Tall Ship Stability

The art of not to capsize

„BOUNTY“ 2012

- Ship not suitable for intended voyage
- Ship maintenance neglected for years
- Pumps out of order
- Crew not familiar with portable emergency pump
- Went to sea even though having received a hurricane warning
- Misdecisions of the captain

→ Total Loss, 2 dead

„´CONCORDIA“ 2010

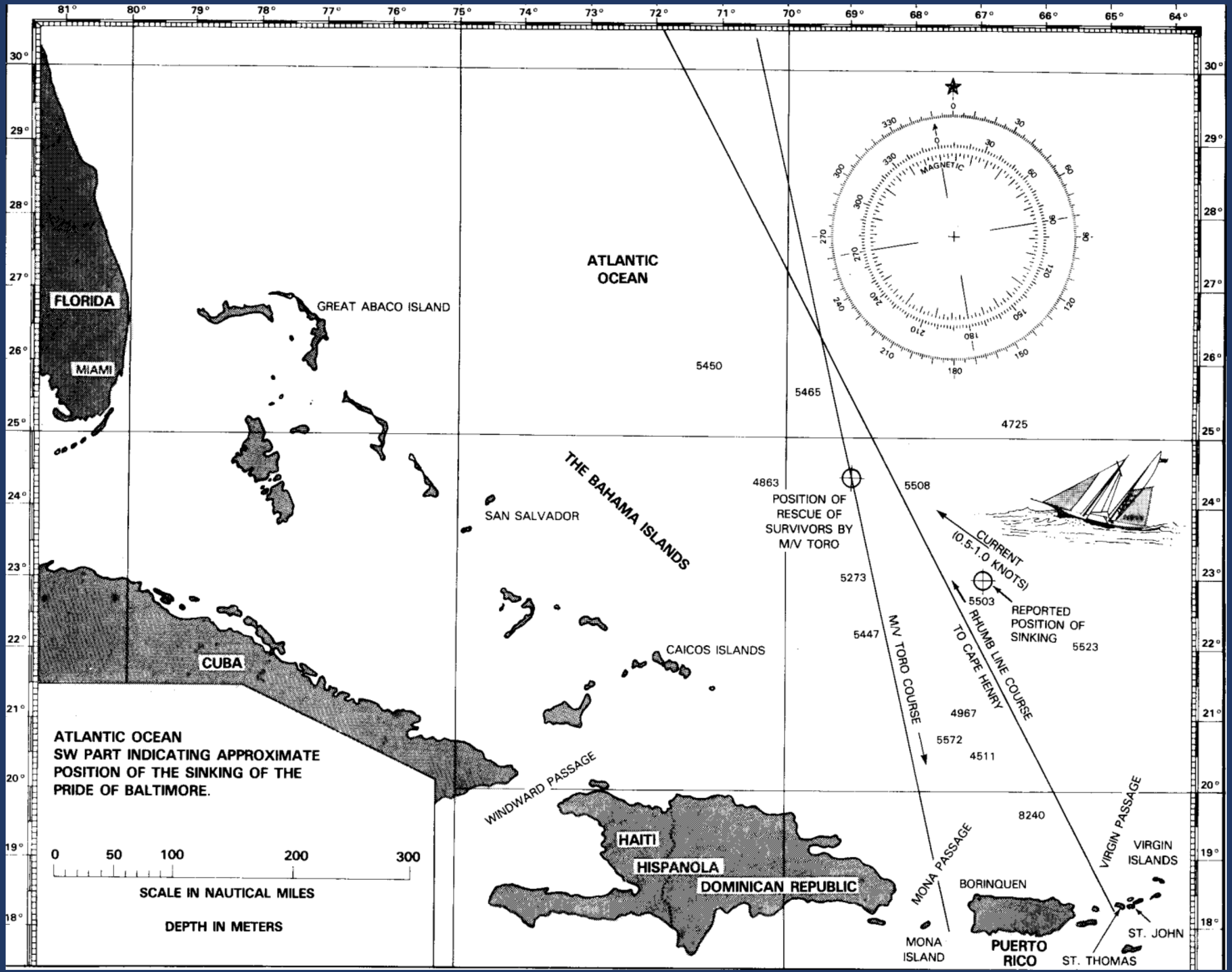
- Captain and officers misinterpreted ship‘s stability
- Reaction to wind increase and squalls too late
- Watertight integrity not sufficient
- Misleading instructions by master
- Master and mates not educated in tall ship stability
- No knockdown drills held

→ Total Loss, all survived after 36 hours in life rafts

„PRIDE OF BALTIMORE“ 1986

- Vessel stability insufficient
- Water ingress through open bulkheads on deck (open for better ventilation)
- Hatch cover not watertight and coamings too low → further water ingress
- Free surfaces

→ Total Loss, 4 dead



Further Stability Accidents

- „MARQUES“ 1984

Loss of stability due to several changes in ship‘s construction, water ingress due to insufficient watertight integrity (bulkheads and decklights open), freeing ports blocked to avoid noise, hatch not closed fully for better ventilation, step cut into coamings for easier access → Total loss, 19 dead

- „ALBATROSS“ 1961

Loss of stability due to several changes in ship‘s construction, water ingress due to insufficient watertight integrity (bulkhaeds and decklights open) → total loss, 6 dead

- „PAMIR“ 1957

Captain and chief mate miscalculate stability of the ship, cargo secured wrongly, too many sails set, Loss of stability due to several changes in ship‘s construction, water ingress due to insufficient watertight integrity (bulkhaeds and decklights open), ballast tanks not flooded, but filled with cargo → total loss, 80 dead

- „NIOBE“ 1932

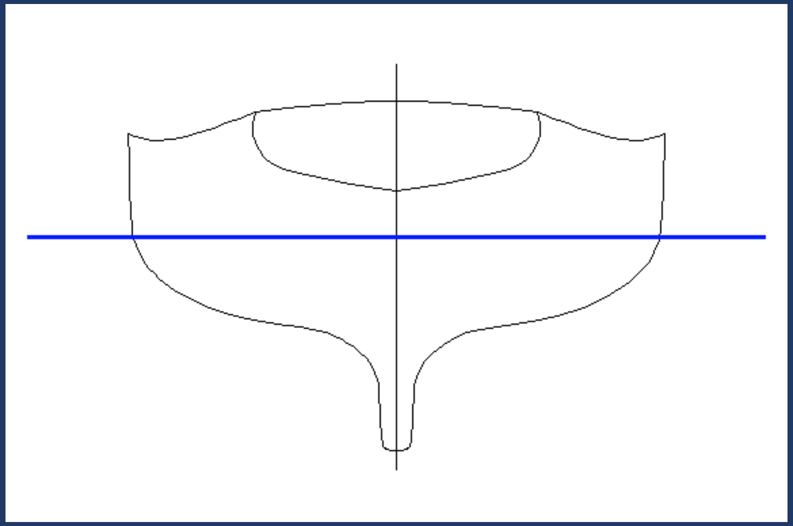
Loss of stability due to several changes in ship‘s construction, water ingress due to insufficient watertight integrity (bulkhaeds and decklights open), ballast tanks not flooded

