UNITED STATES
EXPERIMENTAL MODEL BASIN

NAVY YARD, WASHINGTON, D.C.

U. S. S. WORDEN
PROPULSION AND TURNING PERFORMANCE
MODEL AND FULL SCALE

BY LIEUT. COMDR. A. S. PITRE, (CC), U. S. N.

EXPERIMENTAL MODEL BASIN
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U.S.S. WORDEN

Propulsion and Turning Performance
Model and Full Scale

by

Lieut. Comdr. A. S. Pitre, (CC), U.S.N.

U.S. Experimental Model Basin
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INTRODUCTION

From studies made on the U.S.S. HAMILTON in model and full scale regarding bossings and struts, the Model Basin recommended that for the destroyers, 348-358 class, then under process of construction, bossings be installed in lieu of struts. As a result, the U.S.S. WORDEN (352) building at the Puget Sound Navy Yard, was selected for this substitution, the remaining vessels of this class to be equipped with struts pending definite service test and experience with the WORDEN.

After completion of the WORDEN, arrangements were completed through and by the cooperation of the Chief of Naval Operations for conducting standardization and turning trials on the Rockland Maine trial course. The object of these tests was to determine the degree of fulfillment of the Model Basin predictions in the use of bossings in lieu of struts as regards

(a) propulsive performance

(b) turning and maneuverability performance.

TRIAL PROCEDURE

The basic procedure utilized in the conduct of the various trials was similar to that employed in the case of the U.S.S. HAMILTON, see E.M.B. Report No. 390, the U.S.S. FARRAGUT, see E.M.B. Report No. 397, and as given in Appendix 1.

The type, character, and purpose of the different trials are given below.

A. Standardization Trials - Light Displacement

Standardization trials at a displacement corresponding to 1595 tons were made under the supervision of the Board of Inspection and Survey. Runs were made at RPMs corresponding to 9, 12, 15, 20, 25, 30, 33 knots and full speed by the three run method. These trials were made for comparison with the U.S.S. DEWEY which was equipped with the same design propellers as installed on the U.S.S. WORDEN and was identical in all other respects save that the former possessed struts and the latter bossings.

Standardization Trials - Heavy Displacement.

Standardization trials at a displacement corresponding to 1900 tons were made under supervision of Model Basin representatives. Runs were made at RPMs corresponding to 15, 18, 21, 24, 27, 30, 33 and 36 knots by the two run method.

B. Turning Trials

Turning trials were made at a displacement of 1725 tons for comparison with similar data observed on the U.S.S. FARRAGUT. (See E.M.B. Report No. 397). Runs were made at RPMs corresponding to 15, 20, 25, 30 and 36 knots using 20, 25, 30, and maximum rudder. All turns were made using right rudder.

C. Maneuverability Trials

Maneuverability trials underway were made at a displacement of 1725 tons at speeds of 20, 25 and 30 knots using both 10 and 15 degree rudder. These trials were similar to those made with the U.S.S. FARRAGUT.

Because of lack of time, maneuverability trials from at rest were not made.

HISTORY OF OPERATION

29 May 1935

U.S.S. WORDEN undocked at Navy Yard, Norfolk.

1 June 1935

Vessel left Norfolk for Rockland Maine, arriving 2 June 1935.

3 June 1935

Underway at Rockland making practice runs off the measured mile course. Held anchor tests.

4 June 1935

Trial Board reported on board. Underway at 1015. A total of 19 runs was made. During the turn of the second maximum speed run, a fitting on the gage line from the steering gear ruptured. The loss of oil caused the steering gear to fail. Engines were reversed and ship was brought dead in the water in 52 seconds. Shortly thereafter a leak developed in the main steam line from number two boiler. Repairs were effected on the steering gear, number two boiler was secured, after which standardization at low speeds was continued as long as visibility permitted. Displacement at beginning 1632.1 tons, at end, 1608.1 tons, even keel condition.

5 June 1935

Due to poor visibility caused by fog, no trials were held. Repairs to main steam line completed.

6 June 1935

Underway at 0535. Proceeding to sea, steering gear tests were held enroute. Once at sea, the four hour full power run was made. At the completion of this test, standardization runs, five in number, were made at maximum power, after which the vessel was backed and reversed. Thereafter, standardization runs, three in number were held at 9 knot speed. The WORDEN then returned to its anchorage, the Board of Inspection disembarking. Fuel was taken from the WANDANK in preparation for the turning trials. Displacement beginning of day, 1678 tons, displacement on anchoring 1560 tons. Estimated displacement during five high speed standardization runs, 1580 tons.

7 June 1935

Underway at 0545. Proceeded to turning area. Started turning trials at 0635. Made 36 circles completing at 1640. Returned to anchorage. Displacement at start 1750 tons, displacement at end of day 1698 tons. Average displacement during turning trials, 1725 tons.

8 June 1935

Remained at anchor because of low visibility and fog. U.S.S. WANDANK came alongside to fuel in preparation for heavy standardization trials.

9 June 1935.

Sunday, remained at anchor. Thick fog with zero visibility.

10 June 1935

Preparations completed to get underway at 0630. Fog held vessel at anchorage. Underway at 0900. Impossible to see ranges on standardization course. Started maneuverability runs underway at 0950. Made 13 runs, completing at 1125. Proceeded to standardization course. Made 9 runs, starting at 1149, completing at 1415. Because of low visibility results were not considered accurate. Vessel returned to anchorage. Displacement at start of day, 2027 tons, at end of day 1976 tons.

11 June 1935

Fog still persisted. Made preparation to get underway at 1130. Proceeded to standardization course. Beacons were still obscured. At 1552 made three standardization runs at 15 knots, completing at 1626. Vessel returned to anchorage.

12 June 1935

Fog lifted, weather conditions ideal. Underway at 0500. Proceeded to standardization course. Held standardization trials at 18, 21, 24, 27, 30, 33 and 36 knots using the two run method - a total of 14 runs being made. Completed at 1025. Displacement at beginning of trials, 1961 tons, at end of trials 1910 tons. At the completion of these trials, the vessel left for Norfolk, Va.

RESULTS AND DISCUSSION

A. Standardization Trials.

A-1 Results.

The results of the standardization trials of 4 and 6 July 1935 corrected to a basis of standard conditions are given in Table 1. These values have been used for plotting the curves given in Fig. 1.

TABLE 1

U.S.S. WORDEN

RESULTS OF STANDARDIZATION TRIALS OF 4 AND 6 JUNE 1935

CORRECTED TO A BASIS OF STANDARD CONDITIONS

Run	Starboard		Port		Total		
No.	RPM	SHP	RPM	SHP	Speed	RPM	SHP
1S	184.23	2,445	183.96	2,327	20.55	184.10	4,772
2N	181.59	2,330	181.60	2,238	20.24	181.60	4,568
3S	181.23	2,315	180.49	2,132	20.18	180.86	4,447
4N	238.58	5,795	238.89	5,865	25.48	238.73	11,660
5S	237.40	5,705	237.57	5,750	25.38	237.49	11,455
6N	237.89	5,727	237.53	5,740	25.41	237.66	11,467
7S	294.92	16,180	294.67	11,250	30.48	294.79	22,430
8N	294.00	11,100	294.18	11,200	30.48	294.09	22,300
9S	295.26	11,240	295.36	11,340	30.57	295.31	22,580
10N	341.61	16,540	342.76	16,600	34.73	342.19	33,140
11S	342.09	16,610	341.51	16,490	34.56	341.80	33,100
12N	343.10	16,740	341.29	16,440	34.66	342.20	33,180
14N	130.10	863	128.84	821	14.80	129.47	1,684
15S	130.87	880	129.62	839	14.87	130.25	1,719
16N	131.12	884	130.27	840	14.95	130.18	1,724
17S	102.97	423	103.05	410	12.06	103.01	833
18N	103.61	432	103.52	414	12.23	103.57	846
19N	101.70	407	103.14	409	11.98	102.42	816
1N	414.29	24,150	414.72	24,180	40.47	414.52	48,330
2S	415.03	24,240	415.74	24,270	40.66	415.39	48,510
3N	415.39	24,260	416.20	24,379	40.67	415.85	48,639
4S	413.12	24,020	416.44	24,320	40.62	414.78	48,340
5N	417.23	24,510	419.39	24,650	40.96	418.31	49,160
6S	81.91	208	81.33	186	9.57	81.62	394
7N	79.82	191	78.83	162	9.33	79.33	353
8S	79.69	191	79.04	165	9.31	79.35	356

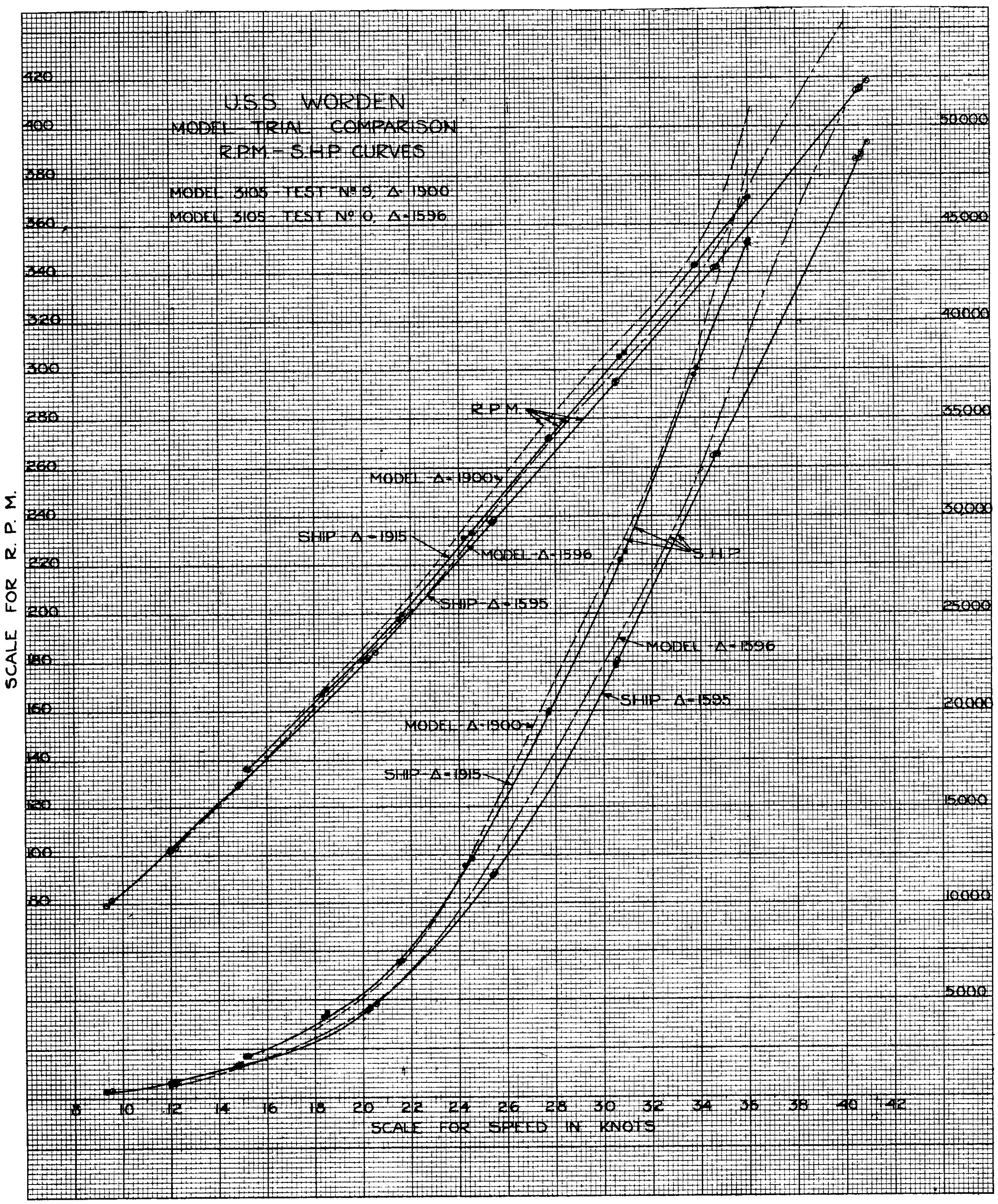

FIG. 1 U.S.S. WORDEN. MODEL-TRIAL COMPARISON FOR DIFFERENT DISPLACEMENTS.

The results of the standardization trials of 11 and 12 June 1935 corrected to a basis of standard conditions are given in Table 2. These values have been used for plotting the curves given in Fig. 1.

Table 3 gives a comparison of trial and model results for a displacement corresponding to 1595 tons. From this table it is found that up to and including 34 knots, the trial RPMs are on the average 1.5 per cent low and the trial SHPs 4.6 per cent low in comparison to model prediction. At 34 knots cavitation sets in, being first evidenced in RPM and then in SHP, the trial values at 40 knots being approximately eight per cent lower than the corresponding predicted values.

TABLE 2

U.S.S. WORDEN

RESULTS OF STANDARDIZATION TRIALS OF 11 AND 12 JUNE 1935

CORRECTED TO A BASIS OF STANDARD CONDITIONS

Run	Starboard		Port		Total		
No.	RPM	SHP	RPM	SHP	Speed	RPM	SHP
1N	169.13	2,151	168.64	2,138	18.52	168.89	4,289
2S	167.65	2,095	165.56	2,025	18.35	166.61	4,120
3N	199.01	3,545	196.63	3,374	21.49	197.82	6,919
4S	199.29	3,562	197.48	3,423	21.63	198.39	6,985
5N	229.61	5,810	232.53	6,091	24.23	231.07	11,901
6S	233.10	6,130	233.69	6,180	24.55	233.04	12,310
7N	271.89	9,980	271.32	9,900	27.70	271.61	19,880
8S	272.98	10,110	271.46	9,941	27.75	272.22	20,051
9N	305.99	14,060	307.96	14,089	30.90	306.98	28,149
10S	306.00	14,060	304.88	13,658	30.67	305.44	27,718
11N	343.14	19,050	342.35	18,178	33.78	342.75	37,228
12S	343.33	19,090	342.73	18,205	33.86	343.03	37,295
13N	368.65	22,330	372.12	21,583	35.94	370.39	43,913
14S	372.00	22,950	369.87	21,181	36.02	370.94	44,131
1N	136.39	1,075	135.85	1,054	15.22	136.12	2,129
2S	136.49	1,080	136.65	1,074	15.14	136.57	2,154

TABLE 3

MODEL TRIAL COMPARISON 4 AND 6 JUNE 1935
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
12	102	103	+1.0	625	750	+20.0
13	112	113	+0.9	925	1,125	+21.6
14	121	122	+0.8	1,250	1,400	+12.0
15	131	131.5	+0.4	1,625	1,725	+ 6.2
16	141	141.0	0	2,000	2,000	0
17	151	149.5	–1.1	2,500	2,375	– 5.0
18	159	161	–1.2	3,000	2,875	– 4.2
19	171.5	168.5	–1.7	3,630	2,475	– 4.3
20	181.5	179	–1.4	4,420	4,250	– 3.8
21	191	189	–1.0	5,330	5,275	– 1.0
22	201	200	–0.5	6,500	6,475	– 0.4
23	212	211	–0.5	8,000	7,750	– 3.1
24	224	222	–0.9	9,670	9,200	– 4.9
25	237	233	–1.7	11,500	10,750	– 6.5
26	249	244	–2.0	13,625	12,500	– 8.3
27	761.5	255	–2.5	15,750	14,400	– 8.6
28	273.0	266	–2.6	17,950	16,450	– 8.4
29	284.0	277	–2.5	20,150	18,700	– 7.2
30	294.0	289.0	–1.7	22,400	21,100	– 5.8
31	304.0	300.0	–1.3	24,625	23,625	– 4.1
32	315.5	312	–1.1	27,000	26,250	– 2.8
33	326.5	323	–1.1	29,625	28,925	– 2.4
34	340	335	–1.5	32,375	31,400	– 3.0
35	355	346.5	–2.4	35,700	34,000	– 3.8
36	374	359	–4.0	39,250	36,500	– 7.0
37	393	371	–5.6	42,500	39,000	– 8.2
38	410	384	–6.3	45,500	41,500	– 8.8
39	427	396	–7.2	48,250	44,000	– 8.8
40	443	408	–7.9	50,750	46,700	– 8.0

Table 4 gives a comparison of trial and model results for a displacement corresponding to 1900 tons. For a range up to and including 33 knots the trial RPMs are on the average 1.8 per cent low in comparison to predicted values. On the other hand the trial SHPs due to the plus and minus variation, indicates, so far as an average is concerned, a minor percentage variation from predicted values. In the cavitation range, both the trial RPM and SHP are approximately 8.5 per cent lower than the corresponding predicted values at 36 knots. The trials were not carried beyond 36 knots.

TABLE 4

MODEL TRIAL COMPARISON 11 AND 12 JUNE 1935

DIFFERENCES EXPRESSED AS PERCENTAGE OF ACTUAL TO PREDICTED VALUES

	RPM			SHP		
Speed Knots	Model	Trial	Per-cent	Model	Trial	Per-cent
16	145	144	-0.7	2,400	2,500	+4.2
17	155	154	-0.6	2,900	3,050	+5.2
18	166	164	-1.2	3,500	3,700	+5.7
19	175	173	-1.1	4,250	4,500	+5.9
20	186	183	-1.6	5,125	5,300	+3.4
21	196	193	-1.5	6,125	6,375	+2.5
22	207.5	204	-1.7	7,500	7,750	+3.3
23	220	215.5	-2.0	9,200	9,300	+1.1
24	232	227	-2.1	11,250	11,250	0
25	245	239.5	-2.2	13,825	13,300	-3.8
26	258	251	-2.7	16,500	15,625	-5.3
27	270	263	-2.6	19,000	18,000	-5.3
28	282.5	274.5	-2.8	21,625	20,550	-5.0
29	294.0	286	-2.7	24,200	23,000	-5.0
30	305.0	298	-2.3	26,500	25,750	-2.8
31	315.5	309	-2.1	28,250	27,500	-2.7
32	326	321	-1.5	32,000	31,625	-1.2
33	338	333	-1.5	35,250	34,750	-1.4
34	352	345	-2.0	38,000	37,000	-2.6
35	373	358	-4.0	43,250	41,000	-5.2
36	404	370	-8.4	47,875	44,000	-8.8

B. Turning Trials.

B-1 Results.

Table 5 gives data for each circle concerning approach speed, nominal rudder angle, actual average rudder angle, and rate of rudder in degrees per second.

TABLE 5

DATA FOR EACH CIRCLE

Circle No.	RPM Ave.	Speed Knots	Nominal Rudder Degrees	Actual Rudder Degrees	Rudder Rate Sec per Degree
1		15.15	20	20	0.55
2	132.3	15.05	20	20.5	0.55
3	132.0	15.02	25	24.7	0.37
4	131.5	14.97	25	23.1	0.42
5	131.8	15.00	30	30.8	0.36
6	131.4	14.95	30	30.4	0.36
7	130.2	14.85	Max.	33.0	0.42
8	128.2	14.62	Max.	33.5	0.38
9	178.6	19.65	20	19.3	0.48
10	179.7	19.78	20	18.9	0.40
11	178.6	19.65	25	25.1	0.36
12	179.8	19.80	25	23.2	0.40
13	182.1	20.01	30	31.1	0.45
14	181.8	19.97	30	30.0	0.38
15	181.8	19.97	Max.	33.0	0.37
16	181.7	19.96	Max.	32.0	0.36
17	239.0	25.36	20	19.4	0.38
18	240.4	25.50	25	24.1	0.36
19	238.7	25.35	30	29.3	0.33
20	240.1	25.48	Max.	32.3	0.36
21	296.8	30.44	20	19.6	0.40
22	300.2	30.74	20	19.5	0.42
23	300	30.72	25	24.0	0.36
24	299.1	30.63	25	24.4	0.37
25	299.1	30.63	30	29.6	0.45
26	299.7	30.67	30	29.5	0.48
27	300.8	30.79	Max.	32.7	0.37
28	301.0	30.80	Max.	32.7	0.38
29	362.5	35.90	20	19.7	0.53
30	360.0	35.70	20	21.2	0.55
31	360.2	35.73	25	25.4	0.48
32	360.4	35.75	25	25.5	0.40
33	360.6	35.76	30	29.5	0.50
34	357.2	35.45	30	30.3	0.48
35	363.9	36.00	Max.	33.5	0.38
36	360.4	35.75	Max.	33.1	0.38

Figs. 2, 3, 4, 5, 6, indicate the different circles obtained at each speed with various rudder angles by the visual (plane table) and photographic method. Table 6 gives a comparison of the tactical diameter, advance, and transfer as observed by visual and photographic methods. These data have been used for plotting Fig. 7 and 8 showing the tactical diameters for different rudder angles. In like manner Figs. 9 and 10 give a comparison for advance and transfer characteristics by both methods. Fig. 11 has been prepared from cross fairing the above data observed photographically to indicate the tactical diameter, advance, and transfer for any given speed with different rudder angles.

