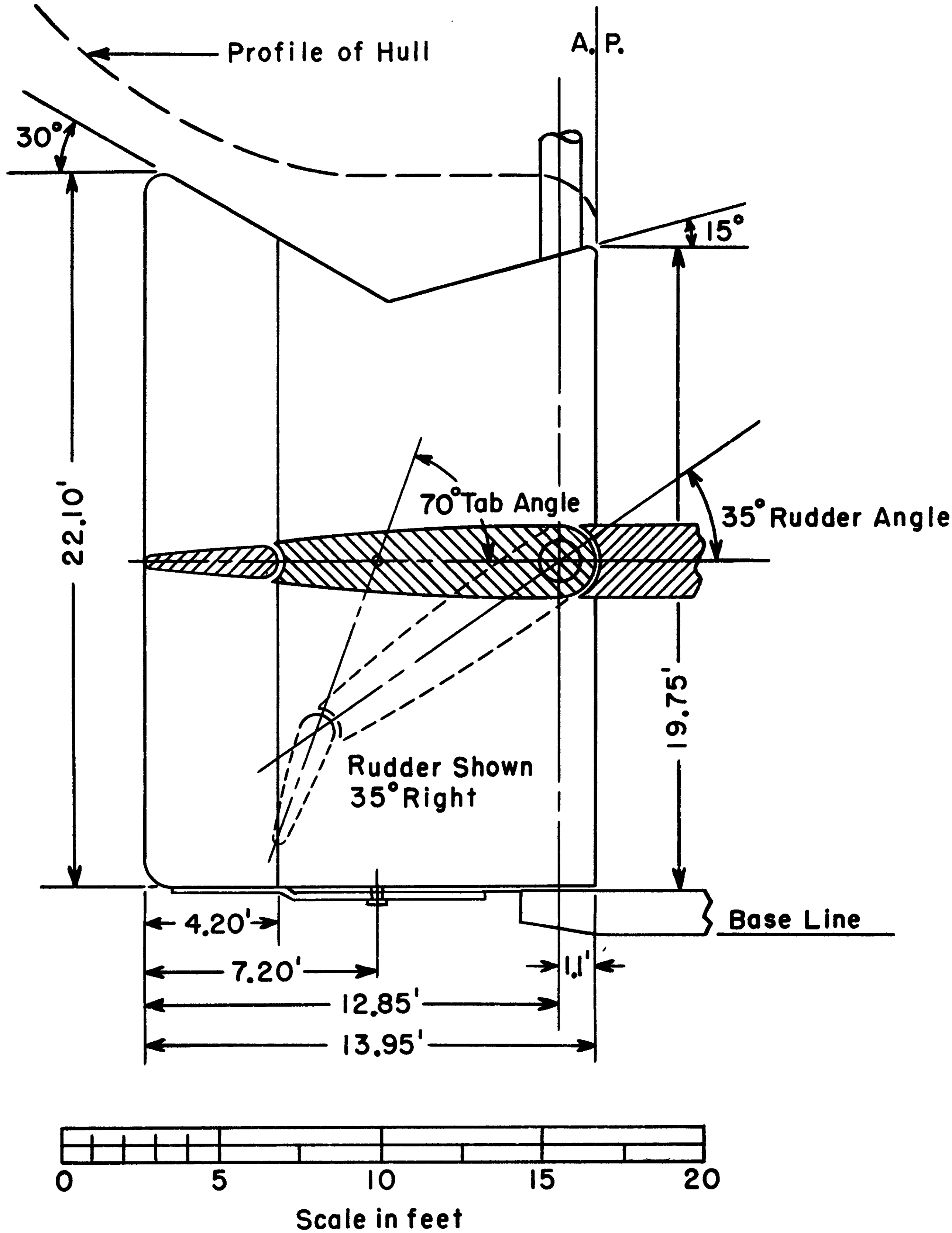


Figure 6 – Outline and Dimensions of Flap Rudder Design for AO108

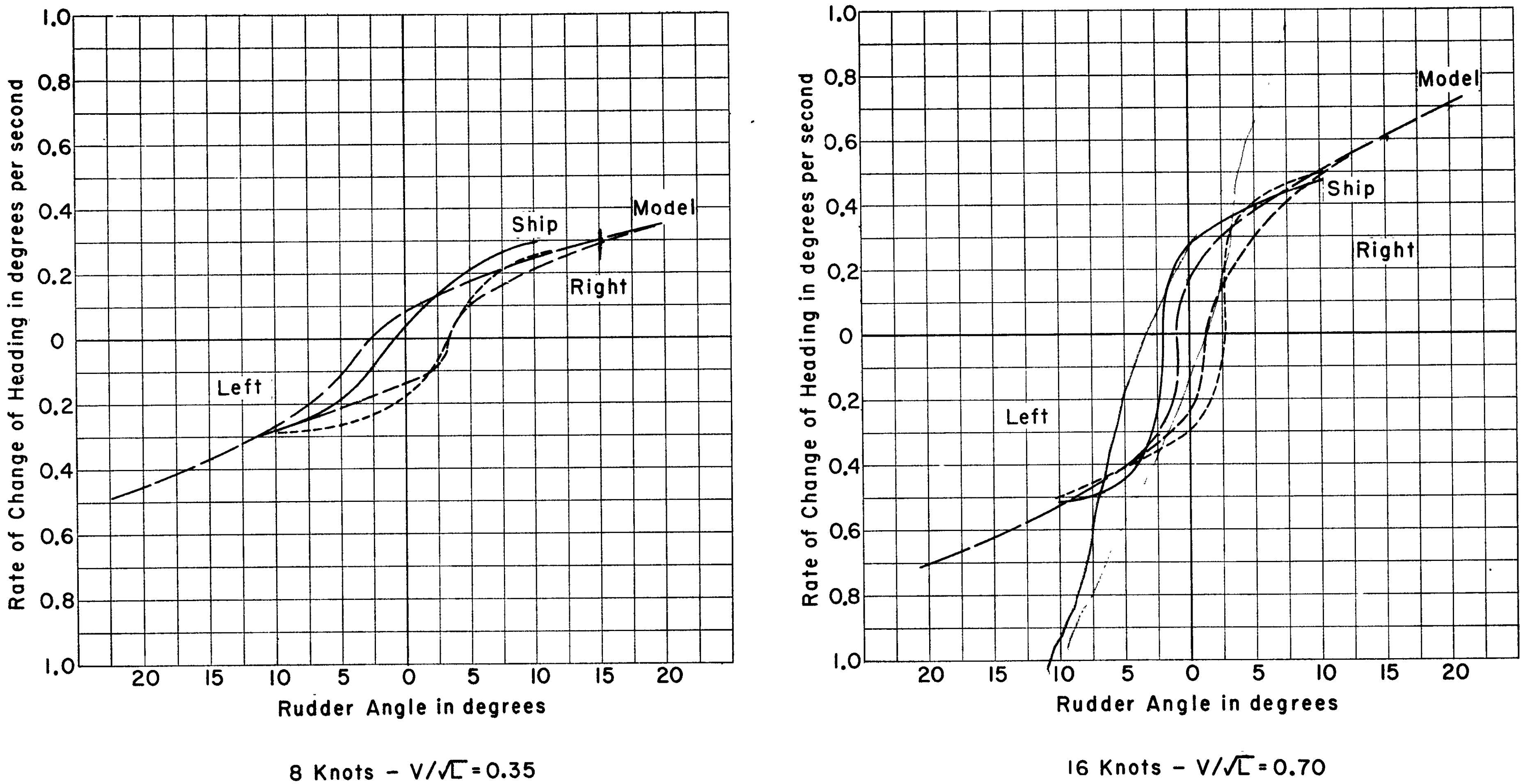


Figure 7 – Rate of Change of Heading for Various Rudder Angles from Full-Scale and Model Spiral Maneuvers of AO 108

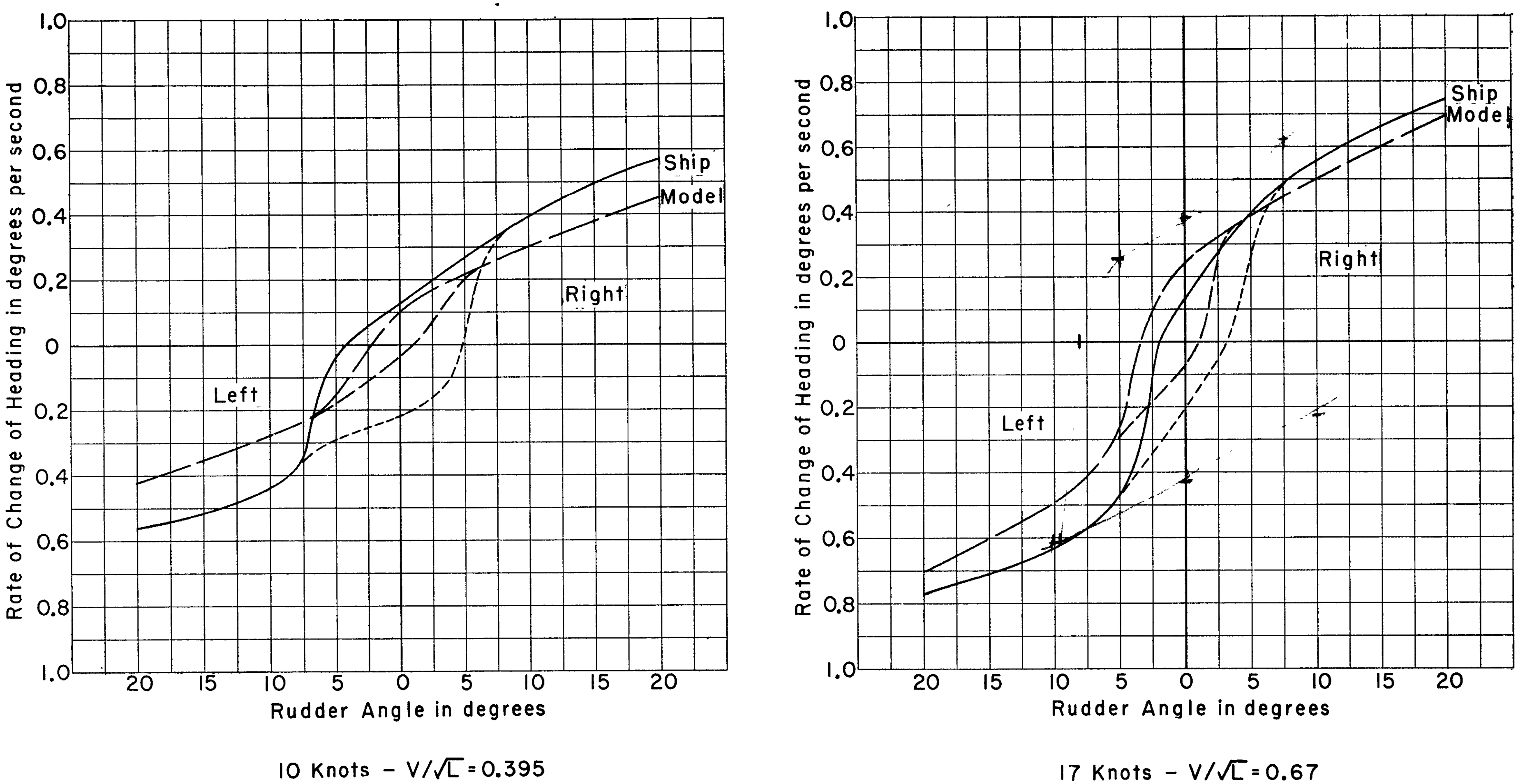


Figure 8 – Rate of Change of Heading for Various Rudder Angles from Full-Scale and Model Spiral Maneuvers of AO 143

