TECHNISCHE HOGESCHOOL DELFT
AFDELING DER MARITIEME TECHNIEK
LABORATORIUM VOOR SCHEEPSHYDROMECHANICA

EXPERIMENTAL DETERMINATION OF THE PERFORMANCE OF FOUR KEEL-HULL COMBINATIONS

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Contents:

1. Introduction.

Experiments with a 3.20 m model of a 63' cruising sloop has been carried out to dertermine the performance for four different keels.
This investigation has been initiated by the Delft Ship Hydrodynamic Laboratory, the Netherlands Yacht Panel and has been supported by Huisman Ship Yards b.v. Vollenhove.

In view of the interest in shallow draft keel-hull performance the following variations have been considered:

1. keel-centreboard
2. shallow draught keel
3. „Scheel" keel
4. „I.O.R" keel

The shallow-draught keel is the same as the fixed keel part of the keel-centreboard combination.
The „Scheel keel" has been designed by H.A.Scheel (US 4089286, 1978). This keel has protuberances at its tip to reduce induced resistance in combination with a relatively low centre of gravity of the keel.
The „I.O.R" keel is included in the series for comparison purposes. The span of this keel is comparable with that of an I.O.R racer of similar size.
The hull lines have been designed by J.de Ridder.

2. Main particulars of the model.

A linear model scale of 1:6 has been used for the experiments, resulting in a 3.2 meter model length. In Table 1 the full scale main dimensions of the considered hull form are summarized.

Table 1

LOA	length over all	19.25 m
LWL	length waterline	15.20 m
BOA	beam over all	5.05 m
Tc	draught canoe body	0.82 m
BWL	beam waterline	4.28 m
∇_c	volume of displacement canoe body	21.50 m^3
Ω_c	wetted surface canoe body	49.36 m^2
C_p	prismatie coefficient	0.55
LCB	longitudinal position of centre of buoyancy	-4.2%

The four keel-hull combinations are given in Figure 1. In this Figure the main dimensions of the keels, including keel-volume and projected area are depicted.

- All keel-hull combinations have been tested at the same volume of displacement of the canoe body and thus at the same waterline, corresponding to a canoe body draught of o.82 m. This resulted in different total displacements due to differences in the keel volumes. The four total displacements are as follows: with I.O.R keel: 22.6 m^3, keel-centreboard: 24.2 m^3, shallow-draught keel: 24.1 m^3, Scheel-keel: 22.9 m^3.
  These differences reflect the design considerations to arrive at an equal righting moments of 625 kgfm/degree, on which the analysis of the results is based.

- The model experiments include a range of four heeling angles (Φ = 0, 10^0, 20^0 and 30^0), speeds up to 15 knots full scale, corresponding leeway angles and a range of static stability.

- The test results have been used to predict the yacht speed on all headings, resulting in polar speed curves for true wind speeds ranging from 10 to 25 knots. Resistance-speed curves are given for the upright condition.
  For the performance prediction the following sail dimensions have been used:

Y = 24.00 m	P = 21.75 m
J = 7.30 m	E = 6.50 m

  In all cases it is assumed that the centre of effort of the sailforce is located at 10.08 m above the waterline.

3. Results.

In the tables 2, 3, 4, and 5 the upright resistance versus ship speed and the performance prediction for the four keel-hull combinations are given. It should be noted that optimum speeds made good (close hauled and running condition) are included in the tables.
The upright resistance curves are given in the figures 2, 3 and 4. In each of this figures the solid lines represent the

I.O.R keel, where as the black dots represent the considered hull-keel combination.

The nomenclature in these tables is as follows:

VTW - true wind speed
VTW-CE - true wind speed at centre of effort
B+BTW - true wind angle
VAW - apparent wind speed
B+BAW - apparent wind angle
VS - ship speed
VMG - speed made good
FI - heeling angle.

A short summary of this performance prediction is given in table 6.

Table 6

VTW knots	I.O.R keel	Keel centreboard	Shallow draught keel	Scheel keel
Maximum speed made good (close hauled)				
10	5.36	5.09	4.97	5.03
15	5.97	5.70	5.61	5.68
20	6.21	5.98	5.85	5.94
25	6.33	6.11	5.88	6.03
Maximum speed made good (Running)				
10	-5.95	-5.85	-5.94	-5.94
15	-7.98	-7.94	-8.02	-7.98
20	-9.20	-9.07	-9.15	-9.14
25	-10.19	-10.03	-10.01	-10.12
Yacht speed V_S, true wind angle 60 degrees				
10	8.58	8.26	8.29	8.34
15	9.03	8.72	8.71	8.84
20	9.22	8.89	8.77	8.97
25	9.29	8.98	8.73	8.98
Yacht speed V_S, true wind angle 90 degrees				
10	8.89	8.59	8.65	8.72
15	9.30	8.96	8.98	9.12
20	9.59	9.24	9.23	9.42
25	9.81	9.46	9.41	9.65

Figures 5, 6, 7 and 8 give the speed polars for the four considered keel-hull combinations for true wind speeds 3.5, 7.0, 10.0 and 13.0 m/s. The yacht speed in these speed polars is given in m/s.

4. Aknowledgment.

The model tests have been carried out by R.Onnink. A.Versluis did the computer work for the performance prediction.

Delft, 23 Oktober 1984

UPRIGHT RESISTANCE DATA

MODEL VM M/S	RTM KG	SHIP VS M/S	VS KNOTS	RES KG	RRS KG	RTS KG
1.100	0.555	2.694	5.24	71.1	3.5	74.6
1.200	0.694	2.939	5.71	83.4	13.9	97.3
1.300	0.835	3.184	6.19	96.6	23.4	120.0
1.400	0.986	3.429	6.67	110.7	33.8	144.5
1.500	1.159	3.674	7.14	125.6	47.6	173.3
1.600	1.362	3.919	7.62	141.4	66.7	208.1
1.650	1.484	4.042	7.86	149.7	80.1	229.8
1.700	1.624	4.164	8.10	158.1	97.2	255.3
1.750	1.810	4.287	8.33	166.7	123.8	290.6
1.800	2.054	4.409	8.57	175.6	162.8	338.4
1.850	2.365	4.532	8.81	184.7	215.8	400.4
1.900	2.729	4.654	9.05	194.0	280.0	474.0
1.950	3.133	4.777	9.29	203.4	352.6	556.0
2.000	3.584	4.899	9.52	213.1	434.9	648.0
2.100	4.635	5.144	10.00	233.2	630.9	864.1
2.200	5.827	5.389	10.48	254.0	856.3	1110.3
2.300	7.120	5.634	10.95	275.7	1102.2	1377.8
2.400	8.513	5.879	11.43	298.1	1368.5	1666.6
2.500	9.806	6.124	11.90	321.4	1612.0	1933.4
2.600	10.931	6.369	12.38	345.5	1817.9	2163.4
2.700	11.817	6.614	12.86	370.4	1971.1	2341.5
2.800	12.583	6.859	13.33	396.1	2097.2	2493.3
2.900	13.380	7.104	13.81	422.6	2228.8	2651.3
3.000	14.229	7.348	14.29	449.8	2370.4	2820.2

POLAR PERFORMANCE DATA

VTW KN.	VTW-CE KN.	B+BTW DEGR	VAW KN.	B+BAW DEGR	VS KN.	VMG KN.	FI DEGR
10.0	10.00	180.0	4.90	180.00	5.098	-5.098	0.0
10.0	10.00	160.0	4.71	133.39	6.165	-5.793	1.2
10.0	10.00	150.0	5.35	111.04	6.739	-5.836	2.5
10.0	10.00	140.0	6.42	92.98	7.327	-5.613	4.6
10.0	10.00	125.0	8.42	73.74	8.093	-4.642	9.4
10.0	10.00	110.0	10.32	60.36	8.524	-2.915	17.4
10.0	10.00	90.0	12.57	46.87	8.593	0.000	23.5
10.0	10.00	80.0	13.66	41.09	8.560	1.486	24.3
10.0	10.00	70.0	14.74	36.00	8.503	2.908	22.8
10.0	10.00	60.0	15.54	31.43	8.263	4.131	20.6
10.0	10.00	52.0	15.80	28.06	7.782	4.791	19.5
10.0	10.00	48.0	15.80	26.42	7.456	4.989	18.9
10.0	10.00	44.0	15.72	24.86	7.067	5.084	18.0
10.0	10.00	42.0	15.64	24.02	6.854	5.093	18.0
10.0	10.00	40.0	15.55	23.26	6.623	5.073	17.2
10.0	10.00	38.0	15.42	22.44	6.374	5.022	17.0
10.0	10.00	36.0	15.27	21.66	6.105	4.939	16.5
10.0	10.00	42.3	15.65	24.15	6.889	5.094	18.0
10.0	10.00	153.1	5.10	117.64	6.556	-5.849	2.0
15.0	15.00	180.0	7.82	180.00	7.180	-7.180	0.0
15.0	15.00	160.0	7.64	137.89	8.425	-7.917	2.7
15.0	15.00	150.0	8.58	119.52	8.764	-7.590	5.5
15.0	15.00	140.0	9.83	104.64	9.007	-6.900	9.6
15.0	15.00	125.0	11.75	87.20	9.178	-5.264	17.2
15.0	15.00	110.0	13.35	72.69	9.103	-3.113	25.3
15.0	15.00	90.0	16.25	56.52	8.962	0.000	25.4
15.0	15.00	80.0	17.57	49.09	8.901	1.546	26.0
15.0	15.00	70.0	18.77	42.02	8.815	3.015	26.9
15.0	15.00	60.0	20.02	35.88	8.717	4.358	25.4
15.0	15.00	52.0	20.78	31.53	8.480	5.221	23.2
15.0	15.00	48.0	20.99	29.48	8.238	5.512	22.1
15.0	15.00	44.0	21.03	27.41	7.880	5.668	21.7
15.0	15.00	42.0	21.00	26.38	7.663	5.695	21.6
15.0	15.00	40.0	20.93	25.36	7.425	5.688	21.6
15.0	15.00	38.0	20.84	24.37	7.161	5.643	21.4
15.0	15.00	36.0	20.71	23.34	6.877	5.563	21.5
15.0	15.00	41.4	20.98	26.07	7.595	5.697	21.6
15.0	15.00	162.8	7.48	143.56	8.308	-7.935	2.1

Table 2: Keel-centreboard.

