USCG MARINE SAFETY CENTER (MSC)

POST-CASUALTY STABILITY ANALYSIS OF LIFTBOAT SEACOR POWER

Revision 4

July 28, 2022

Enclosure (1) To MSC Memo, Serial # A0-2201141

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Date	**Revision**	**Notes**
7 Apr 2022	0	Initial Release
29 Apr 2022	1	Grammatical corrections and minor clarifications. Added Figure 11, Figure 12, Figure 13 and explanations
06 Jun 2022	2	Added and modified text for clarification in the following: Section 3.3, paragraph 3 Section 4, paragraph 3 Section 7.4, paragraph 1 and 2 Section 7.5, paragraph 2 Section 7.6.3, paragraph 1 Section 8.1 Section 8.4, changed section name and text Section 8.7, paragraph 3 Section 8.8
12 Jul 2022	3	Corrected 46 CFR Part 174 metacentric height (GM) criteria cite to 174.255(a)(3) throughout Corrected paragraphs regarding ABS review to CFR Criteria: Section 3.3, paragraph 4 Section 7.6.2.1, paragraph 4 Section 8.2, paragraph 2 Removed Figure 14 and renumbered subsequent figures
28 Jul 2022	4	Modified text in Section 7.4, first sentence to clarify source for ABS' calculations Corrected Table 5 and Figure 10 regarding ABS DrilWind relative wind directions

1. Vessel Description

SEACOR POWER was built as the DIXIE ENDEAVOR in 2002 at SEMCO Shipyard in Lafitte, Louisiana as Hull Number 1009. SEACOR POWER was a 3-leg liftboat, with the following dimensions:

- Length of Hull: 166’6”
- Overall Length of Hull with Helideck: 233’9”
- Depth of Hull: 13’
- Width of Hull at Forward Legs: 103’
- Width of Hull at Stern: 62’
- Outer Diameter of legs: 8’6”
- Leg Length 265’ (extended from 250’ on 22 June 2012)
- Legs are Buoyant (watertight) with partially buoyant pads

2. Regulatory Review

Stability review of and subsequent stability letters for SEACOR POWER were produced by the American Bureau of Shipping (ABS) on behalf the of USCG as outlined in Navigation and Vessel Inspection Circular (NVIC) 3-97: "Stability related review performed by the American Bureau of Shipping for U.S. Flag Vessels."

ABS conducted the stability analysis for SEACOR POWER as outlined in ABS letter and attached analysis, dated 14 August 2002 (961 total pages) and provided as SEACOR POWER U.S. Coast Guard Marine Board of Investigation (MBI) Exhibit 55.

ABS’ stability analysis considered both the as built 250’ legs and the future extension of the legs to 265’ as documented in their letter dated 14 August 2002. Because of this, no subsequent stability analysis of SEACOR POWER was conducted after 2002.

Two stability tests were conducted on SEACOR POWER to establish the vessel’s light weight and center of gravity. The initial stability test was conducted on 25 March 2002, as documented in ABS Stability Letter dated 16 April 2002 (MBI Exhibit 70). After leg extension, a subsequent stability test was conducted on 29 June 2012, with field notes provided as MBI Exhibit 220 and results documented on Page 4-1of SEACOR POWER’s most recent Marine Operations Manual, Revision 4, dated 31 October 2014 (MBI Exhibit 59).

3. Stability Criteria

3.1. The Righting Arm Curve

For a detailed assessment of stability, naval architects examine a vessel's righting arm curve. The righting arm curve is a plot of a vessel's righting arm versus angle of inclination. A righting arm is a measurement of a vessel's ability to right itself when disturbed from its upright position. In general, the greater the righting arm, the better the vessel's stability characteristics. The area under the righting arm curve (measured in foot-degrees), also termed "righting energy," is often used as a measure of the vessel's ability to absorb energy imparted by wind, waves, or other forces.

Righting moments are calculated by multiplying the weight of the ship by its righting arm at each angle of inclination. Heeling moments oppose righting moments and are generated by forces such as wind acting on the vessel at a distance from the vessel's center of buoyancy (the point that it rotates about while floating). When the righting moment and heeling moment are equal, a point of static equilibrium (static inclination angle) is reached. Heeling arms are generated by dividing heeling moments by the weight of the ship for comparison to righting arms.

A stable vessel's righting arm curve has two intersections of the righting arm and heeling arm curves as shown in Figure 1. The first intersection of the wind heeling moment and righting moment (the "first intercept") is a point of stable equilibrium: a heel angle that is caused by the wind force. The second intersection (the "second intercept") is also a point of static equilibrium, but one that represents the loss of stability, any further heeling beyond the second intercept heel angle causes the vessel to capsize.

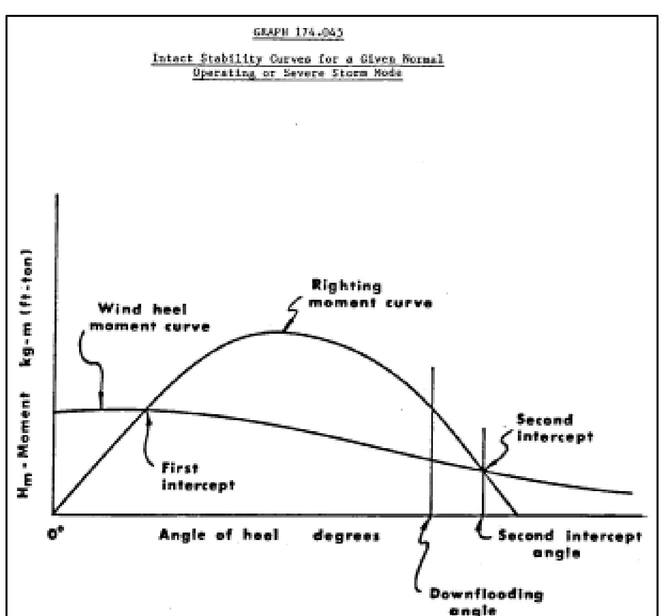

Figure 1: Graph 174.045 from Title 46 Code of Federal Regulations showing the righting arm curve for Mobile Offshore Drilling Units

For a comparison of righting versus heeling energy, area under the righting arm curve (representing restoring energy) is compared to the area under the heeling arm curve (representing upsetting energy). Residual area or energy is the difference between the area under the righting arm curve and the area under the heeling arm curve.

For traditional hull forms with length much greater than breadth, transverse stability (heel and roll) is the by far the most critical direction of inclination; these vessels have much more righting energy in the trimming (fore and aft) direction. Because of this, righting arms for traditional hull forms don't show trim at all. They are generated either by fixing the trim of the vessel or allowing the vessel to trim until the trimming moment is zero ("free trim").

Many liftboats, including SEACOR POWER, have non-traditional hull forms with relatively small length to breadth ratios. Because of this, transverse stability is not always the most critical for liftboats. Inclination of liftboats in a non-transverse direction typically results in less righting energy and may also have a larger heeling moment as the wind profile is rotated. Because of this, "off-axis" stability analysis other than purely port and starboard (around the longitudinal axis) is conducted to find the critical axis of inclination that possesses the worst and most limiting stability characteristics.

For this report, inclination of the liftboat with associated righting and heeling arms will always occur parallel to the direction of the wind: wind from the bow will incline the vessel aft, wind from the port quarter will incline the vessel to the starboard bow. Permitting the wind incident angle and inclination angle to rotate like this is known as an "axis" rotation because we are rotating the port/starboard and fore/aft axis around the vertical axis. For this report, rotations of the axis are measured clockwise relative to the bow with 0º and 360º indicating wind from the bow, 90º indicating wind from the starboard beam, 180º indicating wind from the stern, and 270º indicating wind from the port beam. Positive inclination is away from the direction the wind is coming from (common weather and maritime convention is to provide wind direction as the direction the wind is coming from).

For this report, inclination in the axis perpendicular to the inclination axis will be termed "orthogonal tipping" following the convention of technical papers on the subject (References 1 through 4). For the port beam wind example where the wind is from 270º, positive heel is called *inclination* and is to starboard, positive trim is called *orthogonal tipping* and is aft toward the stern (note that the "right-hand rule" convention typical of engineering calculations is not followed in favor of common maritime convention).

3.2. Liftboat Stability Requirements of the Code of Federal Regulations

Stability regulations for liftboats are contained in Title 46 Code of Federal Regulations Chapter I, Subchapter S (sections of this subchapter will be abbreviated with: §).

3.2.1. Stability Requirements in Part 170 for All Vessels

Although Mobile Offshore Drilling Units (MODUs) are exempt from the intact stability criteria in Part 170 of Subchapter S, liftboats are not explicitly noted as exempt in §170.160.[1] Because of this, either the intact stability criteria listed in §170.170 "Weather Criteria" or §170.173 "Criterion for Vessels of Unusual Proportion and Form" could be applied to liftboats. It is apparent from the stability criteria that most liftboats are not intended to meet §170.170 which is for vessels of "ordinary proportions and form." Most liftboats cannot meet §170.173 because liftboats have very low range of stability (20° or less) with downflooding angles as low as 10-15°. For even the most benign "protected" route, §170.173 requires positive righting arms to 25º, and no submergence of downflooding points to angles of inclination of at least 15º. MSC has historically not applied these criteria to liftboats.[2]

3.2.2. Stability Requirements in Part 174, Specific to Liftboats

Stability regulations specifically applicable to liftboats are listed in Part 174 Subpart H "Special Rules Pertaining to Liftboats", which applies to liftboats inspected under Subchapter L. These regulations include the stability criteria listed in Table 1 on page 11.

Stability criteria contained in Part 174 are silent regarding wind direction. The terms "heel" and "heeling moment" are used throughout but not defined in Part 174, which leaves evaluation of liftboat inclination and wind direction to the interpretation of the naval architects conducting an analysis. Given the hull shape, it is unreasonable to assume that the regulations intend only for an analysis of wind forces acting on the beam and inclining the vessel in a transverse direction (about the longitudinal axis) because this type of analysis will not consider the stability failure directions most likely to affect a liftboat.

The MSC has not documented their policies for varied wind direction or off-axis stability analyses. A review of MSC's past liftboat stability reviews indicate an inconsistent application of off-axis stability prior to 2018.

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[1] As part of the Coast Guard's interim rulemaking for Offshore Supply Vessels, Federal Register Volume 60, No. 221 of November 16, 1995, page 57637 explicitly states: "It was never the Coast Guard's intention to impose on liftboats criteria for stability of conventional ship-shaped hull...Liftboats in restricted service must now, according to § 174.255, meet the criteria for intact, damaged, and on-bottom stability in §174.255 itself."

The final rule for Offshore Supply Vessels (Federal Register Volume 62, No. 182 of September 19, 1997) does not address this issue, nor does it make any changes of §170.160.

The addition of MODU's to the list of vessel types exempt from §170.170 and §170.173 is noted in Federal Register Volume 48, No. 115 of November 4, 1983. Page 50999 of this Federal Register entry explicitly states that MODUs are exempt because "a separate wind heel criterion is applied to MODU's in §174.045. Offshore supply vessels and liftboats did not have specific regulations at that time.

[2] §170.173(a) gives MSC discretion on the applicability of the stability criteria within §170.173

A letter from the Chief of the Naval Architecture Division of the Coast Guard Office of Design and Engineering Standards (CG-ENG-2) dated November 7, 2018, to MiNO Marine, LLC (a naval architecture and professional services firm that designs lift boats) states that Part 174 "is silent on the issue" of off-axis stability but that wind directions should be checked incrementally from 0º to 360º of yaw. This position is also reflected in informal correspondence between the Marine Safety Center, COMDT(CG-ENG-2) and ABS in 2009.

For liftboats and MODUs, Part 174 is also silent regarding whether the vessel should be allowed to trim freely (orthogonally tip) when evaluating righting arm curves (notably, Part 174 is not silent about this for Tugboats, Offshore Supply Vessels, or Hopper Dredges). Using fixed trim is not a suitable way to evaluate liftboat stability; this is due to potentially weak righting characteristics in trim and the location of downflooding points away from amidships where they are particularly affected by trim. For this report, MSC always allowed the model to freely trim and freely tip in the direction orthogonal to inclination.

Overturning moments generated by wind force are calculated using the formula given in §174.055 (Figure 2) which is identical to the formulas in the ABS Rules for Building and Classing Mobile Offshore Drilling Units, 2001 (ABS MODU Rules), and the International Maritime Organization's MODU Code. This formula generates a stepwise wind pressure where the wind pressure is constant from the waterline to 50 feet above the waterline and then increases to higher constant value at each 50-foot increment above the waterline. To calculate an overturning moment, windage areas within each 50-foot block are multiplied by pressure, a "shape factor" (similar to drag coefficient), and then multiplied by the distance from center of lateral resistance to the windage profile's area centroid. The moments generated by each windage area are summed and applied on the model. Figure 3 shows the 50-foot height blocks where windage area is calculated above waterline for SEACOR POWER.

$H = k(v)^2(Ch)(Cs)(A)(h)$

where—

(1) H = wind heeling moment for an exposed surface on the unit in foot-pounds (kilogram-meters);

(2) k = 0.00338 lb./(ft.^{2}-knots^2) (0.0623 (kg-sec^2)/m^4);

(3) v = wind velocity of—

(i) 70 knots (36 meters per second) for normal operating conditions.

(ii) 100 knots (51.5 meters per second) for severe storm conditions.

(iii) 50 knots (25.8 meters per second) for damage conditions.

(4) A = projected area in square feet (square meters) of an exposed surface on the unit;

(5) Ch = height coefficient for “A” from Table 174.055(a);

(6) Cs = shape coefficient for “A” from Table 174.055(b); and

(7) h = the vertical distance in feet (meters) from the center of lateral resistance of the underwater hull to the center of wind pressure on “A”.

Figure 2: Wind heeling moment formula from 46 CFR 174.055

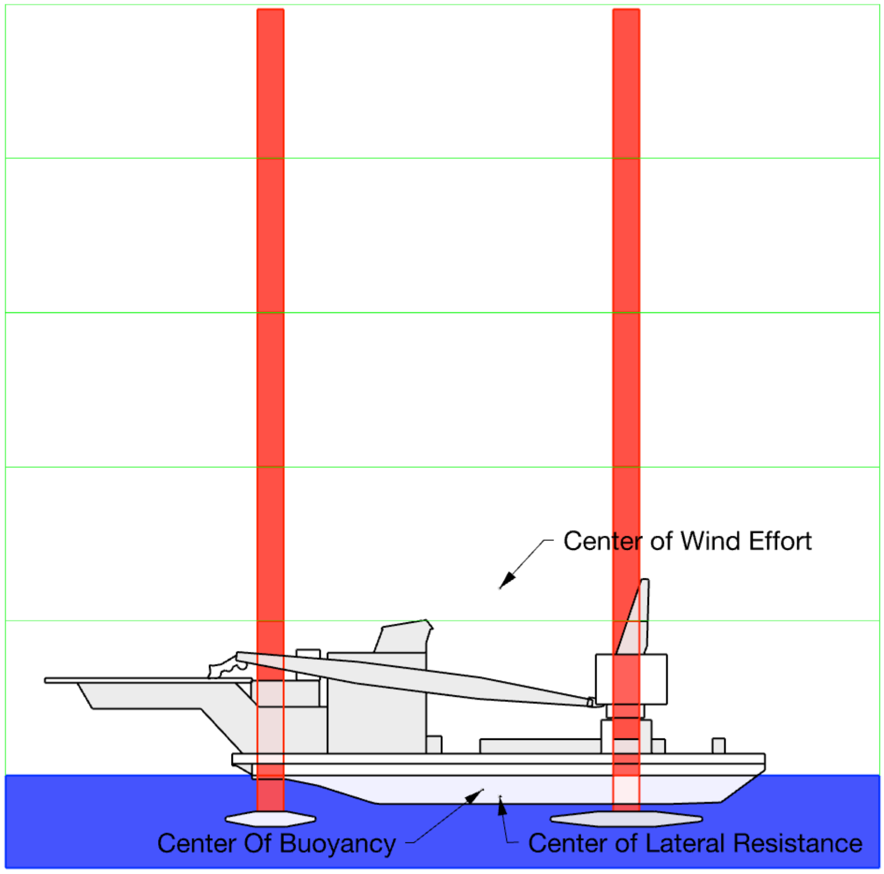

Figure 3: Wind Profile of SEACOR POWER. Each green outlined block represents 50 feet of wind profile height. Legs are highlighted red because they are not allowed to shield other components from the wind. The legs of the SEACOR POWER model are lowered 10 feet in this image.

It should be noted that righting moments are moments that act around the center of buoyancy. Using the heeling moment formula of §174.055, heeling moments are calculated as the product of wind force and the distance of the center of wind effort to the center of lateral resistance not the center of buoyancy. The heeling and righting moments are not acting on the same point as shown in Figure 3. This is notable because the distance between center of lateral resistance and center of buoyancy could increase to a magnitude that invalidates the comparison between §174.055 calculated heeling moment and righting moment. Because liftboat pads (alternatively named spud cans or feet) and legs may not be buoyant, the center of lateral resistance could be much lower than the center of buoyancy. For example, SEACOR POWER has buoyant legs but only partially buoyant pads, so the center of lateral resistance is lower than the center of buoyancy.

MSC also notes that the stepwise wind pressure versus height profile of §174.055 results in lesser pressures when compared to other wind profile standards, including those from the American Petroleum Institute, the Norwegian Petroleum Directorate, the Society of Naval Architects and Marine Engineers, and the wind profile required for uninspected fishing vessels of 46 CFR 28.575. A comparison of these wind profiles is shown in Figure 4.

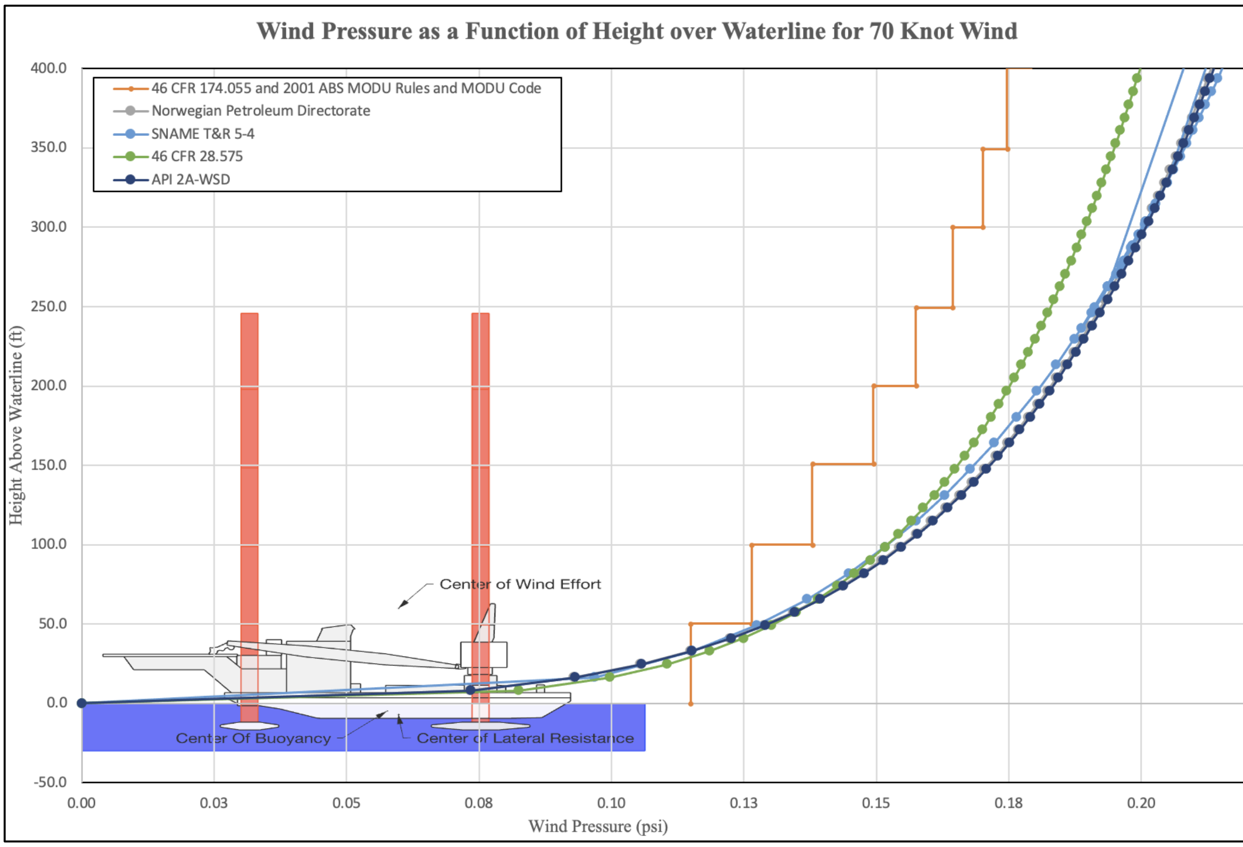

Figure 4: Comparison of wind pressure vs. height standards. The orange-stepped line is the 70-knot, "severe storm condition" wind pressure profile that applied to SEACOR POWER. SEACOR POWER is shown with the legs lowered 10 feet.

3.3. ABS MODU Rules

Classification certificates are required by some flag states and marine insurers. These are issued by third-party, non-governmental classification societies that establish technical standards for construction and operation. In addition to performing stability review of SEACOR POWER on behalf of the U.S. Coast Guard under NVIC 3-97, SEACOR POWER was issued a classification certificate by ABS.

At the time of SEACOR POWER's construction, ABS had its own requirements for liftboat stability which were contained in the ABS Rules for Building and Classing Mobile Offshore Drilling Units, 2001 (ABS MODU Rules). These classification requirements included the stability criteria listed in Table 1. Notably, ABS MODU Rules explicitly require the vessel to satisfy stability criteria with winds from *any* horizontal direction. Like Part 174, the ABS MODU Rules are silent regarding whether the vessel should be allowed to trim freely when checking stability criteria.

ABS MODU Rules for intact stability are similar to the Code of Federal Regulations except that Part 174 also requires residual righting energy and range of stability criteria.

ABS' stability plan review letter (MBI Ex. 55) and calculations indicate that ABS reviewed SEACOR POWER to both ABS MODU Rules and 46 CFR Subchapter S. Calculation summary results provided with that letter and included in MBI Exhibit 55 indicate that ABS identified the CFR criteria as the limiting stability criteria during their review.

	Code of Federal Regulations		**ABS Rules for Building and Classing Mobile Offshore Drilling Units, 2001**	
Intact Stability Criteria	46CFR174.255(a)	46CFR174.045	Part 3, Chapter 3, Section 1	
Service	Restricted	Unrestricted	Restricted	Unrestricted
Wind Direction	Not Specified	Not Specified	Any Horizontal Direction	
Wind Speed (Knots; Normal / Storm)	60 / 70 §174.255(a)(2)	70 / 100 §174.045(a)(2)	>50	70 / 100
Righting Area to Heeling Area Ratio	1.4 §174.255(a)(1)(i)	1.4 §174.045	1.4	1.4
Range of Stability (degrees)	10 §174.255(a)(1)(ii)	No Requirement	Always Positive from Equilibrium to Vanishing	
Residual Righting Energy (ft-degrees)	5 §174.255(a)(1)(iii)	No Requirement	No Requirement	No Requirement
Metacentric Height (GM, feet)	> 1 §174.255(a)(3)	> 0.167 §174.040	> 0	> 0
Damaged Stability Criteria	46CFR174.255(b)	46CFR174.065	Part 3, Chapter 3, Section 1	
Damage Penetration	2.5 feet from the side of hull §174.255(b)(4)	5 feet from side or bottom of hull §174.080(a)	5 feet from hull side, no limit vertically	
Compartments Subjected to Damage	Single compartment (within 1 set of transverse watertight bulkheads)		Single compartment (containing pumps, sea water cooling, or adjacent to the sea)	
Wind Speed (knots)	50 §174.255(b)(1)(ii)	50 §174.045(a)(2)	50	50
Downflood Height Above Waterline	> 0 §174.255(b)(1)	> 0 §174.045(a)	> 0	> 0
Residual Range of Stability	No Requirement	No Requirement	No Requirement[3]	

Table 1: Federal regulatory and ABS classification stability criteria for liftboats built in 2001. SEACOR POWER was a "restricted" liftboat.

[3] A damaged range of stability criteria of 7° + 1.5•Static Angle of Inclination After Damage was introduced to ABS MODU Rules in 2005. This rule did not apply to the SEACOR POWER.

4. Operating Requirements for Afloat Stability

ABS issued SEACOR POWER a stability review letter on August 14, 2002, with associated calculations (MBI Exhibit 55), providing the operating requirements to satisfy stability criteria in the as-built condition with 250-foot legs and for future modification to 265-foot legs. The stability review letter provided operating requirements include a maximum molded draft of 10 feet and maximum vertical centers of gravity for operating and storm survival conditions at drafts of 8, 8.5, 9, 9.5, and 10 feet. ABS' letter prescribes normal operating condition winds of 60 knots and storm survival winds of 70 knots consistent with §174.255(a)(2) requirements for a "restricted" liftboat. Openings that could allow flooding (downflooding points), subdivision, and buoyant volumes are also listed in ABS' letter. These operating stability requirements remain unchanged in the most recent revision of the Marine Operations Manual, Revision 4, dated October 21, 2014 (MBI Exhibit 59).