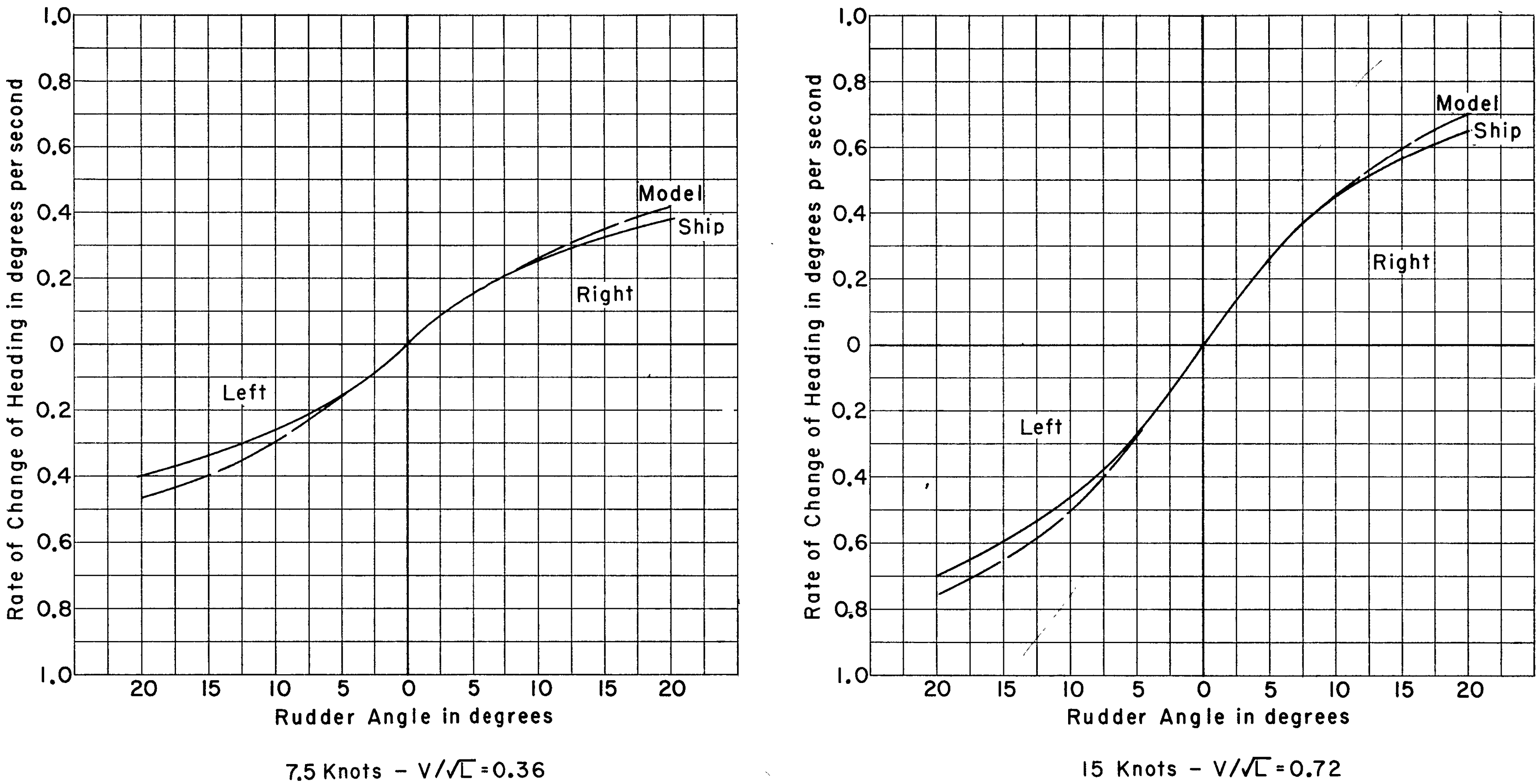


Figure 9 – Rate of Change of Heading for Various Rudder Angles from Full-Scale and Model Spiral Maneuvers of AE 19

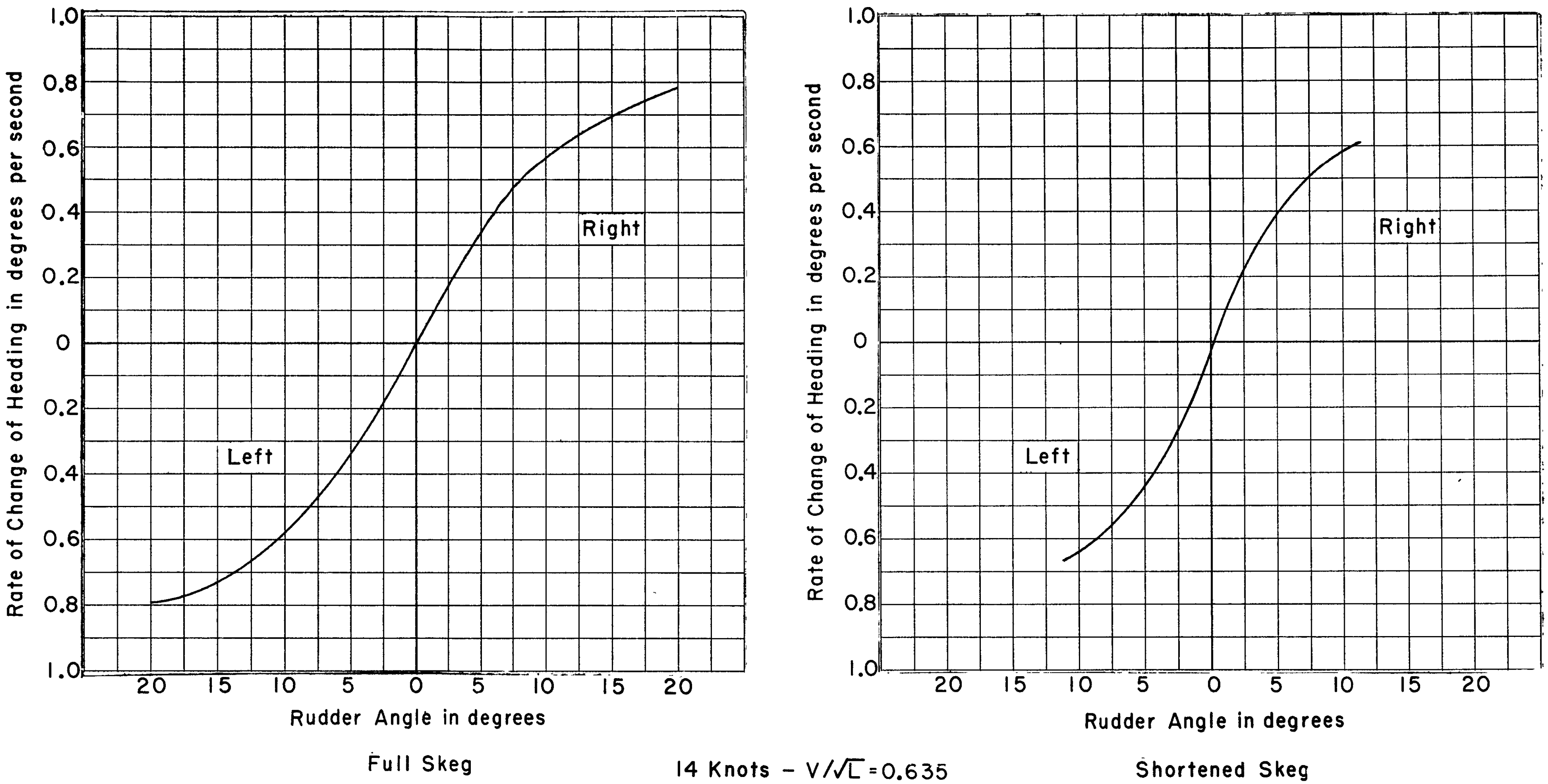


Figure 10 - Rate of Change of Heading for Various Rudder Angles from Model Spiral Tests of AE21 with Full and Shortened Skeg