POLAR PERFORMANCE DATA

VTW KN.	VTW-CE KN.	B+BTW DEGR	VAW KN.	B+BAW DEGR	VS KN.	VMG KN.	FI DEGR
20.0	20.00	180.0	11.31	180.00	8.690	-8.690	0.0
20.0	20.00	160.0	11.47	143.54	9.571	-8.994	4.9
20.0	20.00	150.0	12.36	127.14	9.858	-8.537	9.9
20.0	20.00	140.0	13.44	113.31	10.002	-7.662	16.2
20.0	20.00	125.0	14.77	96.16	9.887	-5.671	26.3
20.0	20.00	110.0	16.89	80.74	9.558	-3.269	27.5
20.0	20.00	90.0	20.06	62.58	9.238	0.000	27.1
20.0	20.00	80.0	21.49	54.09	9.130	1.585	27.9
20.0	20.00	70.0	22.95	46.31	9.012	3.082	28.0
20.0	20.00	60.0	24.26	38.87	8.887	4.444	28.5
20.0	20.00	52.0	25.33	33.85	8.726	5.372	26.4
20.0	20.00	48.0	25.76	31.62	8.553	5.723	24.7
20.0	20.00	44.0	26.00	29.42	8.257	5.940	23.2
20.0	20.00	42.0	26.01	28.26	8.049	5.982	23.0
20.0	20.00	40.0	25.97	27.11	7.794	5.971	23.0
20.0	20.00	38.0	25.88	25.98	7.509	5.917	22.9
20.0	20.00	36.0	25.75	24.86	7.183	5.811	22.9
20.0	20.00	41.4	26.00	27.94	7.982	5.984	23.0
20.0	20.00	166.1	11.16	154.59	9.339	-9.067	2.7

POLAR PERFORMANCE DATA

VTW KN.	VTW-CE KN.	B+BTW DEGR	VAW KN.	B+BAW DEGR	VS KN.	VMG KN.	FI DEGR
25.0	25.00	180.0	15.40	180.00	9.603	-9.603	0.0
25.0	25.00	160.0	15.43	146.72	10.590	-9.951	7.9
25.0	25.00	150.0	16.18	131.85	10.854	-9.400	15.3
25.0	25.00	140.0	16.89	119.44	10.849	-8.311	23.7
25.0	25.00	125.0	17.96	102.66	10.405	-5.968	31.2
25.0	25.00	110.0	20.51	86.14	9.933	-3.397	29.4
25.0	25.00	90.0	23.80	66.58	9.460	0.000	29.1
25.0	25.00	80.0	25.38	57.50	9.294	1.614	29.6
25.0	25.00	70.0	26.98	49.02	9.144	3.127	29.9
25.0	25.00	60.0	28.44	40.96	8.976	4.488	30.6
25.0	25.00	52.0	29.67	35.27	8.827	5.435	29.6
25.0	25.00	48.0	30.30	33.02	8.679	5.808	27.3
25.0	25.00	44.0	30.72	30.74	8.419	6.056	25.3
25.0	25.00	42.0	30.81	29.57	8.216	6.105	24.7
25.0	25.00	40.0	30.79	28.33	7.950	6.090	24.6
25.0	25.00	38.0	30.70	27.12	7.628	6.011	24.6
25.0	25.00	36.0	30.54	25.87	7.256	5.871	24.9
25.0	25.00	41.5	30.81	29.25	8.152	6.108	24.6
25.0	25.00	165.9	15.17	156.44	10.347	-10.036	4.6

Table 2 continued.

UPRIGHT RESISTANCE DATA

MODEL VM M/S	RTM KG	SHIP VS M/S	VS KNOTS	RFS KG	RRS KG	RTS KG
1.100	0.546	2.694	5.24	66.4	10.5	76.9
1.200	0.654	2.939	5.71	77.9	15.8	93.7
1.300	0.779	3.184	6.19	90.2	23.5	113.7
1.400	0.915	3.429	6.67	103.4	32.4	135.7
1.500	1.062	3.674	7.14	117.3	42.3	159.6
1.600	1.242	3.919	7.62	132.1	58.1	190.2
1.650	1.361	4.042	7.86	139.8	72.0	211.8
1.700	1.506	4.164	8.10	147.7	91.0	238.7
1.750	1.678	4.287	8.33	155.8	115.7	271.5
1.800	1.892	4.409	8.57	164.1	149.1	313.2
1.850	2.173	4.532	8.81	172.6	196.8	369.4
1.900	2.516	4.654	9.05	181.3	257.5	438.7
1.950	2.901	4.777	9.29	190.1	327.0	517.2
2.000	3.344	4.899	9.52	199.2	408.7	607.9
2.100	4.357	5.144	10.00	218.0	598.9	816.8
2.200	5.556	5.389	10.48	237.5	828.1	1065.6
2.300	6.946	5.634	10.95	257.7	1097.3	1355.1
2.400	8.392	5.879	11.43	278.8	1377.8	1656.6
2.500	9.525	6.124	11.90	300.6	1589.3	1889.9
2.600	10.519	6.369	12.38	323.1	1769.6	2092.7
2.700	11.445	6.614	12.86	346.4	1934.4	2280.8
2.800	12.301	6.859	13.33	370.5	2082.7	2453.2
2.900	13.086	7.104	13.81	395.3	2214.6	2609.9
3.000	14.004	7.348	14.29	420.8	2374.2	2795.1

POLAR PERFORMANCE DATA

VTW KN.	VTW-CE KN.	B+BTW DEGR	VAW KN.	B+BAW DEGR	VS KN.	VMG KN.	FI DEGR
10.0	10.00	180.0	4.96	180.00	5.040	-5.040	0.0
10.0	10.00	160.0	4.65	132.68	6.244	-5.867	1.1
10.0	10.00	150.0	5.31	109.86	6.856	-5.937	2.4
10.0	10.00	140.0	6.41	91.45	7.498	-5.744	4.5
10.0	10.00	125.0	8.45	73.06	8.198	-4.702	9.3
10.0	10.00	110.0	10.38	59.98	8.613	-2.946	17.0
10.0	10.00	90.0	12.66	46.93	8.645	0.000	22.3
10.0	10.00	80.0	13.78	41.35	8.607	1.495	22.5
10.0	10.00	70.0	14.84	36.20	8.551	2.925	21.2
10.0	10.00	60.0	15.61	31.65	8.290	4.145	18.9
10.0	10.00	52.0	15.84	28.35	7.784	4.792	17.4
10.0	10.00	48.0	15.79	26.82	7.399	4.951	16.5
10.0	10.00	44.0	15.58	25.47	6.874	4.945	15.3
10.0	10.00	42.0	15.43	24.80	6.574	4.885	14.7
10.0	10.00	40.0	15.25	24.15	6.257	4.793	13.9
10.0	10.00	38.0	15.05	23.49	5.919	4.664	13.1
10.0	10.00	36.0	14.79	22.87	5.536	4.479	12.1
10.0	10.00	46.2	15.71	26.20	7.177	4.968	16.0
10.0	10.00	151.9	5.15	113.87	6.735	-5.940	2.1
15.0	15.00	180.0	7.68	180.00	7.319	-7.319	0.0
15.0	15.00	160.0	7.58	137.43	8.516	-8.003	2.6
15.0	15.00	150.0	8.53	118.96	8.858	-7.671	5.4
15.0	15.00	140.0	9.81	104.08	9.105	-6.975	9.3
15.0	15.00	125.0	11.79	86.70	9.282	-5.324	16.7
15.0	15.00	110.0	13.43	72.39	9.194	-3.145	24.7
15.0	15.00	90.0	16.44	56.90	8.978	0.000	23.4
15.0	15.00	80.0	17.78	49.74	8.884	1.543	23.3
15.0	15.00	70.0	18.99	42.87	8.791	3.007	23.5
15.0	15.00	60.0	20.08	36.16	8.711	4.355	24.2
15.0	15.00	52.0	20.85	31.82	8.479	5.220	21.6
15.0	15.00	48.0	21.03	29.84	8.201	5.487	20.2
15.0	15.00	44.0	21.01	27.82	7.793	5.606	19.7
15.0	15.00	42.0	20.94	26.88	7.529	5.595	19.4
15.0	15.00	40.0	20.80	26.03	7.199	5.514	18.8
15.0	15.00	38.0	20.59	25.25	6.800	5.359	18.0
15.0	15.00	36.0	20.32	24.53	6.352	5.139	16.9
15.0	15.00	43.3	21.00	27.50	7.714	5.610	19.7
15.0	15.00	163.0	7.40	143.62	8.387	-8.019	2.0

Table 3: Shallow draught keel.

