Intact Stability Analysis

GOLDEN RAY Capsizing



LT Ian Oviatt, P.E.

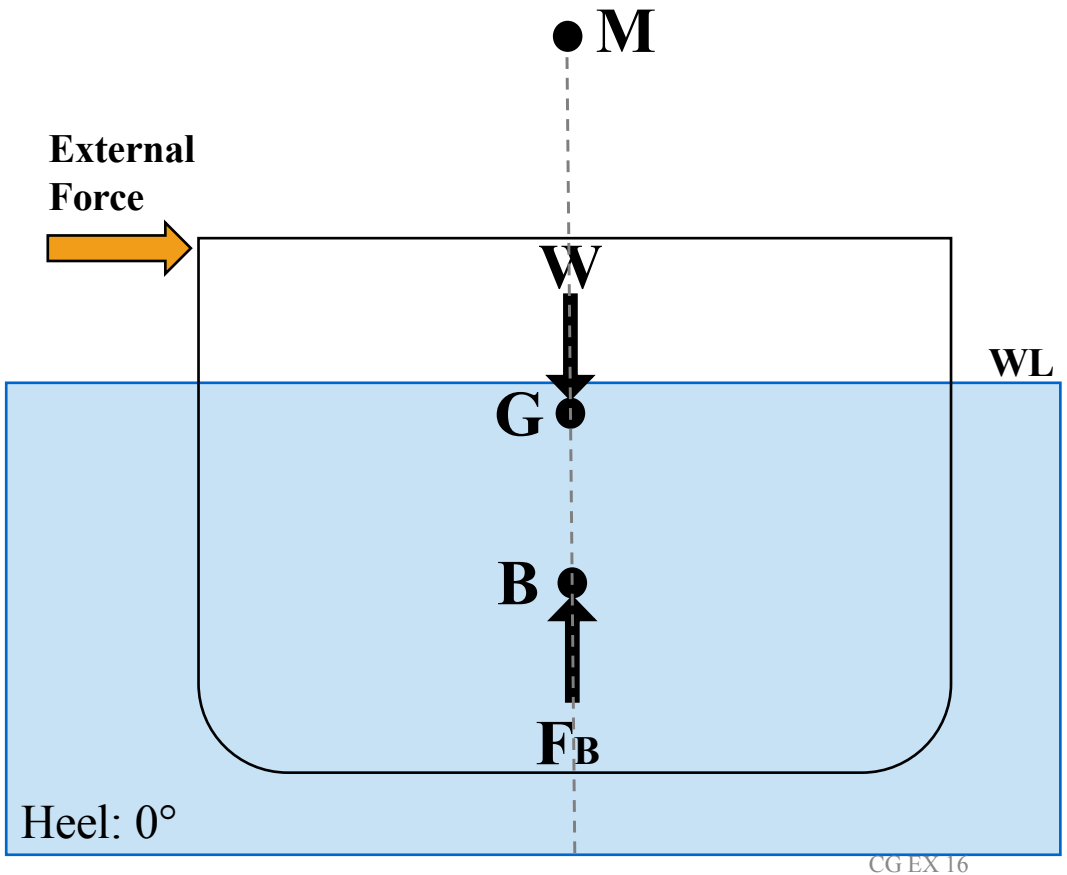
Agenda

- Education & Background
- Basic Theory
- Stability Model
- Results: Capsize Voyage
- Results: Preceding Voyages

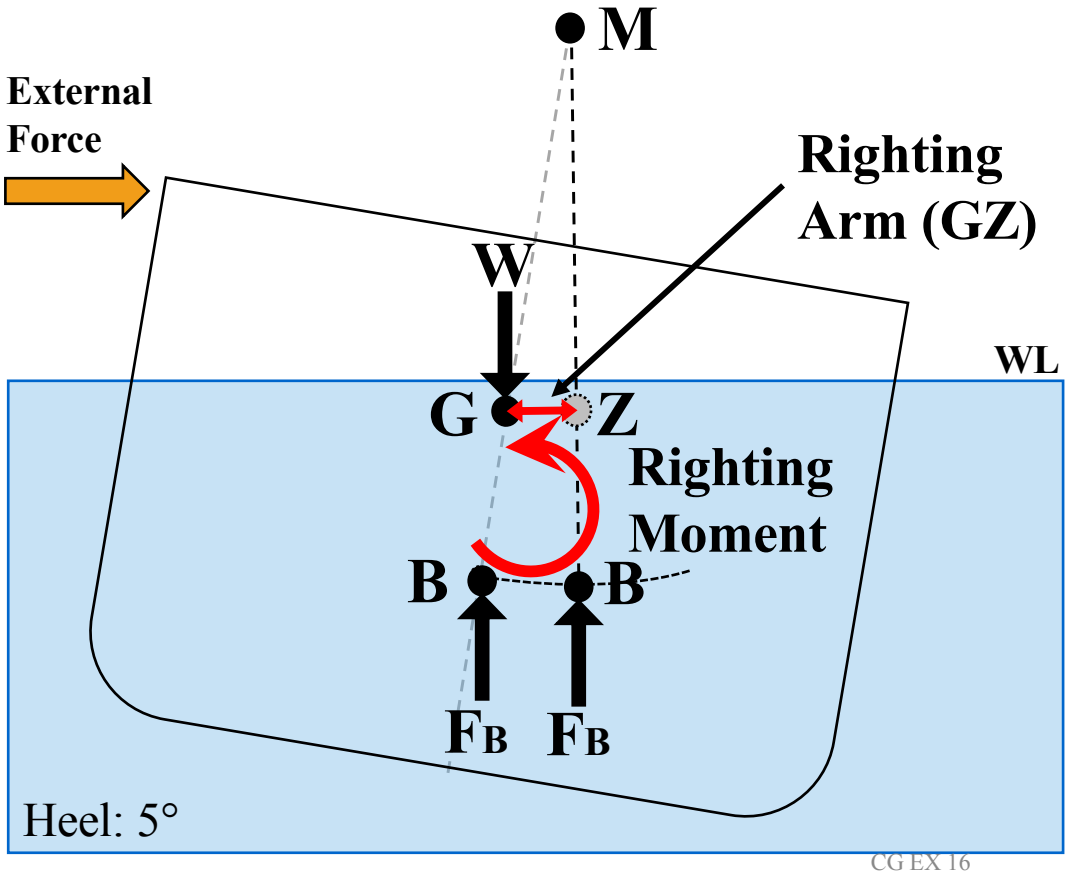
Education & Background

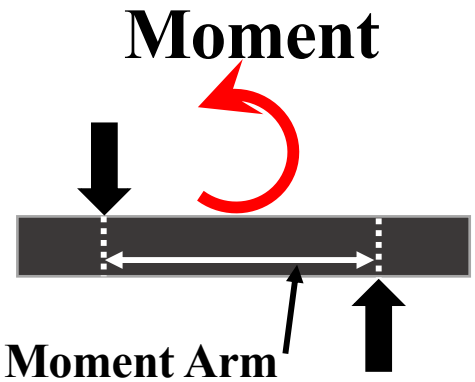
- Naval Architect: USCG Marine Safety Center
- BSE, Naval Architecture & Marine Engineering (USCGA)
- MSE, Naval Architecture & Marine Engineering (Univ. of Mich.)
- MSE, Mechanical Engineering (Univ. of Mich.)
- Professional Engineer: Naval Architecture & Marine Engineering
- Previous USCG Experience Underway and Ashore

Theory: The Righting Arm Curve

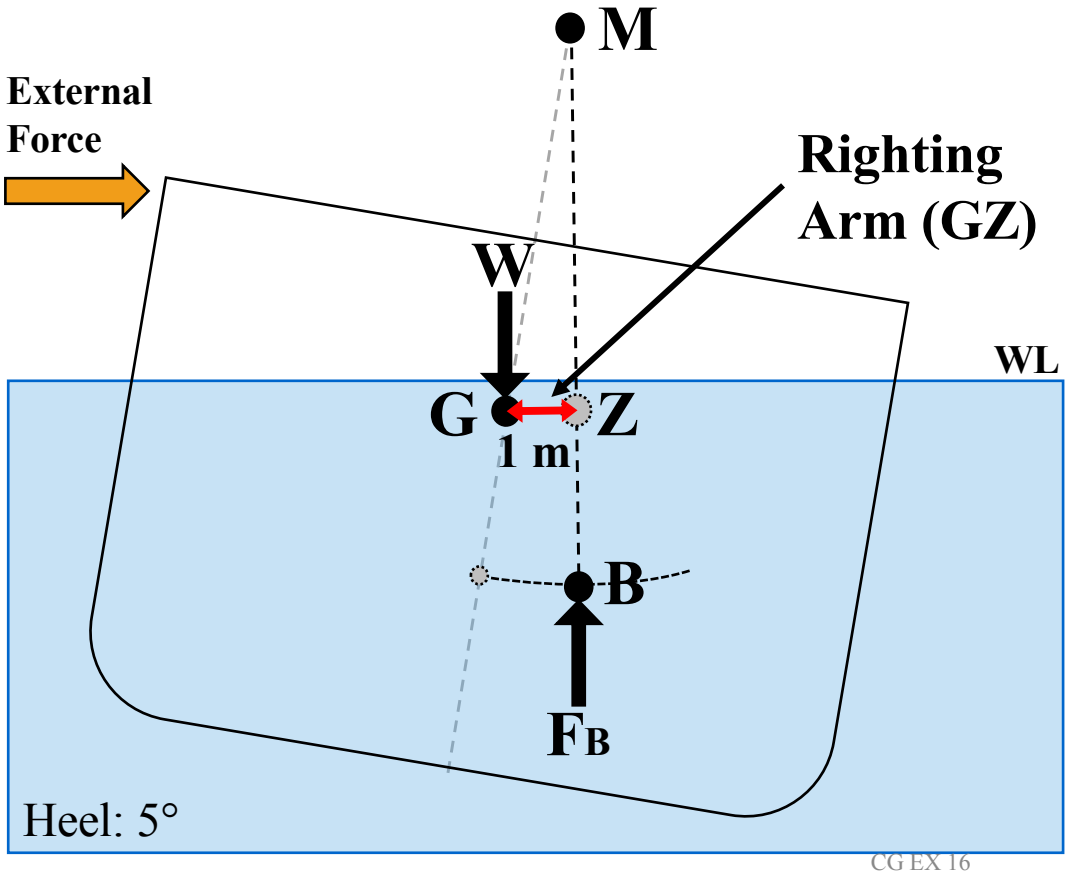


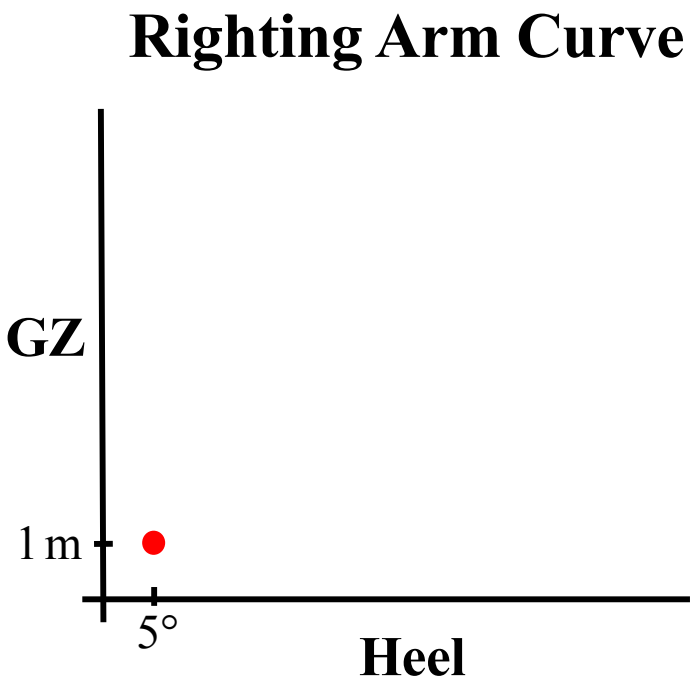
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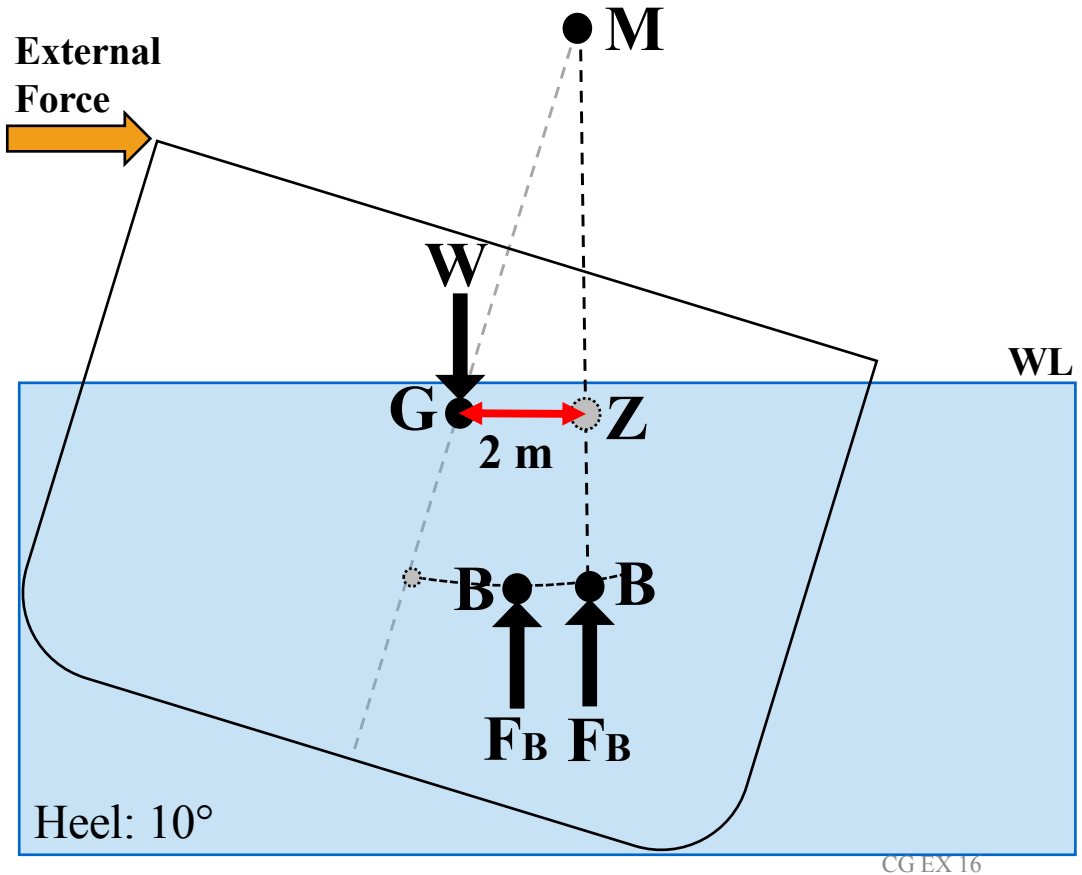


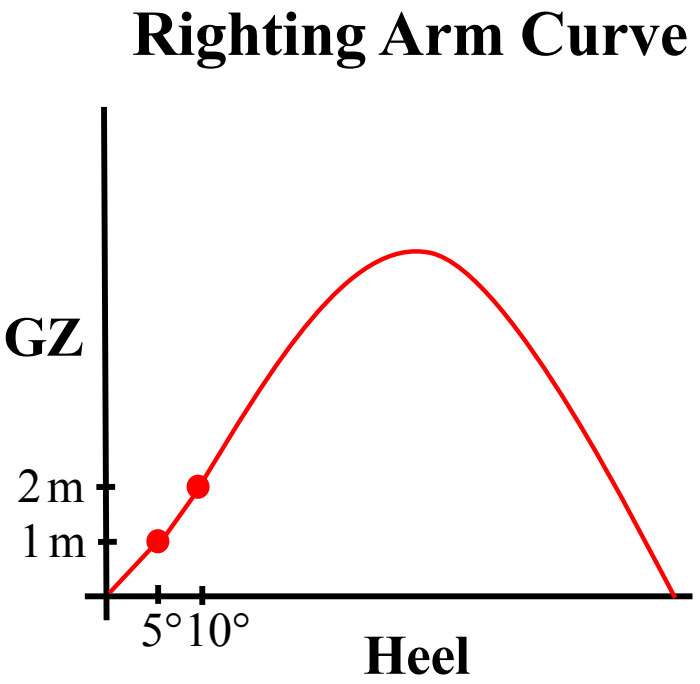
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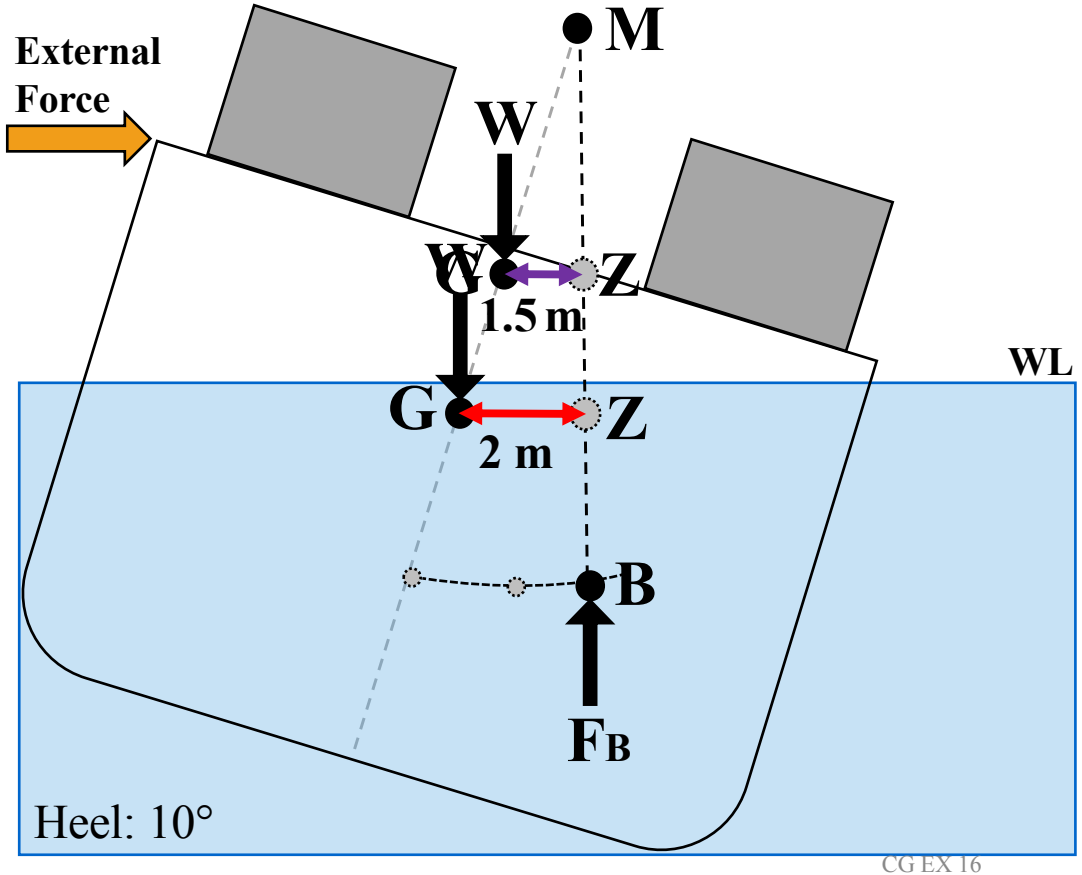