In addition to drafts and corresponding maximum vertical centers of gravity, SEACOR POWER's draft was limited by International Load Line Certificate to 9.75 feet (the summer load line). The Load Line Certificate was issued by ABS on behalf of the U.S. Coast Guard. The Marine Operations Manual, Revision 4 (MBI Exhibit 59), describes this load line draft of 9.75 feet as the maximum allowable draft on page 4-6 (Figure 5).

Trim is not discussed in the ABS stability review letters provided to MSC. ABS calculations for stability were performed with zero initial trim. The Marine Operations Manual includes one discrete trim limit on page 8-13 stating that "the vessel should have no more than 6" of trim by the stern." This page is a calculation worksheet page and the limit appears in finer print and a different color than other text on the page. Deck officers testified at the MBI that they did not use this worksheet to evaluate stability. The source of this limit could not be identified in engineering documentation, however, zero initial operating trim is apparently the only initial trim considered by ABS or SEMCO. Because MBI testimony indicated that SEACOR POWER normally operated with aft trim, this post-sinking analysis report considers aft trims from 0 to 3 feet.

The Operating Manual lists a limiting wave height of 5 feet or twice the freeboard as shown in Figure 5. However, regulatory and ABS MODU Rules stability criteria do not include requirements for stability in waves and the origin of this 5-foot limit is not known.[4] Statutory and class rule requirements for liftboats are evaluated using static, sustained wind, still-water conditions only.

[4] NVIC 8-81, Change 1 (published March 1988 and cancelled by NVIC 8-91 published in May of 1991) included a wave height restriction of twice the freeboard for liftboats (a minimum freeboard requirement of 2 feet was required).

SEACOR Liftboats LLC

Seacor Power
Marine Operations Manual

4.2.2 Operating Limits in Afloat Mode

4.2.2.1 ENVIRONMENT, LOADING, AND STOWAGE

The following afloat limits and conditions have been approved by the USCG.

Table 4-6 Restrictions when Afloat

Loadline Draft or Maximum Allowable Draft	9.75 Feet – The loadline draft is not to be exceeded under any circumstances
Maximum Trim	Vessel shall not be trimmed by the bow at any time.
Wind Speed (legs fully raised)	70 Knots
Wave Height	5 Feet
Wave Period	not available
Maximum Deck Load	1,000,000 lbs. (446.43 LT)
Load Line Displacement	3,049.916 LT
Maximum Seas (jacking operations)	5 Feet (trough to crest) – Field moves in excess of 5 feet are prohibited.
Maximum Seas (underway)	Twice the freeboard or 5 Feet (trough to crest) whichever is the most conservative.
Maximum Deck Load Height (average)	26' above main deck
Route	Limited to GOM not more than 12 hours from harbor of safe refuge or location where vessel may elevate to survive 100 knots of wind
Safe Harbor	Maximum water depth 70 ft.
WT Doors, Hatches, and Manholes	Must be closed and dogged or bolted.
Deck Cargo	Must be secured.
Cranes	Booms must be stowed and secured
Bilges	Must be pumped to minimum content at all times

Stability shall be calculated prior to moving the vessel to ensure that the variable load does not exceed the maximum allowable and the KG (VCG) does not exceed the Maximum Allowable VCG Curve.

Figure 5: Operating limits in afloat mode for SEACOR POWER (Marine Operations Manual, page 4-6)

Seacor Power
Marine Operations Manual

SEACOR Liftboats LLC

8.16 AVCG CURVE

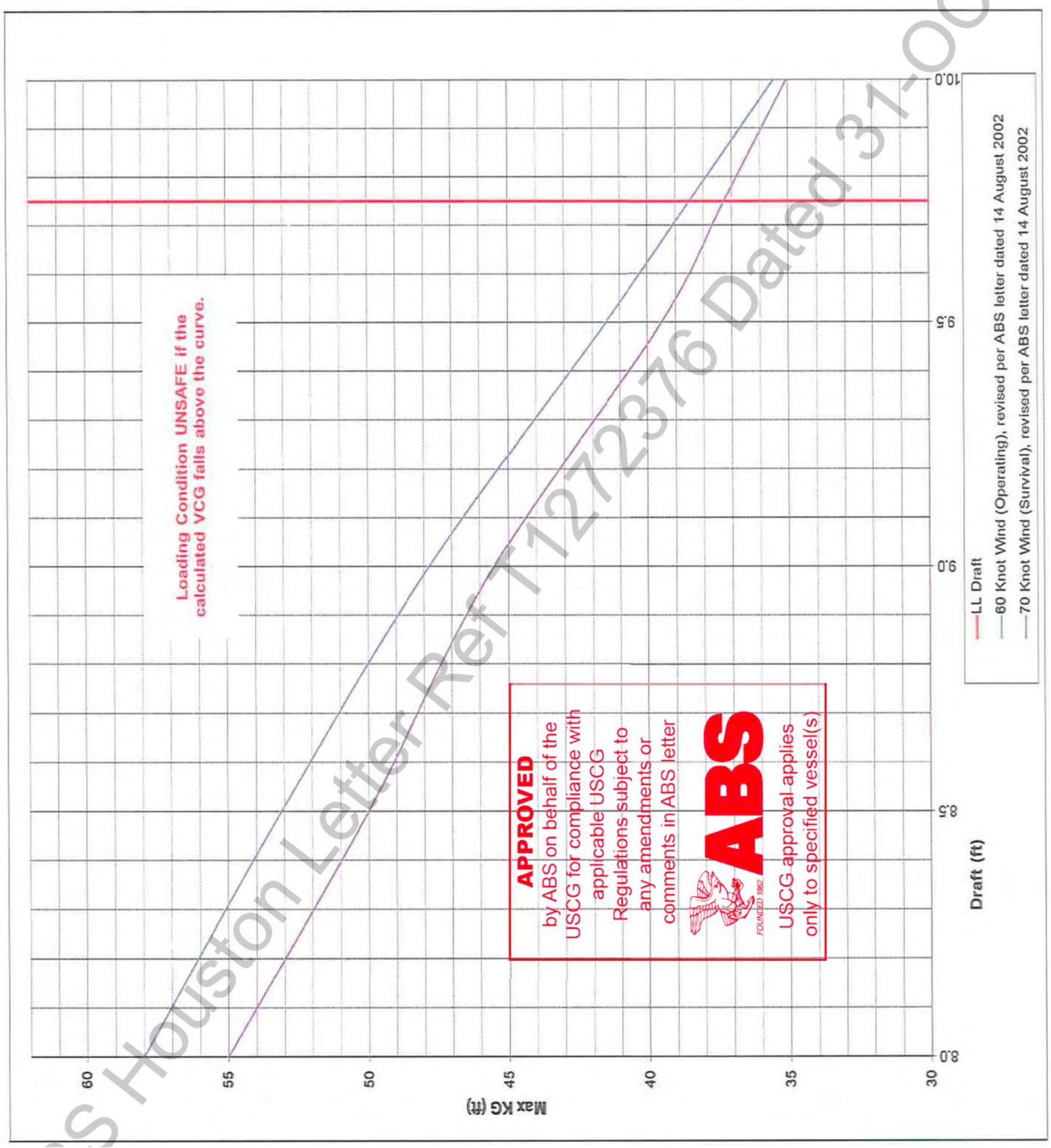

Figure 6: Allowable vertical center of gravity curve approved by ABS (Marine Operations Manual, page 8-25)

5. Stability Tests

Stability tests are performed to determine the "lightship" weight and center of gravity of a vessel. Lightship weight (or "light weight") consists of the weight of the permanent structure and machinery in an operational condition (including spares and equipment necessary for operation). Stability tests are required by Subpart F. During a stability test, the weight is determined through a deadweight survey (by measuring the drafts and surveying the vessel for items to add, relocate, or remove to establish lightship weight). The center of gravity is determined using an inclining test (test weights are moved on the vessel and the resulting heel angles are measured). Stability tests are performed to determine weight and center of gravity only, they do not indicate operational stability of the vessel.

SEACOR POWER had two recorded stability tests conducted by SEMCO. The first test was conducted March 25, 2002, after construction. The second test was conducted June 29, 2012, after the legs were extended 15 feet. This test was witnessed by representatives of ABS and the U.S. Coast Guard. MSC used field notes to independently check the 2012 stability test results, arriving at similar light weight and center of gravity as SEMCO.

Regulatory stability limits were provided in SEACOR POWER's Marine Operating Manual as a maximum vertical center of gravity at a given draft (with assumed zero heel and trim) as shown in Figure 6. Because the stability test results do not affect these stability limits, requirements prescribed by ABS in 2002 continued to apply after the leg extension and second stability test in 2012. The additional weight and higher vertical center of gravity of the extended legs is provided in the Marine Operations Manual (MBI Exhibit 59). The crew of the vessel could use these lightship characteristics to calculate the condition of the vessel and ensure that the calculated vertical center of gravity for the vessel's condition remained below the approved maximum vertical center of gravity curve (Figure 6) for given drafts.

6. Departure and Loss Loading Condition

Departure of SEACOR POWER from Port Fourchon on April 13, 2021, was recorded by several cameras within the port (a still image is shown in Figure 7). Visual observation indicates that the vessel was at a draft of approximately 9.25 feet (the waterline appears to be near the bottom of the Plimsol Mark's ring, which is at this draft) with a trim of approximately 2.5 feet aft as measured using the difference in visible fore and aft drafts. Heel angle is not clearly visible, but some slight starboard heel is observed, and MSC assumed a starboard heel of 0.25°.

Cargo manifests indicate SEACOR POWER loaded approximately 100 long tons of cargo before departure (MBI Exhibits 24-30). Survivor testimony indicated that cargo was not secured on deck. This post-sinking stability analysis assumes the cargo remains without shifting.

Tank loading of consumable liquids was reported by SEACOR POWER's HelmConnect system just prior to capsize at 1510 on April 13, 2021 (MBI Exhibit 86). This system indicated the liquid loads shown in Table 2. In addition to this liquid load, the off-duty Chief Engineer stated that preload tanks (Tanks C, E, G, K, Q, and S) typically had 6" of seawater in them.

Tank	Quantity	Volumetric Unit
Port Fuel Day Tank	4,747	Gallons
Port Fuel Tank	8,775	Gallons
Starboard Fuel Day Tank	4,918	Gallons
Starboard Fuel Tank	10,387	Gallons
Fresh Water	28,396	Gallons
M.E. 15W-40	352	Gallons
Dirty Oil	187	Gallons
Jacking Hydraulic Oil	4,578	Gallons
Port Crane Hydraulic Oil	454	Gallons
Starboard Crane Hydraulic Oil	534	Gallons

Table 2: Reported consumable tank loading from HelmConnect system reported at 1510 on 13 April 2021

Figure 7: Departure image of SEACOR POWER in Port Fourchon on 13 April 2021

7. MSC's Independent Stability Analysis

MSC conducted a post-casualty regulatory stability analysis of SEACOR POWER to determine if the operating conditions of the vessel met regulatory stability criteria. MSC did not conduct any stability analysis or stability oversight of ABS as part of SEACOR POWER's initial certification in 2002 or subsequent leg lengthening in 2012.

7.1. Model Construction

MSC developed a computer hull model to analyze the vessel using a combination of two software programs: McNeel's Rhinoceros (Version 7) and Creative Systems' GHS (Version 18). MSC’s model was developed by using SEACOR POWER's general arrangement and tank arrangement drawings (MBI Exhibits 98-100).

The origin for measurements of the MSC hydrostatics model is the molded bow. On the drawings, the molded bow is positioned at Frame -2, along the centerline. The baseline is the molded flat bottom. As noted in Section 3.1, wind and inclination directions provided in this report are given in clockwise degrees relative to the bow (winds from dead/directly ahead toward dead/directly astern are 0°, winds from the port side toward the starboard side are 270°) unless otherwise noted.

The MSC model does not have a buoyant house (it only contributes to wind profile). The legs and pads are buoyant as described by MBI Exhibit 55, ABS' 2002 stability review letter. Box coolers are modeled as hull deductions. The skegs, rudders, and propellers are not modeled. Draft and Plimsol Mark locations are not depicted in the correct location on vessel drawings. MSC measured the position of the draft marks during a site visit to the recovered portion of the vessel: the actual aft draft marks originate at the bottom of the skeg, which is 4 feet below the molded bottom of the hull. The aft draft marks are located 125 feet aft of the bow at the start of the stern propeller aperture (rake). The forward draft mark location is the forward part of the pad well (20 feet aft of the bow).

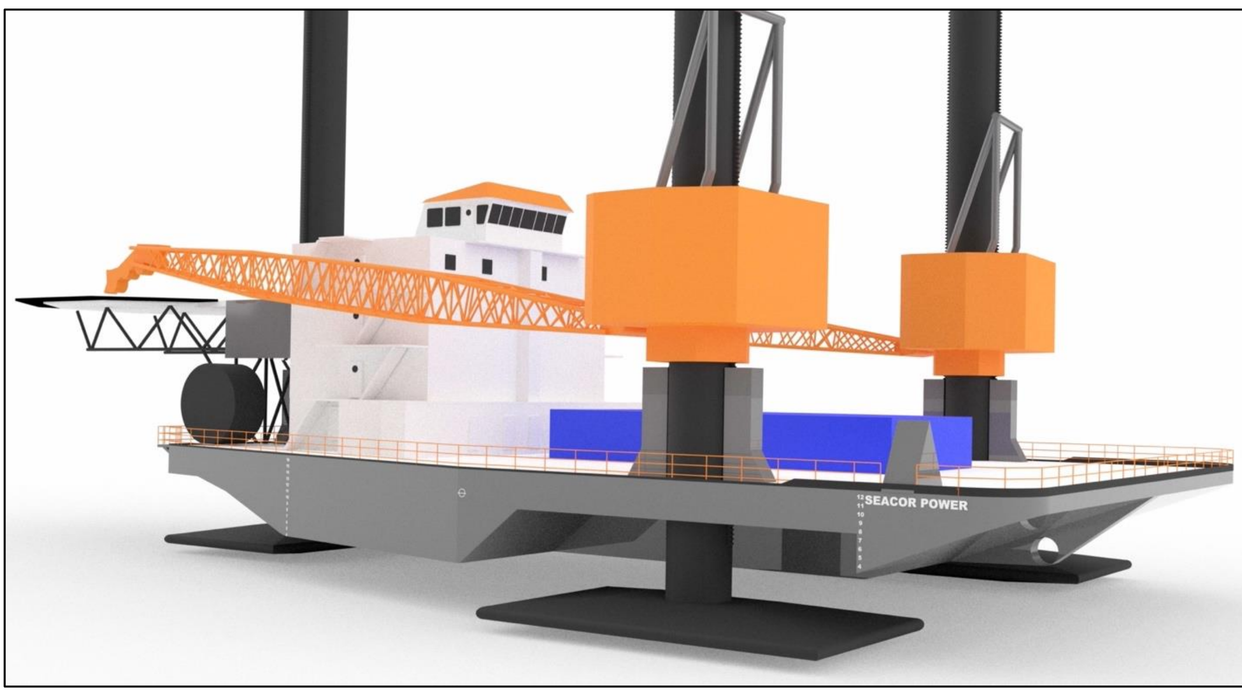

Figure 8: Rhino Model Rendering of MSC's SEACOR POWER Model with Legs Deployed 10 Feet

7.2. Hydrostatics Comparison

Model verification was performed by comparing the MSC model's hydrostatics with the hydrostatics table (at zero heel and trim) provided in the Marine Operating Manual (page 8-24, MBI Exhibit 59). A comparison is provided in Table 3.

Excellent correlation is found between MSC's model and Marine Operations Manual displacements and longitudinal center of buoyancy (LCB) with values matching within 0.3%. Most values match within 1 to 2% for vertical height of the longitudinal metacenter (KML) and vertical height of the transverse metacenter (KMT) with differences noted at drafts near the top of the pads and top part of the leg well (7.5 to 8 feet). As shown on MSC's generated curves of form in Figure 9, this location experiences a drastic change in waterplane area due to the pad wells and buoyant portion of the pads. Differences are assumed to be related to molded pad buoyancy. MSC used an extreme height of 2.5 feet above baseline for the bottom of the pad. The bottom plate thickness of the pad is 1 inch, giving a molded height of the bottom of the pad of 2 feet 7 inches. In general, the MSC model hydrostatics closely match the Marine Operating Manual hydrostatics.

	Marine Operating Manual Hydrostatics				**MSC Model Hydrostatics**			
Draft (ft)	Seawater Displacement (LT)	LCB (ft)	KML (ft)	KMT (ft)	Seawater Displacement (LT)	LCB (ft)	KML (ft)	KMT (ft)
5.00	1289.07	82.52	391.91	182.74	1287.61	82.56	390.91	180.52
5.25	1371.25	82.51	376.62	172.47	1369.84	82.55	378.10	171.92
5.50	1453.82	82.49	357.97	160.95	1452.85	82.55	363.63	162.60
5.75	1535.97	82.47	332.89	146.45	1535.88	82.53	341.91	149.86
6.00	1616.41	82.45	307.19	133.94	1617.22	82.52	312.84	133.78
6.25	1697.36	82.42	301.87	129.25	1698.81	82.50	309.72	129.61
6.50	1779.62	82.38	303.12	126.87	1781.85	82.49	309.49	127.29
6.75	1864.28	82.34	305.46	126.41	1867.15	82.46	310.39	125.94
7.00	1951.48	82.29	307.37	124.91	1954.76	82.41	311.07	125.01
7.25	2040.56	82.23	301.51	120.04	2044.65	82.35	310.83	123.49
7.50	2130.01	82.16	271.38	104.65	2135.65	82.28	299.28	117.10
7.75	2218.50	82.08	281.74	108.51	2225.46	82.20	282.77	108.53
8.00	2309.34	82.00	303.77	138.96	2316.55	82.12	362.44	141.59
8.25	2413.69	81.95	345.64	134.10	2420.95	82.06	345.21	133.66
8.50	2518.52	81.90	335.78	129.55	2525.84	82.00	335.33	129.13
8.75	2623.84	81.83	326.68	125.34	2631.20	81.93	326.21	124.95
9.00	2729.64	81.75	318.26	121.44	2737.03	81.84	317.76	121.08
9.25	2835.92	81.67	310.43	117.82	2843.34	81.76	309.92	117.47
9.50	2942.68	81.58	303.15	114.44	2950.12	81.66	302.62	114.11
9.75	3049.92	81.49	296.34	111.27	3057.37	81.57	295.80	110.97
10.00	3157.62	81.39	289.95	108.30	3165.08	81.46	289.40	108.01
10.25	3265.79	81.28	283.96	105.51	3273.25	81.36	283.38	105.23
10.50	3374.42	81.17	278.28	102.86	3381.88	81.24	277.70	102.61
10.75	3483.50	81.06	272.91	100.36	3490.94	81.13	272.30	100.11
11.00	3593.03	80.95	267.77	97.97	3600.44	81.01	267.14	97.73
11.25	3702.76	80.83	260.12	95.38	3710.15	80.90	259.55	95.17
11.50	3812.48	80.73	252.96	92.96	3819.85	80.79	252.43	92.76
11.75	3922.21	80.63	246.21	90.69	3929.56	80.69	245.70	90.50
12.00	4031.94	80.50	239.84	88.54	4039.27	80.59	239.35	88.36

Table 3: Model Hydrostatic Comparison with Zero Trim. Note: LCB is referenced from molded bow, Seawater Specific Gravity is 1.0256.

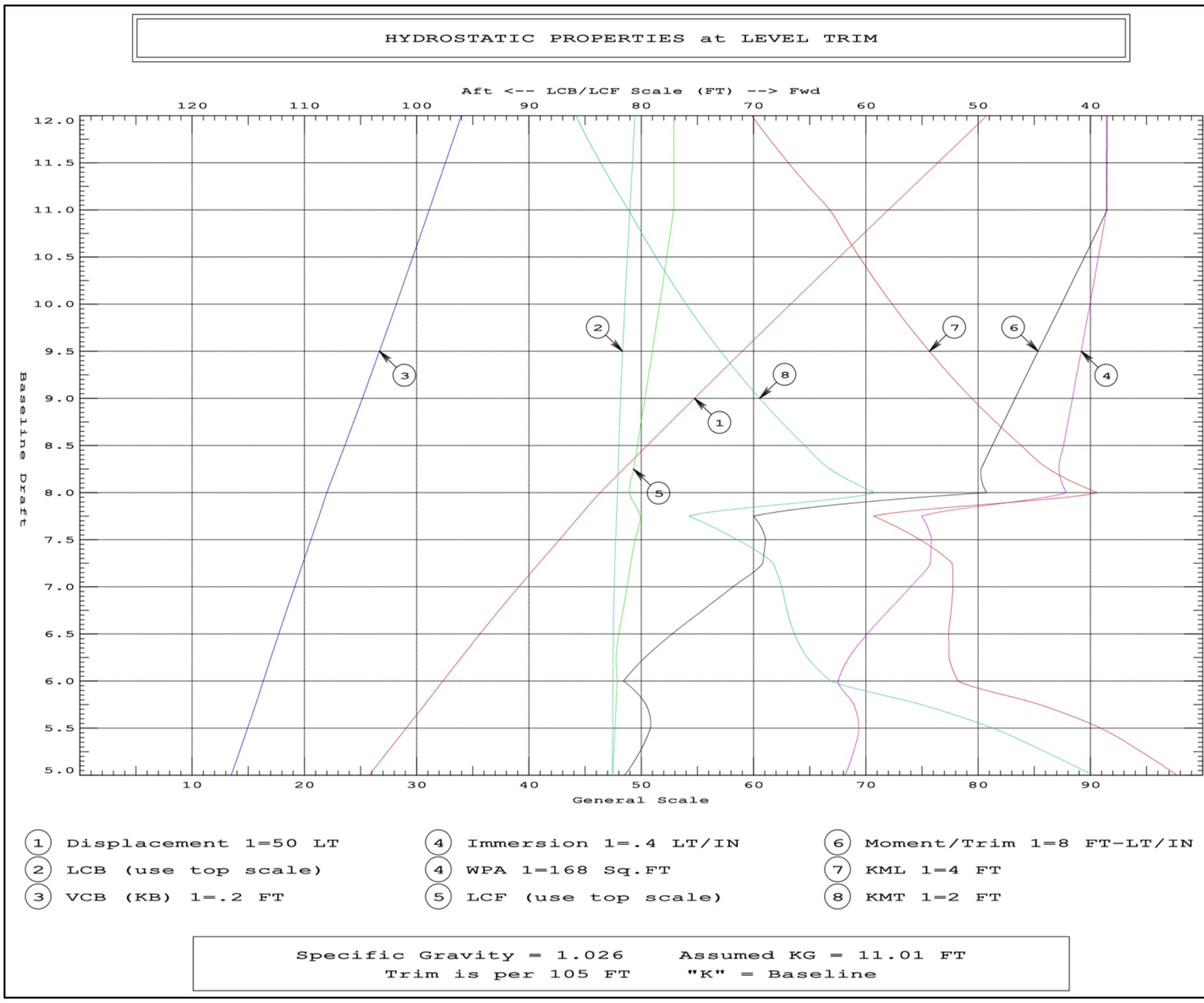

Figure 9: MSC Model Curves of Form

7.3. Light Weight Comparison

Using the MSC model, light weight and center of gravity were calculated using the raw stability test notes from the 2012 stability test (Exhibit 220). These lightship characteristics are compared to the Marine Operations Manual values listed on page 32 of Exhibit 59. It is important to note that the lightship values in Table 4 do not include the legs because they can move vertically and change their vertical centers of gravity.

	Marine Operations Manual Lightship Characteristics	**MSC Calculated Lightship Characteristics**
Lightship Hull Weight, Legs Excluded (Long Tons)	1,664.52	1,687.26
Longitudinal Center of Gravity (ft aft of bow)	89.71	89.95
Transverse Center of Gravity (ft starboard of centerline)	2.32	0.80
Vertical Center of Gravity (ft above baseline)	10.86	11.11

Table 4: Lightship Values comparing SEMCO and MSC Calculations for the Hull Only

MSC and SEMCO calculated light weight characteristics closely match except for transverse center of gravity. The source of the transverse center of gravity discrepancy between MSC and SEMCO calculations cannot be determined based on available information. However, regulatory maximum vertical center of gravity analysis will assume zero initial heel (MSC assumes that any off-center weight is corrected by loading cargo on the opposite side of the centerline so that the resulting initial heel of the vessel is 0°).

7.4. Wind Moment Comparison

MSC generated heeling moments for SEACOR POWER to compare to heeling moments included with ABS' calculations from MBI Exhibit 55. Wind moment comparison for a 9.5-foot draft and 50 knot wind speed is shown in Table 5 and plotted in Figure 10. These values are representative of differences observed across all drafts and wind speeds. As shown, wind moments in all directions calculated by MSC are slightly higher for the upright (0° incline) condition but much higher for inclined conditions with winds from the stern and quarter. MSC values are slightly lower than ABS values for winds from the bow directions.

