UNITED STATES

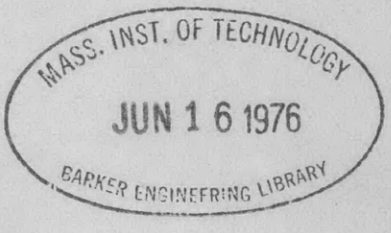
EXPERIMENTAL MODEL BASIN

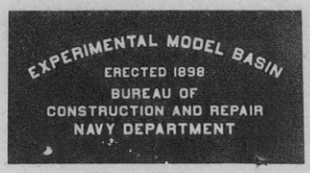
NAVY YARD, WASHINGTON, D.C.

CALIBRATION OF THRUSTMETER

INSTALLED ON THE

U.S.S. HAMILTON





OCTOBER, 1933

REPORT NO. 370

CALIBRATION OF THRUSTMETERS INSTALLED ON THE U.S.S. HAMILTON

U.S. EXPERIMENTAL MODEL BASIN
NAVY YARD, WASHINGTON, D.C.

October, 1933 Report No. 370

CALIBRATION OF KINGSBURY THRUSTMETERS FOR U.S.S. HAMILTON

General

The thrustmeters were designed and built by the Kingsbury Machine Works, Inc. of Philadelphia, Pennsylvania, for use on the U.S.S. HAMILTON in connection with special full-scale trials.

Fig. 1 shows a general view of the arrangement taken on board shortly after installation in April, 1933.

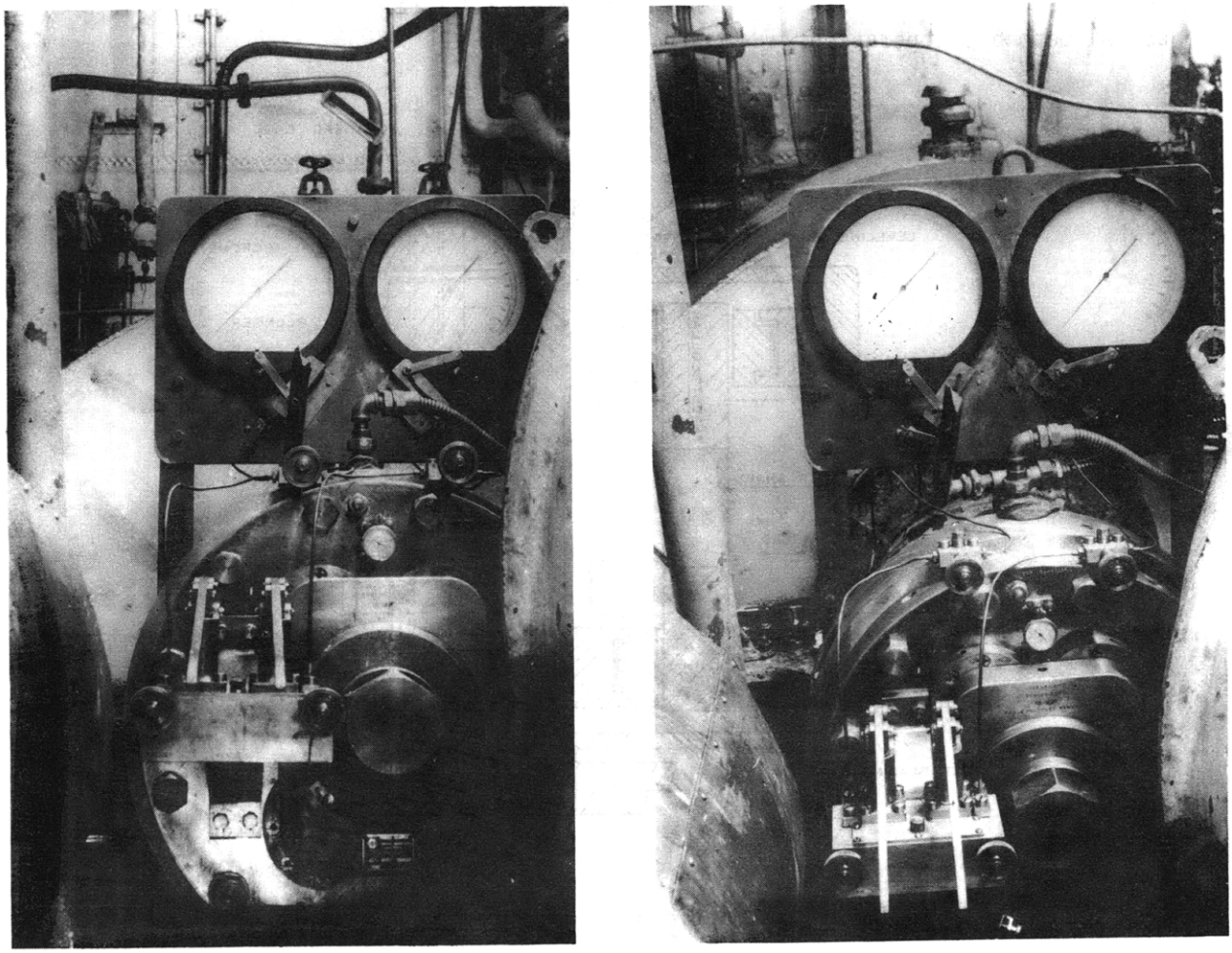


FIG. 1 – U.S.S. HAMILTON – General view of starboard thrustmeter, looking forward, between starboard H.P. and L.P. turbines. Note ahead and astern pressure gages, dial micrometer for indicating cage position, and hand pumps.

Principle of Thrustmeter Operation

A certain portion of the thrust developed at the propeller is required to overcome the gravity effect of the transmission system from turbines to propeller. This gravity effect results from the initial declivity of the shafting system with respect to the designed water line and varying degrees of trim caused by ship's speed. Because of this, the gravity correction is a varying quantity.

To obtain net thrust, the measured thrust must be corrected for gravity effect. It is essential, therefore, to properly measure the gravity effect to establish this correction. Hence, means must be provided for measuring thrust in both directions, ahead and astern.

Method of Thrustmeter Operation

The design of the thrustmeters developed for the U.S.S. HAMILTON embodied the above principle. Fig. 2 gives a diagrammatic arrangement for indicating the actual method of operation.

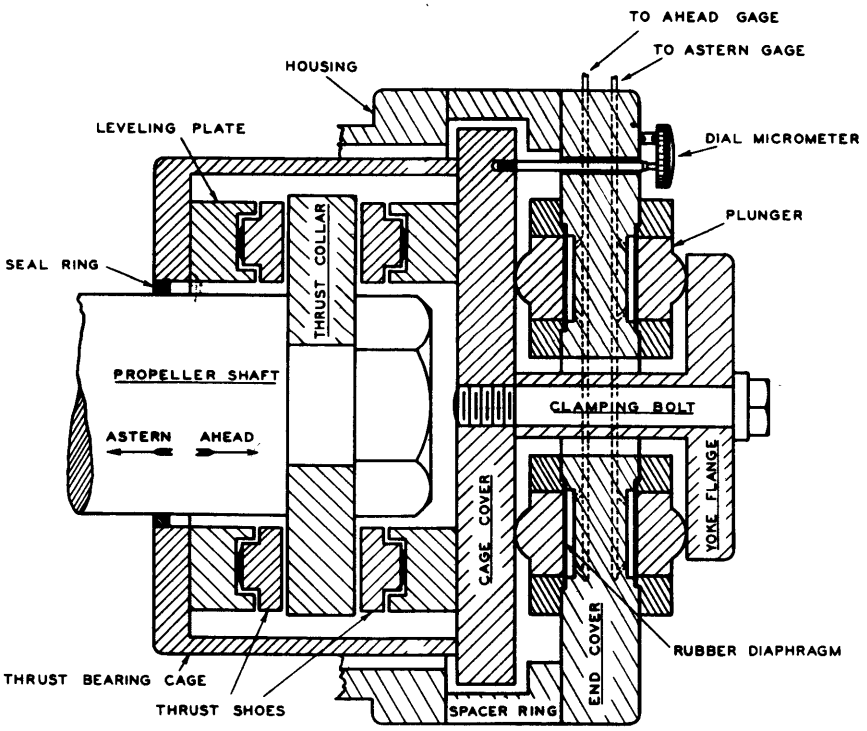


FIG. 2 – Diagrammatic Arrangement of Thrustmeter.

The thrust is transmitted through a thrust collar, clamped against the shaft shoulder, to stationary bearing shoes and leveling plates. The stationary elements are mounted in a strong oil tight bearing cage to which is secured a heavy cover. This cage is free to slide axially in the thrust housing, the travel

being limited, when not measuring thrust, by the lip on the spacer ring for ahead motion and the face of the thrust housing flange for astern motion. Rotation of the bearing cage is prevented by dowels. A dial micrometer is fitted to record the amount of movement of the cage as well as its axial position. When no thrust is being measured, the cage bears directly against the ahead or astern stop.

During thrust measurements, the travel is limited by the pressure-cells. These pressure-cells are provided to measure the thrust, a diagrammatic arrangement of one being given in Fig. 3. This consists of a shallow cavity over which a rubber diaphragm is secured by a steel guide. Fitting neatly within the guide, a plunger bears directly against the rubber diaphragm. For transmitting the thrust from the cage cover and yoke, a hardened steel support is fitted at the end of the plunger.

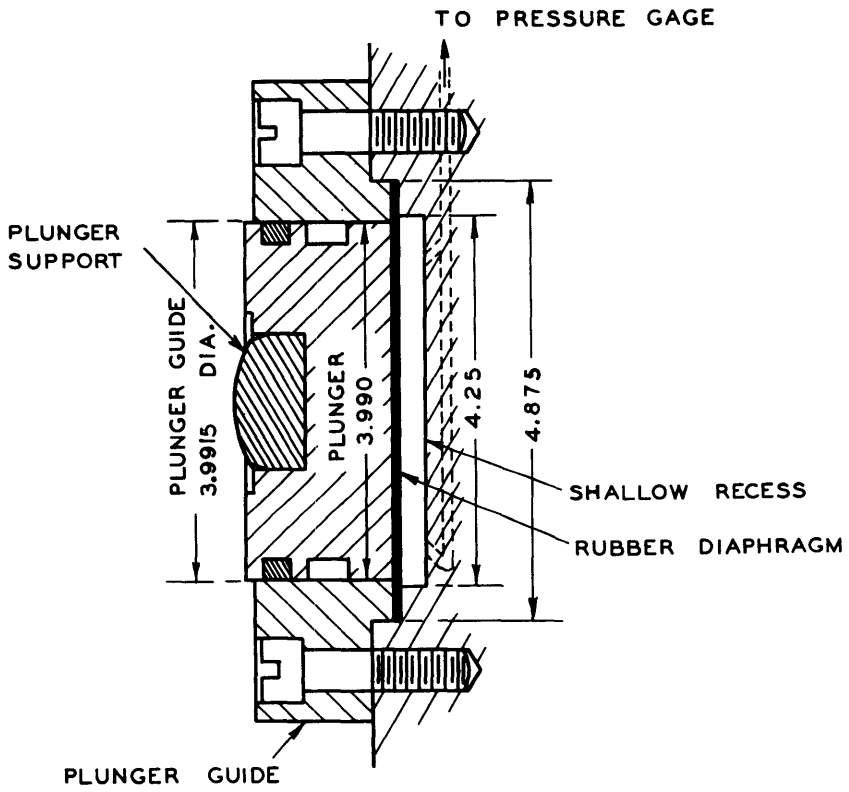


FIG. 3 - Sketch showing Arrangement of Pressure Cell.