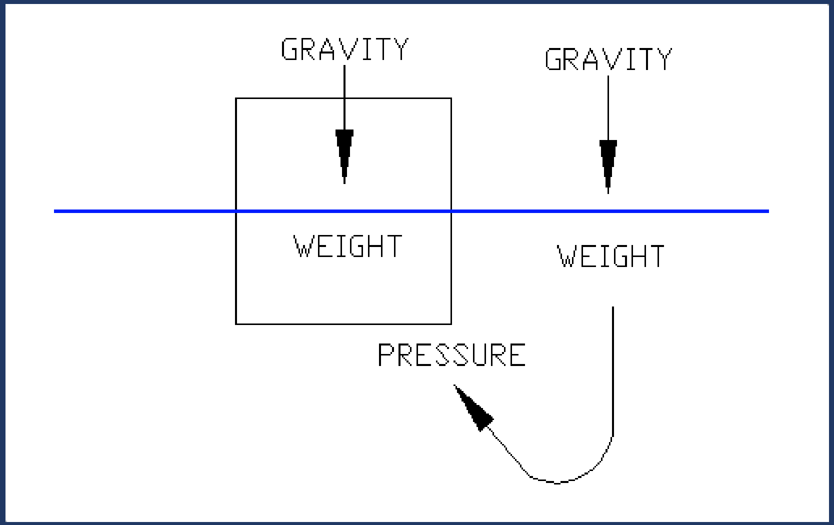
→ Total loss, 69 dead

What is stability?

Stability is the ability of the vessel to return into an upright position after a disturbance.

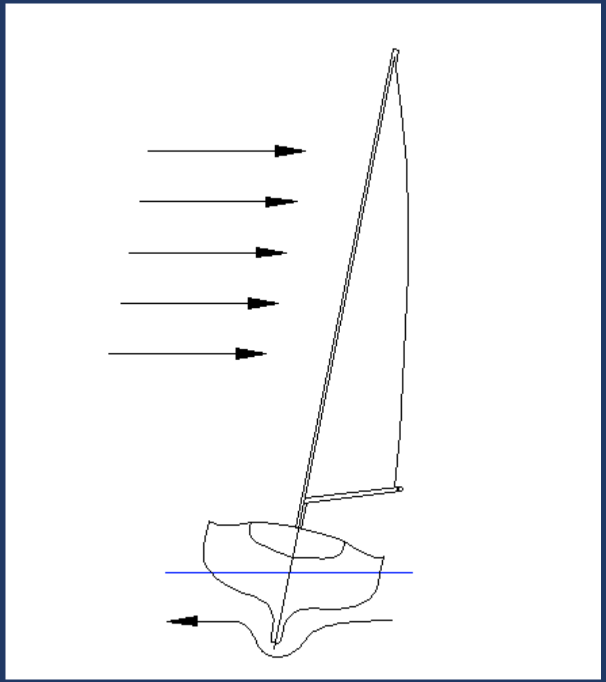
What is stability?

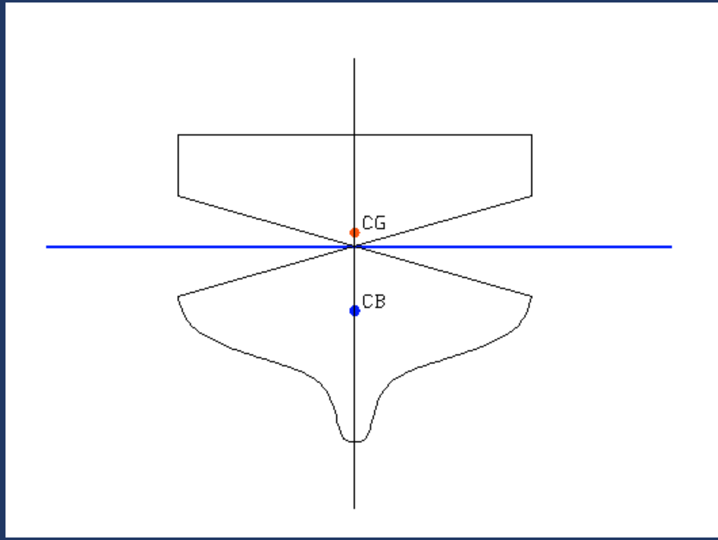


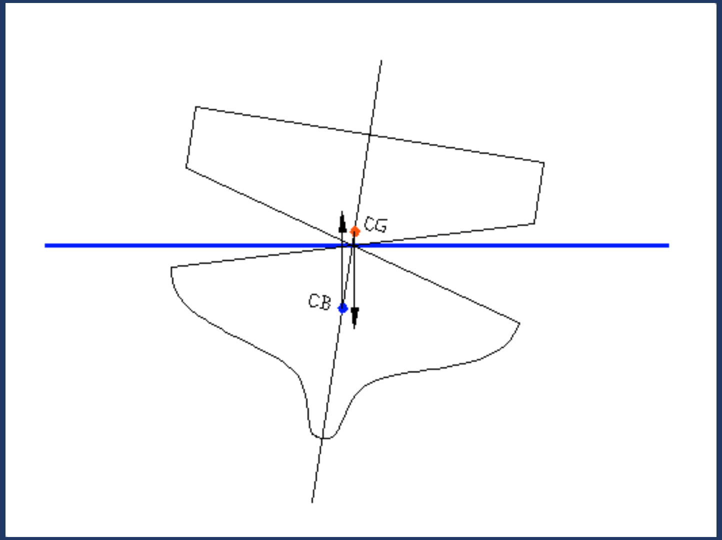


The vessel floats, because it's own weight equals the weight of the water that fits into the hole, it makes → this is called buoyancy (B).

What is stability?

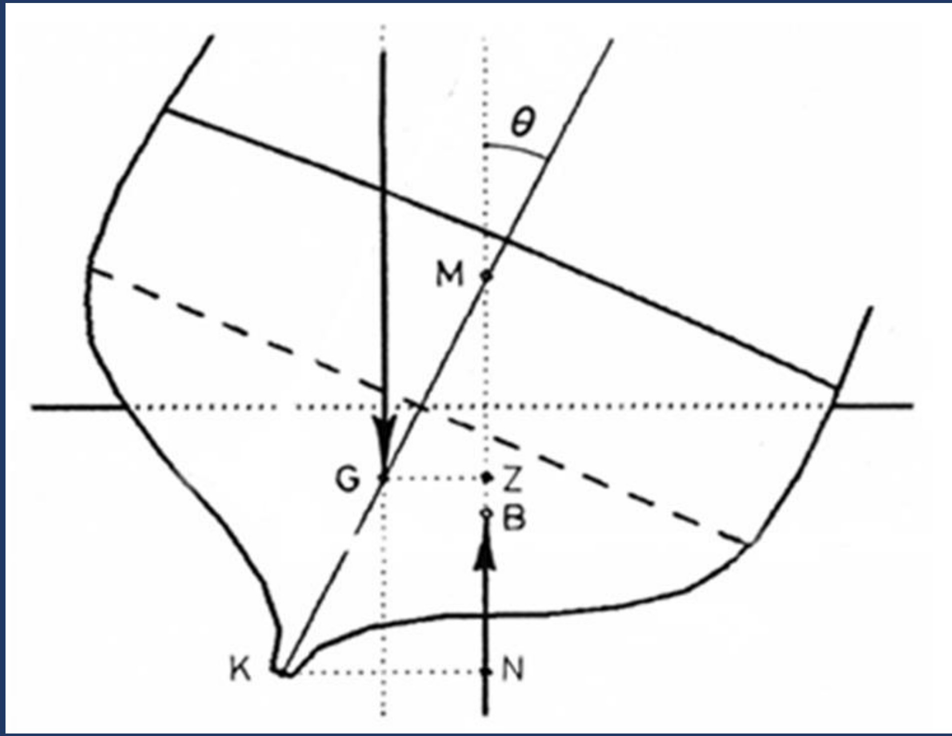






The center of Gavity (CG) is pressing the ship down, the center of buoyancy (CB) is pressing it up. The wind force is pressing it to the side.

