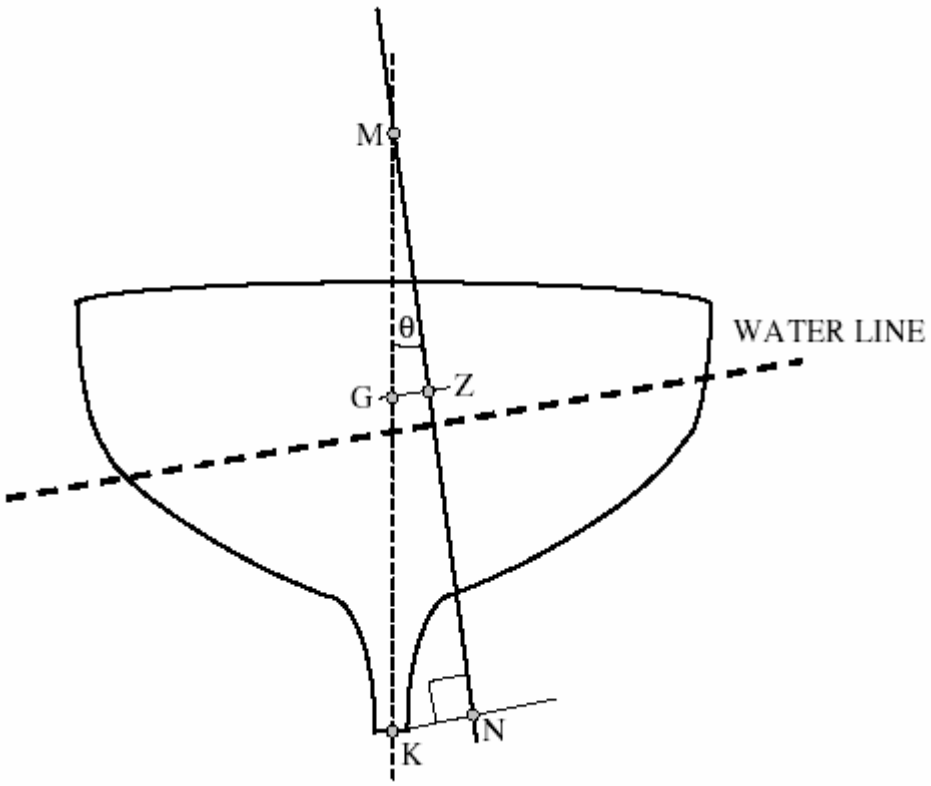
116

ZYGOTE

Stability Information Book



Preface

This booklet is arranged in sections ordered so that the most essential matters are brought to the reader's attention first.

Section 1: Operational Information. This section contains guidance intended to ensure that the level of stability may be judged with reference to a recommended maximum steady angle of heel to prevent downflooding in gusts and squalls.

Section 2: Technical Data and Loading Conditions. This section details the loading conditions upon which the recommended heeling angles are based.

Section 3: Reference Information. This section contains basic information which is necessary for the calculations in Sections 1 and 2. A skipper need not necessarily read this section, but the Beaufort scale and the metric/imperial conversion table may be useful.

Appendices. This section contains a list of abbreviations, a table developed by the Intergovernmental Marine Consultative Organisation to inform naval architects on a means to determine the coefficient k, and Raymond H. Richards' *Stability: Report of Findings* (4 February 2002) on the standard Bristol Channel Cutter 28.

Datum Reference Information

Longitudinal datum = midships (+'ve values forward of midships, -'ve values aft)
Transverse datum = centreline (+'ve values to starboard, -'ve values to port)
Vertical datum = base line (horizontal, intersecting the keel at midships)
Draughts refer to the underside of keel, or an extension thereof.
Trim is defined as: Draught Aft - Draught Fwd
Design trim = Rake of keel = - 1.48 metres

Midships is approximately marked by the vertical stub of the diagonal buttress to the forward gate stanchion. Below in the cabin, the central divider of the bookshelf is a good marker of midships.

The waterline is 1.46 m (Minimum Operating Condition or Arrival Condition) to 1.49 m (Loaded Operating Condition or Departure Condition) above the base line. The mast partners are 2.17 m above the base line.

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GENERAL PARTICULARS

Ship's Name (Australian Register):	Zygote
Official Number (Australian Register):	856597
Home Port:	Brisbane
Model:	Bristol Channel Cutter 28
Hull Identification Number:	SFJBC116G999
Designer:	Lyle C. Hess
Builder:	Sam L. Morse Co. Costa Mesa, California, USA
Build (hand-over) date:	23 November 2000
Initial launch date:	13 November 2000
Yard Number:	116
Owners' Name and Address:	William Ronald Hansen & Meryl Jean Williams 5 Lintang Pantai Jerjak Sungai Nibong, Penang Malaysia

Dimensions

Registered length:	8.55 metres
Registered beam:	3.04 metres
Registered moulded depth amidships:	1.64 metres
Registered estimated speed:	6.8 knots
Registered engine brake power:	20.10 kilowatts
Overall length (bowsprit tip to boomkin tip):	11.506 metres (37' 9")
Length on deck (LOD = LOA_{hull}):	8.559 metres (28' 1")
Waterline length (LWL):	8.001 metres (26' 3")
Air draught (to top of VHF antenna):	13.6 metres (44' 6")
Draught (design):	1.48 metres (4' 10")
Maximum Beam:	3.1 metres (10' 1")
Minimum Freeboard (F_m)	0.66 metres (2'2")
Ballast[1]:	1.905 tonnes (4,200 lbs)
Displacement (design figure):	6.350 t (14,000 lbs)
Displacement range[2]:	6.169 t (13,607 lbs) - 6.498 t (14,327 lbs)
Volume below waterline:	6.195 metres^3 (218.75 cubic ft)
Gross Register Tonnage[3]:	7.25 tons
Net Tonnage:	6.5 tons
Sinkage:	162 kg/cm (909 lb/in)

[1] ballast is 0.181 tonnes (400 lbs) less than a standard BCC28
[2] Arrival Condition – Departure Condition
[3] USCG Simplified Measurement Tonnage Formulas (Title 46 Code of Federal Regulations Part 69 Subpart E)