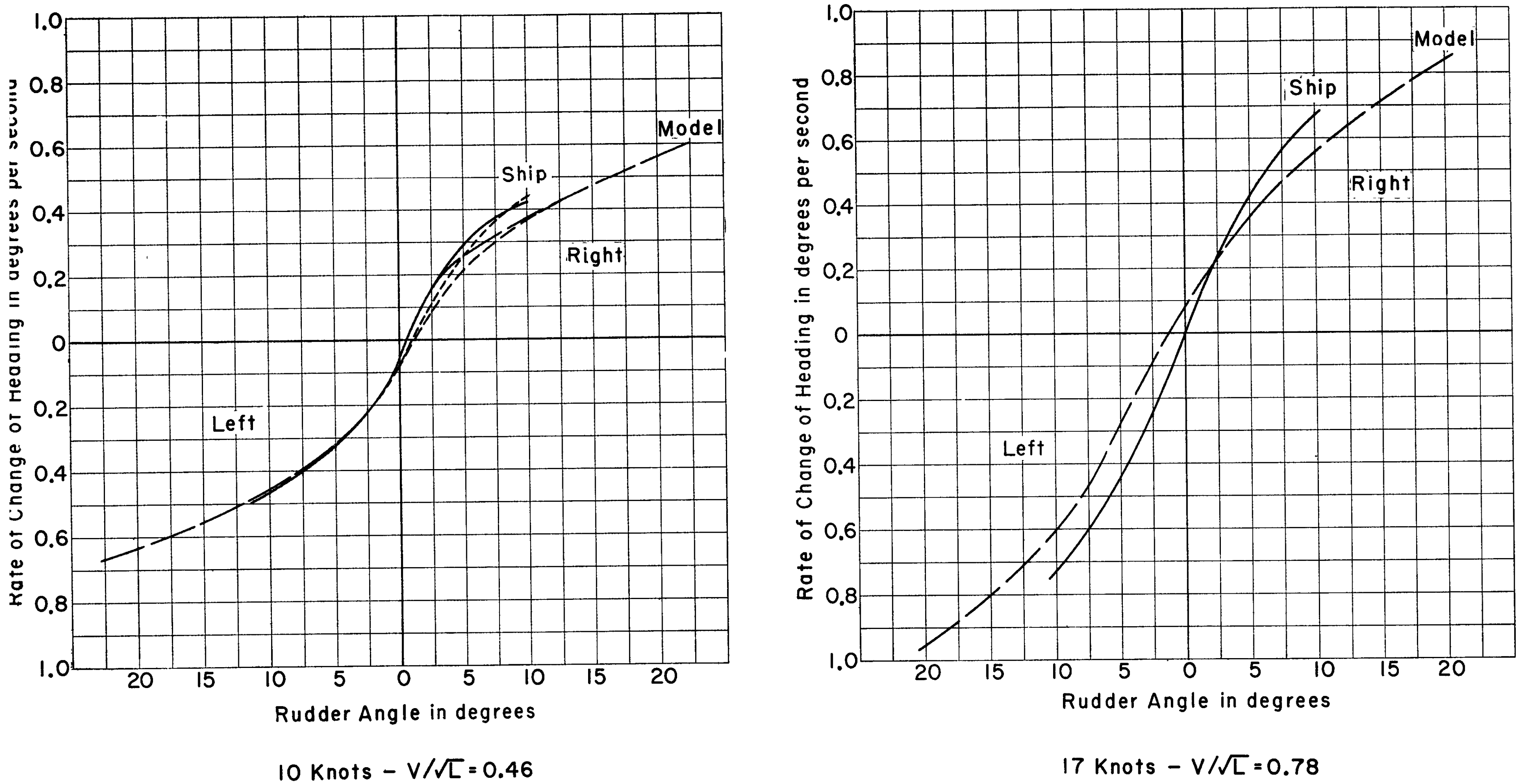
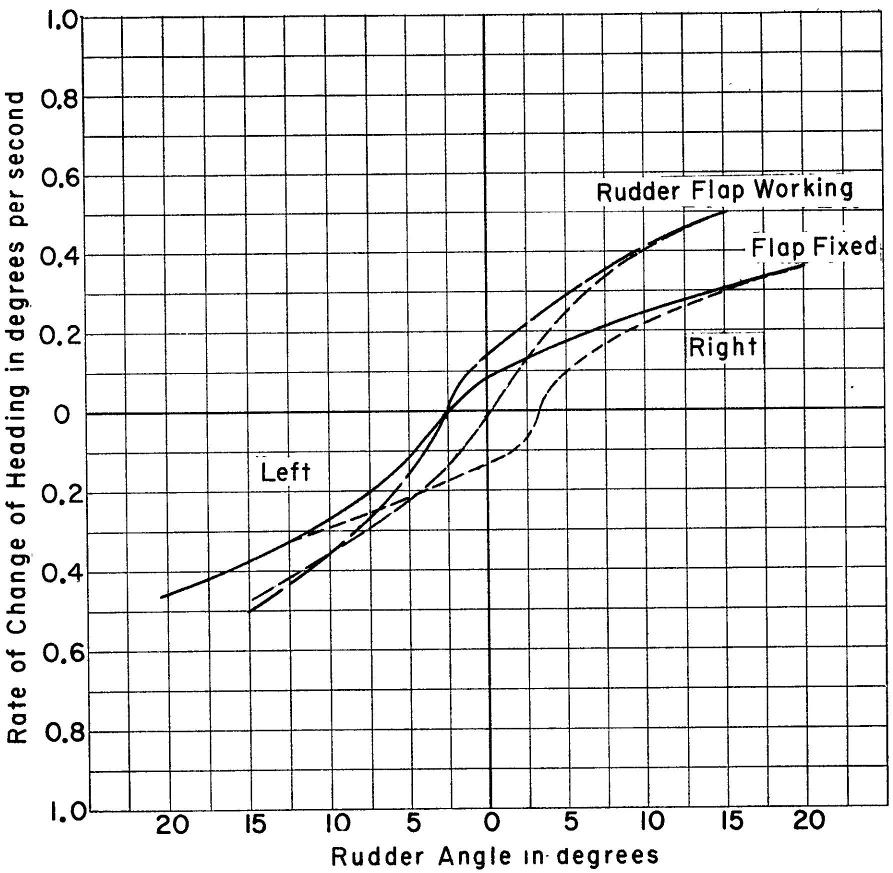
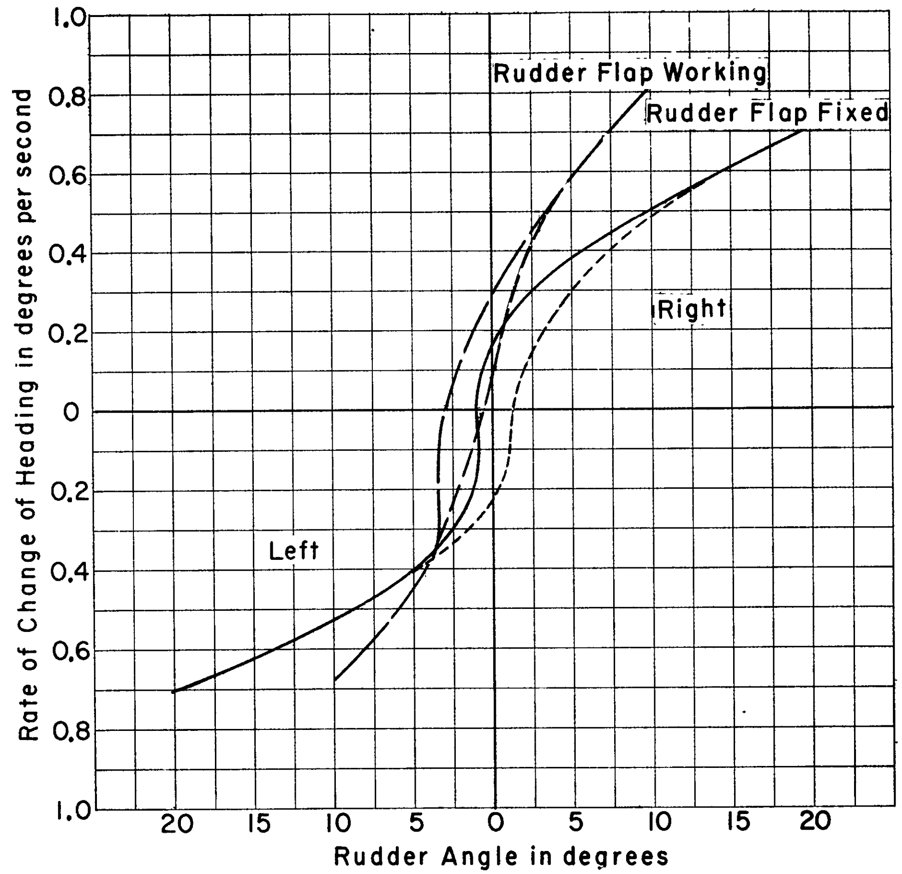


Figure 11–Rate of Change of Heading for Various Rudder Angles from Full-Scale and Model Spiral Maneuvers of AF 58

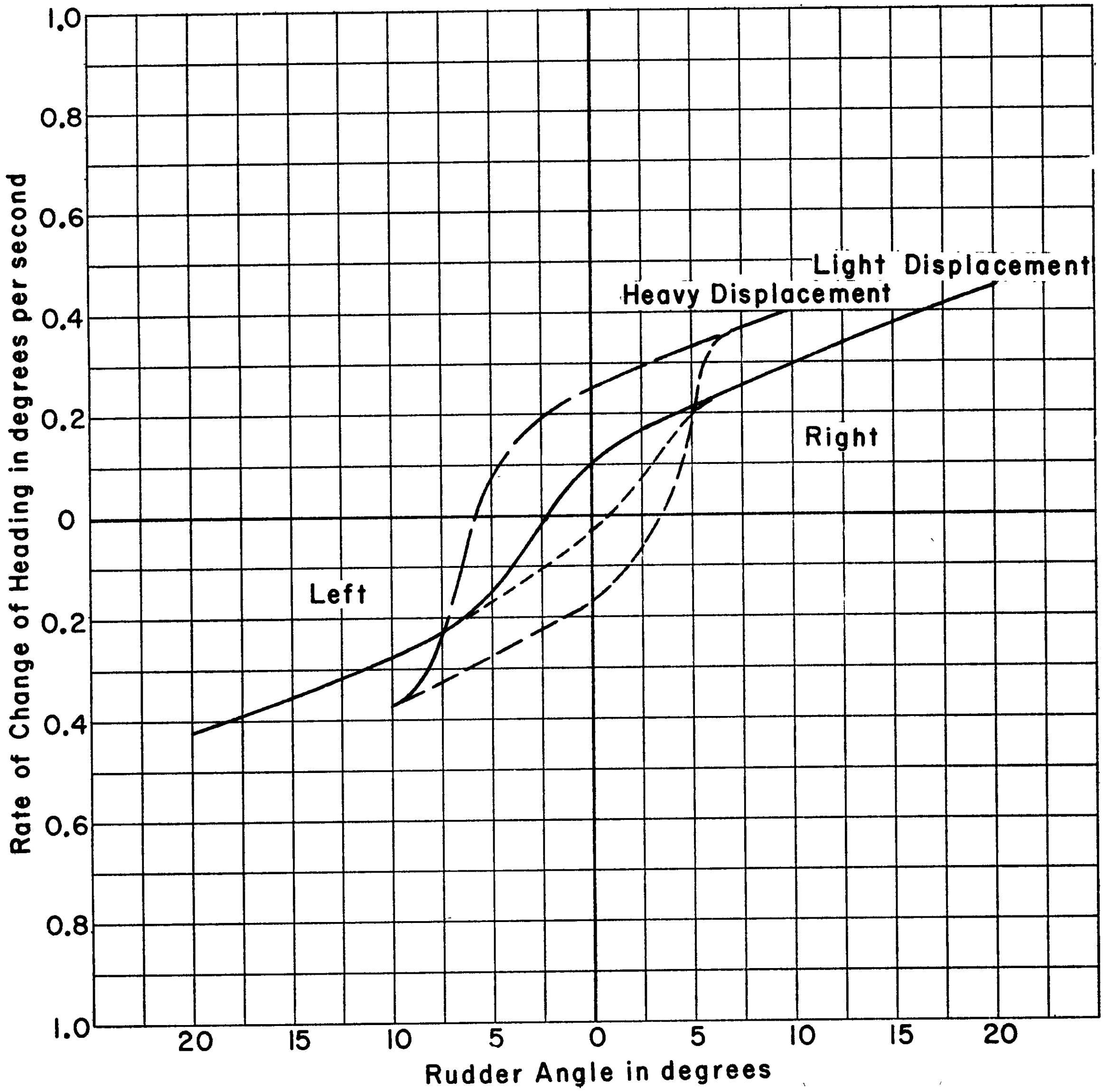


8 Knots – $V/\sqrt{L} = 0.35$



16 Knots – $V/\sqrt{L} = 0.70$

Figure 12 – Rate of Change of Heading for Various Rudder Angles from Model Spiral Tests of AO108 with Rudder Flap Fixed and Working