These pressure-cells are fitted in the end cover plate, the latter being rigidly fixed to the thrust bearing housing. Four pressure-cells, connected as a unit, are used for measuring ahead thrust, and four for astern thrust as given in Fig. 4. For ahead thrust, the cage cover bears directly against the four

hardened steel supports of the ahead pressure-cells. For astern thrust, a heavy yoke is secured to the cage cover by means of a clamping bolt. The yoke bears directly against the hardened steel supports of the astern pressure-cell plungers as shown in Fig. 2.

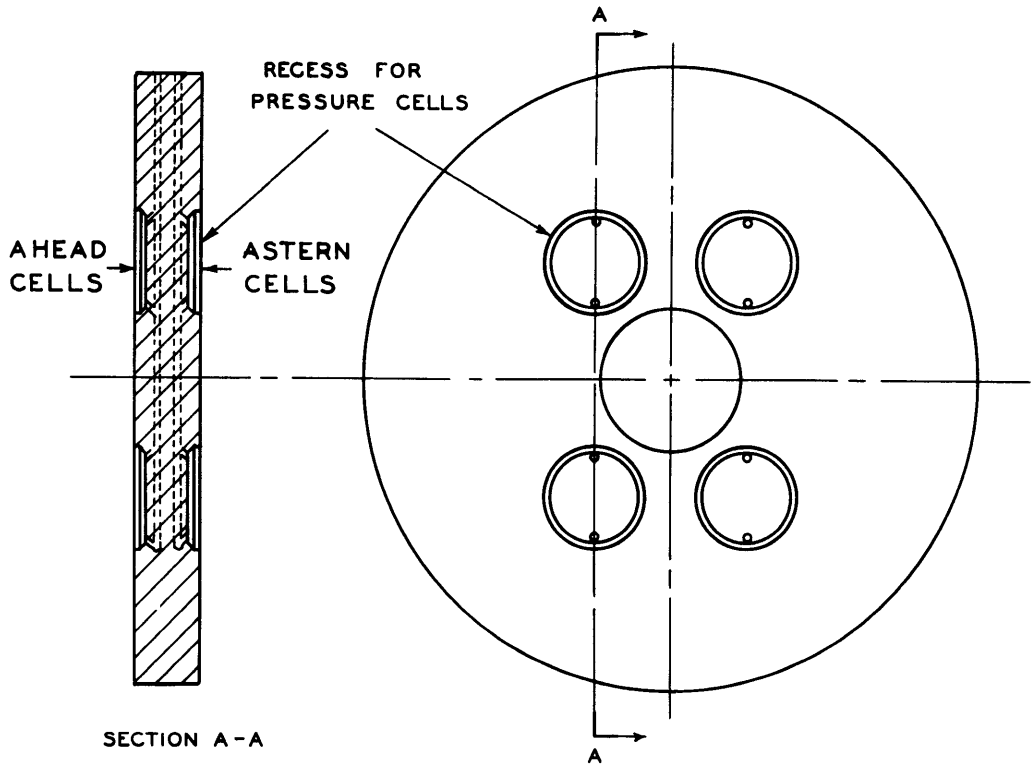


FIG. 4 – Sketch showing Arrangement for fitting Pressure Cells in End Cover.

To measure thrust, castor oil is pumped into the shallow recesses between the rubber diaphragms and the end cover, thereby balancing the plunger load, the pressure being recorded on a special 12-inch indicating Emory gage. The oil pressure is regulated by pumps, one for the ahead group of cells, and one for the astern group of cells, both being mounted as one unit on the end cover (See Fig. 1).

Whether measuring ahead or astern thrust, it is essential to place an initial positive pressure on both the ahead and astern cells. This permits a more accurate balancing of the plunger load as the system then acts in the manner of a loaded spring. With the cage "floating" midway between the stops as indicated by the dial micrometer, thrust measurements are made by taking the difference between ahead and astern gages.

The area of the plungers is such that the actual thrust is intended to be 50 times the difference in gage pressures – these latter are read in pounds per square inch.

Reason for Calibration

The thrustmeters were calibrated to determine the constant to be applied to the gage reading for obtaining the measured thrust.

Apparatus of Calibration

To be of value, the method of calibration had to parallel exactly the actual operating character of the thrustmeters when in use aboard ship. This meant placing the unit vertically and required the use of a horizontal testing machine. A 2,300,000 lb. horizontal testing machine, built by A. H. Emory, was available at the Bureau of Standards and was used to apply and measure the thrust for calibrating the thrustmeters. Even though a large machine, it is accurate and sensitive.

Only the thrust indicating parts of the thrustmeters were used in the calibration. This included the cage cover, the yoke and clamping bolt, the end cover with pressure–cells, pumps and accessories, and the pressure gages.

The end cover plate was bolted rigidly to a frame made from angle iron. This provided the support for the thrustmeter unit and held it in a central position between the ram and the head of the testing machine. The other parts were assembled as required except for the pump unit which was mounted on the frame supporting the end cover. Fig. 5 indicates the general arrangement of assembly. Special spacer blocks were used to limit the movement of the floating parts, these blocks took the place of the spacer ring and thrust bearing housing flange. The dial micrometer was used as on board ship.

Prior to each test, the whole frame and its assembly was aligned by a spirit level. During one of the preliminary tests, it was observed that the movement of the cage cover and yoke relative to the end plate was not as free as it should have been. When installed aboard ship, a radial clearance is intended between the end cover and the yoke. Under the arrangements necessary for this test, the combined weight of the cage cover, yoke and clamping bolt was supported by the yoke bearing on the end cover plate. To overcome this condition and the friction that resulted, a rigid support was secured to the end cover at the highest point. From the ends of this support, flexible flat springs of equal length, pinned to slotted bolts, were fixed to the cage cover and yoke flange. This arrangement, shown in Fig. 6, allowed free movement of the floating parts with no friction.

To transmit the thrust from the testing machine to the thrustmeter parts specially designed steel blocks were used.

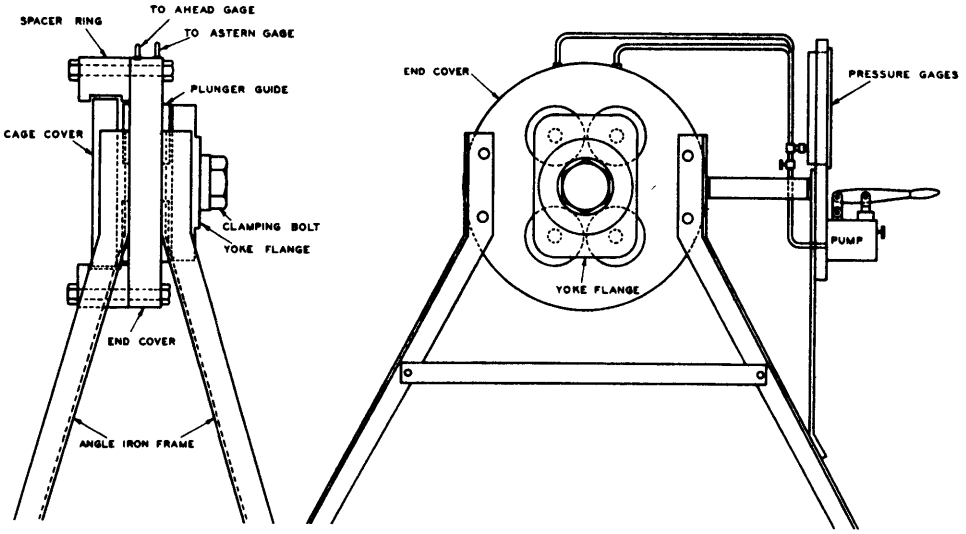


FIG. 5 – Sketch showing general assembly and arrangement of thrustmeter support for calibration.

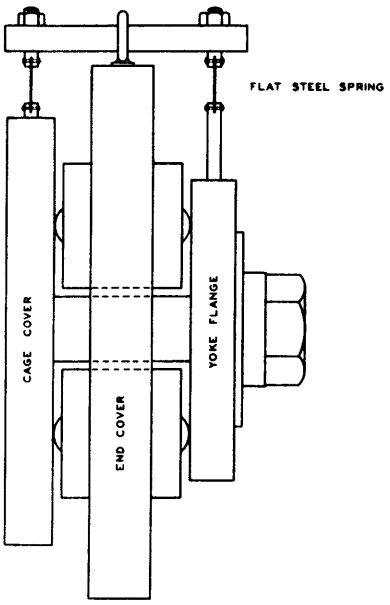


FIG. 6 – Sketch showing method of spring support to carry weight of cage cover and yoke assembly.

For ahead thrust, blocks were placed between the ram of the testing machine and the cage cover, and between the head of the machine and the end cover. As the head of the machine was fixed, this test paralleled exactly the operation when used on board ship. Fig. 7 gives a diagrammatic arrangement.

For astern thrust, an additional set of blocks was provided, one set being placed between the head of the machine and yoke flange, the other set between the ram and end cover plate. This arrangement is shown in Fig. 8.