Operational Information

Arrangement of Tanks, Engines, and Ballast

Figure 1: Tanks, Engines, and Ballast

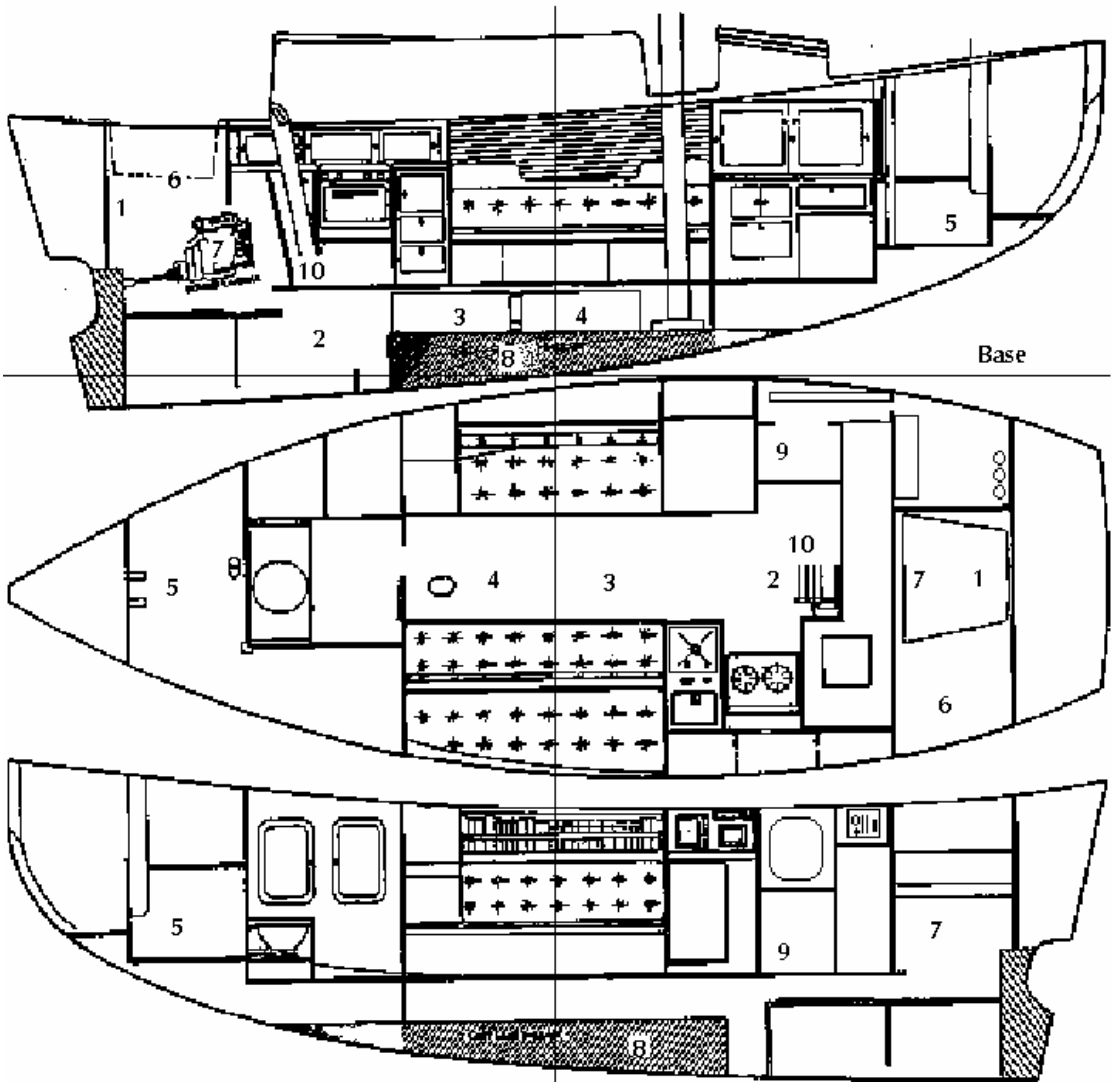


Table 1: Tanks, Engines, and Ballast

No.	Tank	Capacity		Mass	LCG	VCG	TCG
		litres	m^3	tonnes	m	m	m
1	Upper Fuel Tank	121	0.121	0.104	- 3.24	1.27	0
2	Lower Fuel Tank	98	0.098	0.084	- 1.84	0.17	0
3	Aft Freshwater Tank	77.5	0.076	0.076	- 0.82	0.48	0
4	Fore Freshwater Tank	77.5	0.076	0.076	+ 0.17	0.49	0
5	Sewage Holding Tank	60.5	0.061	0.061	+ 3.18	1.54	0
6	Generator Set	n.a.	n.a.	0.099	- 3.0	1.51	- 0.7
7	Auxiliary Engine	n.a.	n.a.	0.142	- 2.6	0.98	0
8	Ballast	n.a.	n.a.	1.905	- 0.58	0.01	0
9	Starboard battery box	n.a.	n.a.	0.089	-1.77	1.15	+ 0.6
10	Midships battery box	n.a.	n.a.	0.059	-1.77	0.83	0