10 Knots – $V/\sqrt{L} = 0.395$

Figure 13 – Rate of Change of Heading for Various Rudder Angles from Model Spiral Tests of AO108 at Light and Heavy Displacement

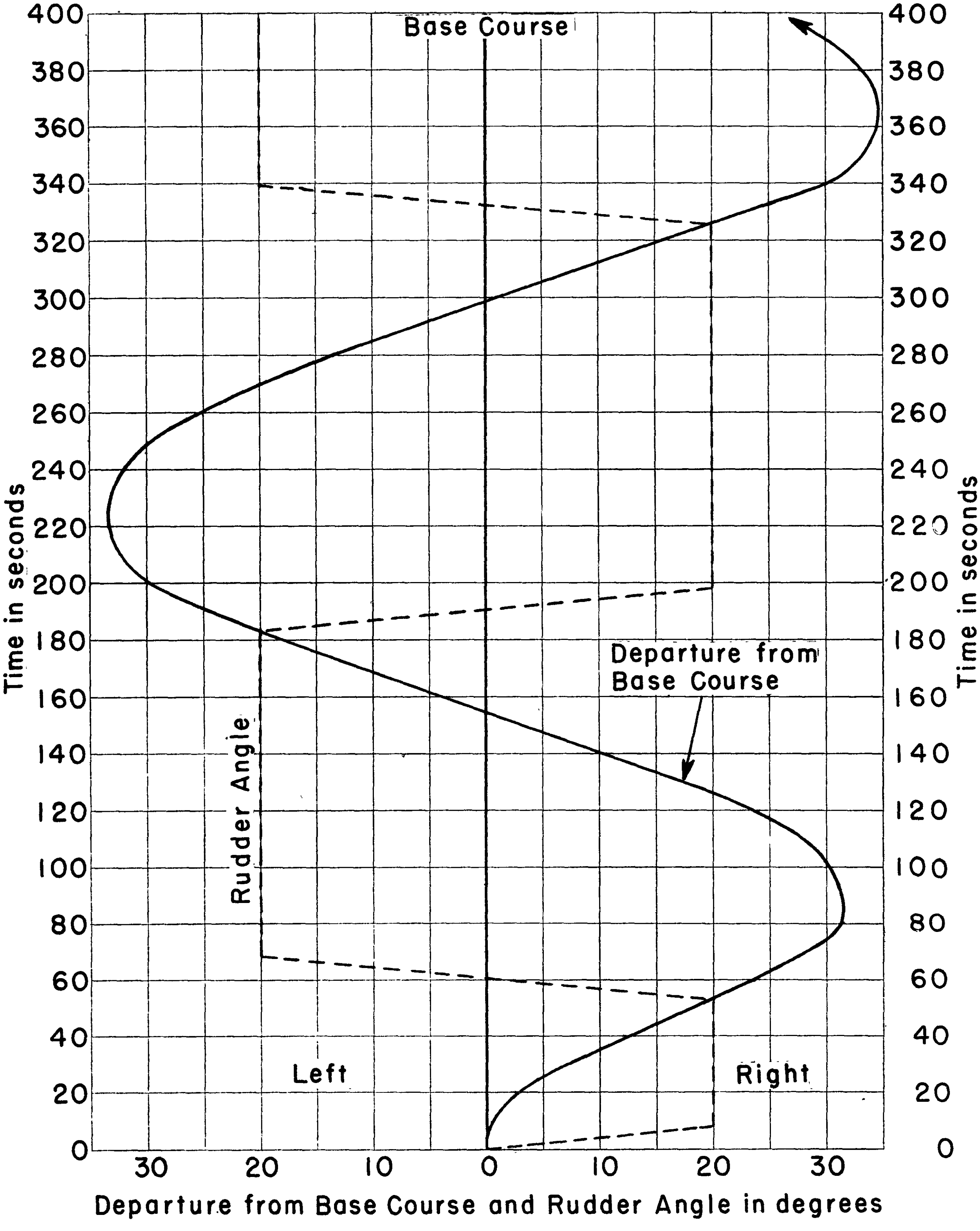


Figure 14 - Zig-Zag Maneuver from Trials of AO 108
Approach Speed 16 knots Rudder Angle 20 degrees

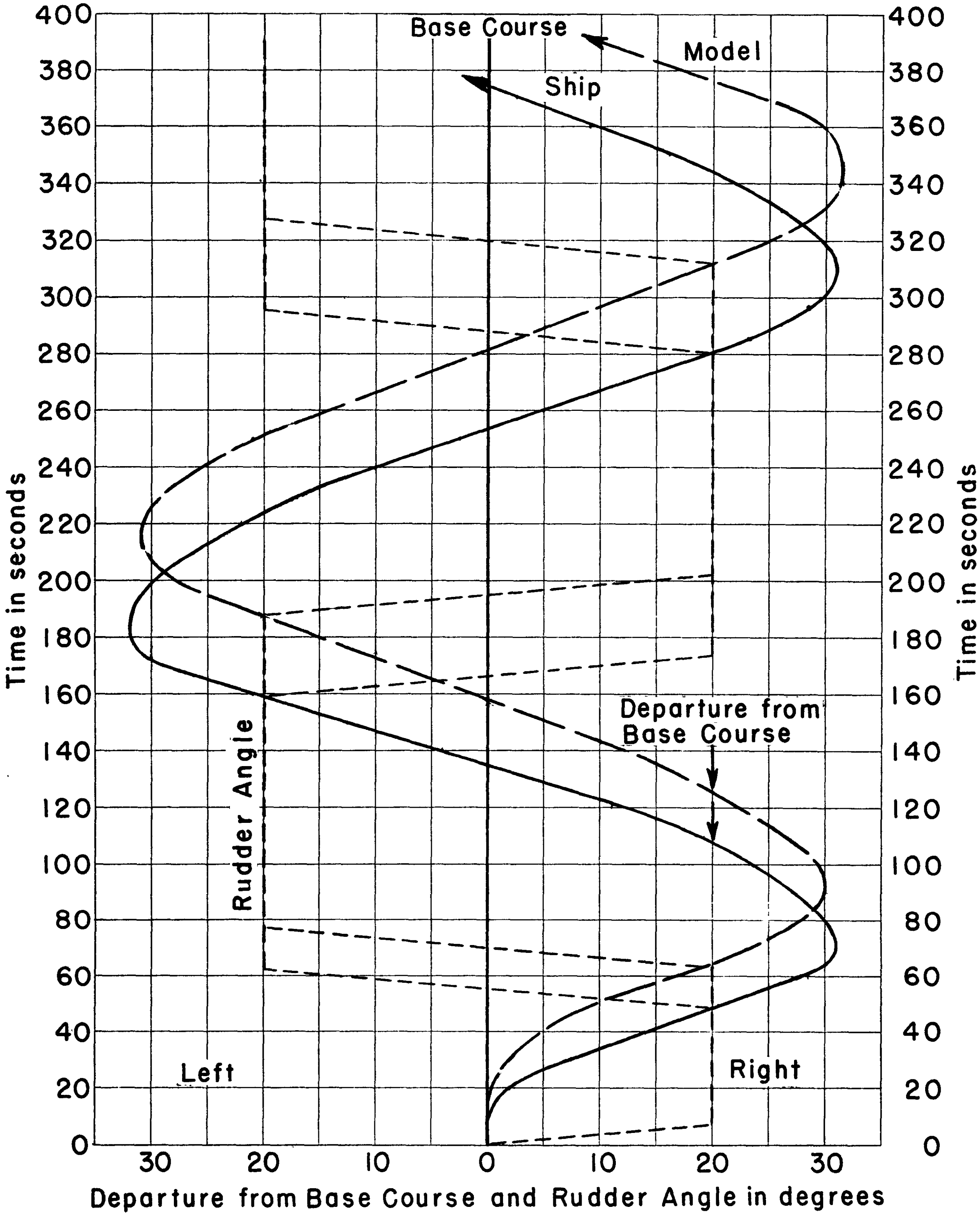


Figure 15- Zig-Zag Maneuvers from Trials of AO 143 and Model Test
Approach Speed 17 knots Rudder Angle 20 degrees