Figs. 12, 13, 14, 15 and 16 give the angles of heel observed photographically for different rudder angles and various speeds. Figs. 17, 18, 19, 20 and 21 give the changes in heading in degrees with time for the different rudder angles at various speeds.

Fig. 22 gives the percentage reduction in speed for changes in course of 45, 90, 180 degrees with different rudder angles at various speeds, the reduction being expressed as a percentage of the approach speed.

B-2 Discussion.

A total of 36 circles was made for this series of trials. Because of an anticipated interference of weather conditions, but four circles were made at 25 knot nominal speed instead of eight.

Of the 36 circles, comparative measurements of tactical diameter and transfer were possible in 32 cases, advance in 27 cases. Data were obtained for every circle but it was not possible to correlate photographic results in three cases and visual results in one case. During two circles numbers 9 and 11, it was not possible to definitely fix the point of turn by the visual method. For this reason no advance measurements are included for these runs by this method.

Table 6 indicates the percentage variation between the results observed visually and photographically. Based on the latter, the tactical diameter, advance, and transfer by visual methods are, on the average, 0.5, 0.4, and 2.2 per cent lower respectively.

To what extent the percentage reductions in speeds, given in Fig. 22, have been influenced by lack of necessary depth, is not possible of evaluation. For an approximate depth of 100 feet, the critical speed is 25 knots. Hence, for speeds up to 25 knots there should exist no appreciable influence. As these trials were conducted at this approximate depth and at speeds of 30 and 36 knots, no doubt some influence has been experienced. The extent of this, especially as regards the percentage reduction, is not considered sufficient to affect the results materially.

Further discussion of other features of these trials will be included hereinafter in the comparison of full scale and model results.

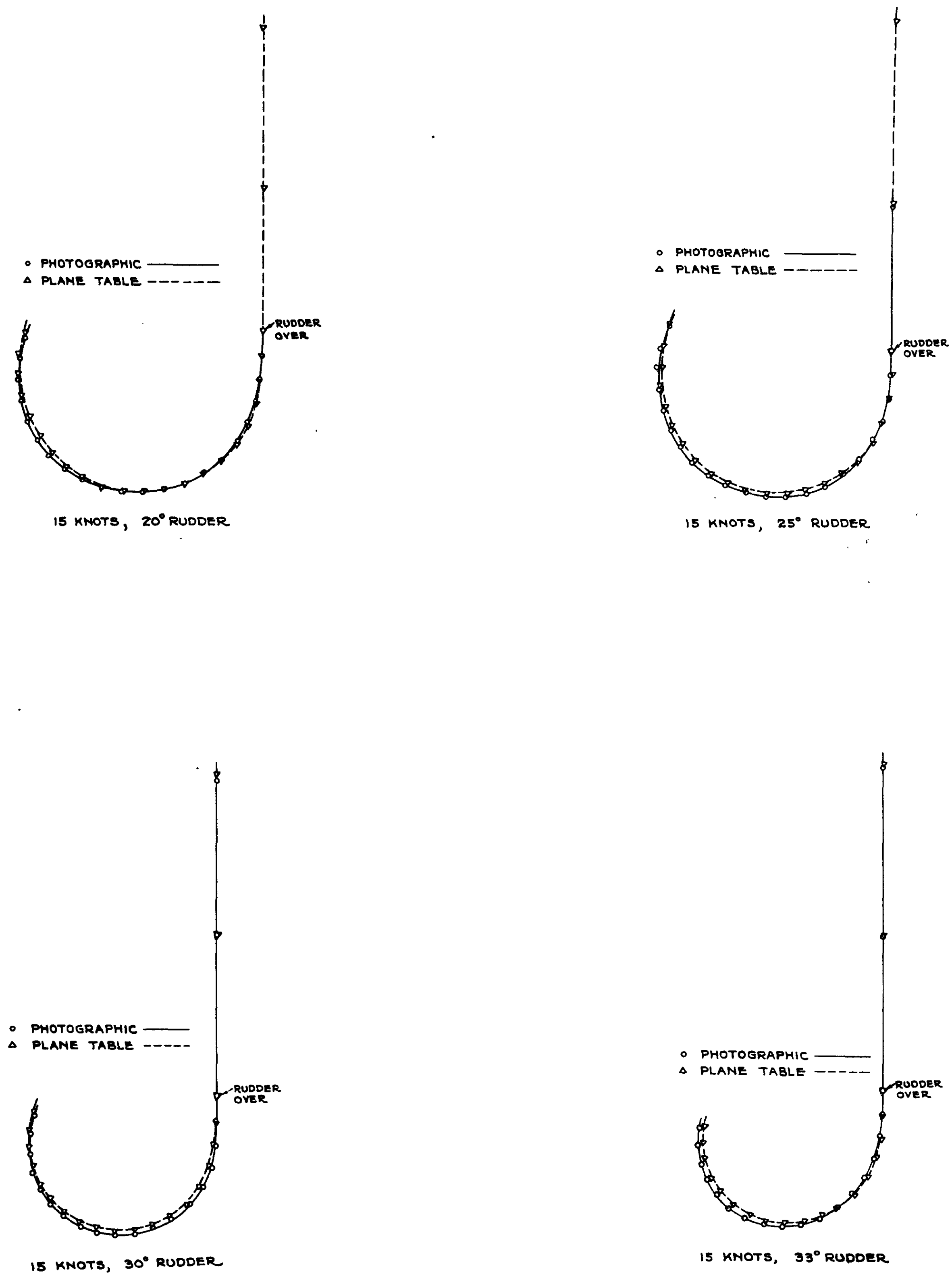

FIG. 2 U.S.S. WORDEN. OBSERVED TURNING CIRCLES, SPEED 15 KNOTS, VARIOUS RUDDER ANGLES.

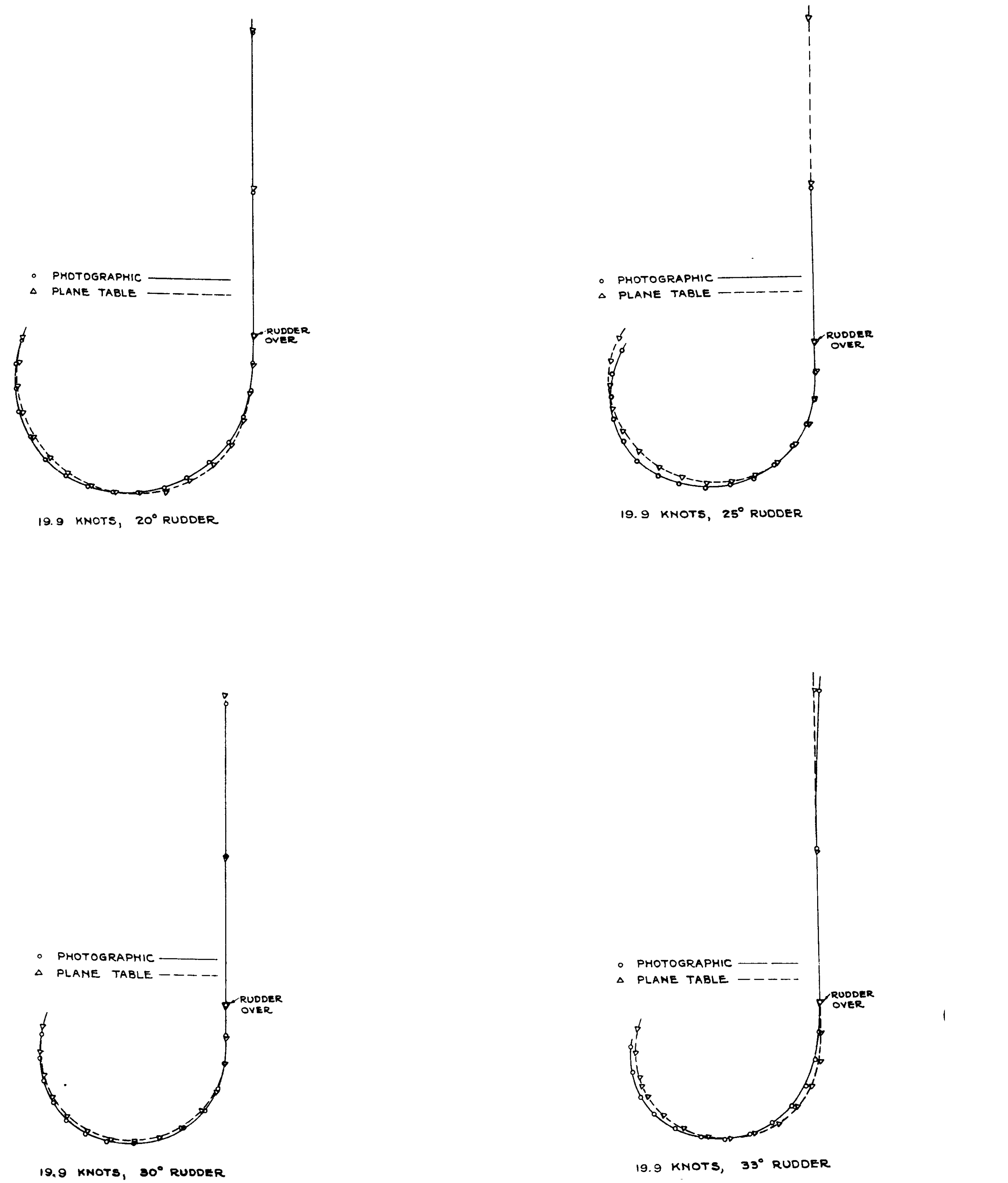

FIG. 3 U.S.S. WORDEN. OBSERVED TURNING CIRCLES, SPEED 19.9 KNOTS, VARIOUS RUDDER ANGLES.

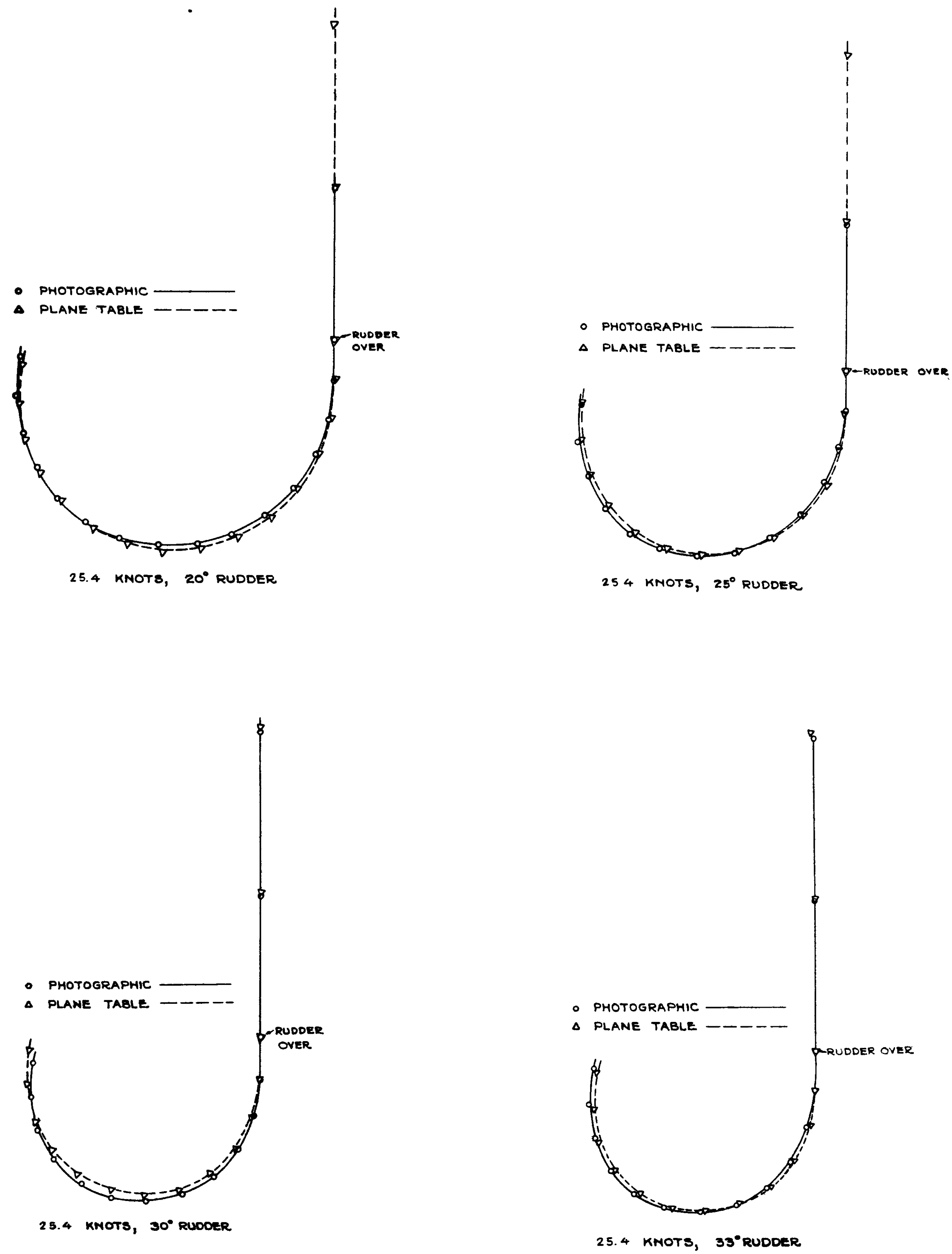

FIG. 4 U.S.S. WORDEN. OBSERVED TURNING CIRCLES, SPEED 25.4 KNOTS, VARIOUS RUDDER ANGLES.

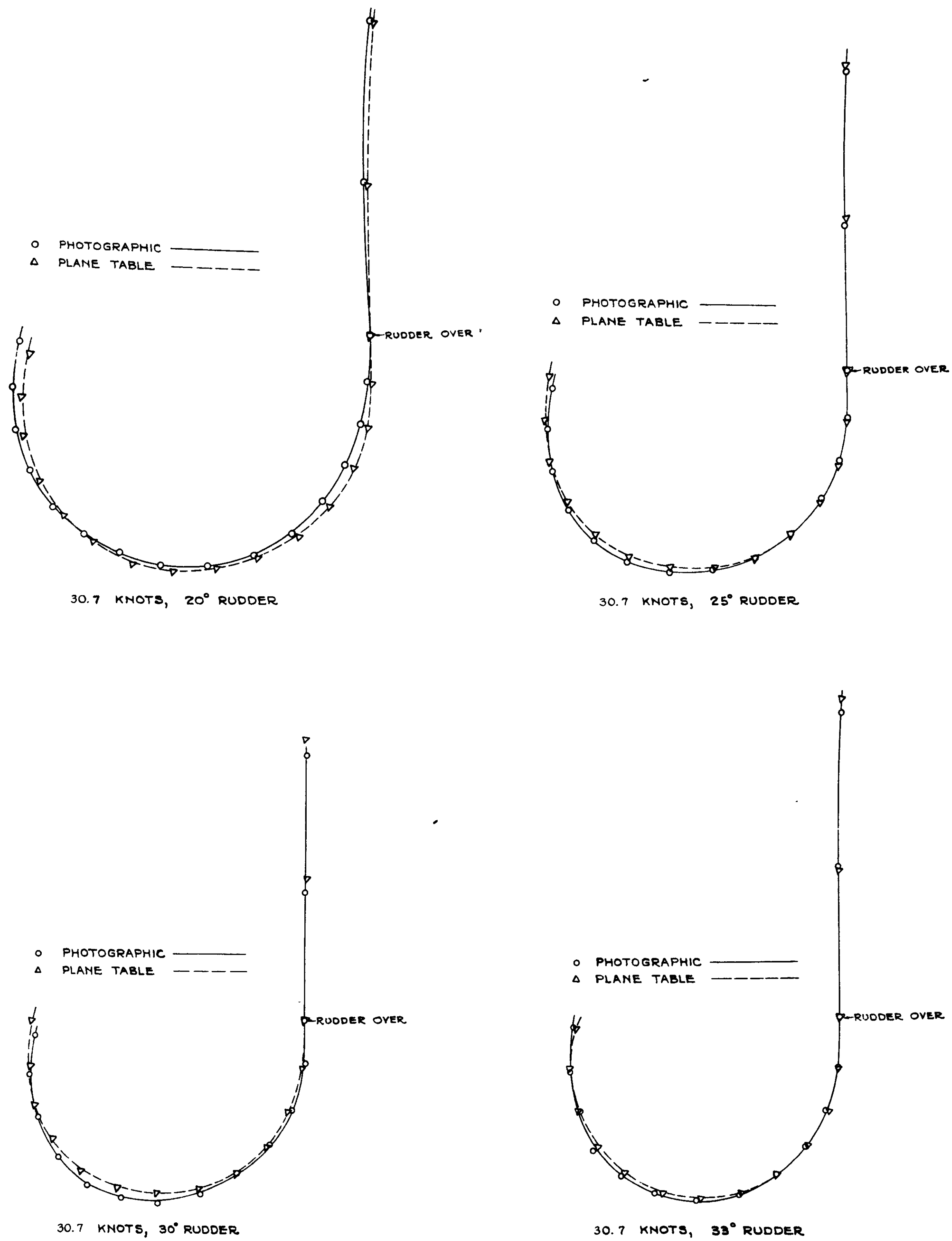

FIG. 5 U.S.S. WORDEN. OBSERVED TURNING CIRCLES, SPEED 30.7 KNOTS, VARIOUS RUDDER ANGLES.

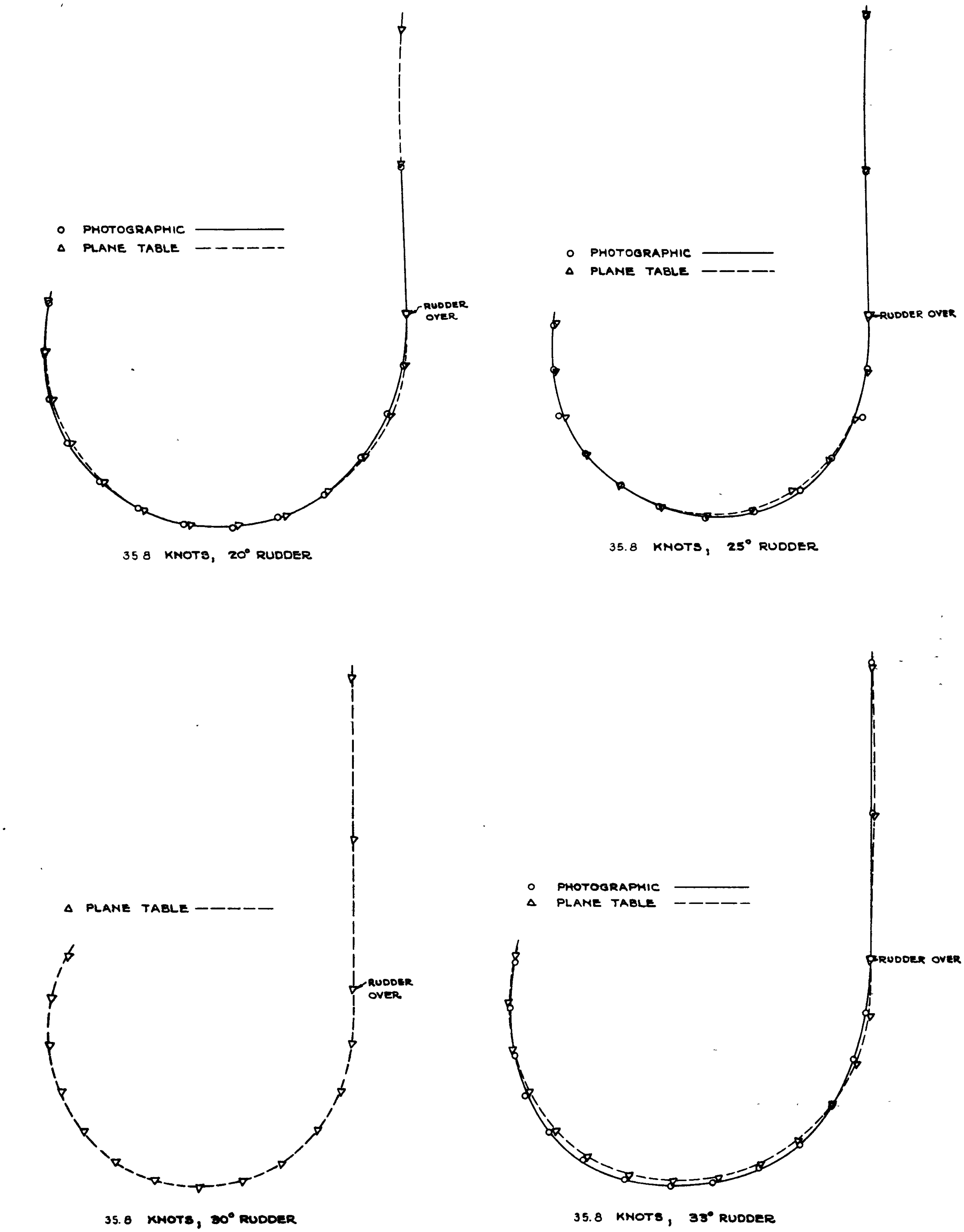

FIG. 6 U.S.S. WORDEN. OBSERVED TURNING CIRCLES, SPEED 35.8 KNOTS, VARIOUS RUDDER ANGLES.

