Stability of battleship under damaged conditions.

Thesis by
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The Kearsarge is a battleship of 12905 tons displacement at full load condition, 368 feet on the water line, 376 feet over all, 25 feet 10¼ inches draft, and 72 feet 2½ inches extreme breadth. A water-tight protective deck extends the whole length of the vessel. Above and under this deck the vessel is subdivided into different compartments by water-tight bulkheads; so that any damage to the vessel may be only local in its extent.

It is the purpose of the present investigation to determine the stability of this vessel when certain of these compartments under the protective deck become opened to the sea without relying the compartments above the protective deck to furnish any

stability whatever. For this purpose a model of 48 size was used. The model is cut at the various bulkheads so that the blocks cut out represent the actual compartments of the vessel. These blocks are kept in place by dowel pins and brass tie rods. To give rigidity to the model, a ½ inch brass tube extends nearly the entire length of the vessel and passes through brackets which are fastened near the ends and at intermediate points of the tube, is bolted to the deck of the model at the centre line. Besides this tube, two strips of hard pine of ½" × ⅞" cross section are also fastened to the deck, one on the port and the other on the starboard side.

Neglecting minor considerations as for instance the thickness of bulkheads etc, we may bring the model to the condition of the damaged vessel by replacing the block which represents the flooded compartment by a lead piece of the same weight, taking care that the center of gravity of the lead shall coincide as nearly as possible, with the center of gravity of the removed block. The buoyant effect of the compartment is then lost while the centre of gravity of the model remains unchanged. The stability is then determined by a system of inclining experiments. To do this a heeling apparatus* is used. This apparatus consists of a fixed horizontal screw on which a known weight can be

moved transversely. The screw is supported by an angle bar on which a scale is graduated to tenths of an inch. By means of a bracket, this whole apparatus is clamped to the brass tube as indicated by the sketch on plate 2. The screw is cut with twenty threads to the inch, and the circumference of the weight is divided into five equal parts, thus giving directly readings to hundreds of an inch. The angle of heel was measured by a pendulum. The scale for the pendulum was graduated to tenths of an inch, and was fixed perpendicular to the upright support, ten inches below the axis of the pendulum, so that the readings give ten times the tangent of the angle of inclination.

The method of determining the righting arms by the above mentioned apparatus is as follows:—

Let W represent the heeling weight in pounds, X, the distance in inches the weight moved over from the upright position, θ, the angle of inclination in degrees, d, the displacement of the model in pounds. Then will $W \times \cos\theta$ = inclining moment and $\frac{W \times \cos\theta}{d}$ = righting arm.

The displacement of the model corresponding to 12905 tons of that of the actual vessel is:—

$$d = \frac{12905 \times 2240}{48^3} = 261.6 \text{ lbs.}$$

The wright of the model including the heeling apparatus is 151.6 lbs, consquently 110 lbs of lead ballast was used. The centre of gravity of the model was brought into coincidence with that of the actual

ship by placing the lead ballast under the protective deck. The location for the lead ballast was determined by the following process:- An inclining experiment was made for the model without ballast and the centre of gravity determined. By taking moments about the base of the model we get:-

$D_L \times CG_L + B \times CG_B = D \times CG$ where

D_L = displacement of model without ballast = 151.6 lbs

D = " " " with " = 261.6 "

B = weight of ballast = 110.0 "

CG = centre of gravity of actual ship = 24.73 feet above base = 6.17 in. above base for model.

CG_L = centre of gravity of model without ballast = 7.3" above base.

CG_B = centre of gravity of lead ballast

By substituting the values in the above equation we get:-

CG_B (centre of gravity of ballast)

$= \frac{261.6 \times 6.17 - 151.6 \times 7.3}{110} = 4.6$" above base

The centres of gravity of the different blocks which represent the actual compartments were all determined by balancing over a steel edge. The stability is calculated under different damaged conditions which will be described later in detail. The observations and results are recorded in tables arranged as follows:

Colum I gives x, the distance the heeling weight moved over from the upright position.

" II gives the readings of the pendulum which are ten times the tangent of the angle of inclination.

" III gives the corresponding angles in degrees.

" IV is the cosine of the angle of inclination.

" V is the inclining arm = x cos θ, where x = distance the heeling weight moved over from the upright position in inches.

Column VI gives the inclining moment
$= W \times \cos\theta$

" VII gives the reading of the spring balance in ounces

" VIII gives the reading of the spring balance in pounds

" IX gives the arm of the upward moment $= 12.2 \cos\theta$

" X gives the upward moment

" XI " " " difference of "

" XII " " " righting arm in inches for the model. This when ~~then~~ multiplied by 48, will give the righting arm in inches for the actual vessel. (Scale of model = $\frac{1}{48}$ of vessel).

Column XIII gives the sine of the angle of inclination

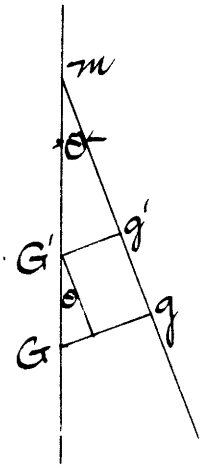
" XIV gives $G_1 G \sin\theta = 0.42 \sin\theta$

" XV " corrected righting arm in inches for the model. This when multiplied by 48 gives the righting arm of actual vessel in inches.

Correction for Change of Centre of Gravity.

The result of the inclining experiment shows that the centre of gravity of the intact model with ballast and heeling apparatus is 0·42 inches lower than that corresponds to the actual vessel at full load condition.

Consequently the righting arms must be reduced in order to get the correct righting arms. The method for reducing the righting arms is given in pages 87-88, Professor Peabody's Naval Architecture, and is quoted here as follows:—



Let G = centre of gravity of loaded model, G' = centre of gravity corresponds to that of the actual vessel at full load condition, Gg = righting arm obtained from inclining experiments and g'G' = actual righting arm. It is evident

that the righting arm should be reduced by the amount

$$Gg - G'g' = GG' \sin\theta.$$

Condition I.

Condition I
Vessel Intact.

The intact model was put into the tank and the above-mentioned observations recorded. The results are shown by the following curve which is plotted with angles for abscissae and righting arms for ordinates. Beyond the maximum the curve may be determined by moving the weight back and heeling the model over until it reaches a position of equilibrum, but this is a position of unstable equilibrum and can not be determined with any degree of accuracy. To overcome this difficulty, a small spring balance of eight ounces capacity was attached to the extreme end of the heeling apparatus to keep

the model from capsizing while the heeling weight was moved over further. The pull on the balance multiplied by the constant distance of the arm (12.2 inches) times the cosine of the angle gives the uplifting moment. The uplifting moment is to be subtracted from the inclining moment due to the heeling weight; the resultant moment divided by the displacement of the model gives the righting arm at that angle. The arrangement for the above-mentioned process is clearly indicated by the sketch on plate 2. The pull on the balance affects the displacement, but the maximum capacity of the balance is only eight ounces while the displacement

of the model is 261.6 pounds, so that the maximum error due to the spring balance is less than 0.2 of one per cent which can be neglected.

The curve is similar to other stability curves determined by graphical methods and needs no further comment.

Intact.