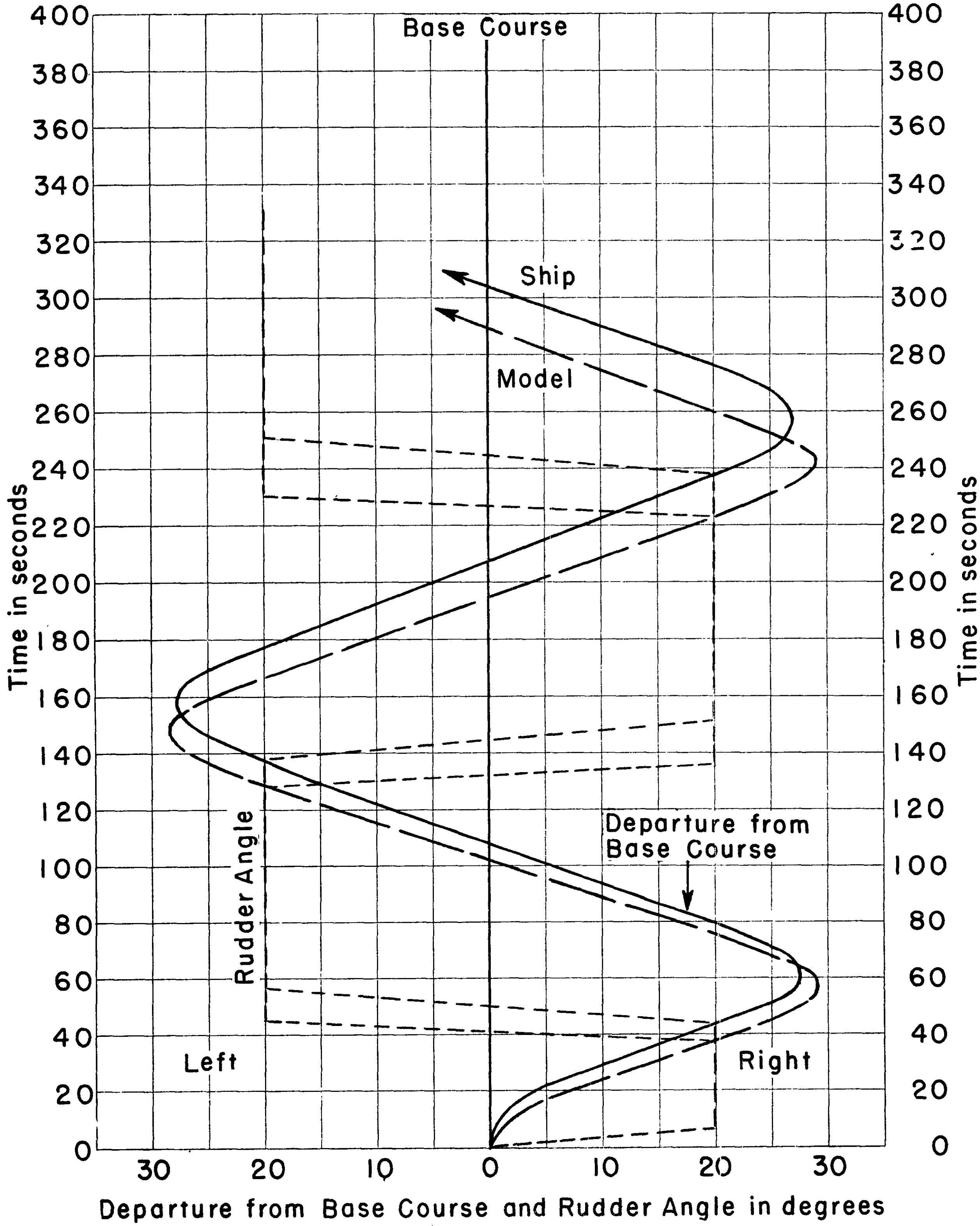


Figure 16 — Zig-Zag Maneuvers from Trials of AE 19 and Model Test
Approach Speed 15 knots Rudder Angle 20 degrees

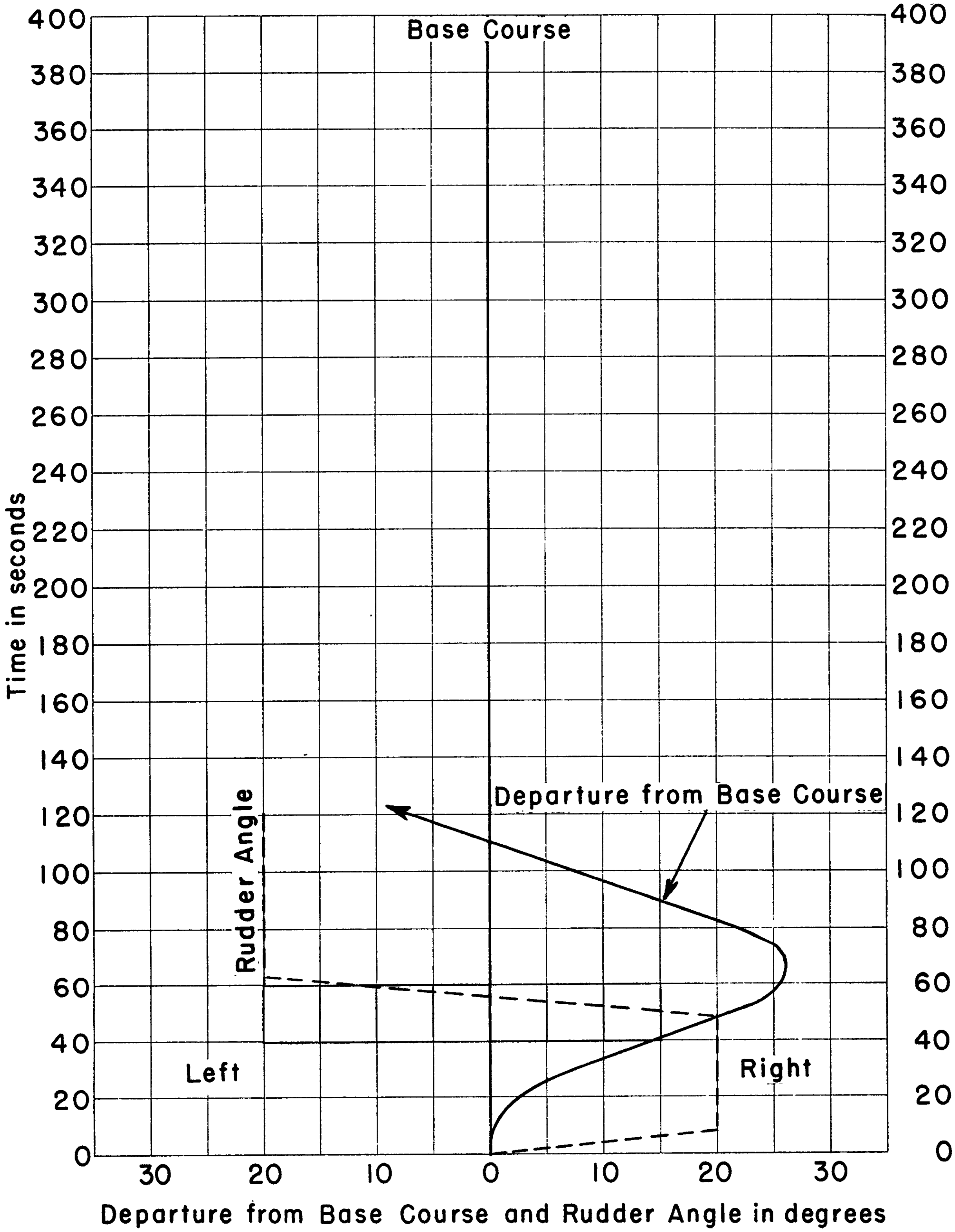


Figure 17 - Zig - Zag Maneuver from Model Test of AE 21
Approach Speed 14 knots Rudder Angle 20 degrees

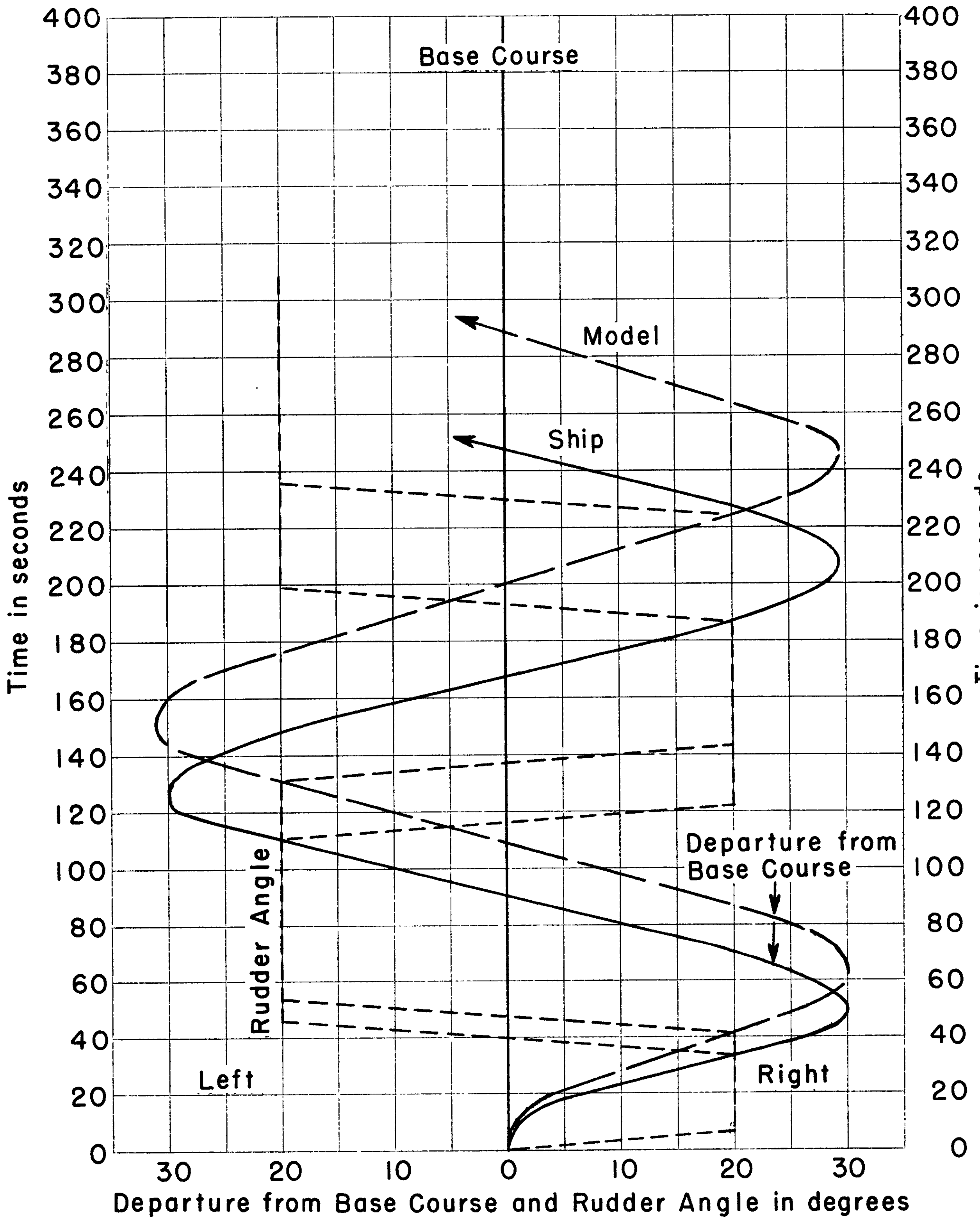


Figure 18 – Zig-Zag Maneuvers from Trials of AF 58 and Model Test
Approach Speed 17 knots Rudder Angle 20 degrees