MSC wind load and moment values are generated using the regulatory shape factors in Table 6. MSC's analysis accounts for shielding between components (other than the legs) and vessel structure as it emerges from the water with heels. It is not known why the values differ so significantly with ABS' values (the proprietary, in-house DRILWIND program used by ABS is now obsolete). Because the largest wind moment differences between ABS and MSC models occurs when wind is coming from the stern and quarter, this may indicate significantly different modeling treatment of the helideck as it inclines and is affected by the wind.

Wind Speed (knots)	Relative Wind Direction (deg)	Draft (ft)	ABS Wind Moment (ft*LT)			MSC Wind Moment (ft*LT)		
			Inclined 0°	Inclined 15°	Inclined 30°	Inclined 0°	Inclined 15°	Inclined 30°
50	180	9.5	2771	3150	3585	2963 (+7%)	5279 (+68%)	8892 (+148%)
50	210	9.5	3021	3396	3815	3275 (+8%)	5702 (+68%)	9209 (+141%)
50	240	9.5	3117	3504	3811	3304 (+6%)	5083 (+45%)	7367 (+93%)
50	270	9.5	3015	3246	3144	2892 (-4%)	3855 (+19%)	4417 (+40%)
50	300	9.5	3120	3168	2962	3304 (+6%)	3235 (+2%)	2829 (-4%)
50	330	9.5	3028	3109	3280	3266 (+8%)	2824 (-9%)	2288 (-30%)
50	340	9.5	2956	3078	3312	3195 (+8%)	2739 (-11%)	2206 (-33%)
50	350	9.5	2867	3021	3314	3079 (+7%)	2673 (-12%)	2140 (-35%)
50	0	9.5	2781	2953	3294	2963 (+7%)	2647 (-10%)	2115 (-36%)

Table 5: Wind Moment Comparison between ABS Model and MSC Model

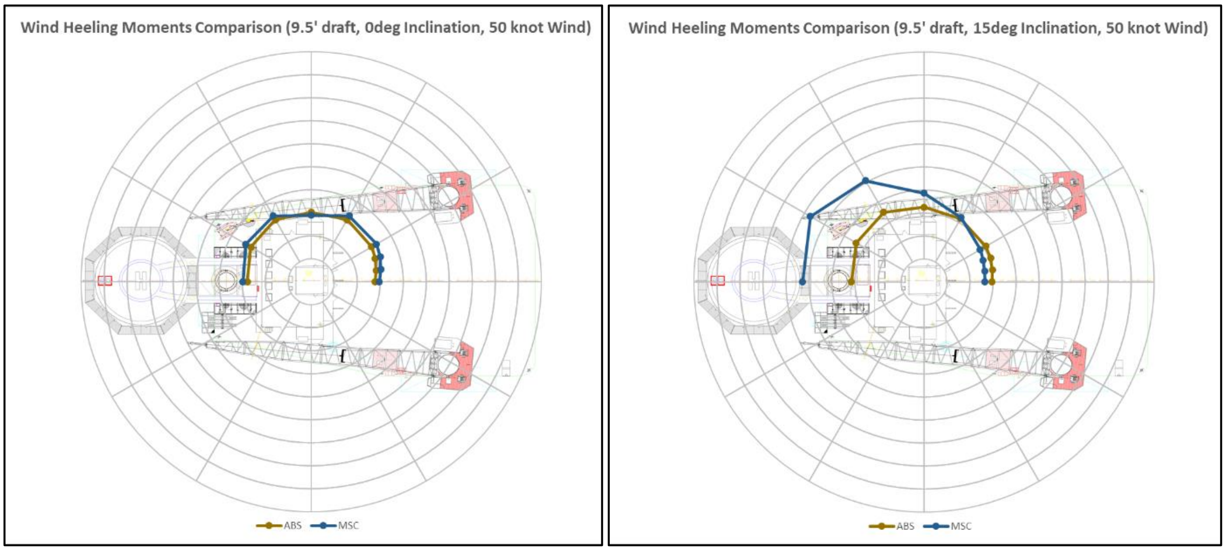

Figure 10: Visual Comparison of MSC and ABS Wind Moments for 9.5-Foot Draft and 50-Knot Wind. 0° inclination on the left, 15° inclination on the right. Each ring represents 1,000 LT•ft of wind inclining moment.

Windage Component	MSC Model Shape Factor	46CFR174.055 Component
Hull	1.0	Hull (1.0)
Legs	0.5	Cylindrical Shape (0.5)
Crane Boom	0.9	Two Open Truss Work (30% each) Isolated Structural Shape (1.5)
Crane Parts (cab, boom tip, mast)	1.5	Isolated Structural Shape (1.5)
Deck Handrail	0.45	Open Truss Work (30%) Isolated Structural Shape (1.5)
Deck House, Radiators, Emergency Generator Room	1.0	Deckhouse (1.0)
Deck Equipment (Jack Towers, Anchor Windlass, Hose Reel)	1.0	not provided
Helideck	1.0	not provided
Helideck Safety Mesh	1.0	not provided
Below Helideck Projected Framing	1.3	Under deck areas (1.3)
Deck Cargo	1.0	not provided

Table 6: MSC Model Shape Factors for Components of Wind Profile

7.5. Stability Limits for SEACOR POWER

Table 7 reproduces the drafts and maximum VCG's that were listed on ABS' letter of 14 August 2002 for a leg length of 265 feet with the legs fully raised (the bottom of the pad or can is 2.5 feet above base line). This table matches the maximum VCG curve provided in the Marine Operations Manual for SEACOR POWER (Figure 6).

Draft (feet)	Allowable VCG Operating (feet ABL)	Allowable VCG Storm Survival (feet ABL)
8.00	58.00	55.00
8.50	53.10	50.00
9.00	47.80	45.50
9.50	41.50	39.50
10.00	35.50	35.05

Table 7: Table of Drafts and Maximum Allowable Vertical Centers of Gravity as listed in ABS' Stability Analysis Letter dated 14 August 2002

MSC conducted stability analysis using the values provided for drafts from 8.5 feet to 10 feet. An 8-foot draft was not evaluated because it results in a displacement significantly less than SEACOR POWER's light weight displacement, which corresponds to a draft at the longitudinal center of floatation of 8.8 feet. Although SEACOR POWER's allowable trim was limited to 6" by the Marine Operations Manual, MSC checked each of the above listed values for aft trims of 0, 0.5, 1, 2, and 3 feet. Drafts in the trimmed conditions were assigned at the longitudinal center of floatation.

7.6. Stability Analysis Conducted by MSC

For each angle of heel or inclination, the model was allowed to orthogonally tip to an angle such that the orthogonal tipping moment was zero. This is commonly referred to as the "free to trim" method.

To calculate wind overturning moments for each angle the model was inclined, a new wind profile area was calculated allowing components to shield others (e.g. the deckhouse could shield the crane boom and no wind force would be applied on the shielded part of the crane boom).[5] The exception to this is the legs of the SEACOR POWER model, which cannot provide shielding or be shielded (the starboard leg cannot be shielded by the port leg even though it is directly behind it with beam winds). Leg shielding allowances are prohibited by §174.055(b)(1).

Free surface effects of partially filled tanks are not included in MSC's analysis of the allowable vertical centers of gravity because free surface effects are calculated as a formal VCG correction in the Marine Operating Manual when evaluating an actual condition to ensure it falls under the maximum VCG curve. However, true free surface effect (the actual shifting of liquid center of gravity based on inclination angle) is calculated by MSC when evaluating the departure and casualty conditions where tank contents are known (Part 174 is silent on the treatment of free surface effect for liftboats). The true free surface method within GHS software used by MSC

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[5] This is performed using GHS' wind banding method using default band widths of 4 inches (0.1 meters). GHS describes this method as:

> *Instead of taking the areas of each component individually, the profile areas of all components of each part are projected onto a common set of horizontal bands. This approach accounts for shielding between components. (...) Wind pressure is applied at the height of each band's center.*

most closely models actual inclined conditions of the tanks, especially at angles of inclination greater than 5°.

To evaluate the metacentric height (GM) criteria, MSC used the initial slope of the righting arm curve to calculate metacentric height in the incline direction.[6]

7.6.1. Criterion for Vessels of Unusual Proportion and Form

MSC evaluated each draft and maximum vertical center of gravity condition using the Criterion for Vessels of Unusual Proportion and Form, §170.173. No axis rotation was used in these analyses and wind force is not modeled. In all conditions, SEACOR POWER fails the §170.173 criteria by large margins because maximum righting arm, downflooding and capsize occur at much lower heel angles than 15° for maximum righting arm and 30°, the minimum range of stability that the criteria require for an open ocean route.

We note that §170.173 was not evaluated by ABS as part of their review of SEACOR POWER, nor would it have been if MSC had conducted the stability analysis. However, liftboats are not explicitly exempt from this criteria as discussed in Section 3.2.1 above.

7.6.2. Fixed Intervals

MSC conducted a stability analysis with wind directions at 15° intervals from 0º to 360° relative. This interval approach represents winds "from any horizontal direction" as specified in ABS MODU Rules and CG-ENG-2's letter to MiNO Marine. No assumption of symmetry was made because the wind profile is not symmetrical (the hose reel and anchor windlass are located on the starboard side).

For this analysis, the model was inclined directly away from the specified direction of the wind. For each angle of inclination parallel with the wind, the model was allowed to freely orthogonally tip (known as free trim for the beam wind condition).

Graphical representations of this analysis method are shown in Figure 11 and Figure 12. In each of the conditions shown, the inclination angles (0°, equilibrium, 5°, 10°, and downflooding angles) are prescribed and the hydrostatics software solved for orthogonal tip angle.

[6] This is performed using the "GM MODU" method of calculation within GHS. This accounts for non-zero initial inclination angles using the initial slope of the righting arm curve as the GM.

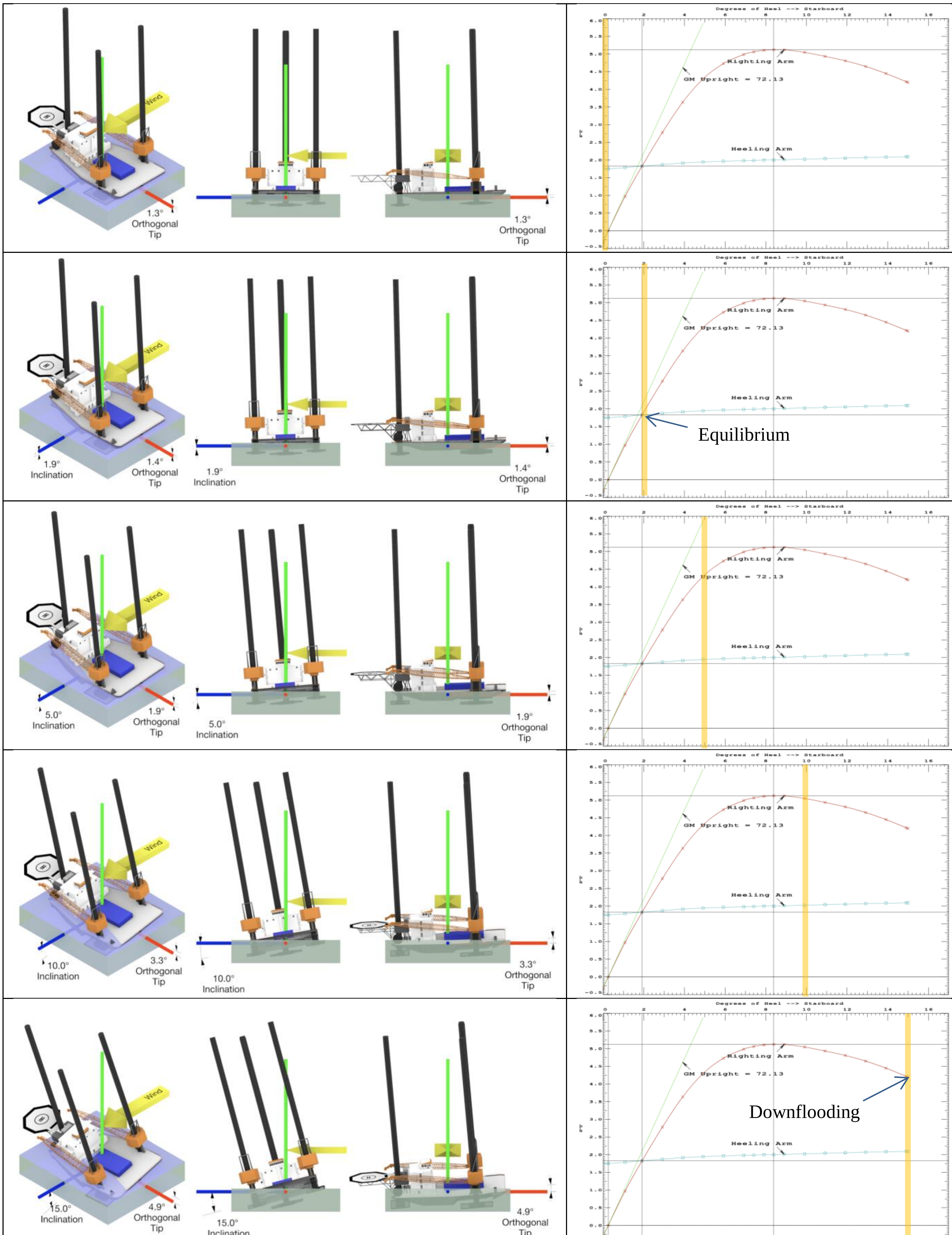


Figure 11: Fixed Axis Method with Winds from 270° Relative for the Casualty Condition with 70 Knot Winds (Page 634 of Appendix D)

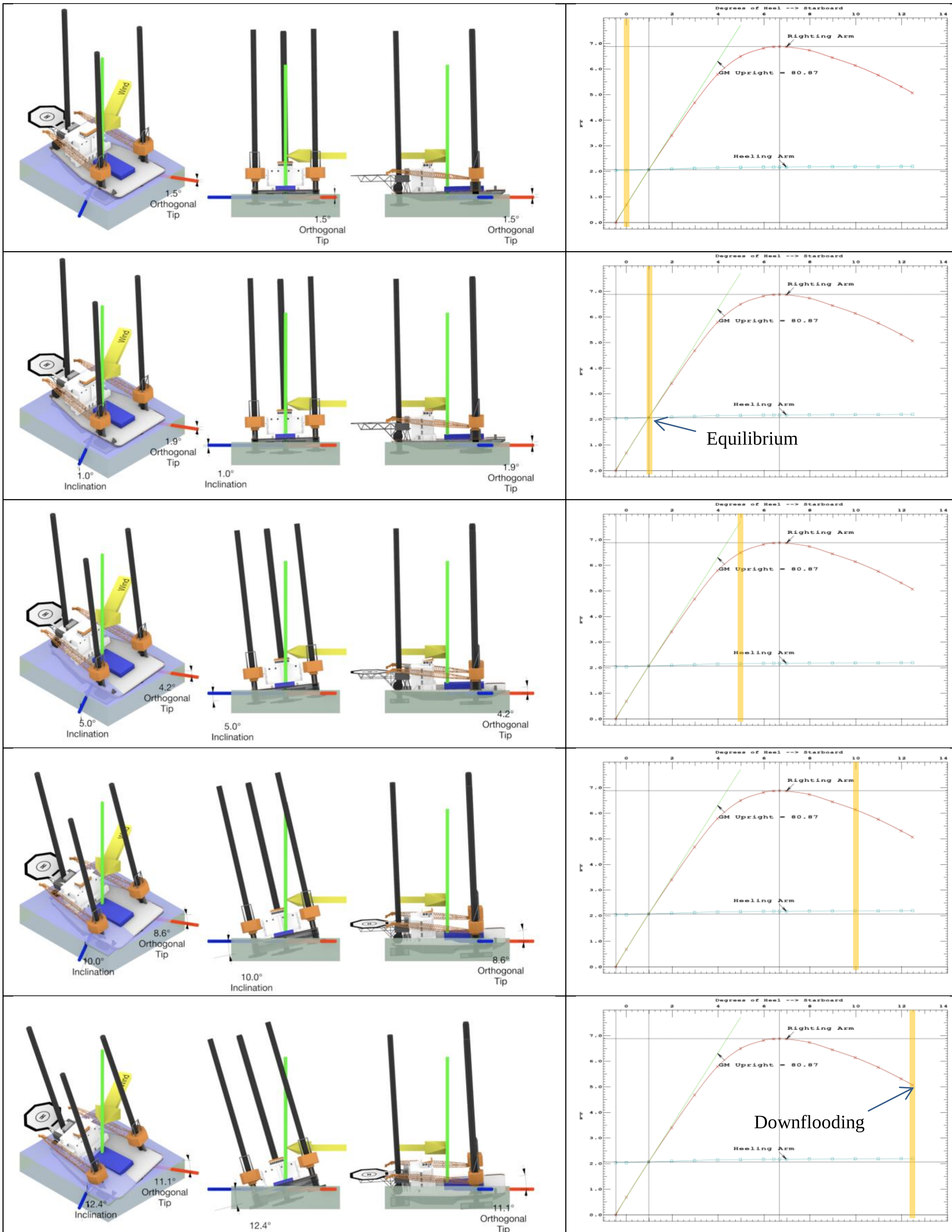


Figure 12: Fixed Axis Method with Winds from 240° Relative for the Casualty Condition with 70 Knot Winds (Page 632 of Appendix D)

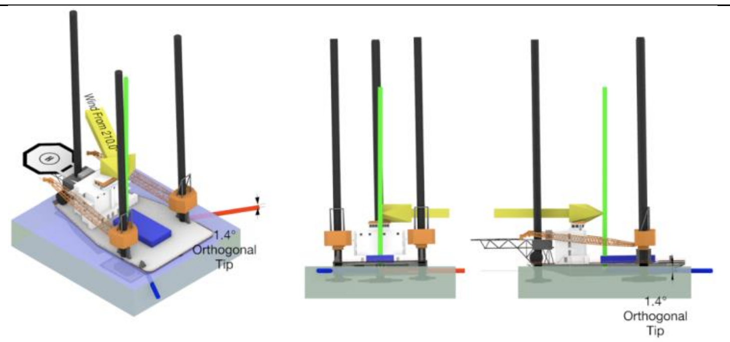
7.6.2.1. Fading Stability

This analysis method experiences a well-known issue known as fading stability described in References 1 through 4. Fading stability is a function of the righting moment of the vessel and is not related to the overturning moment caused by wind. To create a righting arm curve, we assign the model an inclination angle and calculate the righting arm (for beam winds, heel angles are assigned and the righting arms are calculated). When the axis is rotated such that inclination is mostly toward the bow or stern, assigned inclination angles are mostly trim angles with only a small heeling angle component. As assigned inclination angles are increased, the model loses stability in the orthogonal direction and the righting arm curve is truncated. In the direction of inclination 0-45º off the bow or stern, the righting arms are much higher than in the orthogonal direction where they are weaker. This is not a realistic phenomenon for static stability because the model also has a fixed twist or yaw rotation angle. An actual vessel is free to twist or yaw to a different axis angle where the weakest righting energy is present (e.g., wind on the port quarter will turn the vessel to port and heel it toward starboard, not heel it toward the bow).

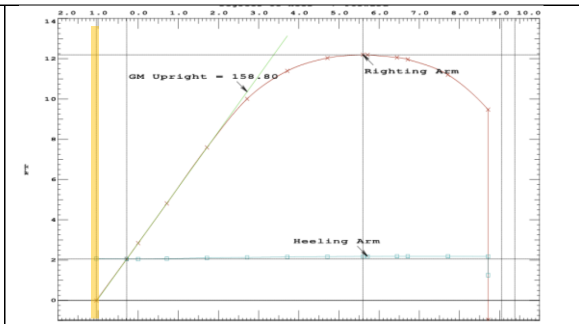
For the SEACOR POWER model, fading stability occurs with winds 0° to 45º off the bow or stern. Although these inclination directions possess the greatest initial righting energy for SEACOR POWER, the model cannot incline to the specified angle and maintain stability in the orthogonal direction. This causes the analysis to be incomplete, especially regarding the range of stability criteria in §174.255(a)(ii) which requires the range of positive stability to extend 10º from the angle of static equilibrium (the first intercept of the heeling arm and righting arm curves).

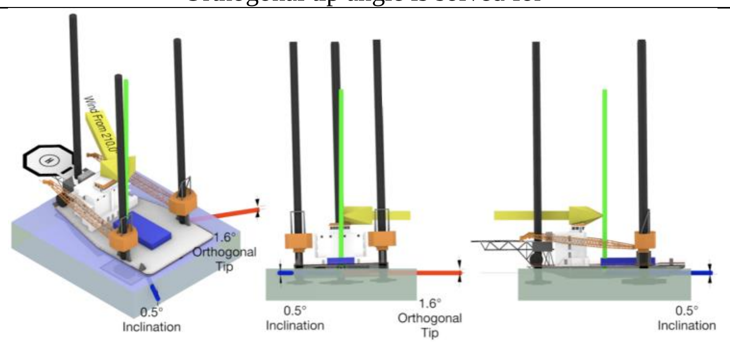
An example of a failing condition for SEACOR POWER is shown in Figure 13 where the winds are 70 knots from 210º relative (port quartering).[7] The area under the righting arm curve is much larger than under the heeling arm curve; however, at 8.7º of inclination, the SEACOR POWER model lost stability in the orthogonal tipping direction. In this condition, the model was not able to attain a range of 10º of positive stability from the initial inclined angle of -0.3º to a vanishing stability point further than 9.7º due to fading stability (the attained range of stability is only 9.0°. Note that the initial inclined angle starts at less than zero because this condition has initial aft trim).

[7] In the MSC Stability Analysis, the GHS software graphically indicated fading stability by showing a vertical line at the location where the righting arm is truncated. Righting arm curves that are truncated by reaching the downflooding point terminate without this vertical line.

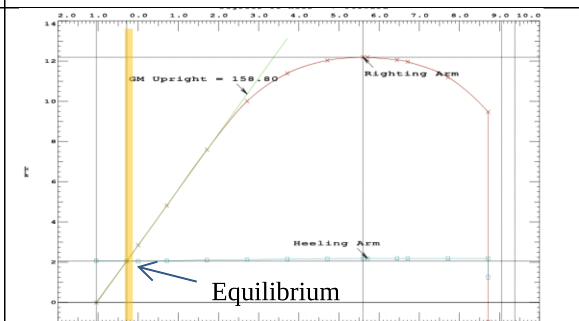


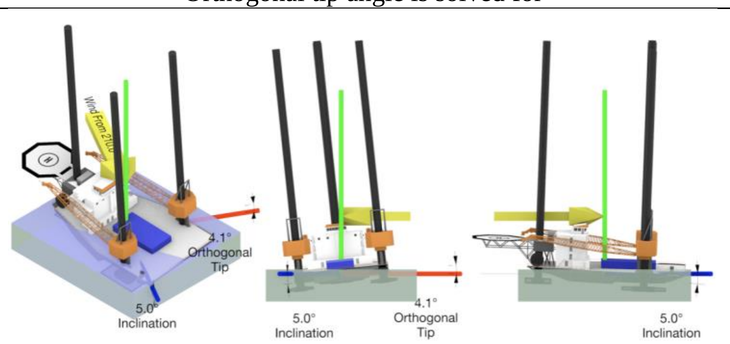
Inclination angle starts at -1° (the vessel has initial aft trim)
Orthogonal tip angle is solved for



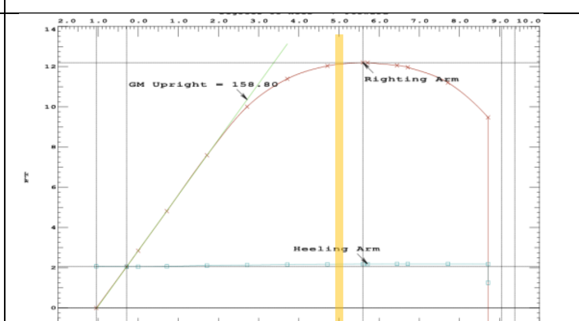


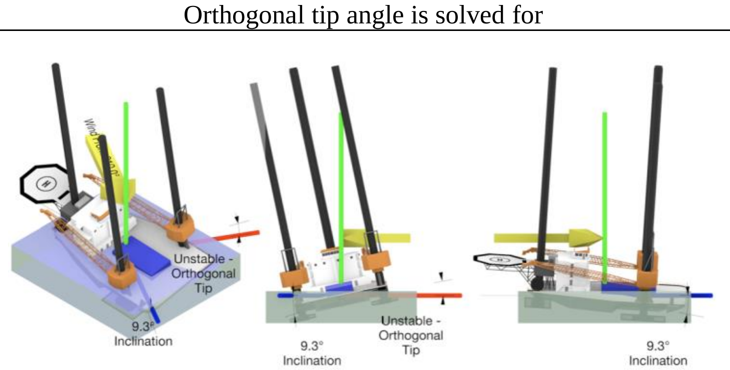
Inclination angle prescribed at 0.5° (equilibrium)
Orthogonal tip angle is solved for





Inclination angle prescribed at 5°
Orthogonal tip angle is solved for





Inclination angle prescribed at 9.3°
Orthogonal tip angle is solved for and capsize occurs

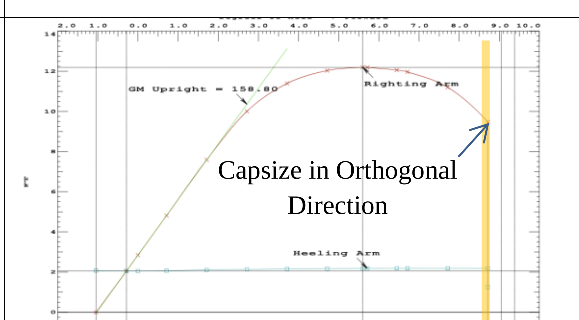


Figure 13: Fixed Axis Method with Winds from 210° Relative for the Casualty Condition with 70 Knot Winds, Demonstrating Fading Stability (failure due to Orthogonal Tipping, Page 630 of Appendix D)

MSC analysis also indicates that wind directions very near the bow (15° and 345°) can result in the model narrowly failing the range of stability criteria. For these cases where winds are mostly from the bow and the stern is submerging with inclination, the downflooding points submerge just prior to orthogonal tipping, or just prior to loss of stability in the orthogonal direction. An example of this is shown in Figure 14 representing an initial 9.5-foot draft with no trim and 60 knot winds from 15° (the starboard bow) and inclination angles measured toward 195° (the port quarter). Downflooding occurs at 10° of inclination with an orthogonal tip angle of 10°. The true heel and trim at these inclination angles are 12° port heel and 12 feet of aft trim. This condition is measurable on the model. It represents failure of §174.255(a)(ii) prior to fading stability (orthogonal tipping capsize). However, the failure (high orthogonal tipping angle) is related to fading stability.