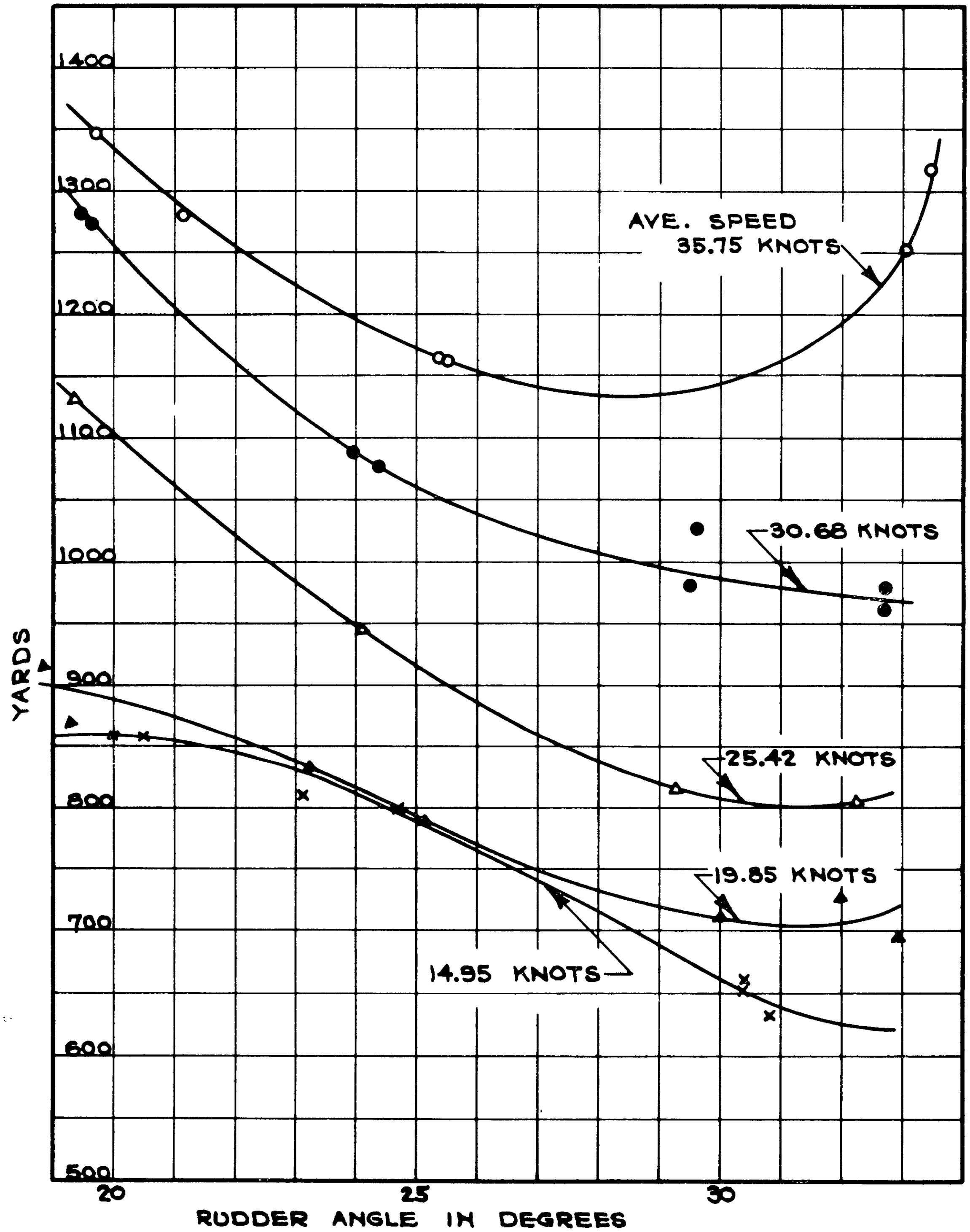

FIG. 7 U.S.S. WORDEN. TACTICAL DIAMETER FOR DIFFERENT SPEEDS AND RUDDER ANGLES OBSERVED BY PHOTOGRAPHIC METHOD.

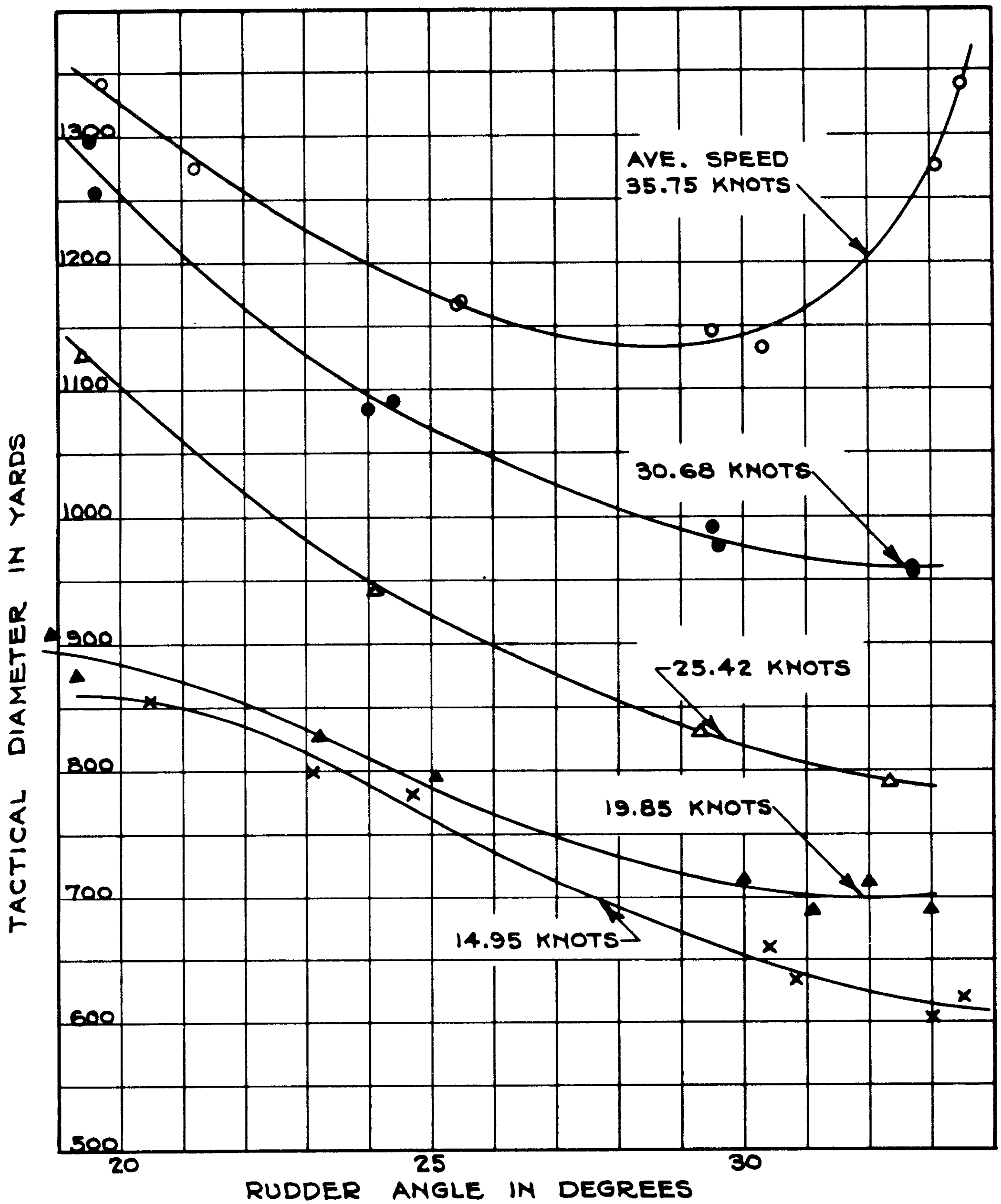

FIG. 8 U.S.S. WORDEN. TACTICAL DIAMETER FOR DIFFERENT SPEEDS AND RUDDER ANGLES OBSERVED BY VISUAL METHOD.

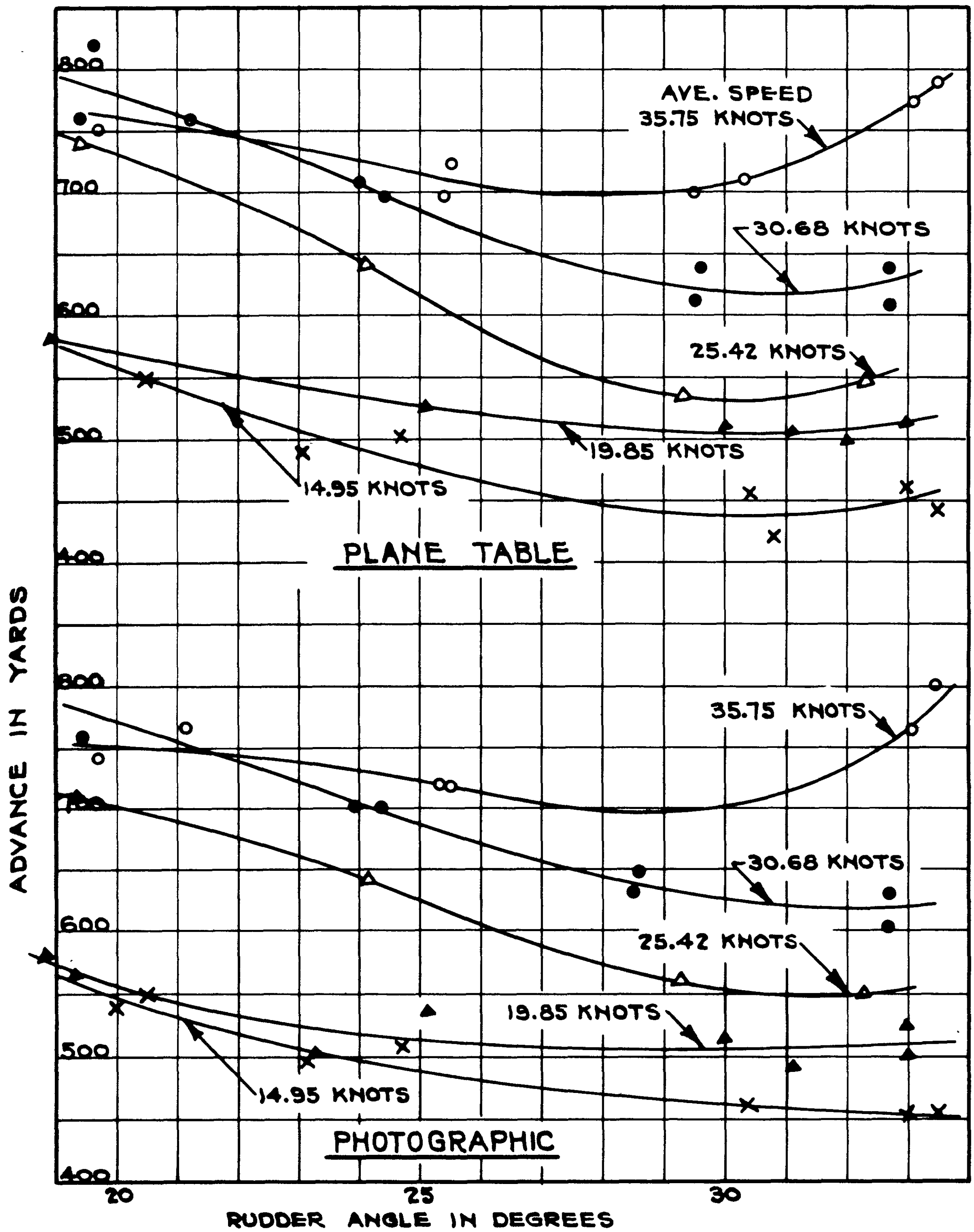

FIG. 9 U.S.S. WORDEN. ADVANCE FOR DIFFERENT SPEEDS AND RUDDER ANGLES OBSERVED BY VISUAL AND PHOTOGRAPHIC METHODS.

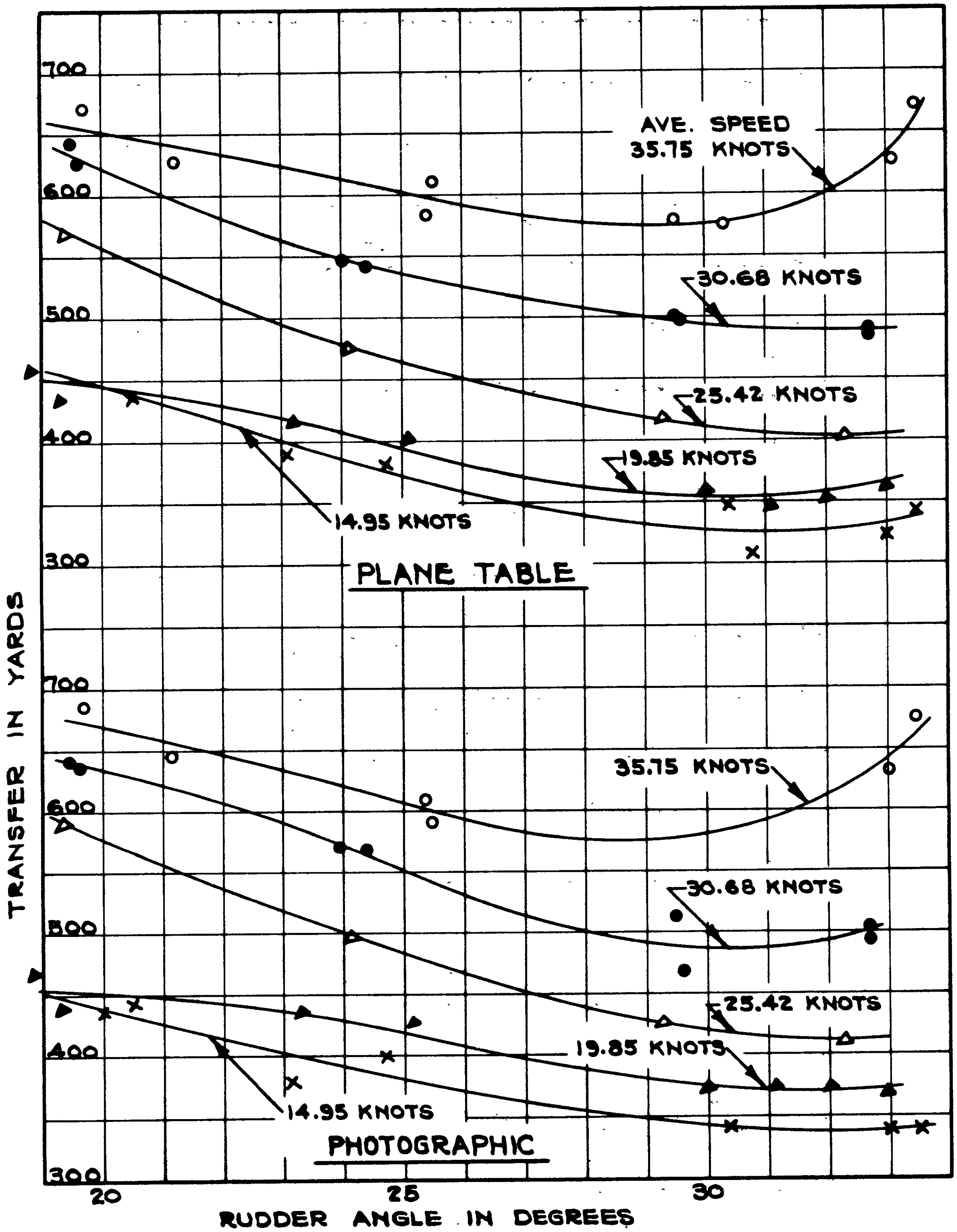

FIG. 10 U.S.S. WORDEN. TRANSFER FOR DIFFERENT SPEEDS AND RUDDER ANGLES OBSERVED BY VISUAL AND PHOTOGRAPHIC METHODS.

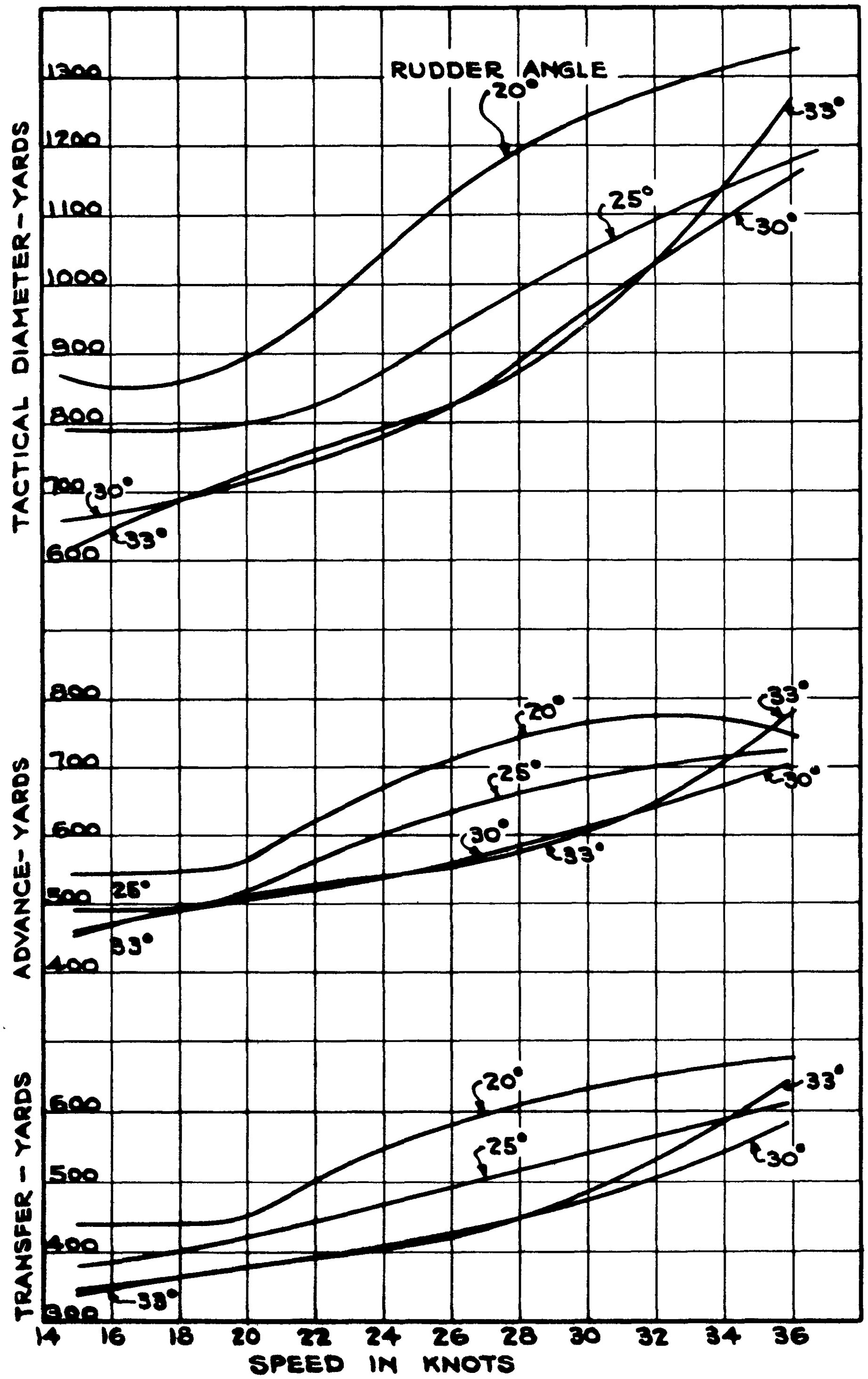

FIG. 11 U.S.S. WORDEN. TACTICAL CHARACTERISTICS FOR DIFFERENT SPEEDS AND RUDDER ANGLES.