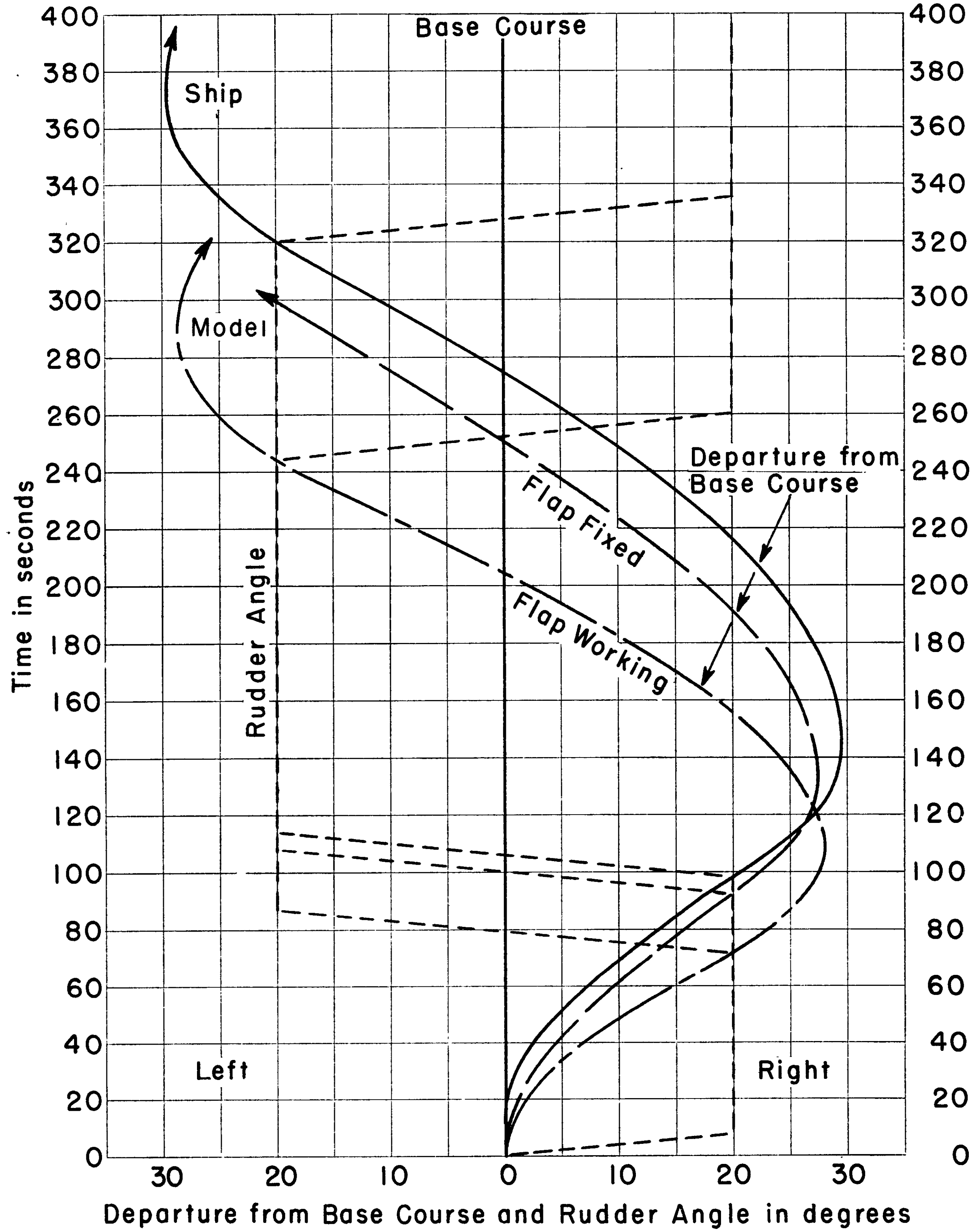


Figure 19 - Zig-Zag Maneuvers from Trials of AO 108 and Model Tests with Rudder Flap Fixed and Working
Approach Speed 8 knots Rudder Angle 20 degrees

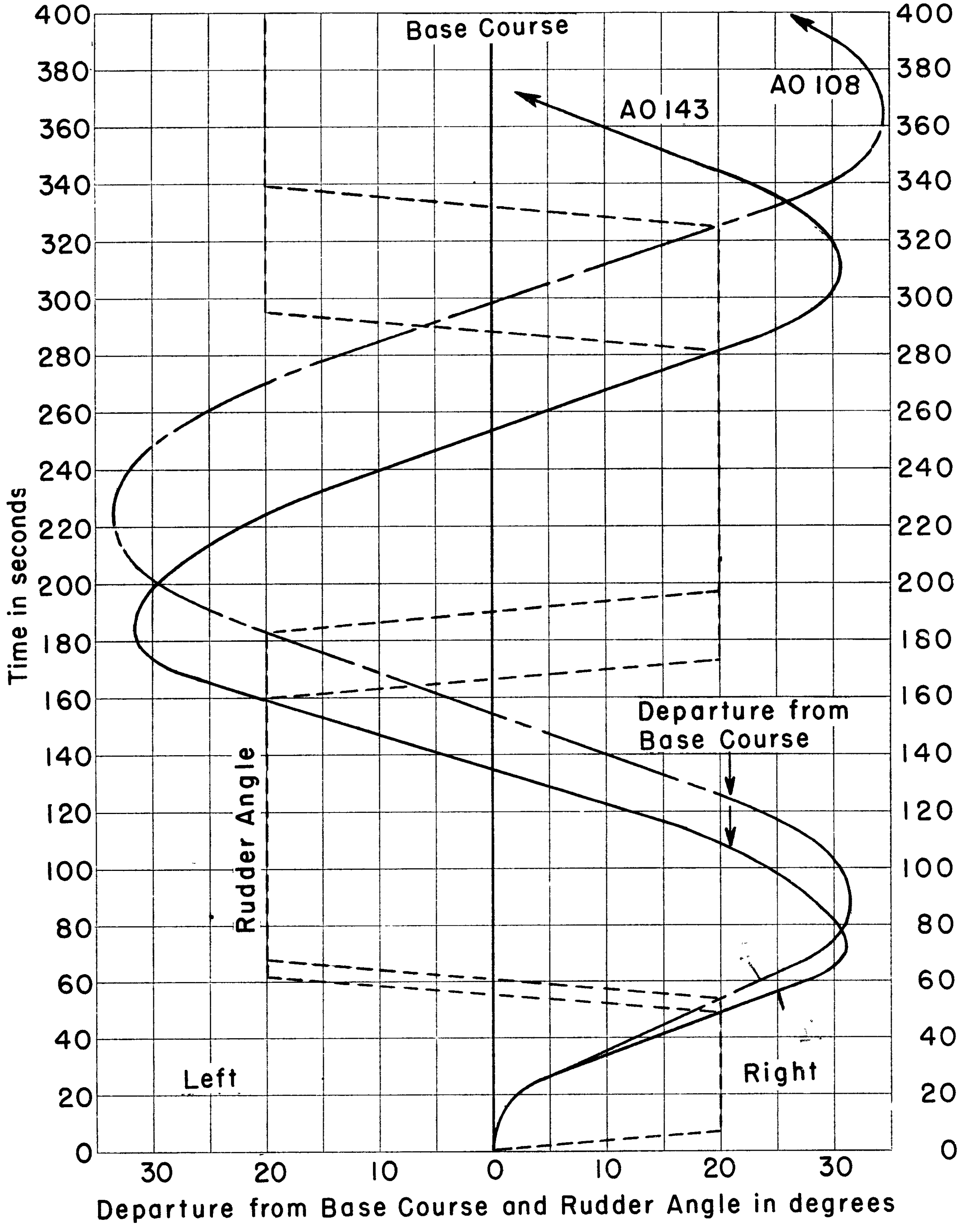


Figure 20 – Zig-Zag Maneuvers from Trials of AO 108 and AO 143
AO 108 – Approach Speed 16 knots $V/\sqrt{L} = 0.70$
AO 143 – Approach Speed 17 knots $V/\sqrt{L} = 0.67$

APPENDIX

TRIAL AGENDA
FOR SPECIAL MANEUVERING TRIALS
USS DIAMOND HEAD (AE19)

The purpose of these trials is to investigate the directional stability and control characteristics of the ship. The trials which are to be conducted at speeds of 7 1/2 and 15 knots are divided into four groups. The rudder should be moved at a normal rate and consistent for each test. It is desired that the trials be conducted with the ship ballasted to a trim as close to even keel as practicable.

Runs in group 2, runs 17 and 18 of group 3, and runs in group 4 should begin on an approach course which is with or against the wind (zero or 180 degrees relative wind).

The data which should be recorded during the trials by ship' personnel and trial observers include the following: Approach Speed (pit-log), propeller rpm (tachometer), path of the ship during maneuvers (D.R.T), heading of ship (gyro-compass repeater), times to complete various phases of runs and total time for maneuver (stop watches), rudder angle settings (visual observation), wind velocity and direction of true wind, and drafts and trim. A list of ship' personnel needed for these trials will be found on the last page.

GROUP 1 SPIRAL MANEUVERS

Run No.	Approach Speed in knots	Rudder Angle in degrees	Procedure
1	7 1/2	10 R 7 R 5 R 2 R 0 2 L 5 L 7 L 10 L repeat in reverse order	The helmsman will hold the rudder at each angle specified until a steady rate of change of heading has been obtained. Upon signal the rudder will be shifted to the next setting and again held until a steady rate is obtained, etc.
2	15	Same as Run 1	Same as Run 1

Note: The normal time required to complete a run in this group is approximately 45 minutes. The angles specified or procedure may be varied depending upon the turning rates obtained, and when the swing of the ship changes direction.

GROUP 2 DETERMINATION OF NEUTRAL RUDDER ANGLE

Run No.	Approach Speed in knots	Rudder Angle in degrees	Procedure
3	7 1/2	3 R	After the ship is steady on course the rudder will be set at the desired angle and held until the ship has changed heading 5-10 degrees, or remains on course.
4	7 1/2	2 R	
5	7 1/2	1 R	
6	7 1/2	0	
7	7 1/2	1 L	
8	7 1/2	2 L	
9	7 1/2	3 L	
10	15	3 R	
11	15	2 R	
12	15	1 R	
13	15	0 R	
14	15	1	
15	15	2 L	
16	15	3 L	

Note: Runs in this group require 5 to 10 minutes time. The angle specified or test procedure may be varied depending upon the results of the tests in Group 1 or preceeding runs.

GROUP 3 DIRECTIONAL STABILITY

Run No.	Approach Speed in knots	Rudder Angle in degrees	Procedure
17	7 1/2	0-10R-0	After the ship is steady on course, lay the rudder to 10 degrees right and hold until the ship' heading has changed 10 degrees - shift rudder to zero and hold until a steady rate of change of heading has been obtained.
18	15	0-10R-0	Same as Run 17
19	7 1/2	2 R	To begin the run the ship should be swinging left at a rate of 0.2 deg/sec. On signal the helmsman will shift the rudder to the specified angle and hold until a new rate of swing has been obtained.
20	7 1/2	5 R	
21	7 1/2	10 R	
22	7 1/2	2 R	
23	7 1/2	5 R	
24	7 1/2	10 R	
25	15	2 R	Same as for Runs 19-24 except initial swing prior to shifting the rudder should be 0.8 deg/sec.
26	15	5 R	
27	15	10 R	
28	15	2 R	
29	15	5 R	
30	15	10 R	

Note: Time required to complete a run in this group is 10 to 15 minutes. Rate of swing, rudder angle, or procedure may be changed depending upon results of other tests.