POLAR PERFORMANCE DATA

VTW KN.	VTW-CE KN.	B+BTW DEGR	VAW KN.	B+BAW DEGR	VS KN.	VMG KN.	FI DEGR
20.0	20.00	180.0	11.22	180.00	8.780	-8.780	0.0
20.0	20.00	160.0	11.40	143.29	9.653	-9.071	4.8
20.0	20.00	150.0	12.31	126.79	9.947	-8.614	9.6
20.0	20.00	140.0	13.43	112.87	10.102	-7.739	15.8
20.0	20.00	125.0	14.85	95.67	10.006	-5.739	25.6
20.0	20.00	110.0	17.01	80.54	9.637	-3.296	26.8
20.0	20.00	90.0	20.42	63.13	9.226	0.000	24.4
20.0	20.00	80.0	21.92	55.13	9.059	1.573	24.1
20.0	20.00	70.0	23.31	47.53	8.902	3.045	23.8
20.0	20.00	60.0	24.51	39.99	8.774	4.387	24.6
20.0	20.00	52.0	25.44	34.50	8.650	5.326	23.9
20.0	20.00	48.0	25.80	32.08	8.476	5.672	22.8
20.0	20.00	44.0	25.99	30.00	8.118	5.840	20.7
20.0	20.00	42.0	25.94	28.90	7.848	5.832	20.5
20.0	20.00	40.0	25.83	27.91	7.504	5.749	19.8
20.0	20.00	38.0	25.58	27.03	7.030	5.540	19.2
20.0	20.00	36.0	25.21	26.22	6.437	5.208	18.6
20.0	20.00	43.2	25.98	29.58	8.024	5.845	20.6
20.0	20.00	166.2	11.08	154.59	9.421	-9.150	2.6

POLAR PERFORMANCE DATA

VTW KN.	VTW-CE KN.	B+BTW DEGR	VAW KN.	B+BAW DEGR	VS KN.	VMG KN.	FI DEGR
25.0	25.00	180.0	15.32	180.00	9.684	-9.684	0.0
25.0	25.00	160.0	15.38	146.58	10.652	-10.010	7.7
25.0	25.00	150.0	16.16	131.64	10.912	-9.450	15.0
25.0	25.00	140.0	16.91	119.07	10.935	-8.377	23.1
25.0	25.00	125.0	17.88	102.30	10.531	-6.040	31.4
25.0	25.00	110.0	20.75	85.97	10.008	-3.423	28.2
25.0	25.00	90.0	24.49	67.40	9.413	0.000	25.3
25.0	25.00	80.0	26.11	58.84	9.168	1.592	24.9
25.0	25.00	70.0	27.68	50.81	8.939	3.057	24.0
25.0	25.00	60.0	28.99	42.91	8.732	4.366	24.3
25.0	25.00	52.0	29.91	36.63	8.613	5.303	25.0
25.0	25.00	48.0	30.40	33.99	8.480	5.674	23.8
25.0	25.00	44.0	30.69	31.53	8.174	5.880	22.5
25.0	25.00	42.0	30.72	30.44	7.904	5.874	21.5
25.0	25.00	40.0	30.59	29.44	7.493	5.740	20.7

Table 3 continued.

UPRIGHT RESISTANCE DATA

MODEL VM M/S	RTM KG	SHIP VS M/S	VS KNOTS	RFS KG	RRS KG	RTS KG
1.100	0.548	2.694	5.24	62.3	16.9	79.2
1.200	0.657	2.939	5.71	73.1	23.2	96.3
1.300	0.767	3.184	6.19	84.6	28.9	113.5
1.400	0.904	3.429	6.67	97.0	38.9	135.9
1.500	1.071	3.674	7.14	110.1	54.5	164.6
1.600	1.275	3.919	7.62	123.9	76.9	200.8
1.700	1.529	4.164	8.10	138.5	108.9	247.4
1.800	1.921	4.409	8.57	153.9	169.8	323.7
1.900	2.476	4.654	9.05	170.0	264.7	434.7
1.950	2.818	4.777	9.29	178.3	325.5	503.8
2.000	3.196	4.899	9.52	186.8	394.1	580.9
2.100	4.101	5.144	10.00	204.4	562.5	766.9
2.200	5.208	5.389	10.48	222.7	773.4	996.1
2.300	6.501	5.634	10.95	241.7	1023.6	1265.3
2.400	7.770	5.879	11.43	261.4	1267.4	1528.8
2.500	8.850	6.124	11.90	281.9	1469.3	1751.1
2.600	9.843	6.369	12.38	303.0	1651.3	1954.3
2.700	10.760	6.614	12.86	324.9	1816.0	2140.9
2.800	11.611	6.859	13.33	347.4	1965.4	2312.8

POLAR PERFORMANCE DATA

VTW KN.	VTW-CE KN.	B+BTW DEGR	VAW KN.	B+BAW DEGR	VS KN.	VMG KN.	FI DEGR
10.0	10.00	180.0	4.97	180.00	5.026	-5.026	0.0
10.0	10.00	160.0	4.65	132.62	6.250	-5.873	1.1
10.0	10.00	150.0	5.32	110.03	6.839	-5.923	2.4
10.0	10.00	140.0	6.41	92.31	7.401	-5.670	4.4
10.0	10.00	125.0	8.44	73.37	8.152	-4.676	9.1
10.0	10.00	110.0	10.39	59.96	8.623	-2.949	16.8
10.0	10.00	90.0	12.66	46.43	8.723	0.000	23.5
10.0	10.00	80.0	13.79	40.92	8.684	1.508	23.5
10.0	10.00	70.0	14.85	35.85	8.613	2.946	22.3
10.0	10.00	60.0	15.63	31.41	8.336	4.168	19.9
10.0	10.00	52.0	15.85	28.17	7.815	4.811	18.3
10.0	10.00	48.0	15.81	26.67	7.434	4.974	17.3
10.0	10.00	44.0	15.67	25.19	6.990	5.028	16.2
10.0	10.00	42.0	15.56	24.48	6.727	4.999	15.5
10.0	10.00	40.0	15.40	23.81	6.427	4.924	14.7
10.0	10.00	38.0	15.17	23.20	6.065	4.779	13.9
10.0	10.00	36.0	14.87	22.68	5.627	4.553	12.7
10.0	10.00	44.4	15.69	25.34	7.041	5.029	16.4
10.0	10.00	153.2	5.05	116.80	6.652	-5.938	1.9
15.0	15.00	180.0	7.75	180.00	7.254	-7.254	0.0
15.0	15.00	160.0	7.61	137.65	8.472	-7.961	2.6
15.0	15.00	150.0	8.54	119.01	8.849	-7.663	5.4
15.0	15.00	140.0	9.80	103.91	9.133	-6.996	9.2
15.0	15.00	125.0	11.80	86.35	9.356	-5.366	16.6
15.0	15.00	110.0	13.43	71.79	9.326	-3.190	25.2
15.0	15.00	90.0	16.24	55.81	9.123	0.000	26.4
15.0	15.00	80.0	17.63	48.71	9.032	1.568	26.2
15.0	15.00	70.0	18.86	41.76	8.936	3.056	27.0
15.0	15.00	60.0	20.04	35.40	8.839	4.420	26.6
15.0	15.00	52.0	20.83	31.30	8.564	5.272	23.7
15.0	15.00	48.0	21.04	29.43	8.285	5.544	22.0
15.0	15.00	44.0	21.05	27.45	7.887	5.673	21.4
15.0	15.00	42.0	20.99	26.56	7.628	5.669	20.8
15.0	15.00	40.0	20.89	25.65	7.342	5.625	20.3
15.0	15.00	38.0	20.76	24.82	7.019	5.531	19.4
15.0	15.00	36.0	20.55	24.01	6.634	5.367	18.5
15.0	15.00	43.2	21.03	27.10	7.791	5.677	21.2
15.0	15.00	162.3	7.47	142.48	8.370	-7.975	2.1

Table 4: „Scheel" keel.