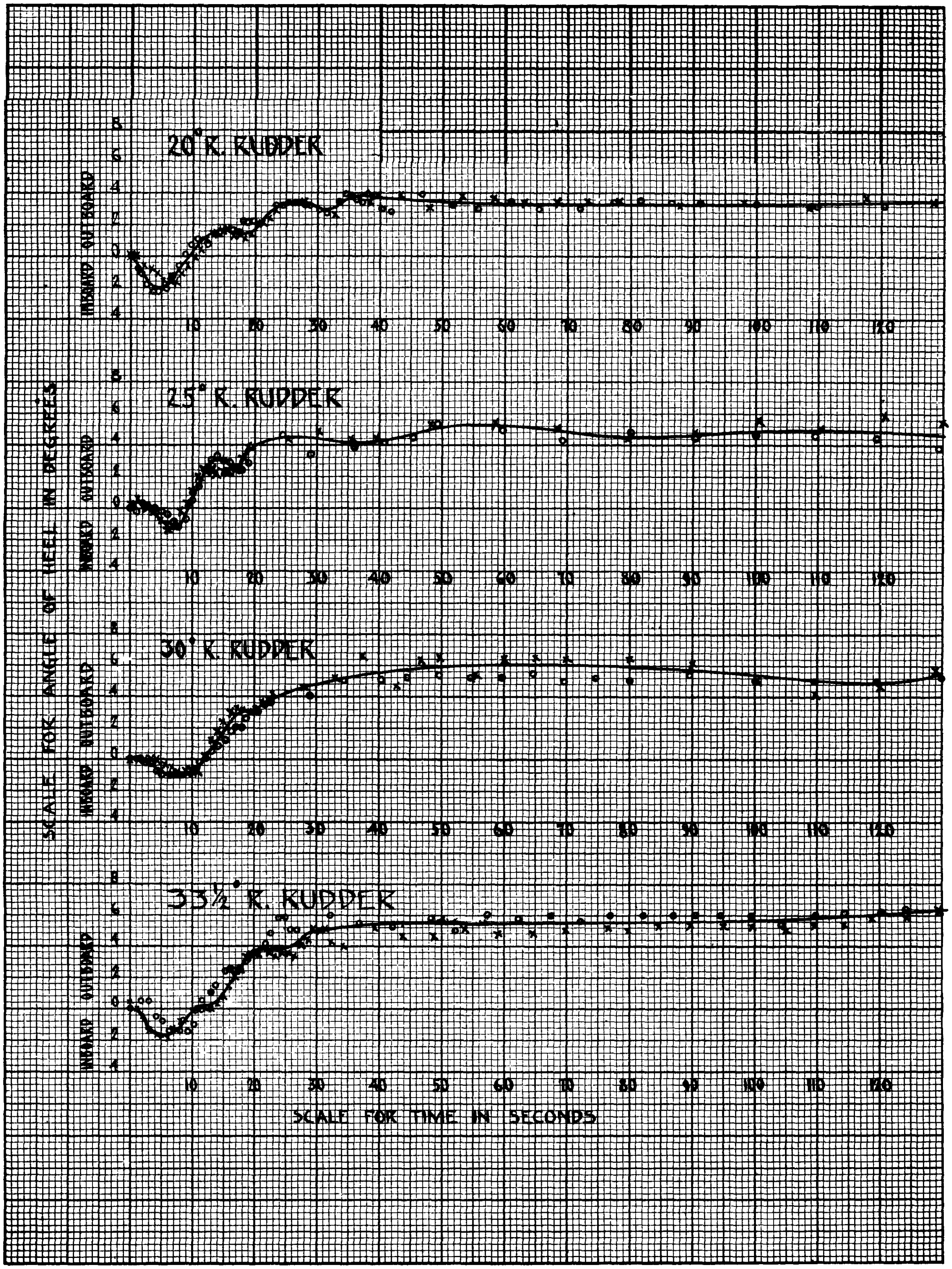

FIG. 12 U.S.S. WORDEN. ANGLES OF HEEL WHILE TURNING FOR A SPEED OF 15 KNOTS AND DIFFERENT RUDDER ANGLES.

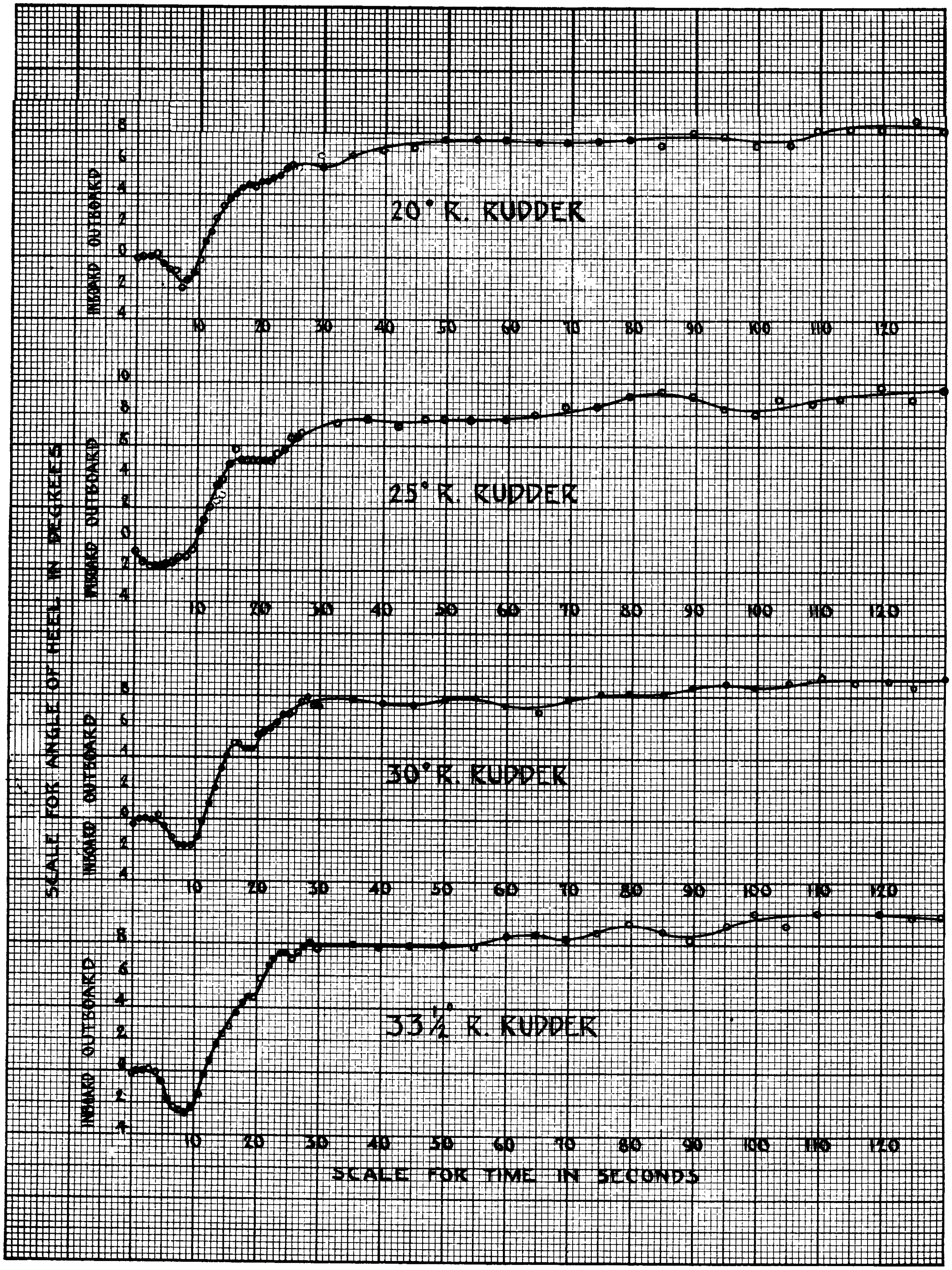

FIG. 13 U.S.S. WORDEN. ANGLES OF HEEL WHILE TURNING FOR A SPEED OF 19.9 KNOTS AND DIFFERENT RUDDER ANGLES.

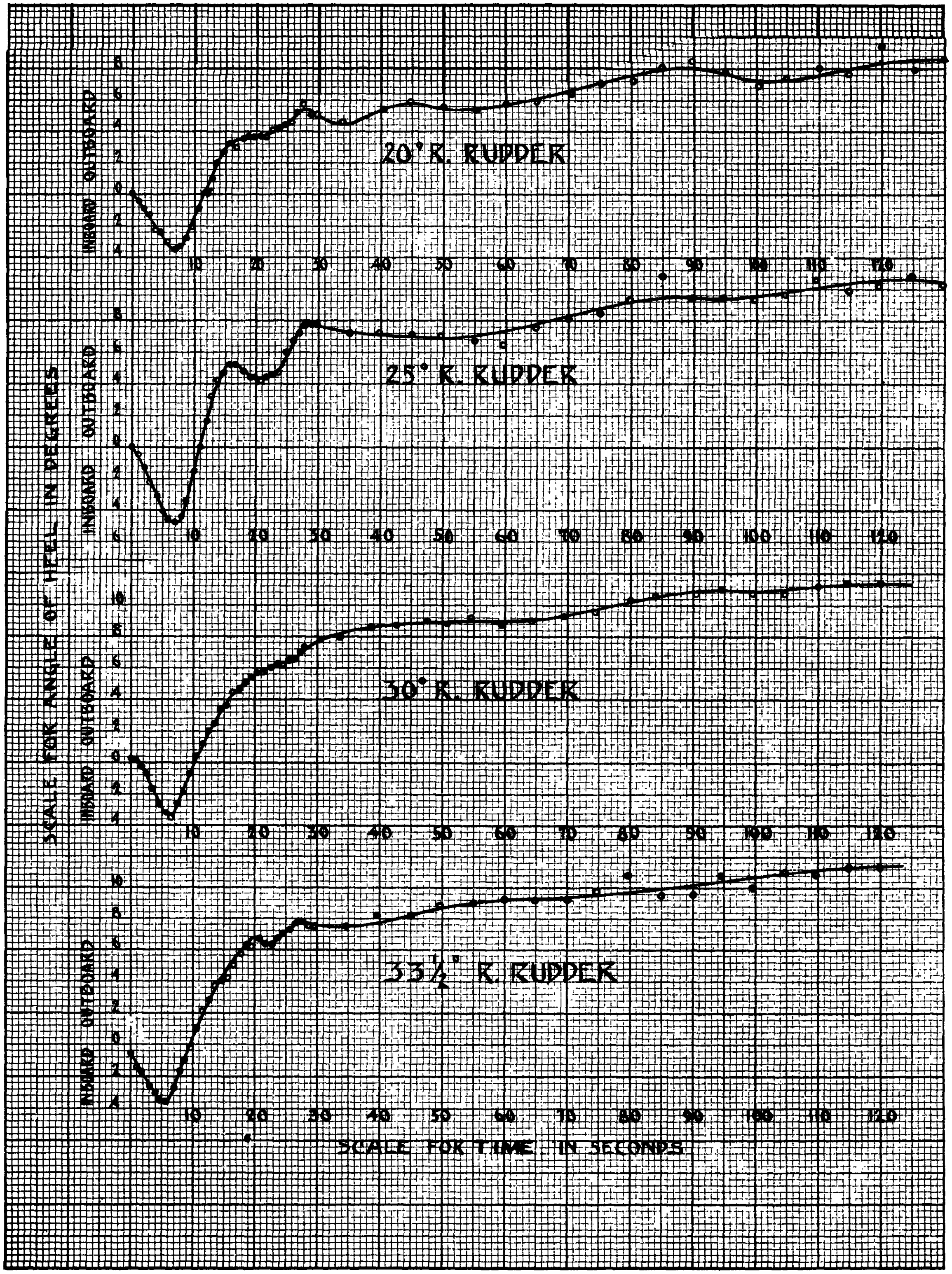

FIG. 14 U.S.S. WORDEN. ANGLES OF HEEL WHILE TURNING FOR A SPEED OF 25.4 KNOTS AND DIFFERENT RUDDER ANGLES.

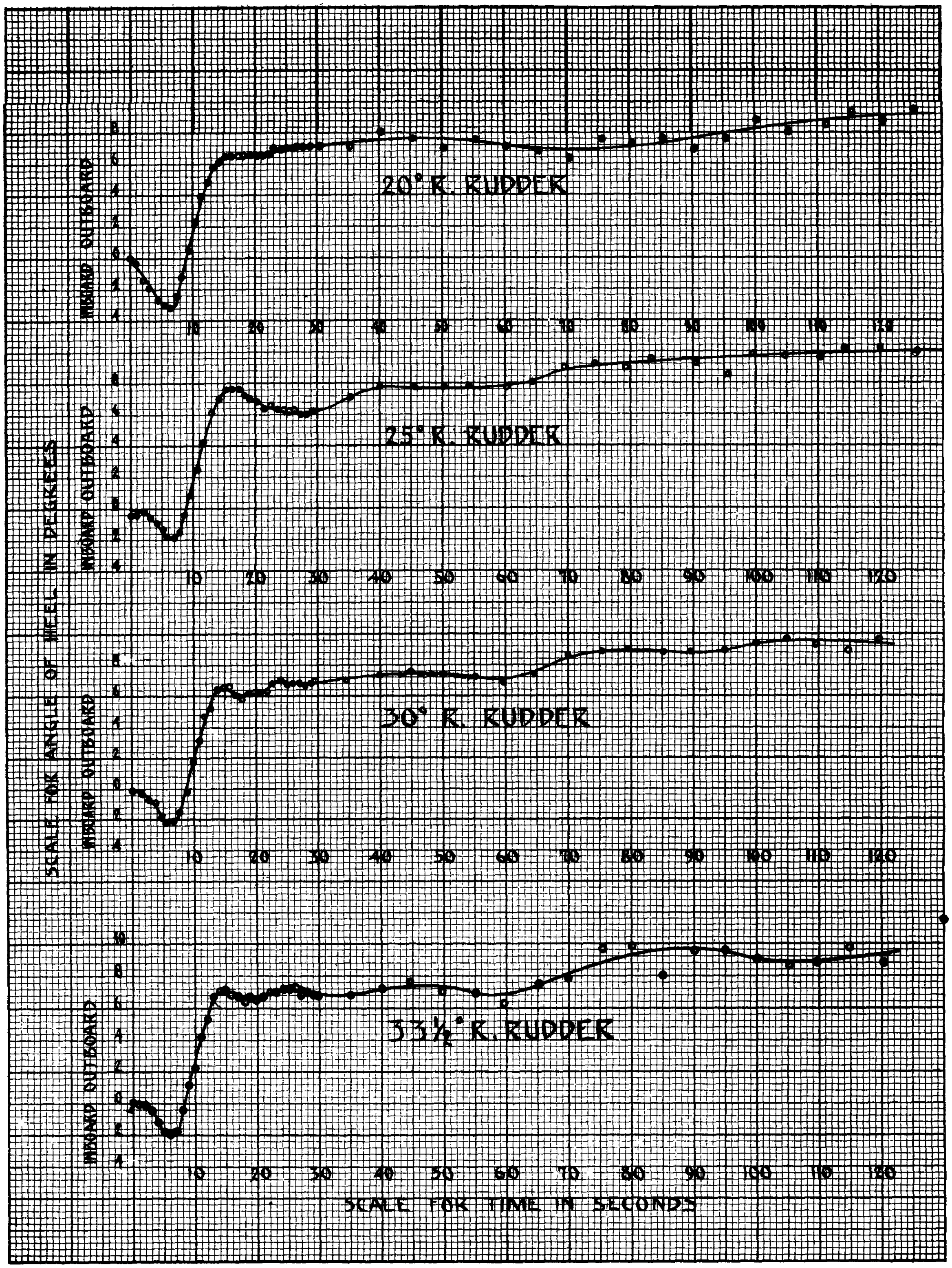

FIG. 15 U.S.S. WORDEN. ANGLES OF HEEL WHILE TURNING FOR A SPEED OF 30.7 KNOTS AND DIFFERENT RUDDER ANGLES.

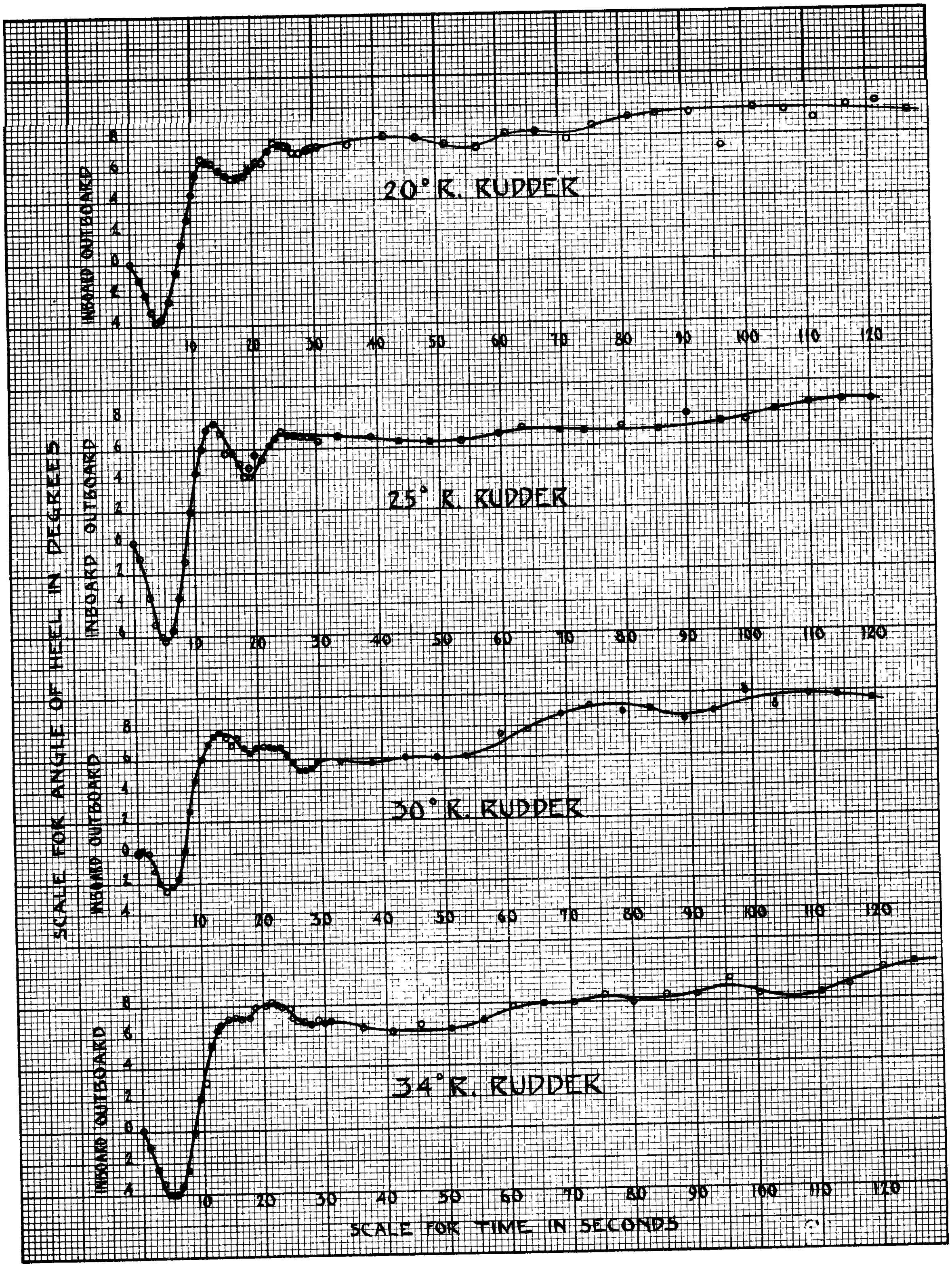

FIG. 16 U.S.S. WORDEN. ANGLES OF HEEL WHILE TURNING FOR A SPEED OF 35.8 KNOTS AND DIFFERENT RUDDER ANGLES.