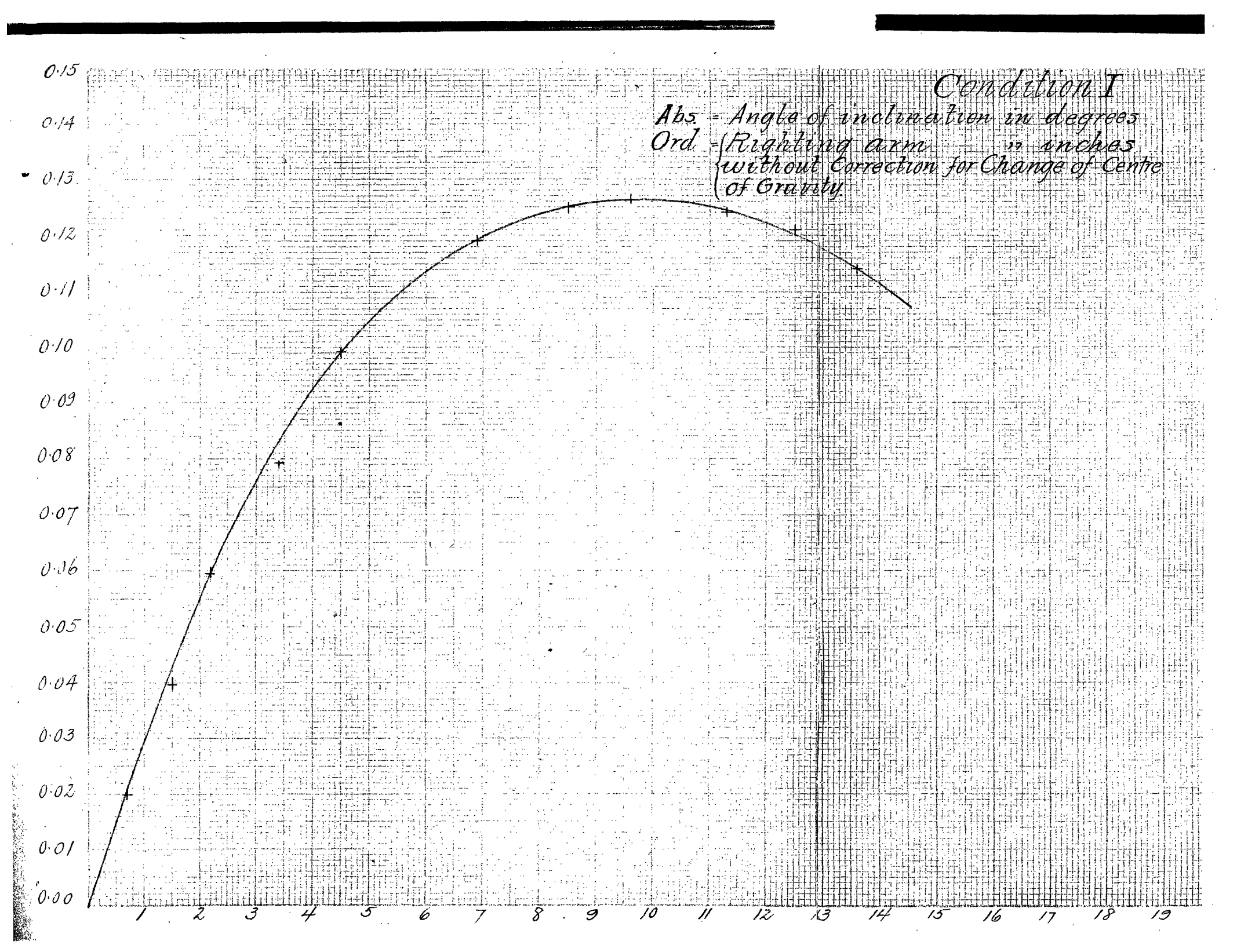
I	II	III	IV	V	VI
0·5	0·12	0·7	·9999	0.499	5.198
1·0	0·26	1·5	·9997	0·999	10·39
1·5	0·38	2·2	·9993	1·498	15·57
2·0	0·60	3·4	·9982	1·995	20·75
2·5	0·78	4·5	·9969	2·496	25·95
3·0	1·20	6·9	·9928	2·989	31·10
3·17	1·49	8·5	·9890	3·136	32·64
3·22	1·69	9·6	·9860	3·175	33·02
3·32	2·00	11·3	·9806	3·259	33·90
3·40	2·20	12·5	·9763	3·319	34·50
3·45	2·42	13·6	·9720	3·350	34·84

Intact

VII	VIII	IX	X	XI	XII
				5.198	.01985
				10.39	.0397
				15.57	.0595
				20.75	.0793
				25.95	.0992
				31.10	.1190
				32.64	.1250
				33.02	.1263
2.0	0.125	11.97	1.50	32.40	.1240
3.9	0.244	11.91	2.90	31.61	.1210
6.8	0.425	11.86	5.04	29.80	.1141

Intact

XIII	XIV	XV			
.0122	.0051	.0148			
.0262	.0110	.0287			
.0384	.0161	.0434			
.0593	.0249	.0544			
.0785	.0330	.0662			
.0120	.0504	.0686			
.1478	.0620	.0630			
.1668	.0700	.0563			
.1959	.0824	.0416			
.2164	.0910	.0300			
.2351	.0986	.0155			


Condition I
Abs. = Angle of inclination in degrees
Ord. = Righting arm " inches
without Correction for Change of Centre of Gravity
0·15
0·14
0·13
0·12
0·11
0·10
0·09
0·08
0·07
0·06
0·05
0·04
0·03
0·02
0·01
0·00
1
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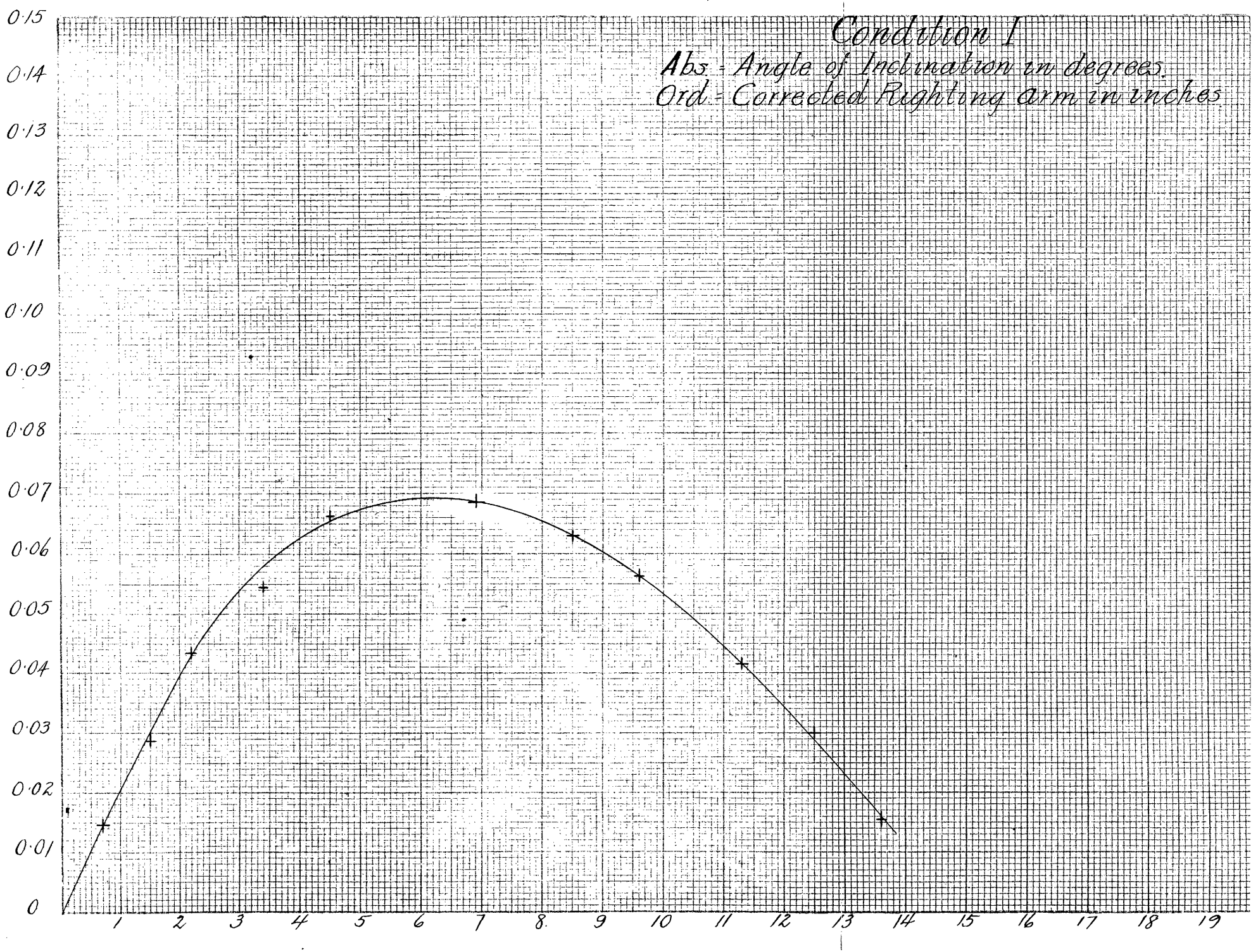
14
15
16
17
18
19