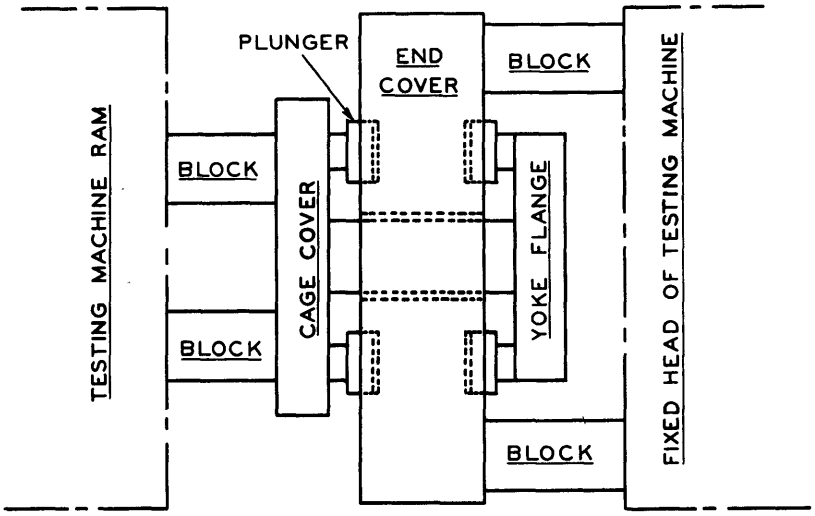


FIG. 7 – Calibration of ahead pressure cells.
Arrangement of blocks for transmitting thrust from testing machine.

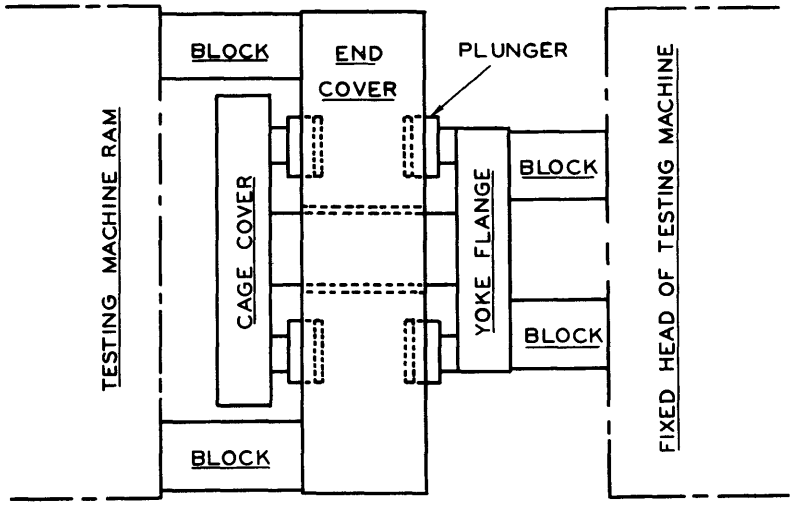


FIG. 8 – Calibration of astern pressure cells.
Arrangement of blocks for transmitting thrust from testing machine.

To avoid any eccentricity of loading, all blocks for each design were welded together to form a rigid unit. This permitted machining the bearing surfaces parallel.

A leakage of castor oil was discovered in the lower outboard astern pressure-cell of the port thrustmeter, just prior to testing. This unit was disassembled and the rubber diaphragm was found punctured in two places directly over the two inlet oil holes. Because of lack of time, a new diaphragm of the same dimensions was made from a high grade rubber obtained at the Bureau of Standards.

Method of Calibration

The cells, end cover passages, and piping were filled with clean castor oil as instructed by the manufactors. All air bubbles were eliminated.

The extreme limits of movement of the floating parts were determined by pumping up on the ahead or astern cells, and releasing the pressure on the opposite cells. Readings on the dial micrometer were made for each limit. These limits were also checked by inserting feelers between the spacer blocks and the cage cover. Pressure was then placed equally in the astern and ahead cells and the assembly was floated in its mid-position as determined by dial micrometers.

When no thrust was applied to the meter, both the ahead and astern gages were made to read between 800 and 1000 pounds per square inch to provide the full range from zero to approximately 85000 pounds thrust. With no thrust, the difference between the gage readings was established as zero thrust. Thrust was applied in increments of 1000, 2000, and 2500 pound increments, up to 85000 pounds, different combinations being used. In all cases, the difference in readings of the two gages was taken for the indicated thrust.

After each run, a check run was made at 5000 pound increments.

After calibrating the thrustmeters, the pressure gages were calibrated at the Bureau of Standards. The results are given in Tables 1, 2, 3, and 4, on pages 10 to 13 inclusive.

From the gage calibration, the original gage readings were corrected. The original data, together with the corrections, are given as listed below.

Table 5 – Starboard Thrustmeter, Measurement of Thrust on Ahead Cells, pages 14 and 15.

Table 6 – Starboard Thrustmeter, Measurement of Thrust on Astern Cells, pages 16 and 17.

Table 7 – Port Thrustmeter, Measurement of Thrust on Ahead Cells, pages 18 and 19.

Table 8 – Port Thrustmeter, Measurement of Thrust on Astern Cells, pages 20 and 21.

Results of Test

The corrected gage readings were used with the thrust indicated on the machine for plotting the thrustmeter calibration. These curves are listed below.

Fig. 9 - Calibration for Ahead Thrust Starboard Thrustmeter
Fig. 10 - Calibration for Ahead Thrust Starboard Thrustmeter
Fig. 11 - Calibration for Astern Thrust Starboard Thrustmeter
Fig. 12 - Calibration for Astern Thrust Starboard Thrustmeter
Fig. 13 - Calibration for Ahead Thrust Port Thrustmeter
Fig. 14 - Calibration for Ahead Thrust Port Thrustmeter
Fig. 15 - Calibration for Astern Thrust Port Thrustmeter
Fig. 16 - Calibration for Astern Thrust Port Thrustmeter

These figures will be found on pages 23 to 31 inclusive.

As all of these curves possessed slight shape characteristics, it was found that the effective area of the diaphragms had a varying characteristic. The mean effective areas between different pressure ranges, as determined by the mean slopes of the calibration curves, are given in Table 9, page 22

Discussion of Results

Reverting to Fig. 3, it is observed that the rubber diaphragm is secured at a diameter of 4.25 inches, whereas the plunger diameter within the steel guide, bearing against the diaphragm, is 3.99 inches. Because of the relative motion of the plunger, slight changes in the effective diameter of the rubber diaphragm will result. For the extreme cases found on calibration, an effective area of 48.8 square inches signifies a decrease of 0.0245 inches in the radius, whereas an effective area of 52.6 square inches signifies an increase of 0.051 inches in the radius—the designed radius being 1.995 inches. This corresponds to an increase of approximately 2.5 per cent and a decrease of 1.2 per cent in the radius.

Conclusion

It is believed that the calibration is satisfactory.

TABLE 1

CALIBRATION for 12" STARBOARD AHEAD EMORY PRESSURE GAGE.

Test Pressure Pounds	Gage Reading Pounds per sq. inch Up	Down	Ave.	Ave. Correction
0	35	32.5	35	-35
100	130	127.5	130	-30
200	230	227.5	230	-30
300	330	330	330	-30
400	432.5	432.5	432.5	-32.5
500	532.5	532.5	532.5	-32.5
600	632.5	632.5	632.5	-32.5
700	732.5	732.5	732.5	-32.5
800	832.5	832.5	832.5	-32.5
900	932.5	932.5	932.5	-32.5
1000	1030	1030	1030	-30
1100	1130	1132.5	1132.5	-32.5
1200	1230	1230	1230	-30
1300	1330	1332.5	1332.5	-32.5
1400	1430	1432.5	1432.5	-32.5
1500	1530	1530	1530	-30
1600	1627.5	1630	1630	-30
1700	1727.5	1727.5	1727.5	-27.5
1800	1825	1825	1825	-25
1900	1925	1925	1925	-25
2000	2022.5	2022.5	2022.5	-22.5
2100	2122.5	2122.5	2122.5	-22.5
2200	2222.5(estimated)		2222.5	-22.5

Readings, averages and corrections are to the nearest 2.5 lbs. per sq. in.
The temperature of the gage during the test was approximately 80° Fahrenheit.

B.S.Test No.V1-1/612-36-15.

TABLE 2

CALIBRATION for 12" STARBOARD ASTERN EMORY PRESSURE GAGE.

Test Pressure Pounds	Gage Reading Pounds per sq. inch Up	Down	Ave.	Ave. Correction
0	-5(est.)	-5(est.)	-5	+5
100	95	95	95	+5
200	195	197.5	197.5	+2.5
300	295	295	295	+5
400	395	395	395	+5
500	492.5	495	495	+5
600	592.5	595	595	+5
700	692.5	695	695	+5
800	792.5	795	795	+5
900	892.5	895	895	+5
1000	992.5	995	995	+5
1100	1092.5	1095	1095	+5
1200	1192.5	1195	1195	+5
1300	1290	1292.5	1292.5	+7.5
1400	1390	1392.5	1392.5	+7.5
1500	1490	1492.5	1492.5	+7.5
1600	1590	1592.5	1592.5	+7.5
1700	1687.5	1690	1690	+10
1800	1787.5	1790	1790	+10
1900	1890	1890	1890	+10
2000	1987.5	1990	1990	+10
2100	2090	2090	2090	+10
2200	2190		2190	+10

Readings, averages and corrections are to the nearest 2.5 lbs. per square inch. The temperature of the gage during the test was approximately 80° Fahrenheit.

B.S.Test No.V1-1/612-36-15.

TABLE 3

CALIBRATION for 12" PORT AHEAD EMORY PRESSURE GAGE.

Test Pressure Pounds	Gage Reading Pounds per sq. inch			
	Up	Down	Ave.	Ave. Correction
0	0	0	0	0
100	100	100	100	0
200	200	200	200	0
300	300	300	300	0
400	400	400	400	0
500	502.5	502.5	502.5	-2.5
600	602.5	602.5	602.5	-2.5
700	707.5	707.5	707.5	-7.5
800	805	805	805	-5
900	905	905	905	-5
1000	1005	1005	1005	-5
1100	1105	1105	1105	-5
1200	1205	1205	1205	-5
1300	1305	1305	1305	-5
1400	1405	1405	1405	-5
1500	1505	1505	1505	-5
1600	1602.5	1602.5	1602.5	-2.5
1700	1702.5	1702.5	1702.5	-2.5
1800	1800	1802.5	1802.5	-2.5
1900	1900	1900	1900	0
2000	2000	2000	2000	0
2100	2100	2100	2100	0
2200	2200		2200	0

Readings, averages and corrections are to the nearest 2.5 lbs. per sq. in.
The temperature of the gage during the test was approximately 80° Fahrenheit.

B.S.Test No.V1-1/612-36-15.

TABLE 4

CALIBRATION for 12" PORT ASTERN EMORY PRESSURF GAGE.