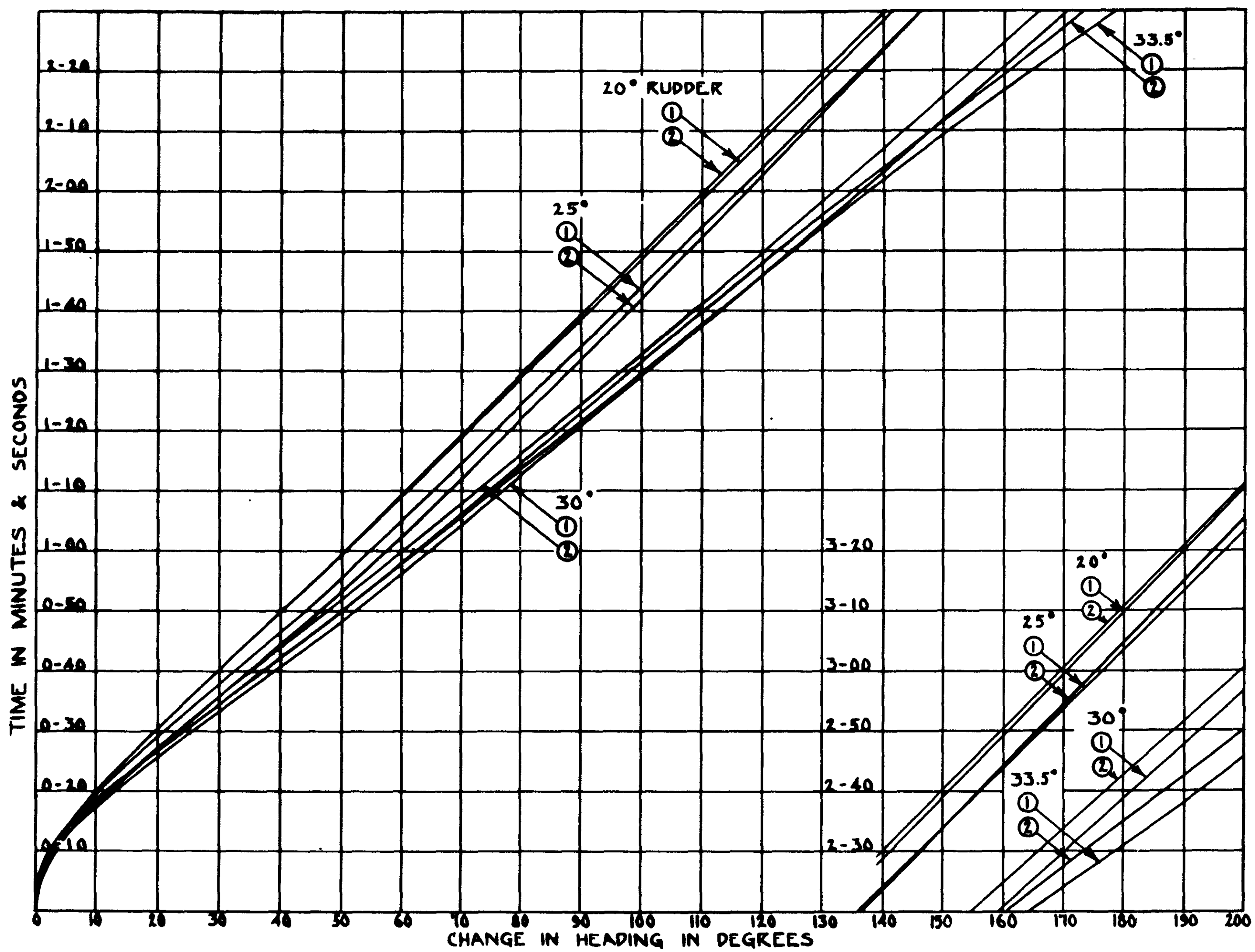

FIG. 17 U.S.S. WORDEN. CHANGE IN HEADING VERSUS TIME FOR A SPEED OF 15 KNOTS AND DIFFERENT RUDDER ANGLES.

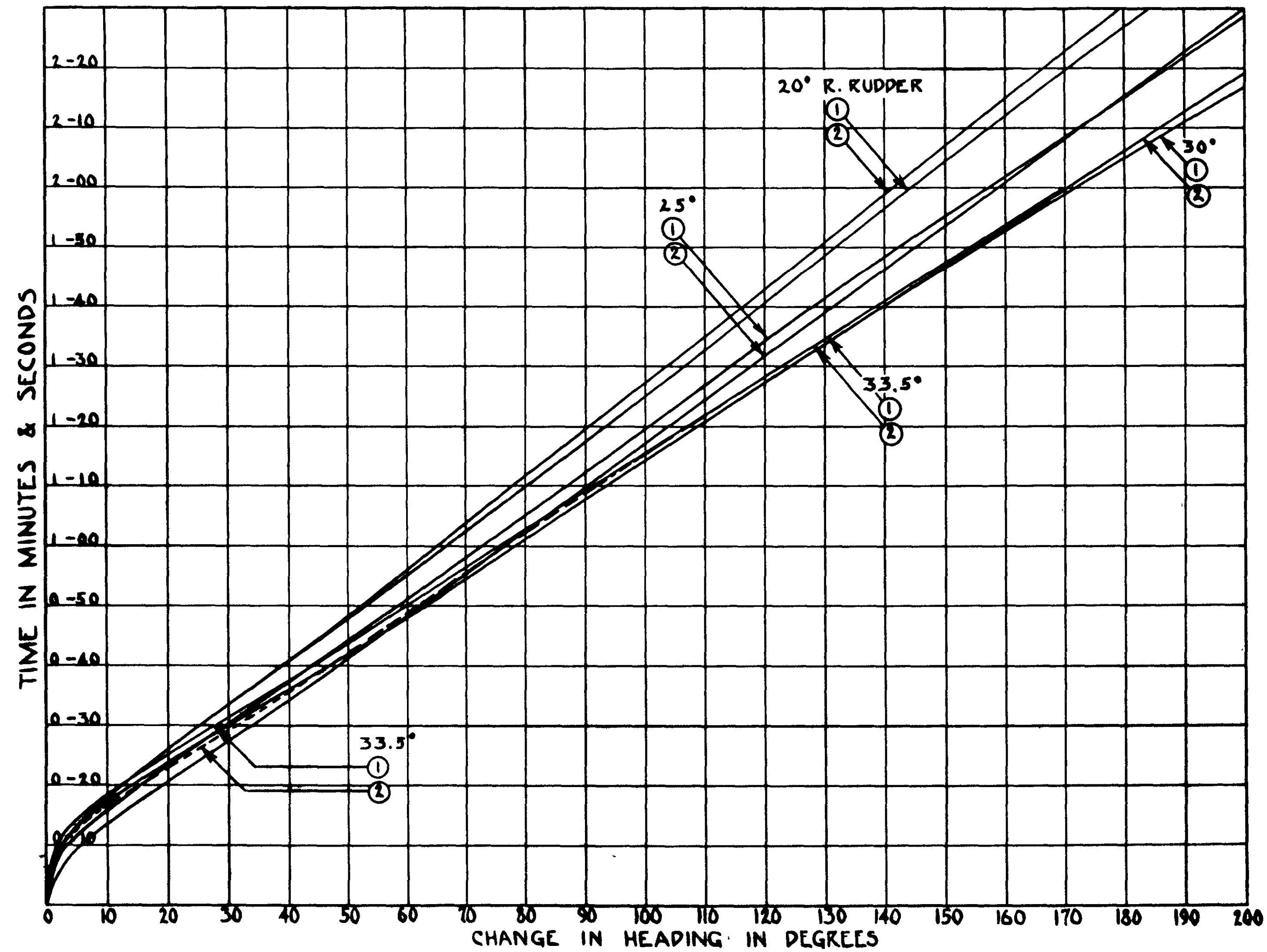

FIG. 18 U.S.S. WORDEN. CHANGE IN HEADING VERSUS TIME FOR A SPEED OF 19.9 KNOTS AND DIFFERENT RUDDER ANGLES.

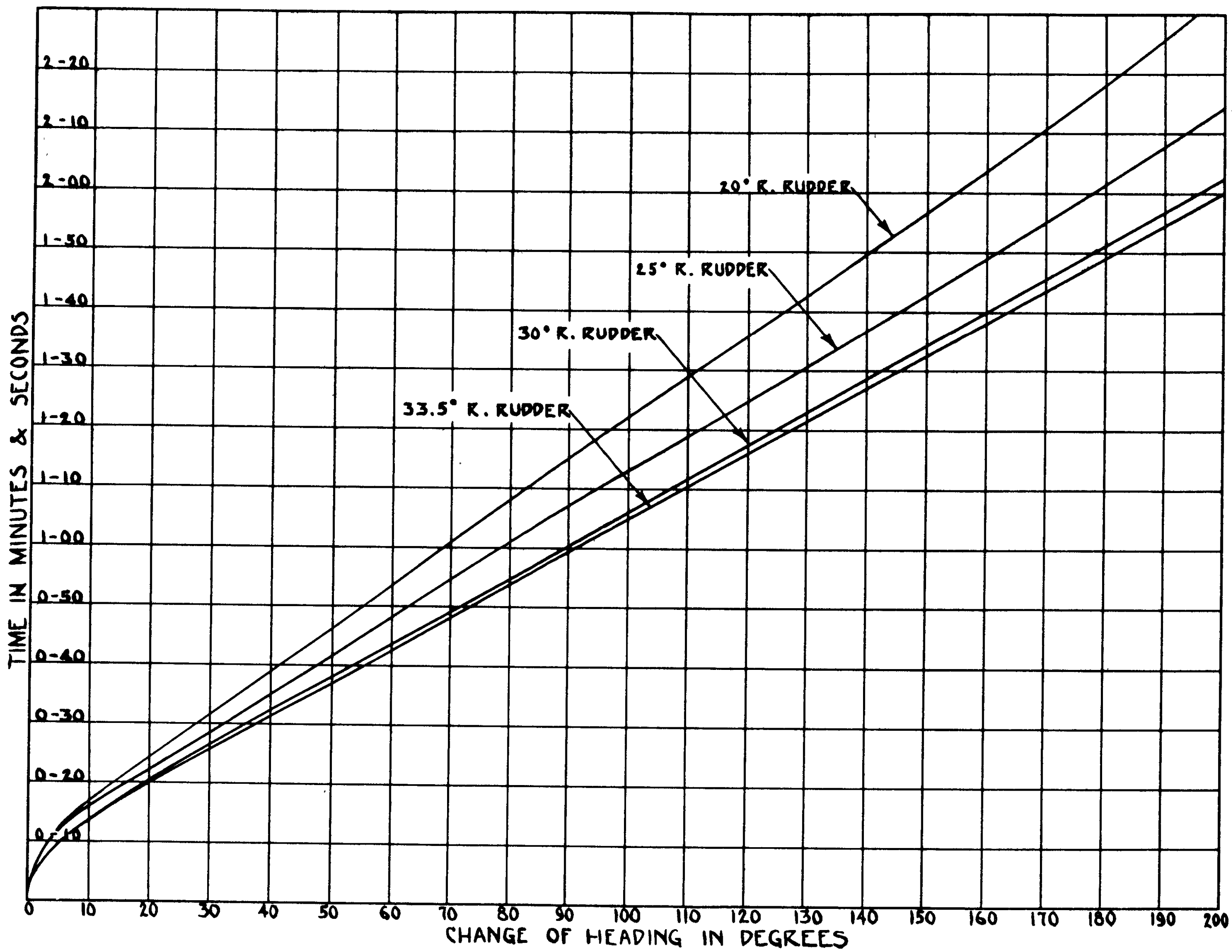

FIG. 19 U.S.S. WORDEN. CHANGE IN HEADING VERSUS TIME FOR A SPEED OF 25.4 KNOTS AND DIFFERENT RUDDER ANGLES.

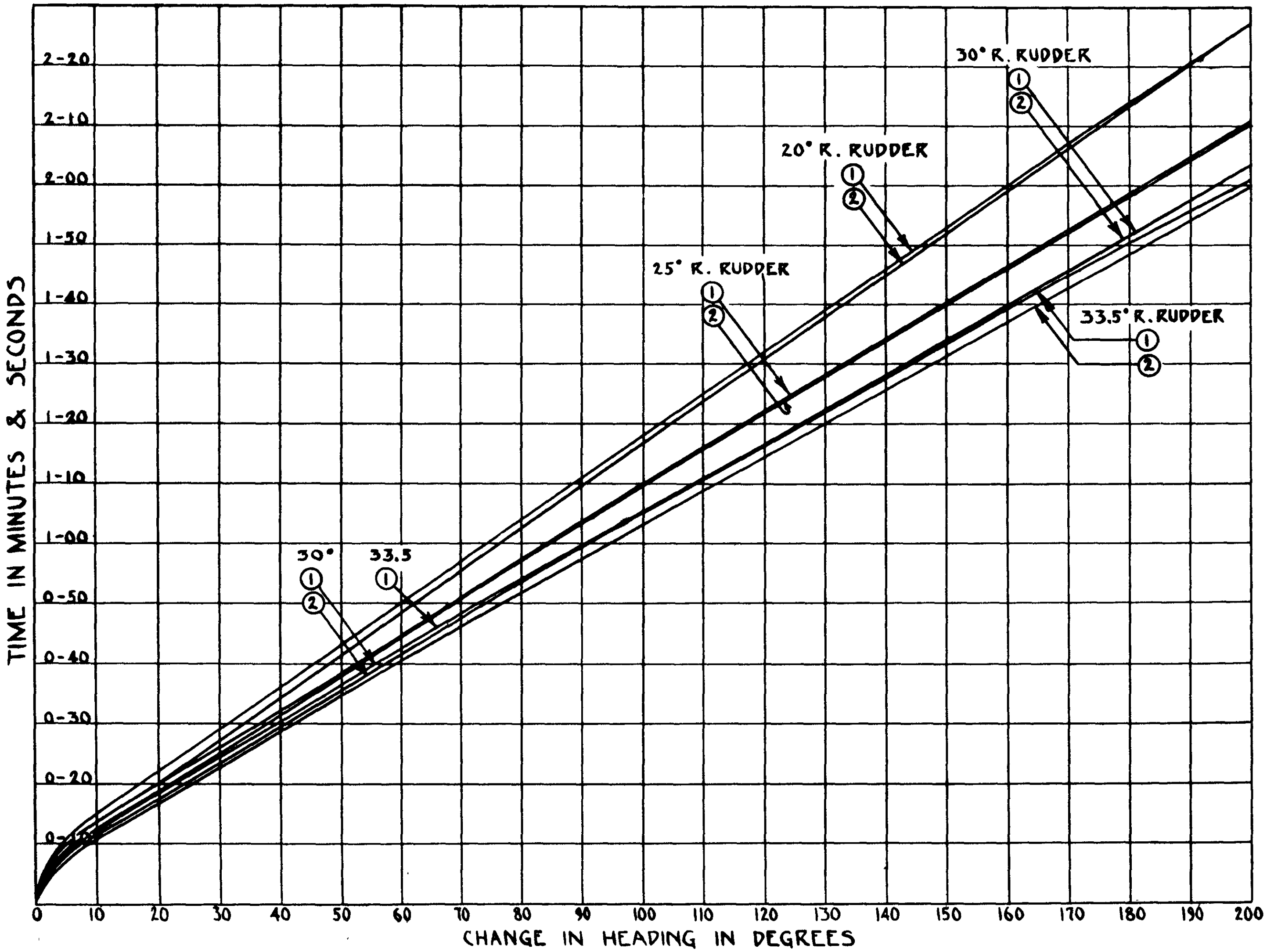

FIG. 20 U.S.S. WORDEN. CHANGE IN HEADING VERSUS TIME FOR A SPEED OF 30.7 KNOTS AND DIFFERENT RUDDER ANGLES.

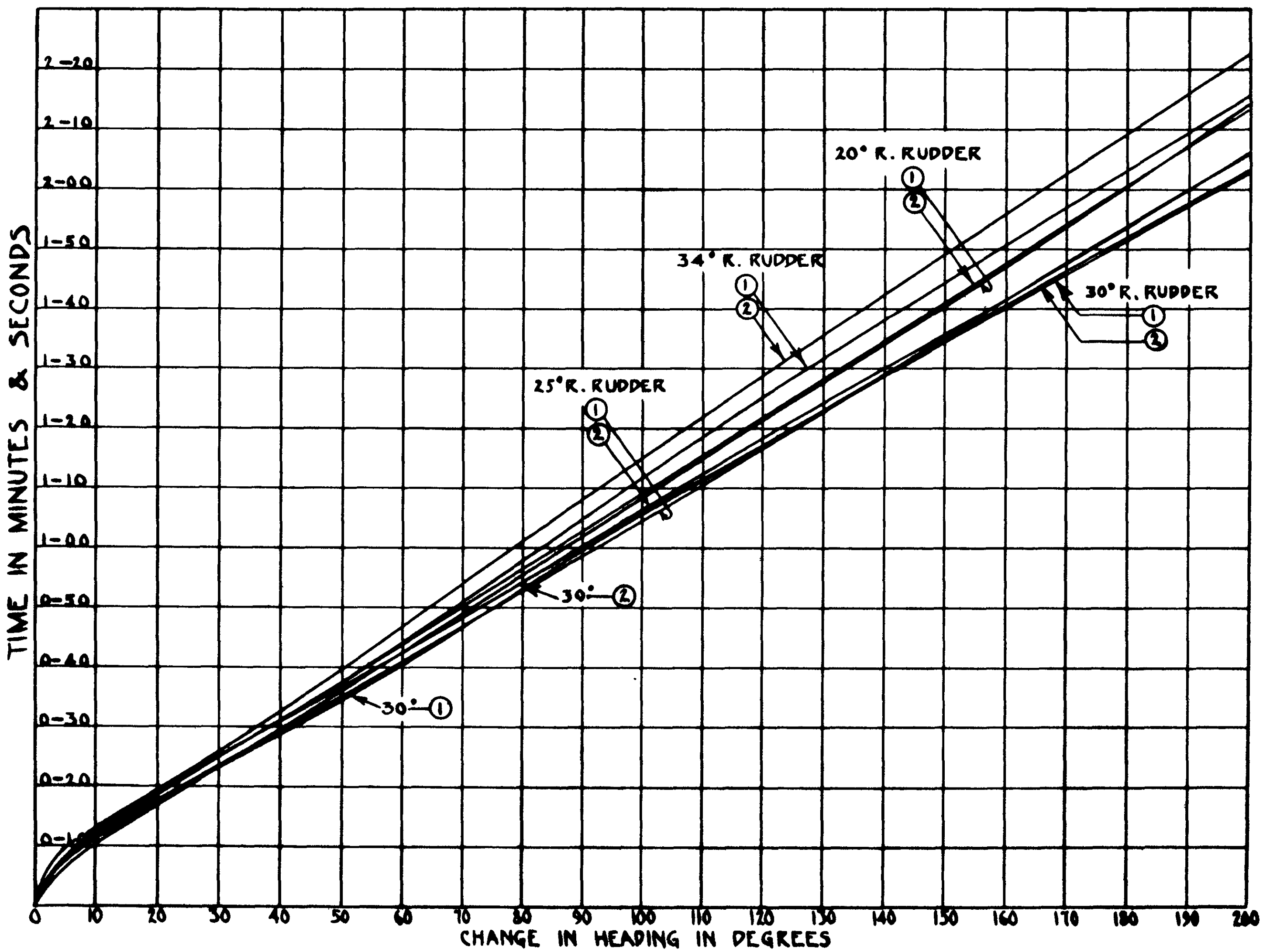

FIG. 21 U.S.S. WORDEN. CHANGE IN HEADING VERSUS TIME FOR A SPEED OF 35.8 KNOTS AND DIFFERENT RUDDER ANGLES.

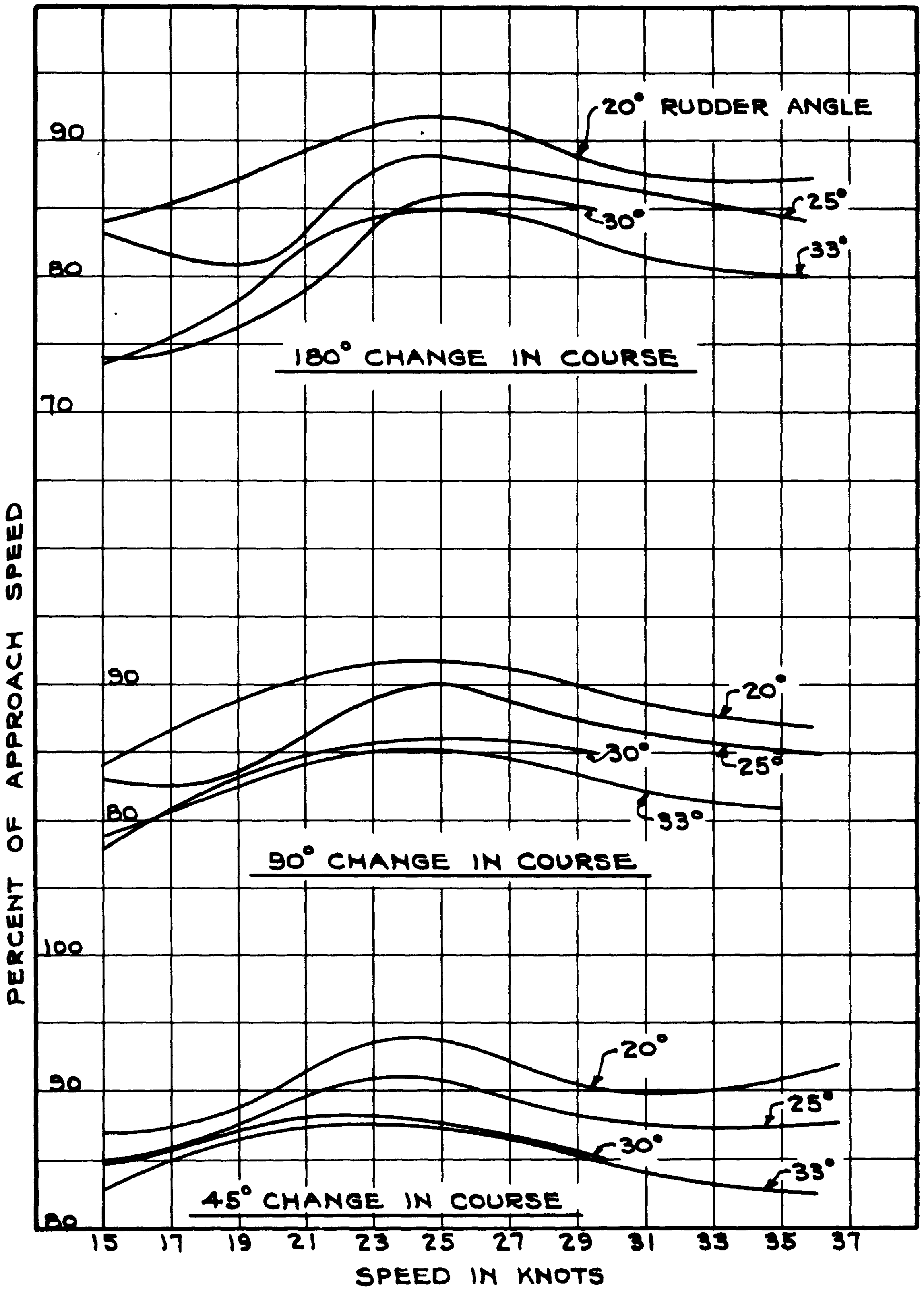

FIG. 22 U.S.S. WORDEN. PERCENTAGE REDUCTION IN SPEED FOR DIFFERENT CHANGES OF COURSE AT VARIOUS SPEEDS AND RUDDER ANGLES.