When the wind direction was from 135° for 8.5- and 9-foot drafts, the stability analysis software failed to calculate ratio, range, and residual area criteria. An inspection of the righting arm curves indicates that ratio and residual area criteria are satisfied in these cases that all result in fading stability.

OPERATE: DRAFT:9.5FT, TRIM:0.0FT, VCG:41.50FT

Fixed Axis, Wind 15 deg Relative

HEELING MOMENT specification
Band width: 0.328
Wind pressure toward aft
Baseline draft: 9.500
Trim: zero, Heel: zero
Inclination axis rotated 105.00 degrees CW

Part	HCF	Arm	Force(LT)	Moment
HULL	1.88	6.36	2.48	15.78
LEGS	137.55	142.03	7.16	1,016.78
LEGP	137.55	142.03	7.16	1,016.78
LEGA	137.55	142.03	7.16	1,016.77
DECK	19.15	23.63	6.79	160.57
CRANE	35.47	39.95	15.15	605.08
HOUSE.C	22.63	27.12	12.78	346.50
HELODK	18.21	22.69	6.09	138.12
DECKCAR6-5.C	6.73	11.21	2.25	25.26
DECKCAR13.C	13.12	17.60	2.37	41.66
DECKCAR19-5.C	19.69	24.17	2.37	57.18
DECKCAR26.C	26.25	30.73	2.37	72.71
Total wind heeling moment aft				4,513.18

Distances in FEET. Moment in Ft-LT

LIM	46CFR174.255 CRITERION		Min/Max		Attained
(1)	Abs Ratio from abs 0 deg to Flood or RAzero	>	1.400		5.704 P
(2)	Angle from Equilibrium to Flood or RAzero	>	10.00	deg	*9.32 F*
(3)	Res. Area from Equilibrium to Flood or RAzero	>	5.00	Ft-deg	74.05 P
(4)	GM Upright	>	1.00	Ft	215.07 P

Inclination Axis rotated 105.00 degrees CW

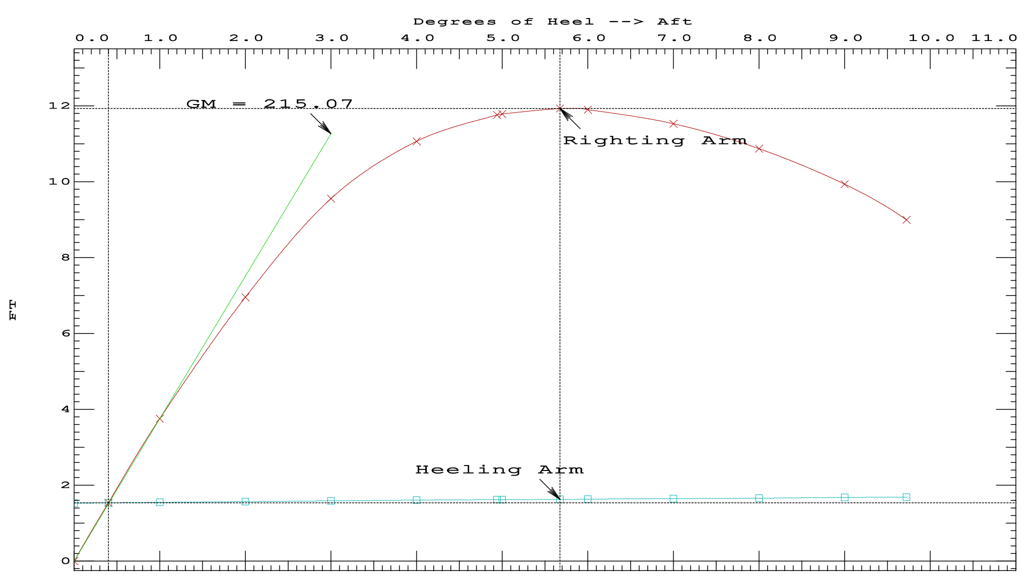


Figure 14: GHS output for 60-knot wind, 9.5-foot draft with zero trim downflooding occurring prior to fading stability with wind from 15° relative

CG-ENG-2's 2018 letter to MiNO Marine indicated that, at non-critical yaw angles where righting energy meets minimum requirements by a large enough margin, reduced range of stability is mitigated adequately. For all conditions that failed §174.255(a)(1)(ii) range of stability criteria, the righting energy meets the criteria of §174.255(a)(1)(iii). It is not apparent if the margin is large enough to satisfy the stated goal of CG-ENG-2's letter.

7.6.2.2. Beam Wind Directions

When only beam winds are considered, MSC's SEACOR POWER model passed the intact stability criteria for 60 knot operational winds and for 70 knot storm survival winds for each draft and vertical center of gravity listed in Table 7. These results are provided as wind directions from port (270°) and starboard (90°) in the fixed interval analysis.

As discussed above in Section 3.2, Part 174 is silent regarding wind direction and MSC does not have written guidance on how the Coast Guard applies these criteria or how it should be required on behalf of the Coast Guard when ABS reviews stability using the provisions of NVIC 3-97.

7.6.2.3. Fixed Interval Stability Analysis Results

The following graphics (Figure 15 to Figure 24) provide the fixed interval stability analysis results using bullseye plots. Plots on the left are for 60-knot wind operating conditions. Plots on the right show 70-knot wind storm survival conditions. Four pairs of plots are provided for each aft trim analyzed: 0 feet, 0.5 feet, 1 foot, 2 feet, and 3 feet. Yellow highlighted cells indicate calculation limitations (typically capsize in the orthogonal tipping direction before prescribed inclination angles have been reached). Red cells indicate failure of the stability criterion. The rings have the following information:

- The inner ring of each plot is the wind direction
- The second ring is the attained Righting Area to Heeling Area Ratio: §174.255(a)(1)(i)
- The third ring is the attained Range of Stability Criterion: §174.255(a)(1)(ii)
- The fourth ring is the attained Residual Righting Energy Criterion: §174.255(a)(1)(iii)
- The fifth ring is the attained Metacentric Height (GM) Criterion: §174.255(a)(3)
- The Sixth ring indicates the failure mode, either downflooding, capsize (in the incline direction), or orthogonal tipping (in the orthogonal to incline direction)
- The Seventh, outermost ring indicates the final true heel and trim that the righting arm plot achieved (true heel means transverse inclination with positive to starboard and negative to port, true trim means longitudinal inclination, positive is aft and negative is forward).

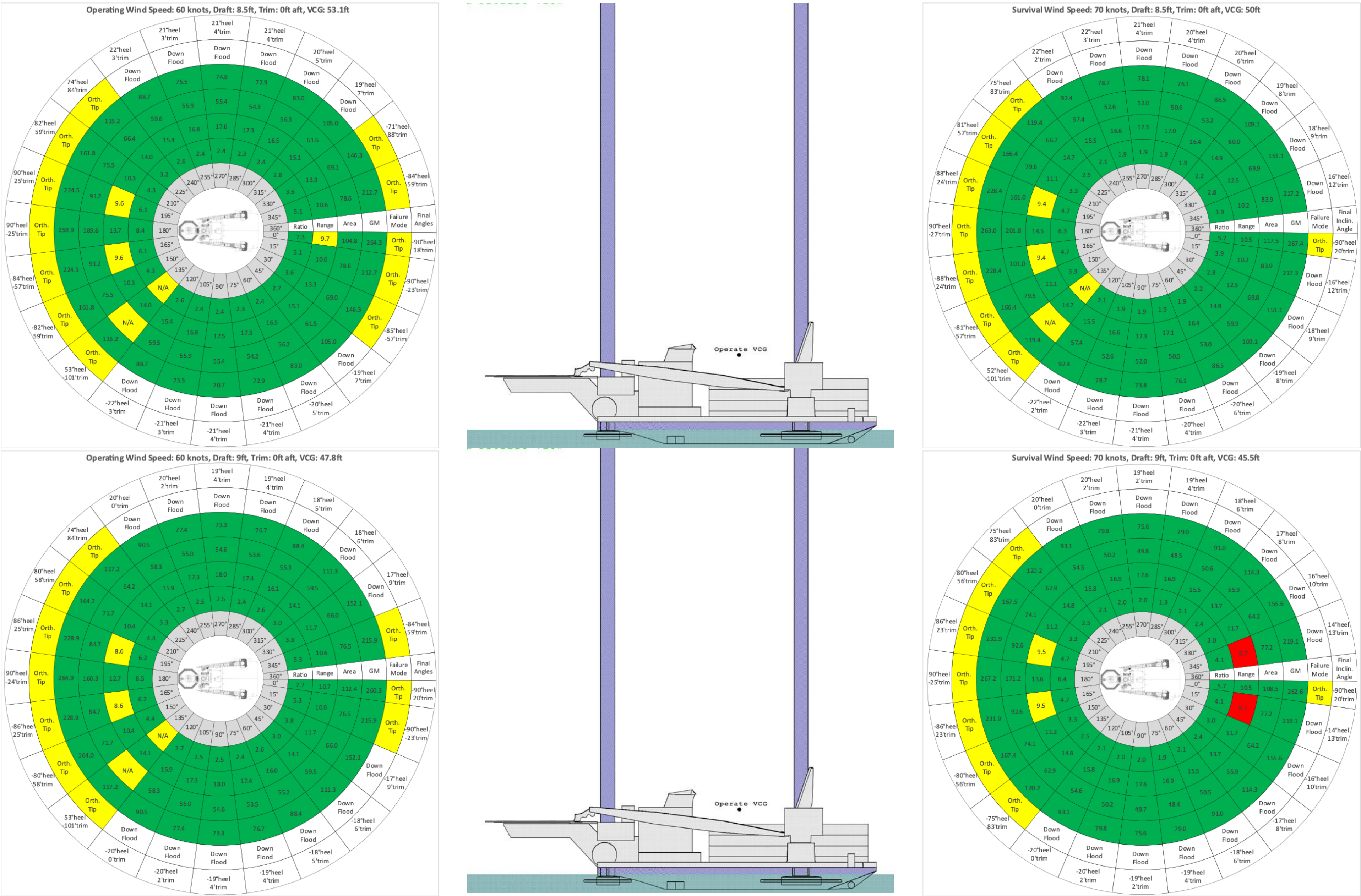


Figure 15: MSC Fixed Interval Analysis Results for 60-knot wind (left) and 70-knot wind (right). 8.5-foot draft (top), 9-foot draft (bottom). Trim is zero

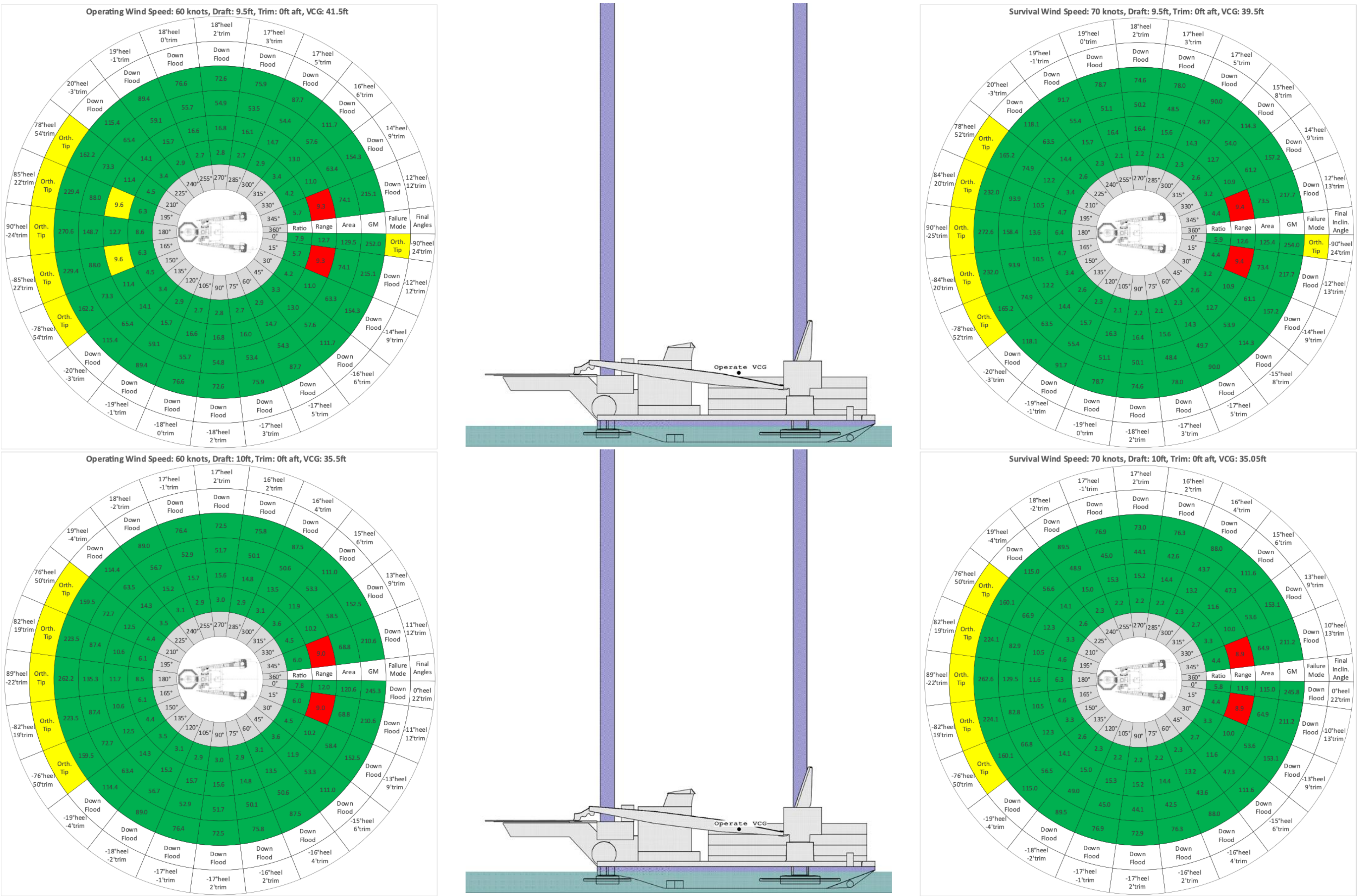


Figure 16: MSC Fixed Interval Analysis Results for 60-knot wind (left) and 70-knot wind (right). 9.5-foot draft (top), 10-foot draft (bottom). Trim is zero

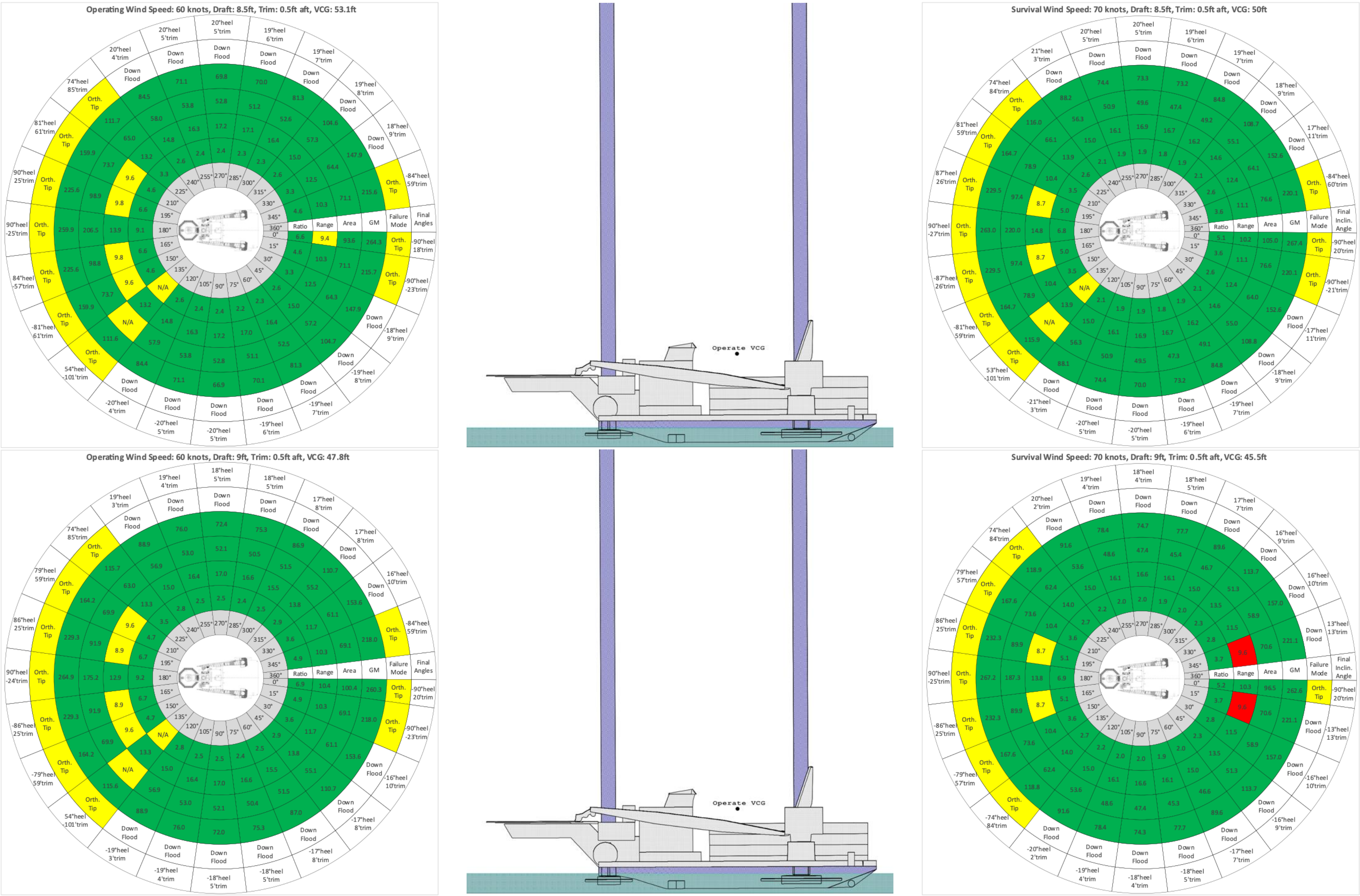


Figure 17: MSC Fixed Interval Analysis Results for 60-knot wind (left) and 70-knot wind (right). 8.5-foot draft (top), 9-foot draft (bottom). Trim is 0.5 feet

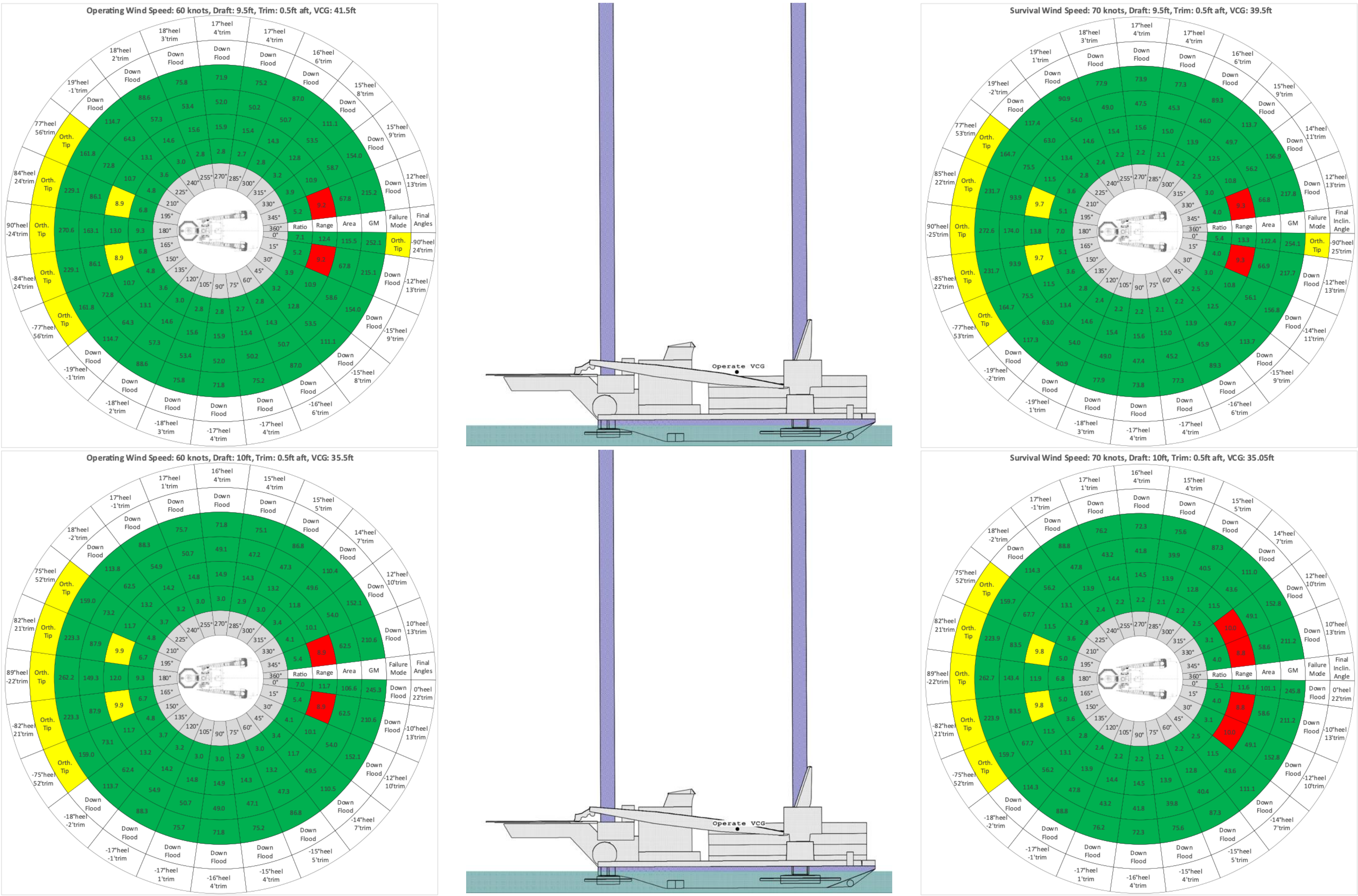


Figure 18: MSC Fixed Interval Analysis Results for 60-knot wind (left) and 70-knot wind (right). 9.5-foot draft (top), 10-foot draft (bottom). Trim is 0.5 feet