Test Pressure Pounds	Gage Reading Pounds per sq. inch Up	Down	Ave.	Ave. Correction
0	2.5	2.5	2.5	-2.5
100	102.5	102.5	102.5	-2.5
200	202.5	202.5	202.5	-2.5
300	300	302.5	302.5	-2.5
400	402.5	402.5	402.5	-2.5
500	500	502.5	502.5	-2.5
600	602.5	602.5	602.5	-2.5
700	700	702.5	702.5	-2.5
800	800	802.5	802.5	-2.5
900	900	902.5	902.5	-2.5
1000	1000	1000	1000	0
1100	1100	1100	1100	0
1200	1197.5	1200	1200	0
1300	1297.5	1300	1300	0
1400	1397.5	1400	1400	0
1500	1497.5	1500	1500	0
1600	1597.5	1600	1600	0
1700	1700	1700	1700	0
1800	1797.5	1800	1800	0
1900	1897.5	1897.5	1897.5	+2.5
2000	1997.5	1997.5	1997.5	+2.5
2100	2097.5	2097.5	2097.5	+2.5
2200	2197.5		2197.5	+2.5

Readings, averages and corrections are to the nearest 2.5 lbs. per sq. in.
The temperature of the gage during the test was approximately 80° Fahrenheit.

B.S.Test No.V1-1/612-36-15.

TABLE 5

ORIGINAL DATA FOR CALIBRATION OF
AHEAD PRESSURE CELLS - STARBOARD THRUSTMETER

- DESIGNATION OF COLUMN HEADINGS -

Col. 1 Ahead Gage Reading
2 Correction from Gage Calibration
3 Corrected Ahead Gage Reading
4 Astern Gage Reading
5 Correction from Gage Calibration
6 Corrected Astern Gage Reading
7 Difference Col. 3 and Col. 6
8 Difference Corrected to Zero
9 Measured Thrust

POUNDS PER SQUARE INCH								POUNDS
1	2	3	4	5	6	7	8	9
1022	-30	992	986	+5	991	1	0	0
1045	-30	1015	957	+5	962	53	52	2,500
1075	-30	1045	932	+5	937	108	107	5,100
1100	-32	1068	920	+5	925	143	142	7,500
1130	-32	1098	893	+5	898	200	199	10,000
1157	-32	1125	873	+5	878	247	246	12,500
1183	-32	1151	853	+5	858	293	292	15,000
1214	-30	1184	830	+5	835	349	348	17,580
1240	-30	1210	812	+5	817	393	392	20,000
1271	-30	1241	790	+5	795	446	445	22,500
1300	-32	1268	771	+5	776	492	491	25,000
1329	-32	1297	751	+5	756	541	540	27,500
1357	-32	1325	732	+5	735	590	589	30,000
1388	-32	1356	712	+5	717	639	638	32,500
1419	-32	1387	694	+5	699	688	687	35,000
1450	-32	1428	673	+5	678	750	749	37,600
1478	-32	1446	654	+5	659	787	786	40,000
1509	-30	1479	635	+5	640	839	838	42,500
1536	-30	1506	616	+5	621	885	884	45,000
1569	-30	1539	596	+5	601	938	937	47,500
1597	-30	1567	579	+5	584	983	982	50,000
1629	-30	1599	558	+5	563	1036	1035	52,600
1657	-30	1627	542	+5	547	1080	1079	55,000
1687	-30	1657	524	+5	529	1128	1127	57,600
1722	-27	1695	504	+5	509	1186	1185	60,100
1750	-27	1723	487	+5	492	1231	1230	62,500
1778	-27	1751	471	+5	476	1275	1274	65,000
1810	-25	1785	453	+5	458	1327	1326	67,500
1839	-25	1814	438	+5	443	1371	1370	70,000
1871	-25	1846	421	+5	426	1420	1419	72,500
1902	-25	1877	405	+5	410	1467	1466	75,000
1935	-25	1910	389	+5	394	1516	1515	77,500
1965	-25	1940	373	+5	378	1562	1561	80,000
2000	-22	1978	356	+5	361	1617	1616	82,500
2030	-22	2008	342	+5	347	1661	1660	85,000
1000	-30	970	964	+5	969	1	0	0
1000	-30	970	958	+5	963	7	0	0
1008	-30	978	950	+5	955	23	16	1,000
1019	-30	989	941	+5	946	43	36	2,000

POUNDS PER SQUARE INCH								POUNDS
1	2	3	4	5	6	7	8	9
1031	-30	1001	934	+5	939	62	55	3,040
1043	-30	1013	926	+5	931	82	75	4,000
1055	-30	1025	918	+5	923	102	95	5,000
1001	-30	971	958	+5	963	8	1	0
1001	-30	971	960	+5	965	6	0	0
1010	-30	980	951	+5	956	24	18	1,000
1067	-30	1037	912	+5	917	120	114	6,000
1126	-32	1094	873	+5	878	216	210	11,000
1184	-32	1152	833	+5	838	314	308	16,000
1244	-30	1214	792	+5	797	417	411	21,000
1303	-30	1273	754	+5	759	514	508	26,000
1364	-32	1332	715	+5	720	612	606	31,000
1424	-32	1392	678	+5	683	709	703	36,000
1485	-32	1453	690	+5	640	813	807	41,100
1546	-30	1516	601	+5	606	910	904	46,000
1605	-30	1575	566	+5	571	1004	998	51,000
1666	-30	1636	531	+5	536	1100	1094	56,000
1727	-27	1700	495	+5	500	1200	1194	61,000
1788	-27	1761	462	+5	467	1294	1288	66,000
1850	-25	1825	430	+5	435	1390	1384	71,000
1914	-25	1889	398	+5	403	1486	1480	76,000
1976	-25	1951	367	+5	372	1579	1573	81,000
2041	-22	2019	337	+5	342	1677	1671	86,000
1000	-30	970	958	+5	963	7	1	0

TABLE 6

ORIGINAL DATA FOR CALIBRATION OF
ASTERN PRESSURE CELLS - STARBOARD THRUSTMETER

- DESIGNATION OF COLUMN HEADINGS -

Col. 1 Ahead Gage Reading
2 Correction from Gage Calibration
3 Corrected Ahead Gage Reading
4 Astern Gage Reading
5 Correction from Gage Calibration
6 Corrected Astern Gage Reading
7 Difference Col. 3 and Col. 6
8 Difference Corrected to Zero
9 Measured Thrust

POUNDS PER SQUARE INCH								POUNDS
1	2	3	4	5	6	7	8	9
904	-32	872	860	+5	865	-7	0	0
881	-32	849	895	+5	900	51	58	2,500
862	-32	830	924	+5	929	99	106	5,000
844	-32	812	954	+5	959	147	154	7,500
822	-32	790	988	+5	993	203	210	10,000
800	-32	768	1020	+5	1025	257	264	12,700
783	-32	751	1050	+5	1055	304	311	15,200
766	-32	734	1076	+5	1081	347	354	17,500
749	-32	717	1107	+5	1112	395	402	20,000
728	-32	696	1142	+5	1147	451	458	22,500
712	-32	680	1172	+5	1177	497	504	25,000
692	-32	660	1208	+5	1213	553	560	27,600
676	-32	644	1239	+5	1244	600	607	30,000
659	-32	627	1268	+5	1273	646	653	32,500
636	-32	604	1308	+7	1315	711	718	35,600
624	-32	592	1332	+7	1339	747	754	37,500
608	-32	576	1365	+7	1372	796	803	40,000
592	-32	560	1395	+7	1402	842	849	42,500
575	-32	543	1429	+7	1436	893	900	45,000
557	-32	525	1463	+7	1470	945	952	47,500
542	-32	510	1496	+7	1503	993	1000	50,000
527	-32	495	1530	+7	1537	1042	1049	52,500
511	-32	479	1564	+7	1571	1092	1099	55,000
897	-32	865	854	+5	859	-6	0	0
990	-32	958	950	+5	955	-3	0	0
950	-32	918	1014	+5	1019	101	104	5,000
912	-32	880	1075	+5	1080	200	203	10,000
875	-32	843	1137	+5	1142	299	302	15,000
838	-32	806	1202	+5	1207	401	404	20,000
800	-32	768	1265	+5	1270	502	505	25,000
767	-32	735	1324	+7	1331	596	599	30,000
731	-32	699	1391	+7	1398	699	702	35,000
697	-32	665	1456	+7	1463	798	801	40,000
661	-32	629	1526	+7	1533	904	907	45,000
631	-32	599	1585	+7	1592	993	996	50,000
599	-32	567	1650	+7	1657	1090	1093	55,000
581	-32	549	1684	+7	1691	1142	1145	57,500
566	-32	534	1715	+10	1725	1191	1194	60,000

POUNDS PER SQUARE INCH								POUNDS
1	2	3	4	5	6	7	8	9
550	-32	518	1750	+10	1760	1242	1245	62,500
535	-32	503	1782	+10	1792	1289	1292	65,000
520	-32	488	1817	+10	1827	1339	342	67,500
506	-32	474	1851	+10	1861	1387	1390	70,000
490	-32	458	1884	+10	1894	1436	1439	72,500
475	-32	443	1919	+10	1929	1486	1489	75,000
458	-32	426	1952	+10	1962	1536	1539	77,500
444	-32	412	1985	+10	1995	1583	1586	80,000
426	-32	394	2023	+10	2033	1639	1642	82,600
412	-32	380	2055	+10	2065	1685	1688	85,000
980	-32	948	944	+5	949	1	0	0
980	-32	948	944	+5	949	1	0	0
972	-32	940	960	+5	965	25	24	1,050
965	-32	933	972	+5	977	44	43	2,000
958	-32	926	984	+5	989	63	62	3,020
950	-32	918	995	+5	1000	82	81	4,030
942	-32	910	1007	+5	1012	102	101	5,000
934	-32	902	1019	+5	1024	122	121	6,000
927	-32	895	1030	+5	1035	140	139	7,000
919	-32	887	1043	+5	1048	161	160	8,030
913	-32	881	1054	+5	1059	178	177	9,000
905	-32	873	1067	+5	1072	199	198	10,000
980	-32	948	944	+5	949	1	0	0

TABLE 7

ORIGINAL DATA FOR CALIBRATION OF
AHEAD PRESSURE CELLS - PORT THRUSTMETER

- DESIGNATION OF COLUMN HEADINGS -

Col. 1 Ahead Gage Reading
2 Correction from Gage Calibration
3 Corrected Ahead Gage Reading
4 Astern Gage Reading
5 Correction from Gage Calibration
6 Corrected Astern Gage Reading
7 Difference Col. 3 and Col. 6
8 Difference Corrected to Zero
9 Measured Thrust