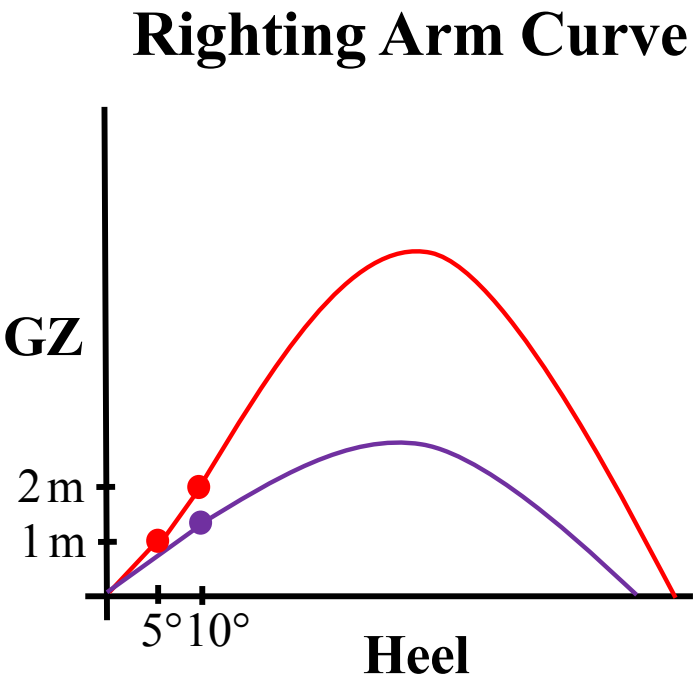
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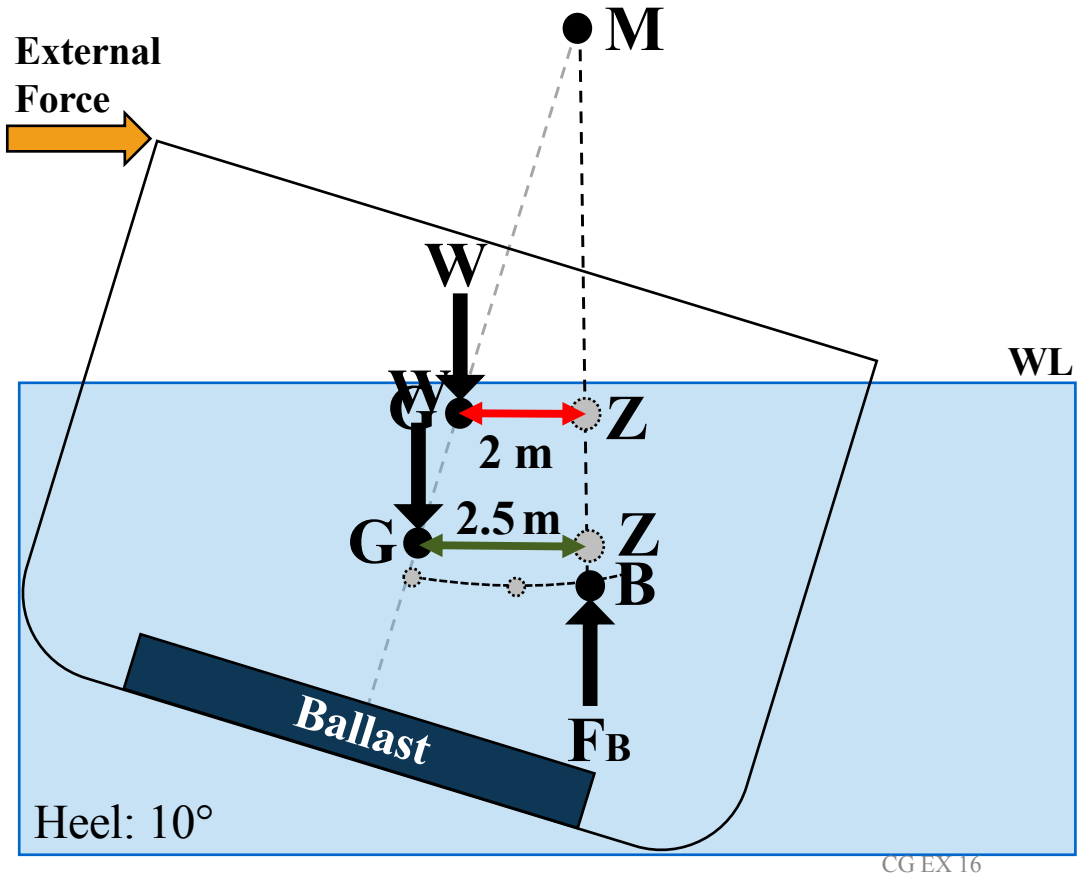


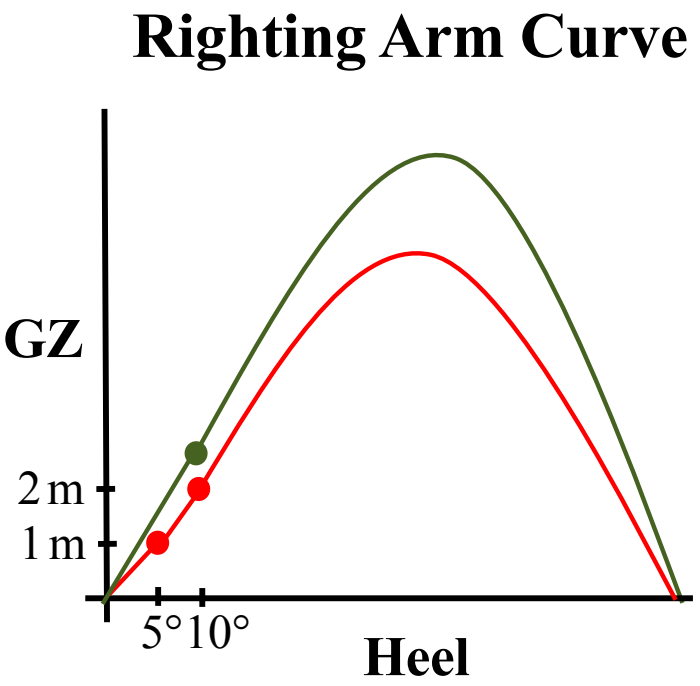
Theory: The Righting Arm Curve



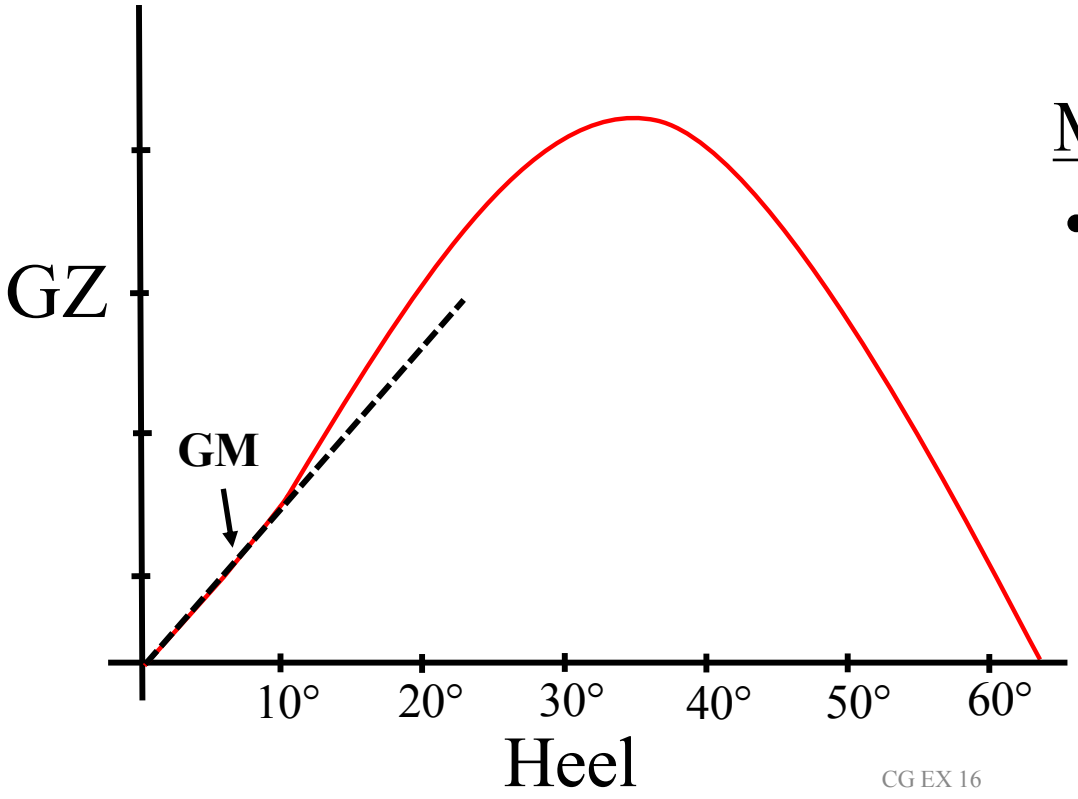


Theory: The Righting Arm Curve





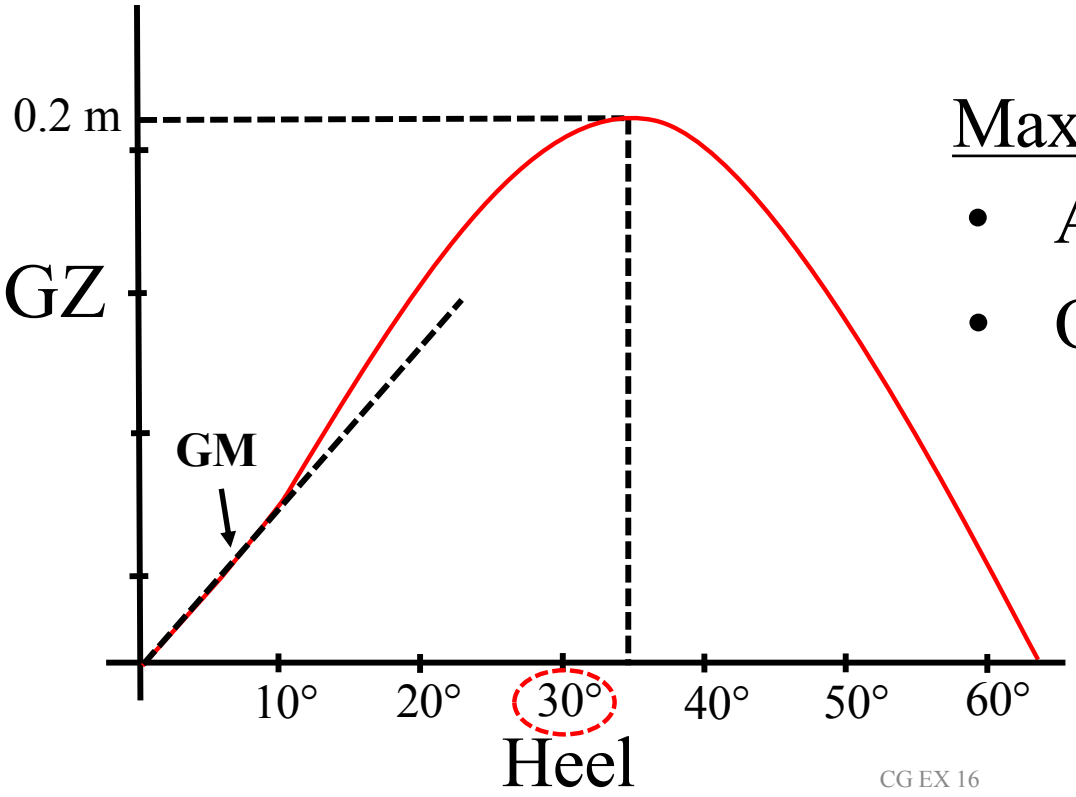
Theory: 2008 IMO Intact Stability Code



Metacentric Height (GM)

- At least 0.15 m

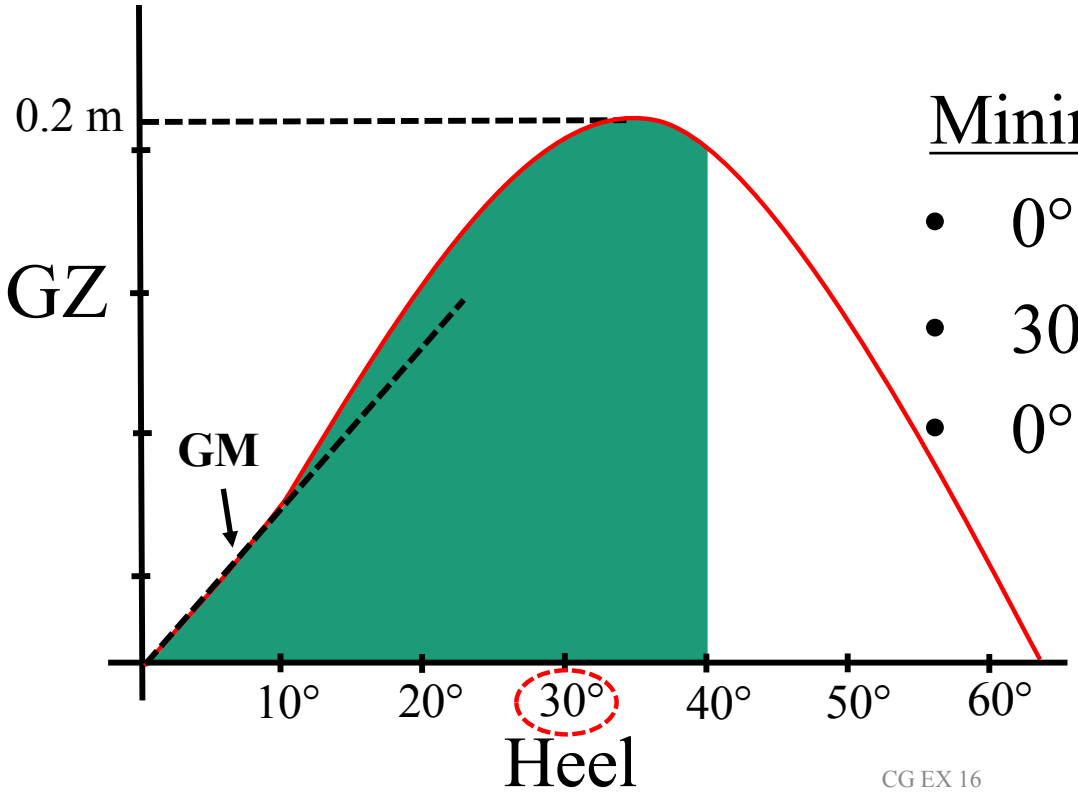
Theory: 2008 IMO Intact Stability Code



Maximum Righting Arm (GZ)

- At least 0.2 m
- Occur at 30° heel or greater

Theory: 2008 IMO Intact Stability Code



Minimum Area under Curve

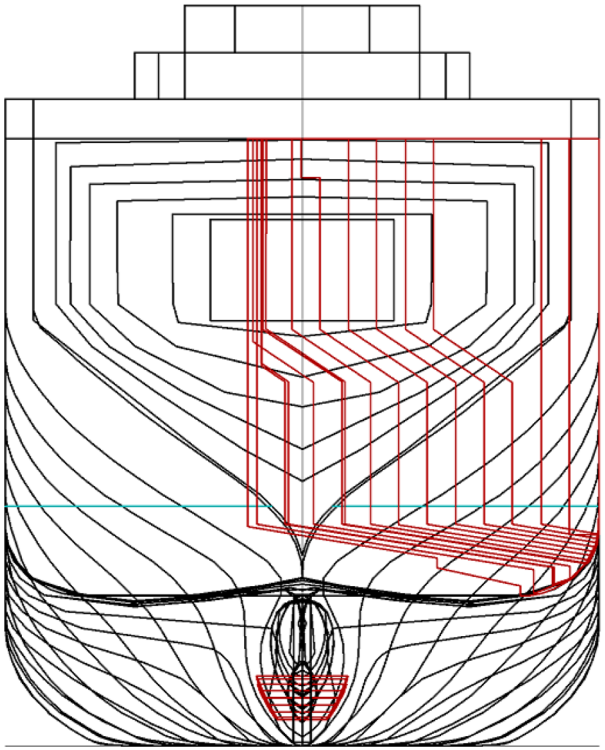
- 0° - 30°
- 30° - 40° (or downflooding)
- 0° - 40° (or downflooding)

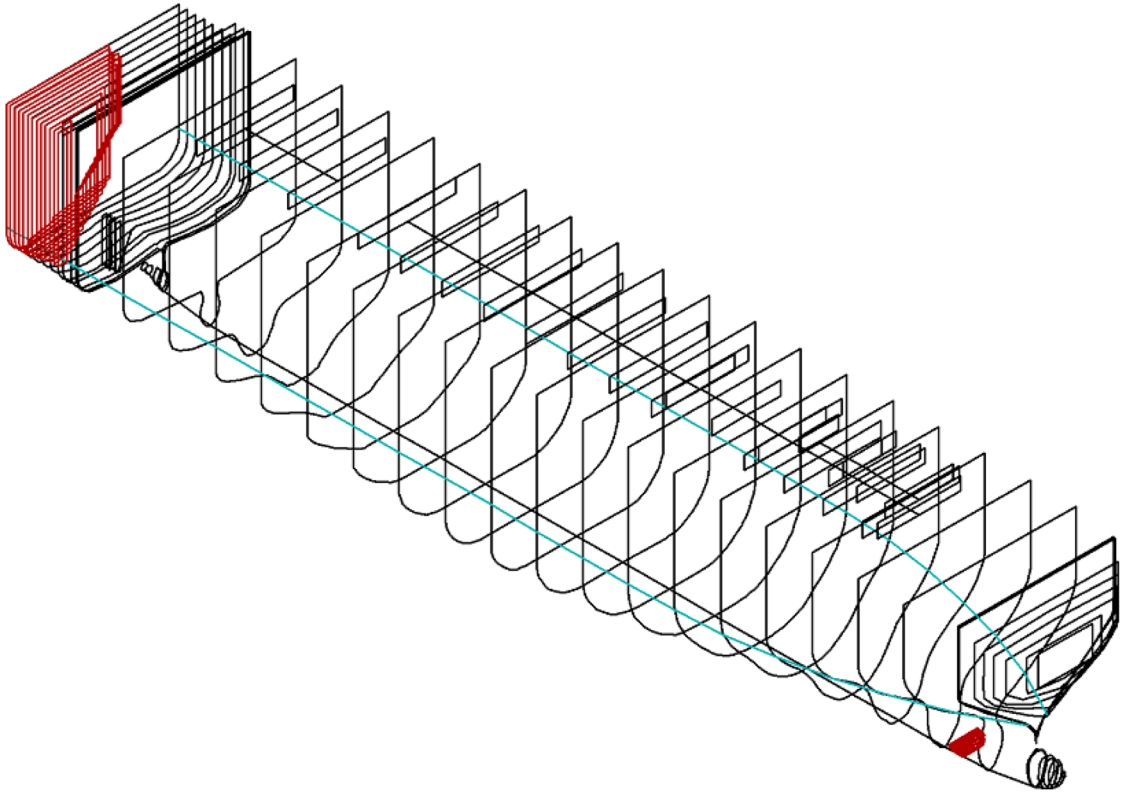
Theory: 2008 IMO Intact Stability Code

Severe Wind & Rolling Criteria

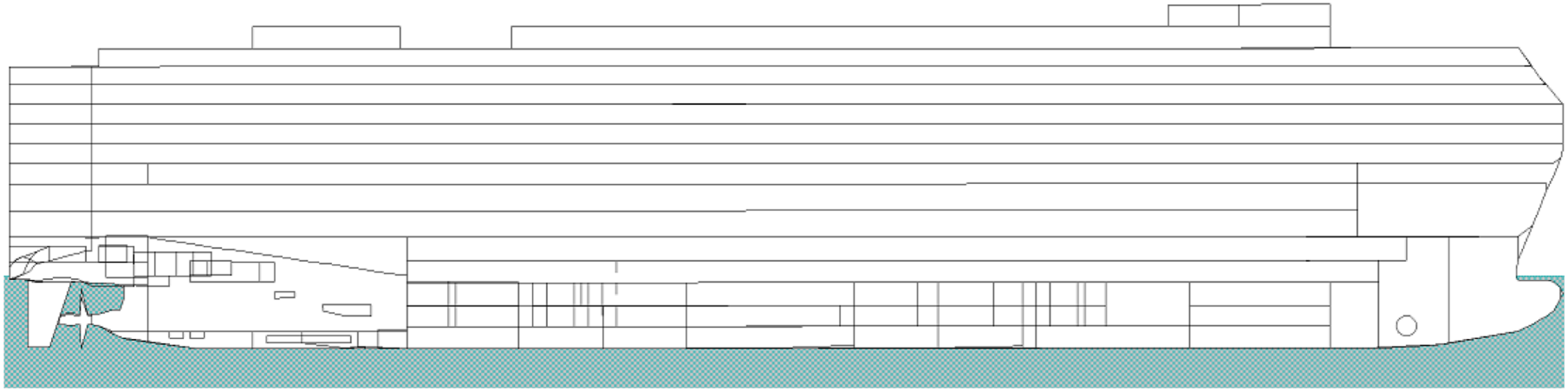
- Beam wind
- Wave induced roll

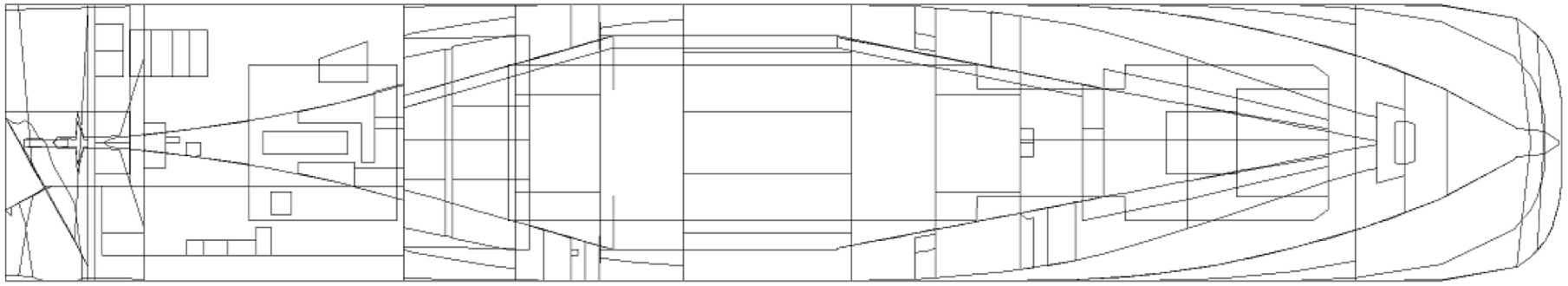
Computer Model Development





Computer Model Development





Computer Model Loading

	Weight (MT)	VCG (m-AB)
Lightship	21433.0	18.3
Tanks	4600.8	3.9
Cargo	8780.2	24.3
Misc. Deadweight	230.4	25.3
Total	**35044.4**	**18.2**