Sail Plan

Figure 2: Sailplan

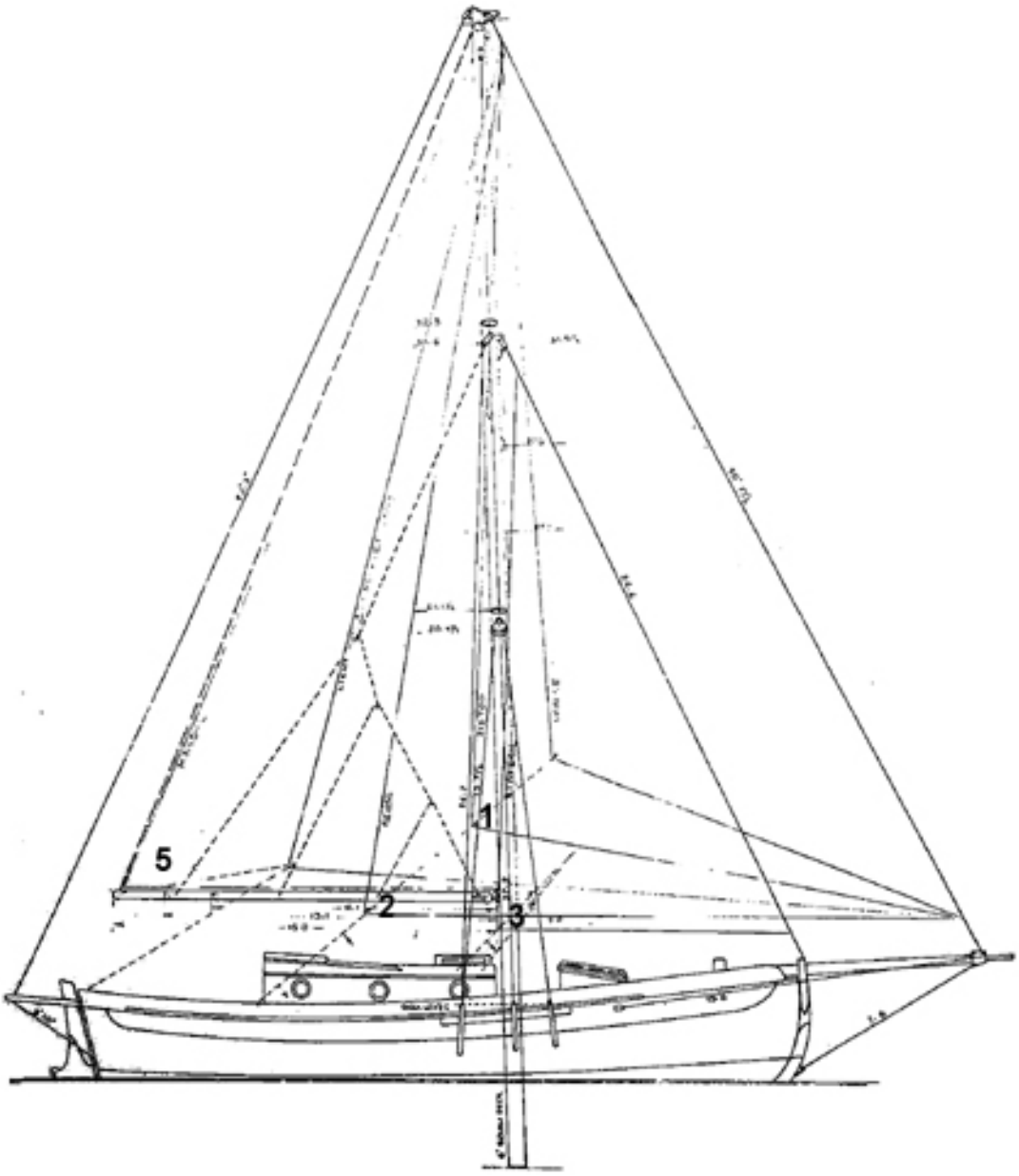


Table 2: Sail plan

No.	Sail	Area (m^2)	Height of centroid above base line (m)
1	Jib top	27.591	6.82
2	Genoa	37.508	6.67
3	Staysail	11.456	5.31
4	Storm jib	7.78	4.76
5	Main sail	23.503	6.07
6	Trysail	6.41	5.13

Angles of Deck Immersion and Downflooding

The angle of downflooding is the angle of heel at which progressive flooding will occur because an opening is immersed.

Table 3: Angles of Deck Immersion and Downflooding

Opening	Area of Opening (m^2)	Angle of Heel causing Downflooding	
		Departure Condition	Arrival Condition
Deck Edge/Sheer Planks	n.a.	27.8°	29.1°
Anchor warp hawse pipe (port)	0.006		
Scuttle hatch	0.476		
Skylight	0.36		
Portlight (1)	0.024		
Portlights (3)	0.072		
Cabin vent (dorade)	0.008		
Main hatch (boarded)	0.403		
Main hatch (no boards)	0.519		
Cockpit locker	0.245		
Lazarette	0.222		

Critical Flooding is deemed to occur when the lower edges of openings have an aggregate area (m^2) greater than:

Eqn 1 *Downflooding = Vessel displacement (tonnes)/1500*

Departure condition = 6.7/1500 = 0.0045 m^2
Arrival condition = 6.3/1500 = 0.0042 m^2

The master should note that each of the deck openings has an area in excess of the Critical Flooding area of 0.0042m^2. An open anchor warp hawse pipe, cockpit locker, portlight, main hatch, skylight, or scuttle hatch would significantly reduce the ability of the vessel to withstand downflooding. With these openings securely closed, the safety of the vessel is enhanced considerably.

Notes on Stability for the Guidance of the Master

Compliance with the stability criteria indicated in the booklet does not ensure immunity against capsizing regardless of the circumstances or absolve the master from his/her responsibilities.

The master should therefore exercise prudence and good seamanship having regard to the season of the year, experience of the crew, weather forecasts and navigational zone, and should take appropriate action as to the speed, course and sail setting warranted by the prevailing conditions.

Before a voyage commences care should be taken to ensure large items of equipment, including the anchors, dinghy, jerry jugs, and stores are properly stowed to minimise the possibility of both longitudinal and transverse shifting under the effect of acceleration caused by pitching and rolling, or in the event of a knockdown to 90°.

In adverse weather conditions and where the possibility exists of encountering a severe gust, squall or large breaking wave, the scuttle hatch, skylight, portlights, and cabin vents, should be closed and securely fastened to prevent the ingress of water. Storm boards should be erected and fitted in the scuttle hatch and main hatch.

The number of slack tanks should be minimised, although no single tank is likely to contribute to negative stability. Decanting fuel from deck-stored jerry jugs should be accomplished when conditions allow. The number of deck-stored jerry jugs should be minimised. Bilge water should be minimised.

The amount of sail carried is at the discretion of the master and his/her decision will have to take into account many factors. In assessing the risks of downflooding, the master should be guided by Figures 3 and 4 below.

Figure 3 shows the maximum recommended steady heel angle to prevent downflooding in gusts. Operation of the vessel at a heel angle greater than 35° would result in downflooding if the vessel encountered the strongest possible gust in the prevailing turbulent airstream, which could exert a heeling moment equal to twice that of the mean wind.

Figure 4 shows the maximum recommended steady heel angle to prevent downflooding in squalls. Operation of the vessel at a greater heel angle would result in downflooding if it were to encounter the heeling effects of a squall arising from a storm cell or frontal system which may result in a heeling moment many times greater than that of the mean wind. For this reason the master should have regard to the maximum steady heel angle curves presented for a range of squall speeds.

By noting the inclinometer and anemometer, the master should be able to determine the risk of capsizing due to gusts or squalls that may occur in the prevailing weather system. He/She may then decide to shorten sail together with other actions he/she considers necessary.

Capsize is seldom from wind forces alone. A BCC28 hit beam-on by a breaking wave taller than the boat's maximum beam (3.1 m) is likely to be inverted.

Additional care should be taken when sailing with the wind from astern because, in the event of the vessel broaching or a gust striking the vessel on the beam, the heeling effects of the wind may be increased to a dangerous level even if the prior heel angle were small.

Maximum Steady Heel Angle to Prevent Downflooding in Gusts

Figure 3: Maximum Steady Heel Angle, Gusts

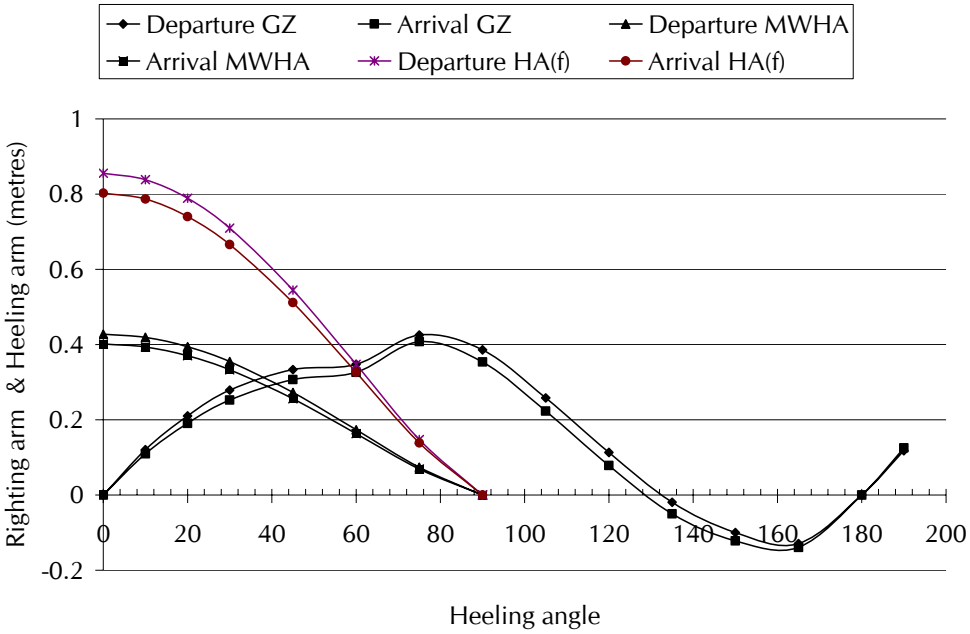


Figure 3 shows the Heeling Arms (HA_f) needed to push a Bristol Channel Cutter 28 to a heel angle of 60°, the angle of assumed downflooding (θ_f).