What is stability?

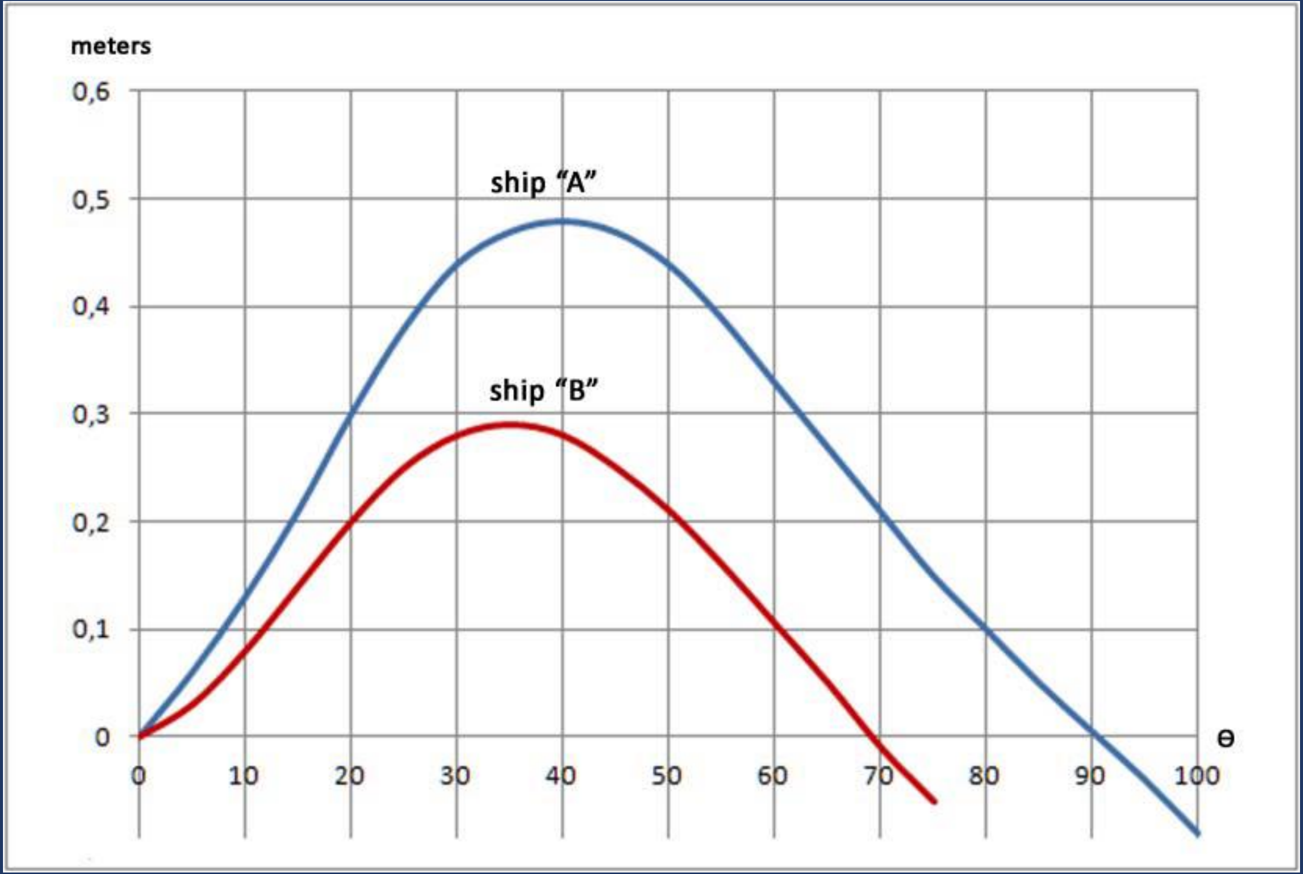


K	point of reference on baseline (keel)
G	Centre of gravity
M	Metacentre
B	Centre of buoyancy
Z	horizontal projection of G at a given heeling angle ϴ
N	horizontal projection of K at a given heeling angle ϴ

$$GZ = KN - (KG \times \sin \Theta)$$

What is stability?

GZ = KN – (KG x sin Ɵ)



Characteristic graphic of each ship is laid down in ship's papers.

What is stability?

Difficult calculations necessary....

			Meta-zentrum	=	6,805	(KMB)
Formschwerpunkt	38,94	(PF)	KG	=	5,79	
Gewichtsschwerpunkt	38,67	(PG)	GM	=	1,02	
Trimmender Hebelarm	-0,27	(ht)	corr.	=	0,04	
Trimmendes Moment	-837,20		GM corr.	=	0,98	
ETM	3315,00		Z 1 corr.	=	5,75	
Trimm	-0,253					

Bezeichnung	Masse	X	Z	Y	Mx	Mz
BESATZUNG und EFFEKTEN	6,00	38,70	9,60	NIL	232,20	57,60
PASSAGIERE und EFFEKTEN	4,00	35,00	12,00		140,00	48,00
DIESELÖL	225,00	31,21	3,16	NIL	7.021,29	711,75
SCHMIERÖL	4,00	36,00	6,00	NIL	144,00	24,00
HYDRAULIKÖL	0,70	36,00	5,00	NIL	25,20	3,50
BALLAST	266,00	45,16	1,18	NIL	12.013,09	313,45
FRISCHWASSER	186,00	43,34	3,25	NIL	8.062,16	604,58
ABWÄSSER	30,00	39,99	0,60	NIL	1.199,55	18,00
VORRÄTE	37,00	59,00	6,00	NIL	2.183,00	222,00
LEERES SCHIFF	2.291,00	37,93	6,83	NIL	86.897,63	15.647,53
VERDRÄNGUNG	3.049,70	38,67	5,79	NIL	117.918,1	17.650,41