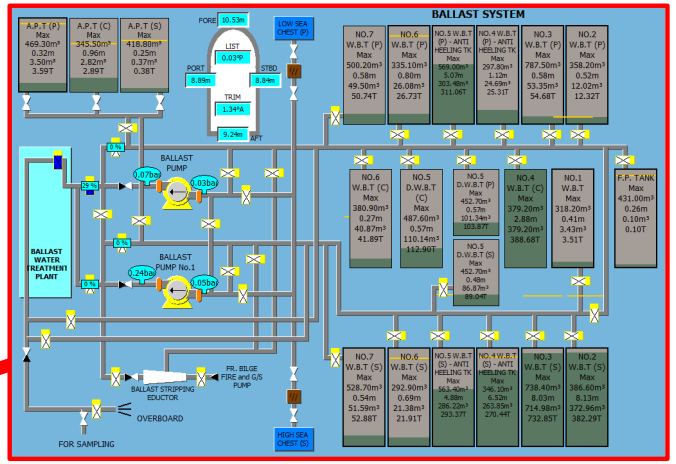
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Stability Test:
October 13, 2017

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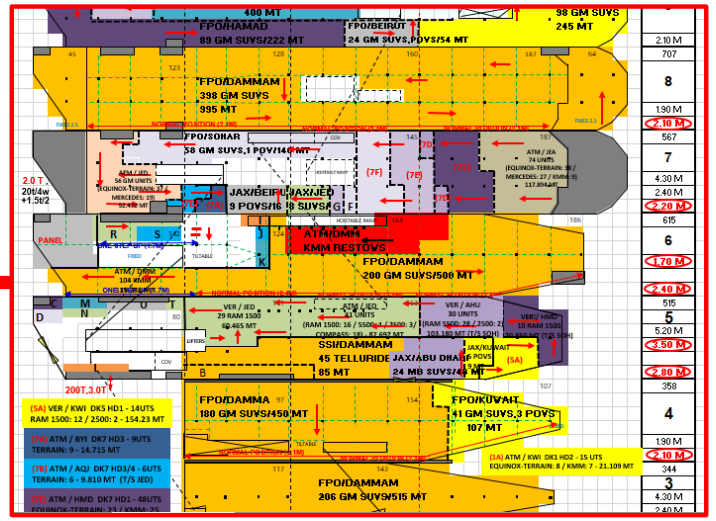


GOLDEN RAY

Trim & Stability Booklet

Computer Model Loading

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Computer Model Loading

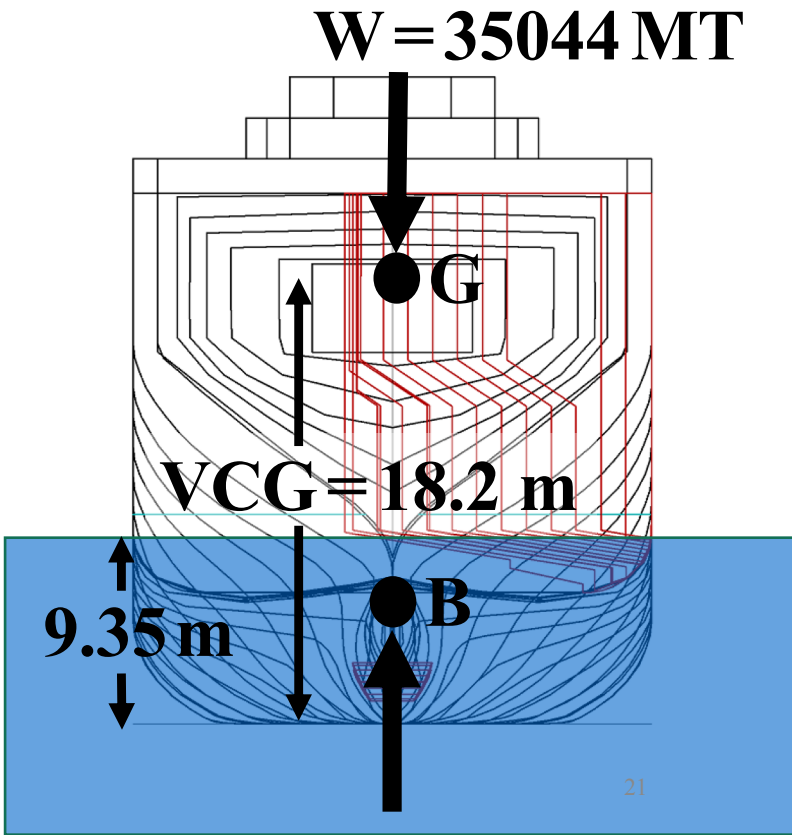
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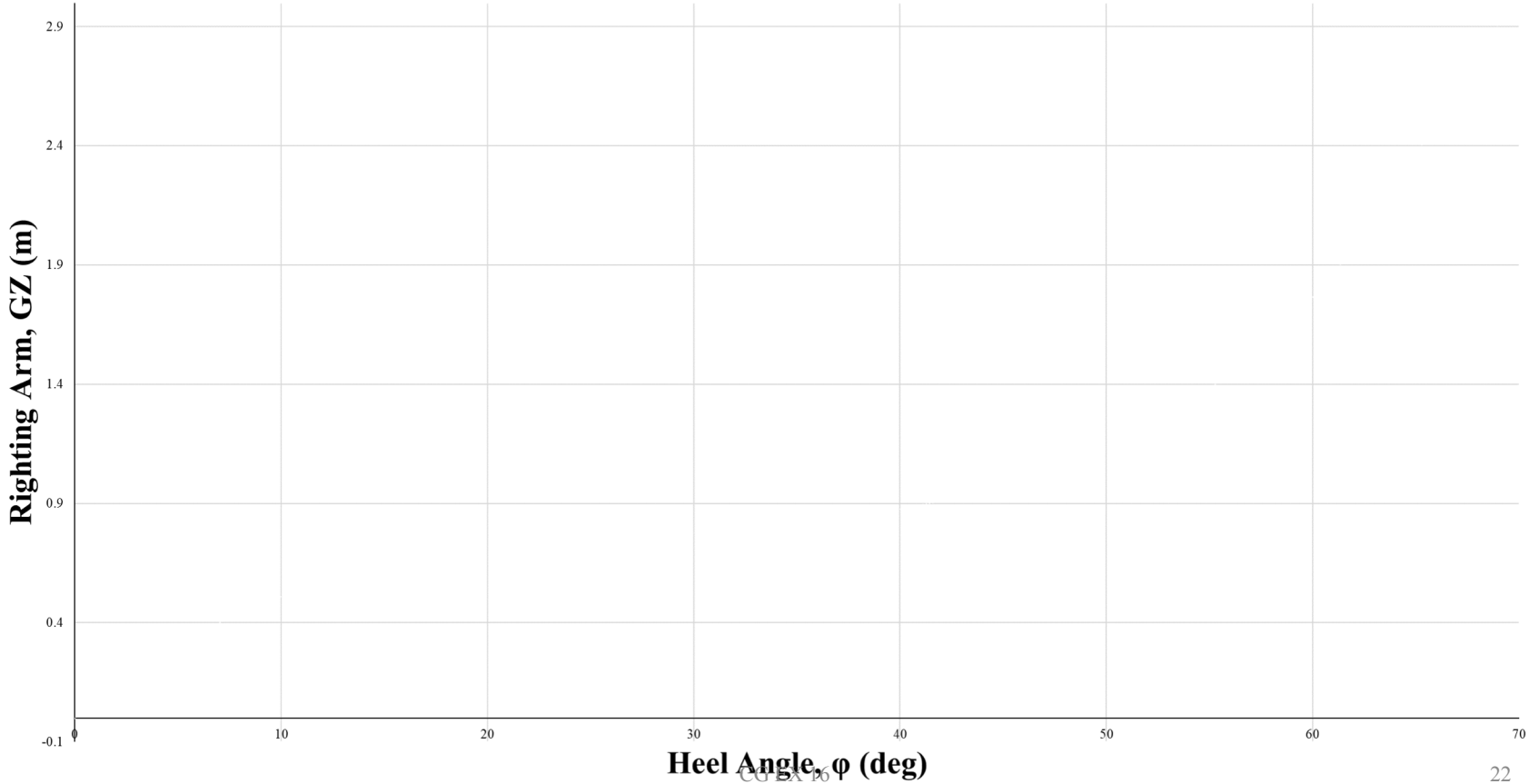
Trim & Stability Booklet

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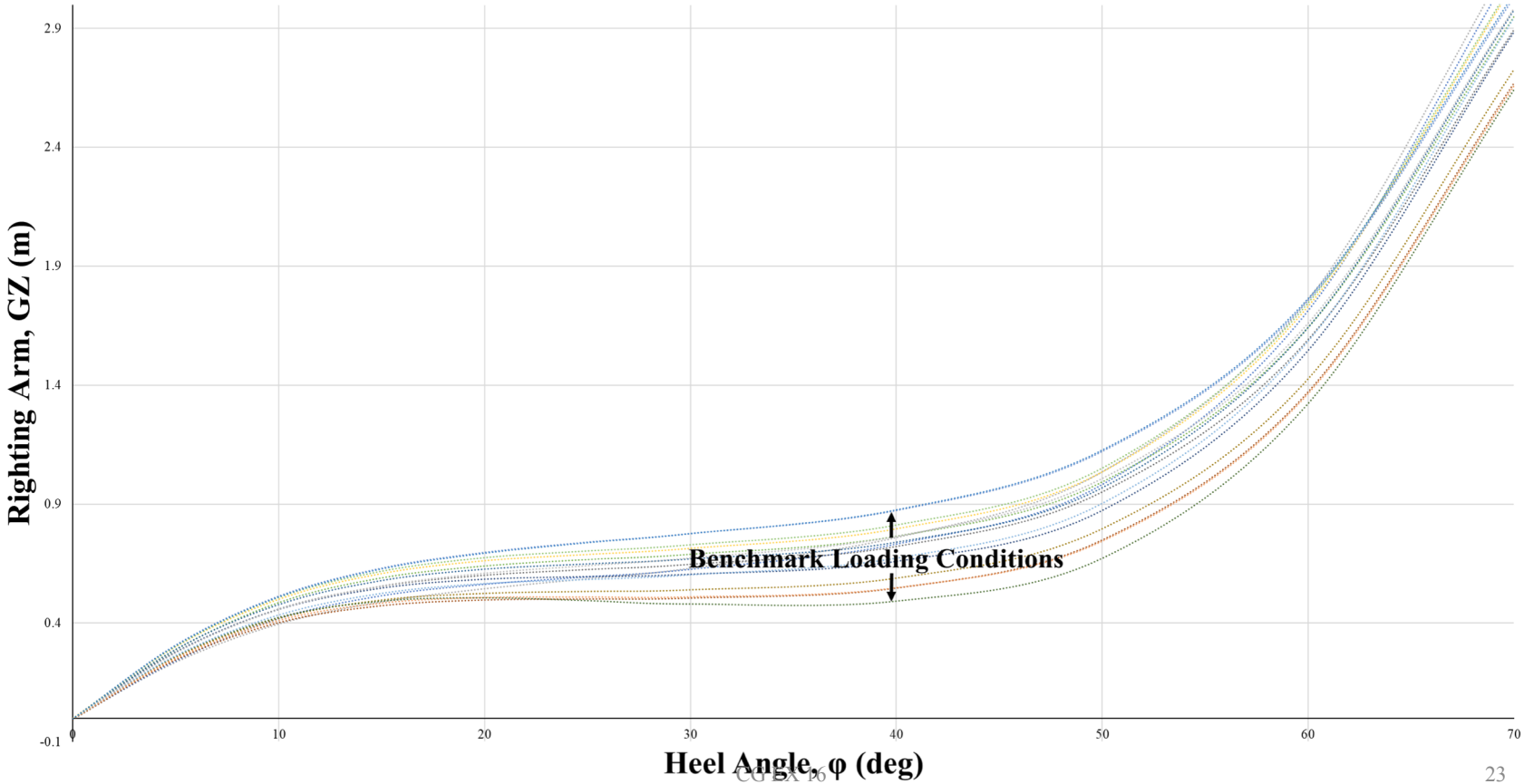
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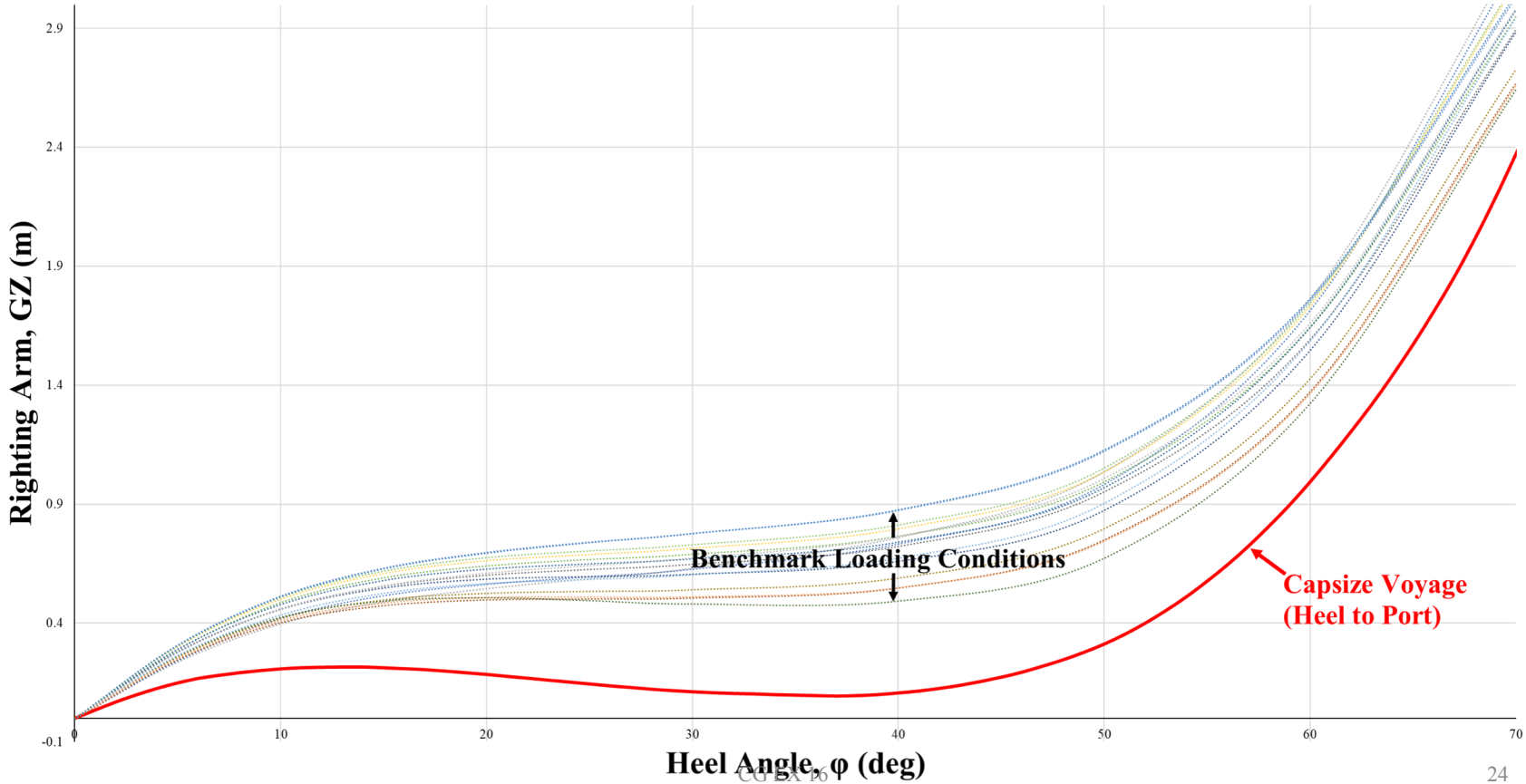
Righting Arm Curve: Capsize Voyage



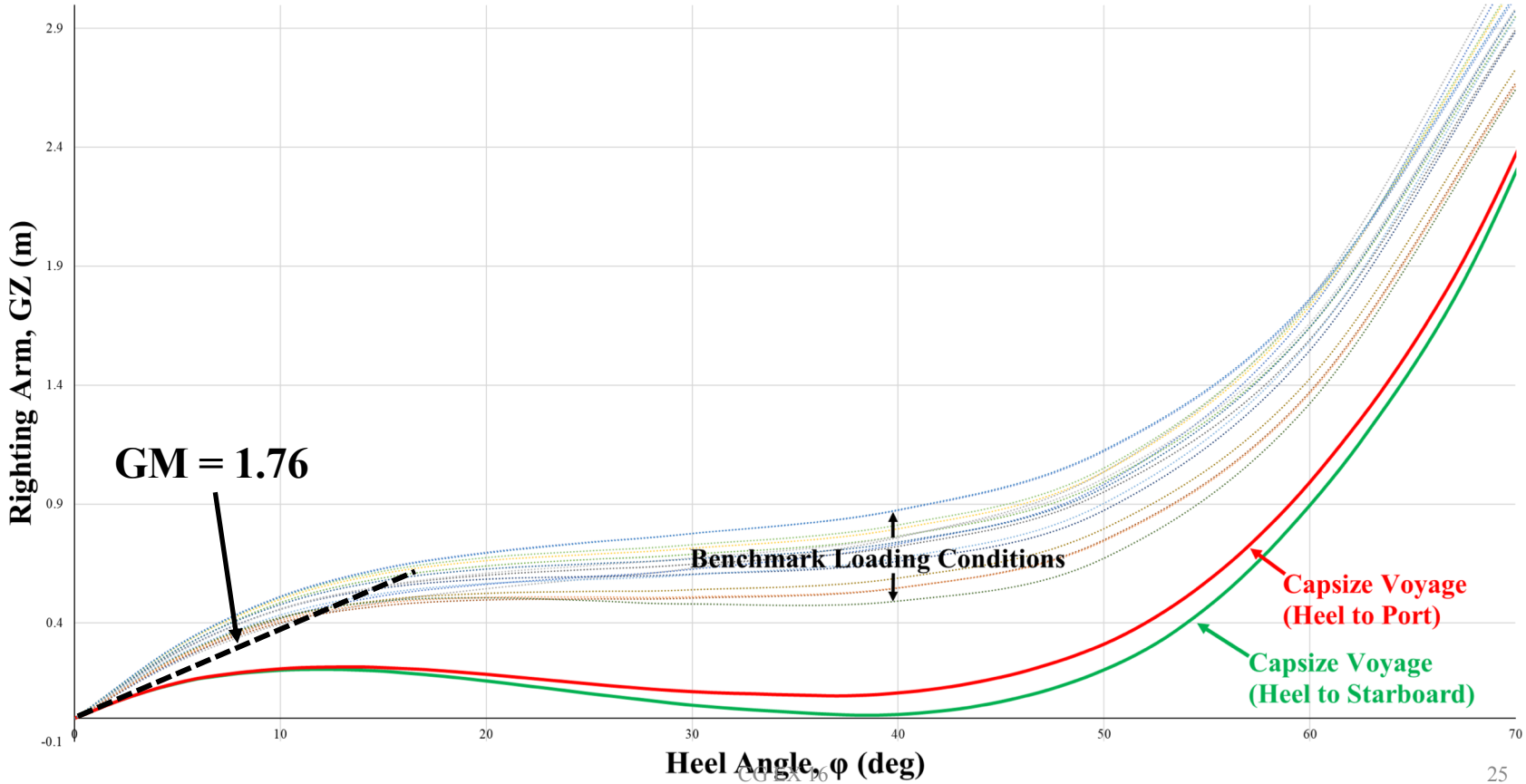
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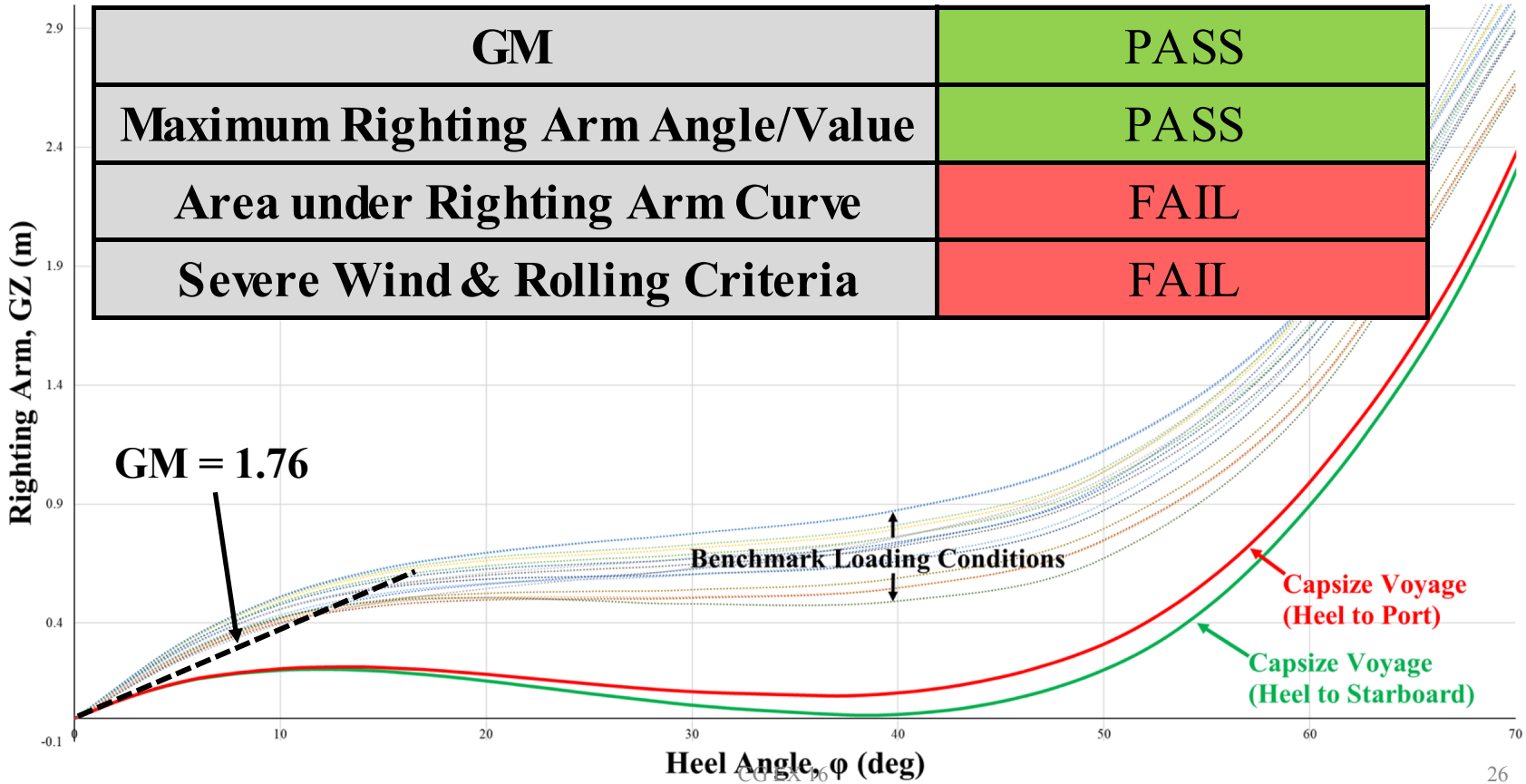