If the vessel were upright, the HA_{60} (or HA_f) would have to be 0.8 metres or greater. The HA_f curves intersect the GZ curves at a heel of 60°, when the righting arm is exactly equal to the heeling arm.

The Mean Wind Heeling Arm (MWHA) curves show the heeling arms that are half the magnitude of the HA_f. The MWHA curves intersect the GZ curves at 38° (Departure condition) and 35° (Arrival condition). The Maximum Steady Heel Angle (Gusts) is therefore 35°, the lower of the two.

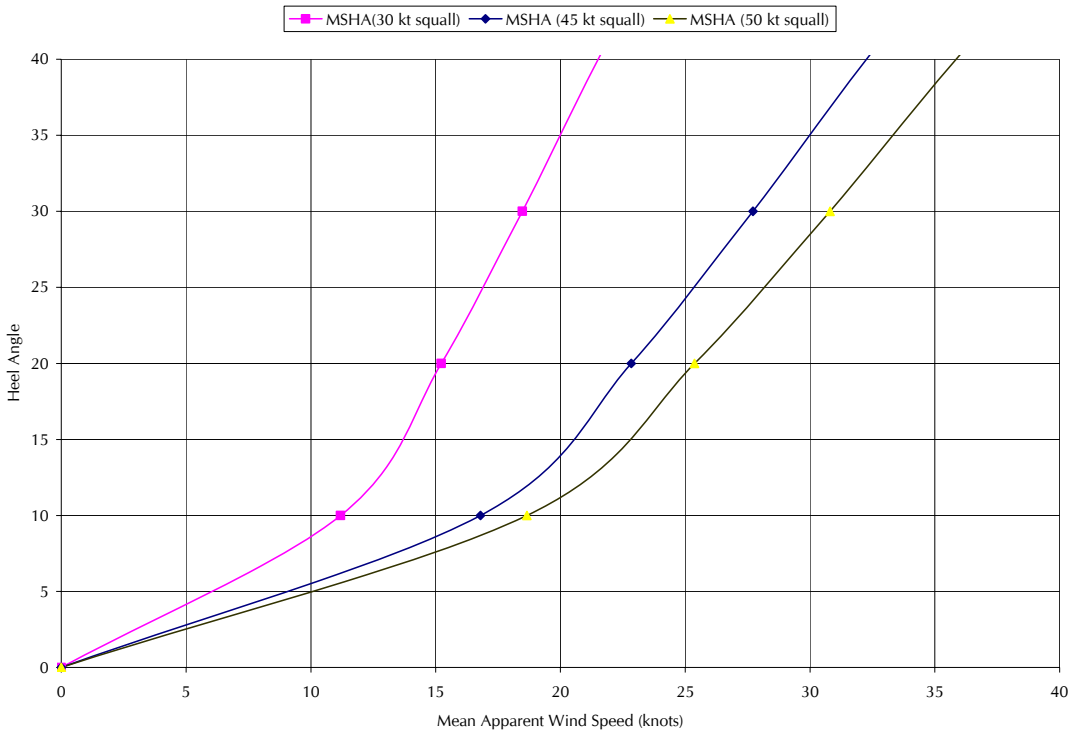
Gusting Conditions

When sailing in a steady wind, the vessel heels to the angle at which the heeling arm (HA) curve intersects the righting arm (GZ) curve. When struck by a gust the heel angle will increase to the intersection of the gust heeling arm curve with the GZ curve. The heeling moment increases in proportion to the square of the apparent wind speed.

Operation of the vessel at a Mean Wind Heel Angle less than 35° ensures critical downflooding openings would not be immersed if it were to encounter the strongest gust, in the prevailing turbulent airstream, which could exert a heeling moment equal to twice that of the mean wind (ie mean apparent wind has increased in velocity by $1.4 = \sqrt{2}$).

Maximum Steady Heel Angle to Prevent Downflooding in Squalls

Figure 4: Maximum Steady Heel Angle, Squalls



Squall Conditions

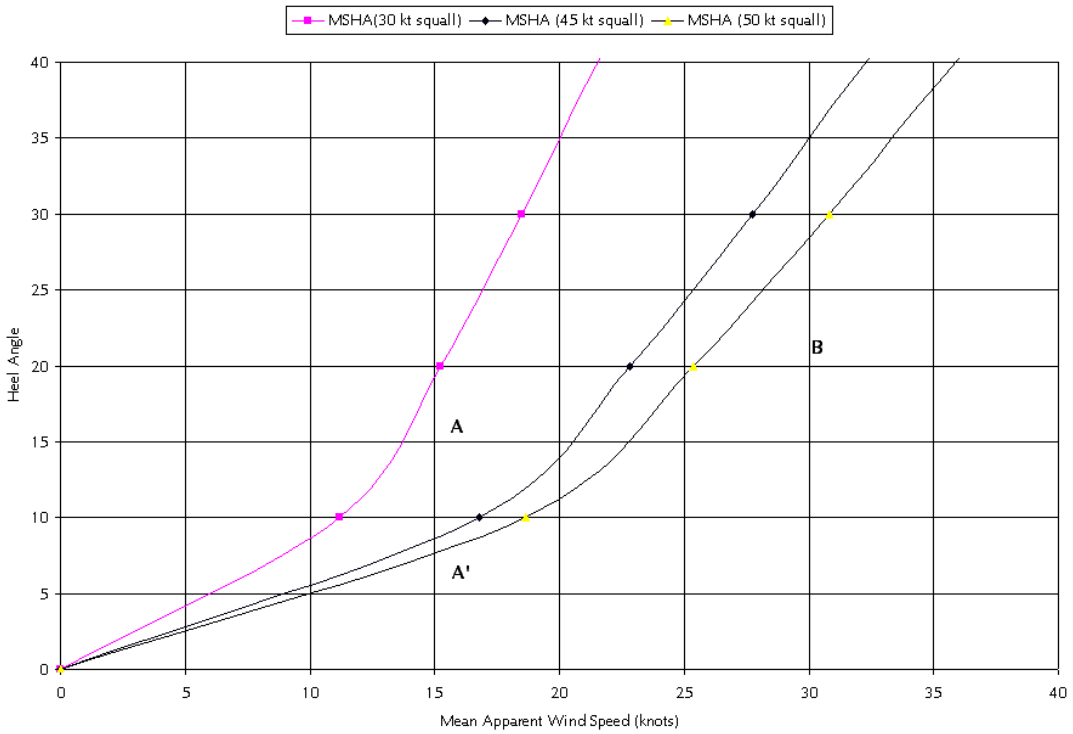
Curves of maximum steady heel angle indicate the range of mean or steady heel angles beyond which the vessel will suffer downflooding in the event of a squall.