Condition I
Abs = Angle of Inclination in degrees.
Ord = Corrected Righting arm in inches
0·15
0·14
0·13
0·12
0·11
0·10
0·09
0·08
0·07
0·06
0·05
0·04
0·03
0·02
0·01
0
1
2
3
4
5
6
7
8
9
10
11
12
13
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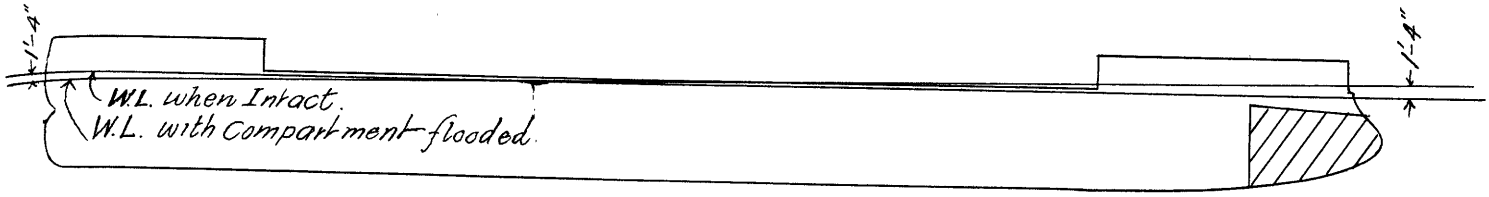
Condition II

Condition II.



The forward trimming tank, occupying the space between frames number 6 and the stem. This block was removed and replaced by a lead piece of the same weight as before mentioned. Under this condition, as nearly as could be rated, the model floated at a water line 1'-4" above the load line forward, and 1'-4" below the load line aft. The curve for this case shows less stability than the curve for condition I.

Condition II

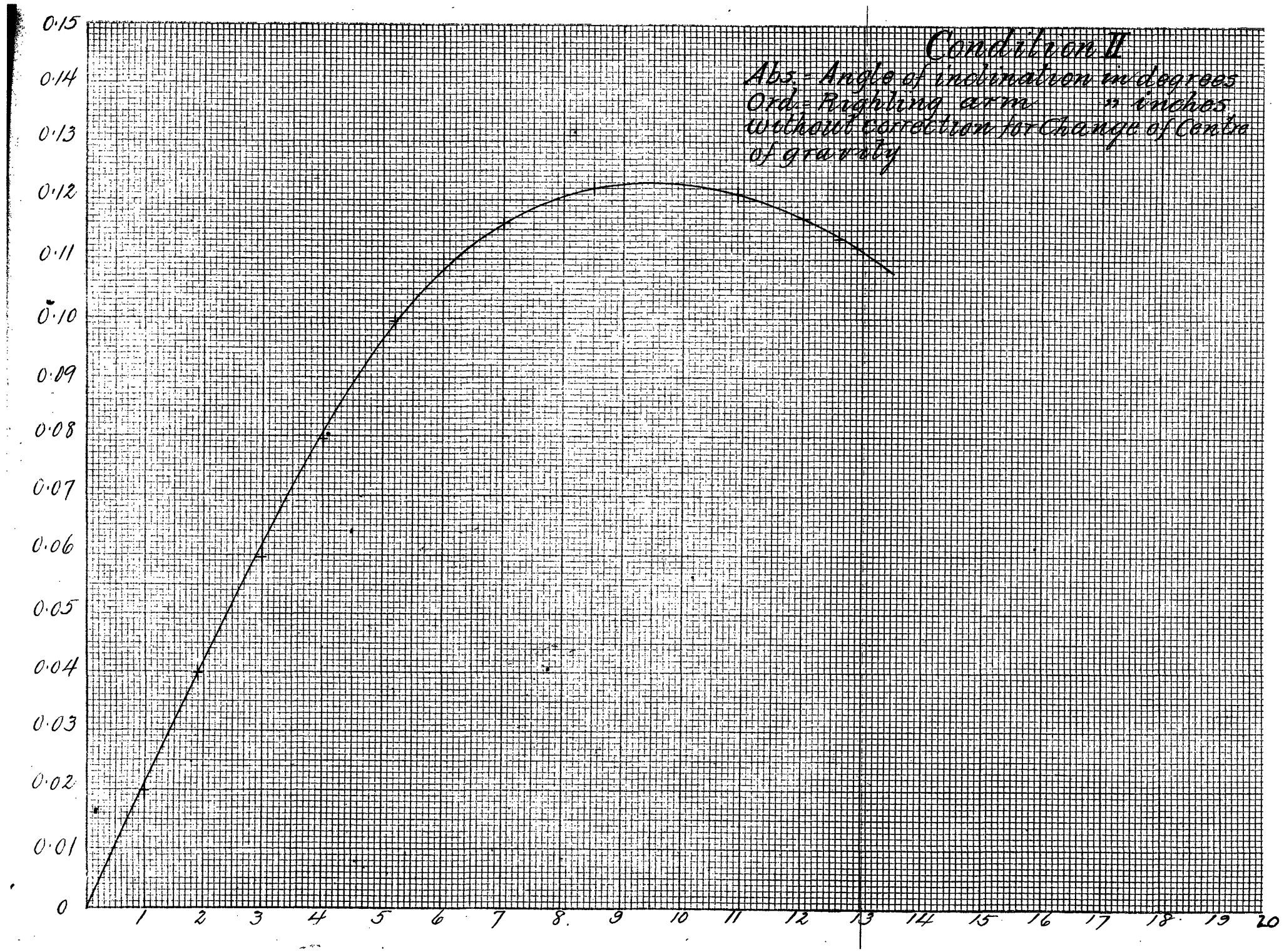
I	II	III	IV	V	VI
0.50	0.18	1.0	0.9998	0.499	5.19
1.00	0.33	1.9	0.9995	0.999	11.39
1.50	0.52	3.0	0.9986	1.4980	15.60
2.00	0.69	4.0	0.9976	1.9950	20.75
2.50	0.91	5.2	0.9959	2.4950	25.95
2.93	1.23	7.0	0.9925	2.910	30.30
3.10	1.49	8.5	0.9890	3.063	31.90
3.20	1.93	10.9	0.9820	3.140	32.64
3.30	2.13	12.0	0.9781	3.229	33.59
3.40	2.24	12.6	0.9759	3.319	34.50
3.43	2.29	12.9	0.9748	3.340	34.77