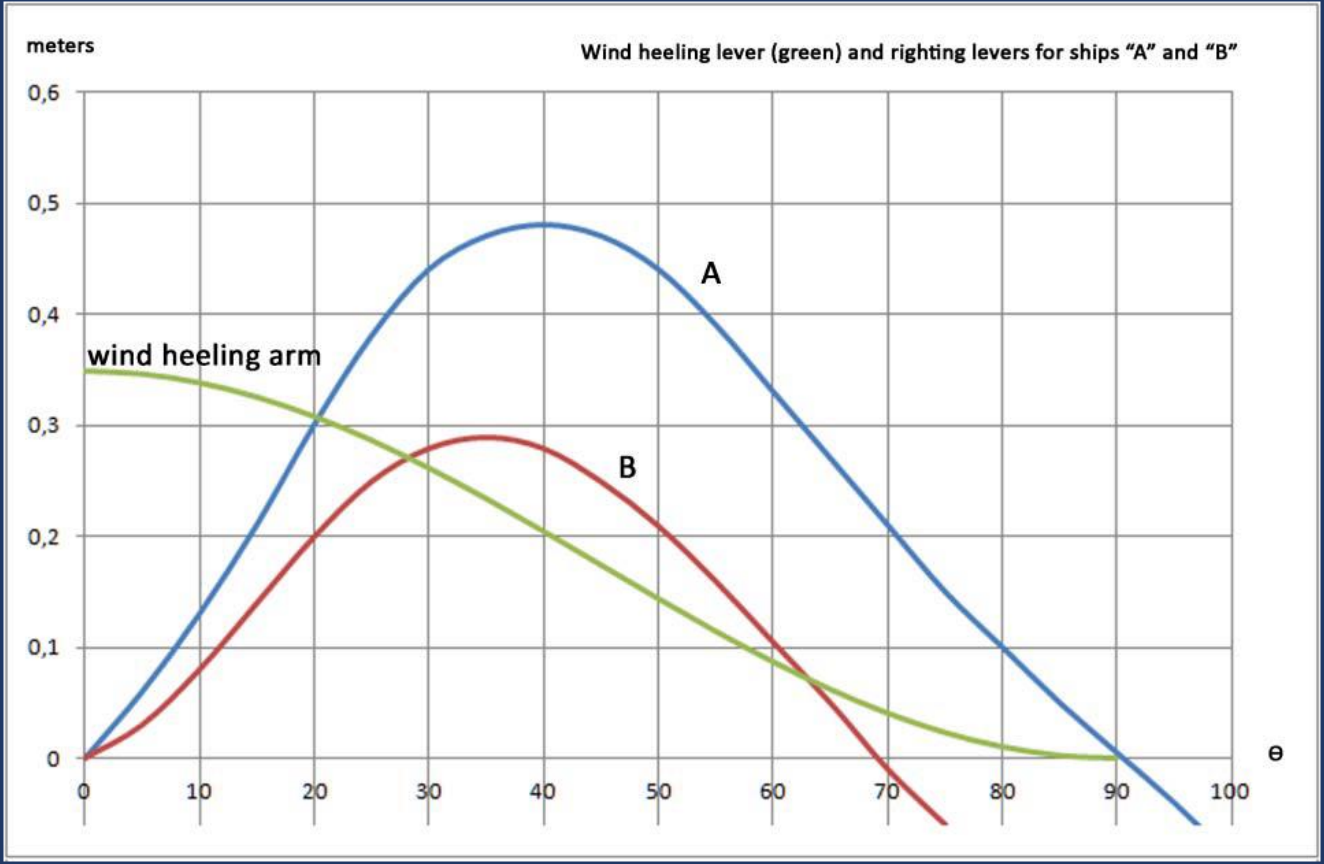
	Tiefgang bei Lpp/2		= 5,08			
		Fuß	m			
Berechnete Tiefgänge	Vorne:	16,25	4,95		Mittel	Trimm
	Achtern:	17,08	5,21		5,08	-0,253
Abgelesene Tiefgänge	Vorne:	15,75	5,11		Mittel	
	Achtern:	16,75	5,13		5,12	-0,020

	0°	10°	20°	30°	45°	60°	75°	90°
KN	0,000	1,182	2,355	3,504	4,926	5,710	6,001	5,861
KG x sin Θ	0,000	0,998	1,966	2,874	4,064	4,978	5,552	5,748
GZ	0,000	0,184	0,389	0,630	0,862	0,732	0,449	0,113

The Heeling Moment

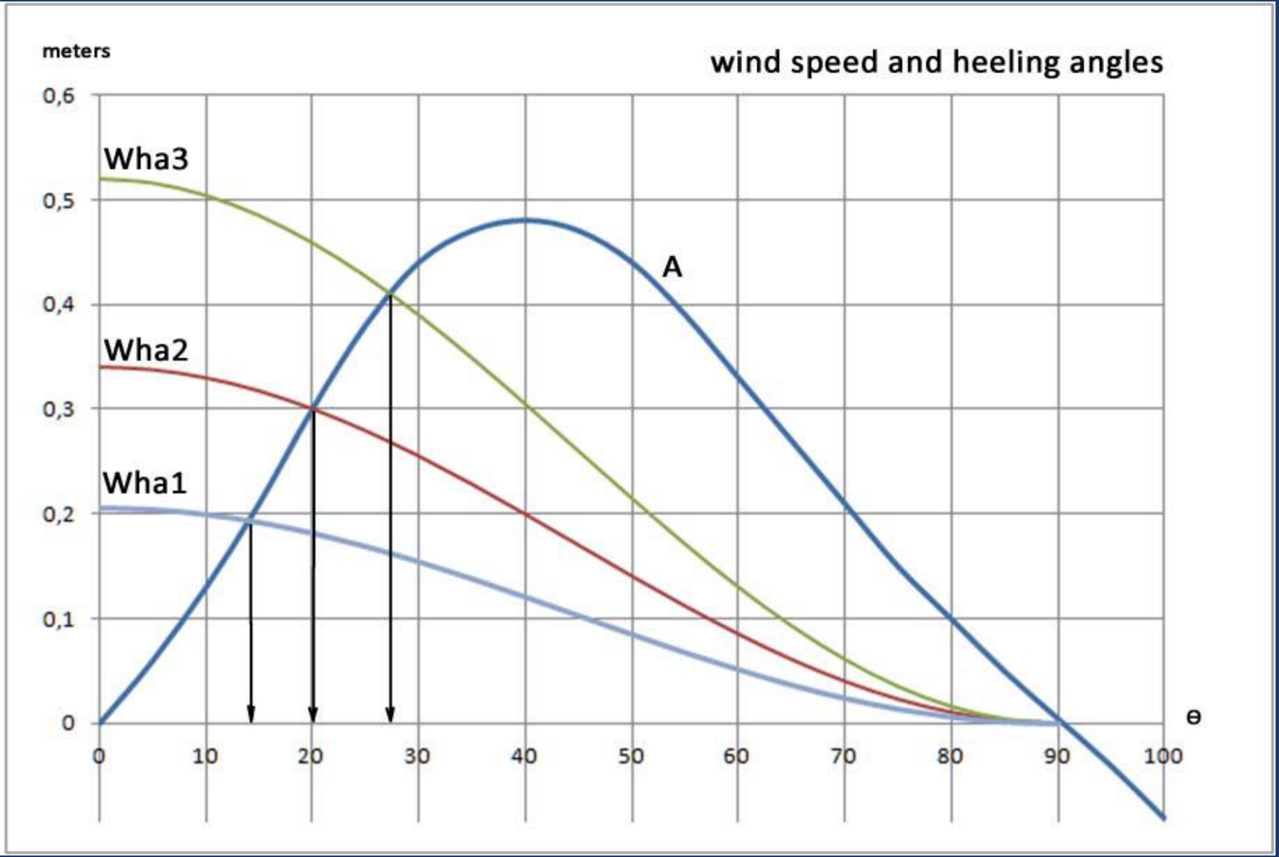
Another curve added:

The green line represents the heeling arm of a steady wind force.