POUNDS PER SQUARE INCH								POUNDS
1	2	3	4	5	6	7	8	9
824	-5	819	815	-2	813	6	0	0
847	-5	842	791	-2	789	53	47	2,000
869	-5	864	775	-2	773	91	85	4,000
891	-5	886	754	-2	752	134	128	6,050
913	-5	908	739	-2	737	171	165	8,000
939	-5	934	719	-2	717	217	211	10,050
960	-5	955	703	-2	701	254	248	12,000
983	-5	978	686	-2	684	294	288	14,000
1009	-5	1004	668	-2	666	338	332	16,100
1031	-5	1026	652	-2	650	376	370	18,050
1054	-5	1049	636	-2	634	415	409	20,000
1078	-5	1073	621	-2	619	454	448	22,000
1103	-5	1098	605	-2	603	495	489	24,000
1129	-5	1124	588	-2	586	538	532	26,000
1152	-5	1147	572	-2	570	577	571	28,000
1175	-5	1170	558	-2	556	614	608	30,000
1201	-5	1196	541	-2	539	657	651	32,050
1224	-5	1219	527	-2	525	694	688	34,000
1249	-5	1244	513	-2	511	733	727	36,000
1275	-5	1270	497	-2	495	775	769	38,050
1303	-5	1298	482	-2	480	818	812	40,100
1324	-5	1319	470	-2	468	851	845	42,000
1349	-5	1344	456	-2	454	890	884	44,050
1373	-5	1368	444	-2	442	926	920	46,000
1401	-5	1396	429	-2	427	969	963	48,080
1433	-5	1428	414	-2	414	1014	1008	50,300
1451	-5	1446	405	-2	403	1043	1037	52,000
1476	-5	1471	393	-2	391	1080	1074	54,000
1504	-5	1499	380	-2	378	1121	1115	56,000
1528	-5	1523	367	-2	365	1158	1152	58,000
1555	-5	1550	355	-2	353	1197	1192	60,080
1577	-5	1572	344	-2	342	1230	1224	62,000
1606	-2	1604	330	-2	328	1276	1270	64,100
1631	-2	1629	320	-2	318	1311	1305	66,000
1657	-2	1655	308	-2	306	1349	1343	68,000
1684	-2	1682	298	-2	296	1386	1380	70,000
1714	-2	1712	285	-2	283	1429	1423	72,050
1740	-2	1738	272	-2	270	1468	1462	74,000
1766	-2	1764	260	-2	258	1506	1500	76,000
1797	-2	1795	247	-2	245	1550	1544	78,100

POUNDS PER SQUARE INCH								POUNDS
1	2	3	4	5	6	7	8	9
1822	-2	1820	236	-2	234	1586	1580	80,000
1860	-2	1858	222	-2	220	1638	1632	82,500
1895	0	1895	209	-2	207	1688	1682	85,000
809	-5	804	798	-2	796	8	0	0
810	-5	805	796	-2	794	11	0	0
818	-5	813	780	-2	778	35	24	1,000
883	-5	878	729	-2	727	151	140	6,450
938	-5	933	692	-2	690	243	232	11,000
996	-5	991	652	-2	650	341	330	16,000
1059	-5	1054	612	-2	610	444	433	21,050
1117	-5	1112	567	-2	565	547	536	26,000
1178	-5	1173	540	-2	538	635	624	31,000
1241	-5	1236	505	-2	503	733	722	36,040
1302	-5	1297	471	-2	469	828	817	41,000
1365	-5	1360	437	-2	435	925	914	46,020
1427	-5	1422	405	-2	403	1019	1008	51,000
1494	-5	1489	373	-2	371	1118	1107	56,000
1557	-5	1552	342	-2	340	1212	1201	61,040
1622	-2	1620	312	-2	310	1310	1299	66,000
1689	-2	1687	284	-2	282	1405	1399	71,000
1758	-2	1756	255	-2	253	1503	1492	76,000
1828	-2	1826	227	-2	225	1601	1590	81,000
1900	0	1900	202	-2	200	1700	1689	86,000
808	-5	803	793	-2	791	11	0	0

TABLE 8

ORIGINAL DATA FOR CALIBRATION OF
ASTERN PRESSURE CELLS - PORT THRUSTMETER

- DESIGNATION OF COLUMN HEADINGS -

Col. 1 Ahead Gage Reading
2 Correction from Gage Calibration
3 Corrected Ahead Gage Reading
4 Astern Gage Reading
5 Correction from Gage Calibration
6 Corrected Astern Gage Reading
7 Difference Col. 3 and Col. 6
8 Difference Corrected to Zero
9 Measured Thrust

POUNDS PER SQUARE INCH								POUNDS
1	2	3	4	5	6	7	8	9
854	-5	849	849	-2	847	-2	0	0
845	-5	840	863	-2	861	21	23	1,100
839	-5	834	873	-2	871	37	39	2,020
833	-5	828	875	-2	873	45	47	3,000
823	-5	818	899	-2	897	79	81	4,080
818	-5	813	910	-2	908	95	97	5,000
811	-5	806	924	-2	922	116	118	6,060
805	-5	800	935	-2	933	133	135	7,020
797	-5	792	949	-2	947	155	157	8,020
789	-7	782	964	-2	962	180	182	9,180
785	-7	778	972	-2	970	192	194	10,000
778	-7	771	984	-2	982	211	213	11,000
771	-7	764	997	-2	995	231	233	12,000
762	-7	755	1013	-0	1013	258	260	13,000
756	-7	749	1023	0	1023	274	276	14,000
750	-7	743	1034	0	1034	291	293	15,000
740	-7	733	1051	0	1051	318	320	16,150
735	-7	728	1060	0	1060	332	334	17,000
727	-7	720	1074	0	1074	354	356	18,000
718	-7	711	1091	0	1091	380	382	19,150
715	-7	708	1099	0	1099	391	393	20,000
702	-7	695	1125	0	1125	430	432	22,000
687	-2	685	1152	0	1152	467	469	24,000
674	-2	672	1177	0	1177	505	507	26,000
659	-2	657	1204	0	1204	547	549	28,000
644	-2	642	1229	0	1229	587	589	30,060
630	-2	628	1255	0	1255	627	629	32,000
616	-2	614	1282	0	1282	668	670	34,000
602	-2	600	1309	0	1309	709	711	36,000
589	-2	587	1335	0	1335	748	750	38,000
576	-2	574	1361	0	1361	787	789	40,000
560	-2	558	1394	0	1394	836	838	42,150
550	-2	548	1416	0	1416	868	870	44,000
535	-2	533	1449	0	1449	916	918	46,100
524	-2	522	1474	0	1474	952	954	48,040
514	-2	512	1500	0	1500	988	990	50,000
501	-2	499	1522	0	1522	1023	1025	52,000
489	0	489	1553	0	1553	1064	1066	54,000
476	0	476	1581	0	1581	1105	1107	56,000
464	0	464	1610	0	1610	1146	1148	58,000

POUNDS PER SQUARE INCH								POUNDS
1	2	3	4	5	6	7	8	9
450	0	450	1635	0	1635	1185	1187	60,000
440	0	440	1666	0	1666	1226	1228	62,000
428	0	428	1697	0	1697	1269	1271	64,080
415	0	415	1725	0	1725	1310	1312	66,050
405	0	405	1751	0	1751	1346	1348	68,000
395	0	395	1779	0	1779	1384	1386	70,000
384	0	384	1808	0	1808	1424	1426	72,000
372	0	372	1838	0	1838	1466	1468	74,060
362	0	362	1864	0	1864	1502	1504	76,000
350	0	350	1896	+2	1898	1548	1550	78,100
340	0	340	1925	+2	1927	1587	1589	80,100
330	0	330	1950	+2	1952	1622	1624	82,000
848	-5	843	844	-2	842	-1	0	0
855	-5	850	850	-2	848	-2	0	0
817	-5	812	916	-2	914	102	104	5,000
781	-7	774	979	-2	977	203	205	10,100
746	-7	739	1045	0	1045	306	308	15,150
713	-7	706	1106	0	1106	400	402	20,050
680	-2	678	1170	0	1170	492	494	25,000
642	-2	640	1239	0	1239	599	601	30,150
609	-2	607	1303	0	1303	696	698	35,000
578	-2	576	1370	0	1370	794	796	40,000
546	-2	544	1439	0	1439	895	897	45,000
515	-2	513	1509	0	1509	996	998	50,050
485	0	485	1577	0	1577	1092	1094	55,000
455	0	455	1648	0	1648	1193	1195	60,000
425	0	425	1717	0	1717	1292	1294	65,000
396	0	396	1788	+2	1790	1394	1396	70,000
369	0	369	1861	+2	1863	1494	1496	75,080
344	0	344	1930	+2	1932	1588	1590	80,000
318	0	318	2002	+2	2004	1686	1688	85,000
854	-5	849	852	-2	850	-1	0	0

TABLE 9

VARIATION OF AVERAGE MEAN EFFECTIVE AREAS.

AHEAD THRUST

PRESSURE RANGE	STARBOARD AVE. EFFECTIVE AREA	PORT AVE. EFFECTIVE AREA
0–20,000	51.0	48.8
20,000–40,000	50.6	50.0
40,000–60,000	51.3	52.6
60,000–80,000	51.4	52.0

ASTERN THRUST

0–20,000	49.4	50.7
20,000–40,000	50.2	50.4
40,000–60,000	51.2	50.0
60,000–80,000	51.0	50.3