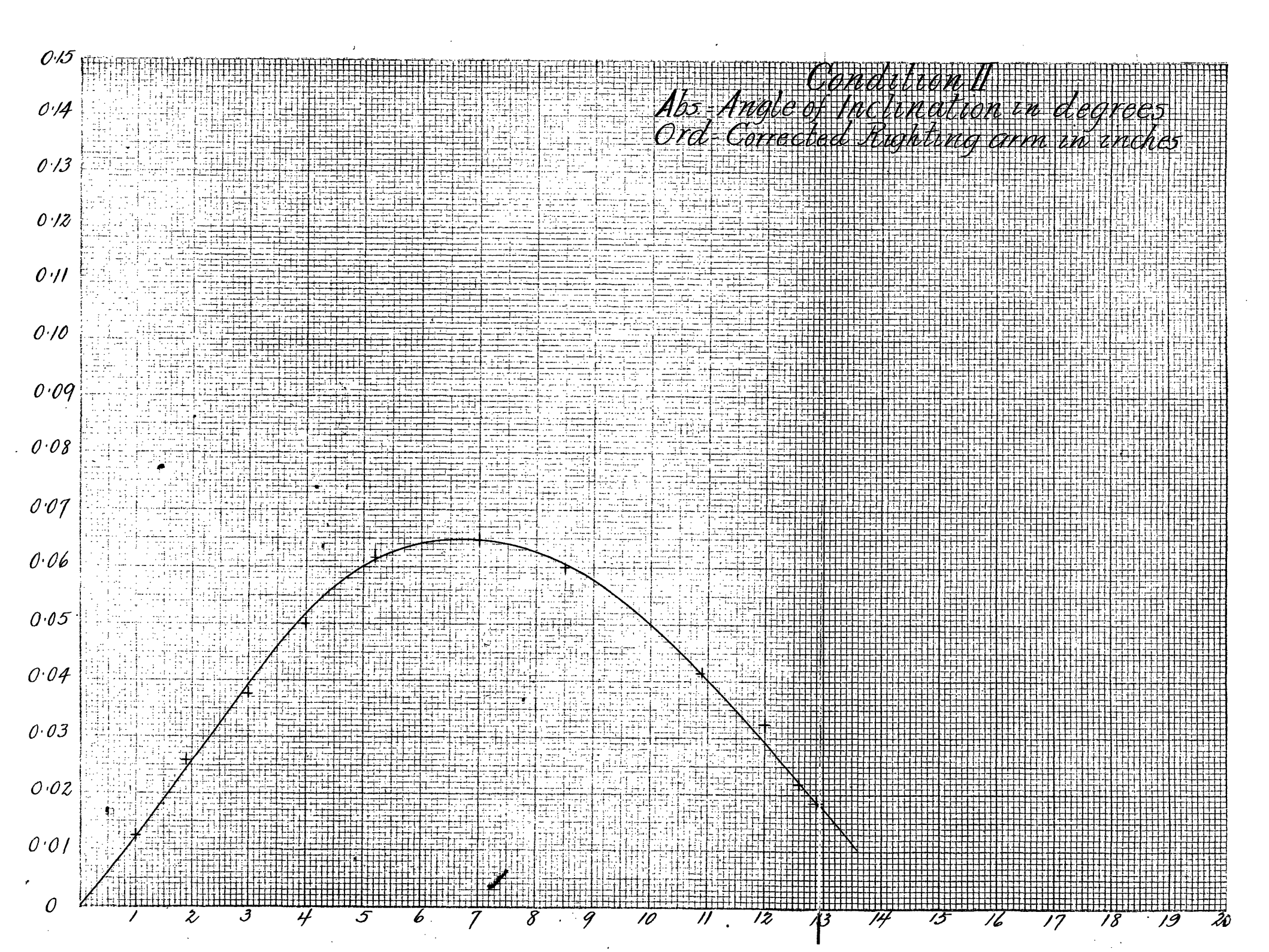
Condition II

VII	VIII	IX	X	XI	XII
				5.19	.01988
				11.39	.03980
				15.60	.05970
				20.75	.07950
				25.95	.09940
				30.30	.1160
				31.90	.1220
1.4	0.085	11.98	1.02	31.62	.1211
4.0	0.251	11.93	3.00	30.59	.1170
6.6	0.410	11.90	4.87	29.63	.1135
7.5	0.458	11.88	5.56	29.21	.1120

Condition II

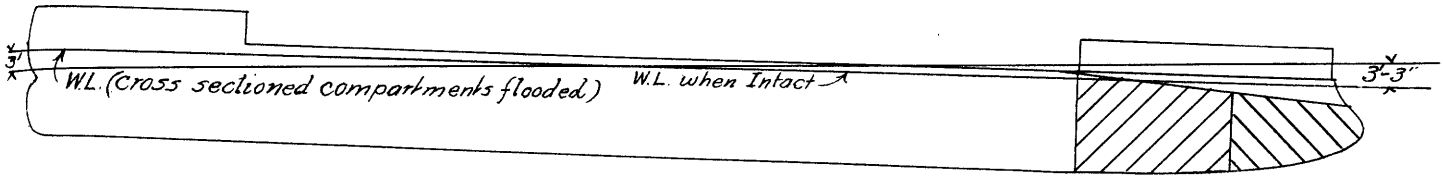
XIII	XIV	XV			
·0175	·0074	·0125			
·0332	·0139	·0259			
·0523	·0220	·0377			
·0698	·0293	·0502			
·0906	·0380	·0618			
·1219	·0512	·0648			
·1478	·0620	·0600			
·1891	·0795	·0416			
·2079	·0844	·0326			
·2181	·0916	·0219			
·2232	·0936	·0184			


Condition II
Abs. = Angle of inclination in degrees
Ord. = Righting arm " inches
Without correction for Change of Centre of gravity
0·15
0·14
0·13
0·12
0·11
0·10
0·09
0·08
0·07
0·06
0·05
0·04
0·03
0·02
0·01
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20


Condition II
Abs - Angle of Inclination in degrees
Ord - Corrected Righting arm in inches
0·15
0·14
0·13
0·12
0·11
0·10
0·09
0·08
0·07
0·06
0·05
0·04
0·03
0·02
0·01
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Condition III

Condition III



The forward trimming tank and the construction stores occupying the space between the stem and frame number 12. These blocks were removed and replaced by a lead weight as before mentioned. Under this condition the model trimmed three feet and three inches by the bow. Inclining experiments were carried through as described for the model intact, and the curve plotted as before.