Righting Arm Curve: Capsize Voyage



IS Code Compliance: Capsize Voyage

GM	PASS
Maximum Righting Arm Angle/Value	PASS
Area under Righting Arm Curve	FAIL
Severe Wind & Rolling Criteria	FAIL

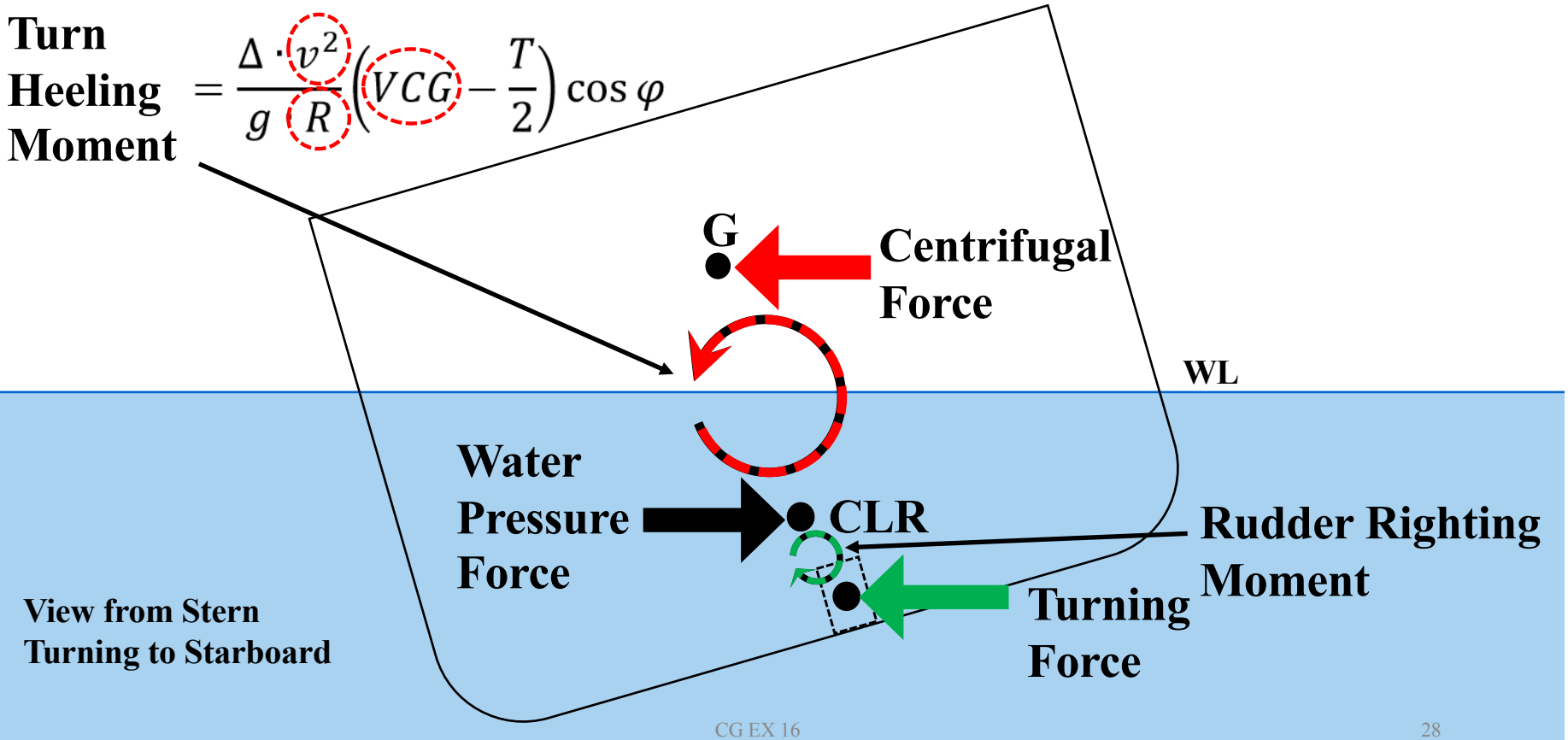


Load Comparison to Benchmark Conditions

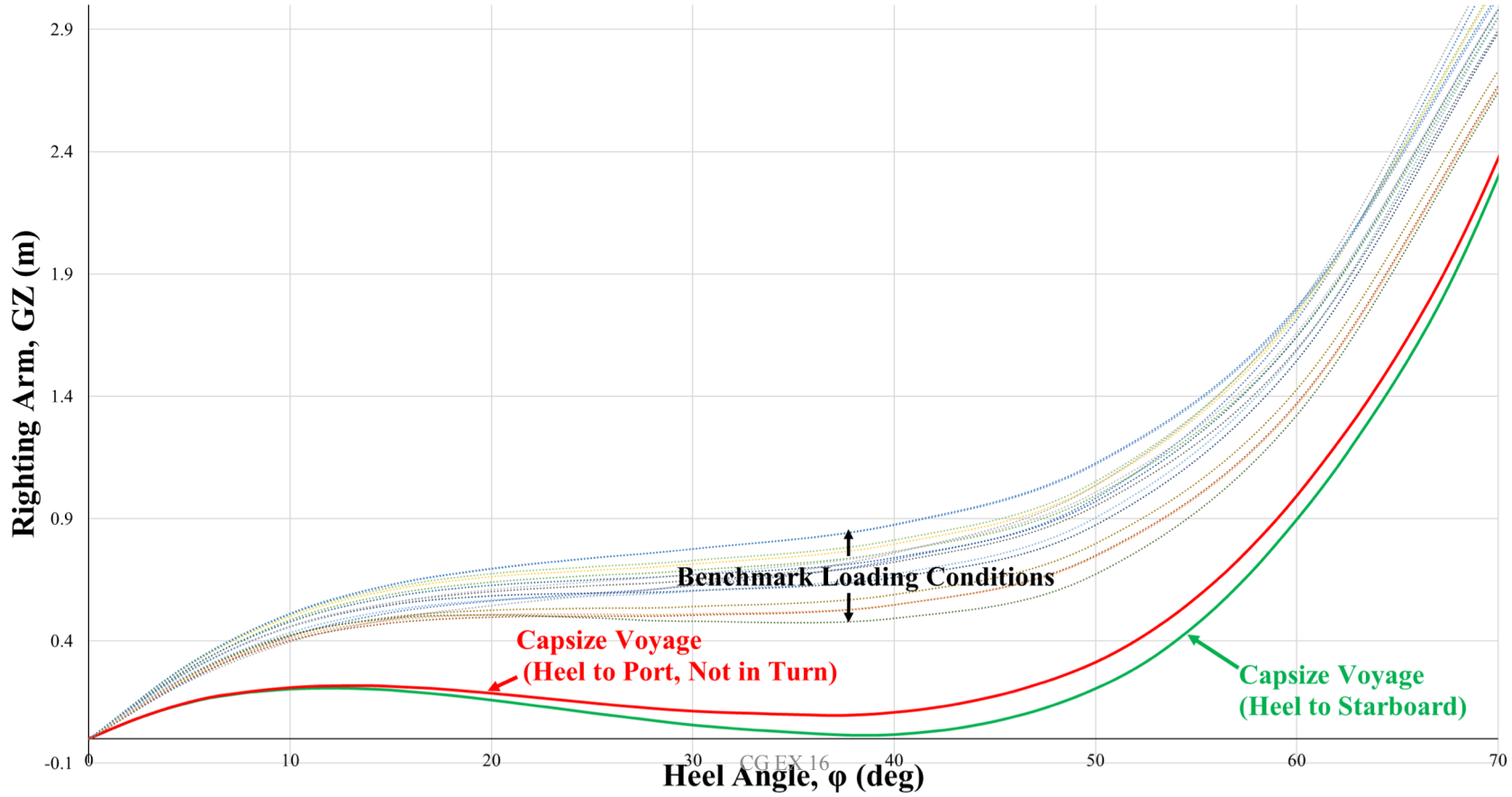
	Total Disp. (MT)	Total Liquid (MT)	Cargo Weight (MT)	Cargo VCG (m)	Vessel VCG (m)
MSC Capsize Voyage	35044	4601	8780	24.3	18.2
T&S Condition 13	35263	4553	7267	19.4	17.0
T&S Condition 18	35704	6529	7742	24.2	17.0

Theory: Stability During Turn

Turn Heeling Moment $= \frac{\Delta \cdot v^2}{g\ R}\left(VCG - \frac{T}{2}\right)\cos\varphi$