CALIBRATION CURVES
FIGS. 9 to 16

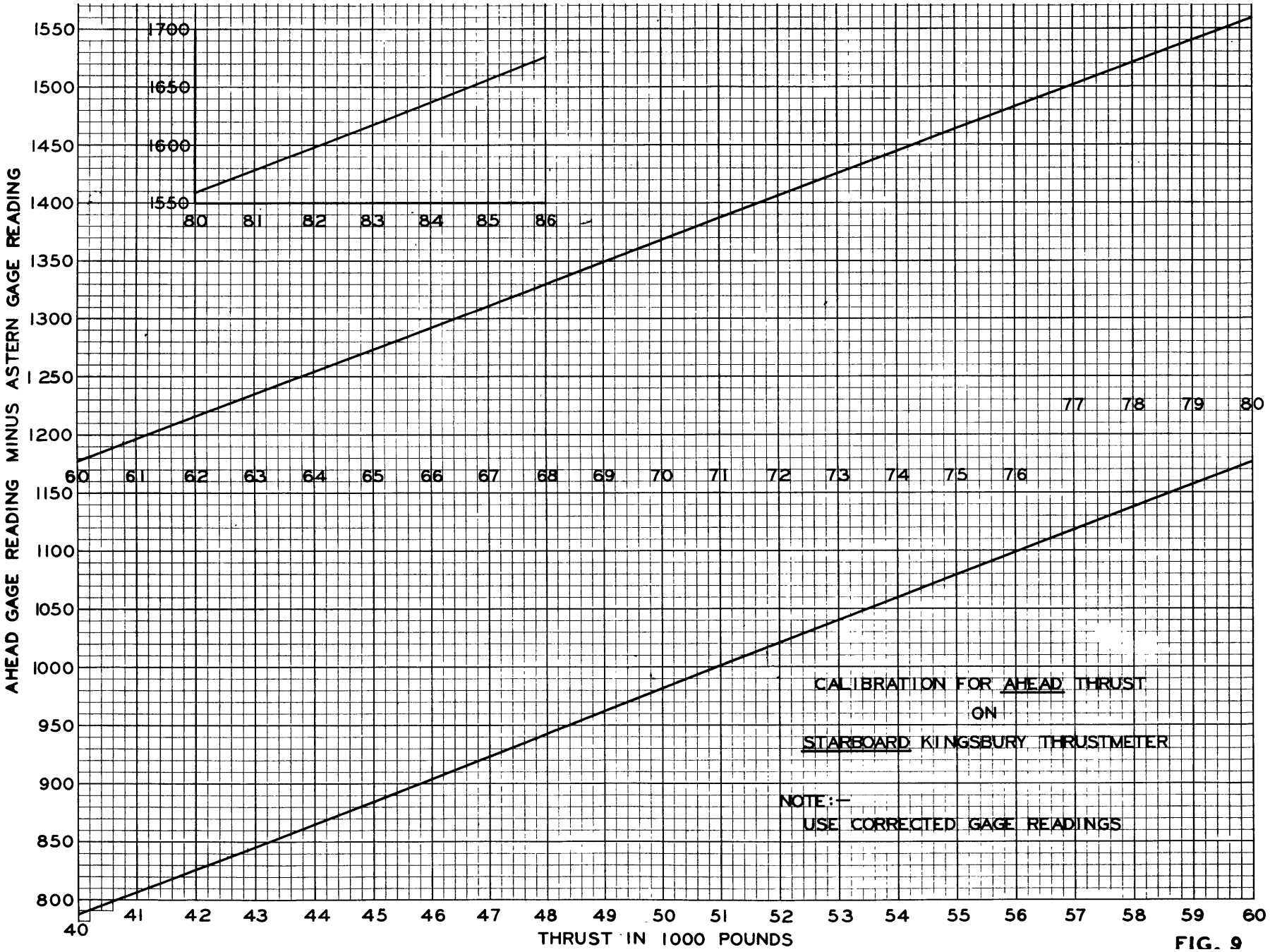

AHEAD GAGE READING MINUS ASTERN GAGE READING
1550
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
1700
1650
1600
1550
80 81 82 83 84 85 86
40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
THRUST IN 1000 POUNDS
CALIBRATION FOR AHEAD THRUST
ON
STARBOARD KINGSBURY THRUSTMETER
NOTE:—
USE CORRECTED GAGE READINGS

FIG. 9

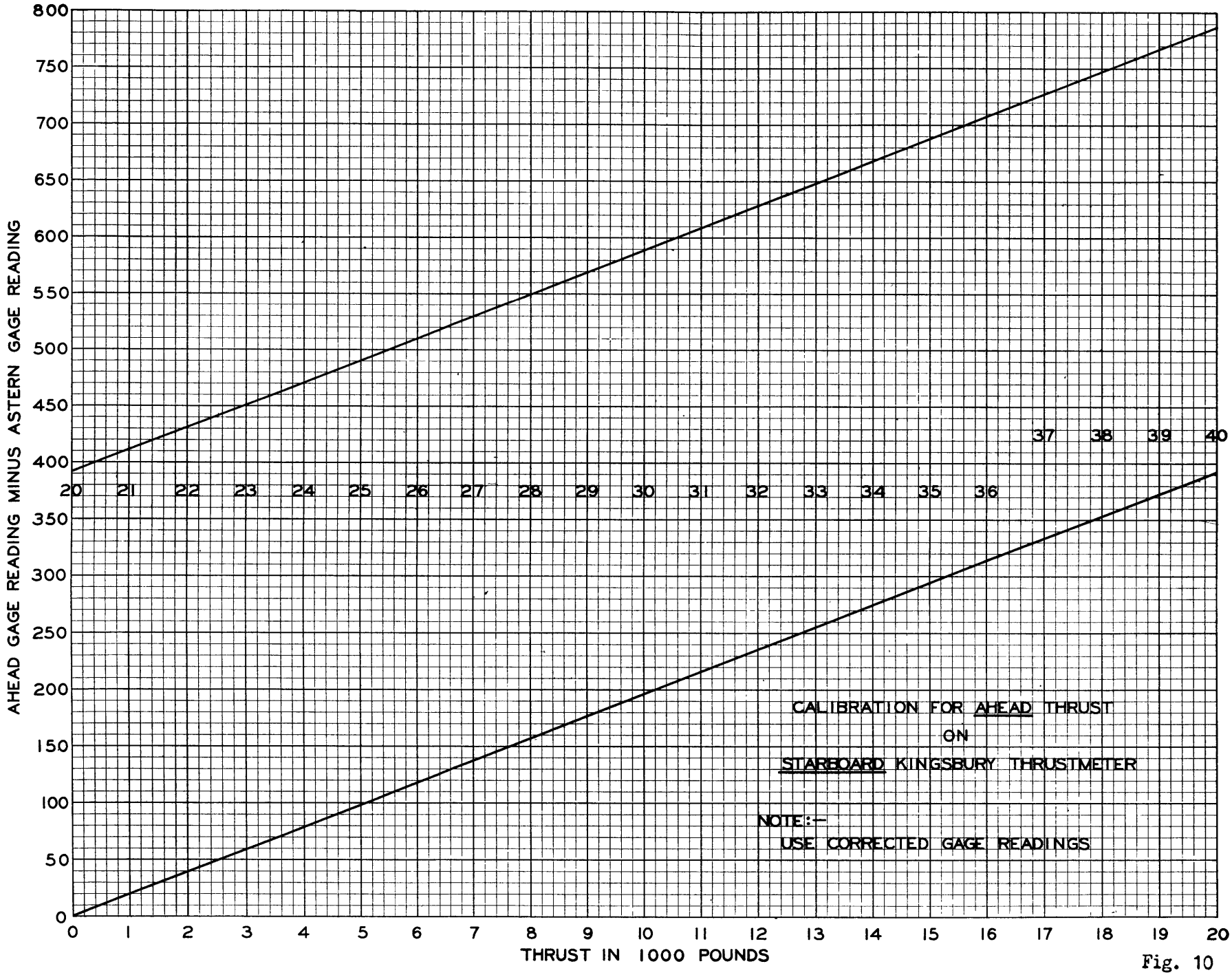

AHEAD GAGE READING MINUS ASTERN GAGE READING
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
THRUST IN 1000 POUNDS
CALIBRATION FOR AHEAD THRUST
ON
STARBOARD KINGSBURY THRUSTMETER
NOTE:-
USE CORRECTED GAGE READINGS

Fig. 10

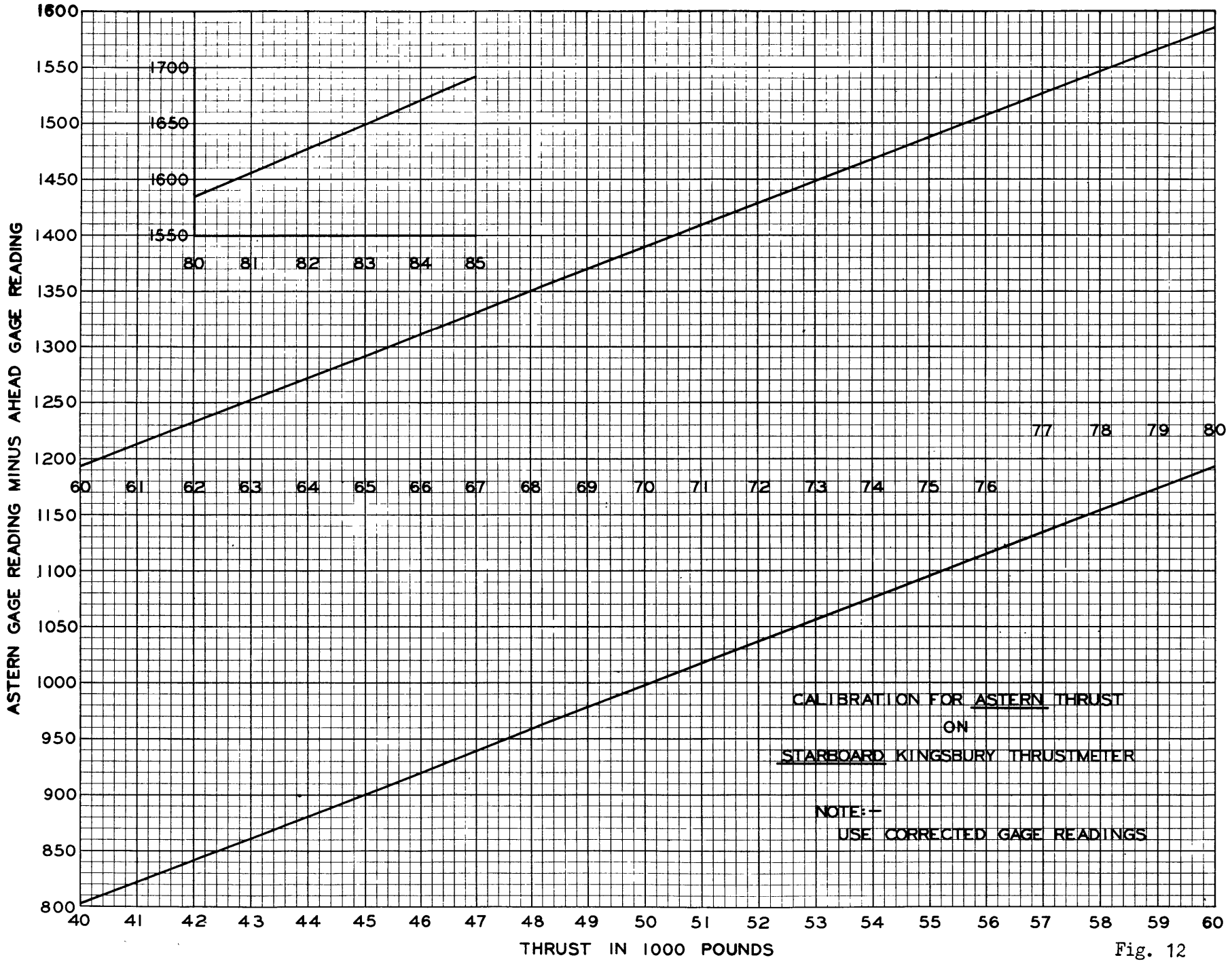

ASTERN GAGE READING MINUS AHEAD GAGE READING
1600
1550
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
1700
1650
1600
1550
80 81 82 83 84 85
60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
THRUST IN 1000 POUNDS
CALIBRATION FOR ASTERN THRUST
ON
STARBOARD KINGSBURY THRUSTMETER
NOTE:-
USE CORRECTED GAGE READINGS