TABLE 6

COMPARISON OF TACTICAL DIAMETER, ADVANCE AND TRANSFER

BY VISUAL (PLANE TABLE) AND PHOTOGRAPHIC METHODS

MEASUREMENTS IN YARDS

DIFFERENCE EXPRESSED AS PERCENTAGE BASED ON RESULTS OF PHOTOGRAPHIC METHOD.

Circle No.	Tactical Diameter			Advance			Transfer		
	Photo.	Visual	Per-cent	Photo.	Visual	Per-cent	Photo.	Visual	Per-cent
1	859	–	–	540	–	–	436	–	–
2	858	856	–0.2	548	548	0	444	435	–2.0
3	799	781	–2.3	507	502	–1.0	399	381	–4.5
4	810	798	–1.5	496	489	–1.4	378	390	+3.2
5	–	633	–	–	419	–	–	308	–
6	652	660	+1.2	462	455	–1.5	342	348	+1.8
7	614	602	–2.0	453	461	+1.8	339	322	–5.0
8	638	619	–3.0	452	442	–2.2	338	341	+0.9
9	870	875	+0.6	564	–	–	438	435	–0.7
10	916	910	–0.7	580	580	0	467	458	–1.9
11	783	794	+1.4	537	526	–2.0	427	402	–5.9
12	833	826	–0.6	502	–	–	435	417	–3.9
13	704	688	–2.3	493	506	+2.6	375	346	–7.7
14	710	715	+0.7	515	511	–0.8	373	360	–3.5
15	694	690	–0.6	524	513	–2.1	369	361	–2.2
16	726	713	–1.8	500	499	–0.2	396	353	–10.9
17	1,133	1,127	–0.5	710	740	+4.2	591	570	–3.6
18	945	936	–0.9	641	640	–0.1	495	475	–4.0
19	816	830	+1.7	560	534	–4.6	426	417	–2.1
20	805	790	–1.9	549	547	–0.4	410	401	–2.2
21	1,274	1,255	–1.5	810	820	+1.2	636	628	–1.2
22	1,283	1,296	+1.0	760	760	0	643	644	+0.1
23	1,088	1,085	–0.3	702	707	+0.7	570	546	–4.2
24	1,076	1,092	+1.5	700	696	–0.6	568	542	–4.6
25	1,026	979	–4.6	648	639	–1.4	468	497	+6.2
26	981	992	+1.1	632	611	–3.3	514	500	–2.7
27	963	960	–0.3	630	637	+1.1	504	484	–4.0
28	980	958	–2.2	604	608	+0.7	492	490	–0.4
29	1,346	1,342	–0.3	743	751	+1.1	686	672	–2.0
30	1,280	1,275	–0.4	766	760	–0.8	645	628	–2.6
31	1,169	1,167	–0.2	720	696	–3.3	609	584	–4.1
32	1,163	1,168	+0.5	719	724	+0.7	591	611	+3.4
33	–	1,146	–	–	700	–	–	578	–
34	–	1,132	–	–	710	–	–	570	–
35	1,319	1,340	+1.6	800	790	–1.2	675	673	–0.3
36	1,253	1,275	+1.7	765	775	+1.3	632	627	–0.8

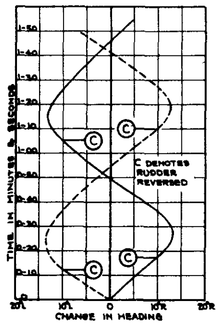

FIG. 23 RUDDER ANGLE 10 DEGREES, SPEED 20.7 KNOTS

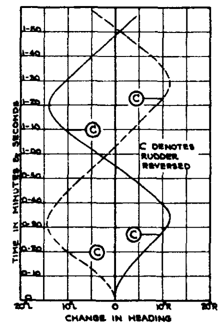

FIG. 25 RUDDER ANGLE 10 DEGREES, SPEED 25.9 KNOTS

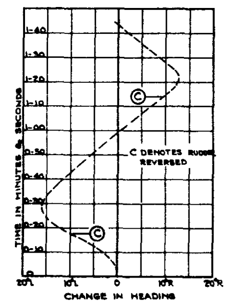

FIG. 27 RUDDER ANGLE 10 DEGREES, SPEED 31.5 KNOTS

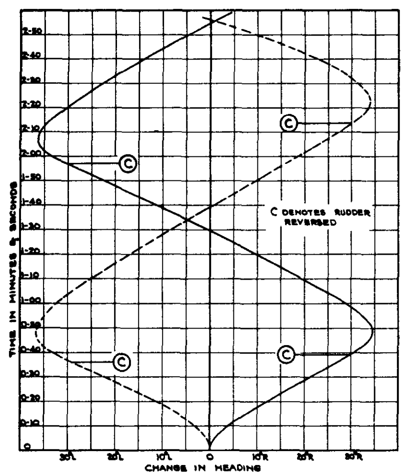

FIG. 24 RUDDER ANGLE 15 DEGREES, SPEED 20.9 KNOTS

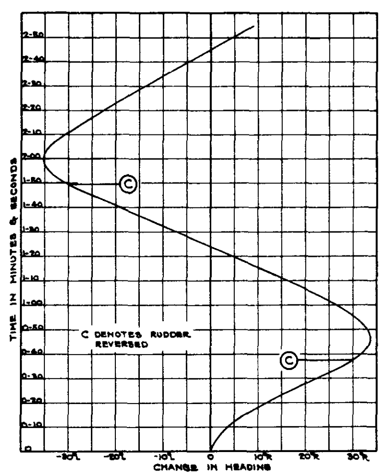

FIG. 26 RUDDER ANGLE 15 DEGREES, SPEED 25.9 KNOTS

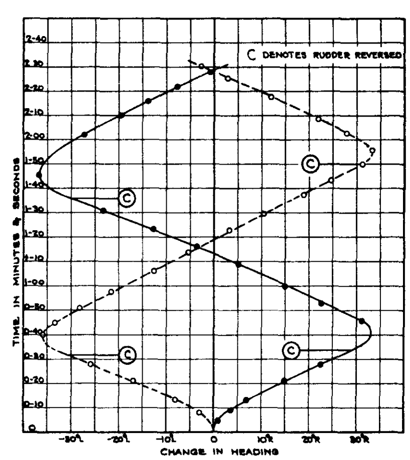

FIG. 28 RUDDER ANGLE 15 DEGREES, SPEED 31.5 KNOTS

MANEUVERABILITY TRIALS UNDERWAY. CHANGE IN HEADING VERSUS TIME FOR DIFFERENT SPEEDS AND RUDDER ANGLES AS INDICATED.

C. Maneuverability Trials.

C-1 Results.

Figs. 23, 24, 25, 26, 27 and 28 give the results of the maneuverability trials underway.

C-2 Discussion.

A total of 13 runs was made for this series of trials. In three cases it was not possible to read the negatives, accordingly, no data are available for these runs. Further discussion will be included in the comparison of full scale results.

STRUTS VS. BOSSINGS
COMPARATIVE PROPULSIVE AND TURNING PERFORMANCE
BASED ON FULL SCALE RESULTS

PROPULSIVE PERFORMANCE

As the U.S.S. DEWEY and WORDEN are identical in all respects as regards propulsive features (both equipped with Bureau of Engineering design propellers) with the exception that the former is equipped with struts in lieu of bossings, installed on the latter, the standardization trials of these vessels will be utilized to determine comparative influence of both installations on propulsive performance.

Fig. 29 gives a comparison of the results of standardization trials of the U.S.S. DEWEY and WORDEN, the displacement being 1595 tons as indicated.

Table 7, taken from Fig. 29, gives a tabular comparison. Up to and including 34 knots, the DEWEY RPMs are, on the average, 2.4 per cent higher than those of the WORDEN. Up to and including 22 knots, the SHPs for both vessels are identical. Hence, for this speed range, the WORDEN develops the same power as the DEWEY on less revolutions. Above this point and up to 34 knots, the DEWEY SHPs are approximately 3.2 per cent higher than those of the WORDEN.

Above 34 knots, the deviation between the two trials increases. At 38.5 knots, the maximum corrected speed reached in the DEWEY trials, the DEWEY RPM and SHP are 4.6 and 8.6 per cent higher respectively than those of the WORDEN. On the other hand, at the same RPM and SHP with which the DEWEY attained a speed of 38.5 knots, the WORDEN at identical RPM and SHP attained a speed of 39.95 knots, this representing an increase of approximately 3.8 per cent in speed for the given values of RPM and SHP.

TABLE 7

SHP AND RPM COMPARISON

U.S.S. DEWEY AND U.S.S. WORDEN

DIFFERENCES EXPRESSED AS A PERCENTAGE BASED ON WORDEN RESULTS

	RPM			SHP		
Speed Knots	WORDEN	DEWEY	Per-cent	WORDEN	DEWEY	Per-cent
9	77	79	+2.6	275	275	0
10	85	88	+3.5	500	500	0
11	94	97	+3.2	700	700	0
12	103	105.5	+2.4	925	925	0
13	112	114.5	+2.2	1,200	1,200	0
14	121.5	124	+2.1	1,450	1,450	0
15	131	133	+1.5	1,750	1,750	0
16	140.5	142.5	+1.4	2,125	2,125	0
17	150	152.0	+1.3	2,550	2,550	0
18	159.5	161.5	+1.3	3,050	3,050	0
19	169.5	172	+1.5	3,625	3,625	0
20	179	182	+1.6	4,375	4,375	0
21	190	193	+1.6	5,375	5,375	0
22	200	204	+2.0	6,375	6,375	0
23	211	215	+1.9	7,625	7,700	+1.0
24	222	227	+2.2	8,050	8,250	+2.5
25	234	239	+2.1	10,675	10,900	+2.1
26	244.5	251	+2.7	12,500	12,800	+2.4
27	256.0	262.5	+2.5	14,650	14,950	+2.0
28	267.0	274	+2.6	16,500	17,200	+4.2
29	278	286	+2.9	18,750	19,600	+4.5
30	289	298	+3.1	21,125	22,100	+4.6
31	300	310	+3.3	23,700	24,700	+4.2
32	312	322	+3.2	26,200	27,200	+3.8
33	323.5	333.5	+3.1	28,750	29,800	+4.0
34	334.5	346	+3.4	31,400	32,500	+3.5
35	346.5	359	+3.6	34,000	35,500	+4.4
36	358	372	+3.9	36,500	38,500	+5.5
37	370	386	+4.3	39,200	41,750	+6.5
38	382	400	+4.7	41,750	45,000	+7.8
38.5	388	406	+4.6	43,000	46,700	+8.6

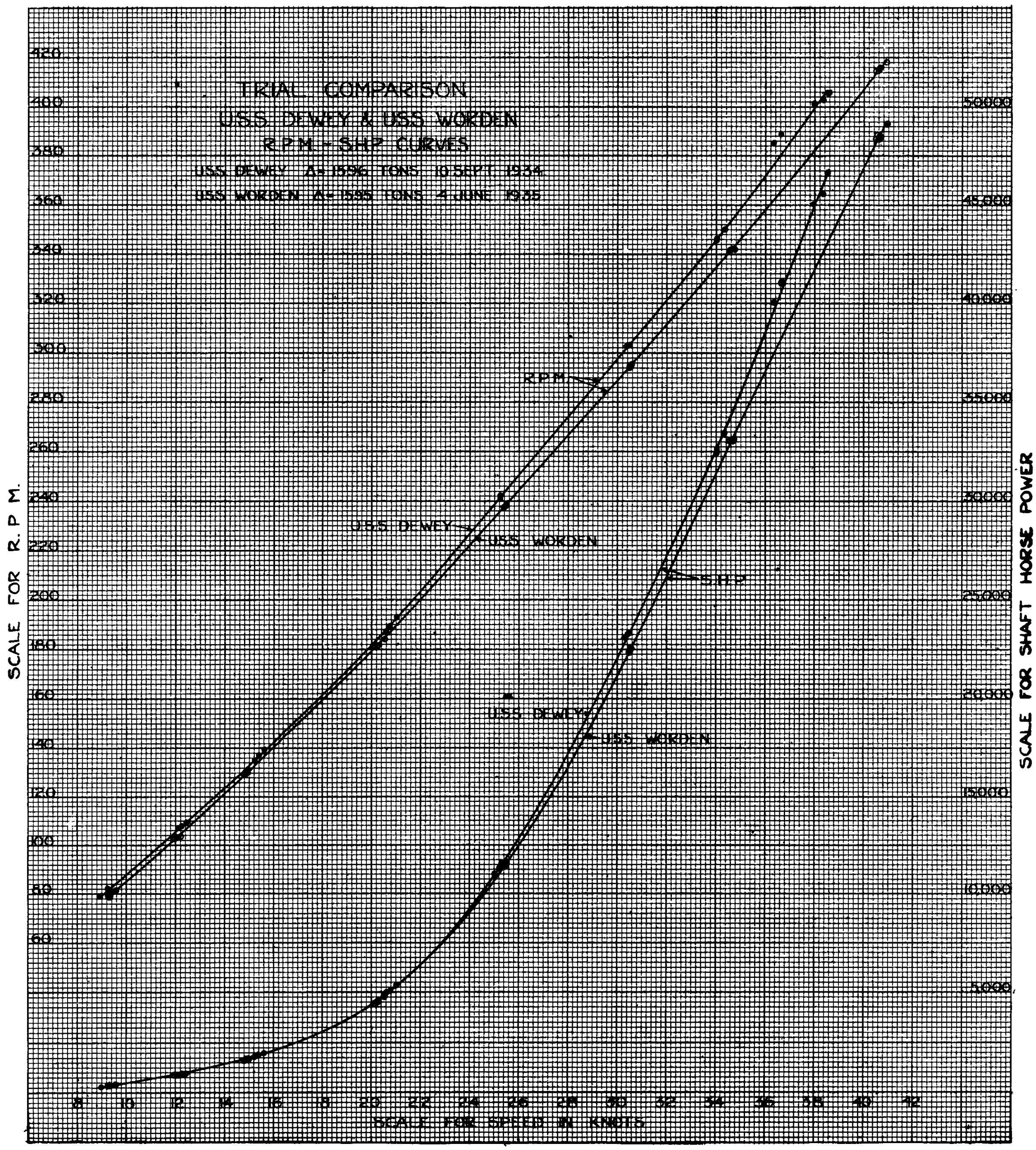

FIG. 29 EFFECT OF STRUTS AND BOSSINGS ON PROPULSION. COMPARISON OF FULL SCALE STANDARDIZATION TRIALS U.S.S. DEWEY (STRUTS) AND U.S.S. WORDEN (BOSSINGS). TRIAL RESULTS CORRECTED TO STANDARD CONDITIONS.

TURNING PERFORMANCE

As both the WORDEN and FARRAGUT are equipped with the same design rudder and are identical with the exception that the former is equipped with bossing and the latter, struts, a comparison of the tactical characteristics can be obtained from the turning trials of these vessels. (NOTE: Though the FARRAGUT was equipped with the Model Basin design propeller and the WORDEN with the Bureau of Engineering design, the relative effects of these propellers on the turning circles are negligible.)

The turning trials of the FARRAGUT were made in July 1934 as referenced hereinbefore. Fig. 30 gives a comparison of tactical diameter with struts and bossings, the displacement being 1725 tons. Fig. 31 gives a similar comparison for the advance and transfer characteristics. Table 8, taken from Fig. 30, indicates the percentage difference in tactical diameter, while Tables 9 and 10, taken from Fig. 31, give a similar comparison for advance and transfer measurements.

These comparisons indicate a variable increase with speed and rudder angle. To determine the pattern of this variation, Fig. 32 has been plotted from values given in Tables 8, 9, and 10, showing the percentage increase in tactical diameter, advance and transfer, for a given rudder angle at various speeds. As regards tactical diameter, the maximum increase is found in the 20 to 25 knot speed range. At 30 knots, the increase is a minimum. At 35 knots, with maximum rudder, 33 degrees, the increase approaches a maximum again. A similar pattern is evidenced in the advance observations with the exception of the value at 25 knot and 33 degree rudder angle. On the other hand, the range of variation in the percentage increase of transfer is less than either the advance or tactical diameter increase.

Though rudder C cavitated with the strut installation, the results at maximum speed and rudder angle indicate a more pronounced cavitation with the bossing installation. Since both vessels were equipped with rudders from the same design, the tactical results are comparative as regards the interaction of this rudder design and the different stern conditions. The chief reason for the substitution of struts by bossings is to make the necessary changes in direction of stream flow to the propeller to secure increased propulsive efficiency. For this reason the "patterns" of flow to the rudders are not similar in the case of strut and bossing installations.

These considerations lead to this fact: The comparative maneuverability of vessels equipped with strut and bossing installation is not a function of a given rudder design, but of rudders designed to the separate conditions imposed by the strut and bossing installation.

ANGLE OF HEEL

Fig. 33 indicates the relative differences in heeling as between struts and bossings. Though a greater inward heel is experienced with bossings, the outward heels are definitely lower than the corresponding maximum values with struts.