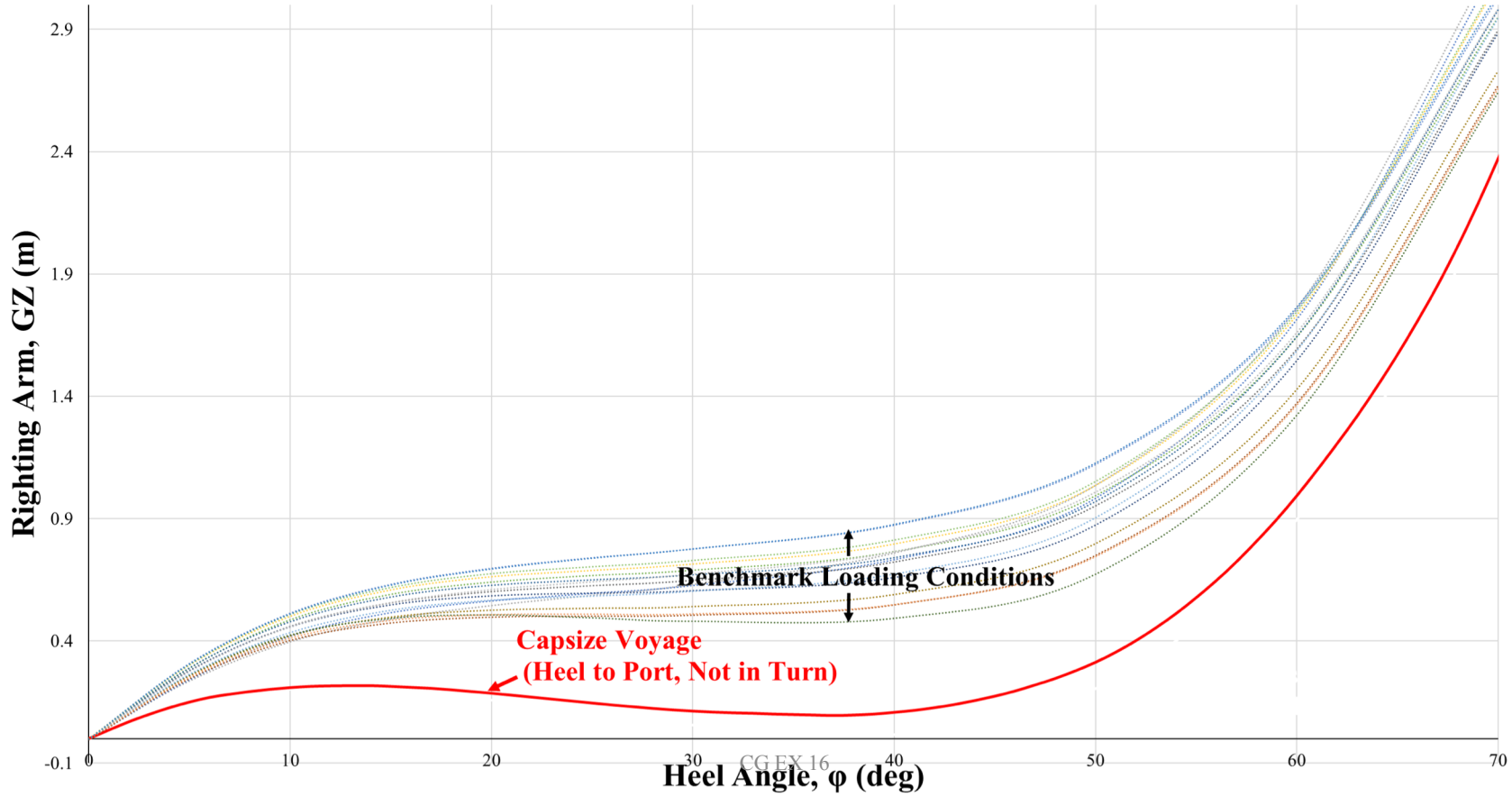


Righting Arm Curve During Turn



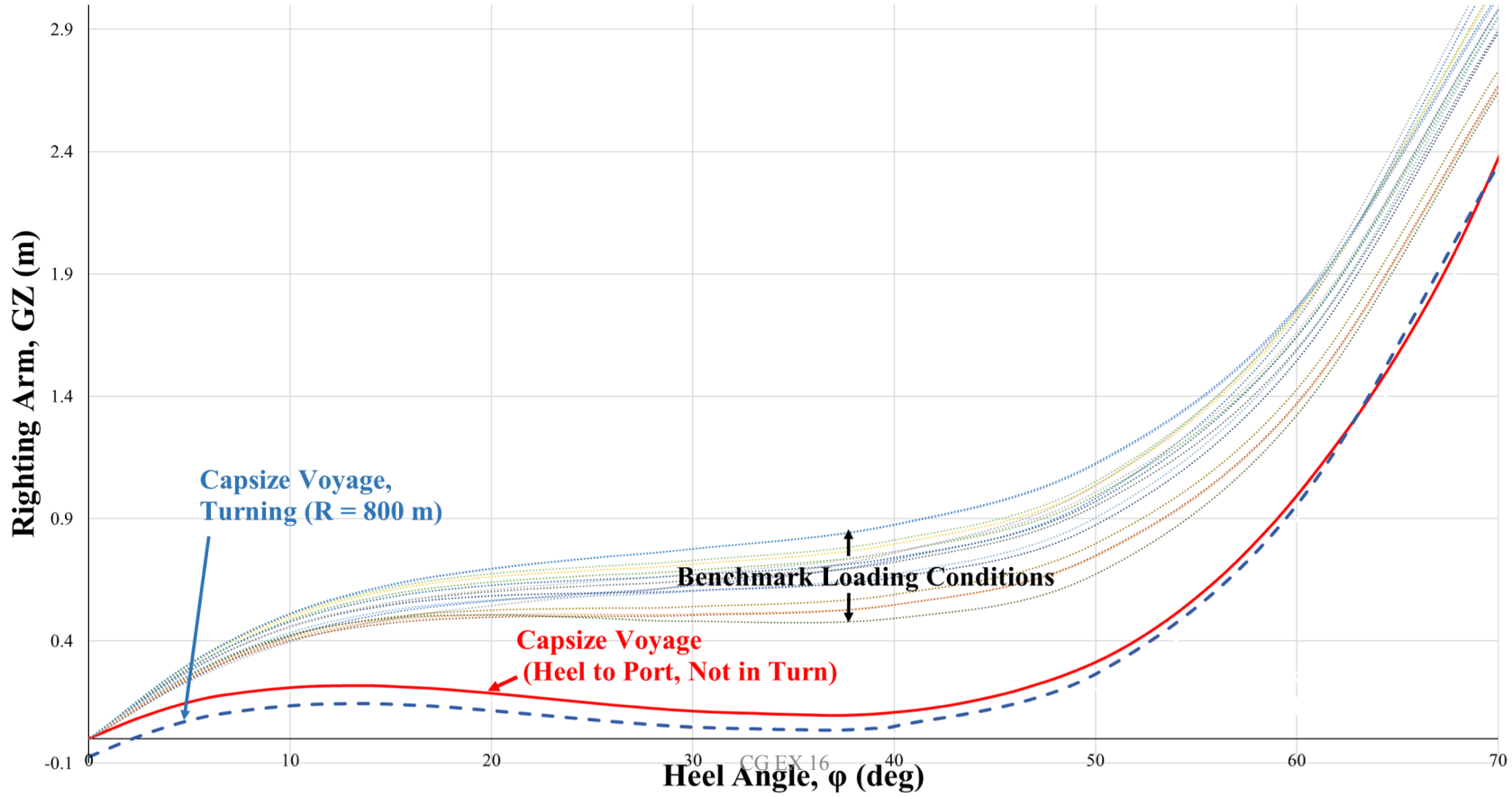
CG EX 16

Righting Arm Curve During Turn



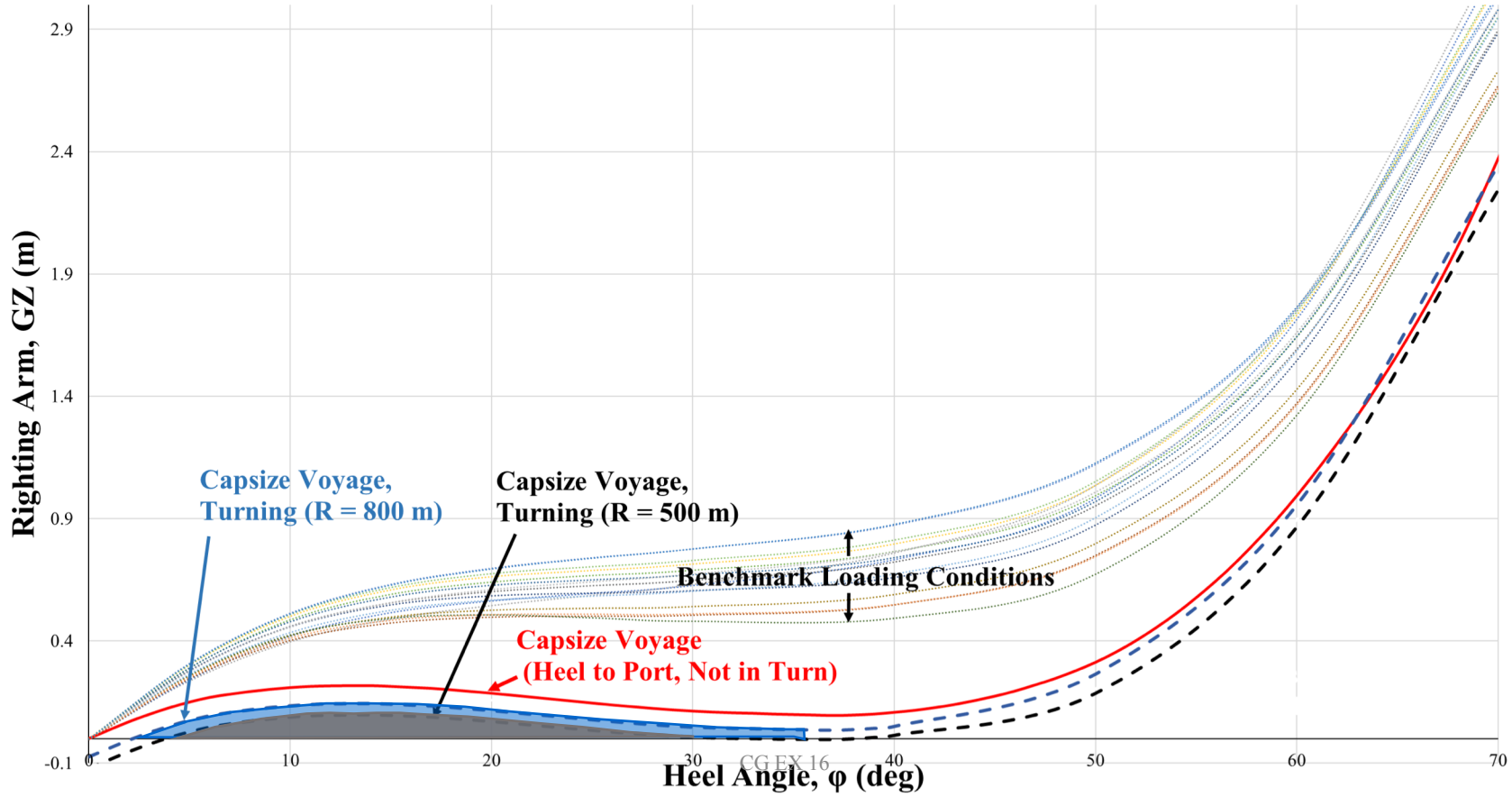
CG EX 16

Righting Arm Curve During Turn

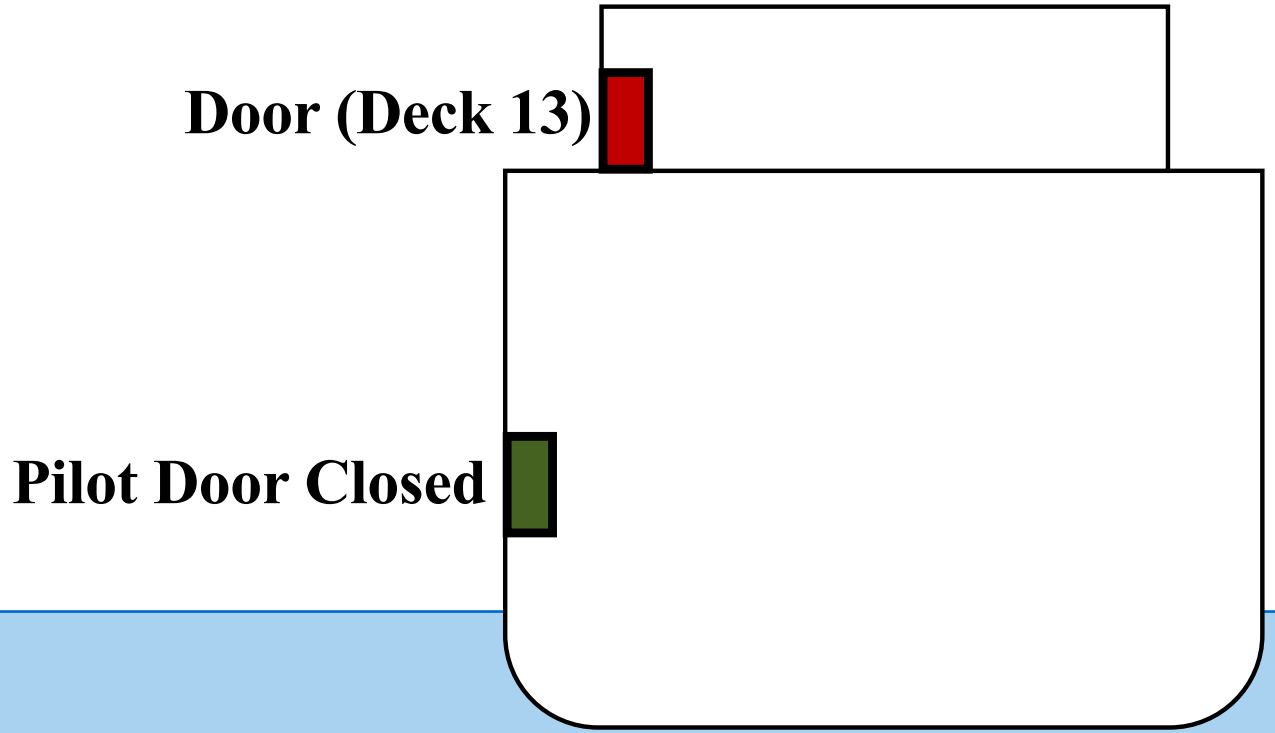


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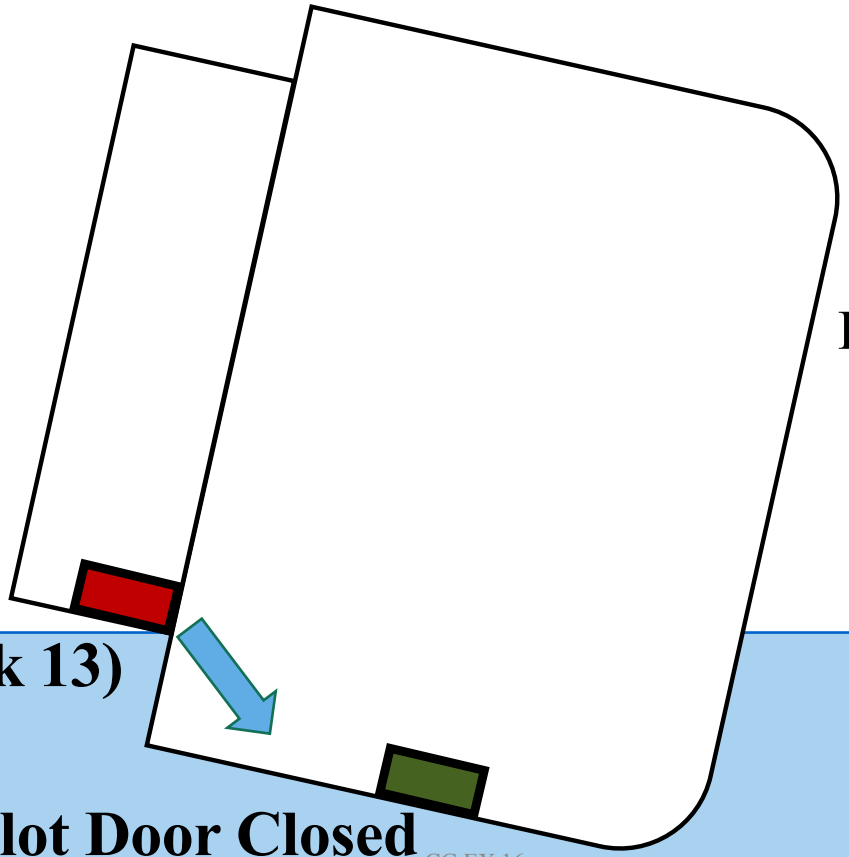
Righting Arm Curve During Turn



Downflooding: Pilot Door Closed



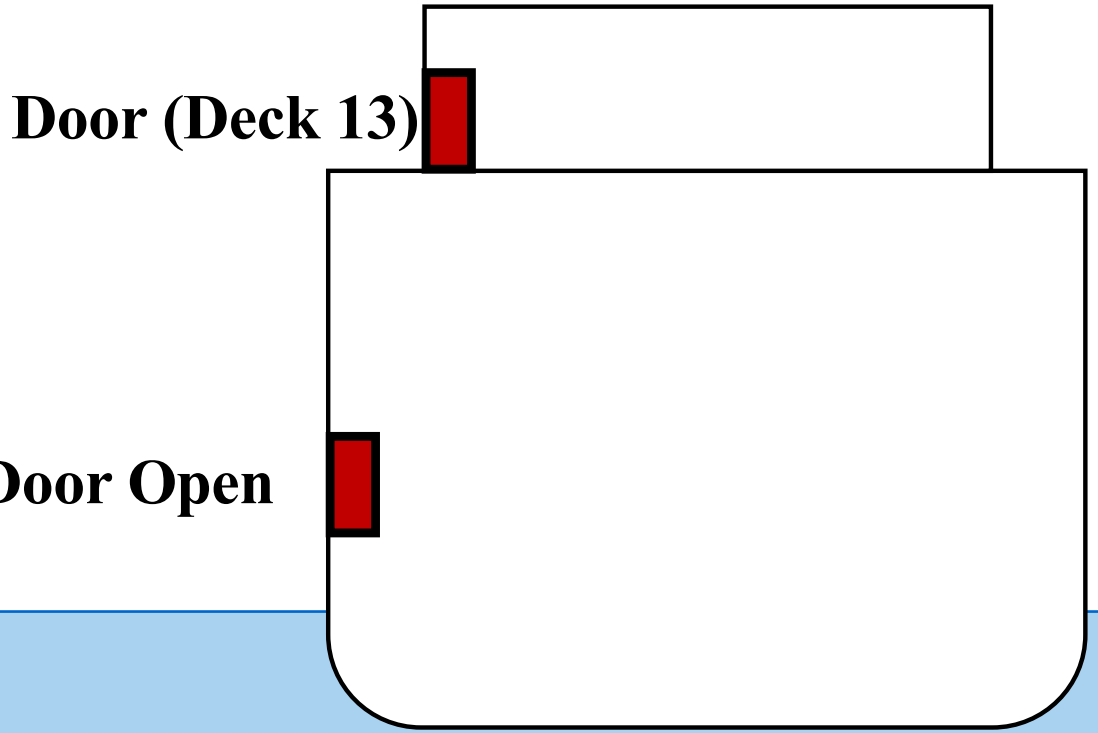
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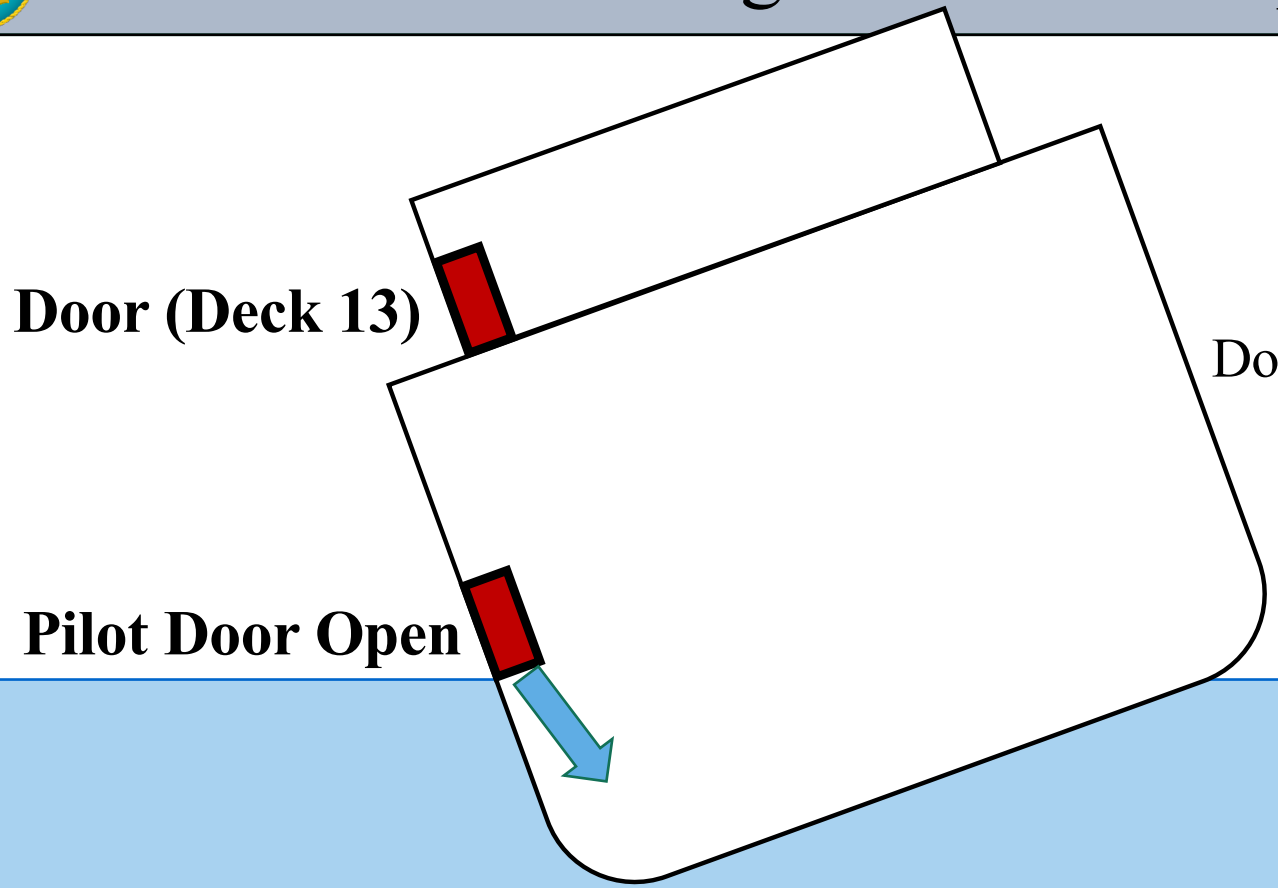
Downflooding Angle:

83°

Downflooding: Pilot Door Open



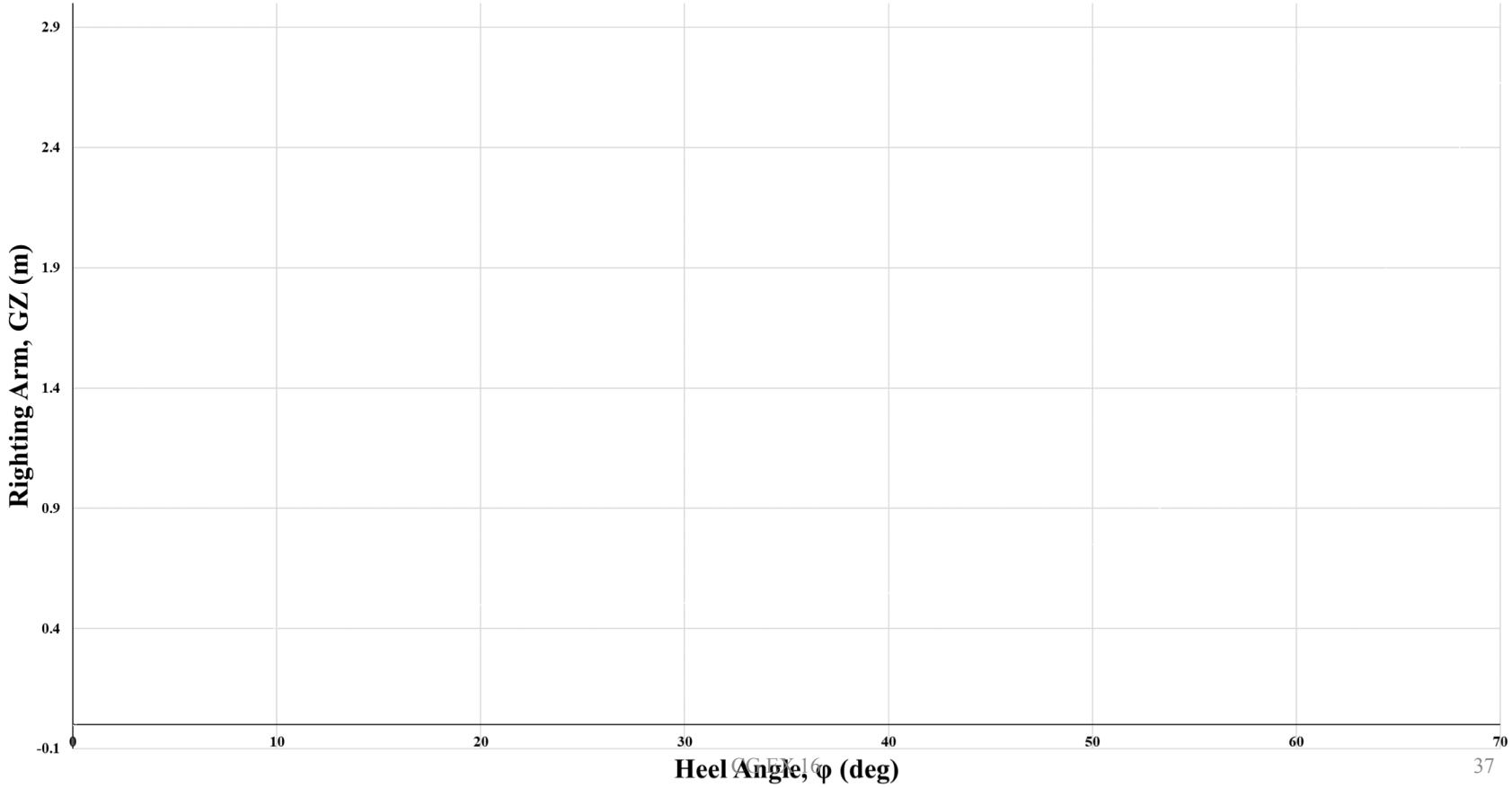
Downflooding: Pilot Door Open



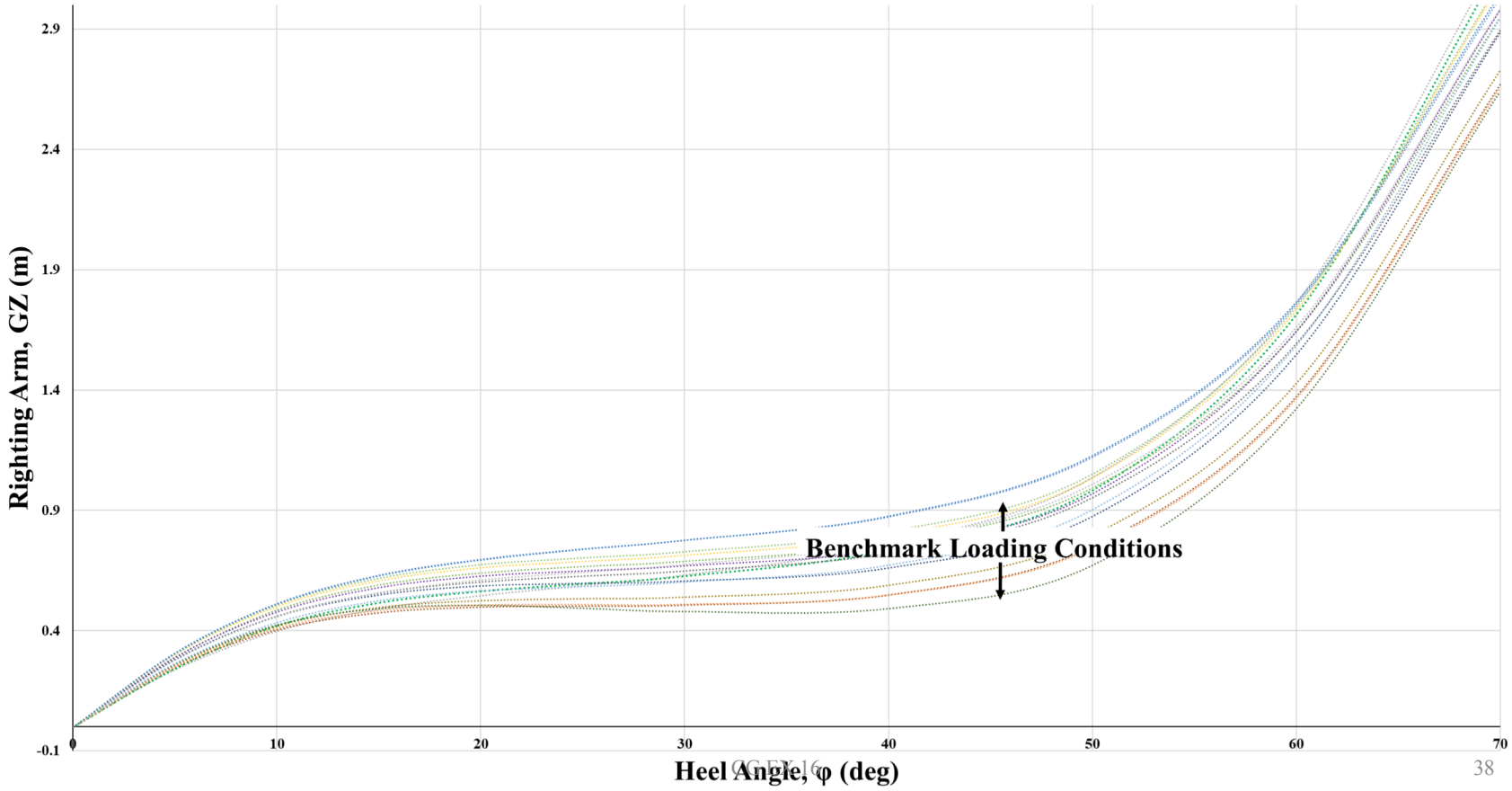
Downflooding Angle:

17°

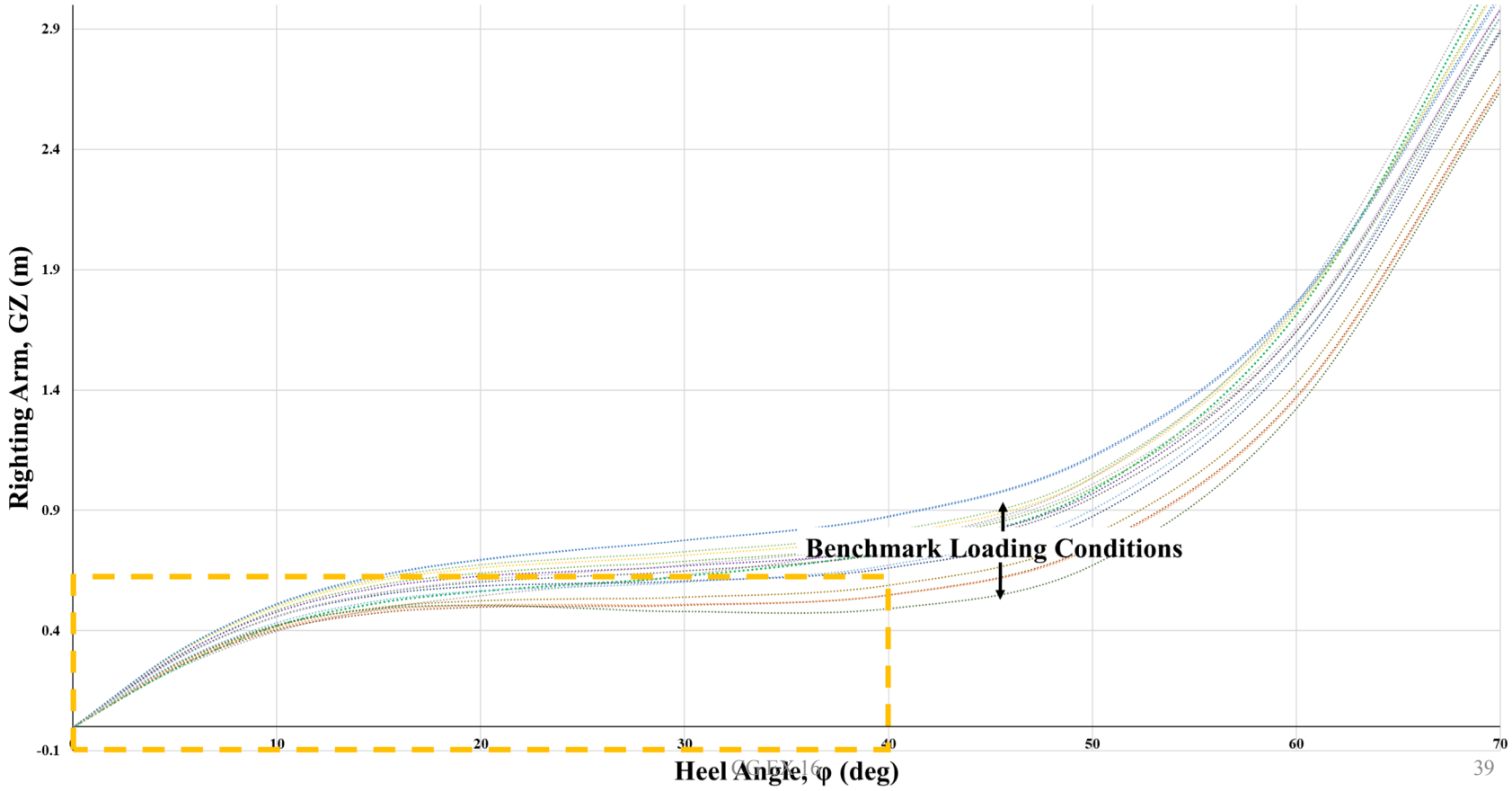
Stability: Preceding Voyages



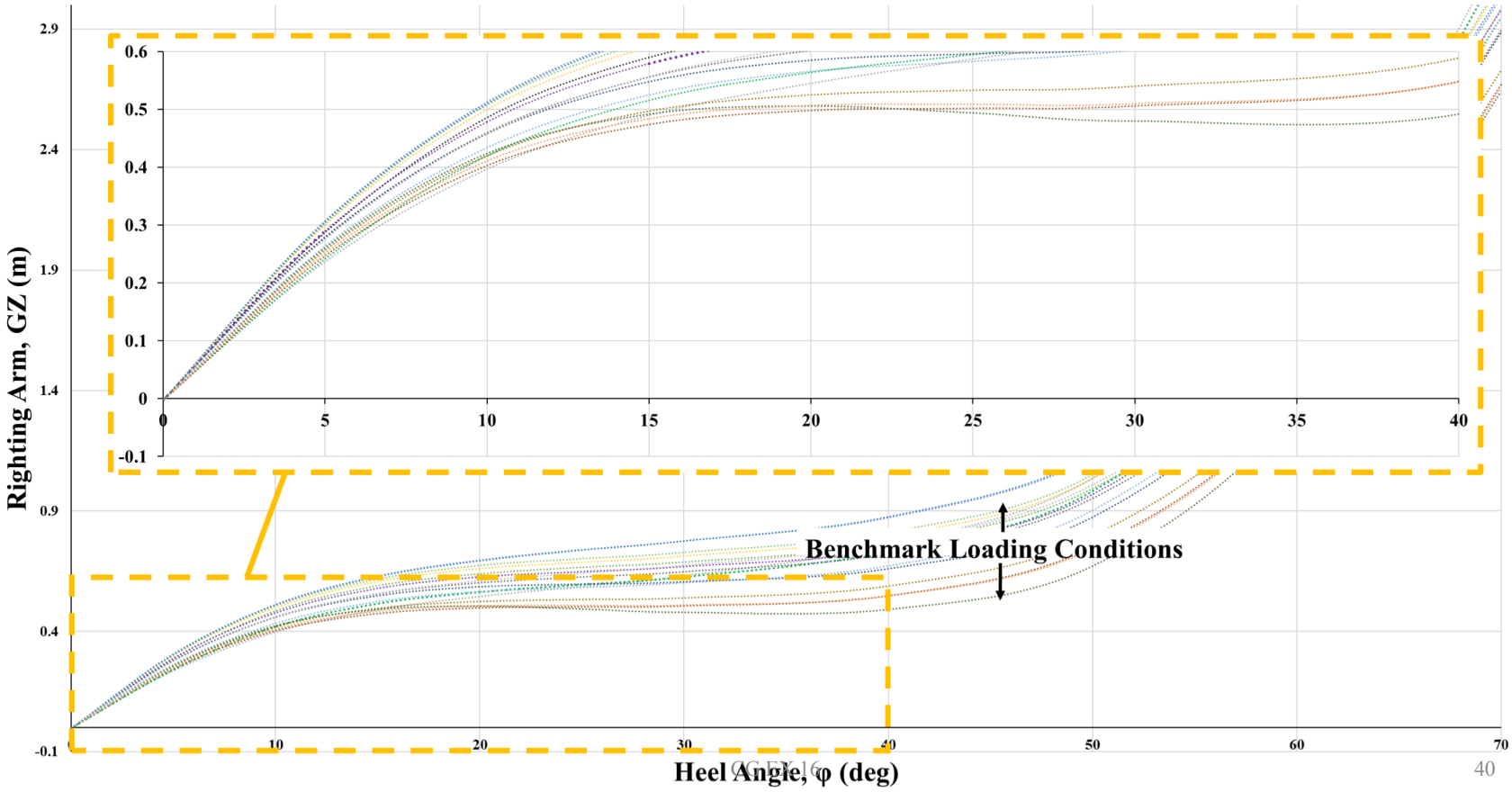
Stability: Preceding Voyages



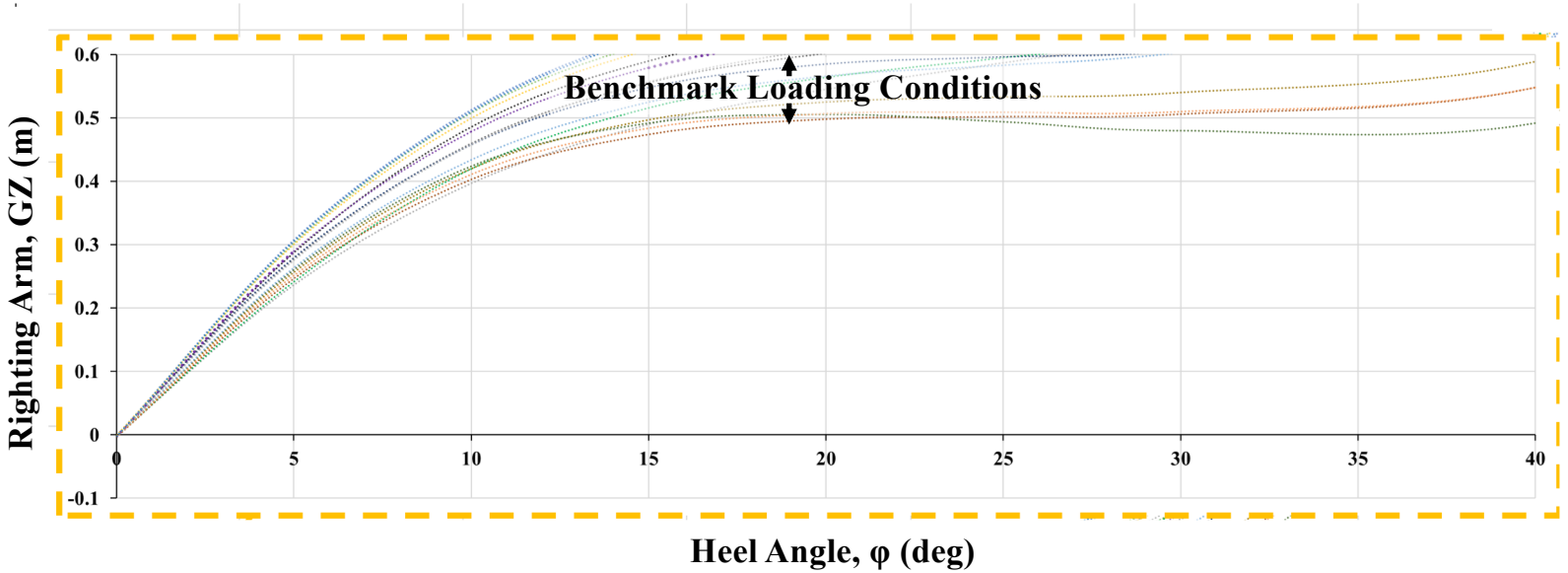
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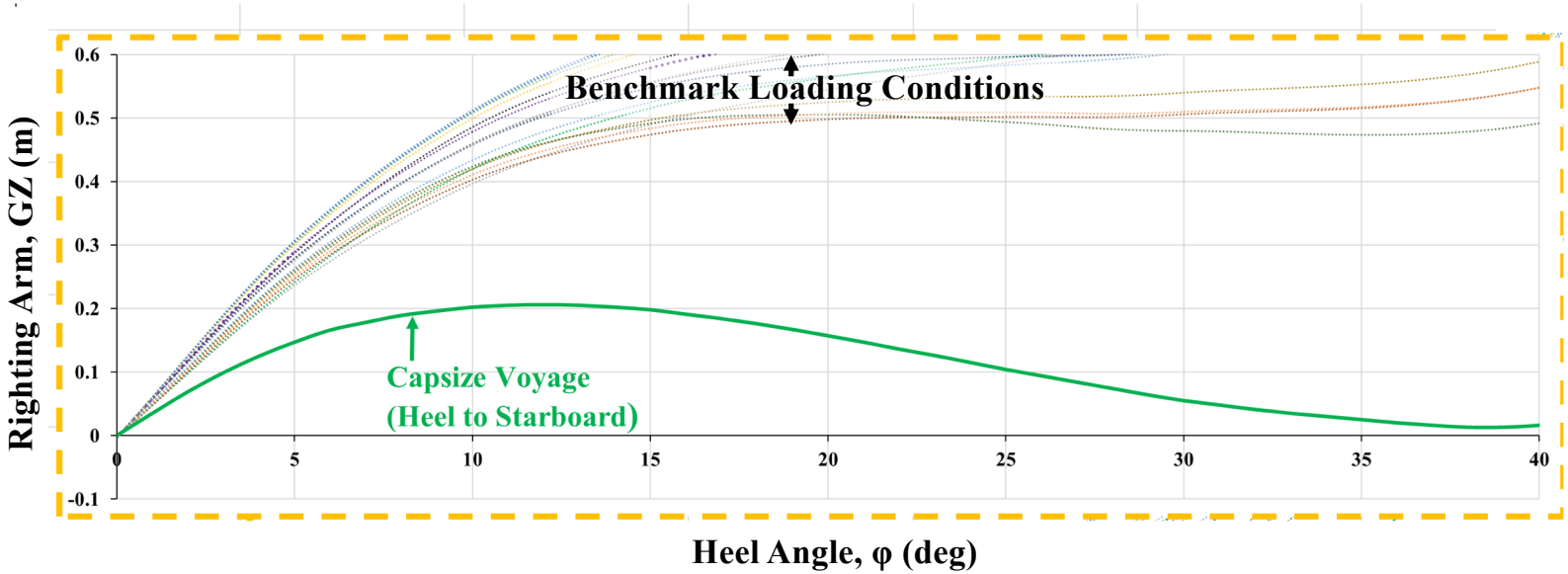
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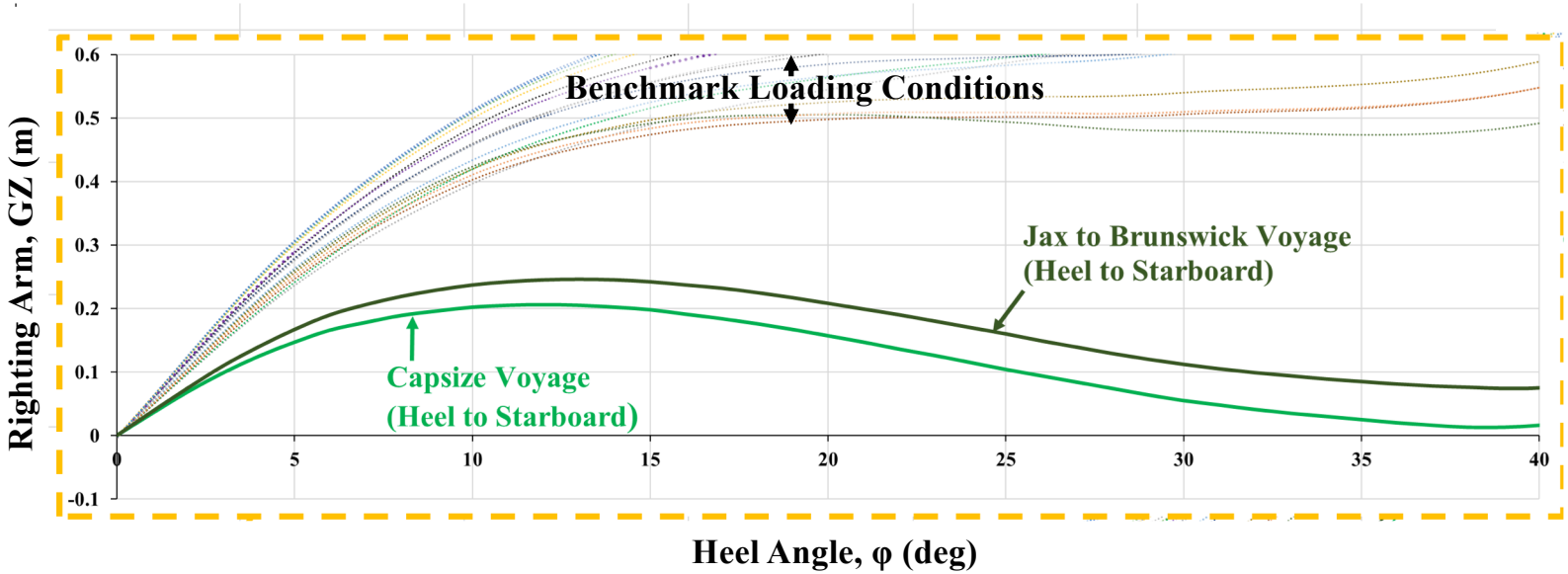
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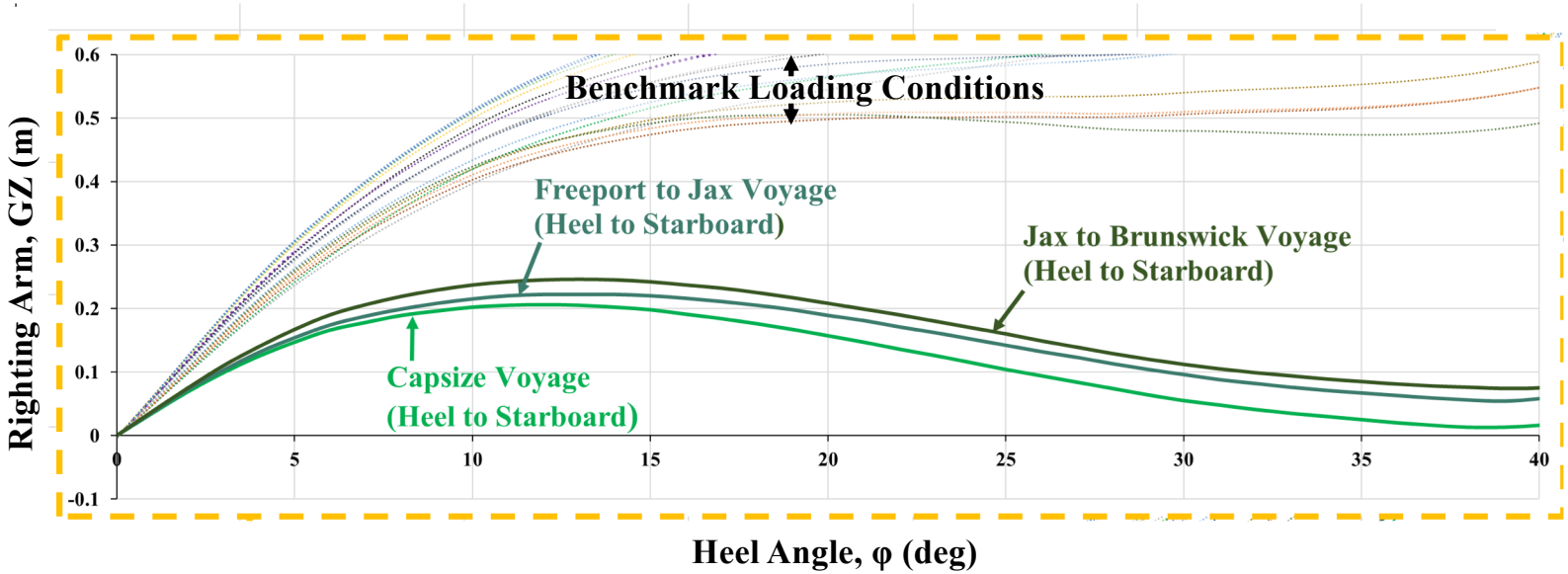
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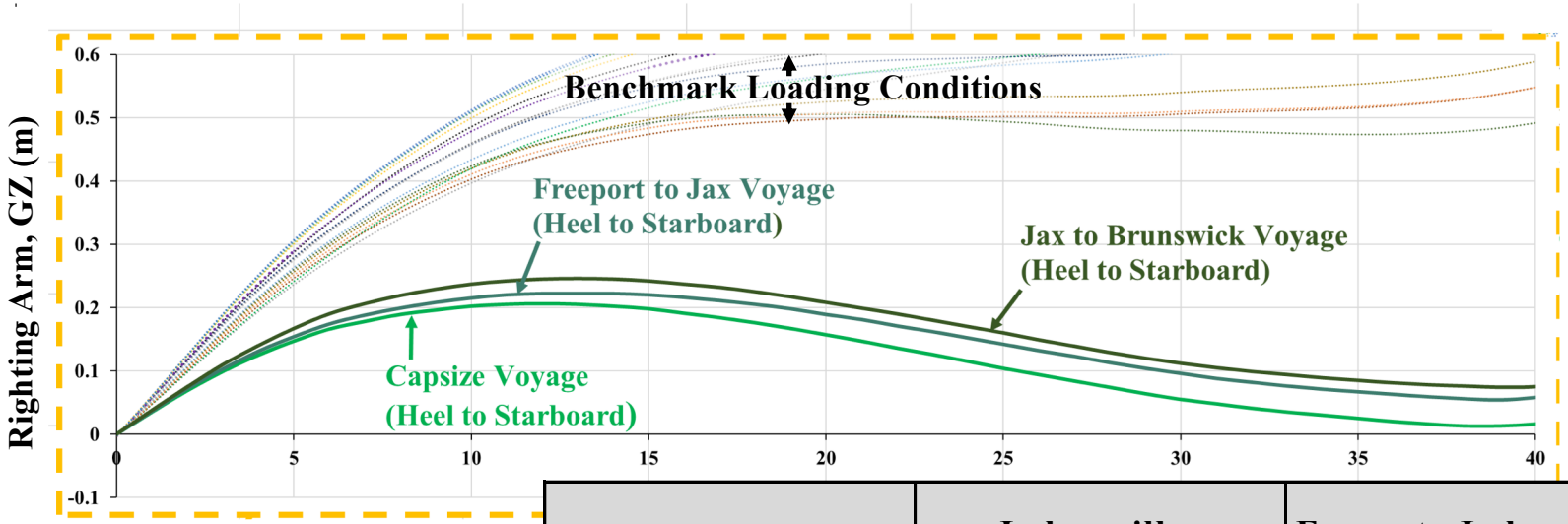
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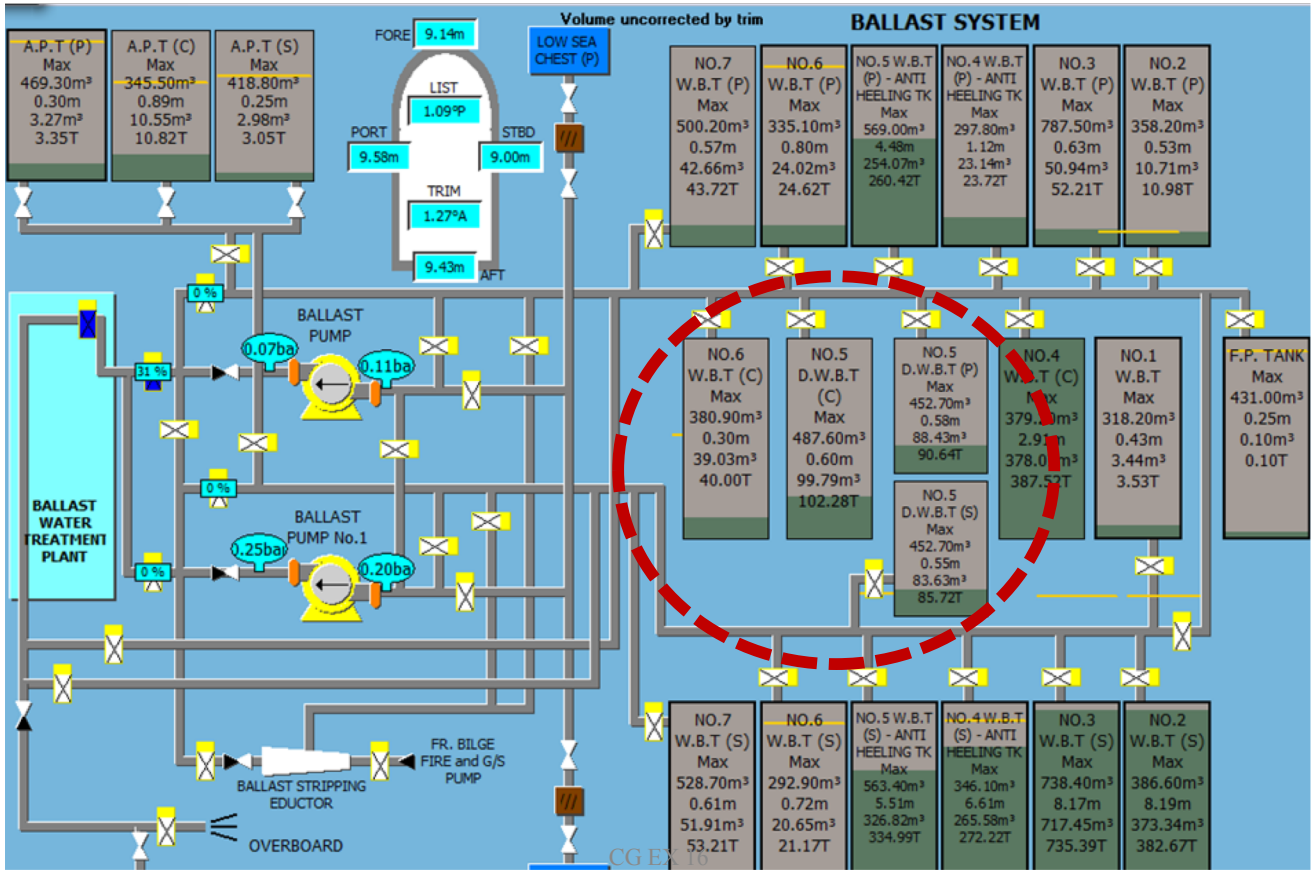