Condition III

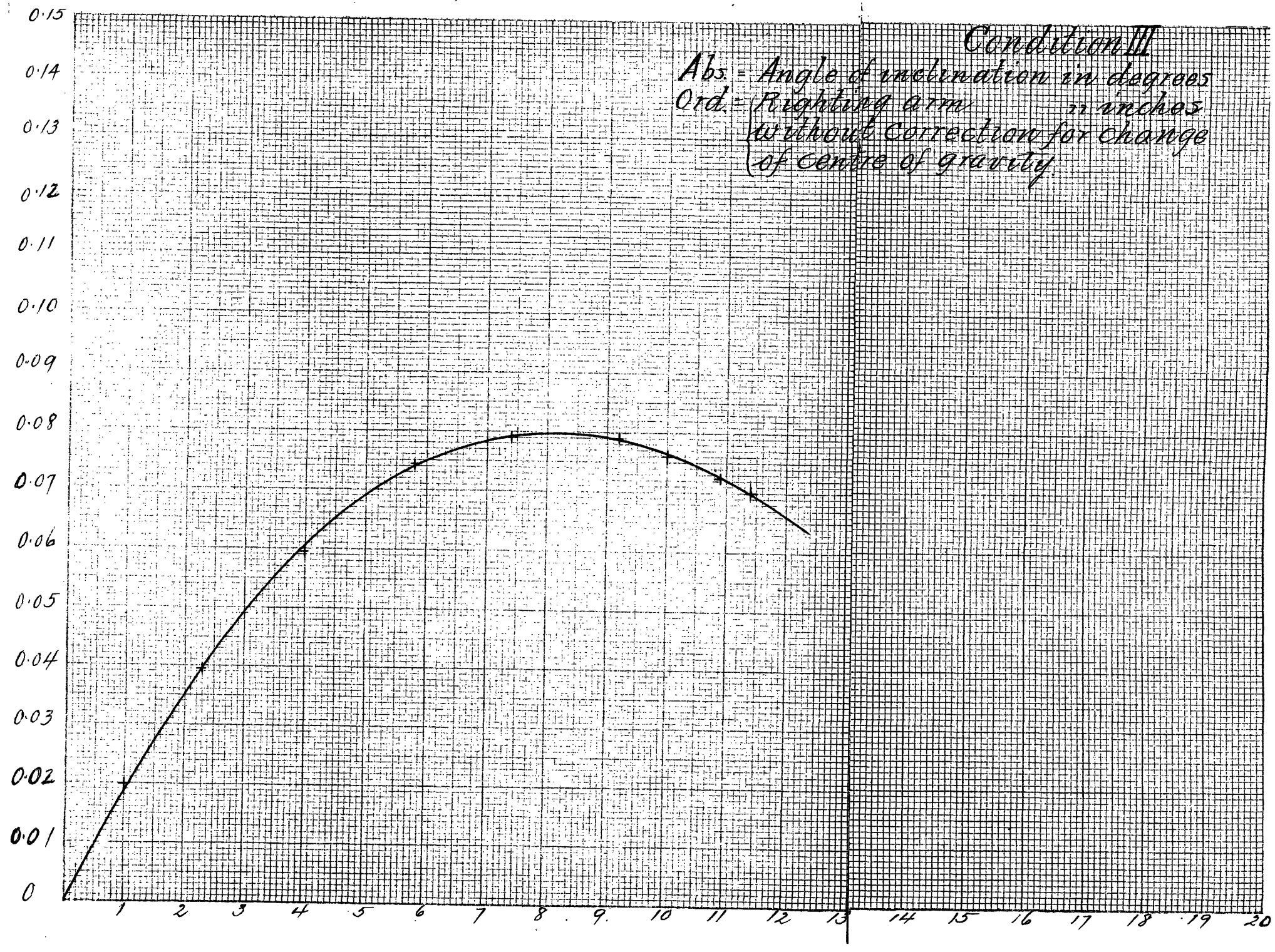
I	II	III	IV	V	VI
0·50	0·17	1·0	·9998	0·4999	5·19
1·00	0·39	2·3	·9992	0·999	14·90
1·50	0·69	4·0	·9976	1·496	15·57
1·88	1·02	5·8	·9949	1·864	19·39
2·00	1·30	7·4	·9917	1·982	20·60
2·10	1·60	9·2	·9871	2·074	21·55
2·20	1·76	10·0	·9848	2·163	22·50
2·30	1·93	10·9	·9820	2·259	23·47
2·35	2·02	11·4	·9803	2·315	23·97

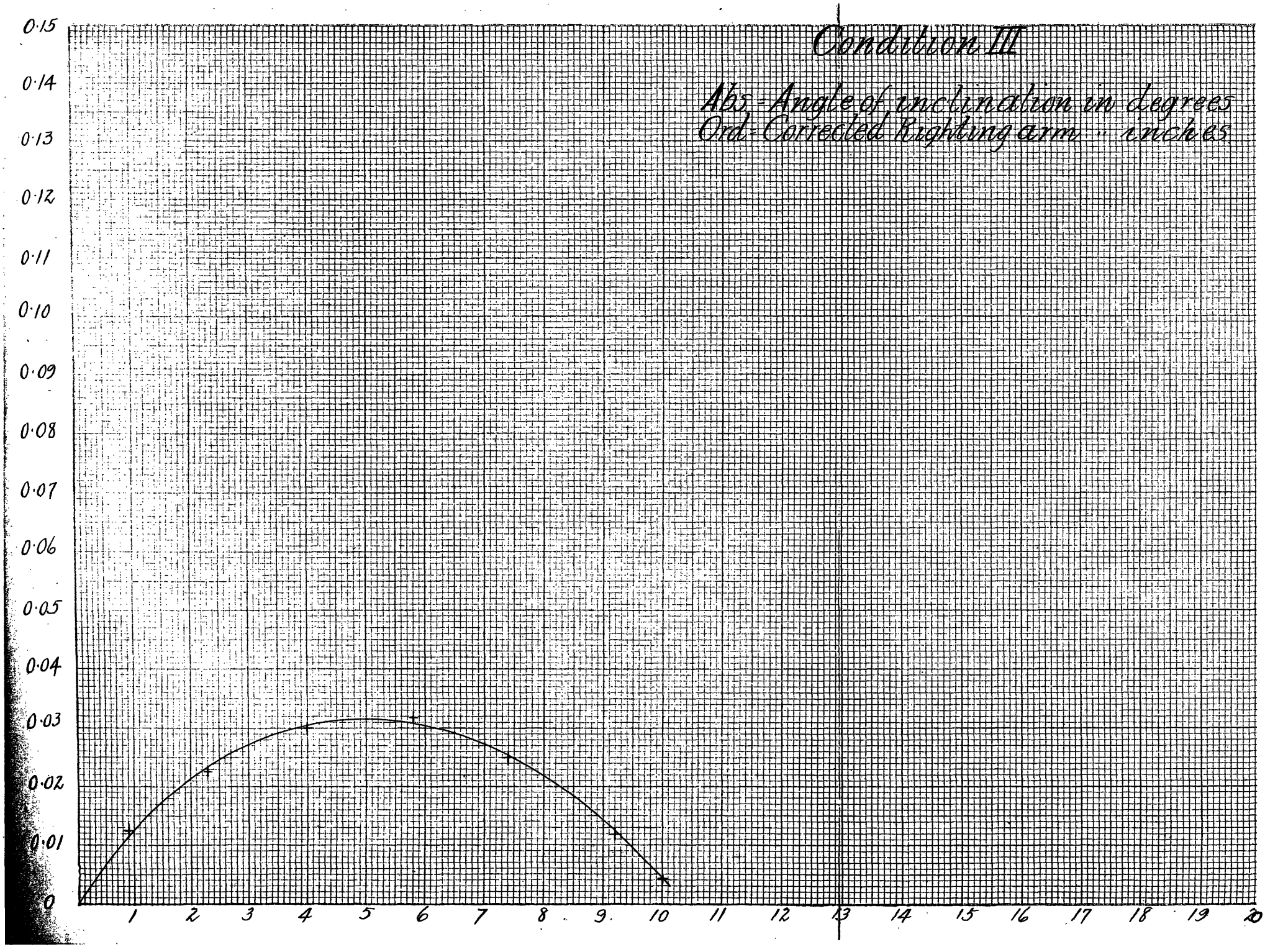
Condition III

VII	VIII	IX	X	XI	XII
				5.19	.01489
				14.90	.0595
				15.57	.0596
				19.39	.0743
				20.60	.0790
1.3	.079	12.02	0.95	20.60	.0790
3.75	.235	11.99	2.77	19.83	.0760
7.4	.464	11.97	5.55	18.92	.0725
7.8	.476	11.95	5.68	18.29	.0700