In Figure 4, the MSHA (30 knot squall) line joins the combinations of mean heel angle and mean apparent wind speed at which a 30 knot squall would push the vessel to a heel angle of 60° (the assumed downflooding angle). For example, a BCC28 sailing to an apparent wind of 11 knots with sails set such that the boat is heeled to 10°, would be heeled to 60° by a 30 knot squall, and knocked down further by squalls of 45 or 50 knots. A BCC28 sailing to winds of 20 knots with sails set such that the boat is heeled to 20° would not be knocked to 60° by a 30 knot squall (ie the intersection of 20 knots and 20° is below the MSHA (30 knot squall) line), but squalls of 45 or 50 knots would pose a danger of downflooding.

Operation of the vessel in cyclonic conditions, particularly in the hours of darkness, when severe squalls are imminent requires the recommended maximum steady heel angle to be reduced depending on the mean apparent wind speed in accordance with the curves presented above.

Using MSHA Curves

Figure 5: Maximum Steady Heel Angle Curves: Squalls



Example A

A BCC28 is reaching, with a steady apparent wind speed of 16 knots. The mean heel angle is 15° (point A). Forecasts and visible cumulo-nimbus clouds suggest squalls may be imminent. Plotting the heel angle and wind speed suggests that the vessel would be in danger of heeling to 60° (the assumed downflooding angle) in squalls in 30 knots. In order to increase safety from downflooding, say, to withstand squalls of up to 45 knots, sails should be handed or reefed to reduce the mean heel angle to 6° or less (point A').

Example B

A BCC28 is beating in gusty conditions with a mean apparent wind speed of 30 knots. The mean heel angle is 20° (point B). No squalls are expected. The heel angle is significantly less than 28°, the heel angle at which the deck floods, and also below the maximum recommended steady heel angle of 38°, so the boat has a good safety margin against downflooding in a strong gust. Plotting these values of wind speed and heel angle also indicates that the vessel would not be vulnerable to downflooding in a squall unless it resulted in a wind speed in excess of 50 knots. No need arises to reduce sail area on grounds of stability.

Technical Data and Loading Conditions

Draught, Freeboard, and Initial Static Stability

Table 4: Draught, Freeboard, and Initial Static Stability

Loading Condition	Departure	Arrival
Draught	1.486 m	1.463 m
Minimum Freeboard (F_m)	0.64 m	0.67 m
Longitudinal location of F_m	- 1.321 m	- 1.321 m
LCG	- 0.171 m	- 0.139 m
VCG	1.463 m	1.496 m
LCB	- 0.171 m	- 0.139 m
VCB	1.139 m	1.121 m

The lower surface of the volume of air trapped below deck that will just support the displacement of the boat is at an F_m of 0.33 m.

Tank Capacities

Table 5: Tank Capacities

Tank	Capacity		Mass	Specific Gravity	Max Breadth	M_{fs}
	litres (US gals)	m^3	tonnes	tonnes/m^3	m	tonne.m at 30° heel
1. Upper Fuel Tank	121 (32)	0.121	0.104	0.86	0.609	0.0026
2. Lower Fuel Tank	98 (26)	0.098	0.084	0.86	0.310	0.0009
3 Aft Freshwater Tank	83 (22)	0.083	0.083	1.021	0.406	0.002
4. Fore Freshwater Tank	83 (22)	0.083	0.083	1.021	0.406	0.002
5. Sewage Holding Tank	60.5 (16)	0.061	0.061	1.025	0.711	0.002

Small tanks, meaning tanks with M_{fs} less than one-thousandth of the minimum vessel displacement at an angle of heel of 30°, contribute little to vessel instability when 50% slack. All of the tanks listed above have M_{fs} less than 0.063 and can be regarded as small tanks.

Loading Conditions and GZ Curves

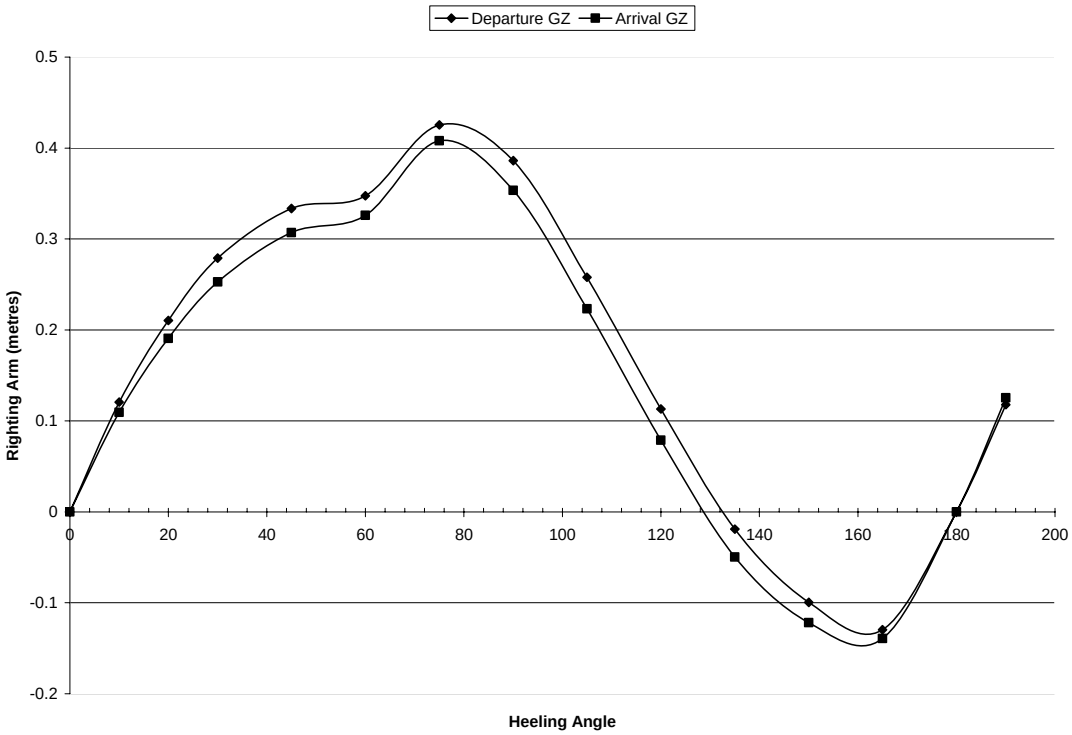
GZ (righting arm) curves for two loading conditions are shown below for angles of heel between 0 and 190 degrees (Figure 6).

Table 6: Loading Conditions

Loading Condition	Displacement (tonnes)	Assumptions
Departure condition	6.498 t	four crew (two below decks) their duffel, full tanks and generous stores
Arrival condition	6.169 t	four crew (two below decks), their duffel, 20% of liquids and half the stores

The GZ curves assume a standard Bristol Channel Cutter 28. The study (see Appendix 3) was performed on 4 February 2002 by Raymond H. Richards, a professional engineer registered in the state of Washington, USA.

Figure 6: Righting Arm (GZ) Curves



The study showed that a standard Bristol Channel Cutter 28 exhibits a range of positive stability to about 132° in the Departure condition and 128° in the Arrival condition. In both loading conditions, the positive area under the righting arm curve greatly exceeds the negative area.