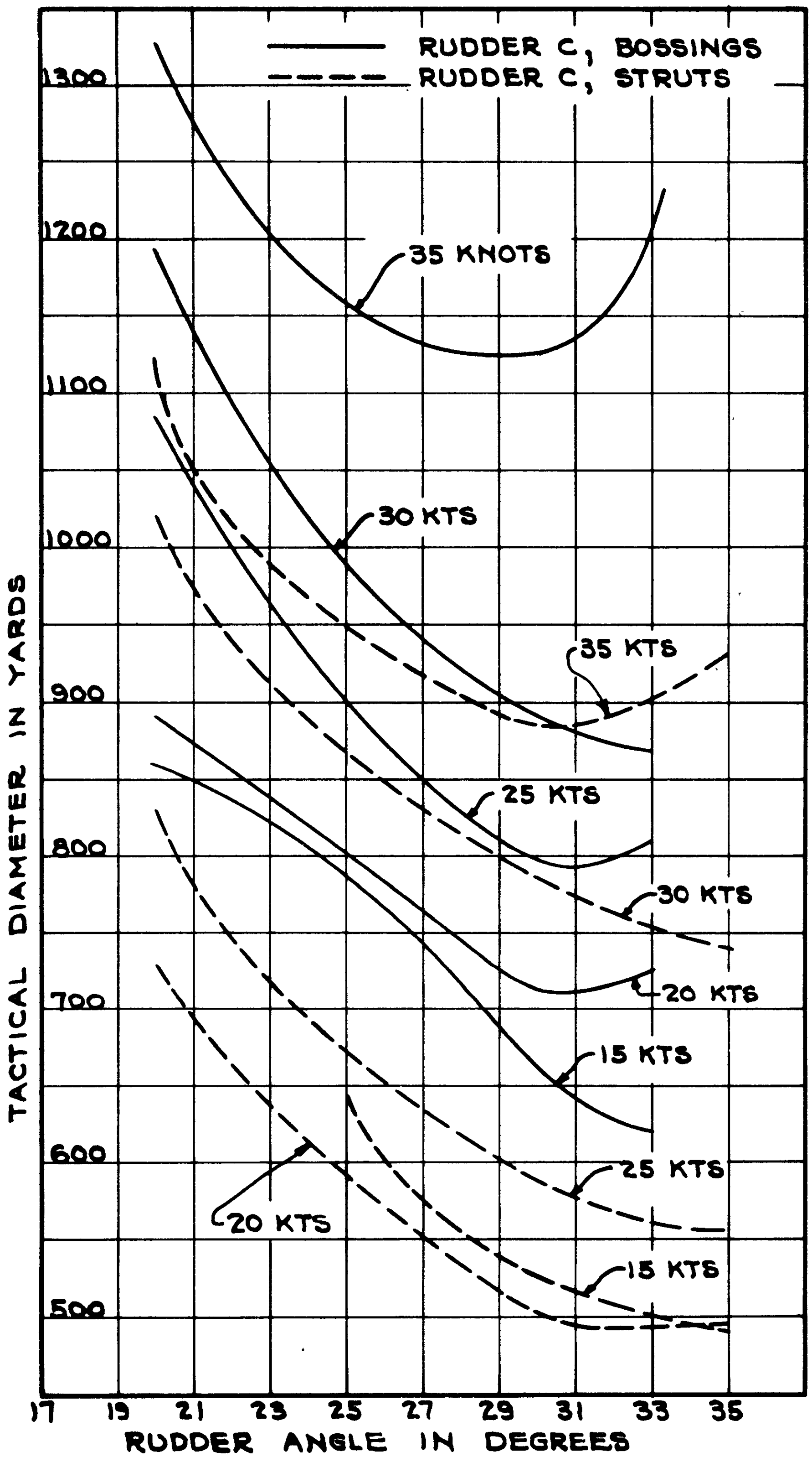

FIG. 30 COMPARISON OF TACTICAL DIAMETER OBSERVATIONS, RUDDER C FROM FULL SCALE TESTS WITH U.S.S. FARRAGUT (STRUTS) AND U.S.S. WORDEN (BOSSINGS) AT VARIOUS SPEEDS AND RUDDER ANGLES.

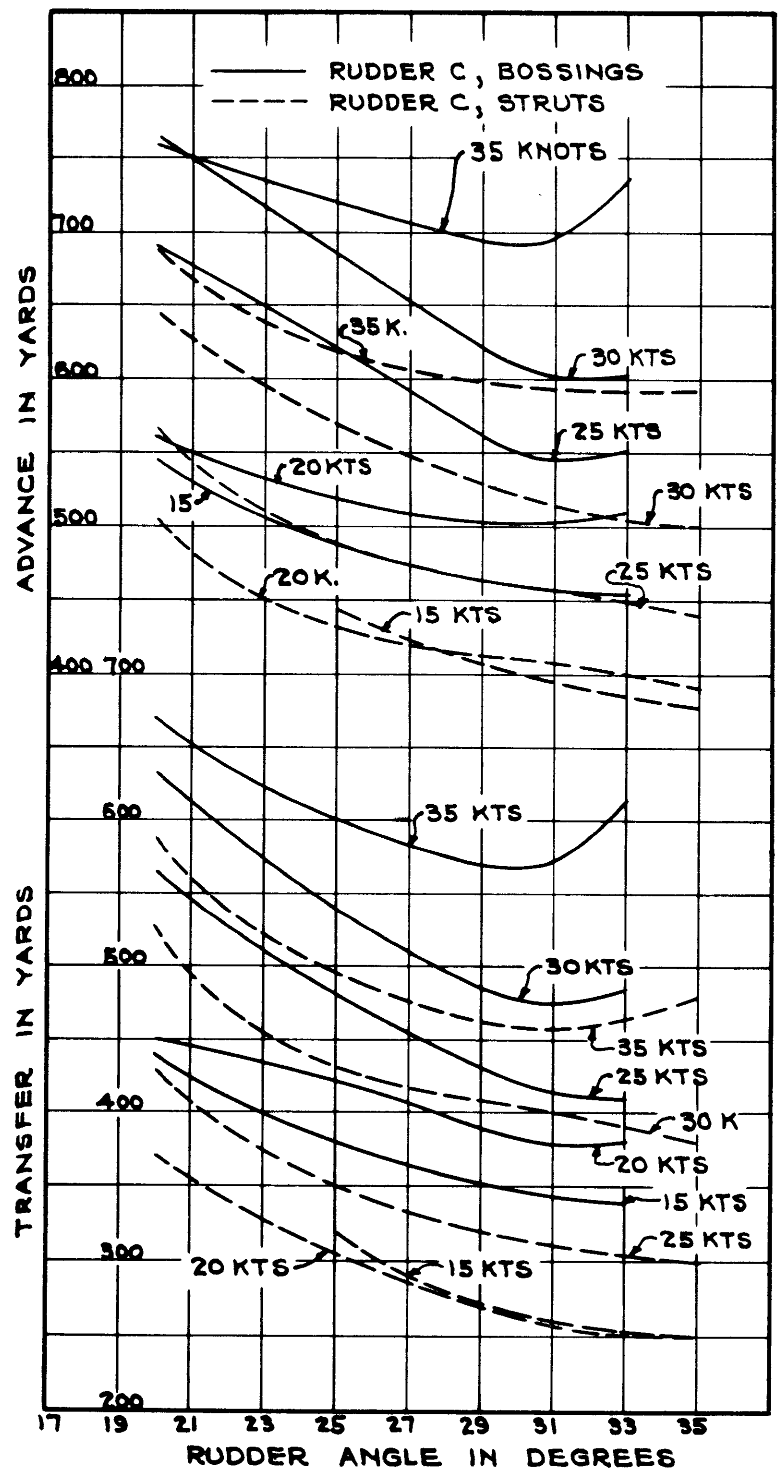

FIG. 31 COMPARISON OF ADVANCE AND TRANSFER OBSERVATIONS, RUDDER C, FROM FULL SCALE TESTS WITH U.S.S. FARRAGUT (STRUTS) AND U.S.S. WORDEN (BOSSINGS) AT VARIOUS SPEEDS AND RUDDER ANGLES.

TABLE 8

STRUTS VS. BOSSINGS

COMPARATIVE EFFECT ON TACTICAL DIAMETER

FROM MEASUREMENTS IN FULL SCALE – U.S.S. FARRAGUT (STRUTS) U.S.S. WORDEN (BOSSINGS)

MEASUREMENT IN YARDS. PERCENTAGE DIFFERENCE BASED ON RESULTS WITH STRUTS

Speed Knots	Rudder Angle Degrees	Struts	Bossings	Diff.	% inc.
15	20		860		
	25	645	790	145	22.5
	30	525	660	135	25.7
	33	500	620	120	24.0
20	20	730	890	160	21.9
	25	590	800	210	35.6
	30	500	710	210	42.0
	33	495	725	230	46.4
25	20	830	1,085	255	30.7
	25	670	900	230	34.3
	30	585	795	210	35.9
	33	560	810	250	44.6
30	20	1,020	1,190	170	16.7
	25	870	990	120	13.8
	30	785	890	105	13.5
	33	750	870	120	16.0
35	20	1,125	1,325	200	17.8
	25	945	1,155	210	22.2
	30	885	1,125	240	27.1
	33	905	1,250	345	38.1

TABLE 9

STRUTS VS. BOSSINGS

COMPARATIVE EFFECT ON ADVANCE

FROM MEASUREMENTS IN FULL SCALE – U.S.S. FARRAGUT (STRUTS) U.S.S. WORDEN (BOSSINGS)

MEASUREMENT IN YARDS. PERCENTAGE DIFFERENCE BASED ON RESULTS WITH STRUTS.

Speed Knots	Rudder Angle Degrees	Struts	Bossings	Diff.	% inc.
15	20				
	25	445	490	45	11.2
	30	400	460	60	15.0
	33	385	455	70	18.2
20	20	505	560	55	10.9
	25	430	520	90	20.9
	30	410	505	95	23.2
	33	400	510	90	22.5
25	20	565	690	125	22.1
	25	490	620	130	26.5
	30	460	550	110	23.9
	33	450	550	100	22.2
30	20	645	767	120	18.6
	25	570	685	105	18.4
	30	520	610	90	17.3
	33	505	600	95	18.8
35	20	690	760	70	10.1
	25	620	720	100	16.1
	30	595	690	95	15.9
	33	590	740	150	20.3

TABLE 10

STRUTS VS. BOSSINGS

COMPARATIVE EFFECT ON TRANSFER

FROM MEASUREMENTS IN FULL SCALE – U.S.S. FARRAGUT (STRUTS) U.S.S. WORDEN (BOSSINGS)

MEASUREMENT IN YARDS. PERCENTAGE DIFFERENCE BASED ON RESULTS WITH STRUTS

Speed Knots	Rudder Angle Degrees	Struts	Bossings	Diff.	% inc.
15	25	320	380	60	18.7
	30	265	345	80	30.1
	33	255	340	85	33.3
20	20	370	450	80	21.6
	25	305	420	115	37.7
	30	260	380	120	46.1
	33	250	380	130	52.0
25	20	430	565	135	31.4
	25	350	480	130	37.2
	30	315	420	105	33.3
	33	305	410	105	34.4
30	20	530	630	100	18.9
	25	430	540	110	25.6
	30	405	475	70	17.3
	33	390	485	95	24.3
35	20	590	670	80	13.5
	25	495	600	105	21.2
	30	455	565	90	19.8
	33	465	615	150	32.3

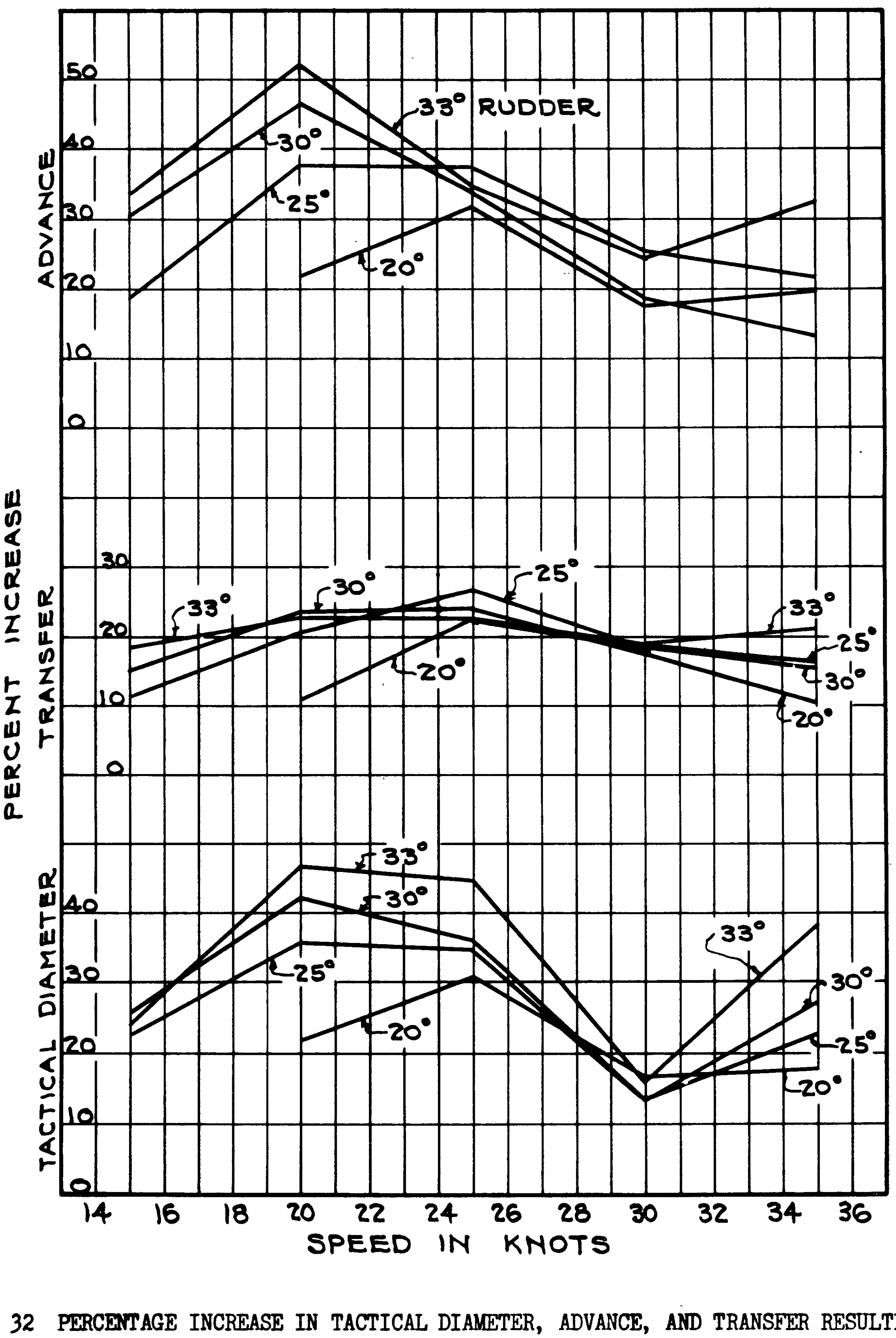

FIG. 32 PERCENTAGE INCREASE IN TACTICAL DIAMETER, ADVANCE, AND TRANSFER RESULTING FROM SUBSTITUTION OF STRUTS WITH BOSSINGS FOR DIFFERENT SPEEDS AND RUDDER ANGLES.

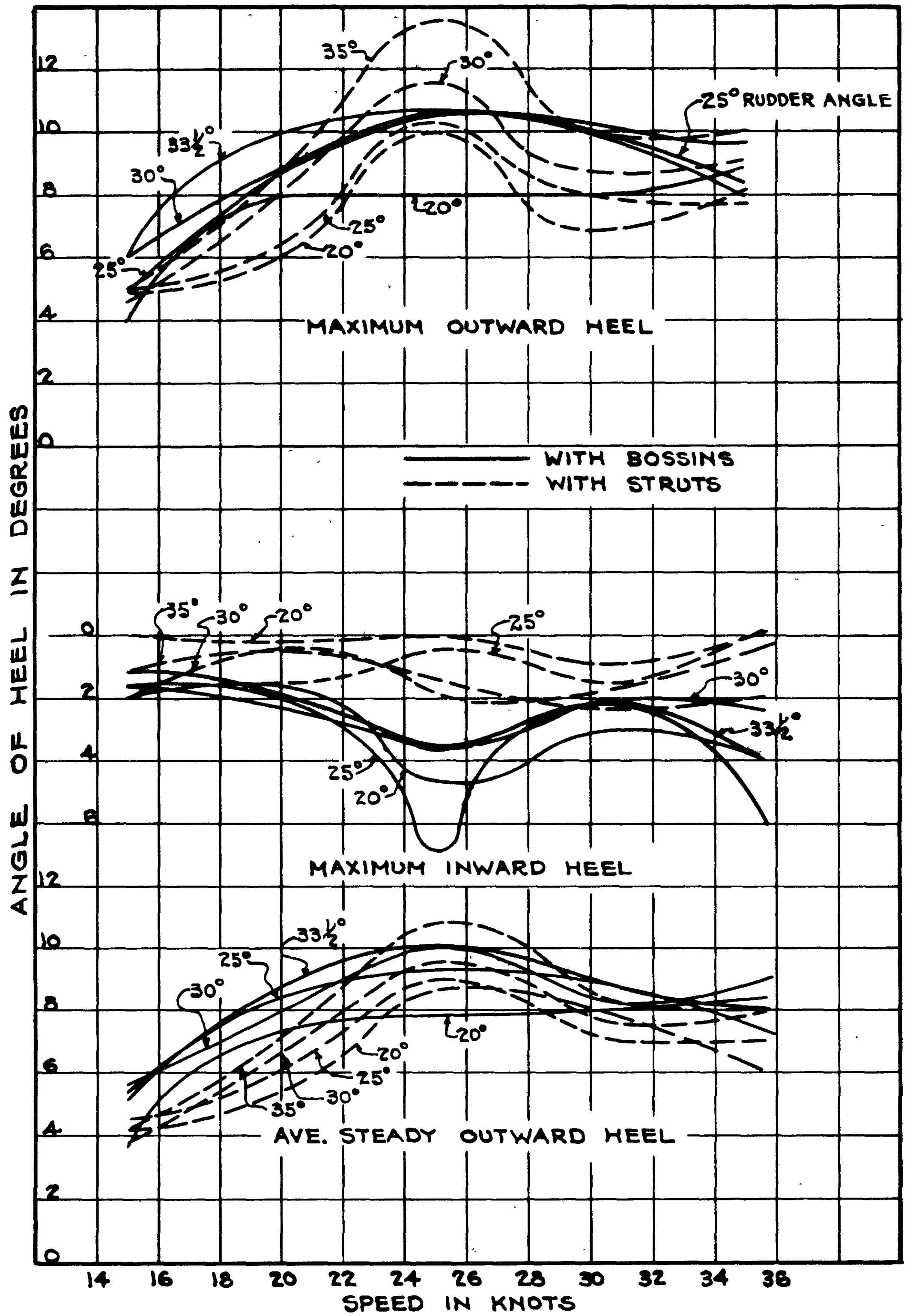

FIG. 33 COMPARISON OF HEELING CHARACTERISTICS, STRUTS AND BOSSINGS, FOR DIFFERENT RUDDER ANGLES AT VARIOUS SPEEDS.

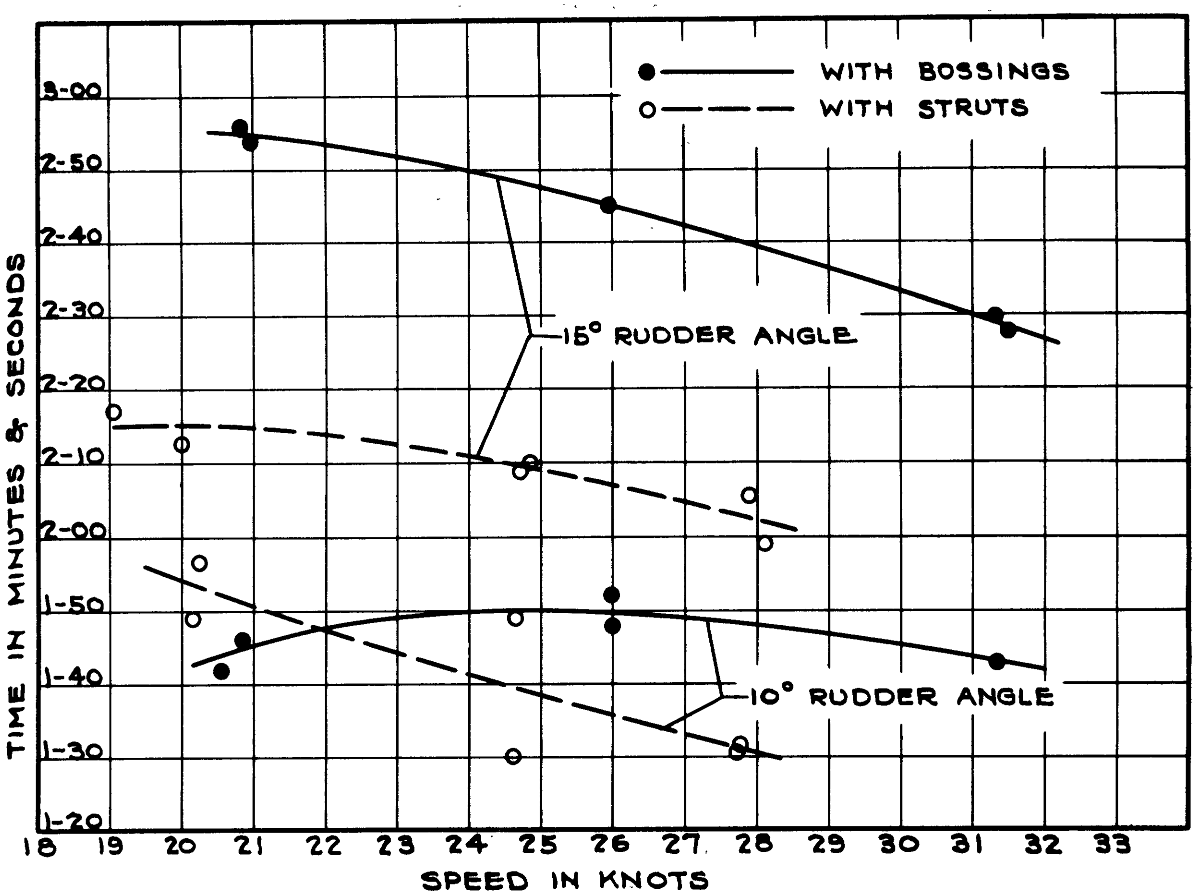

FIG. 35 COMPARISON OF TIMES REQUIRED TO COMPLETE A DEFINITE MANEUVER, STRUTS AND BOSSINGS, FOR DIFFERENT RUDDER ANGLES AT VARIOUS SPEEDS. (SEE FIGS. 23 TO 28 INC.)