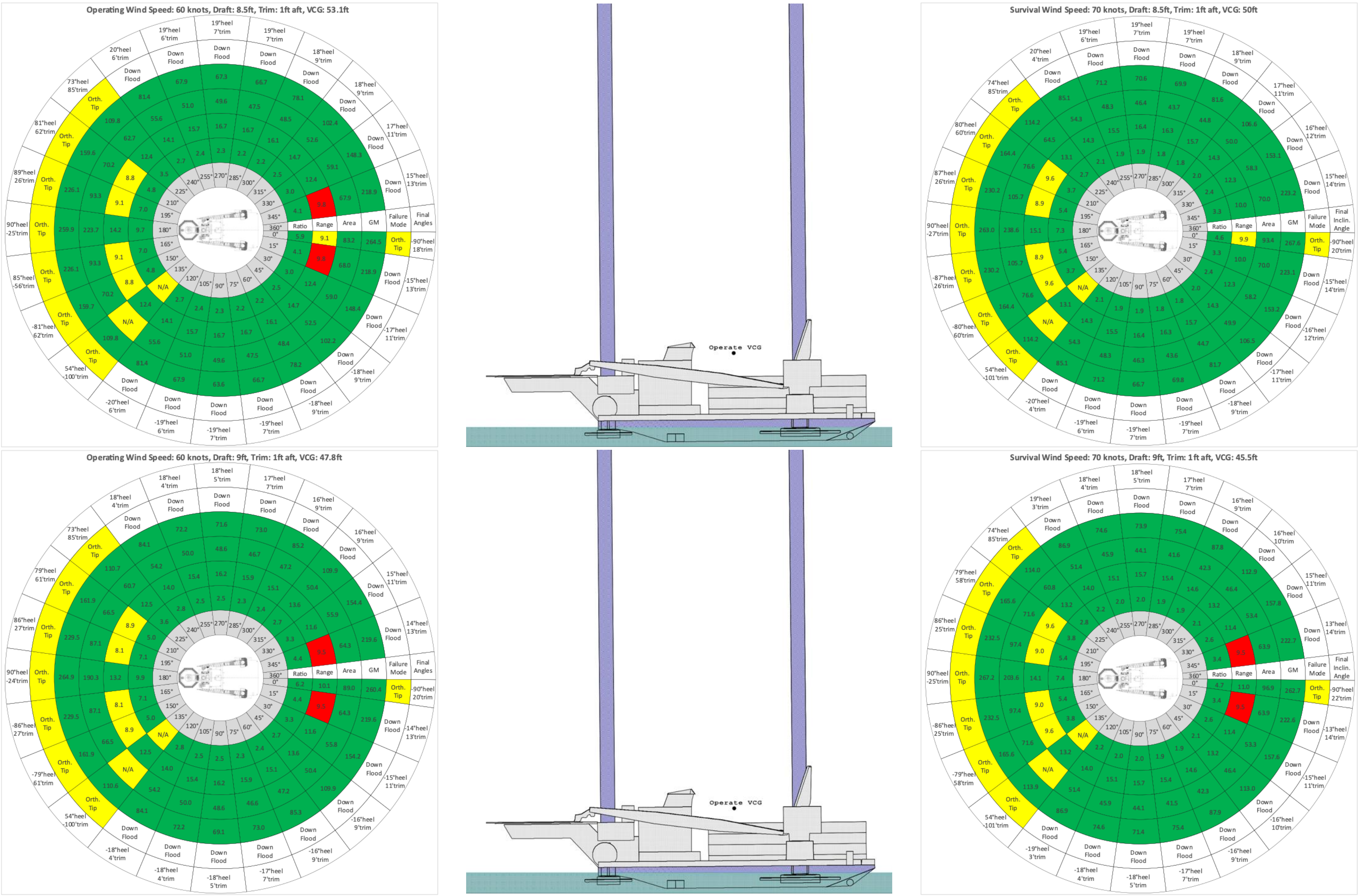


Figure 19: MSC Fixed Interval Analysis Results for 60-knot wind (left) and 70-knot wind (right). 8.5-foot draft (top), 9-foot draft (bottom). Trim is 1-foot

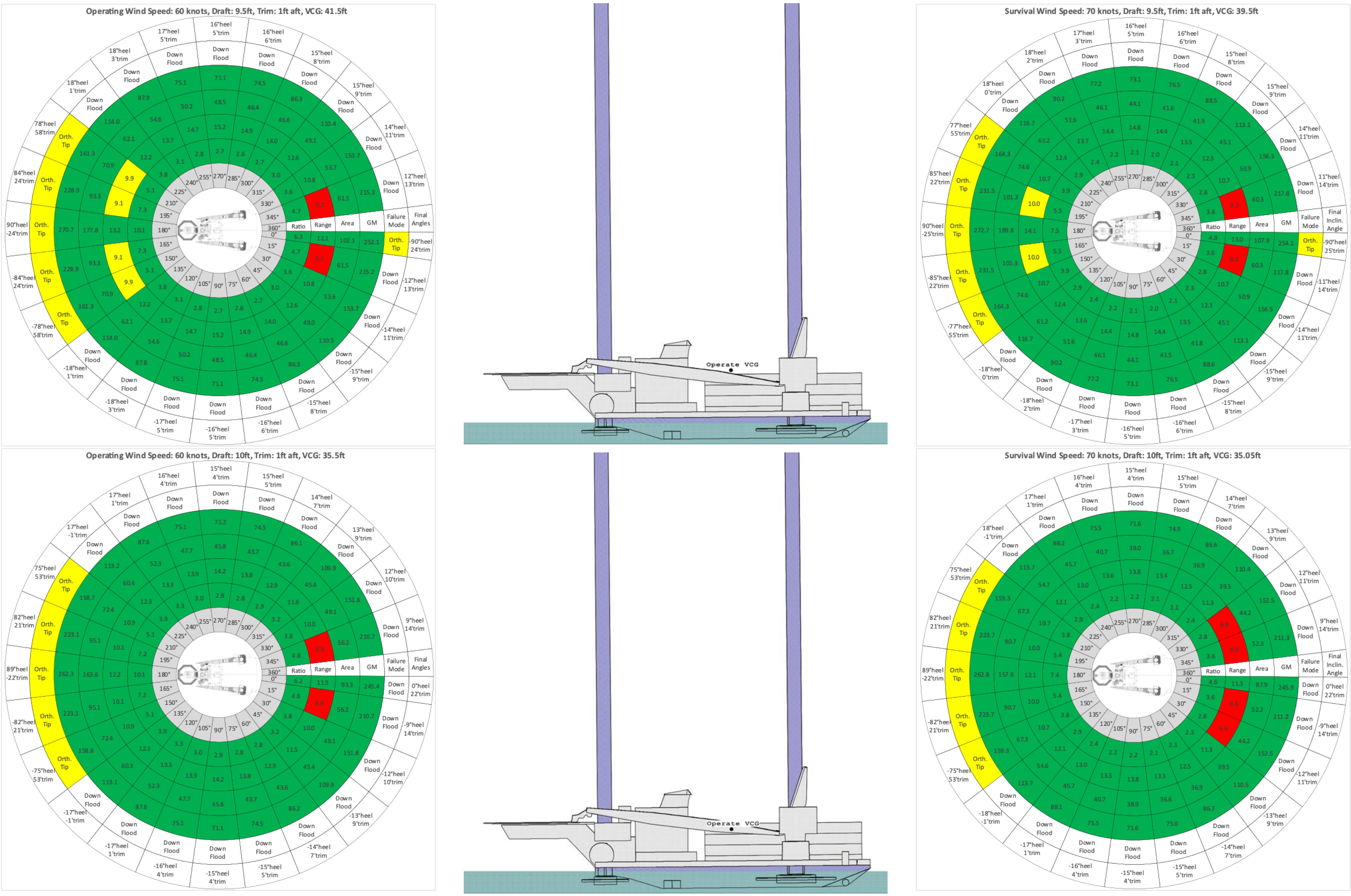


Figure 20: MSC Fixed Interval Analysis Results for 60-knot wind (left) and 70-knot wind (right). 9.5-foot draft (top), 10-foot draft (bottom). Trim is 1-foot

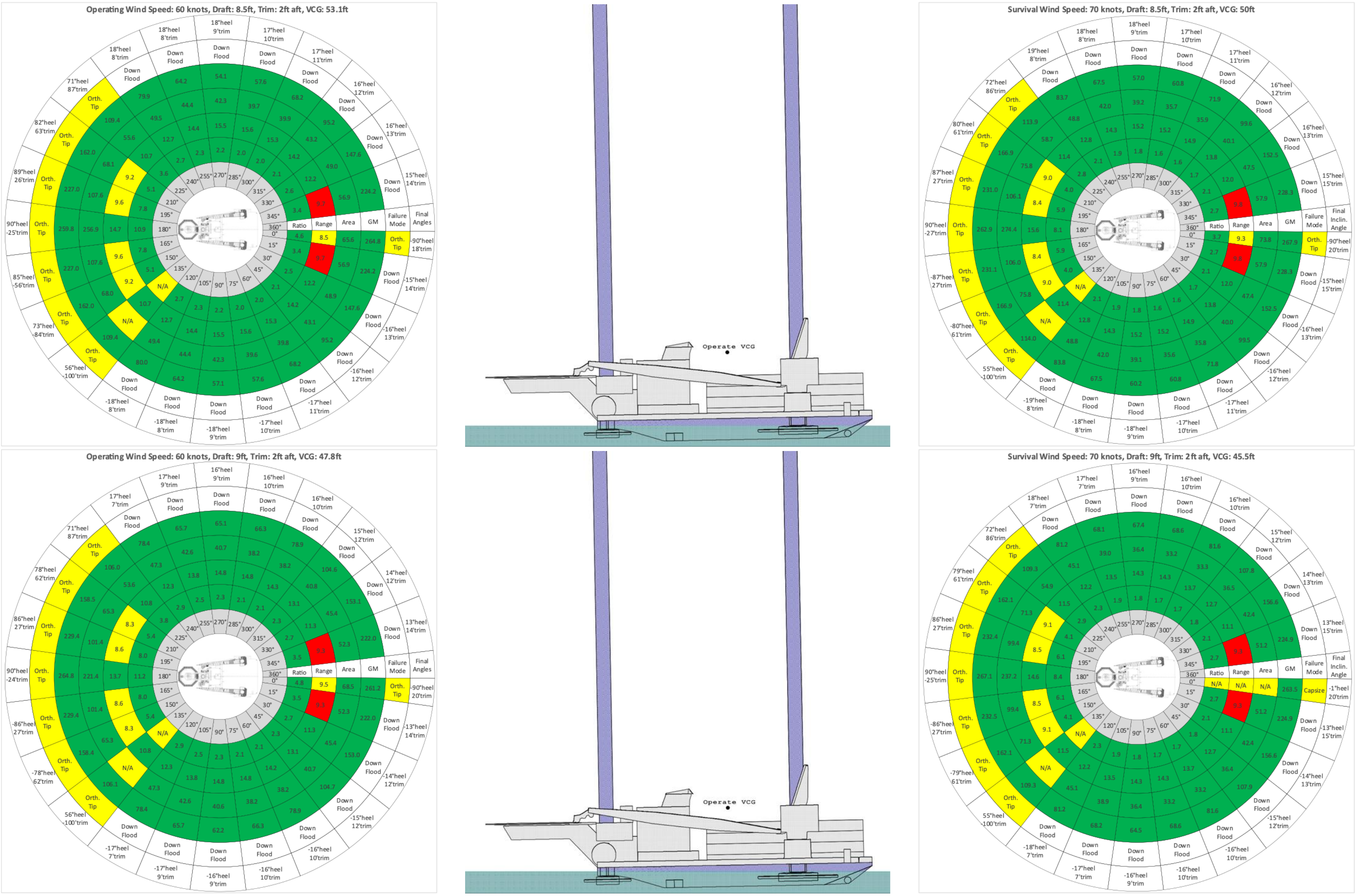


Figure 21: MSC Fixed Interval Analysis Results for 60-knot wind (left) and 70-knot wind (right). 8.5-foot draft (top), 9-foot draft (bottom). Trim is 2 feet

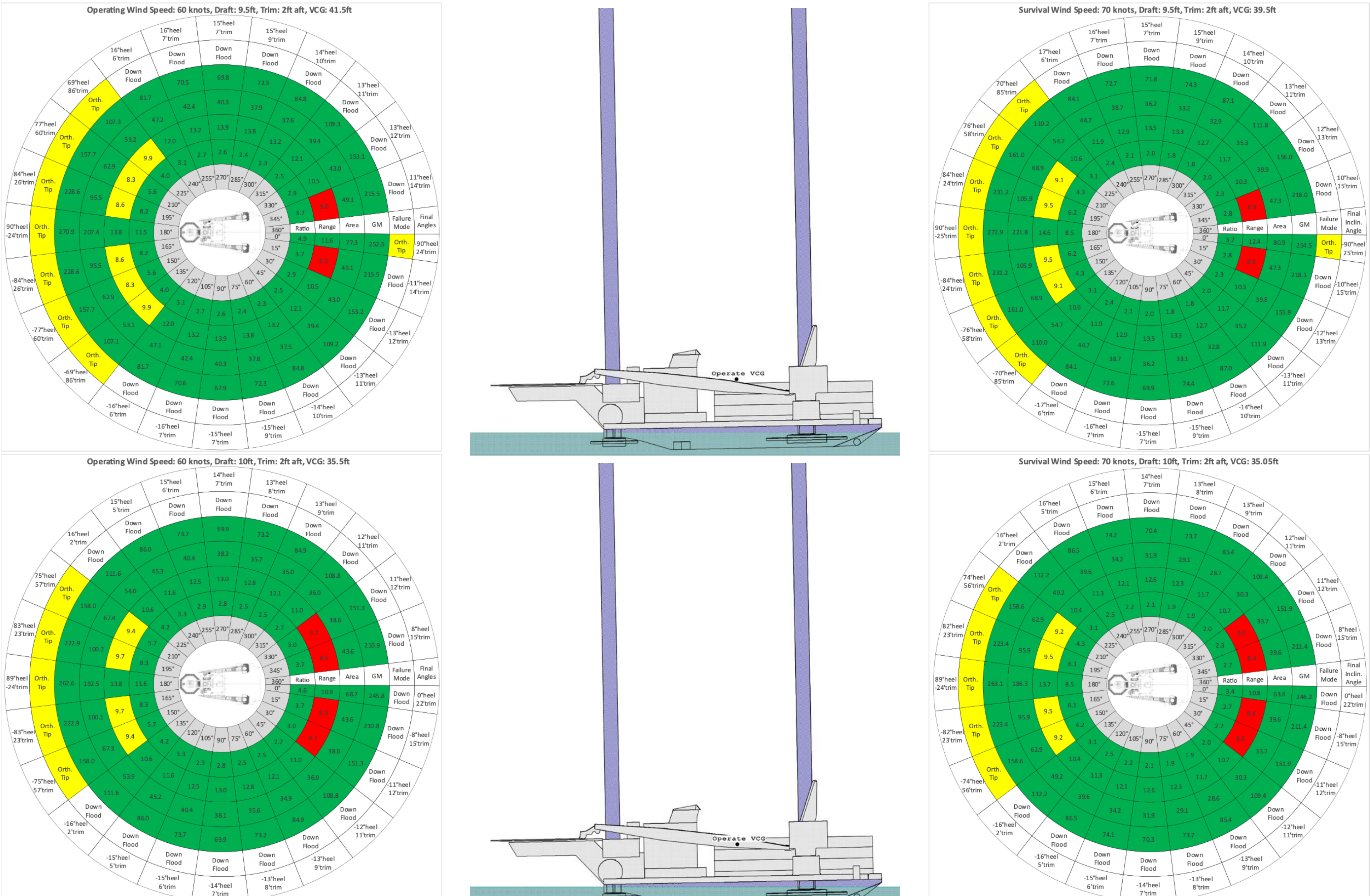


Figure 22: MSC Fixed Interval Analysis Results for 60-knot wind (left) and 70-knot wind (right). 9.5-foot draft (top), 10-foot draft (bottom). Trim is 2 feet

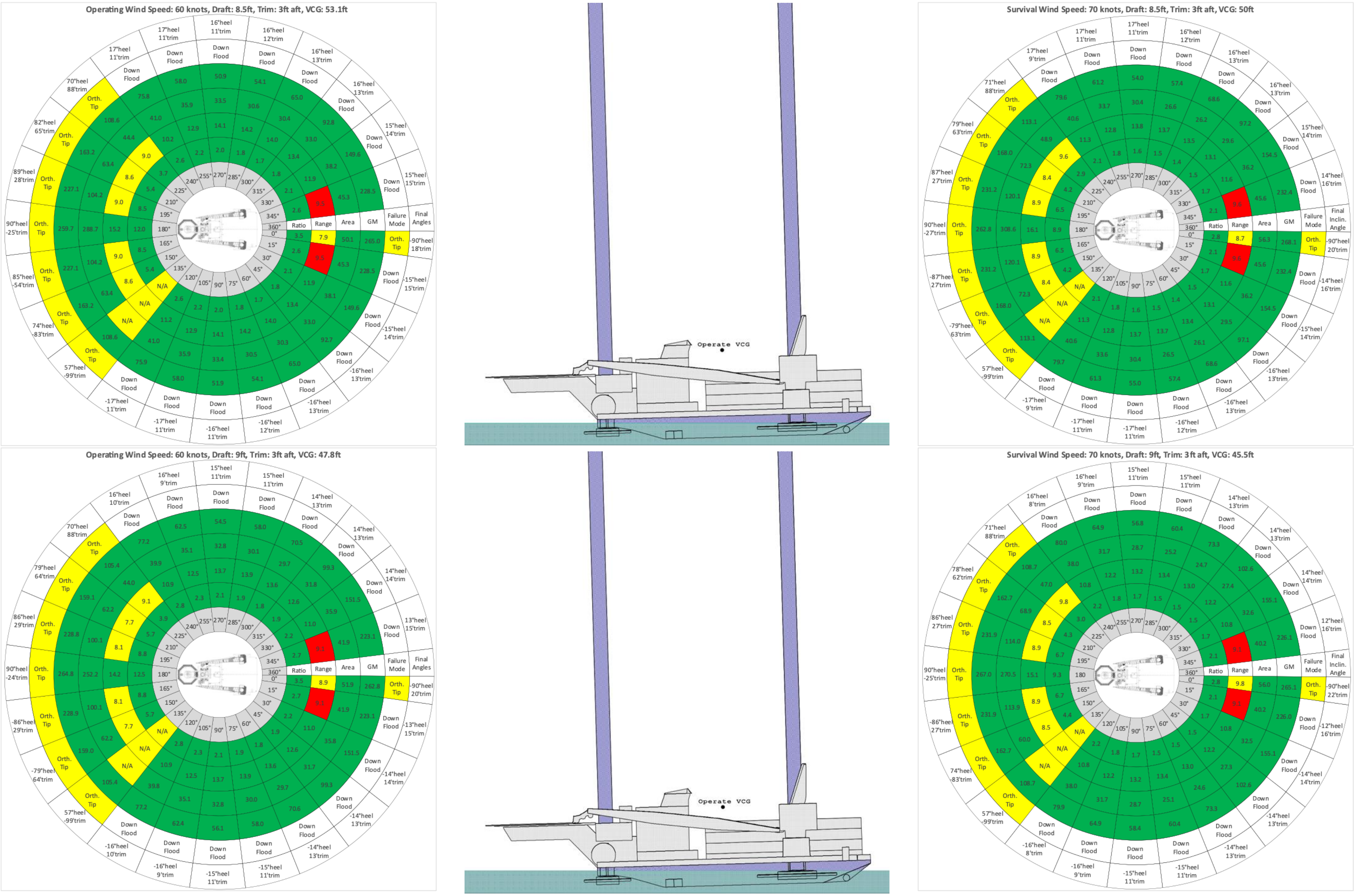


Figure 23: MSC Fixed Interval Analysis Results for 60-knot wind (left) and 70-knot wind (right). 8.5-foot draft (top), 9-foot draft (bottom). Trim is 3 feet

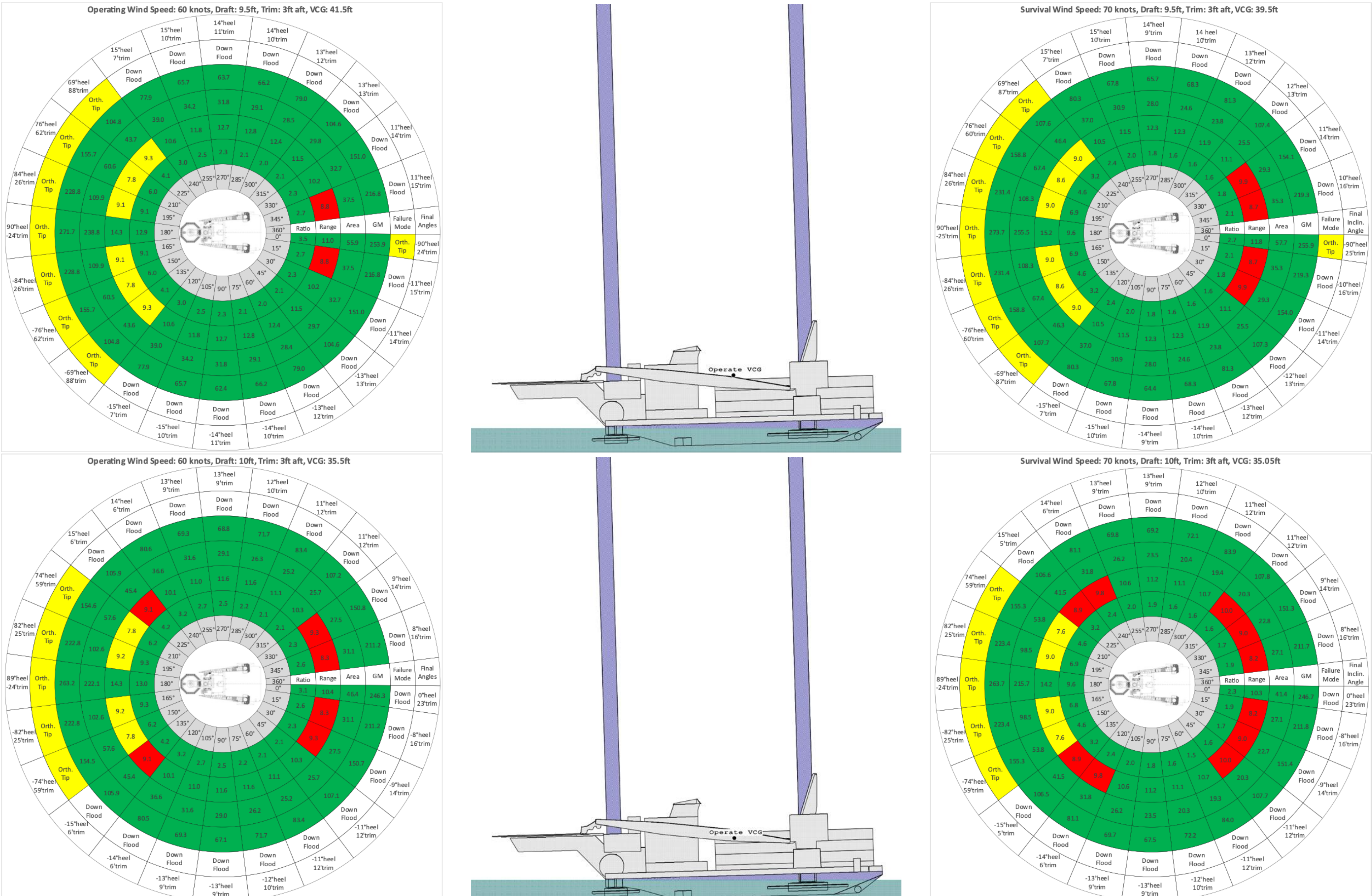


Figure 24: MSC Fixed Interval Analysis Results for 60-knot wind (left) and 70-knot wind (right). 9.5-foot draft (top), 10-foot draft (bottom). Trim is 3 feet

7.6.3. Varied Axis (Free-Twist) by Minimum Residual Righting Arm Ascent

MSC also evaluated stability of the SEACOR POWER model by allowing free rotation of the inclination axis. Reference 4 introduces the foundation of this method in 2006; the method was not available at the time of SEACOR POWER's stability analysis in 2002. Using this method, the axis or yaw angle of the model is allowed to rotate essentially changing the direction of the wind as the vessel inclines. As the inclination angle is assigned, the wind and inclination axes are free to rotate around the vessel and the residual righting arm is measured. Residual righting arm is the difference between the righting arm and heeling arm. For the next angle of inclination, the axes are rotated and the axis angle chosen is the one that has the least residual righting arm (this forms a curve with the least slope or minimum ascent).[8] This method is no longer susceptible to fading stability because the slope of the residual righting arm curve is steeper when inclining toward the bow or stern.

A graphical representation of this analysis method is shown in Figure 25.

By varying the axis to identify the axis rotations that have the least righting arm slope, this method indicates the path of least energy required to incline the vessel. However, there is no constraint on axis rotation and the axis may drastically change between inclination angles (this would indicate rapid yawing of the vessel and is likely not a reasonable result). For a valid resulting minimum energy path, the axis angles should remain somewhat adjacent. However, MSC does not have any technical basis for the specific number of degrees the axis angle can change with each angle of inclination while maintaining the validity of this method.

The SEACOR POWER model narrowly failed two high-trim conditions when using the varied axis method. The 8.5-foot draft, 3-foot aft trim and 9.5-foot draft with 3-foot aft trim conditions both failed the §174.255(a)(1)(i) ratio criteria for the survival wind speed of 70 knots. The required ratio of righting area to heeling area is 1.4 and the failure margin was within rounding error for both cases (increasing the numerical precision beyond reasonable values indicates attained ratios of 1.377 and 1.397 respectively).

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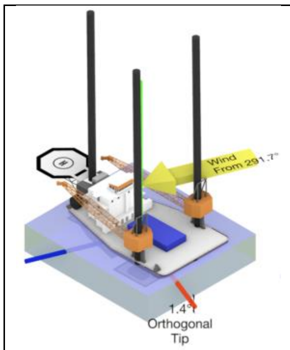
[8] This varied axis method is GHS' "minimum ascent" method of varying the inclination axis for righting arm calculation. This method is similar in application to methods described in References 1 through 4.