Changing from the standard specifications usually changes the GZ curve for the worst. Adding mass above the waterline (eg jib roller-furling gear, mast steps, radar antenna, and deck-mounted dinghy) and reducing mass below the waterline (eg less lead ballast) will raise the Centre of Gravity.

Table 7: Righting Arm (GZ) Curve markers

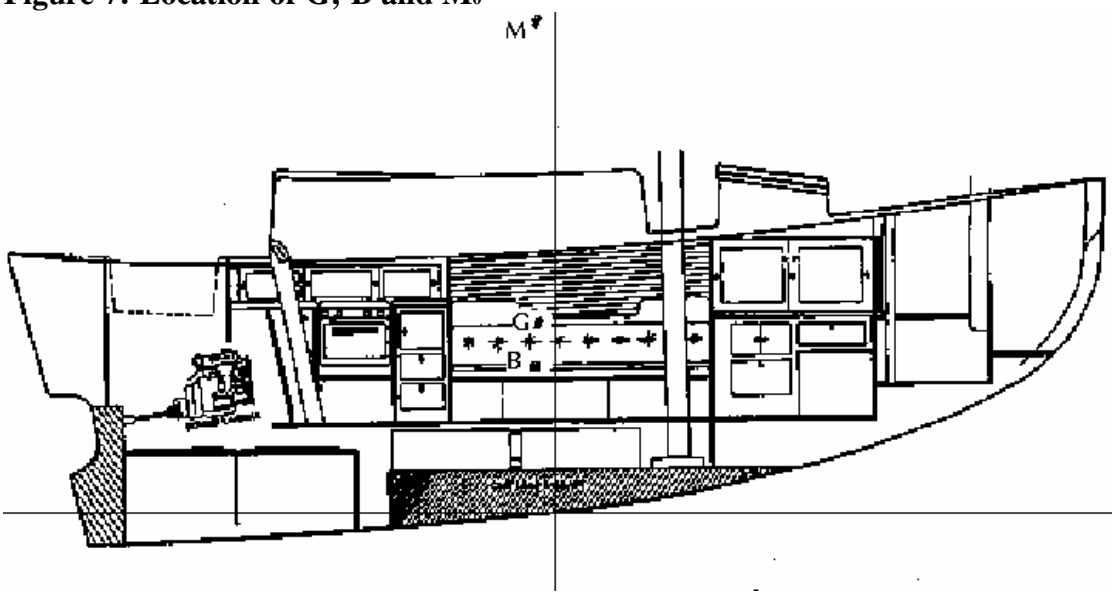
Loading Condition	Departure	Arrival
Righting Arm Maximum	0.429 m at 78°	0.409 m at 78°
Righting Arm Minimum	- 0.135 m at 162°	- 0.148 m at 159°
Righting Arm at heel of 30°	0.279 m	0.253 m
Angle of Vanishing Stability	132.2°	128.5°
GM_0	0.695 m	0.631 m
Area under GZ curve up to 30°	4.759 m.radians	4.313 m.radians
Area under GZ curve up to 40°	7.79 m.radians	7.09 m.radians
Area between 30° & 40°	3.03 m.radians	2.78 m.radians
Ratio of pos've : neg've area	8.86:1	6.77:1

A GZ curve defines static stability, when the yacht is stationary in smooth water, not dynamic stability.

Desirable GZ curves have:

- steep slope at 0 – 10° heel, showing resistance to small heeling moments;
- large maximum Righting Arm;
- large Righting Arm at 90° heel, showing the amount of moment available to right the boat when knocked down;
- large Angle of Vanishing Stability (not less than 130° - 2Δ);
- small minimum Righting Arm, indicating the size of wave that would roll the inverted boat over (best if less than half RA_{max});
- slope of curve at 170 - 180° heel should be less steep than at 0 – 10°;
- large positive area, representing a large amount of energy needed to capsize the boat;
- small negative area, representing the energy needed to roll the boat back up;
- large ratio of positive area to negative area, representing the ratio between the size of wave needed to capsize the boat to the size of wave needed to right an inverted boat.

Figure 7: Location of G, B and M_0



Reference Information

Calculating Free Surface Moments

When a tank is completely filled with liquid, no movement of the liquid is possible and the effect on the ship's stability is the same as if the tank contained solid material.

Immediately a quantity of liquid is withdrawn from the tank the situation changes and the stability of the ship is adversely affected by what is known as the 'free surface effects'. This adverse effect on the stability is referred to as a 'loss in GM' or as a 'virtual rise in VCG' and is calculated as follows:

Eqn 2: *Loss in GM due to Free Surface Effects*

$$= \frac{\textit{Free Surface Inertia } (m^4) \textit{ x Density of Liquid in Tank } (Tonnes/m^3)}{\textit{Displacement of Vessel (Tonnes)}}$$

$$= \frac{\textit{Free Surface Moment (Tonne.m)}}{\textit{Displacement of Vessel (Tonnes)}}$$

The free surface moments (M_{fs}) listed in Table 4 refer to isolated tanks, not those that are cross-coupled.

In general, tanks with maximum breadth of or greater than 60% of the vessel's maximum beam contribute significantly to stability. Small tanks, defined as tanks with M_{fs} less than 0.01 of the minimum displacement of the vessel, contribute insignificantly to loss of stability.

To determine free surface corrections, the tanks assumed slack should be those which develop the greatest free surface moment, M_{fs} at a 30^0 inclination, when 50% full.

The value of M_{fs} for each tank may be derived, using the 'k coefficient' technique:

Eqn 3: $$M_{f.s.} = vb\gamma k\sqrt{\delta}$$

where:
M_{fs} = free surface moment at a 30^0 inclination in meter-tons;
v = tank total capacity in m^3;
b = tank maximum breadth in m;
γ = specific weight of liquid in the tank in t/m^3;
$\delta = \frac{v}{blh}$ = tank block coefficient;
h = tank maximum height in m;
l = tank maximum length in m; and

k = dimensionless coefficient, associated with the ratio b/h, determined from a table published by the IMCO (see Appendix 2).

Small tanks need not be included in computations if they satisfy the following condition using the value of k corresponding to the angle of inclination of 30^0:

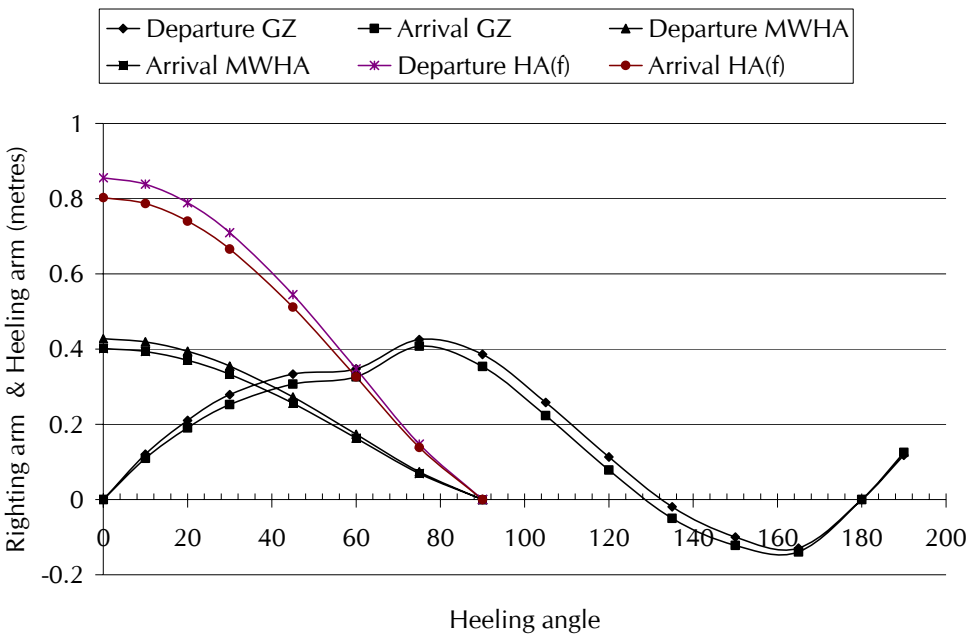
Eqn 4: $$\nu b \gamma k \sqrt{\delta} < 0.01 \Delta_{min}$$