Condition III

XIII	XIV	XV			
·0175	·0074	·0125			
·0401	·0168	·0227			
·0698	·0294	·0302			
·1011	·0424	·0319			
·1288	·0540	·0250			
·1599	·0671	·0119			
·1736	·0728	·0042			
·1891	·0795	-0·002			
·1977	·0830	-0·013			


Condition III
Abs. = Angle of inclination in degrees
Ord. = Righting arm " inches
without correction for change
of centre of gravity.
0·15
0·14
0·13
0·12
0·11
0·10
0·09
0·08
0·07
0·06
0·05
0·04
0·03
0·02
0·01
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20


Condition III
Abs = Angle of inclination in degrees
Ord = Corrected Righting arm .. inches
0·15
0·14
0·13
0·12
0·11
0·10
0·09
0·08
0·07
0·06
0·05
0·04
0·03
0·02
0·01
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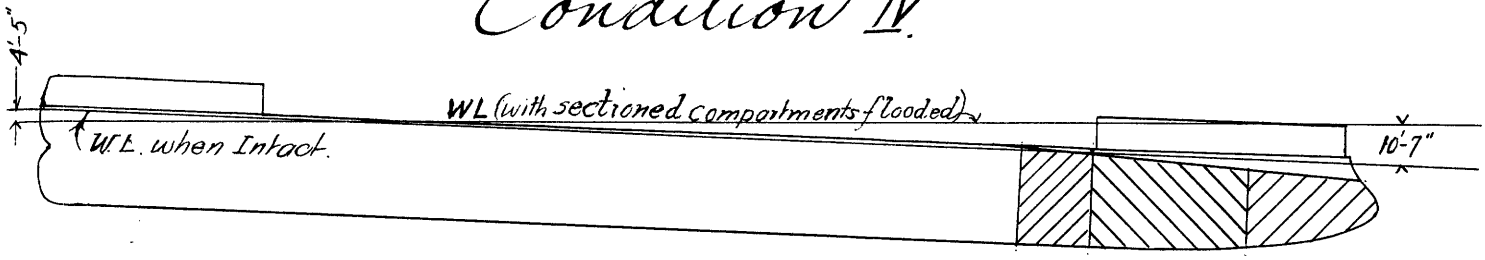
Condition IV

Condition IV.



The trimming tank, construction stores, chain locker and hold. These blocks were removed and replaced by a lead weight as described before. Under this condition the model floated at a water line 10 feet 7 inches above the load line forward, and 4 feet 5 inches below the load line aft. The model is practically submerged and the curve for this case shows marked decrease of stability. When the change of centre of gravity is corrected the righting arms are all negative.

Condition IV

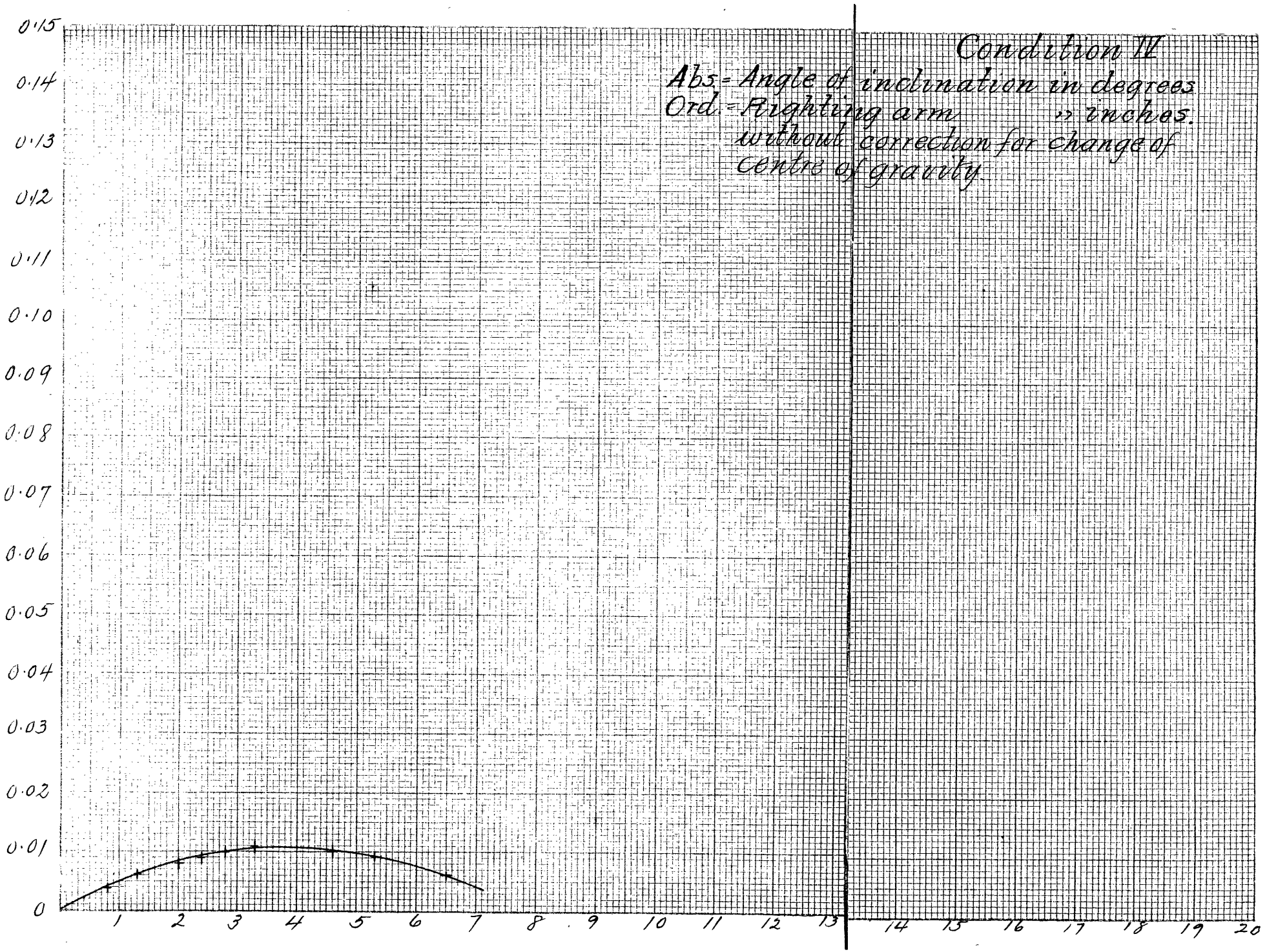
I	II	III	IV	V	VI
0·10	0·14	0·8	·9999	·0999	1·039
0·15	0·23	1·3	·9997	·1499	1·599
0·20	0·35	2·0	·9994	·1998	2·074
0·225	0·42	2·4	·9991	·2230	2·319
0·25	0·49	2·8	·9988	·2495	2·598
0·275	0·58	3·3	·9983	·2742	2·858
0·30	0·81	4·6	·9968	·2990	3·110
0·40	0·93	5·3	·9957	·3980	4·141
0·50	1·14	6·5	·9936	·4970	5·170