RATE OF TURNING

Fig. 34 indicates the time necessary to make a 45, 90, and 180 degree change in course at different speeds and various rudder angles.

MANEUVERABILITY UNDERWAY

Fig. 35 gives a measure of the time required to complete a specific maneuver as a measure of the vessel's maneuverability with struts and bossings. For the maneuver with 15 degree rudder, the bossings require approximately 30 per cent more time. For the maneuver with 10 degree rudder, the results obtained at 20 knots are not consistent with the remainder of the data.

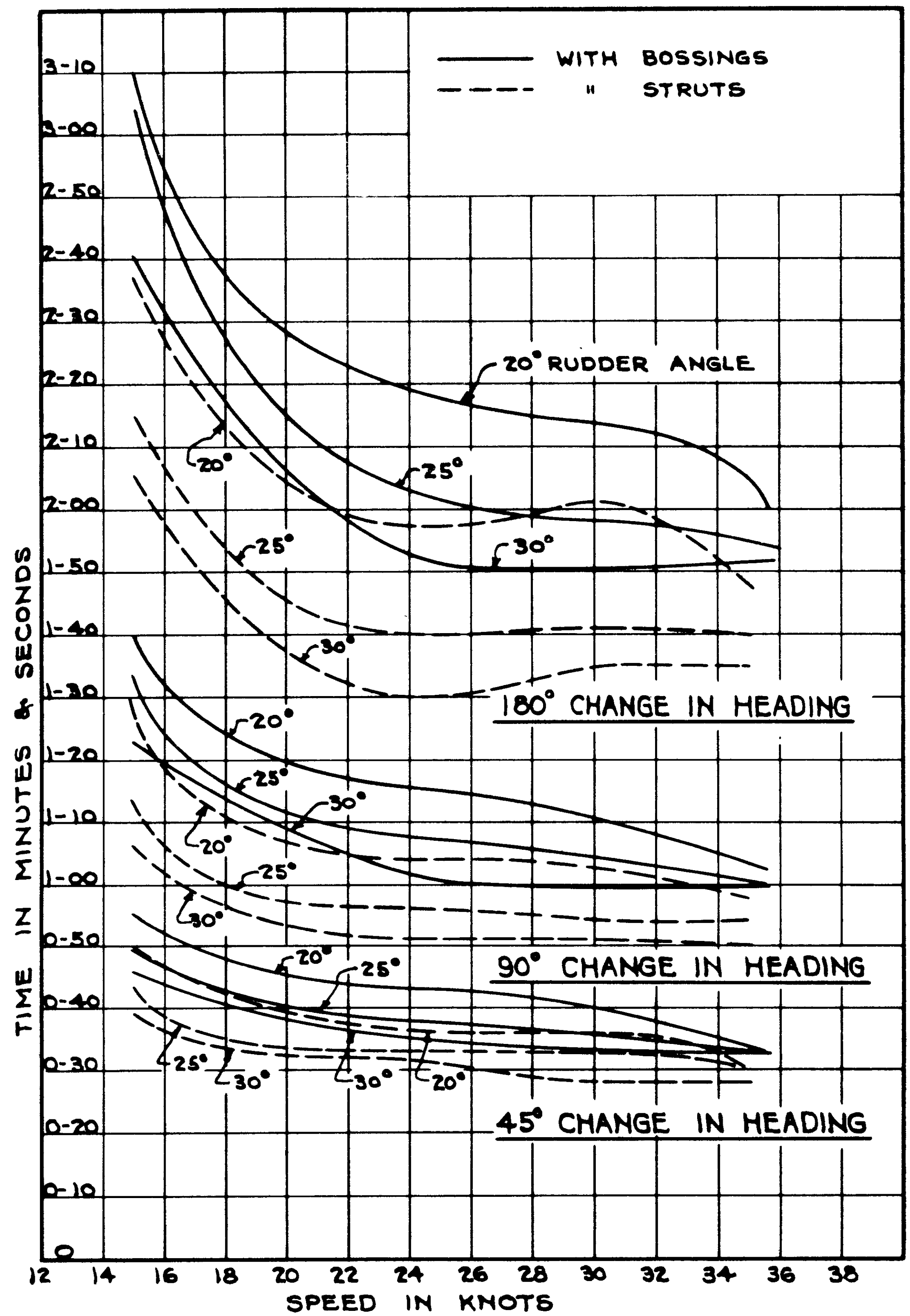

FIG. 34 COMPARISON OF TIME TO EFFECT GIVEN CHANGES IN HEADING, STRUTS AND BOSSINGS FOR DIFFERENT RUDDER ANGLES AT VARIOUS SPEEDS.

MODEL - TRIAL COMPARISON

STANDARDIZATION RESULTS

The comparison of speed and power between model prediction and full scale results has been indicated hereinbefore. As no thrust was measured during these trials, it is not possible to analyze propeller efficiency in model and full scale. Hence it is not possible to determine the cause or causes of the average deviations obtained in RPM and SHP between model prediction and full scale results.

TACTICAL CHARACTERISTICS

From full scale tests in the case of the FARRAGUT, it was observed that the average rate of turning the rudder, both for rudder A and C, averaged 0.54 seconds per degree. In the case of the WORDEN, the average rate was found to be 0.415 seconds per degree. This difference in rate amounts to a reduction of 21 per cent based on the FARRAGUT results.

In the case of the model tests of the FARRAGUT, it was observed that the rate of rudder movement did possess some influence. This, together with the tendency of rudder C to cavitate, caused the model tests to be erratic. When model tests were repeated on a basis of comparative times as determined from full scale, the model and full scale results did not deviate beyond the range of experimental error.

Comparison of model and full scale turning results in the case of the WORDEN discloses serious deviations as given in Fig. 36. In this case, the model has indicated serious cavitation that did not materialize in full scale. For the range up to the inception of cavitation in model scale, the full scale results are approximately 25 per cent less than those predicted.

This comparison indicates the difficulties associated with model tests made under adverse conditions and but limited facilities.

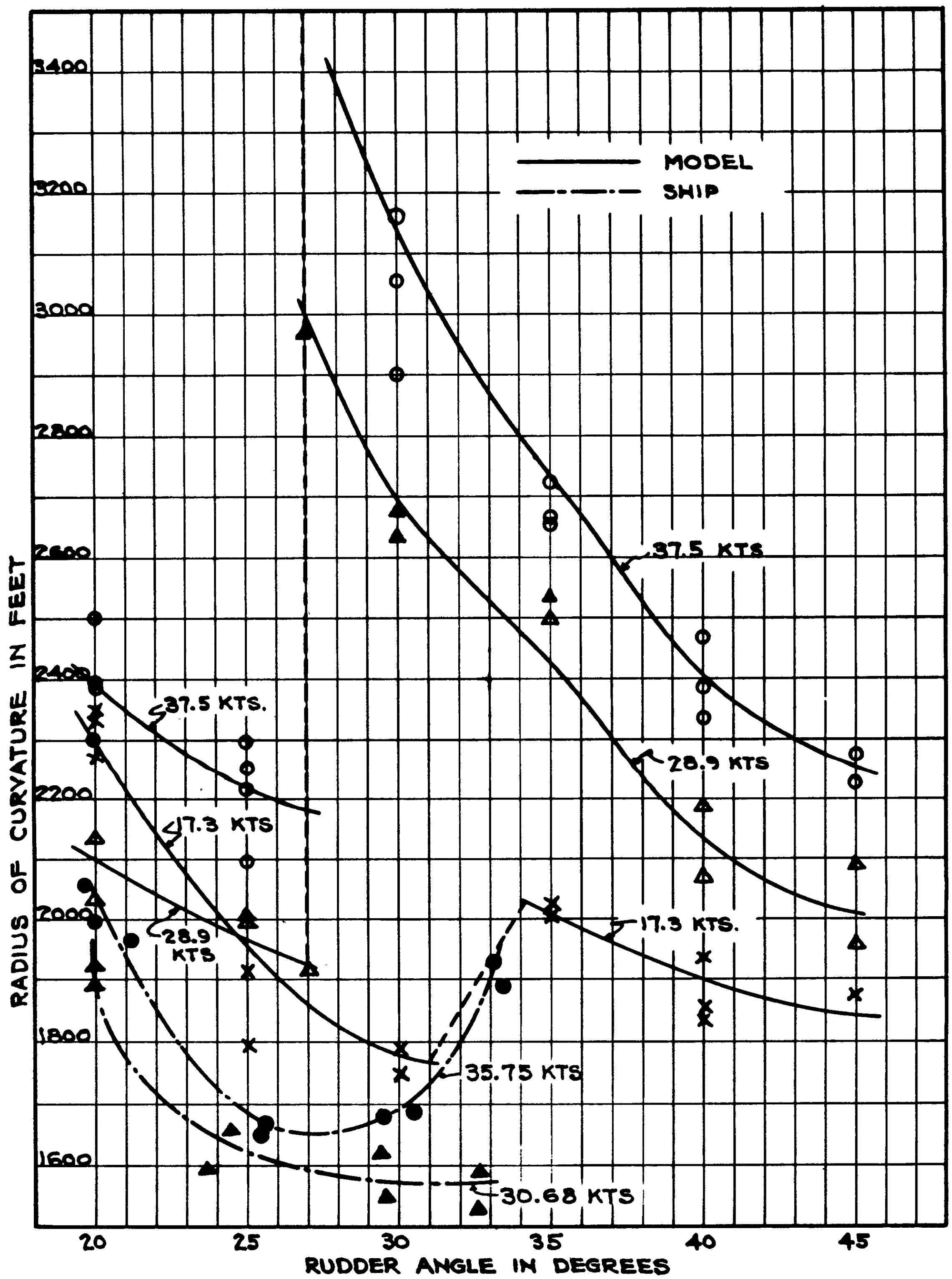

FIG. 36 COMPARISON OF RADIUS OF CURVATURE IN FIRST QUADRANT IN FEET, MODEL – TRIAL, RUDDER C, BOSSING INSTALLATION, FOR DIFFERENT RUDDER ANGLES AND VARIOUS SPEEDS.

CONCLUSIONS

From the results of the preceding analysis, the following conclusions are warranted.

A. The substitution of bossings for struts provides a means for increasing the propulsive efficiency of vessels of the destroyer class.

B. The increase in propulsive efficiency is measurable throughout the whole speed range, the maximum increase occurring at maximum power. Translated into saving of power for a given speed, full scale results in this one instance show this saving at maximum speed to be better than 8 per cent.

C. With rudders of similar design, the maneuverability of a vessel equipped with bossings is not the equal of one equipped with struts.

D. The maneuverability of vessels equipped with struts and bossings rests on the use of rudders designed to the type of installation and the flow imposed. Since the model basin possesses no adequate facilities for making model turning tests with twenty foot models, the research essential for determining the basic facts and procedure cannot be undertaken.

APPENDIX I
MODIFICATION IN TEST PROCEDURE

The procedure employed in conducting standardization trials was similar to that heretofore developed and utilized.

The method and equipment employed in obtaining photographic observations of turning circles, in the case of the U.S.S. FARRAGUT, is given in E.M.B. Report No. 397, the shore use of two cameras being detailed in Appendix 4. To obtain similar observations with this latter method in the case of the U.S.S. WORDEN, the equipment was redesigned and manufactured as shown in Fig. 37.

With reference to Fig. 37, a disc "A", graduated in degrees, was fixed to a table (not visible) the latter mounted on a tripod "B". The camera, stopwatch, lenses, prism, and mirror were mounted on a common base "C" which was pivoted around the graduated disc and table at "D". The stopwatch "E", mirror "F", and focusing lens "G" comprised the system for conveying the image of the stopwatch to the camera. Similarly an index "M", a prism "N", and a focusing lens "O" were used to obtain the image of the bearing.

Directing the axis of the camera at a fixed object, provided the bearing of the base line. Thereafter, directing the axis of the camera at the vessel at each observation interval during the turn provided the bearing of the vessel at that interval. These bearings, related to the bearing of the fixed object gave means for plotting the bearing of the vessel at each observed interval. The curve of intersections of simultaneous bearings from the two stations thus determined the turning circle of the vessel.

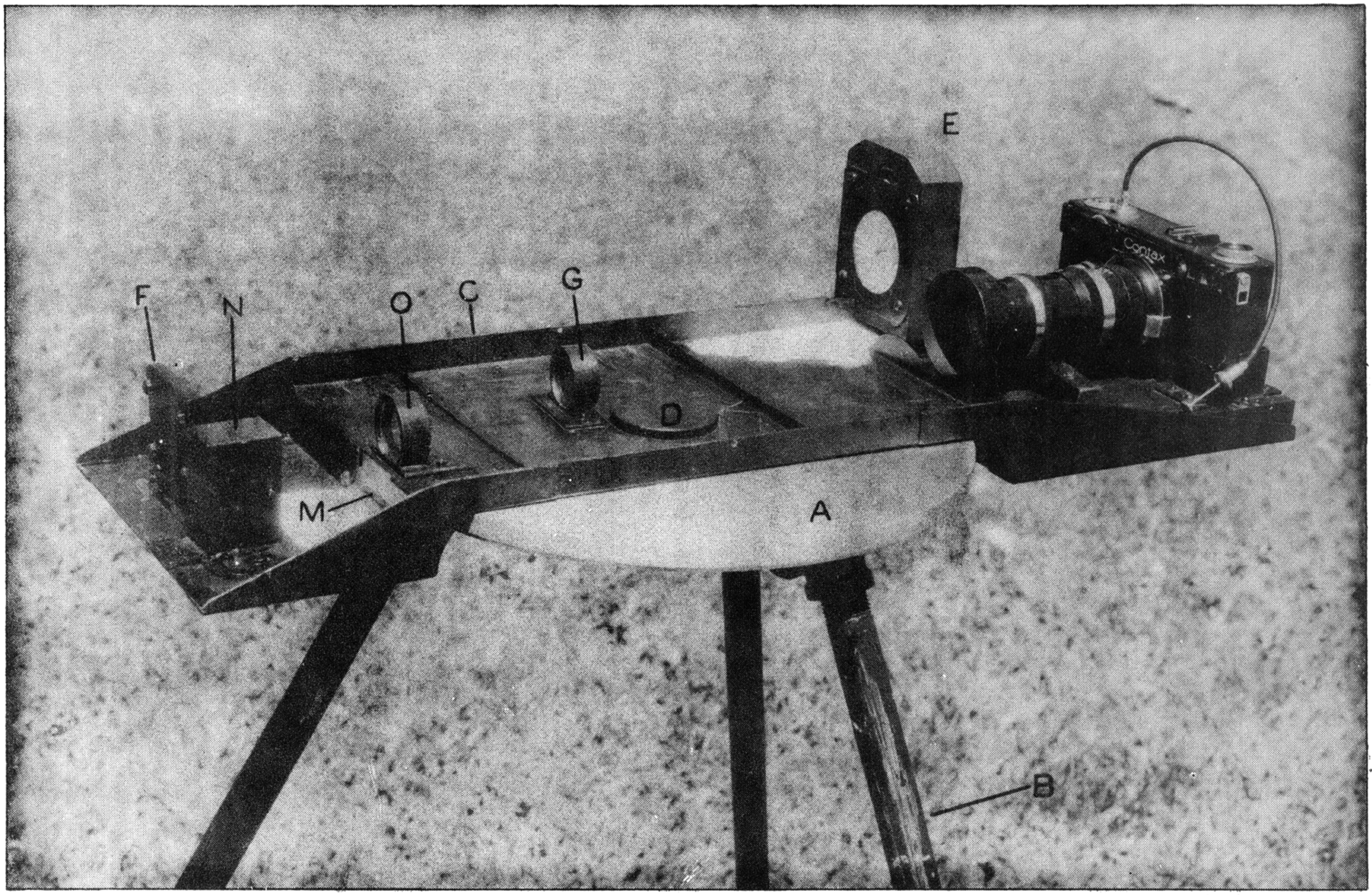

FIG 37. VIEW OF CAMERA EQUIPMENT USED TO OBTAIN PHOTOGRAPHIC BEARINGS OF THE U.S.S. WORDEN DURING TURNING TESTS BY THE TWO CAMERA METHOD FROM SHORE.

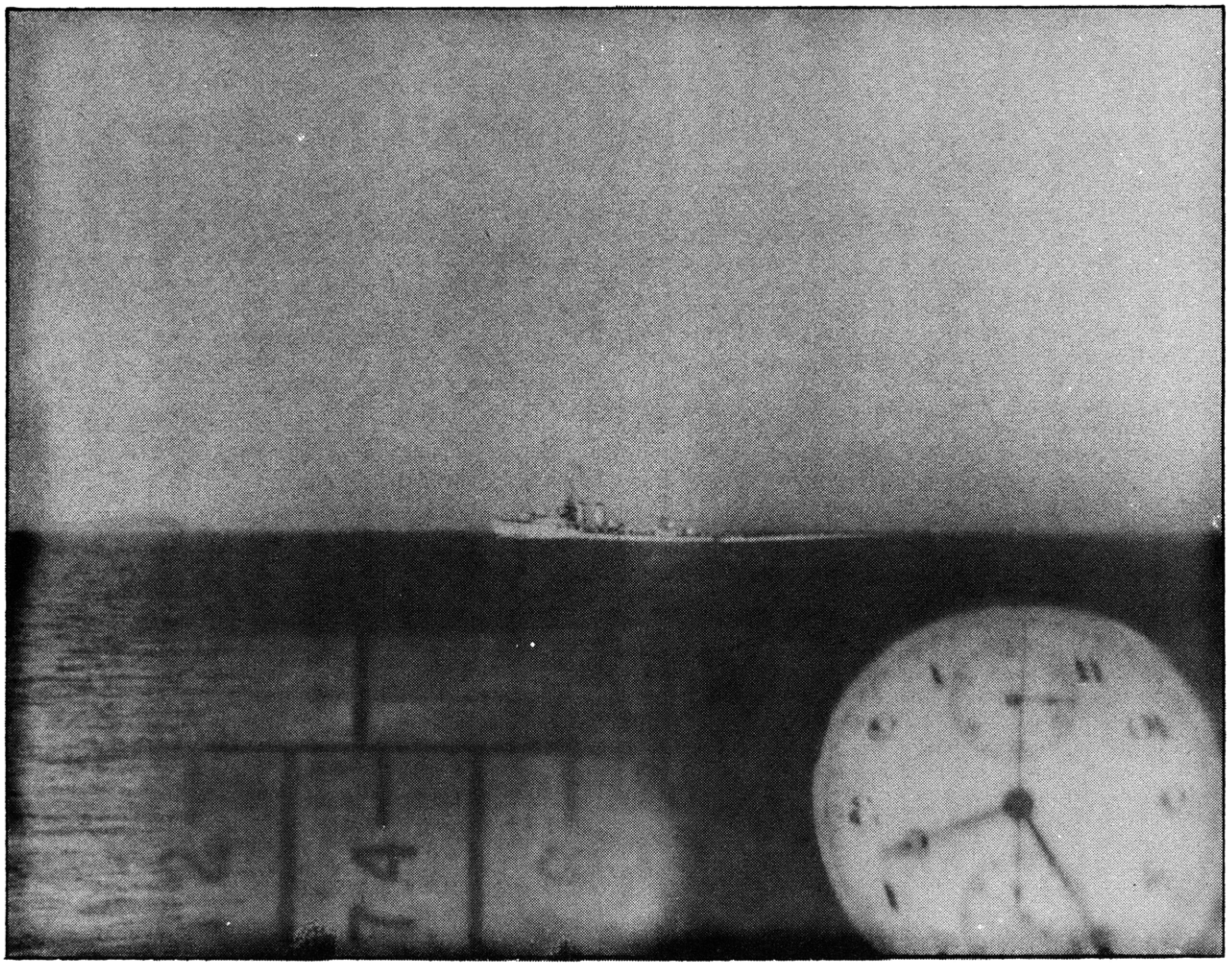

FIG. 38 NEGATIVE SHOWING PHOTOGRAPHIC OBSERVATIONS MADE BY EQUIPMENT SHOWN IN FIG. 37 FOR ONE TURN DURING TURNING TESTS OF THE U.S.S. WORDEN.

In case the axis of the camera did not coincide exactly with the point on the vessel – the foremast – selected for observation, correction could be applied to obtain the true bearing. These true bearings were then plotted on a time base as shown in E.M.B. Report No. 397, Appendix 4, Fig. 130, for obtaining simultaneous bearing values from the two shore stations.

The chief advantage of this equipment was the greater speed and rapidity with which the bearings could be obtained from the records. A sample of these records is given in Fig. 38.