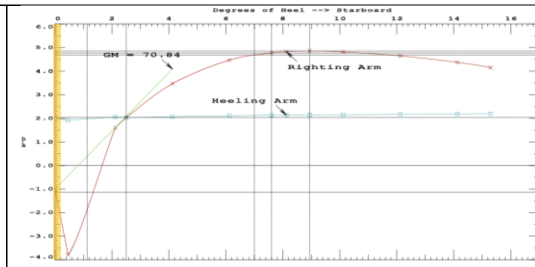


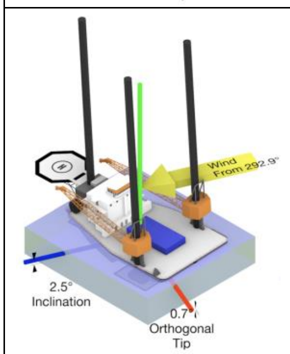
Axis varied for minimum ascent

Degrees of Axis	Trim	Heel	Displacement Weight(LT)	Residual Arms in Trim	Residual Arms in Heel	Res. Area	Flood Pt Height
21.72	1.36a	0.00	2,943.0	0.00	-3.001	0.00	11.47 (1)
83.76	0.13p	0.46a	2,943.1	0.00	-5.707	-2.01	5.16 (4)
29.01	0.65a	2.12s	2,943.1	0.00	-0.456	-7.12	3.57 (4)
22.94	0.72a	2.50s	2,943.1	0.00	0.002	-7.21	3.34 (4)
21.80	0.48a	4.12s	2,943.2	0.00	1.402	-6.02	9.46 (1)
21.73	0.32a	6.12s	2,942.7	0.00	2.362	-2.13	8.07 (1)
21.73	0.27a	7.60s	2,943.1	0.00	2.644	1.58	0.00 (3)
22.04	0.22a	8.12s	2,943.1	0.00	2.687	2.96	6.48 (1)
21.90	0.21a	8.94s	2,943.1	0.00	2.713	5.17	5.80 (1)
21.71	0.22a	10.12s	2,943.1	0.00	2.661	8.35	4.79 (1)
21.52	0.21a	12.12s	2,943.1	0.00	2.479	13.49	2.99 (1)
20.71	0.32a	14.12s	2,943.1	0.00	2.191	18.18	1.12 (1)
20.07	0.43a	15.29s	2,943.1	0.00	1.959	20.61	0.01 (1)

Distances in FEET. Specific Gravity = 1.025. Area in Ft-Deg.

Inclination angle (shown as "Heel" in the table) is prescribed at 0°
Twist (yaw) axis and orthogonal tip (shown as "Trim" in the table) are solved for



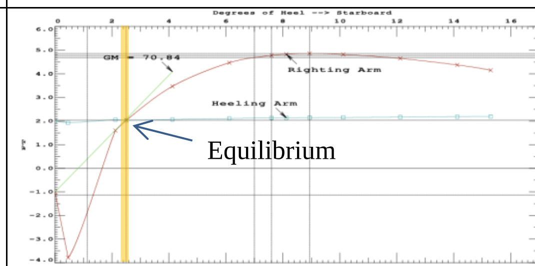


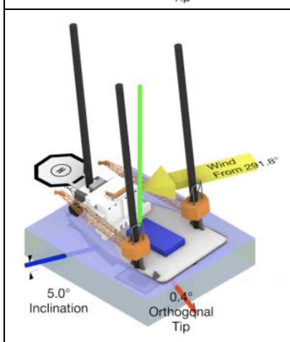
Axis varied for minimum ascent

Degrees of Axis	Trim	Heel	Displacement Weight(LT)	Residual Arms in Trim	Residual Arms in Heel	Res. Area	Flood Pt Height
21.72	1.36a	0.00	2,943.0	0.00	-3.001	0.00	11.47 (1)
83.76	0.13p	0.46a	2,943.1	0.00	-5.707	-2.01	5.16 (4)
29.01	0.65a	2.12s	2,943.1	0.00	-0.456	-7.12	3.57 (4)
22.94	0.72a	2.50s	2,943.1	0.00	0.002	-7.21	3.34 (4)
21.80	0.48a	4.12s	2,943.2	0.00	1.402	-6.02	9.46 (1)
21.73	0.32a	6.12s	2,942.7	0.00	2.362	-2.13	8.07 (1)
21.73	0.27a	7.60s	2,943.1	0.00	2.644	1.58	0.00 (3)
22.04	0.22a	8.12s	2,943.1	0.00	2.687	2.96	6.48 (1)
21.90	0.21a	8.94s	2,943.1	0.00	2.713	5.17	5.80 (1)
21.71	0.22a	10.12s	2,943.1	0.00	2.661	8.35	4.79 (1)
21.52	0.21a	12.12s	2,943.1	0.00	2.479	13.49	2.99 (1)
20.71	0.32a	14.12s	2,943.1	0.00	2.191	18.18	1.12 (1)
20.07	0.43a	15.29s	2,943.1	0.00	1.959	20.61	0.01 (1)

Distances in FEET. Specific Gravity = 1.025. Area in Ft-Deg.

Inclination angle (shown as "Heel" in the table) is prescribed at 2.5° (equilibrium)
Twist (yaw) axis and orthogonal tip (shown as "Trim" in the table) are solved for



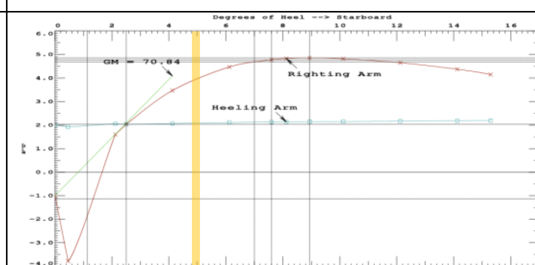


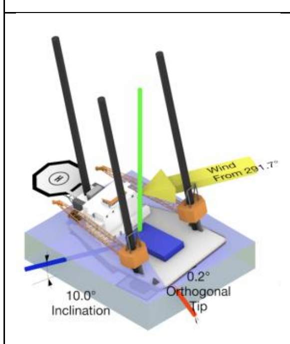
Axis varied for minimum ascent

Degrees of Axis	Trim	Heel	Displacement Weight(LT)	Residual Arms in Trim	Residual Arms in Heel	Res. Area	Flood Pt Height
21.72	1.36a	0.00	2,943.0	0.00	-3.001	0.00	11.47 (1)
83.76	0.13p	0.46a	2,943.1	0.00	-5.707	-2.01	5.16 (4)
29.01	0.65a	2.12s	2,943.1	0.00	-0.456	-7.12	3.57 (4)
22.94	0.72a	2.50s	2,943.1	0.00	0.002	-7.21	3.34 (4)
21.80	0.48a	4.12s	2,943.2	0.00	1.402	-6.02	9.46 (1)
21.73	0.32a	6.12s	2,942.7	0.00	2.362	-2.13	8.07 (1)
21.73	0.27a	7.60s	2,943.1	0.00	2.644	1.58	0.00 (3)
22.04	0.22a	8.12s	2,943.1	0.00	2.687	2.96	6.48 (1)
21.90	0.21a	8.94s	2,943.1	0.00	2.713	5.17	5.80 (1)
21.71	0.22a	10.12s	2,943.1	0.00	2.661	8.35	4.79 (1)
21.52	0.21a	12.12s	2,943.1	0.00	2.479	13.49	2.99 (1)
20.71	0.32a	14.12s	2,943.1	0.00	2.191	18.18	1.12 (1)
20.07	0.43a	15.29s	2,943.1	0.00	1.959	20.61	0.01 (1)

Distances in FEET. Specific Gravity = 1.025. Area in Ft-Deg.

Inclination angle (shown as "Heel" in the table) is prescribed at 5°
Twist (yaw) axis and orthogonal tip (shown as "Trim" in the table) are solved for



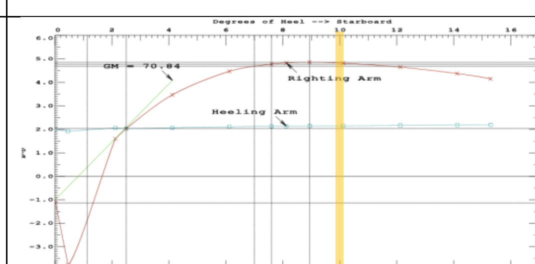


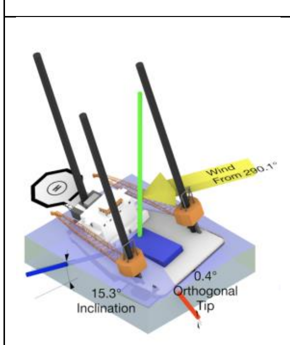
Axis varied for minimum ascent

Degrees of Axis	Trim	Heel	Displacement Weight(LT)	Residual Arms in Trim	Residual Arms in Heel	Res. Area	Flood Pt Height
21.72	1.36a	0.00	2,943.0	0.00	-3.001	0.00	11.47 (1)
83.76	0.13p	0.46a	2,943.1	0.00	-5.707	-2.01	5.16 (4)
29.01	0.65a	2.12s	2,943.1	0.00	-0.456	-7.12	3.57 (4)
22.94	0.72a	2.50s	2,943.1	0.00	0.002	-7.21	3.34 (4)
21.80	0.48a	4.12s	2,943.2	0.00	1.402	-6.02	9.46 (1)
21.73	0.32a	6.12s	2,942.7	0.00	2.362	-2.13	8.07 (1)
21.73	0.27a	7.60s	2,943.1	0.00	2.644	1.58	0.00 (3)
22.04	0.22a	8.12s	2,943.1	0.00	2.687	2.96	6.48 (1)
21.90	0.21a	8.94s	2,943.1	0.00	2.713	5.17	5.80 (1)
21.71	0.22a	10.12s	2,943.1	0.00	2.661	8.35	4.79 (1)
21.52	0.21a	12.12s	2,943.1	0.00	2.479	13.49	2.99 (1)
20.71	0.32a	14.12s	2,943.1	0.00	2.191	18.18	1.12 (1)
20.07	0.43a	15.29s	2,943.1	0.00	1.959	20.61	0.01 (1)

Distances in FEET. Specific Gravity = 1.025. Area in Ft-Deg.

Inclination angle (shown as "Heel" in the table) is prescribed at 10°
Twist (yaw) axis and orthogonal tip (shown as "Trim" in the table) are solved for





Axis varied for minimum ascent

Degrees of Axis	Trim	Heel	Displacement Weight(LT)	Residual Arms in Trim	Residual Arms in Heel	Res. Area	Flood Pt Height
21.72	1.36a	0.00	2,943.0	0.00	-3.001	0.00	11.47 (1)
83.76	0.13p	0.46a	2,943.1	0.00	-5.707	-2.01	5.16 (4)
29.01	0.65a	2.12s	2,943.1	0.00	-0.456	-7.12	3.57 (4)
22.94	0.72a	2.50s	2,943.1	0.00	0.002	-7.21	3.34 (4)
21.80	0.48a	4.12s	2,943.2	0.00	1.402	-6.02	9.46 (1)
21.73	0.32a	6.12s	2,942.7	0.00	2.362	-2.13	8.07 (1)
21.73	0.27a	7.60s	2,943.1	0.00	2.644	1.58	0.00 (3)
22.04	0.22a	8.12s	2,943.1	0.00	2.687	2.96	6.48 (1)
21.90	0.21a	8.94s	2,943.1	0.00	2.713	5.17	5.80 (1)
21.71	0.22a	10.12s	2,943.1	0.00	2.661	8.35	4.79 (1)
21.52	0.21a	12.12s	2,943.1	0.00	2.479	13.49	2.99 (1)
20.71	0.32a	14.12s	2,943.1	0.00	2.191	18.18	1.12 (1)
20.07	0.43a	15.29s	2,943.1	0.00	1.959	20.61	0.01 (1)

Distances in FEET. Specific Gravity = 1.025. Area in Ft-Deg.

Inclination angle (shown as "Heel" in the table) is prescribed at 15.3° (downflooding)
Twist (yaw) axis and orthogonal tip (shown as "Trim" in the table) are solved for

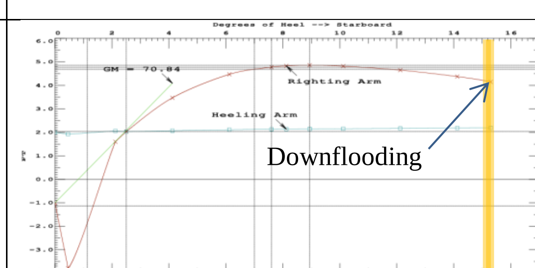


Figure 25: Varied Axis Method for the Casualty Condition with 70 Knot Winds (Page 640-641 of Appendix D)

7.6.4. Damaged Stability

MSC evaluated damaged stability to the criteria listed in §174.255(b) and the 2001 ABS MODU Rules. This was performed by damaging tanks and compartments along the starboard side of SEACOR POWER using the required damage and penetration extent and checking the location of the downflooding points when a 50 knot was applied at 15° intervals around the port side. Table 8 shows the damaged compartments checked. MSC assumed that results on the port and starboard side were symmetric and only conducted analysis of tanks on the starboard side. The ABS MODU Rules' range of stability criterion after damage was not checked by MSC (it was introduced by ABS in 2005, after SEACOR POWER's initial certification).

MSC analysis of starboard engine room flooding indicated failure of the 2001 ABS MODU Rules criteria with an initial (prior to damage) 10-foot draft, 3 feet of aft trim, and 50-knot winds from 285° relative (15° forward of the port beam); in this condition, the model capsized with the force of the 50-knot wind. Although a 10-foot draft was included in ABS' stability review and subsequently reviewed here, this draft would exceed the 9.75-foot maximum draft (as prescribed by the load line). Because no 9.75-foot draft was included in the ABS stability review, the 10-foot draft was apparently used to ensure stability at the load line draft was acceptable.

Additionally, MSC identified four damage cases that were apparently not part of ABS' 2002 stability review (as provided in MBI Exhibit 55). Three of these cases involved damaging the outer preload tank and adjacent leg which is within the extent of damage for both the §174.255(b) and ABS MODU Rules Criteria (MSC Damage cases 4, 5, and 9). A fourth damage case (MSC Damage Case 8) involves two compartments where Tank T and Tank V are both within the transverse extent of damage. These four damage cases did not result in failure of the stability criteria in MSC's analysis.

MSC Damage Case	Compartments Damaged	Assigned Per-meability	Notes:
1	Forepeak	0.95	• Adjacent to the Sea • Required by §174.255(b) • Required by 2001 ABS MODU Rules
2	Tank A (centerline)	0.95	• Single Bottom, Not on Side Shell • Not Required by CFR or 2001 ABS MODU Rules
3	Tank E (starboard)	0.95	• Single Bottom, Not on Side Shell • Not Required by CFR or 2001 ABS MODU Rules
4	Tank F (starboard) and Starboard Leg	0.95	• Required by §174.255(b) • Required by 2001 ABS MODU Rules
5	Tank K (starboard) and Starboard Leg	0.95	• Required by §174.255(b) • Required by 2001 ABS MODU Rules
6	Tank M (starboard)	0.95	• Required by §174.255(b) • Required by 2001 ABS MODU Rules
7	Tank O (starboard	0.95	• Required by §174.255(b) • Required by 2001 ABS MODU Rules
8	Tank T and Tank V (starboard)	0.95	• Required by §174.255(b) • Required by 2001 ABS MODU Rules
9	Tank V (Starboard) and Aft Leg	0.95	• Required by §174.255(b) • Required by 2001 ABS MODU Rules
10	Starboard Engine Room	0.85	• Not Adjacent to the Sea, but Contains Pumps • Not Required by CFR • Required by 2001 ABS MODU Rules

Table 8: Damaged Stability Cases for MSC Analysis

7.7. Departure Condition Analysis

7.7.1. MSC Assumed Departure Loading Condition

Section 6 provides details of the observed capsize condition. MSC used those observations to create a model loading condition for departure. Because the actual location of deck cargo is not known, MSC used the observed draft at the Plimsol Mark (9.25 feet) and the trim (2.5 feet aft) to calculate the displacement. Heel was assumed to be 0.25° to starboard. The following weights were deducted from the displacement to solve for the unknown weight and location of other items (primarily deck cargo):

- Lightship weight and centers of gravity (as calculated by SEMCO and shown in Table 4)
- Weight of loaded consumable tanks as reported by HelmConnect and centers of gravity calculated using modeled tanks
- 6-inch heights of seawater within the preload tanks as measured from their bottom-most point.

The remaining weight and center of gravity to attain the displacement from the observed draft and trim was calculated as one fixed weight item: the cargo and unknown weight. The vertical center of gravity of this weight was assumed at 3 feet above deck (16 feet above baseline). The cargo and unknown weight magnitude was calculated as 190 long tons with a center of gravity 105 feet aft of the bow and 16 feet port of centerline. The magnitude of weight reasonably represents the cargo weight and weight growth for a vessel that was last inclined 9-years prior.[9]

A detailed description of the assumed departure condition is shown in Figure 26 with a comparison to the departure image in Figure 27.

[9] The cargo manifests account for approximately 100 long tons of cargo weight which would have had a longitudinal center of gravity on the deck forward of the house (the forward end of the house is 105 feet aft of the bow). Cargo manifest weights are generally not accurate and the crew of SEACOR POWER weighed items as they were craned onboard on 13 April 2021, but these records were lost in the capsizing. The remaining 90 long tons of calculated unknown weight to attain the departure drafts and trim cannot be identified; MSC assumed that it is weight located longitudinally within the engine rooms and superstructure. This 90-ton unknown weight represents approximately 3.5% of the lightship weight of SEACOR POWER. Marine Technical Note 4-95 and International Maritime Organization Maritime Safety Committee Circular 1229 identifies an acceptable tolerance for lightship displacement (weight) discrepancies of 2% which is of similar magnitude to the calculated unknown weight of 3.5%.

Precasualty Condition - Drafts from Video
Using SEMCO and MOM Lightship Characteristics

WEIGHT and DISPLACEMENT and LATERAL PLANE and FREEBOARD STATUS

Baseline draft: 8.054 @ 20.00a, 9.475 @ 79.67a, 10.554 @ 125.00a
Trim: Aft 2.50/105.00, Heel: Stbd 0.25 deg.

Part			Weight(LT)	LCG	TCG	VCG	
LIGHT SHIP			1,663.91	89.71a	2.32s	10.82	
port leg and pad			285.53	45.00a	45.50p	107.80	
stbd leg and pad			285.53	45.00a	45.50s	107.80	
aft leg and pad			285.53	160.50a	0.00	107.80	
cargo+unknown weight			190.17	105.04a	16.37p	16.00	
Total Fixed			**2,710.67**	**88.82a**	**0.27s**	**41.83**	
	Gals.	**SpGr**	**Weight(LT)**	**LCG**	**TCG**	**VCG**	**RefHt**
TANKC.P	1829.7	1.025	6.99	37.45a	18.92p	0.37	-0.61
TANKE.S	1829.7	1.025	6.99	37.45a	19.42s	0.37	-0.61
TANKG.P	181.6	1.025	0.69	79.43a	40.49p	0.92	-0.98
TANKK.S	181.6	1.025	0.69	79.43a	41.01s	0.92	-0.98
DIESEL.P	8774.6	0.870	28.44	67.80a	24.15p	2.05	-4.08
DIESEL.S	10387	0.870	33.67	67.76a	24.18s	2.42	-4.83
POTWTR.P	14198	1.000	52.90	67.63a	4.16p	4.63	-9.25
POTWTR.S	14198	1.000	52.90	67.63a	4.17s	4.63	-9.25
DIESELDAY.P	4747.2	0.870	15.39	92.48a	39.30p	3.58	-7.16
DIESELDAY.S	4917.7	0.870	15.94	92.48a	39.34s	3.71	-7.42
WASTEOIL.P	187.0	0.924	0.64	97.59a	34.93p	0.26	-0.53
LUBEOIL.S	352.0	0.924	1.21	97.53a	32.50s	5.66	-1.98
TANKQ.P	25.5	1.025	0.10	125.69a	17.35p	0.09	-0.30
TANKS.S	25.5	1.025	0.10	125.69a	20.98s	0.09	-0.30
HYDRAULIC.C	4577.8	0.924	15.76	134.87a	0.00s	7.29	-10.26
Total Tanks			**232.39**	**74.12a**	**0.73s**	**3.75**	
Total Weight			**2,943.06**	**87.66a**	**0.31s**	**38.82**	
			Displ(LT)	**LCB**	**TCB**	**VCB**	
HULL		1.025	2,775.44	88.65a	0.47s	5.42	-7.58
LEGS		1.025	54.85	44.95a	45.50s	5.17	-7.58
LEGP		1.025	54.20	44.95a	45.50p	5.13	-7.58
LEGA		1.025	58.57	160.45a	0.00	5.52	-7.58
Total Displacement		**1.025**	**2,943.06**	**88.46a**	**0.46s**	**5.41**	
		Righting Arms:		0.00	0.00s		

Part	LPA	LCP	HCP	LPA	LCP	HCP
HULL	1196.6	82.18a	-4.44	350.6	80.92a	1.95
LEGS	212.3	45.05a	-3.61	2204.9	48.27a	129.34
LEGP	208.9	45.05a	-3.27	2208.3	48.28a	129.54
LEGA	152.8	160.55a	-5.39	2183.1	163.77a	128.06
DECK				1662.8	94.52a	11.53
CRANE				2562.9	84.47a	32.46
HOUSE.C				1366.8	125.11a	22.50
HELODK				1144.6	176.55a	17.27
DECKCAR6-5.C				634.1	52.87a	7.42
Total Lateral Plane->	**1770.5**	**80.11a**	**-4.29**	**14318.1**	**96.33a**	**70.48**

Distances in FEET.

Least freeboard is 1.32 Ft located at 166.50a
Least extra freeboard (to margin line) is 1.32 Ft located at 166.50a

	Critical Points		LCP	TCP	VCP	Height
(1)	ER Exhaust	FLOOD	120.50a	30.50s	22.00	11.42
(1)	ER Exhaust	FLOOD	120.50a	30.50p	22.00	11.68
(2)	ER Suppy	FLOOD	107.25a	16.50s	22.00	11.79
(2)	ER Suppy	FLOOD	107.25a	16.50p	22.00	11.94
(3)	ER Door	TIGHT	109.75a	35.00s	15.00	4.65
(3)	ER Door	TIGHT	109.75a	35.00p	15.00	4.96
(4)	Galley Door	TIGHT	131.75a	25.00s	15.00	4.17
(4)	Galley Door	TIGHT	131.75a	25.00p	15.00	4.39
(100)	CG		87.66a	0.31s	38.82	29.15
(200)	Port LL Ring Bot		79.67a	51.50p	9.25	0.00
(201)	Draft Marks Fwd		20.00a	51.50p	0.00	-7.83
(201)	Draft Marks Fwd		20.00a	51.50s	0.00	-8.28
(202)	Draft Marks Aft		125.00a	40.89p	-4.00	-14.37
(202)	Draft Marks Aft		125.00a	40.89s	-4.00	-14.73

Distances in FEET.

Figure 26: MSC Departure Condition

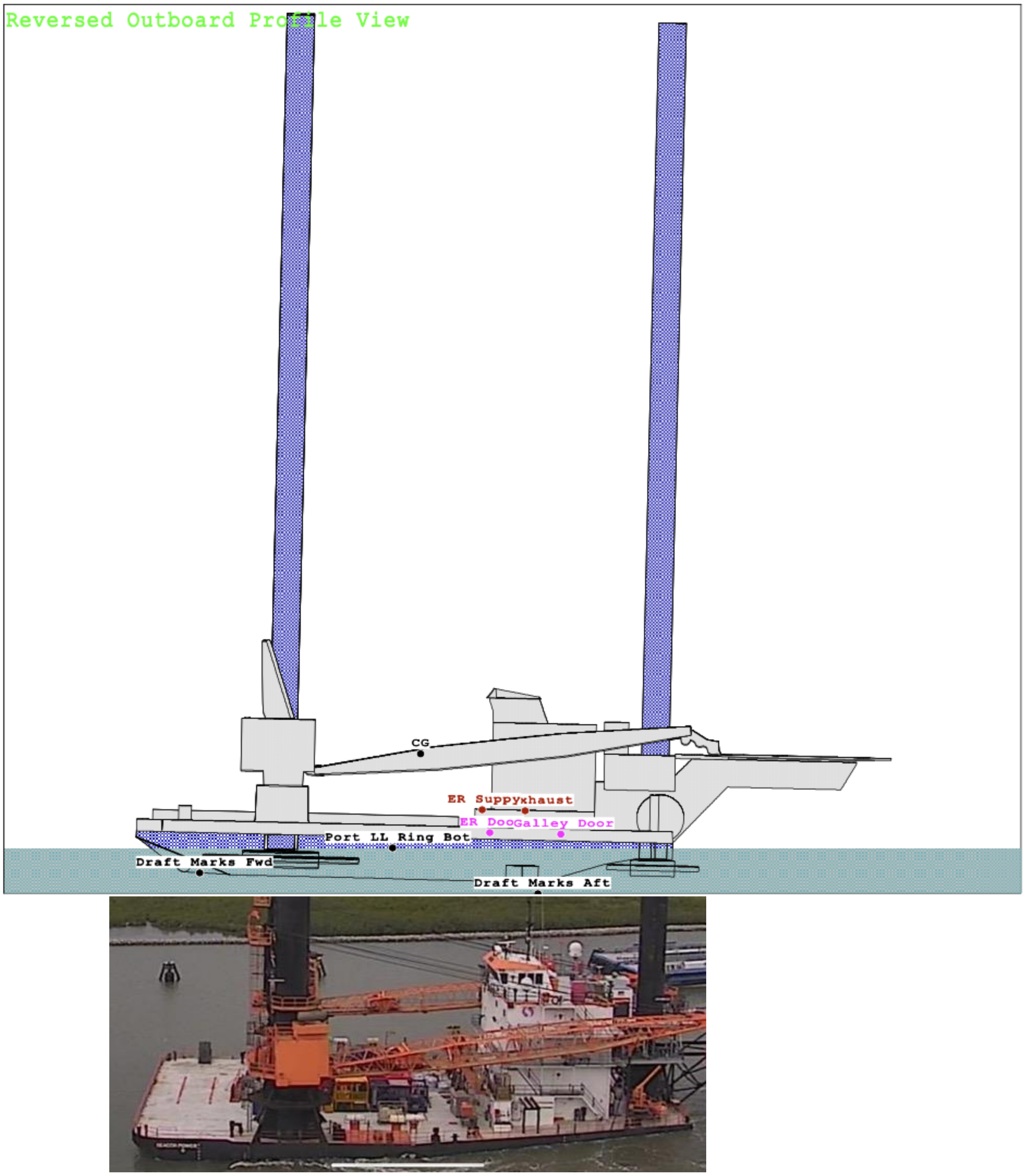


Figure 27: MSC model departure condition outboard profile graphic (top) with image of SEACOR POWER departure from Port Fourchon (bottom), for comparison

7.7.2. Criterion for Vessels of Unusual Proportion and Form

The departure condition is evaluated using the Criterion for Vessels of Unusual Proportion and Form, §170.173. No axis rotations are used in this analysis and wind force is not applied to the model. The departure condition of SEACOR POWER fails the §170.173 criteria by large margins because maximum righting arm (shown in figure 23), downflooding, and capsize occur at much lower heel angles than 15° for maximum righting arm and 30°, the minimum range of stability that the criteria require.