POLAR PERFORMANCE DATA

VTW KN.	VTW-CE KN.	B+BTW DEGR	VAW KN.	B+BAW DEGR	VS KN.	VMG KN.	FI DEGR
20.0	20.00	180.0	11.24	180.00	8.759	-8.759	0.0
20.0	20.00	160.0	11.34	143.05	9.729	-9.143	4.8
20.0	20.00	150.0	12.25	126.41	10.046	-8.700	9.5
20.0	20.00	140.0	13.39	112.37	10.224	-7.832	15.6
20.0	20.00	125.0	14.87	95.01	10.173	-5.835	25.3
20.0	20.00	110.0	16.77	79.74	9.828	-3.362	28.6
20.0	20.00	90.0	20.06	62.01	9.416	0.000	27.6
20.0	20.00	80.0	21.65	54.00	9.253	1.607	27.2
20.0	20.00	70.0	23.06	46.27	9.098	3.112	27.6
20.0	20.00	60.0	24.30	38.69	8.971	4.485	28.7
20.0	20.00	52.0	25.41	33.79	8.804	5.420	26.3
20.0	20.00	48.0	25.80	31.56	8.600	5.754	24.7
20.0	20.00	44.0	26.01	29.54	8.246	5.932	22.6
20.0	20.00	42.0	26.00	28.45	7.993	5.940	22.3
20.0	20.00	40.0	25.90	27.43	7.668	5.874	21.8
20.0	20.00	38.0	25.74	26.46	7.288	5.743	21.3

POLAR PERFORMANCE DATA

VTW KN.	VTW-CE KN.	B+BTW DEGR	VAW KN.	B+BAW DEGR	VS KN.	VMG KN.	FI DEGR
25.0	25.00	180.0	15.24	180.00	9.759	-9.759	0.0
25.0	25.00	160.0	15.29	146.34	10.767	-10.117	7.6
25.0	25.00	150.0	16.07	131.24	11.054	-9.573	14.8
25.0	25.00	140.0	16.86	118.50	11.109	-8.510	22.8
25.0	25.00	125.0	17.54	101.81	10.750	-6.166	33.1
25.0	25.00	110.0	20.30	85.24	10.236	-3.501	30.5
25.0	25.00	90.0	23.95	66.24	9.647	0.000	28.8
25.0	25.00	80.0	25.63	57.56	9.407	1.633	28.5
25.0	25.00	70.0	27.25	49.40	9.181	3.140	28.3
25.0	25.00	60.0	28.60	41.31	8.984	4.492	29.3
25.0	25.00	52.0	29.75	35.43	8.849	5.446	28.9
25.0	25.00	48.0	30.33	33.08	8.685	5.812	27.0
25.0	25.00	44.0	30.74	30.98	8.374	6.024	24.3
25.0	25.00	42.0	30.80	29.93	8.116	6.031	23.3
25.0	25.00	40.0	30.70	28.86	7.740	5.929	22.8
25.0	25.00	38.0	30.50	27.87	7.258	5.719	22.2

Table 4 continued.

UPRIGHT RESISTANCE DATA

MODEL VM M/S	RTM KG	SHIP VS M/S	VS KNOTS	RFS KG	RRS KG	RTS KG
1.100	0.542	2.694	5.24	65.6	9.4	74.9
1.200	0.657	2.939	5.71	76.9	16.0	92.9
1.300	0.781	3.184	6.19	89.0	23.5	112.5
1.400	0.921	3.429	6.67	102.0	33.3	135.3
1.500	1.073	3.674	7.14	115.8	44.3	160.1
1.600	1.262	3.919	7.62	130.3	62.2	192.5
1.650	1.394	4.042	7.86	137.9	78.7	216.7
1.700	1.540	4.164	8.10	145.7	98.1	243.8
1.750	1.724	4.287	8.33	153.7	125.3	279.0
1.800	1.876	4.409	8.57	161.8	145.3	307.2
1.850	2.204	4.532	8.81	170.2	203.1	373.3
1.900	2.513	4.654	9.05	178.8	256.4	435.2
1.950	2.856	4.777	9.29	187.5	316.9	504.4
2.000	3.244	4.899	9.52	196.4	386.8	583.3
2.100	4.172	5.144	10.00	214.9	558.5	773.4
2.200	5.314	5.389	10.48	234.1	775.5	1009.6
2.300	6.528	5.634	10.95	254.1	1006.7	1260.8
2.400	7.764	5.879	11.43	274.8	1241.8	1516.6
2.500	8.894	6.124	11.90	296.3	1452.6	1748.8
2.600	9.822	6.369	12.38	318.5	1618.9	1937.3
2.700	10.680	6.614	12.86	341.4	1768.7	2110.1
2.800	11.493	6.859	13.33	365.1	1908.0	2273.1
2.900	12.329	7.104	13.81	389.5	2051.0	2440.5
3.000	13.194	7.348	14.29	414.6	2199.2	2613.8

POLAR PERFORMANCE DATA

VTW KN.	VTW-CE KN.	B+BTW DEGR	VAW KN.	B+BAW DEGR	VS KN.	VMG KN.	FI DEGR
10.0	10.00	180.0	4.91	180.00	5.086	-5.086	0.0
10.0	10.00	160.0	4.64	132.51	6.262	-5.885	1.2
10.0	10.00	150.0	5.31	109.74	6.868	-5.948	2.5
10.0	10.00	140.0	6.41	91.29	7.517	-5.758	4.6
10.0	10.00	125.0	8.45	72.90	8.222	-4.716	9.5
10.0	10.00	110.0	10.42	59.17	8.763	-2.997	17.7
10.0	10.00	90.0	12.66	45.39	8.892	0.000	25.7
10.0	10.00	80.0	13.82	39.92	8.864	1.539	25.7
10.0	10.00	70.0	14.92	35.02	8.795	3.008	24.4
10.0	10.00	60.0	15.78	30.61	8.579	4.290	21.9
10.0	10.00	52.0	16.04	27.38	8.088	4.979	20.6
10.0	10.00	48.0	16.08	25.74	7.794	5.215	20.0
10.0	10.00	44.0	16.04	24.16	7.443	5.354	19.1
10.0	10.00	42.0	15.95	23.44	7.203	5.353	18.5
10.0	10.00	40.0	15.83	22.77	6.932	5.310	17.7
10.0	10.00	38.0	15.67	22.03	6.646	5.237	17.3
10.0	10.00	36.0	15.49	21.33	6.343	5.132	16.5
10.0	10.00	43.1	16.00	23.81	7.335	5.360	18.8
10.0	10.00	152.0	5.14	114.00	6.741	-5.952	2.2
15.0	15.00	180.0	7.69	180.00	7.313	-7.313	0.0
15.0	15.00	160.0	7.56	137.30	8.542	-8.027	2.6
15.0	15.00	150.0	8.53	118.97	8.857	-7.670	5.5
15.0	15.00	140.0	9.79	103.79	9.156	-7.014	9.5
15.0	15.00	125.0	11.77	86.07	9.410	-5.397	17.1
15.0	15.00	110.0	13.35	71.18	9.437	-3.227	26.3
15.0	15.00	90.0	16.09	54.70	9.300	0.000	28.9
15.0	15.00	80.0	17.52	47.50	9.230	1.603	29.0
15.0	15.00	70.0	18.79	40.54	9.149	3.129	30.0
15.0	15.00	60.0	20.10	34.65	9.033	4.516	28.4
15.0	15.00	52.0	20.94	30.76	8.762	5.394	25.0
15.0	15.00	48.0	21.20	28.69	8.562	5.729	24.0
15.0	15.00	44.0	21.24	26.72	8.182	5.885	23.6
15.0	15.00	42.0	21.26	25.70	8.007	5.951	23.3
15.0	15.00	40.0	21.23	24.73	7.789	5.967	22.9
15.0	15.00	38.0	21.17	23.74	7.560	5.957	22.6
15.0	15.00	36.0	21.04	22.85	7.257	5.871	22.0
15.0	15.00	39.7	21.22	24.58	7.757	5.968	22.9
15.0	15.00	163.9	7.39	145.72	8.306	-7.980	1.8

Table 5: „I.O.R" keel.

POLAR PERFORMANCE DATA

VTW KN.	VTW-CE KN.	B+BTW DEGR	VAW KN.	B+BAW DEGR	VS KN.	VMG KN.	FI DEGR
20.0	20.00	180.0	11.23	180.00	8.772	-8.772	0.0
20.0	20.00	160.0	11.34	143.07	9.727	-9.140	4.8
20.0	20.00	150.0	12.25	126.43	10.046	-8.700	9.8
20.0	20.00	140.0	13.36	112.38	10.234	-7.840	16.0
20.0	20.00	125.0	14.76	94.86	10.219	-5.862	26.1
20.0	20.00	110.0	16.50	79.23	9.923	-3.394	30.4
20.0	20.00	90.0	19.81	61.06	9.586	0.000	29.9
20.0	20.00	80.0	21.39	52.79	9.465	1.644	30.1
20.0	20.00	70.0	22.91	45.08	9.338	3.194	30.3
20.0	20.00	60.0	24.31	37.75	9.221	4.610	30.8
20.0	20.00	52.0	25.46	33.07	9.021	5.554	28.2
20.0	20.00	48.0	25.91	31.01	8.820	5.902	26.1
20.0	20.00	44.0	26.20	28.81	8.573	6.167	24.7
20.0	20.00	42.0	26.19	27.74	8.315	6.180	24.4
20.0	20.00	40.0	26.20	26.63	8.104	6.208	24.0
20.0	20.00	38.0	26.16	25.53	7.841	6.179	23.7
20.0	20.00	36.0	26.07	24.47	7.545	6.104	23.3
20.0	20.00	39.7	26.20	26.49	8.075	6.209	23.9
20.0	20.00	165.5	11.06	153.10	9.503	-9.200	2.9