where:
Δ_{min} = minimum ship displacement in tonnes (metric tons).

The usual remainder of liquids in the empty tanks is not taken into account in computation.

Deriving the Maximum Steady Heel Angle to Prevent Downflooding in Gusts

Figure 8: Mean Wind Heeling Arm and Downflooding Heeling Arm



Eqn 5: $$HA_1 = \frac{GZ_1}{\cos^{1.3}\theta_f}$$

where:
HA_1 = magnitude of the actual wind heeling lever at 0° that would cause the ship to heel to the downflooding angle (θ_f), or 60°, whichever is least;
GZ_1 = magnitude of the righting lever of the ship's GZ curve at the downflooding angle, or 60°, whichever is least;
HA_2 = mean wind heeling arm (MWHA) at any angle θ (= 0.5 x HA_1 x $\cos^{1.3}\theta$); and
θ_f = downflooding angle.

Deriving the Maximum Steady Heel Angle to Prevent Downflooding in Squalls

The wind heeling moment is proportional to the wind pressure, and to the apparent wind speed squared. It is also dependent upon the area, height, shape and camber of the sails, the apparent wind direction and the prevailing wind gradient.

As a sailing vessel heels, the wind heeling moment decreases. At any heel angle (θ) between 0° (upright) and 90°, the wind heeling moment (HM_θ) is related to the upright value by the function:

Eqn 6: $$HM_\theta = HM_0 \cos^{1.3}\theta$$

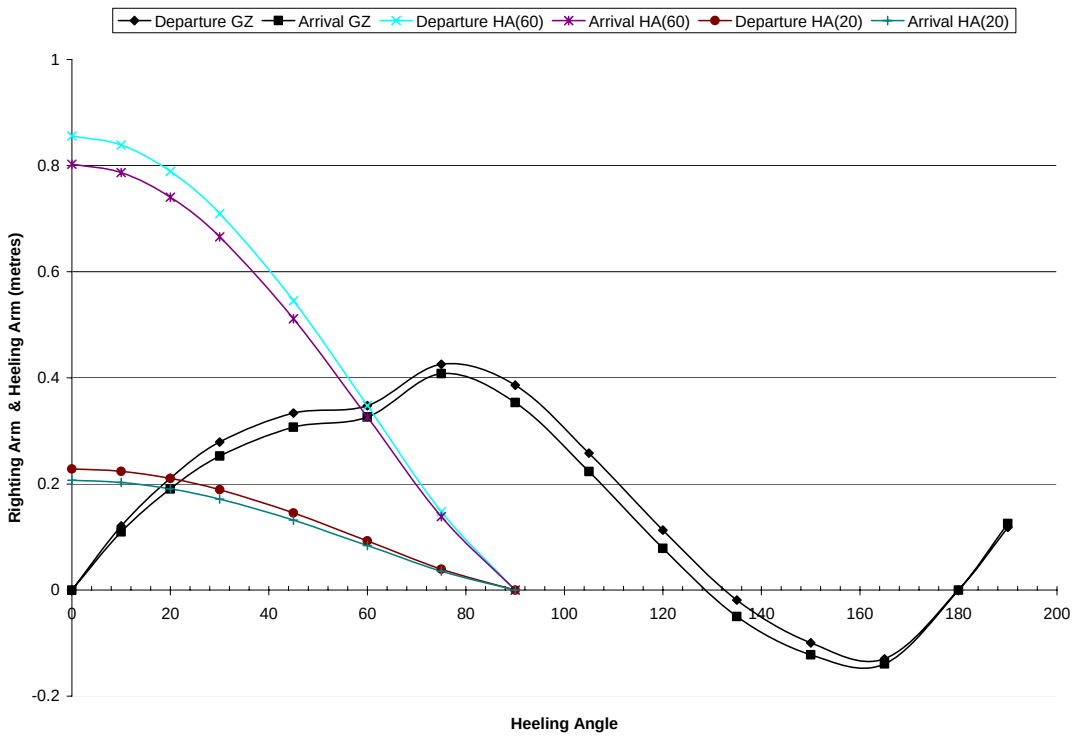
where:
HM_0 = The heeling moment when upright.

The heel angle of a sailing vessel corresponds to the intersection of the heeling arm (HA) curve with the righting arm (GZ) curve, where HA = HM/Displacement.

When subjected to a gust or squall, the vessel will heel to a greater angle such that the heeling arm curve corresponding to the gust wind speed intersects the GZ curve.

Thus for a given heel angle, a heeling arm curve may be deduced. For a given change in wind speed, the resulting change in heel angle can be predicted.

Figure 9: GZ curves, HA_{60} and HA_{20} curves



The vessel will suffer downflooding when the heeling arm curve intersects the GZ curve at the downflooding angle. The situation is illustrated in the diagram where the "heeling arm in squall" curve intersects the GZ curve at 60°. In a scenario

where sufficient sail is set to heel the vessel to the downflooding angle (60° should be used if the downflooding angle exceeds that value) in a squall of, say 45 knots, then the wind speed which would result in any lesser heel angle in these circumstances can be calculated. The upright heeling arm in the squall (HA_1) is derived from:

Eqn 7: $$HA_1 = \frac{GZ_f}{\cos^{1.3}\theta_f}$$

If the steady heel angle is 20° prior to the squall, the corresponding value of the upright heeling arm HA_2 can be calculated:

Eqn 8: $$HA_2 = \frac{GZ_{20}}{\cos^{1.3}20°}$$

The ratio HA_2/HA_1 corresponds to the ratio of wind pressures prior to the squall and in the squall. Thus if a squall speed (V_1) of 45 knots resulted in downflooding, the wind speed prior to the squall (V_2) that would result in a heel angle of 20° would be:

Eqn 9: $$V_2 = V_1 \sqrt{HA_2 / HA_1}$$

In this example, illustrated in Figure 9:

$\theta_f = 60°$
$GZ_f = 0.347$ metres (Departure condition) or 0.326 m (Arrival condition)
$HA_1 = 0.855$ metres (Departure condition) or 0.803 m (Arrival condition)
$GZ_{20} = 0.211$ metres (Departure condition) or 0.191 m (Arrival condition)
$HA_2 = 0.228$ metres (Departure condition) or 0.206 m (Arrival condition)
Hence $V_2 = 23.2$ knots (Departure condition) or 22.8 knots (Arrival condition).