46 CFR 170.173 "Criterion for vessels of unusual proportion and form"
Wind Heeling Moments are Not Used, Heeling Direction is to Starboard

LIM	46CFR170.173(b) CRITERION		Min/Max		Attained
(1)	GM Upright	>	0.49	Ft	72.12 P
(2)	Righting Arm at 30 deg or MaxRA	>	0.66	Ft	UNDEF
(3)	Absolute Angle at MaxRA	>	25.00	deg	8.53 F
(4)	Area from abs 0.245 deg to abs 30	>	10.30	Ft-deg	UNDEF
(5)	Area from abs 0.245 deg to abs 40 or Flood	>	16.90	Ft-deg	UNDEF
(6)	Area from abs 30 deg to abs 40 or Flood	>	5.60	Ft-deg	UNDEF

Relative angles measured from 0.245s

LIM	46CFR170.173(c) CRITERION		Min/Max		Attained
(1)	GM Upright	>	0.49	Ft	72.12 P
(2)	Absolute Angle at MaxRA	>	15.00	deg	8.53 F
(3)	Area from abs 0.245 deg to abs 40 or Flood	>	16.90	Ft-deg	UNDEF
(4)	Area from abs 30 deg to abs 40 or Flood	>	5.60	Ft-deg	UNDEF
(5)	Area from abs 0.245 deg to MaxRA at 15	>	13.10	Ft-deg	28.66 P
(6)	Area from abs 0.245 deg to MaxRA at 30	>	10.30	Ft-deg	22.53 P

Relative angles measured from 0.245s

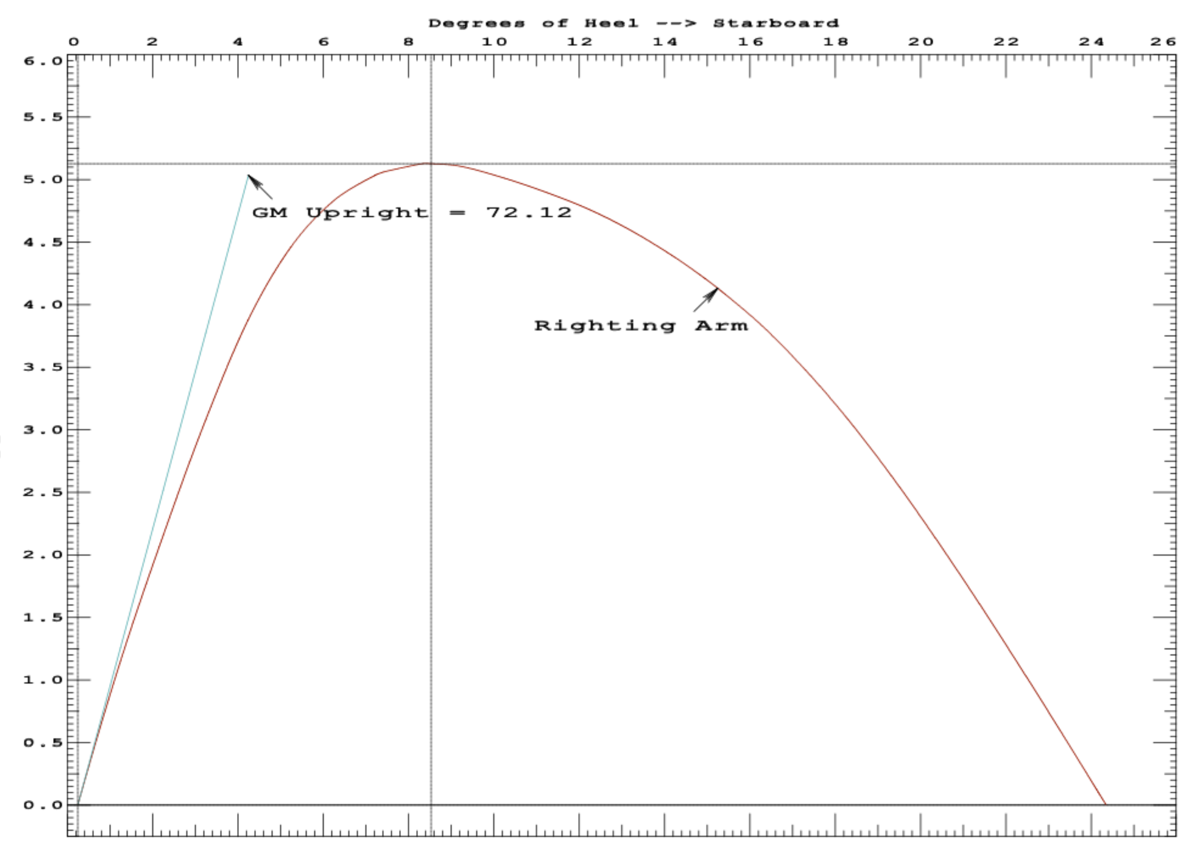


Figure 28: Departure condition analysis results using criterion for vessels of unusual proportions and form

7.7.3. Fixed Interval Stability Analysis with SEACOR POWER Model

The departure condition narrowly fails the range of stability criterion of §174.255(a)(1)(ii) for wind directions of 15°, 225°, and 345° relative for both 60-knot and 70-knot winds. The survival, 70-knot wind condition additionally fails range of stability criterion for a wind direction of 330° relative. For wind directions coming from near the bow directions of 15°, 330°, and 345°, the vessel primarily fails the criteria by orthogonal tipping with large true trims of 15 feet, 13 feet, and 16 feet respectively. When the wind is from the port stern at 225°, the condition very narrowly fails the §174.255(a)(1)(ii) criteria, attaining a 9.99° range of stability for 60-knot wind and 9.69° for 70-knot wind while aft trim is reasonable at 5 feet. As discussed in section 7.6.2 above, these range of stability failures are mostly related to the rotated axis/orthogonal tipping calculation issues. However, in each of the failing range conditions there is a relatively high righting energy which far exceeds the requirements of the ratio criterion of §174.255(a)(1)(i) and the residual righting energy criterion of §174.255(a)(1)(iii).

The results of this analysis are shown graphically in Figure 35. See section 7.6.2.3 on page 30 for a description of the graphics.

7.7.4. Varied Axis Stability Analysis

In addition to the methods discussed in Sections 7.7.2 and 7.7.3, MSC used the Minimum Ascent Method to evaluate the stability of the departure condition and eliminate the calculation issues from orthogonal tipping. Using this method, the SEACOR POWER model passed all intact stability criteria in the departure condition by the margins shown in Table 9 and Table 10, and Figures 24 and 25. In both the 60 and 70-knot wind analyses, the weakest axis converges on wind directions just forward of the port beam at 290° to 292° relative (shown in GHS as 20° to 22°). For both 60 and 70-knot wind conditions, the maximum righting arm occurs at 7.7° of inclination and the range of stability is 15°, limited by downflooding.

Criteria	Requirement	Attained Value	Margin
Righting Area to Heeling Area Ratio, §174.255(a)(1)(i)	> 1.4	2.27	0.87 (162%)
Range of Stability Criterion, §174.255(a)(1)(ii)	> 10°	13.0°	3.0° (130%)
Residual Righting Energy Criterion, §174.255(a)(1)(iii)	> 5 ft•deg	35.2 ft•deg	30.2 ft•deg (712%)
Metacentric Height (GM) Criterion, §174.255(a)(3):	> 1 ft	71.1 ft	70.1 ft (7,100%)

Table 9: MSC varied axis stability analysis results for the departure condition and 60-knot winds

Criteria	Requirement	Attained Value	Margin
Righting Area to Heeling Area Ratio, §174.255(a)(1)(i)	> 1.4	1.64	0.24 (117%)
Range of Stability Criterion, §174.255(a)(1)(ii)	> 10°	12.5°	2.5° (125%)
Residual Righting Energy Criterion, §174.255(a)(1)(iii)	> 5 ft•deg	27.9 ft•deg	22.9 ft•deg (558%)
Metacentric Height (GM) Criterion, §174.255(a)(3):	> 1 ft	69.8 ft	68.8 ft (6,980%)

Table 10: MSC varied axis stability analysis results for the departure condition and 70-knot winds

Varied Axis, Minimum Ascent Method

RESIDUAL RIGHTING ARMS vs HEEL ANGLE

Fixed CG: LCG = 88.82a TCG = 0.27s VCG = 41.83

Axis varied for minimum ascent

Degrees of Axis	Trim	Heel	Displacement Weight(LT)	Residual Arms in Trim	in Heel	Res. Area	Flood Pt Height
21.39	1.38a	0.00	2,943.0	0.00	-2.478	0.00	11.34 (1)
84.02	0.10p	0.53a	2,943.1	0.00	-4.991	-2.00	5.00 (4)
31.08	0.75a	1.72s	2,943.1	0.00	-0.437	-5.21	3.68 (4)
21.34	0.89a	1.97s	2,943.0	0.00	0.004	-5.26	3.49 (4)
21.34	0.54a	3.72s	2,943.1	0.00	1.875	-3.58	9.55 (1)
20.66	0.39a	5.72s	2,943.1	0.00	3.187	1.60	8.13 (1)
21.28	0.28a	7.22s	2,943.1	0.00	3.557	6.66	0.01 (3)
21.28	0.27a	7.72s	2,943.1	0.00	3.580	8.45	6.52 (1)
21.72	0.22a	7.73s	2,943.1	0.00	3.580	8.49	6.50 (1)
21.59	0.20a	9.72s	2,943.1	0.00	3.408	15.44	4.81 (1)
20.54	0.35a	11.72s	2,943.1	0.00	2.985	21.83	3.03 (1)
19.15	0.62a	13.72s	2,943.1	0.00	2.393	27.21	1.19 (1)
15.28	1.50a	14.99s	2,943.1	0.00	1.938	29.97	0.00 (1)

Distances in FEET. Specific Gravity = 1.025. Area in Ft-Deg.

Note: The Center of Gravity shown above is for the Fixed Weight of 2710.67 LT. As the tank load centers shift with heel and trim, the total Center of Gravity varies. The righting arms shown above include the effect of the C.G. variation.

Note: The Residual Righting Arms shown above are in excess of the wind heeling arms derived from the projected wind plane at each heel angle, using the given wind pressure from port.

	Critical Points		LCP	TCP	VCP
(1)	ER Exhaust	FLOOD	120.50a	30.50	22.00
(3)	ER Door	TIGHT	109.75a	35.00	15.00
(4)	Galley Door	TIGHT	131.75a	25.00	15.00

LIM	46CFR174.255 CRITERION		Min/Max		Attained
(1)	Abs Ratio from abs 0 deg to Flood or RAzero	>	1.400		2.270 P
(2)	Angle from Equilibrium to Flood or RAzero	>	10.00	deg	13.02 P
(3)	Res. Area from Equilibrium to Flood or RAzero	>	5.00	Ft-deg	35.24 P
(4)	GM Upright	>	1.00	Ft	71.09 P

GM is derived from the RA curve.

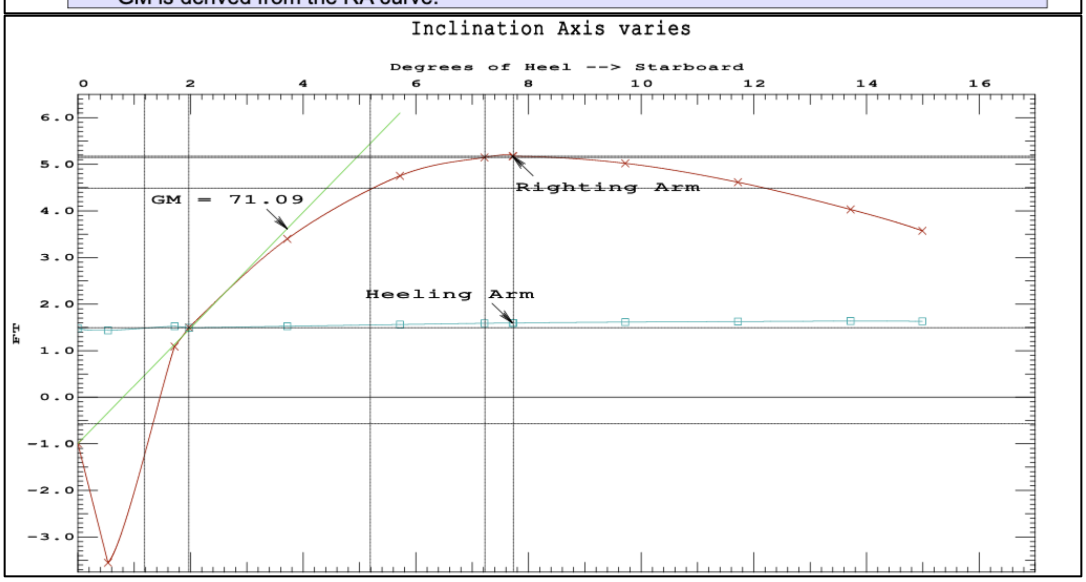


Figure 29: GHS output for varied axis analysis of departure condition with 60-knot winds for the normal operating condition

Varied Axis, Minimum Ascent Method

RESIDUAL RIGHTING ARMS vs HEEL ANGLE

Fixed CG: LCG = 88.82a TCG = 0.27s VCG = 41.83

Axis varied for minimum ascent

Degrees of			Displacement	Residual Arms		Res.	Flood Pt
Axis	Trim	Heel	Weight(LT)	in Trim	in Heel	Area	Height
21.15	1.37a	0.00	2,943.0	0.00	-3.004	0.00	11.34 (1)
84.26	0.11p	0.47a	2,943.1	0.00	-5.803	-2.06	5.05 (4)
29.18	0.65a	2.13s	2,943.3	0.00	-0.449	-7.27	3.42 (4)
21.16	0.79a	2.46s	2,943.0	0.00	0.004	-7.34	3.23 (4)
20.97	0.50a	4.13s	2,943.1	0.00	1.686	-5.88	9.28 (1)
20.78	0.36a	6.13s	2,943.1	0.00	2.773	-1.29	7.81 (1)
21.73	0.23a	7.22s	2,943.1	0.00	2.984	1.83	0.00 (3)
21.63	0.23a	7.75s	2,943.1	0.00	3.003	3.43	6.49 (1)
21.52	0.23a	8.13s	2,943.1	0.00	2.994	4.57	6.17 (1)
21.69	0.18a	10.13s	2,943.1	0.00	2.752	10.32	4.44 (1)
21.53	0.18a	12.13s	2,943.1	0.00	2.285	15.36	2.63 (1)
21.73	0.11a	14.13s	2,943.1	0.00	1.656	19.32	0.76 (1)
22.71	0.12f	14.92s	2,943.1	0.00	1.368	20.52	*-0.01* (1)

Distances in FEET. Specific Gravity = 1.025. Area in Ft-Deg.

Note: The Center of Gravity shown above is for the Fixed Weight of 2710.67 LT. As the tank load centers shift with heel and trim, the total Center of Gravity varies. The righting arms shown above include the effect of the C.G. variation.

Note: The Residual Righting Arms shown above are in excess of the wind heeling arms derived from the projected wind plane at each heel angle, using the given wind pressure from port.

	Critical Points		LCP	TCP	VCP
(1)	ER Exhaust	FLOOD	120.50a	30.50	22.00
(3)	ER Door	TIGHT	109.75a	35.00	15.00
(4)	Galley Door	TIGHT	131.75a	25.00	15.00

LIM	46CFR174.255 CRITERION		Min/Max		Attained
(1)	**Abs Ratio from abs 0 deg to Flood or RAzero**	**>**	**1.400**		**1.641 P**
(2)	**Angle from Equilibrium to Flood or RAzero**	**>**	**10.00**	**deg**	**12.47 P**
(3)	**Res. Area from Equilibrium to Flood or RAzero**	**>**	**5.00**	**Ft-deg**	**27.86 P**
(4)	**GM Upright**	**>**	**1.00**	**Ft**	**69.80 P**

GM is derived from the RA curve.

Inclination Axis varies

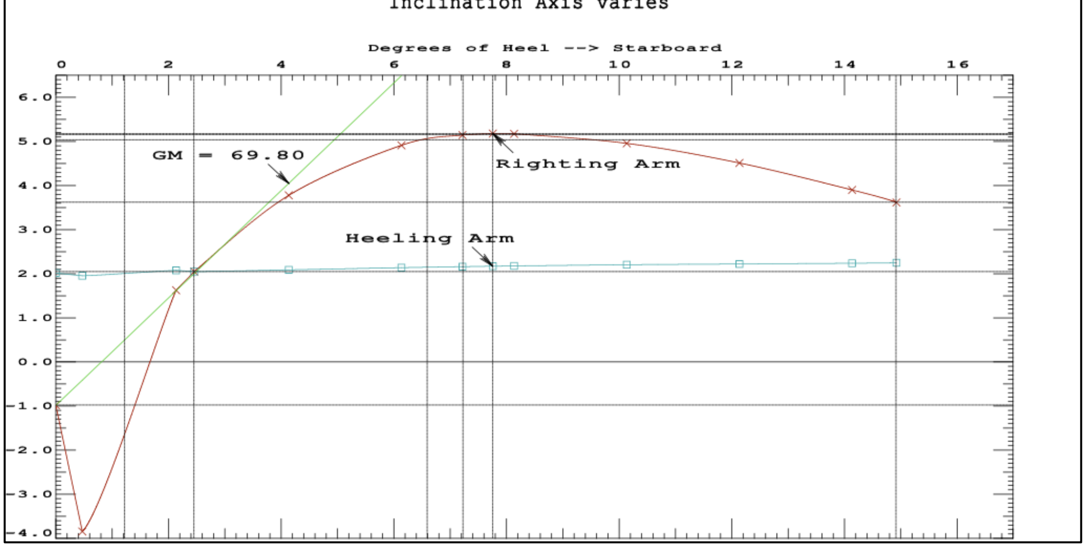


Figure 30: GHS output for varied axis analysis of departure condition with 70-knot winds

7.8. Analysis of Condition at Time of Casualty

7.8.1. MSC Assumed Casualty Loading Condition

MSC generated the capsize condition by lowering the legs of the model by 10 feet, including their vertical center of gravity shift downward. All other weights remain the same. Note that the center of buoyancy and waterplane of SEACOR POWER change because the legs are buoyant; the legs now account for more displacement than at departure while the hull's displacement is reduced.

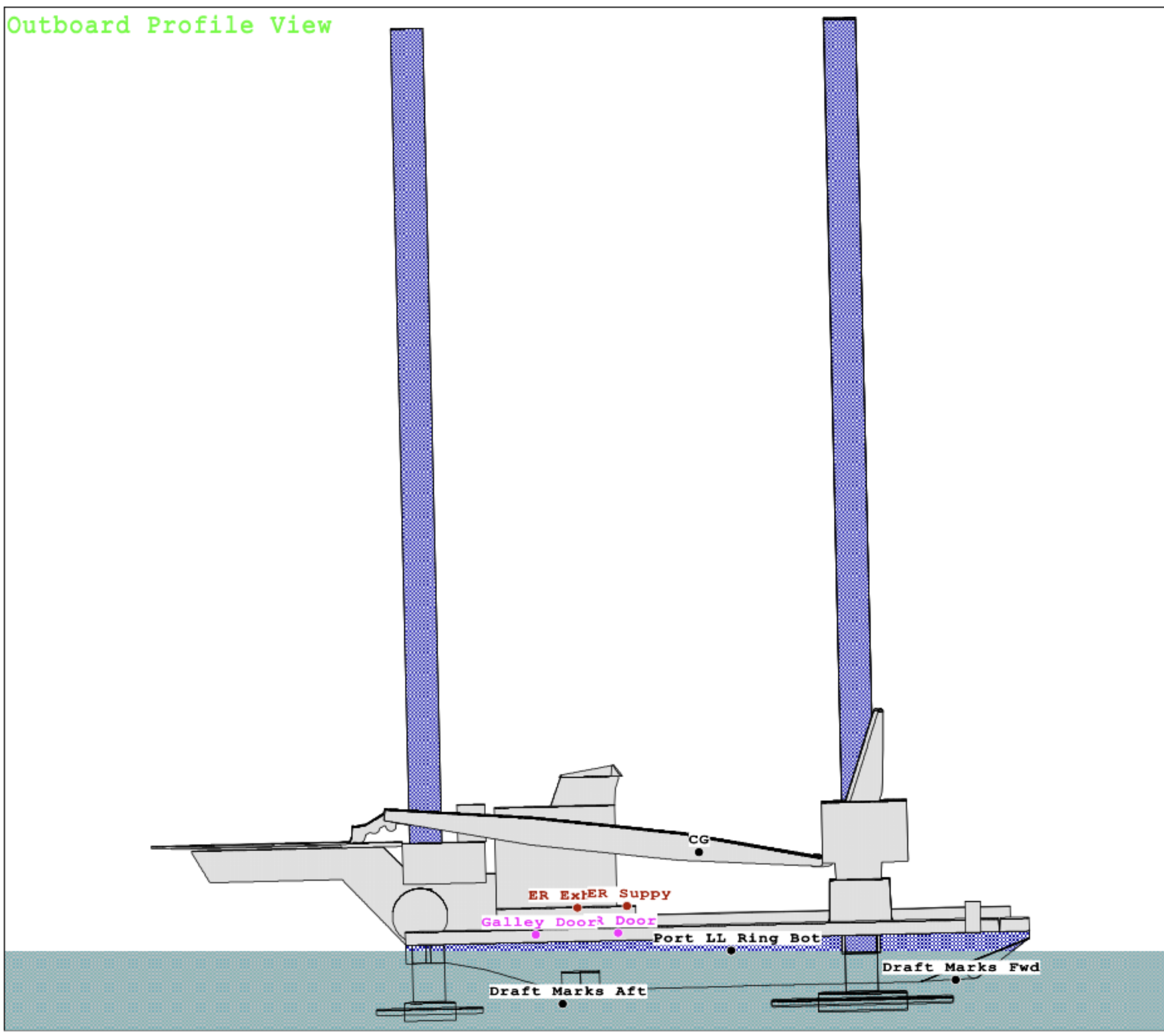


Figure 31: MSC model casualty condition outboard profile graphic

Condition at Time of Capsize - MOM Lightship Characteristics
Based on Leg Deployment and Departure Condition

WEIGHT and DISPLACEMENT and LATERAL PLANE and FREEBOARD STATUS

Baseline draft: 7.957 @ 20.00a, 9.357 @ 79.67a, 10.421 @ 125.00a
Trim: Aft 2.46/105.00, Heel: Stbd 0.25 deg.