POLAR PERFORMANCE DATA

VTW KN.	VTW-CE KN.	B+BTW DEGR	VAW KN.	B+BAW DEGR	VS KN.	VMG KN.	FI DEGR
25.0	25.00	180.0	15.25	180.00	9.751	-9.751	0.0
25.0	25.00	160.0	15.29	146.34	10.768	-10.119	7.8
25.0	25.00	150.0	16.03	131.19	11.091	-9.605	15.1
25.0	25.00	140.0	16.76	118.42	11.172	-8.558	23.4
25.0	25.00	125.0	17.33	101.73	10.815	-6.203	34.1
25.0	25.00	110.0	20.02	84.96	10.309	-3.526	31.9
25.0	25.00	90.0	23.59	65.43	9.812	0.000	30.9
25.0	25.00	80.0	25.37	56.59	9.629	1.672	30.7
25.0	25.00	70.0	27.04	48.24	9.456	3.234	30.9
25.0	25.00	60.0	28.52	40.18	9.288	4.644	31.8
25.0	25.00	52.0	29.84	34.75	9.129	5.620	30.3
25.0	25.00	48.0	30.38	32.32	8.946	5.986	29.0
25.0	25.00	44.0	30.88	30.24	8.697	6.256	26.4
25.0	25.00	42.0	31.02	29.13	8.519	6.331	25.5
25.0	25.00	40.0	30.99	28.01	8.208	6.288	25.1
25.0	25.00	38.0	30.96	26.85	7.926	6.246	24.7
25.0	25.00	36.0	30.85	25.70	7.570	6.124	24.4
25.0	25.00	41.9	31.02	29.06	8.500	6.330	25.4
25.0	25.00	165.5	15.04	155.51	10.522	-10.187	4.7

Table 5 continued.

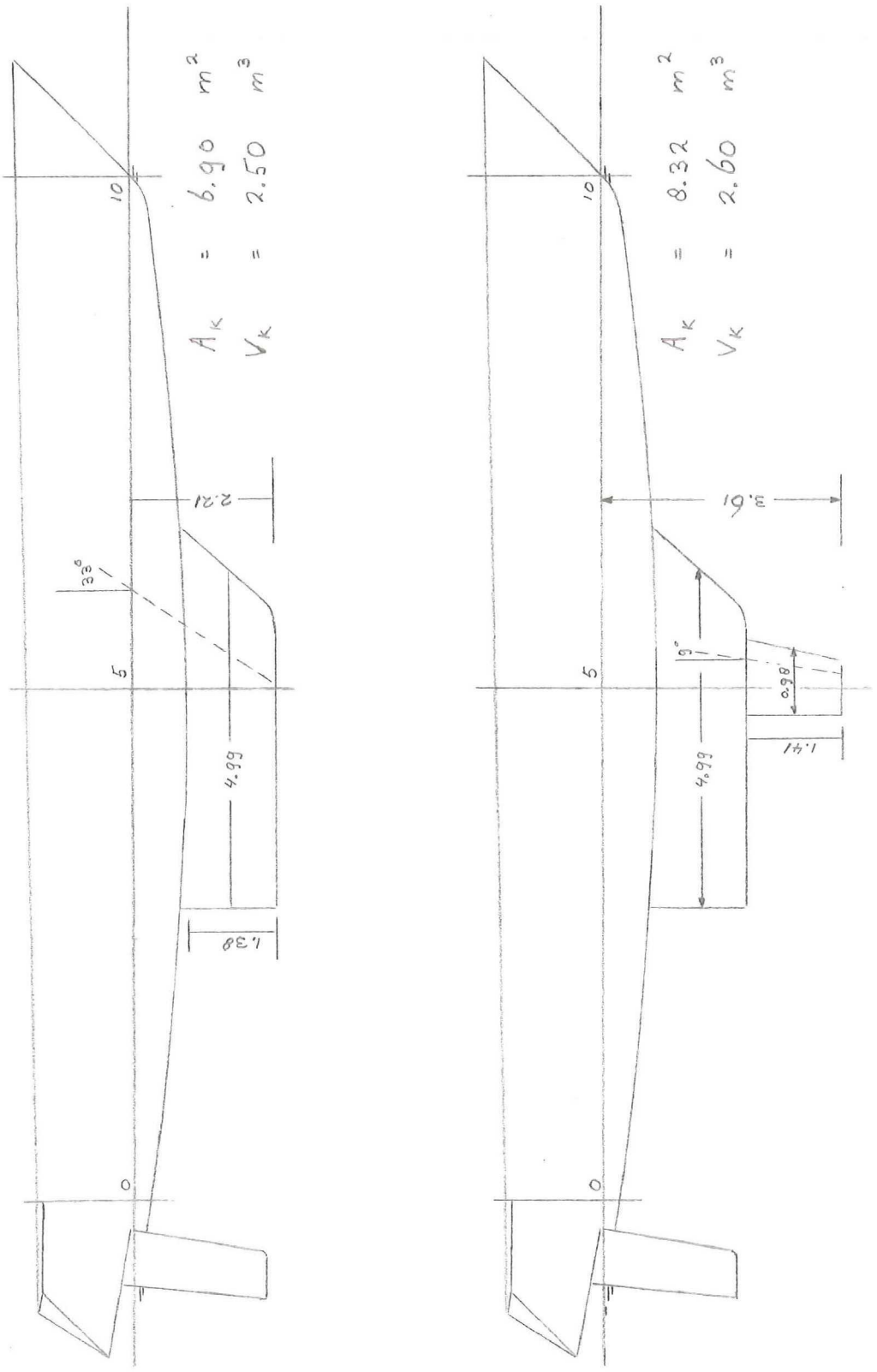

Figure 1: Four keel-hull combinations.

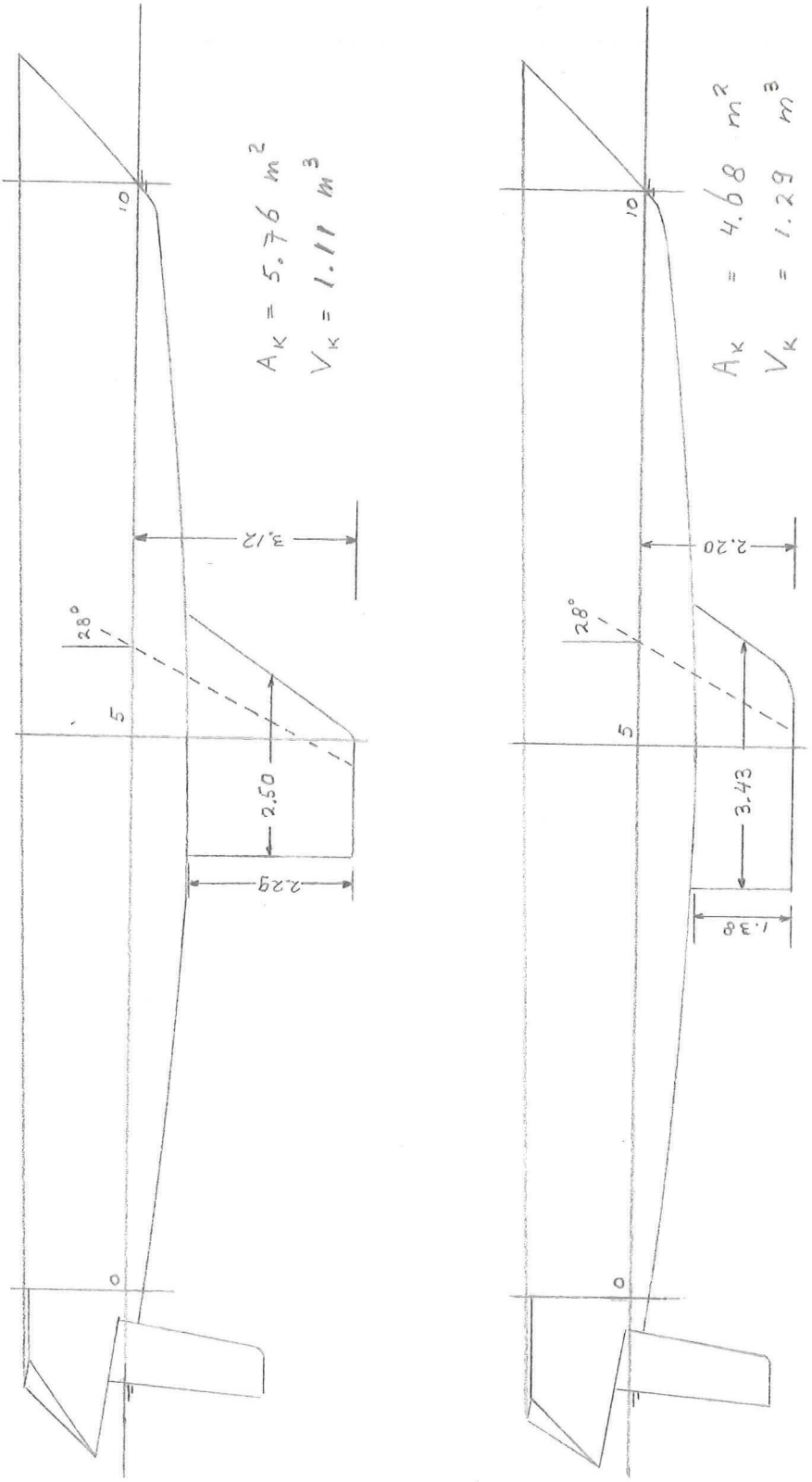

Figure 1 continued.