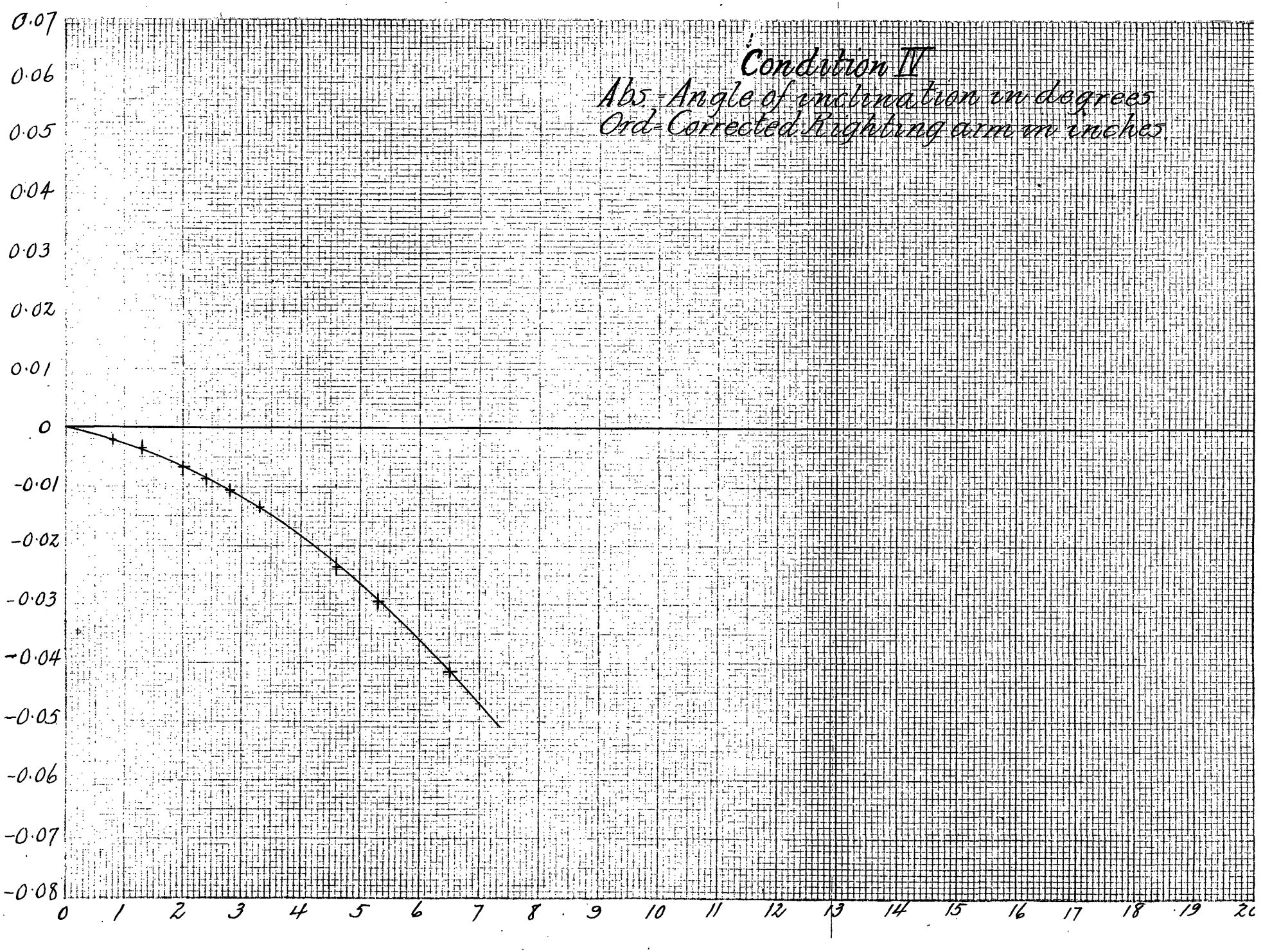
Condition IV

VII	VIII	IX	X	XI	XII
				1.039	.00380
				1.599	.00612
				2.074	.00794
				2.319	.00887
				2.598	.00994
				2.858	.01092
0.65	0.041	12.17	0.494	2.616	.01000
2.3	0.142	12.15	1.724	2.417	.00925
5.0	0.312	12.13	3.578	1.592	.00616

Condition IV

XIII	XIV	XV			
·0140	·0059	-0·0021			
·0227	·0095	-0·0034			
·0343	·0146	-0·0067			
·0419	·0176	-0·0087			
·0488	·0205	-0·0106			
·0576	·0242	-0·0133			
·0802	·0337	-0·0237			
·0924	·0388	-0·0245			
·1132	·0476	-0·0414			


Condition IV
Abs = Angle of inclination in degrees
Ord. = Righting arm " inches.
without correction for change of
centre of gravity
0·15
0·14
0·13
0·12
0·11
0·10
0·09
0·08
0·07
0·06
0·05
0·04
0·03
0·02
0·01
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20


Condition IV
Abs.-Angle of inclination in degrees
Ord-Corrected Righting arm in inches.
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Condition V + VI

Condition V

The engine room on the starboard side of the vessel occupying the space between frames number 51 and number 64.

Under this condition the model was unable to float.

Condition VI

The forward trimming tank, the construction stores, chain locker and hold, and the crews space occupying the space between the stem and fram 17.

Under this condition the model grounded by the bow, and was unstable even in the upright position.

Summation of Results.