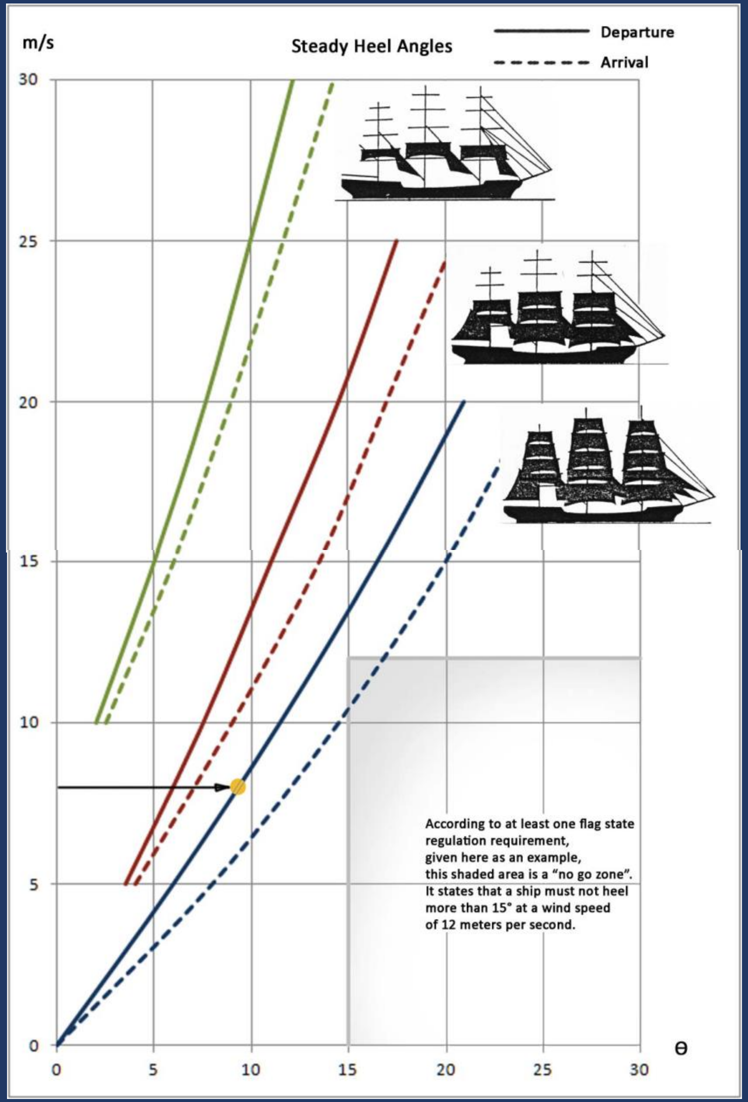
The Heeling Moment

Different heeling angles
at different wind speeds



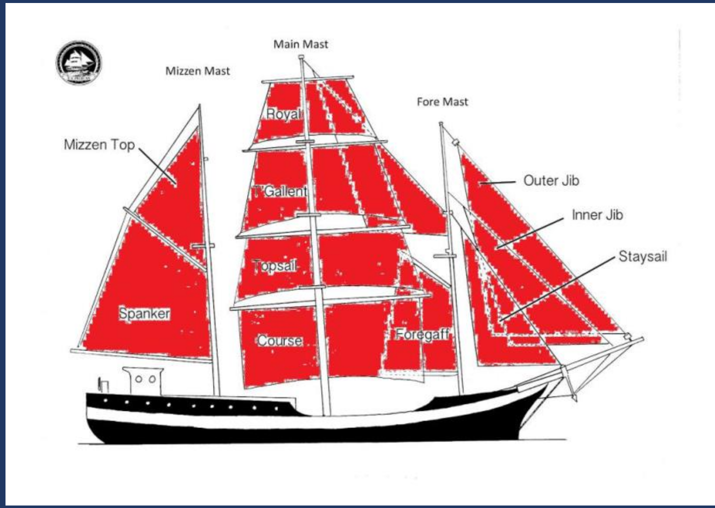
The Heeling Moment

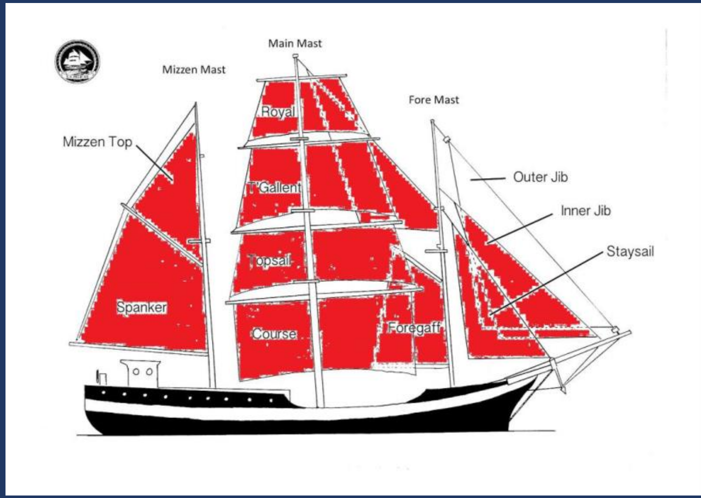
This ship, with all sails set and in departure condition, sailing in a steady wind of 8 m/s, may be expected to heel steadily to about 9°.

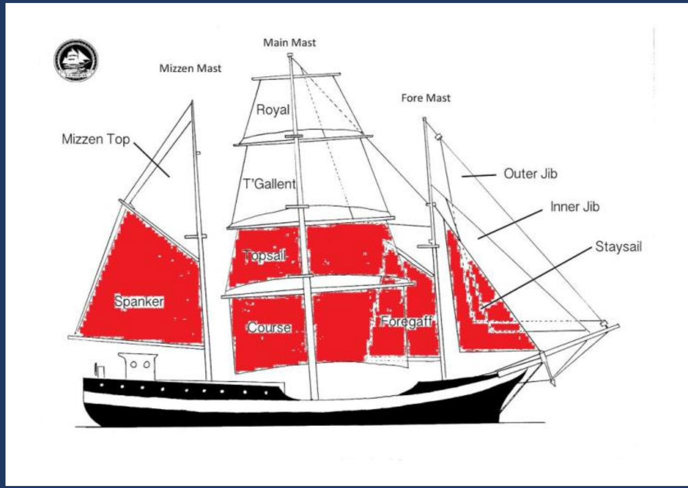


PELICAN OF LONDON

Whenever 16 degrees of steady heeling are reached, sails need to reduced!