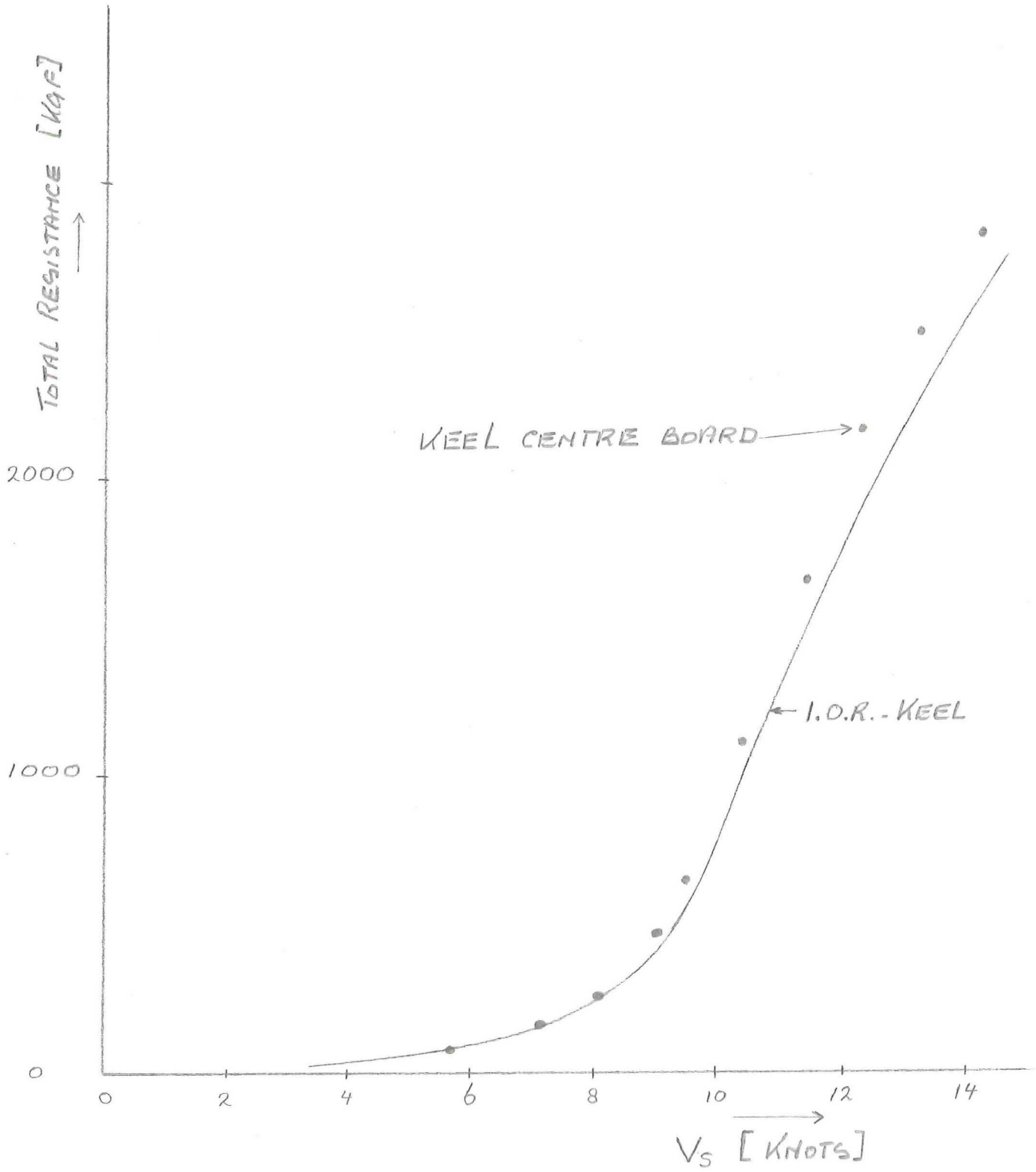

Figure 2: Resistance-speed keel centreboard.

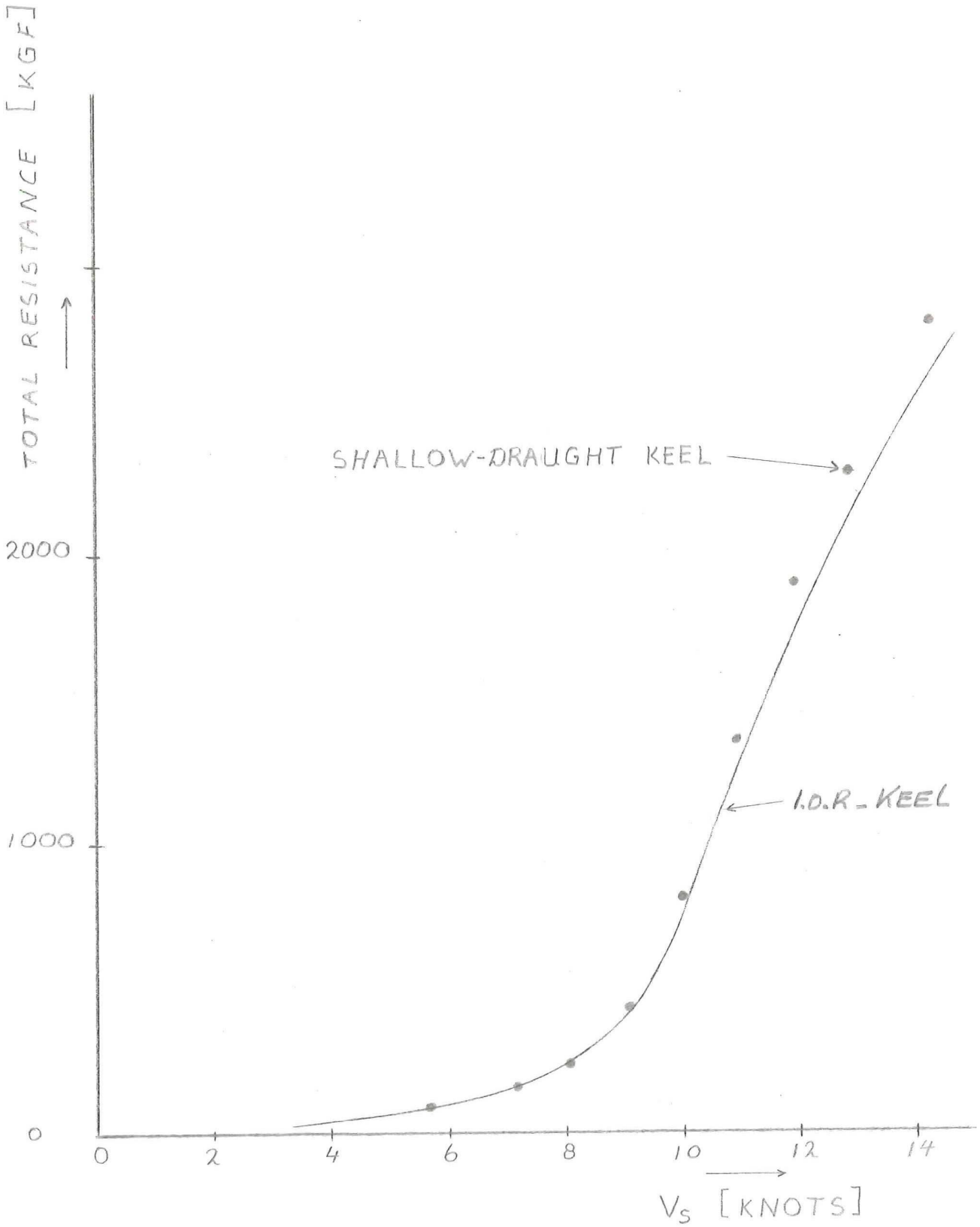

Figure 3: Resistance-speed shallow draught keel.