Stability: Preceding Voyages

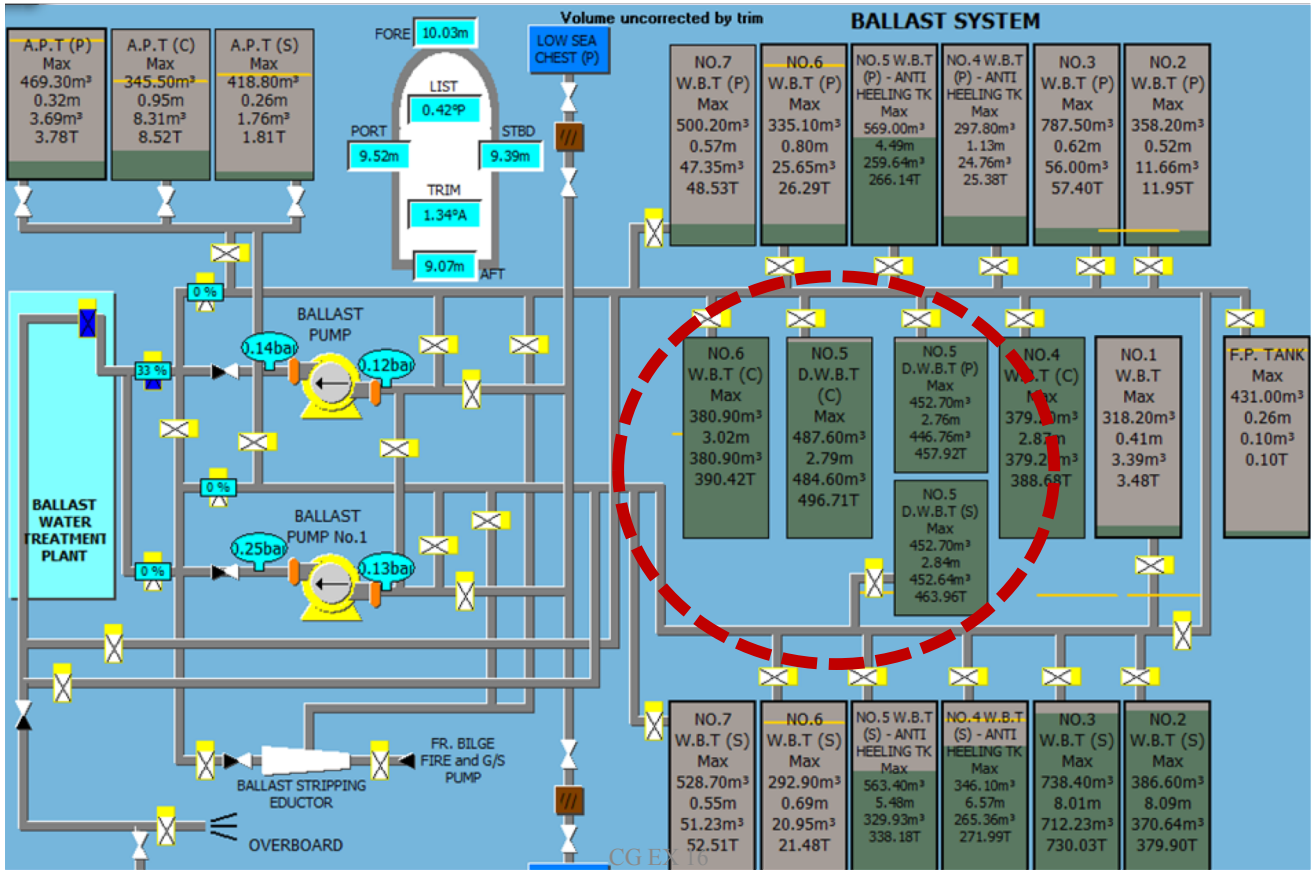


	Capsize Voyage	Jacksonville - Brunswick Voyage	Freeport - Jacksonville Voyage
GM	PASS	PASS	PASS
Maximum Righting Arm Angle/Value	PASS	PASS	PASS
Area under Righting Arm Curve	FAIL	FAIL	FAIL
Severe Wind & Rolling Criteria	FAIL	FAIL	FAIL

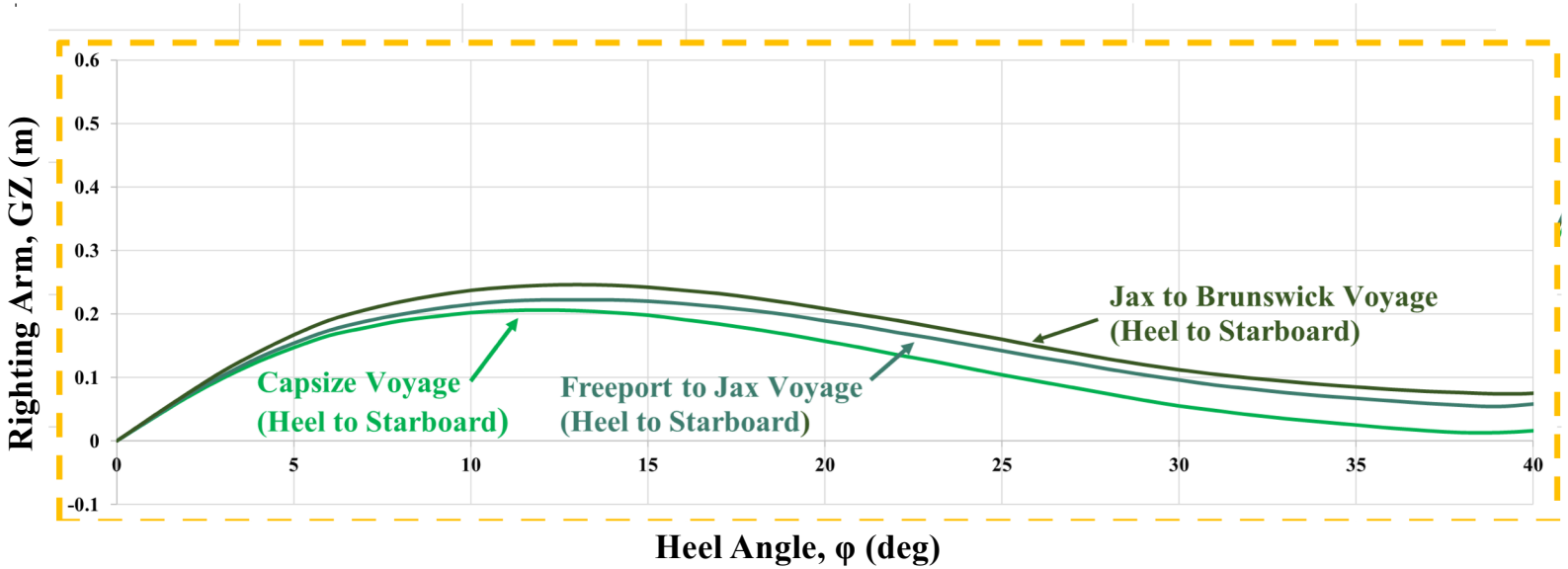
Stability: Additional Ballast



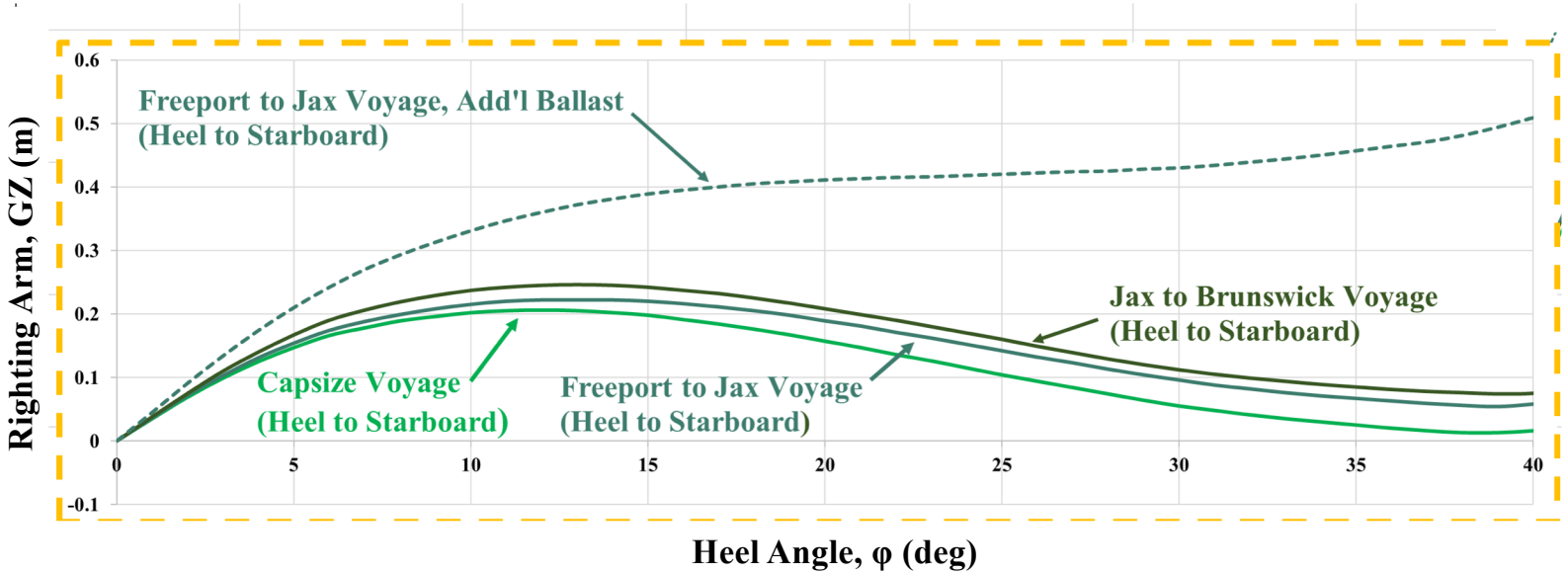
Stability: Additional Ballast



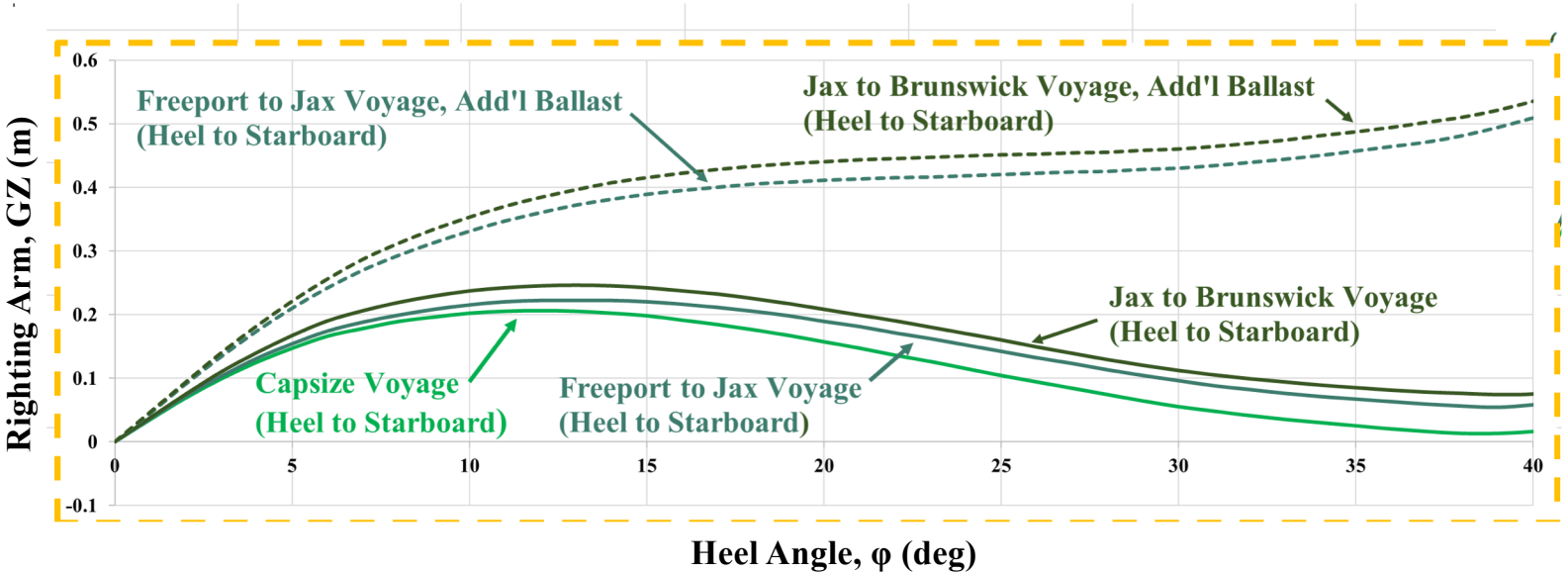
Stability: Additional Ballast



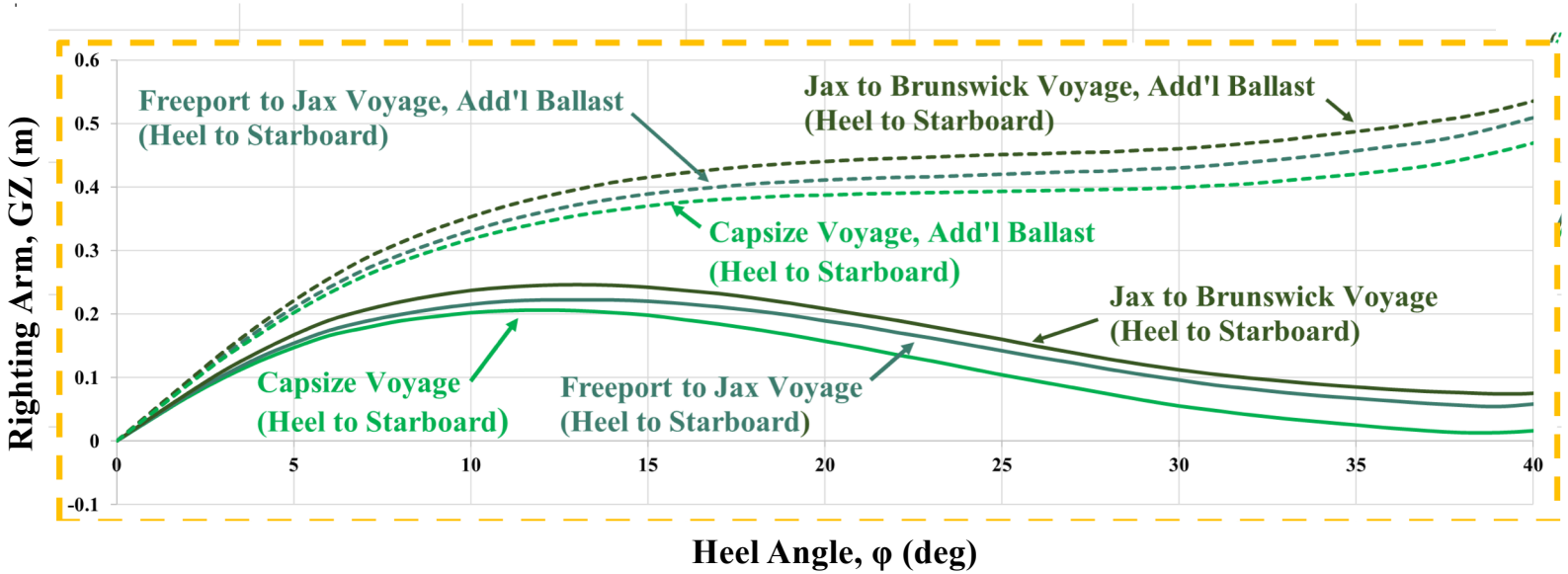
Stability: Additional Ballast



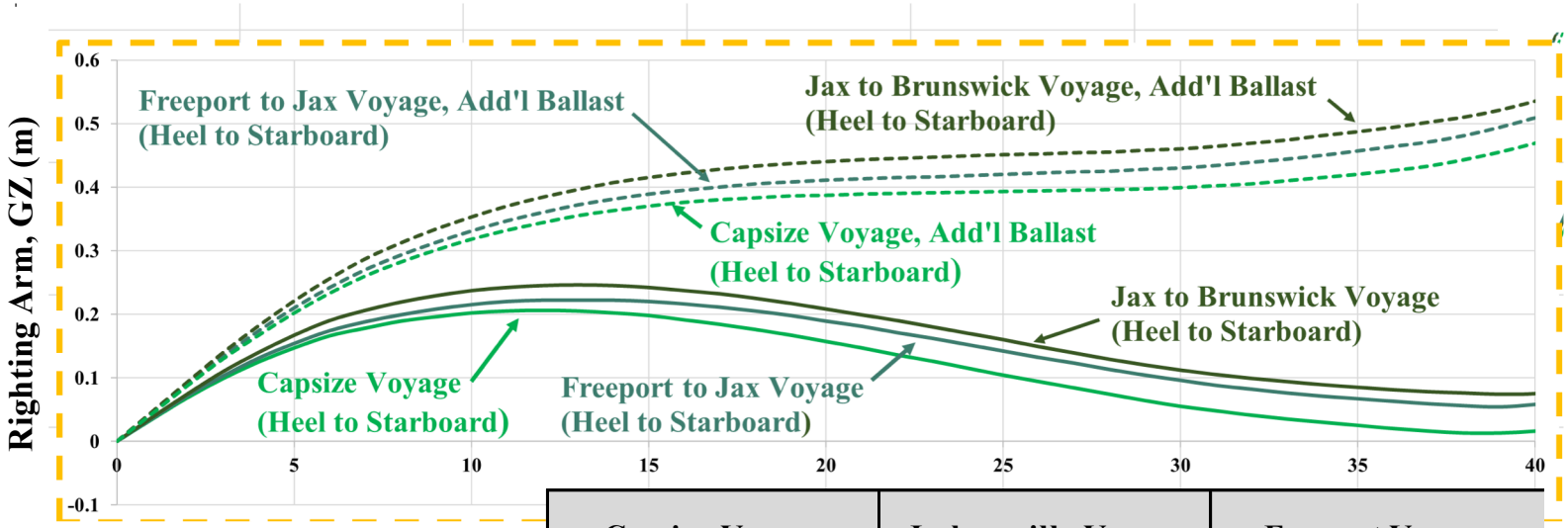
Stability: Additional Ballast



Stability: Additional Ballast



Stability: Additional Ballast



	Capsize Voyage Additional Ballast	Jacksonville Voyage Additional Ballast	Freeport Voyage Additional Ballast
GM	PASS	PASS	PASS
Maximum Righting Arm Angle/Value	PASS	PASS	PASS
Area under Righting Arm Curve	PASS	PASS	PASS
Severe Wind & Rolling Criteria	PASS	PASS	PASS