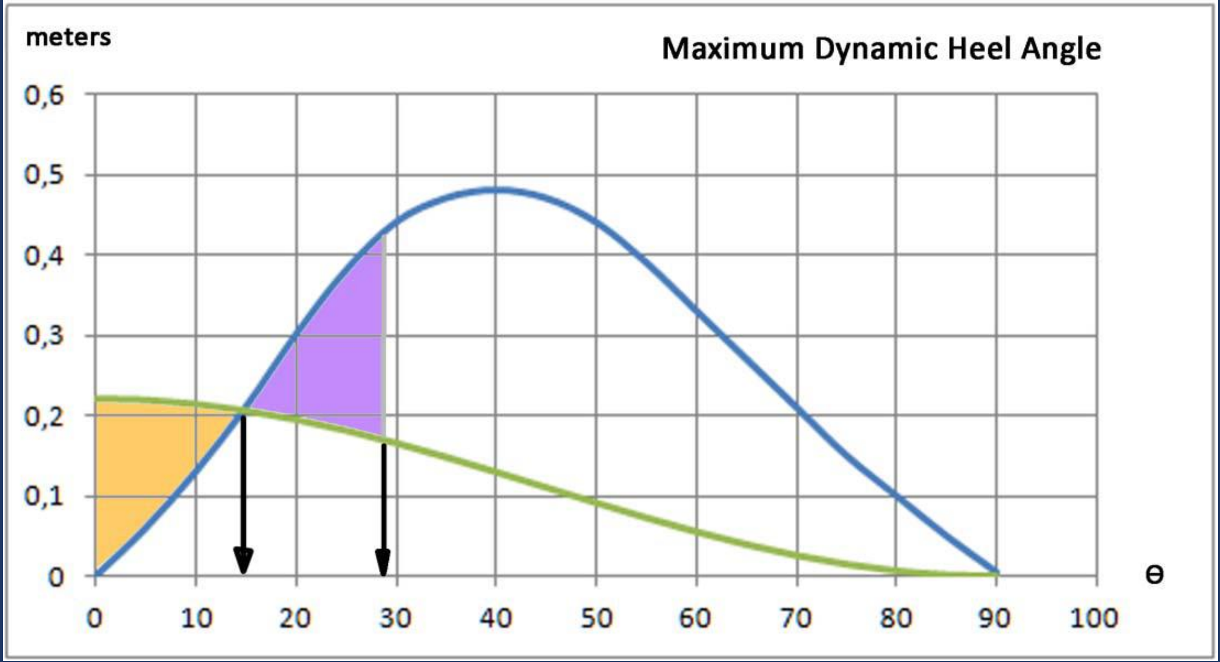




up to 16 kts - up to 22 kts - up to 35 kts

Dynamic Stability

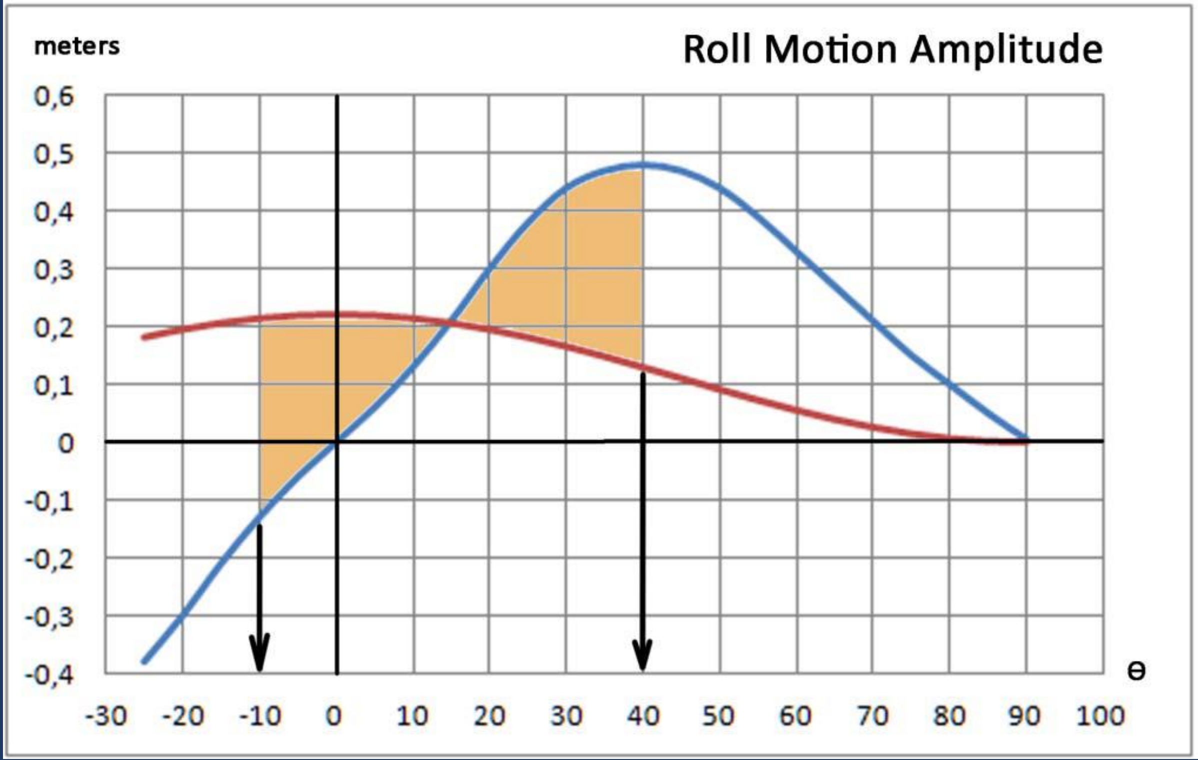
steady heeling angle (15°) and derived heeling angle due to the effect of dynamic forces (28°). The two coloured areas are roughly equal in size.



Roll Motion

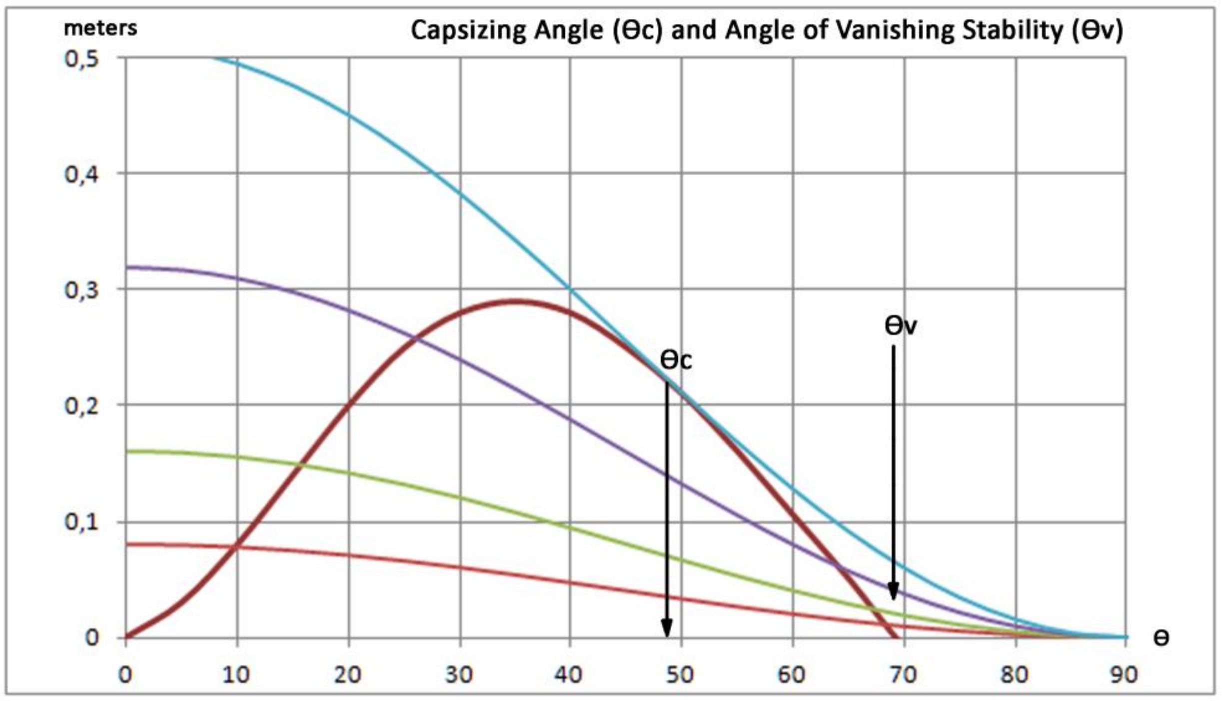
With a given steady heeling angle (15°) the roll motion may be assumed to be between 10° to windward and 40° to leeward (25° to each side).