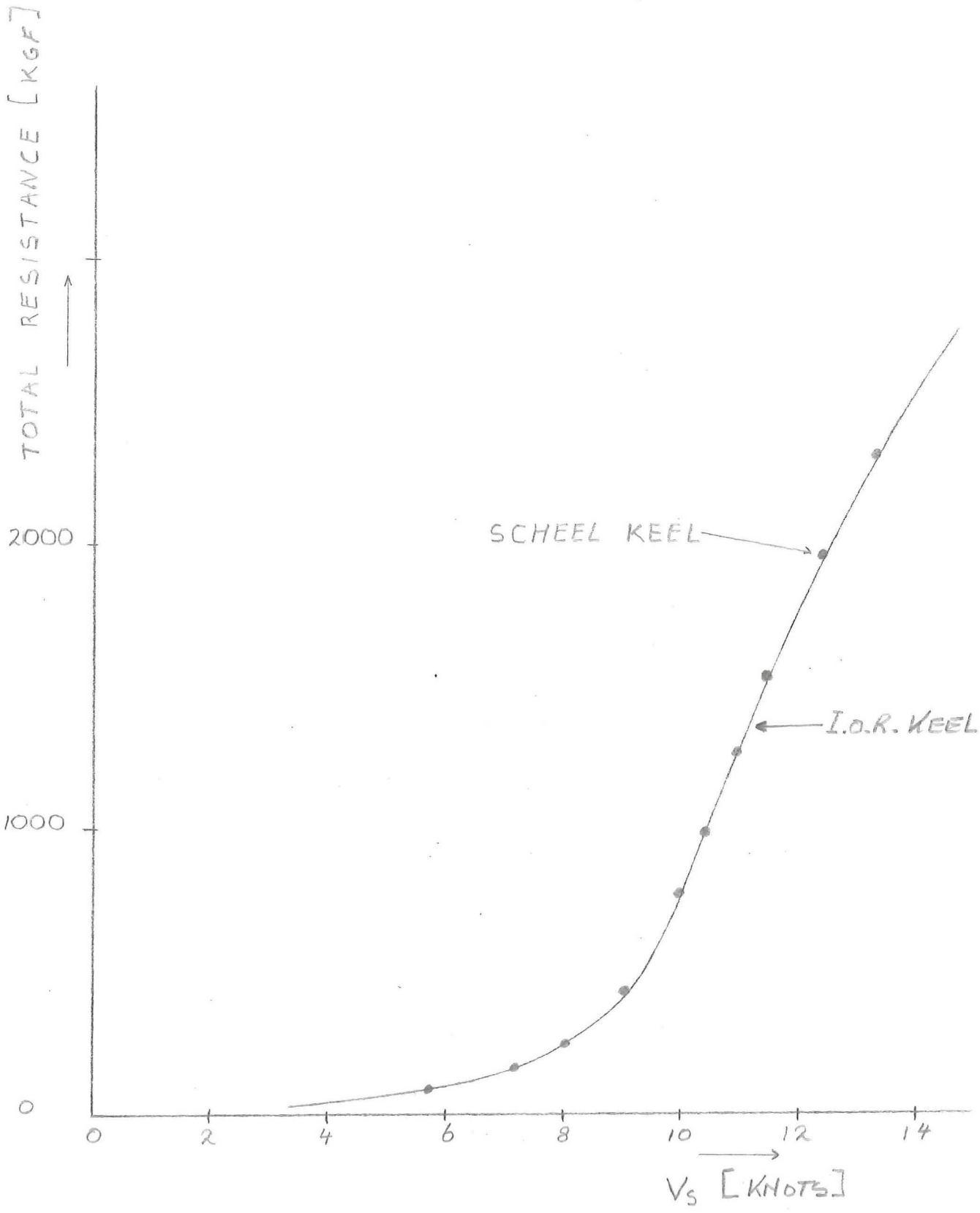

Figure 4: Resistance-speed Scheel keel.

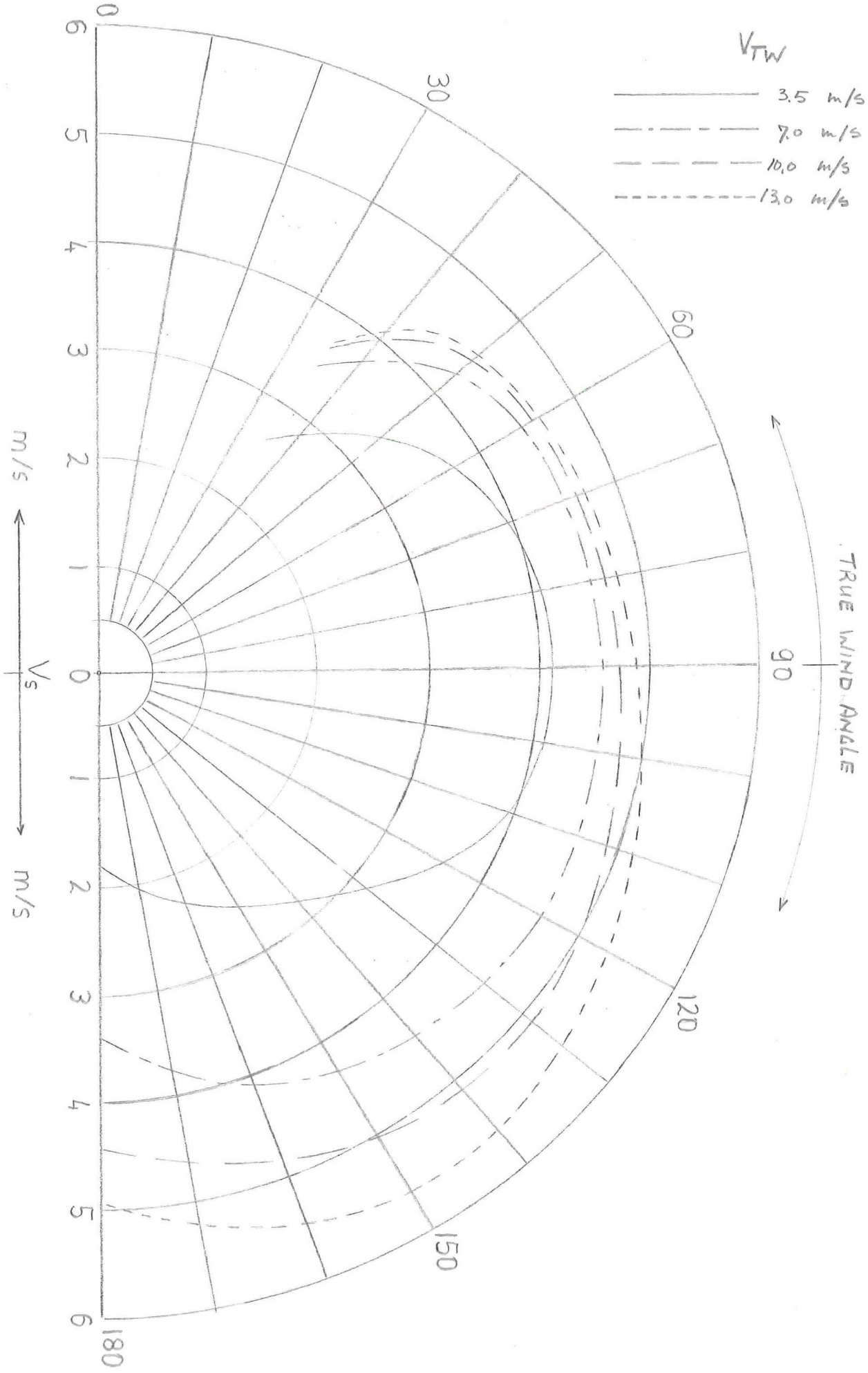

Figure 5: Speed polar keel-centre board.