Thus when sailing with an apparent wind speed of 23 knots at a mean heel angle of 20°, an increase in the apparent wind speed to 45 knots from the same apparent wind angle would result in downflooding if steps could not be taken to reduce the heeling moment.

These values correspond to a point on the 45 knot squall curve (Figure 4) which was derived from a series of such calculations using different steady heel angles. Similarly the curves for other squall speeds were derived using different values for V_1.

These calculations have been performed for both loading conditions and the results corresponding to the Arrival condition presented in this booklet.

Beaufort Scale of Wind Speeds and Corresponding Pressures

Table 8: Windspeed and Pressure

Beaufort Number	General Description	Wind Speeds (knots)	Wind Pressure (kg.f/m^2)
1	Light Air	1 to 3	0.02 - 0.2
2	Light Breeze	4 to 6	0.3 - 0.6
3	Gentle Breeze	7 to 10	0.8 - 1.7
4	Moderate Breeze	11 to 16	2.0 - 4.2
5	Fresh Breeze	17 to 21	4.8 - 7.3
6	Strong Breeze	22 to 27	8 - 12
7	Near Gale	28 to 33	13 - 18
8	Gale	34 to 40	19 - 26
9	Strong Gale	41 to 47	27- 37
10	Storm	48 to 55	38 - 50
11	Violent Storm	56 to 63	52 - 66
12	Hurricane	64 and above	68 and above

Metric-Imperial Conversion

Table 9: Metric-Imperial Conversion

MULTIPLY BY	TO CONVERT FROM	TO OBTAIN	
0.039370	mm	inches	25.4
0.39370	cm	inches	2.54
3.2808	m	feet	0.3048
2.2046	kg	lbs	0.45359
0.00098421	kg	Tons (2240 lbs)	1016.0
0.98421	tonnes(1000 kg)	Tons (2240 lbs)	1.016
2.4999	tonnes per cm	Tons per inch	0.40002
8.2017	tonnes metres units	Ton feet units	0.12193
187.98	Metre Radians	Foot Deg	0.0053198
	TO OBTAIN	**TO CONVERT FROM**	**MULTIPLY BY**

Relationships between Mass and Volume

1 cm^3 of fresh water (Specific Gravity = 1.0) = 1 gram
1000 cm^3 of fresh water (S.G. = 1.0) = 1 kg (1000 grams)
1 m^3 of fresh water (S.G. = 1.0) = 1 tonnes (1000 kg)
1 m^3 of salt water (S.G. = 1.025) = 1.025 tonnes (1025 kg)
1 tonne of salt water (S.G. = 1.025) = 0.975 metres^3
1 m^3 = 35.316 cubic feet
1 cubic foot = 0.0283 m^3

Appendices

Abbreviations

γ	specific gravity/specific weight
δ	block coefficient (of tanks = *v*/blh)
Δ_{min}	minimum displacement
<	less than
B	centre of buoyancy
b	maximum breadth (of a tank)
BCC28	Bristol Channel Cutter 28
cm	centimetres
F_m	minimum freeboard
ft	feet
G	centre of gravity
GM	height of metacentre above centre of gravity
GM_0	initial metacentric height (heel angle = 0°)
GZ	righting lever/arm
h	maximum height (of a tank)
HA	Heeling Arm
HM	Heeling Moment
IMCO	Intergovernmental Marine Consultative Organisation
k	a dimensionless constant (derived from an IMCO table)
kg	kilograms
kg.f	kilogram force
l	maximum length (of a tank)
lbs	pounds
LCB	Longitudinal Centre of Buoyancy
LCG	Longitudinal Centre of Gravity
LOA	Length Overall
LOD	Length on Deck
LWL	Length at Waterline, Load Waterline
M	metacentre
m	metres
m^2	square metres, metres squared
m^3	cubic metres; metres cubed
M_{fs}	Free Surface Moment
m.radians	metre-radians
MSHA	Mean Steady Heel Angle
MWHA	Mean Wind Heeling Arm
RA	Righting Arm
RA_{Max}	Maximum Righting Arm
RA_{Min}	Minimum Righting Arm
t	tonnes
TCG	Transverse Centre of Gravity
US gals	USA gallons
v	volume (of a tank)
VCB	Vertical Centre of Buoyancy
VCG	Vertical Centre of Gravity

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VALUES OF DIMENSIONLESS COEFFICIENT k FOR THE

COMPUTATION OF FREE SURFACE CORRECTION

$k = \frac{\sin\theta}{12}\left(1 + \frac{\tan^2\theta}{2}\right) \times b/h$ where $\cot\theta \geqslant b/h$

$k = \frac{\cos\theta}{8}\left(1 + \frac{\sin\theta}{b/h}\right) - \frac{\cos\theta}{32(b/h)^2}\left(1 + \frac{\cot^2\theta}{2}\right)$ where $\cot\theta \leqslant b/h$

Table 1

b/h	$\cot^{-1}(b/h)$	5°	10°	15°	20°	30°	40°	45°	50°	60°	70°	75°	80°	90°	b/h
20	(2.86°) 0.0833	0.11	0.12	0.12	0.12	0.12	0.10	0.09	0.09	0.07	0.05	0.04	0.03	0.01	20
10	(5.71°) 0.0833	0.07	0.11	0.12	0.12	0.11	0.10	0.10	0.09	0.07	0.05	0.04	0.03	0.01	10
5	(11.31°) 0.0833	0.04	0.07	0.10	0.11	0.11	0.11	0.10	0.10	0.08	0.07	0.06	0.05	0.03	5
3	(18.43°) 0.0834	0.02	0.04	0.07	0.09	0.11	0.11	0.11	0.10	0.09	0.08	0.07	0.06	0.04	3
2	(26.57°) 0.0839	0.01	0.03	0.04	0.06	0.09	0.11	0.11	0.11	0.10	0.09	0.09	0.08	0.06	2
1.5	(33.69°) 0.0847	0.01	0.02	0.03	0.05	0.07	0.10	0.11	0.11	0.11	0.11	0.10	0.10	0.08	1.5
1	(45.00°) 0.0884	0.01	0.01	0.02	0.03	0.05	0.07	0.09	0.10	0.12	0.13	0.13	0.13	0.13	1
0.75	(53.13°) 0.0944	0.01	0.01	0.02	0.02	0.04	0.05	0.07	0.08	0.12	0.15	0.16	0.16	0.17	0.75
0.5	(63.43°) 0.1100	0.00	0.01	0.01	0.02	0.02	0.04	0.04	0.05	0.09	0.16	0.18	0.21	0.25	0.5
0.3	(73.30°) 0.1570	0.00	0.00	0.01	0.01	0.01	0.02	0.03	0.03	0.05	0.11	0.19	0.27	0.42	0.3
0.2	(78.69°) 0.2205	0.00	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.04	0.07	0.13	0.27	0.63	0.2
0.1	(84.29°) 0.4279	0.0[illegible]	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.04	0.06	0.14	1.25	0.1