Fig. 12

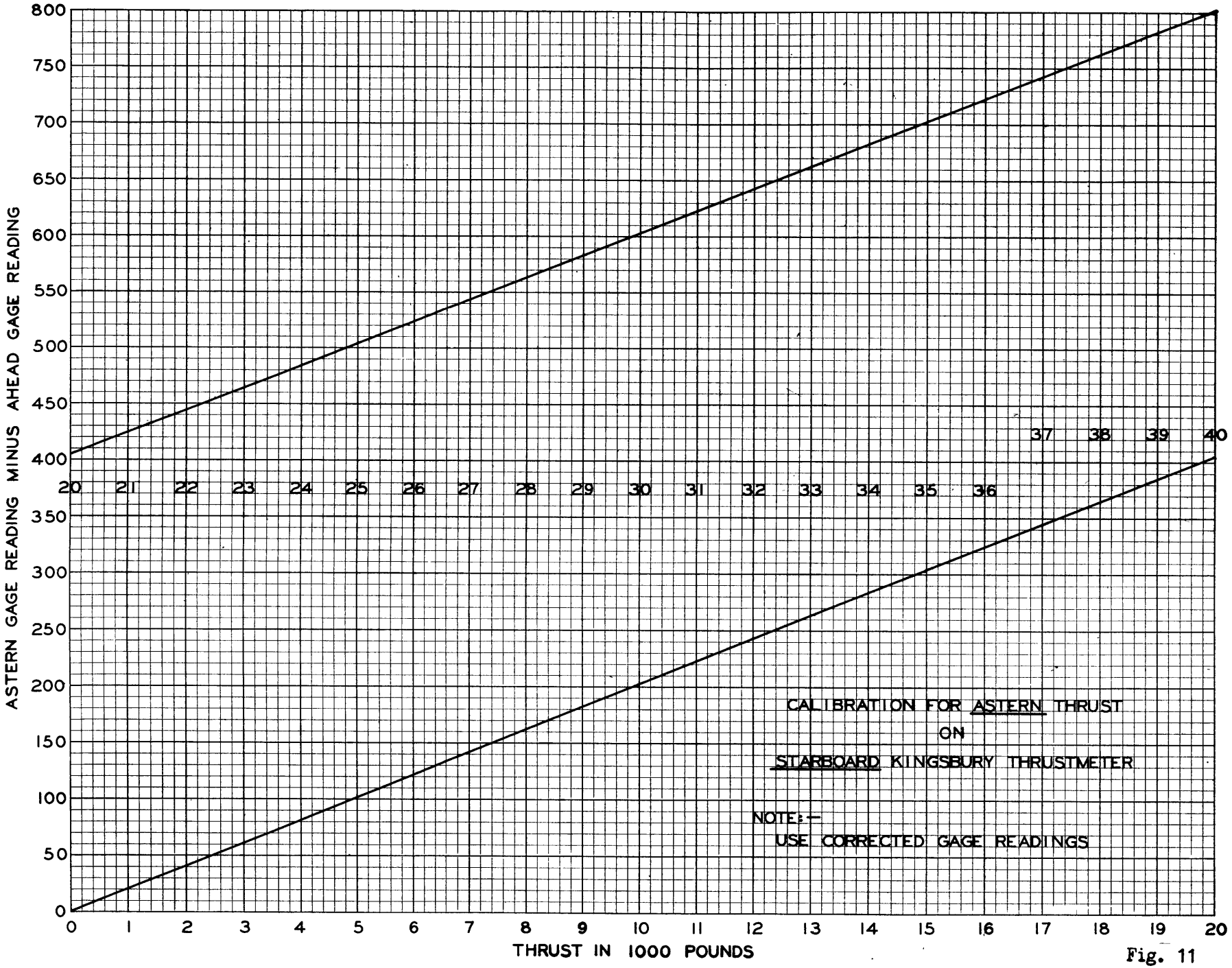

ASTERN GAGE READING MINUS AHEAD GAGE READING
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
THRUST IN 1000 POUNDS
CALIBRATION FOR ASTERN THRUST
ON
STARBOARD KINGSBURY THRUSTMETER
NOTE:—
USE CORRECTED GAGE READINGS

Fig. 11

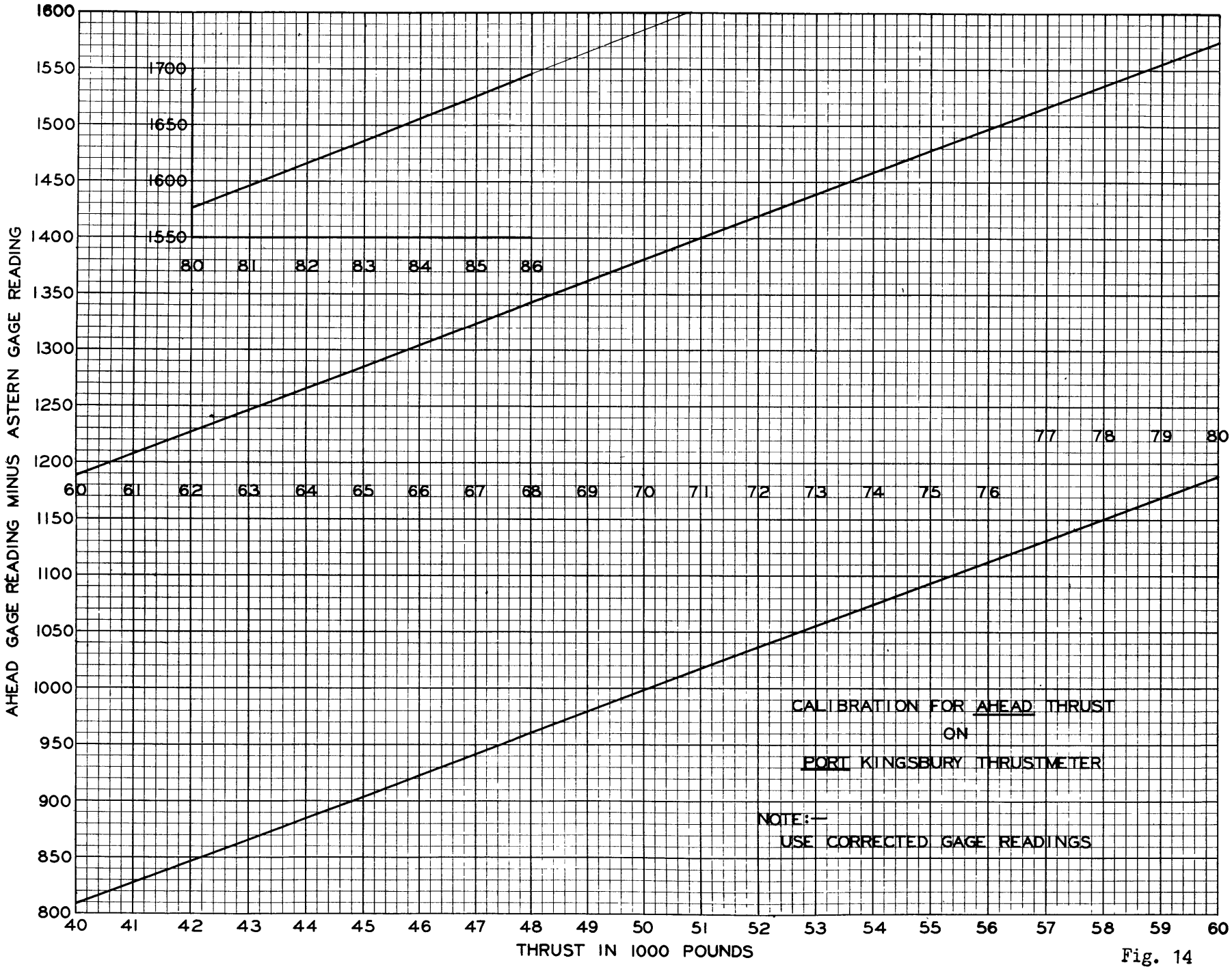

AHEAD GAGE READING MINUS ASTERN GAGE READING
1600
1550
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
1700
1650
1600
1550
80 81 82 83 84 85 86
77 78 79 80
60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76
40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
THRUST IN 1000 POUNDS
CALIBRATION FOR AHEAD THRUST
ON
PORT KINGSBURY THRUSTMETER
NOTE:—
USE CORRECTED GAGE READINGS