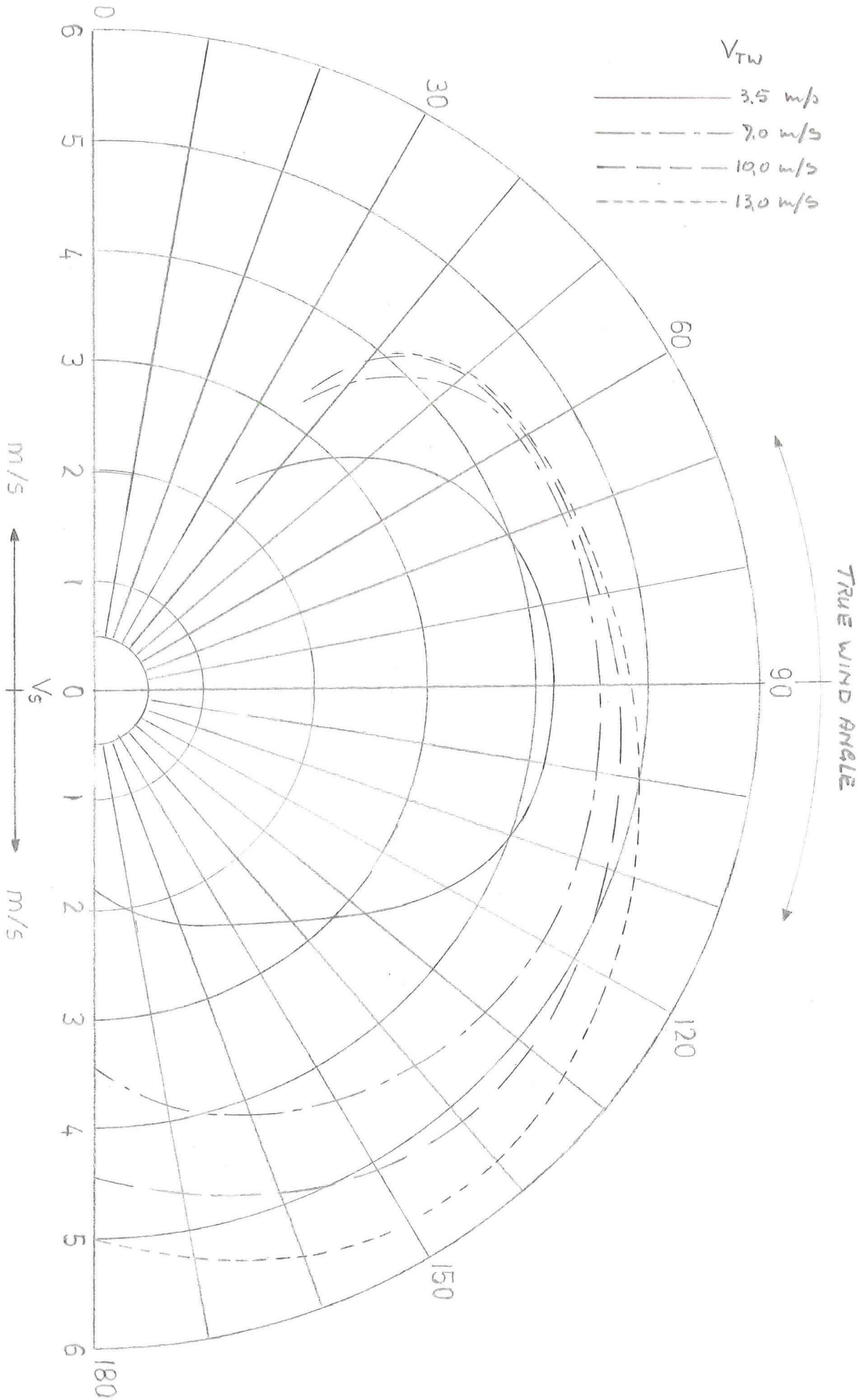

Figure 6: Speed polar shallow draught keel.

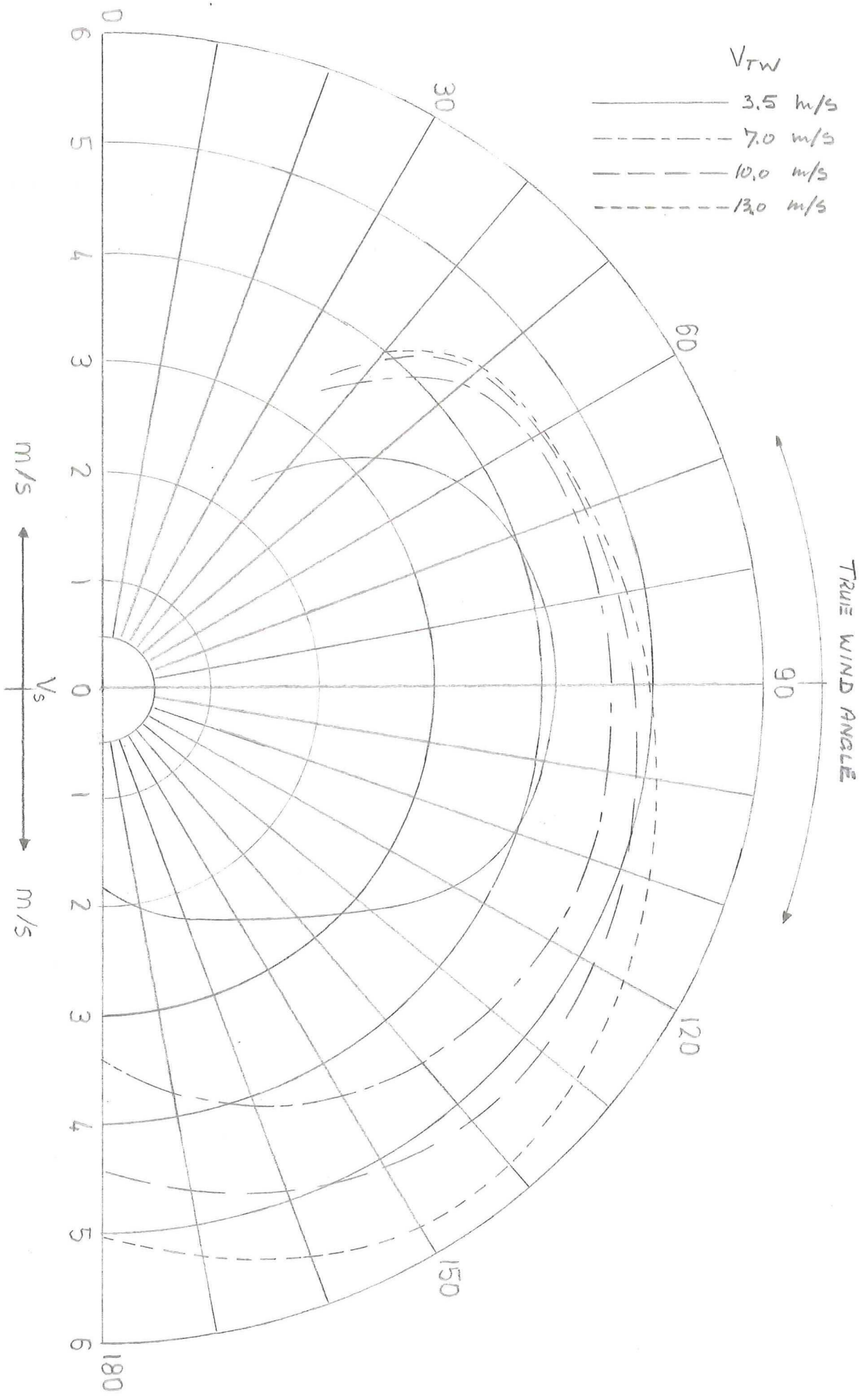

Figure 7: Speed polar Scheel keel.

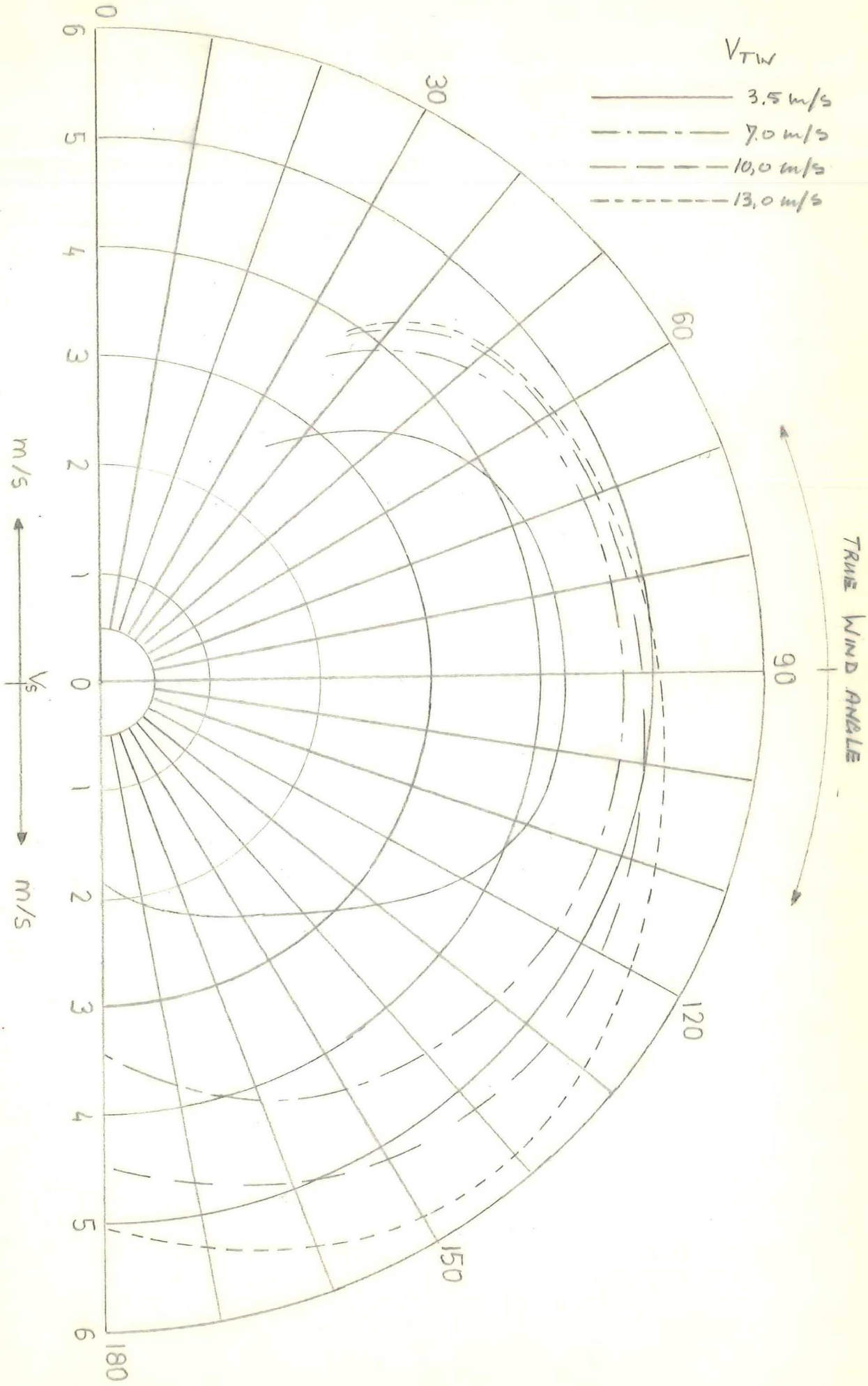

Figure 3: Speed polar I.O.R. keel.