Summary

- Noncompliance with Intact Stability Code in Capsize Voyage
- Turn Heeling Moment Reduced Righting Energy
- Remaining Righting Energy Overcome by Dynamic Effects
- Noncompliance with Intact Stability Code in Preceding Voyages
- Full Compliance with Intact Stability Code with Additional Ballast

Cargo Loading

Capsize Voyage

	Weight (MT)	LCG (m-AP)	TCG (m-CL)	VCG (m-AB)
Deck 13	745.60	98.24	0.14	36.82
Deck 12	805.44	102.95	0.72	34.51
Deck 11	951.00	91.03	1.07	32.00
Deck 10	1010.00	91.56	0.28	29.47
Deck 9	1020.00	92.71	-0.33	26.93
Deck 8	995.00	86.31	-0.15	24.41
Deck 7	620.25	96.81	-0.91	21.71
Deck 6 Raised	155.29	25.57	5.97	18.97
Deck 6 Standard	511.00	121.57	3.42	18.27
Deck 5	525.09	102.25	-1.30	14.87
Deck 4	557.00	99.81	0.02	11.82
Deck 3	515.00	99.12	0.00	9.02
Deck 2	174.34	97.63	-0.83	6.12
Deck 1	195.15	94.04	0.12	3.42
Total	**8780.2**	**95.39**	**0.32**	**24.34**

Jacksonville - Brunswick

	Weight (MT)	LCG (m-AP)	TCG (m-CL)	VCG (m-AB)
Deck 13	745.60	98.24	0.14	36.82
Deck 12	535.28	78.87	-3.00	34.51
Deck 11	933.22	89.48	1.22	32.00
Deck 10	1010.00	91.56	0.28	29.47
Deck 9	1020.00	92.71	-0.33	26.93
Deck 8	995.00	86.31	-0.15	24.41
Deck 7	620.25	96.81	-0.91	21.71
Deck 6 Raised	155.29	25.57	5.97	18.97
Deck 6 Standard	511.00	121.57	3.42	18.27
Deck 5	440.09	105.18	-2.90	14.87
Deck 4	557.00	99.81	0.02	11.82
Deck 3	515.00	99.12	0.00	9.02
Deck 2	174.34	97.63	-0.83	6.12
Deck 1	195.15	94.04	0.12	3.42
Total	**8407.2**	**93.53**	**0.02**	**24.09**

Cargo Loading

Capsize Voyage

	Weight (MT)	LCG (m-AP)	TCG (m-CL)	VCG (m-AB)
Deck 13	745.60	98.24	0.14	36.82
Deck 12	805.44	102.95	0.72	34.51
Deck 11	951.00	91.03	1.07	32.00
Deck 10	1010.00	91.56	0.28	29.47
Deck 9	1020.00	92.71	-0.33	26.93
Deck 8	995.00	86.31	-0.15	24.41
Deck 7	620.25	96.81	-0.91	21.71
Deck 6 Raised	155.29	25.57	5.97	18.97
Deck 6 Standard	511.00	121.57	3.42	18.27
Deck 5	525.09	102.25	-1.30	14.87
Deck 4	557.00	99.81	0.02	11.82
Deck 3	515.00	99.12	0.00	9.02
Deck 2	174.34	97.63	-0.83	6.12
Deck 1	195.15	94.04	0.12	3.42
Total	**8780.2**	**95.39**	**0.32**	**24.34**

Freeport - Jacksonville

	Weight (MT)	LCG (m-AP)	TCG (m-CL)	VCG (m-AB)
Deck 13	745.60	98.24	0.14	36.82
Deck 12	739.74	98.34	-1.89	34.51
Deck 11	933.22	89.48	1.22	32.00
Deck 10	988.00	89.98	0.14	29.47
Deck 9	1020.00	92.71	-0.33	26.93
Deck 8	995.00	86.31	-0.15	24.41
Deck 7	580.25	97.70	-1.76	21.71
Deck 6 Raised	119.29	23.59	10.58	18.97
Deck 6 Standard	500.00	122.68	3.66	18.27
Deck 5	479.12	110.35	-1.15	14.87
Deck 4	557.00	99.81	0.02	11.82
Deck 3	515.00	99.12	0.00	9.02
Deck 2	174.34	97.63	-0.83	6.12
Deck 1	195.15	94.04	0.12	3.42
Total	**8541.7**	**95.36**	**0.11**	**24.33**

Drafts: Capsize Voyage

	MSC Model Salt Water	MSC Model Brackish Water	IMACS Departure	Departure Draft Readings
Taft (m)	9.37	9.39	9.20	9.45
Tfwd (m)	9.26	9.31	9.56	9.40
Tmean (m)	9.32	9.35	9.38	9.43

Drafts: Previous Voyages

Jacksonville - Brunswick

	MSC Model Salt Water	MSC Model Brackish Water	IMACS Departure	Departure Draft Readings
Taft (m)	9.47	9.51	9.49	9.40
Tfwd (m)	8.94	9.07	9.04	9.30
Tmean (m)	9.20	9.29	9.27	9.35

Freeport - Jacksonville

	MSC Model Salt Water	IMACS
Taft (m)	9.36	9.44
Tfwd (m)	9.21	9.23
Tmean (m)	9.29	9.34

Drafts with Additional Ballast

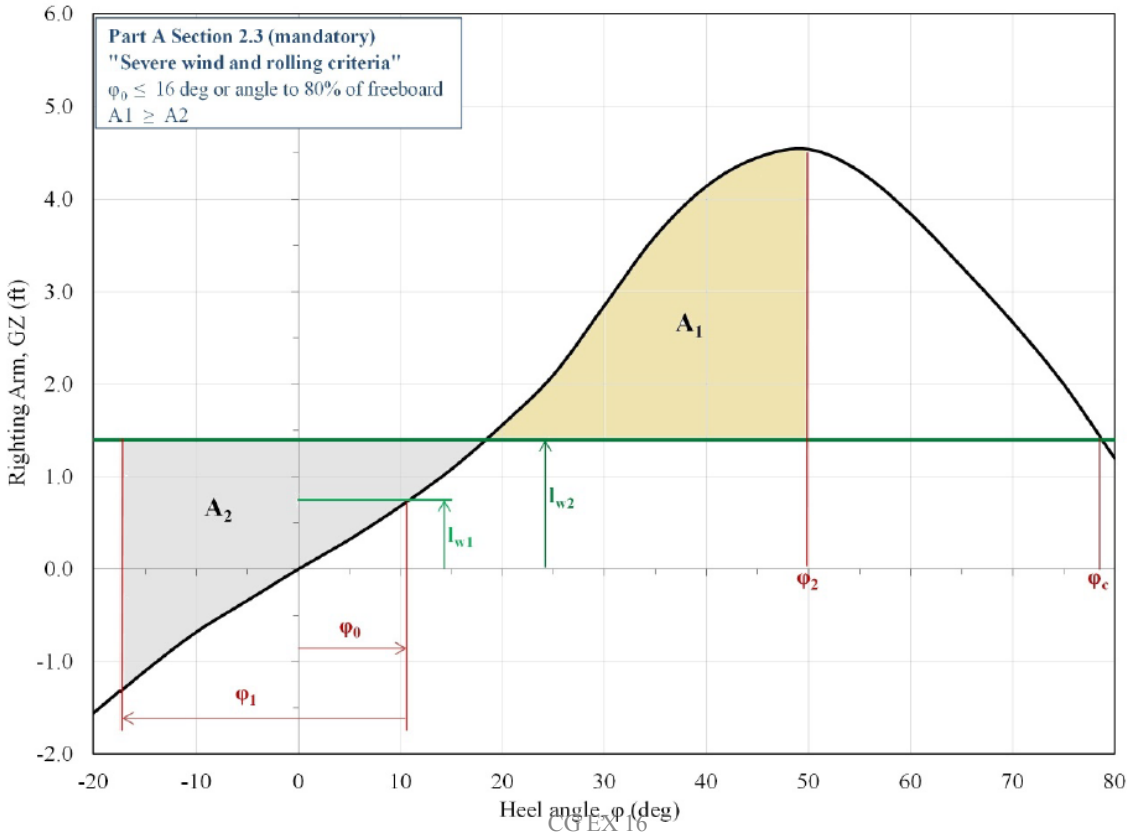
	MSC Loading Condition (Capsize Voyage) Additional Ballast	MSC Loading Condition (Jacksonville Voyage) Additional Ballast	MSC Loading Condition (Freeport Voyage) Additional Ballast
Taft (m)	9.55	9.64	9.54
Tfwd (m)	9.62	9.31	9.57
Tmean (m)	9.59	9.48	9.55

*Drafts represent salt water conditions

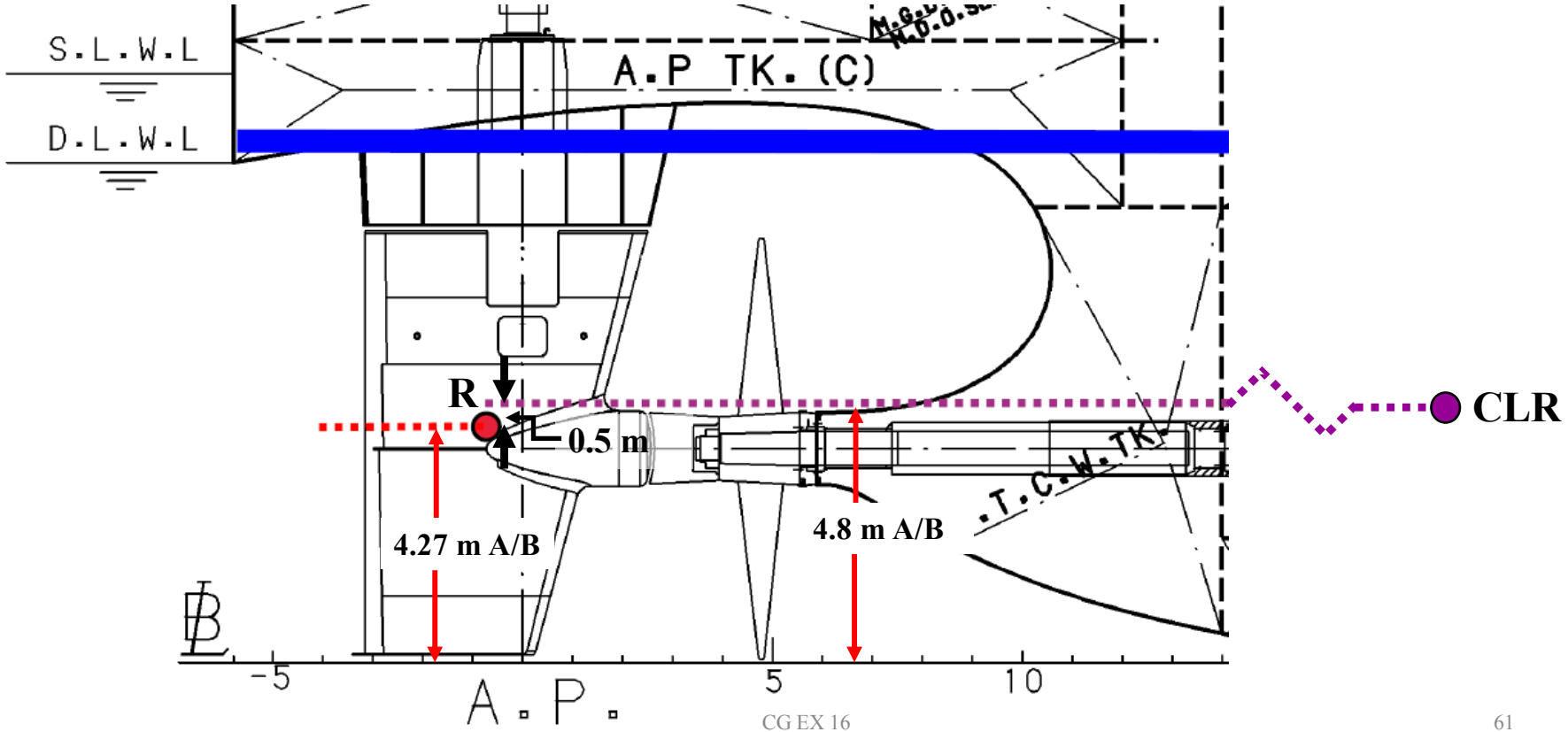
IS Code Compliance: Detailed

	Units	MSC Loading Condition (Capsize Voyage)	MSC Loading Condition (Jacksonville Voyage)	MSC Loading Condition (Freeport Voyage)	Required Value
Part A Section 2.2 - Criteria regarding righting arm curve properties					
Area to 30 degrees	m-rad	0.075	0.095	0.084	At least 0.055 m·rad
Area to 40 degrees/downflooding	m-rad	0.079	0.110	0.095	At least 0.09 m·rad
Area between 30 and 40 degrees/downflooding	m-rad	0.005	0.015	0.011	At least 0.03 m·rad
Maximum righting arm at 30 degrees or greater	m	3.980	4.028	4.056	At least 0.2 m
Angle of maximum righting arm	deg	80.3	80.2	80.4	At least 25 deg
Initial GM	m	1.76	1.91	1.84	At least 0.15 m
Part A Section 2.3 - Severe wind and rolling criteria					
Angle of static heel (φ_0)	deg	6.8	5.5	6.2	Not to exceed 16 deg or angle for 80% of angle to deck edge immersion
Area ratio (A_1/A_2)	m-rad	0 (No Area A1)	0 (No Area A1)	0 (No Area A1)	Greater than 1

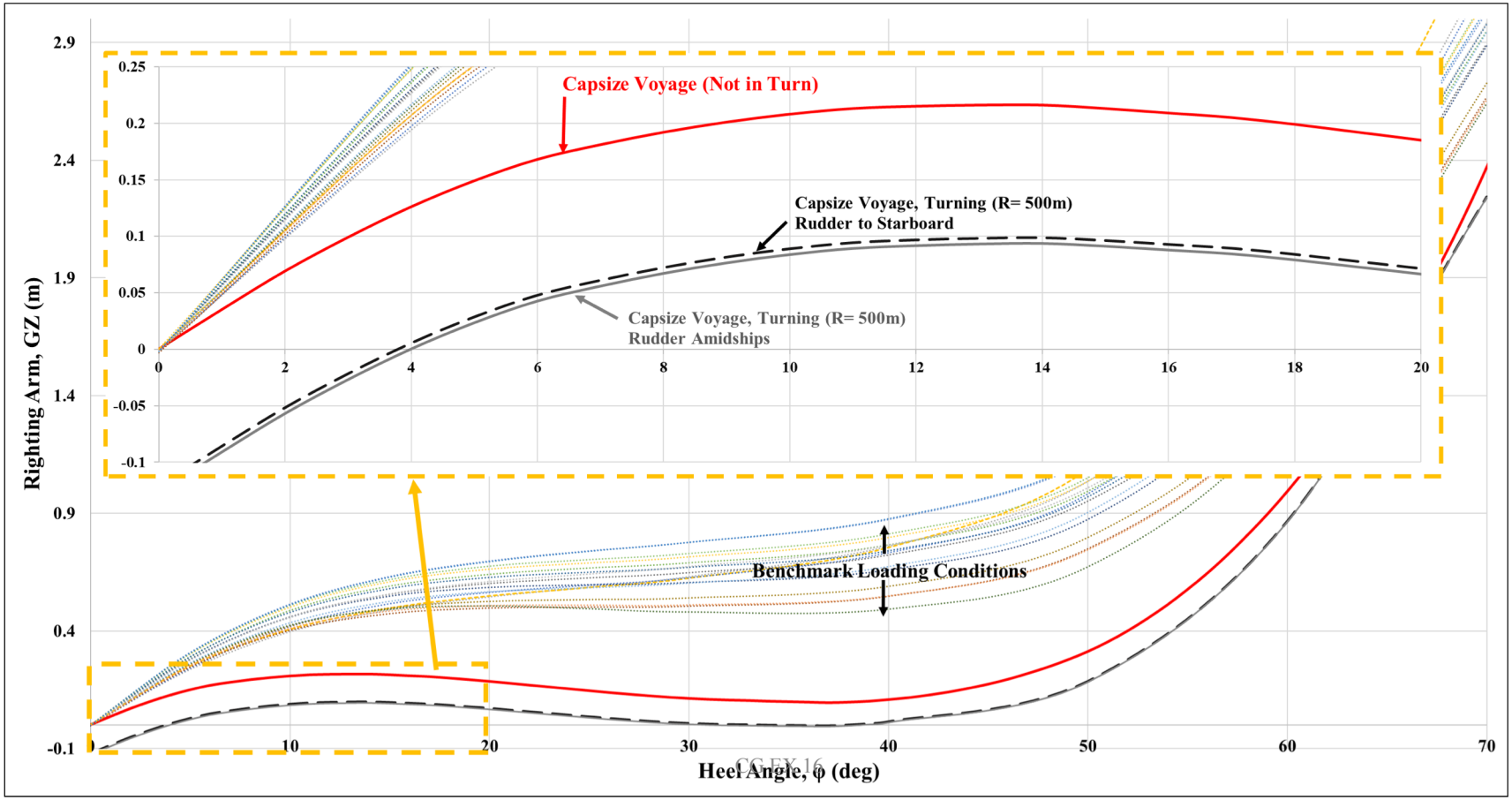
Severe Wind & Rolling Criteria



Stability During Turn: Pressure Centers

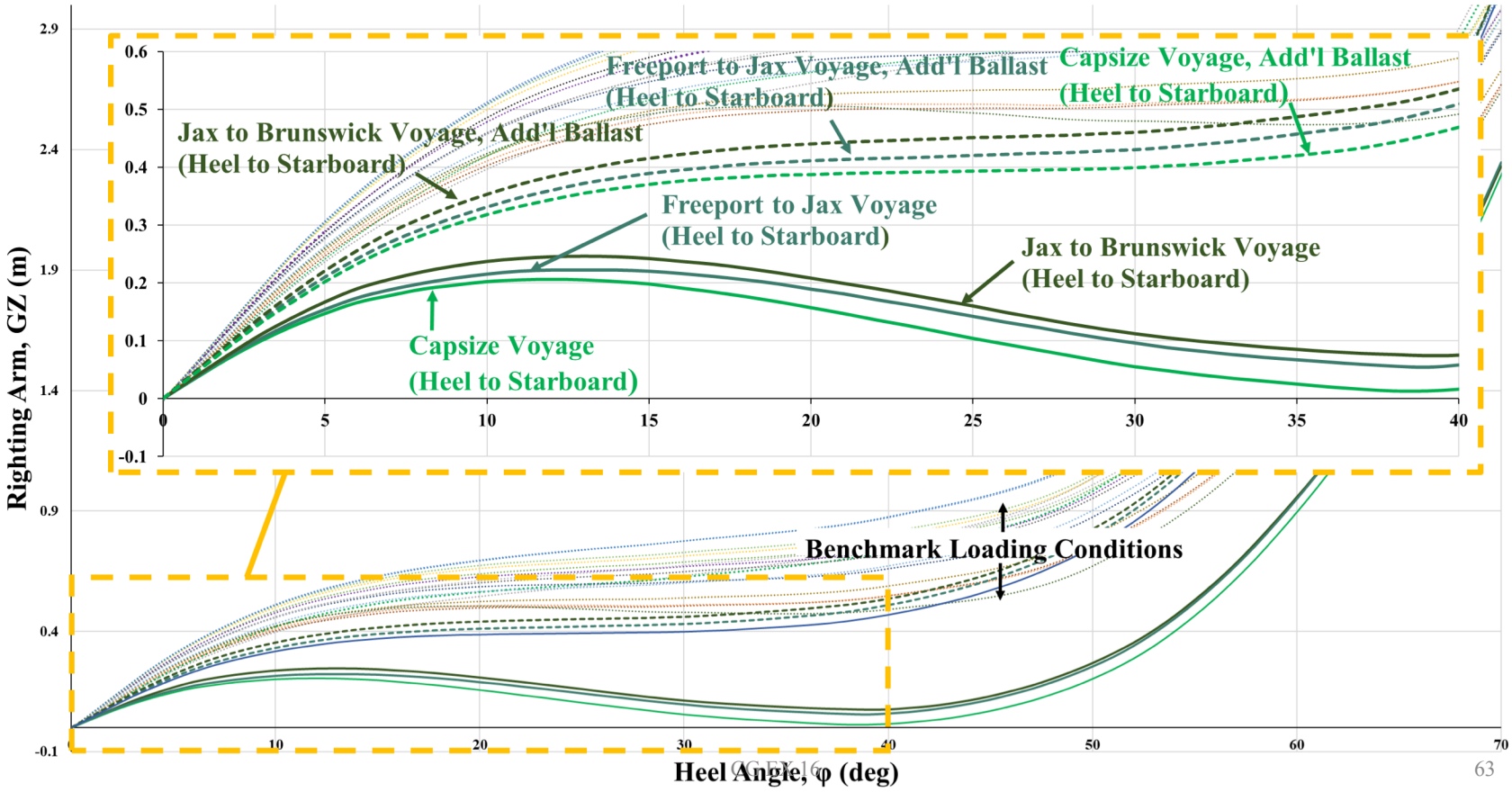


Stability During Turn: Rudder Change



CG EX 16

Additional Ballast & Benchmark



T&S Book Compliance

T&S Min. GM (m)	MSC Calc. GM (m)	Deficiency (m)
2.42	1.76	-0.66

T&S Max KG (m-AB)	MSC Calc. KG (m-AB)	Difference (m)
17.51	18.20	0.69

*Using Drafts from IMACs at departure