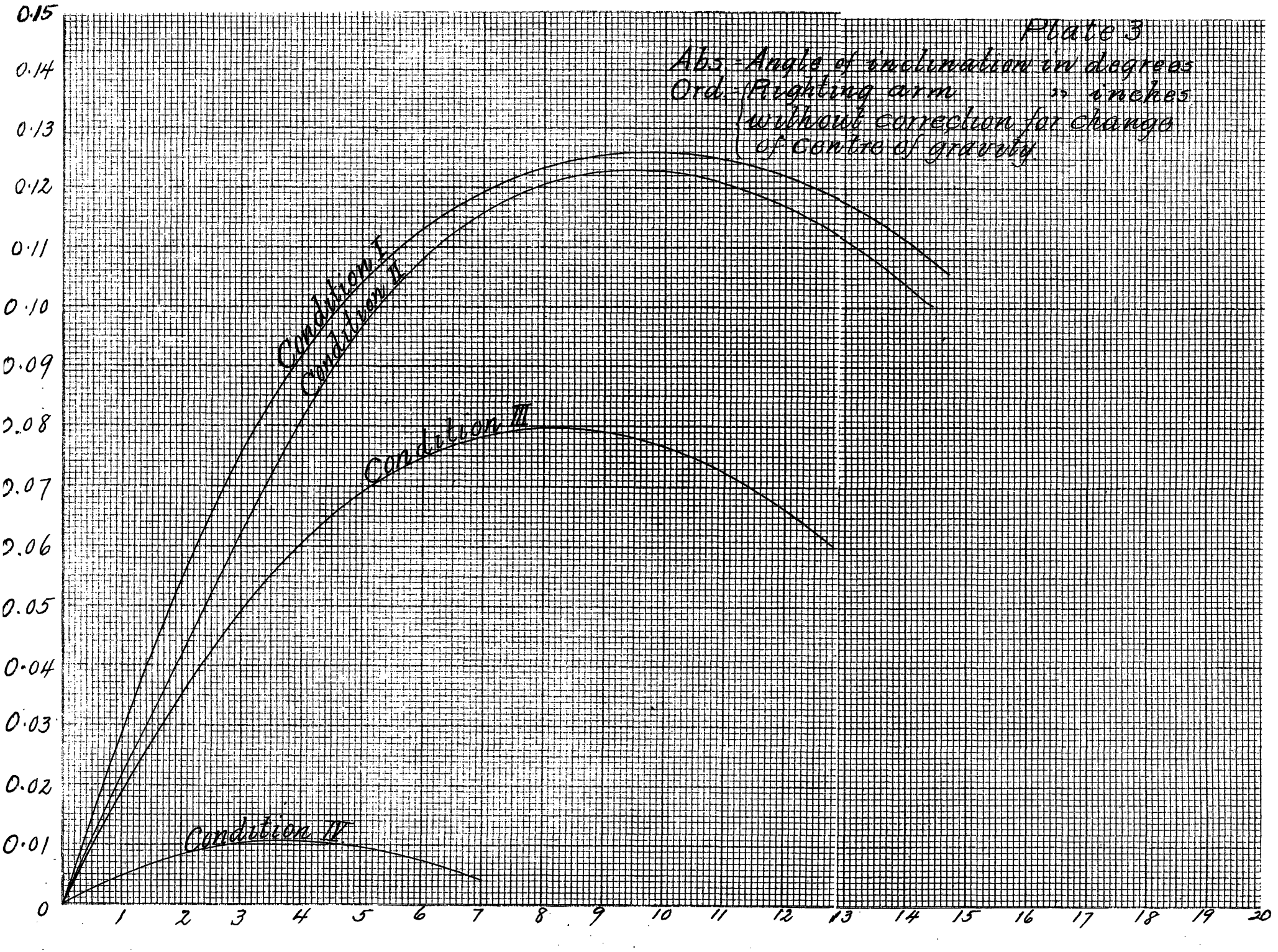


Plate 3
Abs.=Angle of inclination in degrees
Ord.=Righting arm " inches
(without correction for change of Centre of gravity
Condition I
Condition II
Condition III
Condition IV
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1
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17
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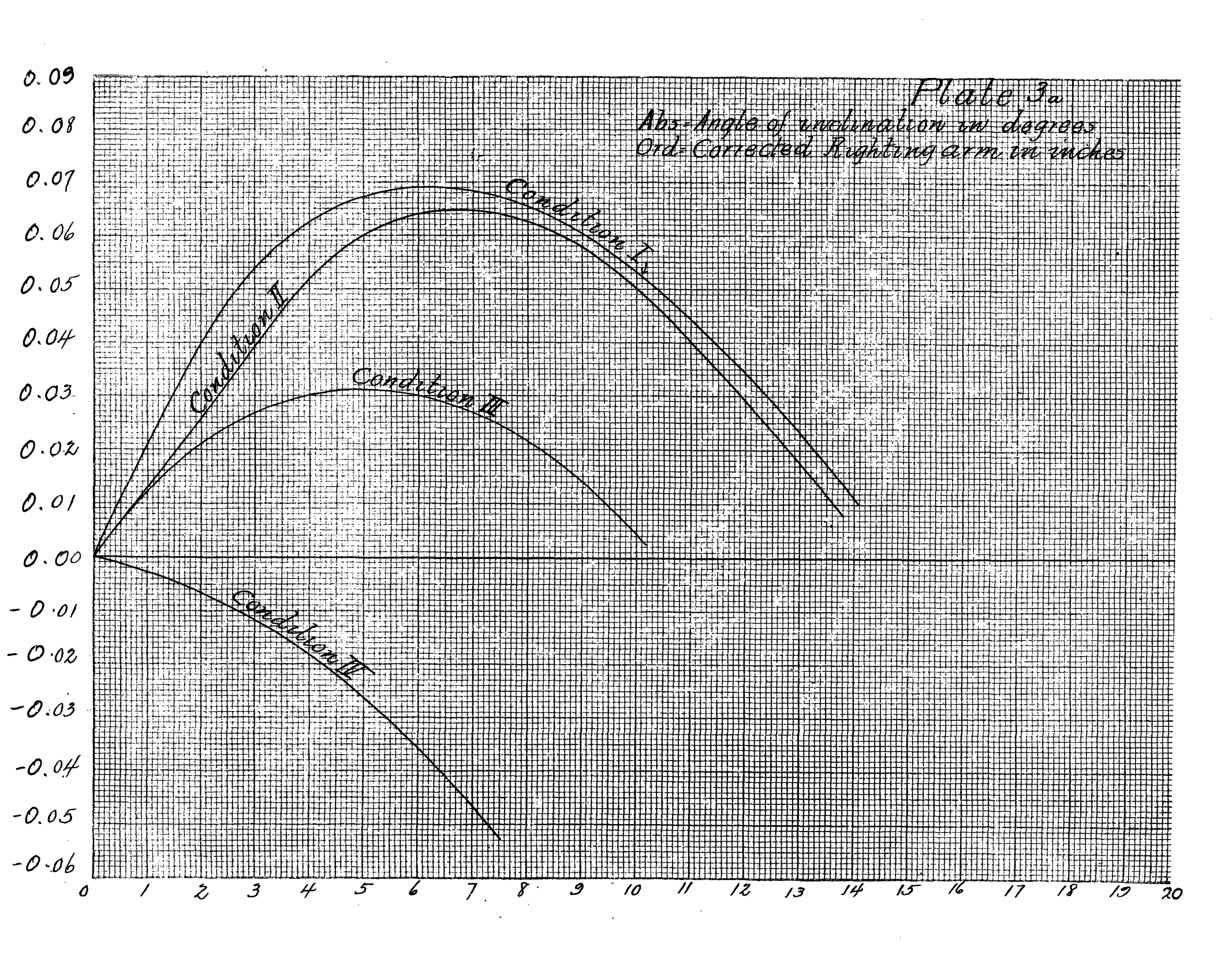
Plate 3a
Abs = Angle of inclination in degrees
Ord = Corrected Righting arm in inches
Condition I
Condition I a
Condition III
Condition III
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Plate 3 and 3a show all the preceding curves for the sake of comparison.

The results of the present investigation show that we have to rely upon the compartments above the protective deck to furnish stability, because the curves show that the stability decreases as the size of the under deck damaged compartment increases.

PLATE I

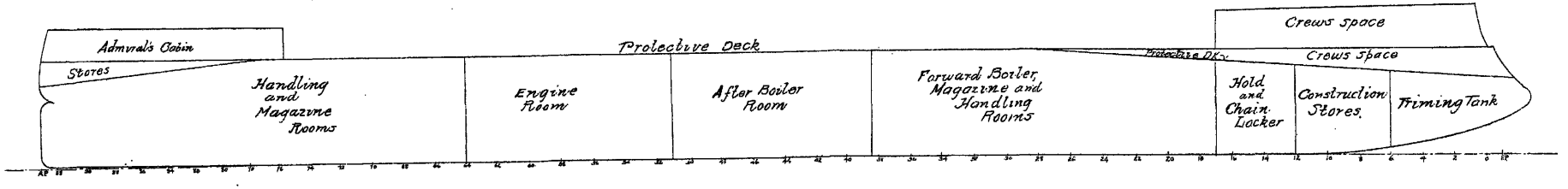
Admiral's Cabin
Stores
Handling and Magazine Rooms
Protective Deck
Engine Room
After Boiler Room
Forward Boiler, Magazine and Handling Rooms
Protective Dk.
Crews Space
Crews Space
Hold and Chain Locker
Construction Stores.
Priming Tank

Plate 2.