Fig. 14

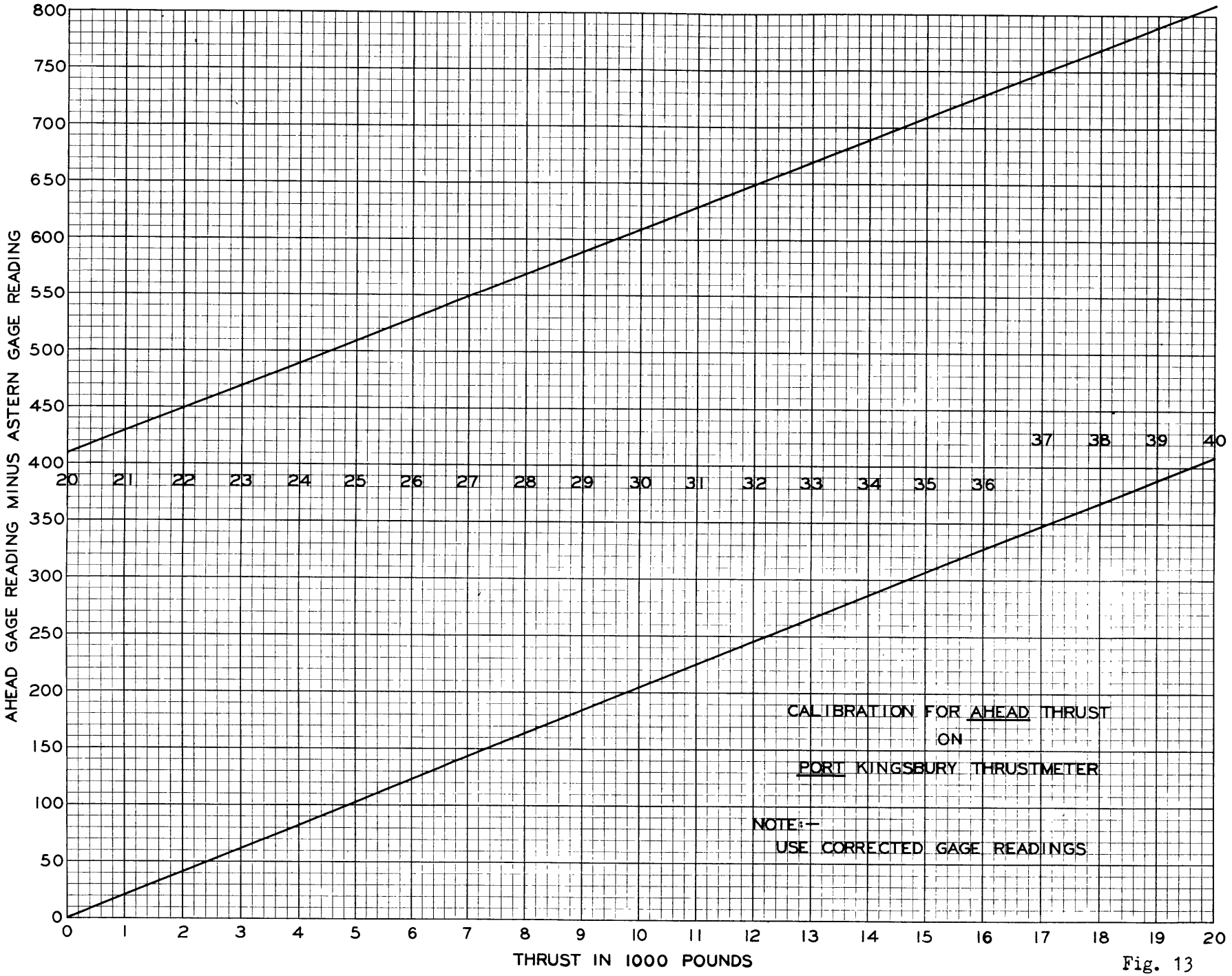

AHEAD GAGE READING MINUS ASTERN GAGE READING
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
THRUST IN 1000 POUNDS
CALIBRATION FOR AHEAD THRUST
ON
PORT KINGSBURY THRUSTMETER
NOTE:—
USE CORRECTED GAGE READINGS

Fig. 13

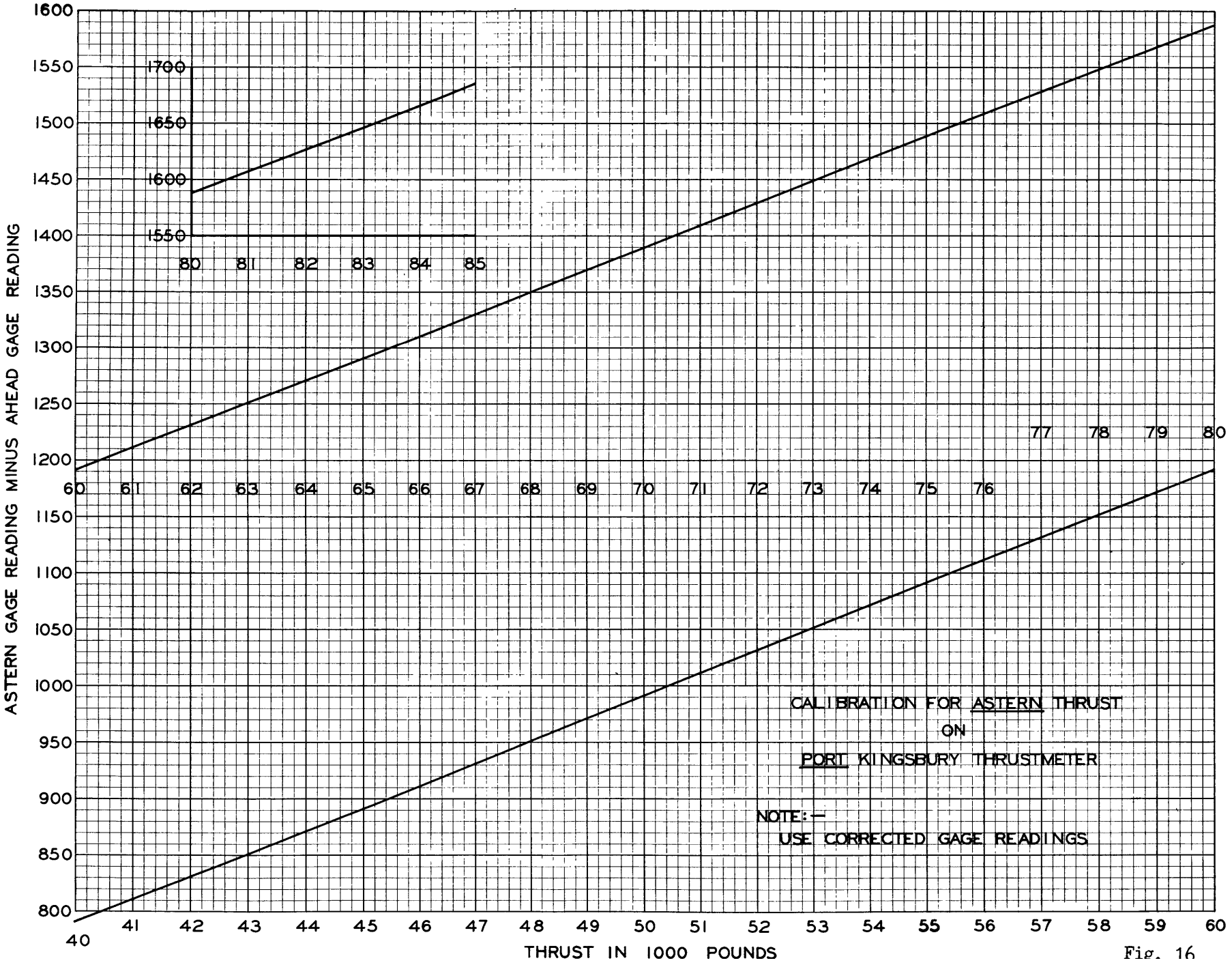

ASTERN GAGE READING MINUS AHEAD GAGE READING
1600
1550
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
1700
1650
1600
1550
80 81 82 83 84 85
60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
THRUST IN 1000 POUNDS
CALIBRATION FOR ASTERN THRUST
ON
PORT KINGSBURY THRUSTMETER
NOTE:—
USE CORRECTED GAGE READINGS

Fig. 16

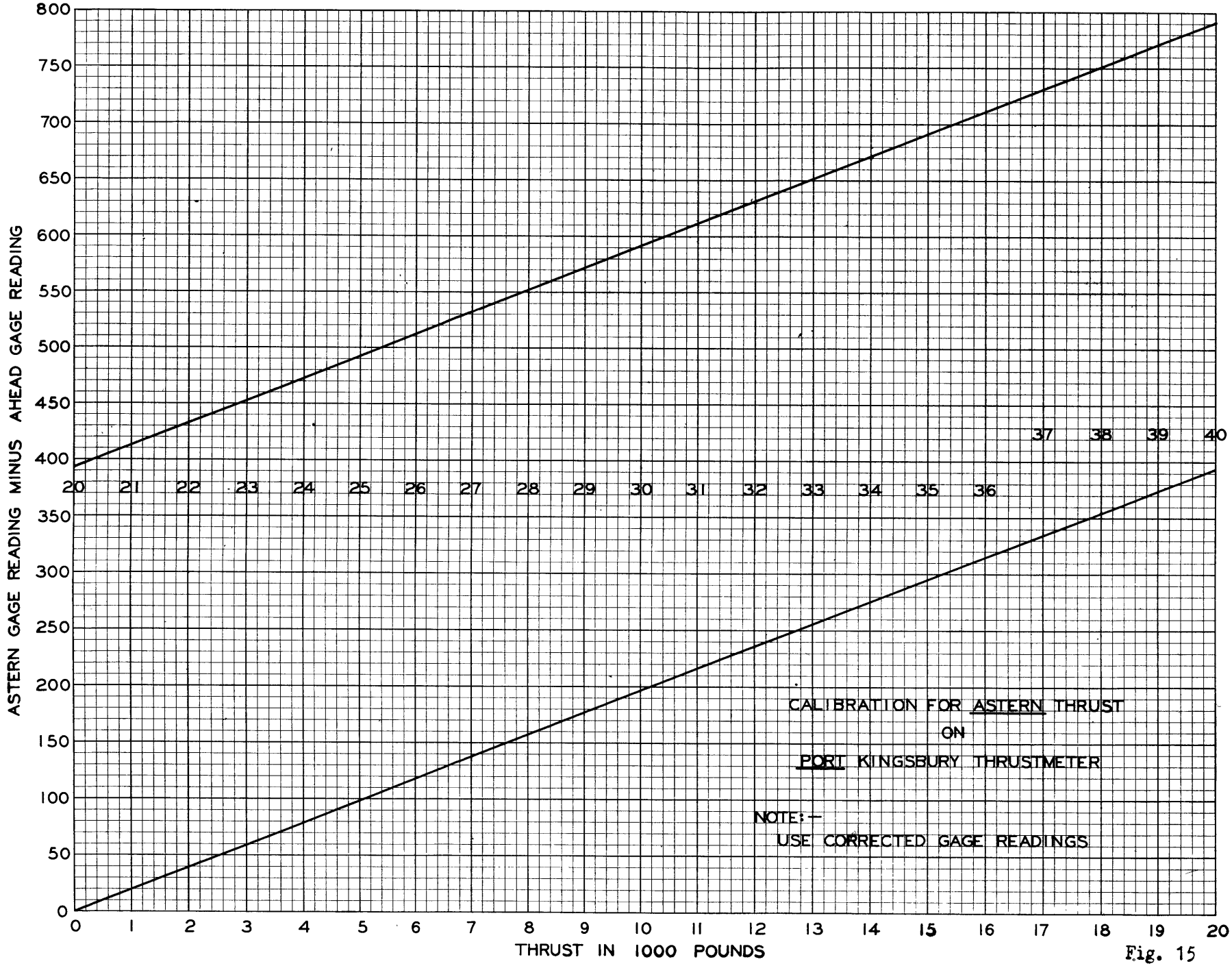

ASTERN GAGE READING MINUS AHEAD GAGE READING
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
THRUST IN 1000 POUNDS
CALIBRATION FOR ASTERN THRUST
ON
PORT KINGSBURY THRUSTMETER
NOTE:-
USE CORRECTED GAGE READINGS

Fig. 15