The coloured areas are not necessarily equal in size.



The Real Threads

Capsize angle and angle of vanishing stability are two very different things.

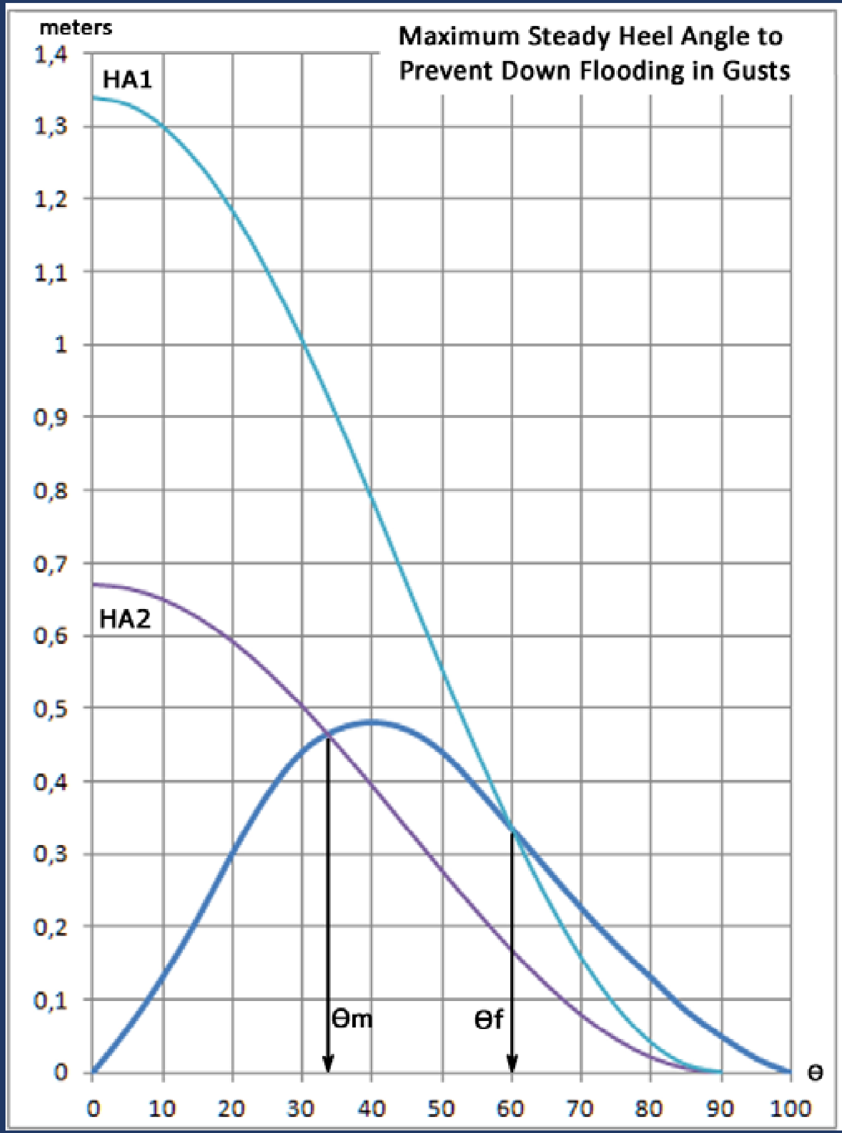


ϴi	angle of deck immersion
ϴf	downflooding angle
ϴc	capsize angle in a squall
ϴv	angle of vanishing stability

Staying Safe in a Gust

The heeling arm (HA1) in gusts to cause downflooding has been found to be:

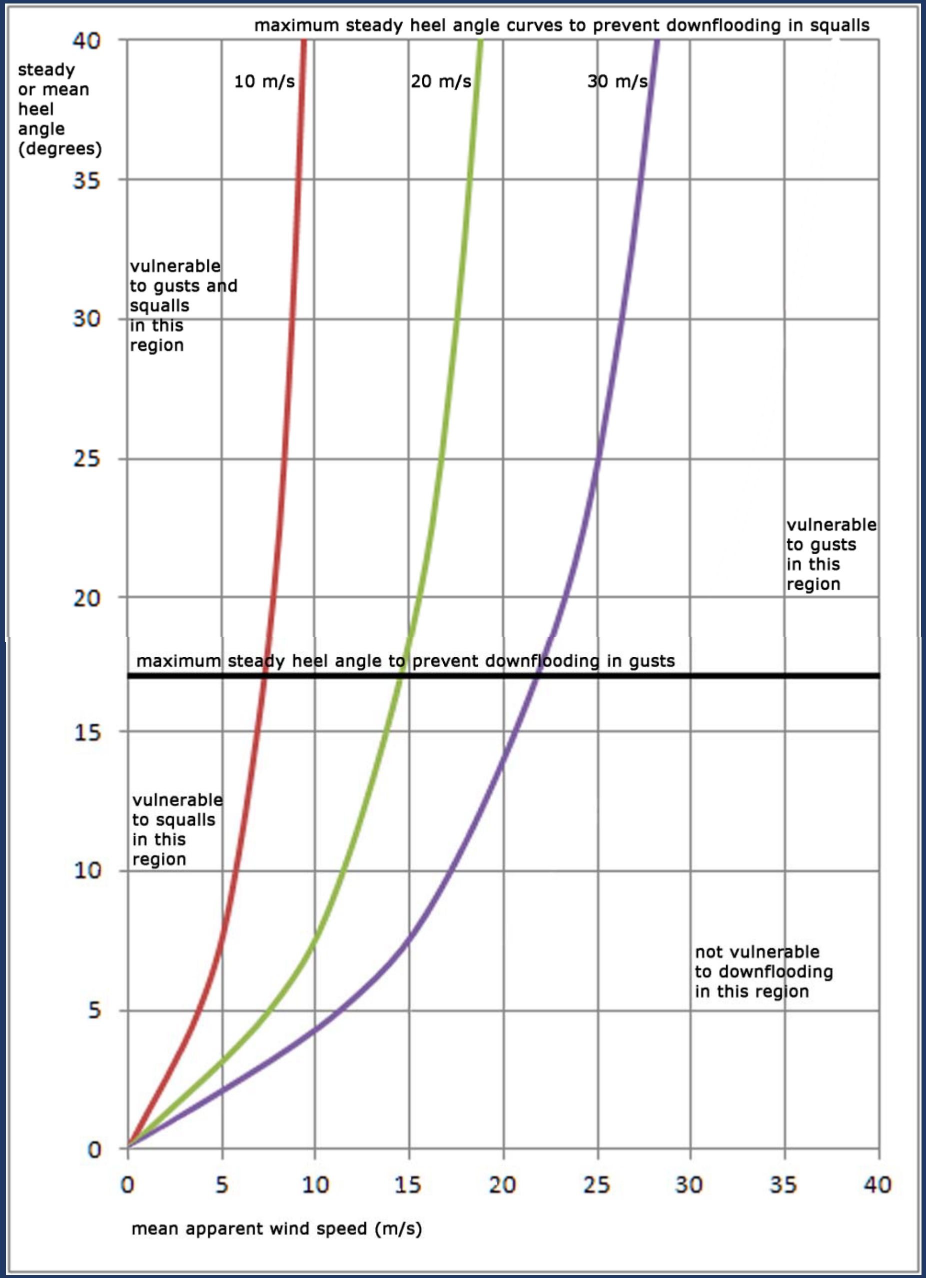
HA1 = GZf / cos 1.3 Θf



Staying Safe in a Gust

Curves of Maximum Steady Heel Angle to prevent down flooding in Squalls

V2	windspeed resulting in ϴX
V1	squall speed X (set to 10, 20, 30 m/s resp.)
HA1	heeling arm to cause ϴf
HA2	heeling arm resulting in ϴa
ϴa	arbitrary heeling angle

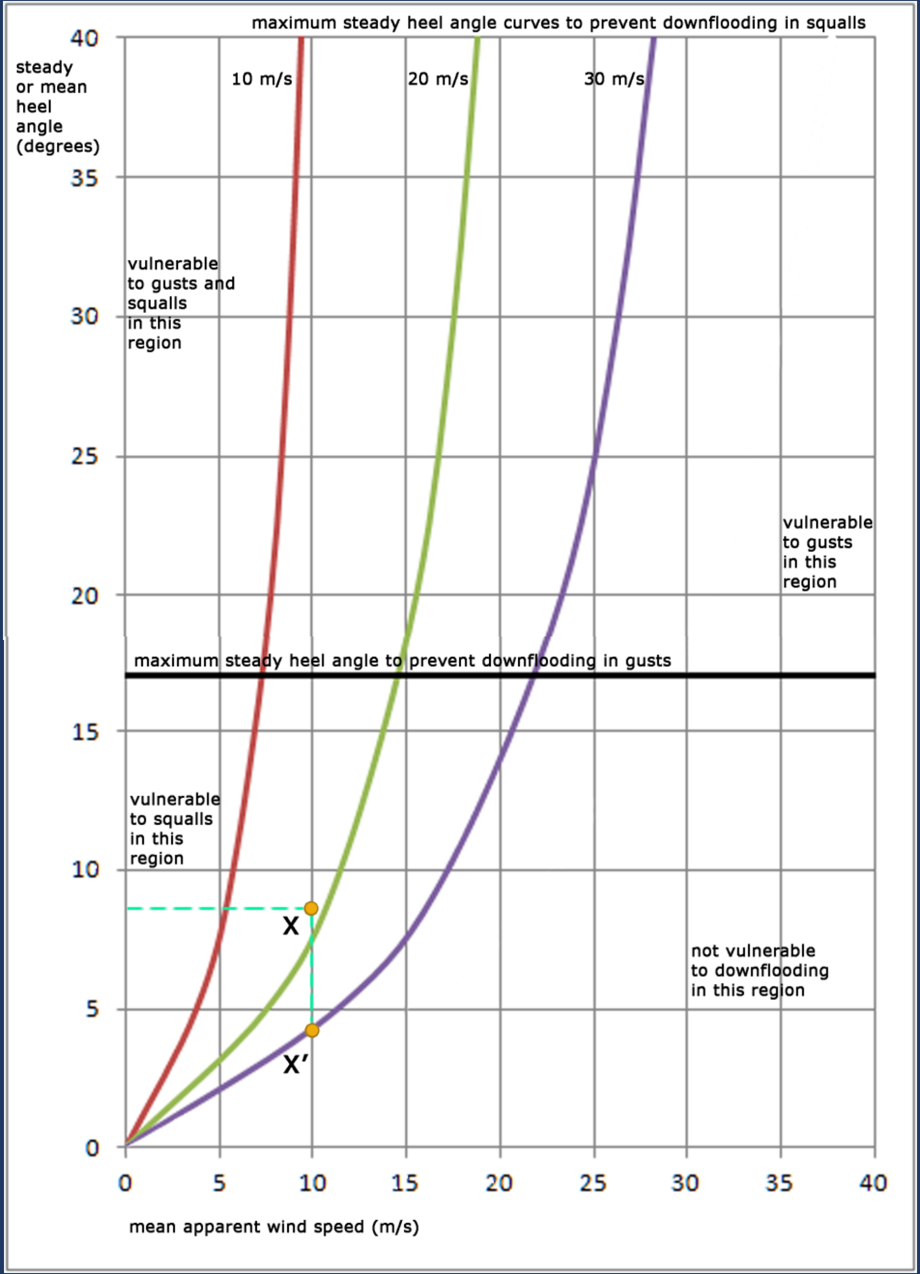


Staying Safe in a Gust

Ship "X" sailing with a mean heel of 8° in what averages to a wind speed of 10 m/s.

This ship will be in danger of heeling to the down flooding angle in squalls of close to 20 m/s.

By bringing down the mean angle of heel to 4° (at X') the same ship would be able to withstand a squall of up to 30 m/s.



If this is well-known, so why did the „CONCORDIA“ and the other ships sink?

Problems

- Mathematical calculations too complicated to perform them in the event of a sudden wind increase
- Stability booklet and tables available on board do not reflect the actual situation
- Wind force and wave height are not steady
- Wind is stronger in mast top than on deck
- Wind does not always blow horizontally; especially in squall it has a considerable vertical component
- Sails vary in effectiveness due to age, size and trim
- The largest heeling does not happen on a beam reach, but when sailing close-hauled
- Greatest care is needed when running downwind as this generates no heeling even in strong winds

What else compromizes stability?

- Structural changes without adjusting fixed ballast
- Changes to make the ship more comfortable or more attractive
- Additional sails that were not part of the original sail plan and calculations
- Wrong stowage of cargo
- Icing
- Free surfaces
- Water ingress
- Green water on deck
- Surfing
- Parametric rolling

What can we do to avoid capsizing?

- Keep our stability booklet up-to-date
- Accept to have less comfort for more safety
- Use only the sails that are part of the confirmed sail plan
- Stick to our watertight integrity scheme
- Never block freeing ports
- Keep port holes closed at sea
- Have aircon running instead of opening doors, hatches or port holes
- Avoid running downwind
- Change course if ship starts rolling heavily
- Use fore-and-aft sails to dampen rolling

Thank you for your attention