GROUP 4 ZIG-ZAG MANEUVERS

Run No.	Approach Speed in knots	Rudder Angle in degrees	Procedure
31	7 1/2	0-20R-20L-20R-20L	1st Execute signal lay rudder to 20°R, hold until 2nd Execute signal (20° change of heading) and shift rudder to 20° L, hold until 3rd Execute signal (40° change of heading) & shift rudder to 20° R, hold until 4th Execute signal (40° change of heading) and shift rudder to 20° L ending run at maximum change of heading.
32	7 1/2	0-20L-20R-20L-20R	Same as Run 31 except reverse directions of rudder movement.
33	15	Same as Run 31	
34	15	Same as Run 32	
35	7 1/2	0-10R-10L-10R-10L	Same as Run 31 except for rudder angle & 10-20 degrees change of heading.
36	7 1/2	0-10L-10R-10L-10R	Same as Run 35 except reverse directions of rudder movement.
37	15	Same as Run 35	Same as Run 35
38	15	Same as Run 36	Same as Run 36

Note: Each run of this group requires approximately 15 minutes time.

SHIP'S PERSONNEL REQUIRED TO ASSIST IN CONDUCTING TRIALS

Number	Location	Duties
1	Bridge	Record True Wind Velocity and Direction
1	Bridge	Talker, Bridge to D.R.T. Plot
1 team	D.R.T.	Plot path of ship during maneuvers
1	D.R.T.	Talker, D.R.T. to bridge.

INSTRUCTIONS FOR D. R. T. TEAM

A D. R. T. plot of the path of the ship during each maneuver should be recorded. The plot should begin on the "Stand-by" signal from the bridge and contain the following information:

(a) Scale of plot (prefer 200 yards to 1 inch).

(b) Direction of True North.

(c) Clock time and ship's heading during approach for run.

(d) Clock time and ship's heading every 10-15 seconds (vary with type of run) during maneuver.

(e) Clock time and ship' heading at each "Execute" signal.

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1. COMSERVPAC CONFIDENTIAL ltr to CNO, FF4-15;tjs,S1, Ser 11.1-0352 of 12 February 1954.

2. BuShips ltr Ser NS715-090 (442) Ser 442-118 of 31 October 1955 to TMB.

3. DTMB Report 1090, "Maneuvering Characteristics of Surface Ships," by S. C. Gover and W. G. Surber, Jr in preparation.

4. DTMB Translation 246, "Collected French Papers on the Stability of Route of Ships at Sea, 1949-1950," January 1953.

5. Kempf, G., "Maneuvering Standards for Ships," Deutsche Schiffahrts-Zeitschrift "Hansa," No. 27/28, 8 July 1944. (See also Experimental Towing Tank (Stevens Institute of Technology) Technical Memorandum No. 89, "Applications of Kempf Maneuverability Test to Six Naval Vessels," by Gimprich, Marvin, and Jacobs, Winnifred R., October 1949).

6. DTMB ltr Ser NS715-090 S24 (545:WGS:mjl) of 16 January 1956 to BuShips.

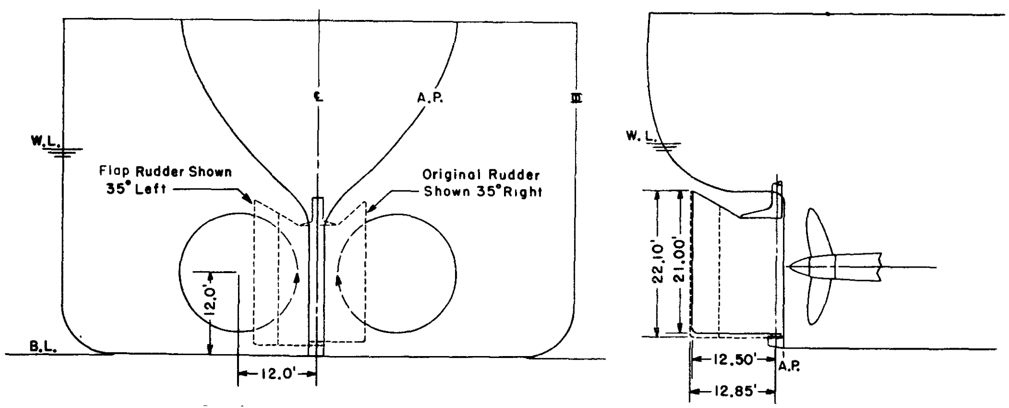
7. DTMB ltr Ser NS715-090 S24 (545:WGS:fm) of 13 April 1956 to BuShips.

8. DTMB Report 1044 "USS RIGEL (AF58) Results of Special Maneuvering Trials," by James A. Higgins, May 1956.

9. DTMB Report 992 "Turning and Maneuvering Tests of Model 4521 representing the Ammunition Ship AE21 Class," by W. G. Surber, Jr and S. C. Gover, March 1956.

10. Society of Naval Architects and Marine Engineers Technical and Research Bulletin No. 1-5, "Nomenclature for Treating the Motion of a Submerged Body Through a Fluid," April 1950.

Vessel	A0108
Length, B.P., ft	525.0
Beam, ft	75.33
Draft, Mean, ft	26.25
Trim by Stern, ft	1.0
Displacement, tons	18,845
Length-Beam Ratio, L/B	6.97
Displacement-Length Ratio, tons/(L/100)^3	130.23
Number of Propellers	2
Propeller Diameter, ft	17.5
Number of Rudders	1
Rudder Area A, sq ft	270
Rudder Area Coefficient, A/(L•H)	0.0196
Rudder Rate, Average, deg/sec	2.7



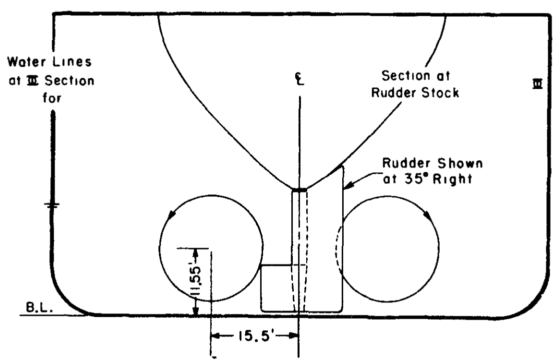
Rudder Angle in degrees	Deviation from Base Course in degrees	Ship Lengths Traveled to Execute 2	3	Turning Rate Coefficient at Execute 2	3	Overswing Angle in degrees after Execute 2	3	Reach in Ship Lengths	Period in Ship Lengths
Unbalanced Rudder Approach Speed 8 knots Speed-Length Ratio 0.35									
10	10	2.39	8.29	6.99	9.71	4.0	8.5	7.15	-
15	15	2.32	7.59	10.10	14.38	5.0	-	6.43	-
20	20	2.39	7.70	13.99	17.87	7.0	-	6.49	-
Unbalanced Rudder Approach Speed 16 knots Speed-Length Ratio 0.70									
10	10	2.73	9.83	7.19	10.30	7.0	-	8.70	-
20	10	1.80	6.49	10.68	10.30	8.0	12.5	5.71	-
20	12	2.06	7.05	11.27	14.76	8.0	-	6.18	-
20	14	2.26	7.52	11.46	15.15	8.0	-	6.49	-
20	16	2.32	8.08	11.85	15.74	9.0	13.5	7.00	-
Flap Rudder Approach Speed 8 knots Speed-Length Ratio 0.35									
10	10	1.65	5.64	10.49	12.43	5.0	6.0	4.81	8.67
15	15	1.72	5.77	14.38	18.65	5.5	8.5	4.92	8.99
20	20	1.80	6.28	19.04	19.82	8.0	9.0	5.25	9.70
Flap Rudder Approach Speed 16 knots Speed-Length Ratio 0.70									
10	10	1.90	7.10	9.91	13.21	8.0	10.0	6.23	-
15	15	1.90	7.05	14.38	16.71	10.3	11.0	6.13	-
20	13	1.44	4.73	16.51	18.26	10.5	12.5	5.04	9.06
20	15	1.70	6.18	16.32	19.04	10.8	14.5	5.35	-
20	17	1.85	6.79	17.48	18.65	11.5	11.5	5.87	9.99

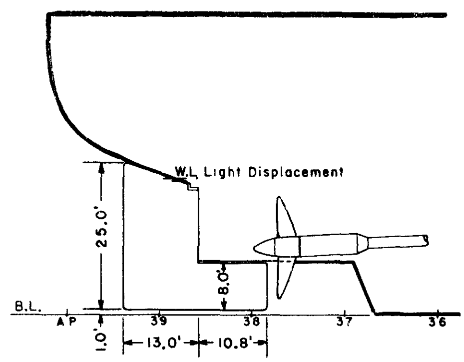
Note: Data from Zig-Zag Maneuvers

Turning Rate Coefficient - Turning rate X length of ship / approach speed
Overswing Angle - Change of heading after 2nd execute before ship reverses direction
Reach - Distance between first execute and when the ship returns to base course
Period - Distance between 2nd execute and 4th execute

DESIGN DATA SHEET (B) - Report 1089

Vessel	A0143
Length, B.P., ft	640.0
Beam, ft	86.0
Draft, Mean, ft	18.875
Trim by Stern, ft	8.75
Displacement, tons	19,000
Length-Beam Ratio, L/B	7.44
Displacement-Length Ratio, tons/$(L/100)^3$	72.48
Number of Propellers	2
Propeller Diameter, ft	18.00
Number of Rudders	1
Rudder Area A, sq ft	392.0
Rudder Area Coefficient, A/(L•H)	0.0325
Rudder Rate, Average, deg/sec	3.0





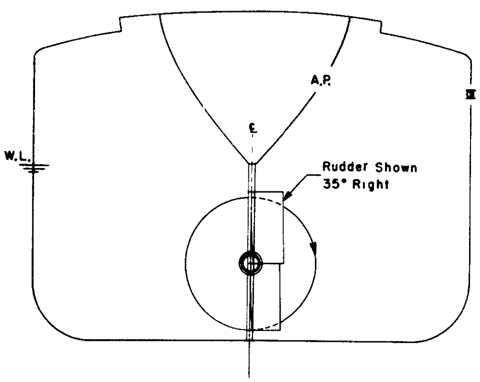
Rudder Angle in degrees	Deviation from Base Course in degrees	Ship Lengths Traveled to Execute 2	3	Turning Rate Coefficient at Execute 2	3	Overswing Angle in degrees after Execute 2	3	Reach in Ship Lengths	Period in Ship Lengths
Approach Speed 10 knots Speed-Length Ratio 0.395									
10	4	1.73	5.38	8.72	8.34	4.0	3.0	4.74	6.24
10	7	1.24	5.53	9.47	9.09	3.5	4.0	4.61	7.73
10	10	1.84	7.20	10.23	10.23	5.0	4.0	5.98	9.47
15	5	1.42	4.24	10.99	10.99	4.5	3.5	3.80	5.11
15	10	1.76	5.58	12.88	12.88	5.0	4.3	4.73	6.89
15	15	2.03	6.51	13.64	13.64	5.0	4.5	5.46	8.55
20	10	1.39	4.46	14.40	15.16	4.8	5.3	3.73	6.01
20	20	2.23	6.98	17.05	15.54	6.5	5.5	5.65	9.04
Approach Speed 17 knots Speed-Length Ratio 0.67									
10	4	1.75	5.65	7.80	8.02	4.0	4.3	5.13	7.24
10	7	2.49	7.66	8.47	9.14	6.3	5.5	6.73	9.26
10	10	2.57	8.04	8.47	9.81	4.3	5.0	6.90	10.03
15	5	2.04	5.25	9.36	11.14	6.0	6.5	4.98	6.28
15	10	2.39	6.75	11.14	12.48	6.0	5.0	5.88	7.97
15	15	3.31	8.64	12.48	12.93	7.5	7.0	7.42	10.15
20	5	1.79	4.77	11.59	13.15	7.3	7.5	4.36	5.73
20	10	2.12	6.23	13.60	14.49	9.0	7.3	5.36	7.42
20	15	2.19	6.68	14.93	14.93	8.0	6.0	5.65	8.52
20	20	2.86	8.42	16.05	15.16	10.0	11.0	7.08	11.19

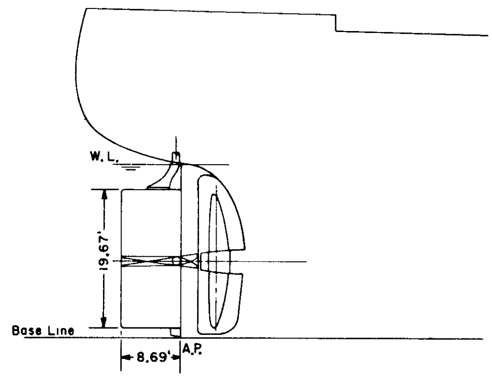
Note: Data obtained from Zig-Zag Maneuvers

Turning Rate Coefficient - Turning rate X length of ship / approach speed
Overswing Angle - Change of heading after 2nd execute before ship reverses direction
Reach - Distance between first execute and when the ship returns to base course
Period - Distance between 2nd execute and 4th execute

DESIGN DATA SHEET (C) - Report 1089

Vessel	AE19
Length, B.P., ft	435.0
Beam, ft	63.0
Draft, Mean, ft	22.75
Trim by Stern, ft	3.5
Displacement, tons	12,100
Length-Beam Ratio, L/B	6.90
Displacement-Length Ratio, tons/$(L/100)^3$	147.0
Number of Propellers	1
Propeller Diameter, ft	19.0
Number of Rudders	1
Rudder Area A, sq ft	170.0
Rudder Area Coefficient, A/(L•H)	0.0172
Rudder Rate, Average, deg/sec	3.5





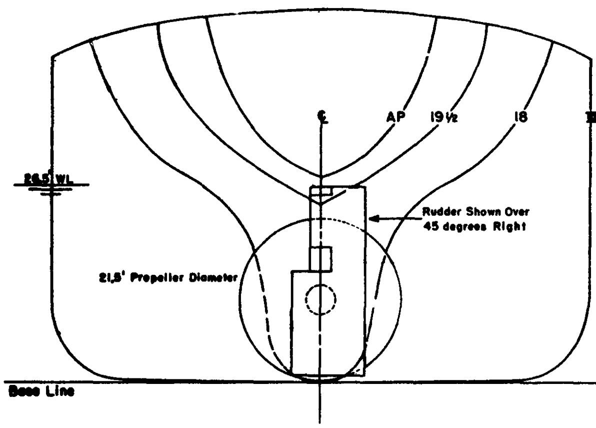
Rudder Angle in degrees	Deviation from Base Course in degrees	Ship Lengths Traveled to Execute 2	3	Turning Rate Coefficient at Execute 2	3	Overswing Angle in degrees after Execute 2	3	Reach in Ship Lengths	Period in Ship Lengths
Approach Speed 7.5 knots Speed-Length Ratio 0.36									
10	10	2.07	6.38	8.58	10.30	4.0	4.0	5.33	8.97
15	15	2.33	6.76	12.01	13.74	6.0	4.5	5.53	9.00
20	20	2.07	6.70	15.11	15.80	7.5	6.0	5.33	9.64
Approach Speed 15 knots Speed-Length Ratio 0.72									
10	10	2.15	7.22	7.38	8.58	5.0	4.7	6.00	10.14
15	15	2.21	7.40	10.65	11.16	6.5	5.5	6.06	10.37
20	20	2.27	7.51	12.36	12.88	9.0	8.5	6.00	10.66

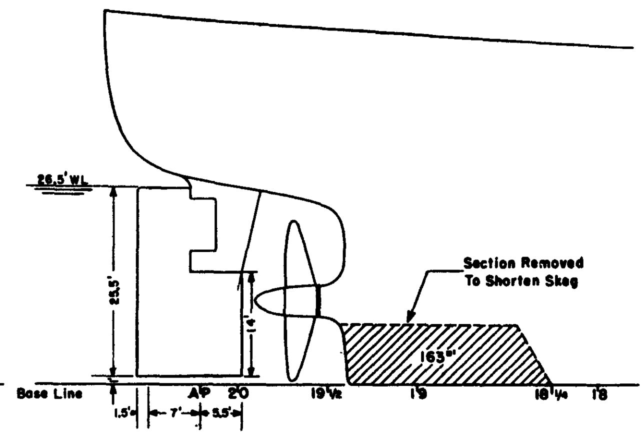
Note: Data obtained from Zig-Zag Maneuvers

Turning Rate Coefficient - Turning rate X length of ship / approach speed
Overswing Angle - Change of heading after 2nd execute before ship reverses direction
Reach - Distance between first execute and when the ship returns to base course
Period - Distance between 2nd execute and 4th execute

DESIGN DATA SHEET (D) - Report 1089

Vessel	**AE21**
Length, B.P., ft	486.0
Beam, ft	72.0
Draft, Mean, ft	26.5
Trim	even keel
Displacement, tons	15,520
Length-Beam Ratio, L/B	6.75
Displacement-Length Ratio, tons/(L/100)^3	135.20
Number of Propellers	1
Propeller Diameter, ft	21.5
Number of Rudders	1
Rudder Area A, sq ft	292.0
Rudder Area Coefficient, A/(L•H)	0.0227
Rudder Rate, Average, deg/sec	2.8





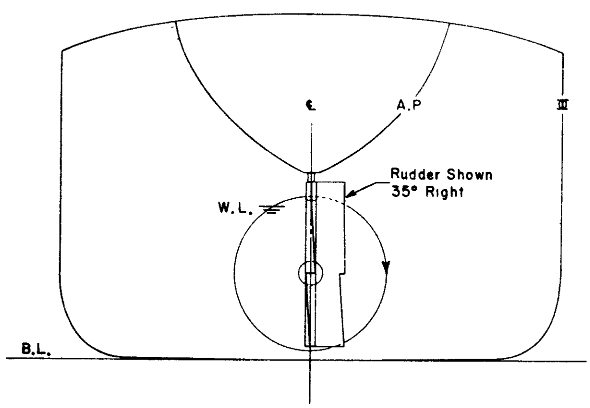
Rudder Angle in degrees	Deviation from Base Course in degrees	Ship Lengths Traveled to Execute 2	Ship Lengths Traveled to Execute 3	Turning Rate Coefficient at Execute 2	Turning Rate Coefficient at Execute 3	Overswing Angle in degrees after Execute 2	Overswing Angle in degrees after Execute 3	Reach in Ship Lengths	Period in Ship Lengths
Approach Speed 14 knots Speed-Length Ratio 0.635 Full Skeg									
10	10	1.70	4.81	9.03	12.32	3.5	5.0	4.38	6.38
10	15	2.43	7.20	9.45	14.37	3.5	6.0	5.40	-
20	20	2.34	-	14.37	-	6.0	-	5.35	-
Approach Speed 14 knots Speed-Length Ratio 0.635 Shortened Skeg									
10	10	1.82	5.54	11.50	15.40	4.5	9.5	4.74	-

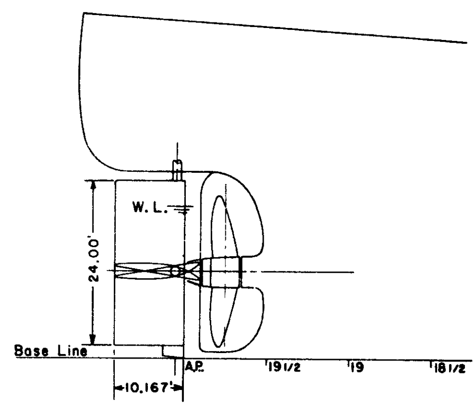
Note: Data from Zig-Zag Maneuvers

Turning Rate Coefficient - Turning rate X length of ship / approach speed
Overswing Angle - Change of heading after 2nd execute before ship reverses direction
Reach - Distance between first execute and when the ship returns to base course
Period - Distance between 2nd execute and 4th execute

DESIGN DATA SHEET (E) - Report 1089

Vessel	AF58
Length, B.P., ft	475.0
Beam, ft	72.0
Draft, Mean, ft	18.63
Trim by Stern, ft	6.08
Displacement, tons	10,230
Length-Beam Ratio, L/B	6.60
Displacement-Length Ratio, tons/(L/100)^3	95.92
Number of Propellers	1
Propeller Diameter, ft	22.0
Number of Rudders	1
Rudder Area A, sq ft	300.0
Rudder Area Coefficient, A/(L•H)	0.0276
Rudder Rate, Average, deg/sec	3.4





Rudder Angle in degrees	Deviation from Base Course in degrees	Ship Lengths Traveled to Execute 2	3	Turning Rate Coefficient at Execute 2	3	Overswing Angle in degrees after Execute 2	3	Reach in Ship Lengths	Period in Ship Lengths
Approach Speed 10 knots Speed-Length Ratio 0.46									
5	5	1.51	5.03	4.95	7.31	2.0	3.7	4.22	8.09
10	10	1.60	5.24	10.01	12.37	4.0	5.0	4.35	7.73
15	15	1.65	5.63	8.44	15.47	6.8	6.2	4.60	8.23
20	20	1.65	5.69	17.16	18.00	7.5	7.5	4.50	8.61
Approach Speed 17 knots Speed-Length Ratio 0.78									
5	5	1.57	6.52	5.29	5.36	3.0	2.0	5.50	8.88
10	10	2.02	6.68	8.54	10.32	5.0	5.3	5.38	8.86
15	15	2,60	7.19	12.01	12.97	7.0	7.5	5.98	9.28
20	20	2.27	7.10	14.62	15.78	8.5	8.0	5.83	9.91

Note: Data obtained from Zig-Zag Maneuvers

Turning Rate Coefficient - Turning rate X length of ship / approach speed
Overswing Angle - Change of heading after 2nd execute before ship reverses direction
Reach - Distance between first execute and when the ship returns to base course
Period - Distance between 2nd execute and 4th execute

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