Part	Gals.	SpGr	Weight(LT)	LCG	TCG	VCG	RefHt
LIGHT SHIP			1,663.91	89.71a	2.32s	10.82	
port leg and pad			285.53	45.00a	45.50p	97.80	
stbd leg and pad			285.53	45.00a	45.50s	97.80	
aft leg and pad			285.53	160.50a	0.00	97.80	
cargo+unknown weight			190.17	105.04a	16.37p	16.00	
Total Fixed			**2,710.67**	**88.82a**	**0.27s**	**38.67**	
TANKB.P	4.9	1.025	0.02	19.85a	38.39p	3.52	-0.33
TANKF.S	4.9	1.025	0.02	19.85a	43.11s	3.52	-0.33
TANKC.P	1828.3	1.025	6.98	37.43a	18.92p	0.37	-0.62
TANKE.S	1828.3	1.025	6.98	37.43a	19.41s	0.37	-0.62
TANKG.P	181.0	1.025	0.69	79.43a	40.50p	0.92	-0.98
TANKK.S	181.0	1.025	0.69	79.43a	41.00s	0.92	-0.98
DIESEL.P	8774.5	0.870	28.44	67.80a	24.15p	2.04	-4.08
DIESEL.S	10387	0.870	33.67	67.75a	24.18s	2.42	-4.83
POTWTR.P	14197	1.000	52.89	67.63a	4.16p	4.63	-9.25
POTWTR.S	14197	1.000	52.89	67.63a	4.17s	4.63	-9.25
DIESELDAY.P	4747.2	0.870	15.39	92.48a	39.30p	3.58	-7.17
DIESELDAY.S	4917.7	0.870	15.94	92.48a	39.34s	3.71	-7.42
WASTEOIL.P	187.0	0.924	0.64	97.59a	34.93p	0.26	-0.53
LUBEOIL.S	352.0	0.924	1.21	97.52a	32.50s	5.66	-1.98
TANKQ.P	25.9	1.025	0.10	125.69a	17.40p	0.09	-0.30
TANKS.S	25.9	1.025	0.10	125.69a	20.93s	0.09	-0.30
HYDRAULIC.C	4577.8	0.924	15.76	134.87a	0.00s	7.29	-10.26
Total Tanks			**232.42**	**74.11a**	**0.73s**	**3.75**	
Total Weight			**2,943.08**	**87.66a**	**0.31s**	**35.91**	

		SpGr	Displ(LT)	LCB	TCB	VCB	RefHt
HULL		1.025	2,727.41	88.67a	0.47s	5.34	-7.49
LEGS		1.025	70.88	44.96a	45.50s	-2.88	-7.49
LEGP		1.025	70.25	44.96a	45.50p	-2.98	-7.49
LEGA		1.025	74.54	160.46a	0.00	-2.16	-7.49
Total Displacement		**1.025**	**2,943.09**	**88.39a**	**0.44s**	**4.76**	
Righting Arms:				0.00	0.00s		

Part	LPA	LCP	HCP	LPA	LCP	HCP
HULL	1183.8	81.92a	-4.37	362.5	81.81a	2.00
LEGS	296.5	44.89a	-11.07	2120.6	48.11a	124.39
LEGP	293.1	44.89a	-10.80	2123.9	48.11a	124.59
LEGA	236.6	160.42a	-11.58	2099.2	163.61a	123.14
DECK				1661.7	94.52a	11.66
CRANE				2562.8	84.46a	32.58
HOUSE.C				1366.6	125.10a	22.63
HELODK				1144.2	176.53a	17.42
DECKCAR6-5.C				633.8	52.87a	7.53
Total Lateral Plane->	**2010.0**	**80.30a**	**-7.14**	**14075.3**	**96.43a**	**67.22**

Distances in FEET.

Least freeboard is 1.47 Ft located at 166.50a
Least extra freeboard (to margin line) is 1.47 Ft located at 166.50a

	Critical Points		LCP	TCP	VCP	Height
(1)	ER Exhaust	FLOOD	120.50a	30.50s	22.00	11.55
(1)	ER Exhaust	FLOOD	120.50a	30.50p	22.00	11.81
(2)	ER Suppy	FLOOD	107.25a	16.50s	22.00	11.92
(2)	ER Suppy	FLOOD	107.25a	16.50p	22.00	12.06
(3)	ER Door	TIGHT	109.75a	35.00s	15.00	4.79
(3)	ER Door	TIGHT	109.75a	35.00p	15.00	5.09
(4)	Galley Door	TIGHT	131.75a	25.00s	15.00	4.31
(4)	Galley Door	TIGHT	131.75a	25.00p	15.00	4.53
(100)	CG		87.66a	0.31s	35.91	26.36
(200)	Port LL Ring Bot		79.67a	51.50p	9.25	0.11
(201)	Draft Marks Fwd		20.00a	51.50p	0.00	-7.73
(201)	Draft Marks Fwd		20.00a	51.50s	0.00	-8.18
(202)	Draft Marks Aft		125.00a	40.89p	-4.00	-14.24
(202)	Draft Marks Aft		125.00a	40.89s	-4.00	-14.59

Distances in FEET.

Figure 32: MSC Casualty Condition

7.8.2. Criterion for Vessels of Unusual Proportion and Form

MSC evaluated the casualty condition using the Criterion for Vessels of Unusual Proportion and Form, §170.173. No axis rotation is used in this analysis and wind force is not modeled. The casualty condition of SEACOR POWER also fails the §170.173 criteria by large margins because downflooding and capsize occur at much lower heel angles than 15° for maximum righting arm and 30°, the minimum range of stability that the criteria require.

7.8.3. Fixed Interval Stability Analysis with SEACOR POWER Model

The casualty condition narrowly fails the range of stability criterion of §174.255(a)(1)(ii) for wind directions of 0°, 15°, and 345° relative for both 60-knot and 70-knot winds. For each of these wind directions coming from near the bow, the vessel primarily fails the criteria by orthogonal tipping with large true trims of 19 feet, 16 feet and 15 feet respectively. Stability, as measured by these criteria, is improved when compared to the departure condition when the legs are fully raised.

The results of this analysis are shown graphically in Figure 35. See section 7.6.2.3 on page 30 for a description of the graphics.

7.8.4. Varied Axis Stability Analysis

In the casualty condition, MSC also used the Minimum Ascent Method to evaluate the stability of the casualty condition and eliminate the calculation issues from orthogonal tipping. Using this method, the SEACOR POWER model passed all intact stability criteria in the casualty condition by the margins shown in Table 11 and Table 12. In both the 60 and 70-knot wind analyses, the weakest axis converges on wind directions just forward of the port beam at 291° to 293° relative (shown in GHS as 21° to 23°). For both 60 and 70-knot wind conditions, the maximum righting arm occurs at 8.9° of inclination and the range of stability is 15°, limited by downflooding.

Criteria	Requirement	Attained Value	Margin
Righting Area to Heeling Area Ratio, §174.255(a)(1)(i)	> 1.4	2.28	0.88 (163%)
Range of Stability Criterion, §174.255(a)(1)(ii)	> 10°	13.4°	3.4° (134%)
Residual Righting Energy Criterion, §174.255(a)(1)(iii)	> 5 ft•deg	35.3 ft•deg	30.3 ft•deg (706%)
Metacentric Height (GM) Criterion, §174.255(a)(3):	> 1 ft	72.3 ft	71.3 ft (7,230%)

Table 11: MSC varied axis stability analysis results for the casualty condition and 60-knot winds

Criteria	Requirement	Attained Value	Margin
Righting Area to Heeling Area Ratio, §174.255(a)(1)(i)	> 1.4	1.64	0.24 (117%)
Range of Stability Criterion, §174.255(a)(1)(ii)	> 10°	12.8°	2.5° (128%)
Residual Righting Energy Criterion, §174.255(a)(1)(iii)	> 5 ft•deg	27.8 ft•deg	22.9 ft•deg (556%)
Metacentric Height (GM) Criterion, §174.255(a)(3):	> 1 ft	70.8 ft	68.8 ft (7,080%)

Table 12: MSC varied axis stability analysis results for the casualty condition and 70-knot winds

Varied Axis, Minimum Ascent Method

RESIDUAL RIGHTING ARMS vs HEEL ANGLE

Fixed CG: LCG = 88.82a TCG = 0.27s VCG = 38.67

Axis varied for minimum ascent

Degrees of			Displacement	Residual Arms		Res.	Flood Pt
Axis	Trim	Heel	Weight(LT)	in Trim	in Heel	Area	Height
22.24	1.36a	0.00	2,943.0	0.00	-2.494	0.00	11.47 (1)
83.36	0.13p	0.53a	2,943.1	0.00	-4.881	-1.97	5.10 (4)
31.52	0.74a	1.68s	2,943.1	0.00	-0.448	-5.03	3.83 (4)
21.80	0.87a	1.97s	2,943.0	0.00	0.004	-5.10	3.63 (4)
21.76	0.54a	3.68s	2,943.2	0.00	1.621	-3.63	9.74 (1)
21.61	0.36a	5.68s	2,943.1	0.00	2.777	0.90	8.39 (1)
21.83	0.25a	7.60s	2,943.1	0.00	3.208	6.72	0.00 (3)
21.56	0.28a	7.68s	2,943.1	0.00	3.218	7.01	6.85 (1)
21.77	0.23a	8.96s	2,943.1	0.00	3.282	11.17	5.78 (1)
21.61	0.24a	9.68s	2,943.1	0.00	3.261	13.53	5.17 (1)
21.03	0.30a	11.68s	2,943.1	0.00	3.099	19.89	3.40 (1)
19.52	0.56a	13.68s	2,943.2	0.00	2.844	25.83	1.55 (1)
18.71	0.73a	15.32s	2,943.2	0.00	2.533	30.24	0.00 (1)

Distances in FEET. Specific Gravity = 1.025. Area in Ft-Deg.

Note: The Center of Gravity shown above is for the Fixed Weight of 2710.67 LT. As the tank load centers shift with heel and trim, the total Center of Gravity varies. The righting arms shown above include the effect of the C.G. variation.

Note: The Residual Righting Arms shown above are in excess of the wind heeling arms derived from the projected wind plane at each heel angle, using the given wind pressure from port.

	Critical Points		LCP	TCP	VCP
(1)	ER Exhaust	FLOOD	120.50a	30.50	22.00
(3)	ER Door	TIGHT	109.75a	35.00	15.00
(4)	Galley Door	TIGHT	131.75a	25.00	15.00

LIM	46CFR174.255 CRITERION		Min/Max		Attained
(1)	Abs Ratio from abs 0 deg to Flood or RAzero	>	1.400		2.275 P
(2)	Angle from Equilibrium to Flood or RAzero	>	10.00	deg	13.35 P
(3)	Res. Area from Equilibrium to Flood or RAzero	>	5.00	Ft-deg	35.34 P
(4)	GM Upright	>	1.00	Ft	72.25 P

GM is derived from the RA curve.

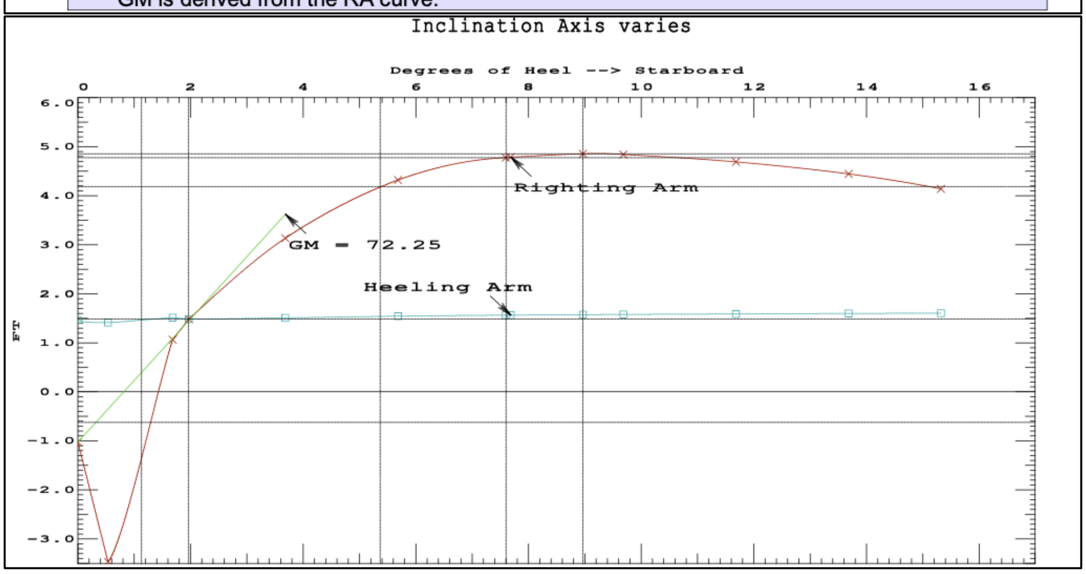


Figure 33: GHS output for varied axis analysis of casualty condition with 60-knot winds. Note that axis angles in GHS are measured clockwise from 270° relative.

Varied Axis, Minimum Ascent Method

RESIDUAL RIGHTING ARMS vs HEEL ANGLE

Fixed CG: LCG = 88.82a TCG = 0.27s VCG = 38.67

Axis varied for minimum ascent

Degrees of Axis	Trim	Heel	Displacement Weight(LT)	Residual Arms in Trim	in Heel	Res. Area	Flood Pt Height
21.72	1.36a	0.00	2,943.0	0.00	-3.001	0.00	11.47 (1)
83.76	0.13p	0.46a	2,943.1	0.00	-5.707	-2.01	5.16 (4)
29.01	0.65a	2.12s	2,943.1	0.00	-0.456	-7.12	3.57 (4)
22.94	0.72a	2.50s	2,943.1	0.00	0.002	-7.21	3.34 (4)
21.80	0.48a	4.12s	2,943.2	0.00	1.402	-6.02	9.46 (1)
21.73	0.32a	6.12s	2,942.7	0.00	2.362	-2.13	8.07 (1)
21.73	0.27a	7.60s	2,943.1	0.00	2.644	1.58	0.00 (3)
22.04	0.22a	8.12s	2,943.1	0.00	2.687	2.96	6.48 (1)
21.90	0.21a	8.94s	2,943.1	0.00	2.713	5.17	5.80 (1)
21.71	0.22a	10.12s	2,943.1	0.00	2.661	8.35	4.79 (1)
21.52	0.21a	12.12s	2,943.1	0.00	2.479	13.49	2.99 (1)
20.71	0.32a	14.12s	2,943.1	0.00	2.191	18.18	1.12 (1)
20.07	0.43a	15.29s	2,943.1	0.00	1.959	20.61	0.01 (1)

Distances in FEET. Specific Gravity = 1.025. Area in Ft-Deg.

Note: The Center of Gravity shown above is for the Fixed Weight of 2710.67 LT. As the tank load centers shift with heel and trim, the total Center of Gravity varies. The righting arms shown above include the effect of the C.G. variation.

Note: The Residual Righting Arms shown above are in excess of the wind heeling arms derived from the projected wind plane at each heel angle, using the given wind pressure from port.

	Critical Points		LCP	TCP	VCP
(1)	ER Exhaust	FLOOD	120.50a	30.50	22.00
(3)	ER Door	TIGHT	109.75a	35.00	15.00
(4)	Galley Door	TIGHT	131.75a	25.00	15.00

LIM	46CFR174.255 CRITERION		Min/Max		Attained
(1)	**Abs Ratio from abs 0 deg to Flood or RAzero**	>	1.400		1.639 P
(2)	**Angle from Equilibrium to Flood or RAzero**	>	10.00	deg	12.79 P
(3)	**Res. Area from Equilibrium to Flood or RAzero**	>	5.00	Ft-deg	27.82 P
(4)	**GM Upright**	>	1.00	Ft	70.84 P

GM is derived from the RA curve.

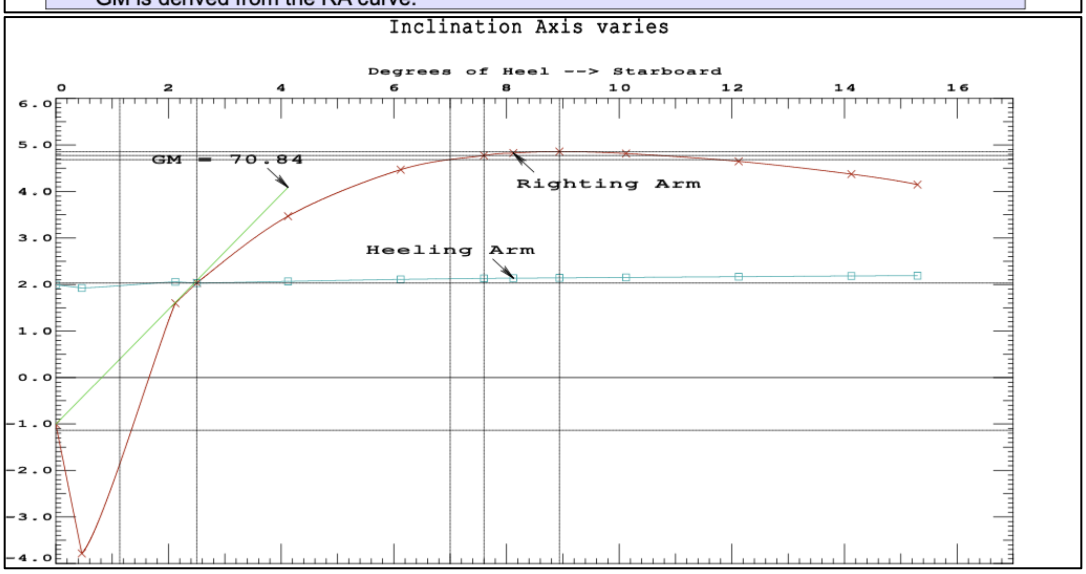


Figure 34: GHS output for varied axis analysis of casualty condition with 70-knot winds. Note that axis angles in GHS are measured clockwise from 270° relative

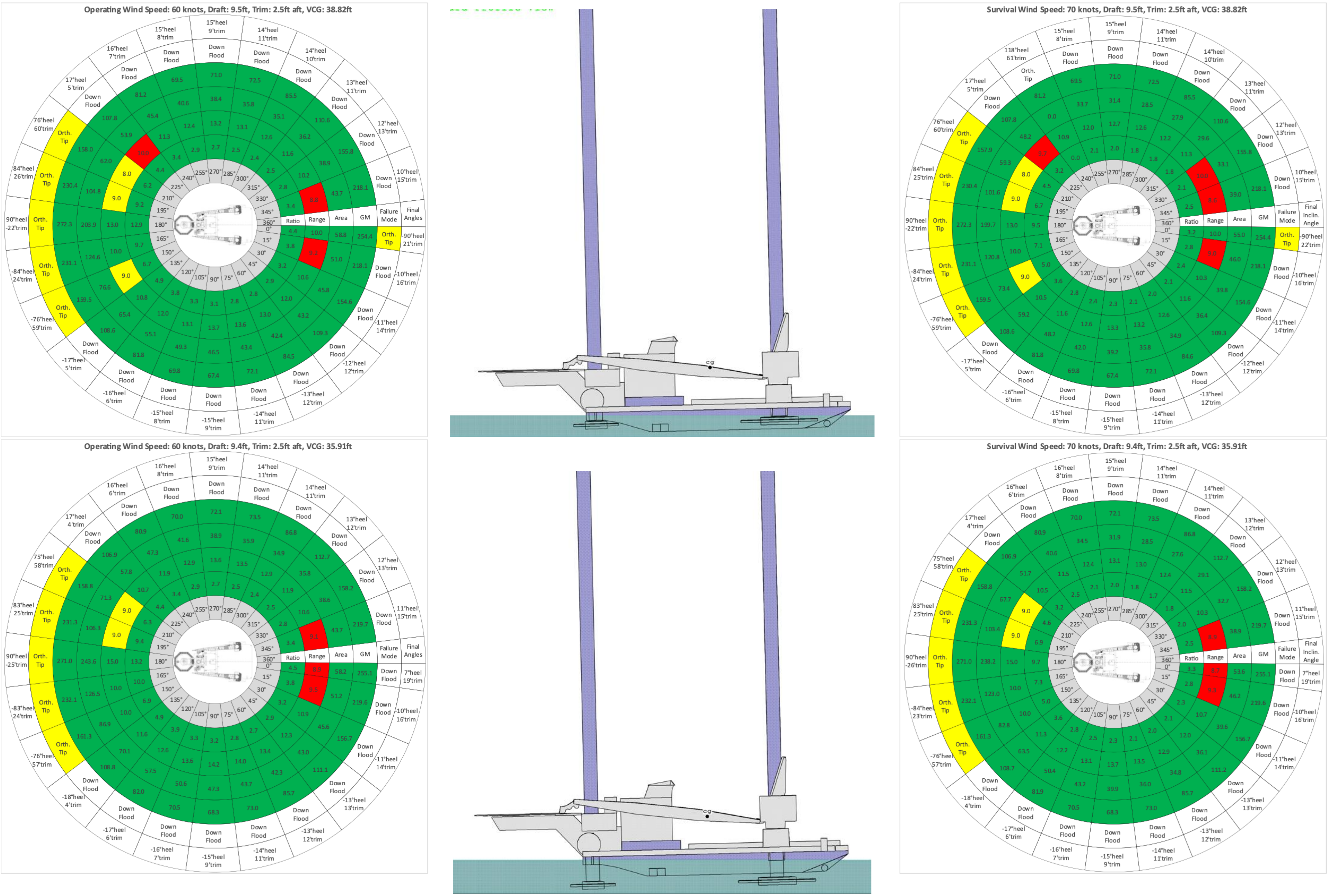


Figure 35: MSC Fixed Interval Analysis Results for 60-knot wind (left) and 70-knot wind (right). Departure Condition (top), Casualty Condition (bottom).

8. Conclusions

8.1. When trim was limited to zero, SEACOR POWER passed the stability criteria in the 2001 ABS MODU Rules

The MSC model passed ABS MODU Rules for intact and damaged stability for all zero trim conditions and wind directions. When aft trim was considered, MSC's analysis indicated that, at an initial 10-foot draft with 3 feet of aft trim, damage to the starboard engine room, and 50-knots of wind from a direction of 285° relative (15° forward of the port beam), SEACOR POWER would capsize and thus not meet the requirement that downflood points remain above the waterline. However, this condition was outside the allowable operating range of the vessel as SEMCO and ABS only considered zero trim in their analyses and the Marine Operations Manual contained a 6-inch aft trim limit. Additionally, the molded load line draft of SEACOR POWER was 9.75 feet which is below the analyzed 10-foot draft.

8.2. SEACOR POWER did not pass the regulatory standards of Part 174 for all wind directions

MSC analysis indicated many off-axis wind conditions that resulted in capsize in the orthogonal tipping direction--prior to attaining the required 10° inclination range.

In 2002, ABS used a different model to analyze SEACOR POWER. Comparison of MSC and ABS model wind overturning moments indicated significantly different modeling treatment of the helideck. This may be the reason why the ABS model indicated that SEACOR POWER passed each of the regulatory criteria in 2002.

8.3. SEACOR POWER passed the regulatory standards of Part 174 for beam winds

MSC analysis indicates that, for solely beam wind directions, SEACOR POWER passed all stability criteria of Part 174. This includes intact criteria for 60-knot winds, 70-knot winds, and damaged stability criteria for 50-knot winds and the range of drafts and allowable vertical centers of gravity prescribed by ABS in 2002. In addition to the zero trim conditions prescribed by ABS, MSC checked aft trims up to 3 feet.

The departure and casualty condition also passed all stability criteria of Part 174 for beam winds.

8.4. SEACOR POWER was operated with significant aft trim which was not considered in any stability analysis

The Marine Operations Manual includes a 6" limit on aft trim, but this note appears only on a calculation sheet and not in any other areas of the manual relevant to afloat stability and crewmembers stated that they did not use this worksheet. The SEMCO and ABS stability analyses only considered zero trim for SEACOR POWER. No statements requiring zero trim or stating that stability was only reviewed with zero trim are given by ABS in plan review or stability letters. Trim has a significant and mostly negative effect on stability and should be considered for an accurate stability analysis when trimmed loading conditions are anticipated.

8.5. SEACOR POWER did not meet the regulatory standards of §170.173

By precedent, MSC does not review liftboats using §170.173, the criterion for vessels of unusual proportion and form. However, liftboats are not explicitly exempt from this criterion (like MODUs). MSC's SEACOR POWER model did not satisfy this criterion in any operational condition, including the departure and casualty conditions.

8.6. SEACOR POWER passed Part 174 intact stability criteria using the varied axis method

When MSC applied the "minimum ascent" method of varied-off-axis stability analysis, SEACOR POWER passed all intact stability criteria for all conditions, including the departure and casualty condition. This method of stability analysis is not typically performed as part of a regulatory or class analysis; however, it is well documented in technical papers on the subjects of orthogonal tipping and free twist.

8.7. Regulatory stability analysis calculation requirements are not clear

As noted in CG-ENG-2's letter to MiNO Marine, Part 174 is silent on the direction of wind required for liftboat stability analysis. Although the ABS MODU Rules and CG-ENG-2's letter both require winds from any direction, the analysis technique to perform this analysis is not defined. Traditional righting arm curves only consider one direction of inclination: heel, while the trim direction must either be held constant or allowed to vary until the trimming moment is zero throughout calculation of the righting arm. The shape of liftboats makes the varied trim assumption problematic for calculation purposes when using the fixed-interval, off-axis stability analysis method because of fading stability. These calculation problems make the stability curves truncate prior to completion (vanishing stability is usually where the righting arm curve crosses the x-axis). Due to this truncation, some of the required stability criteria, especially range of stability, is problematic to calculate.

The term "critical axis" is used in both ABS Rules and CG-ENG-2's letter but not defined in regulation or either of these documents. Critical axis can be assumed as the axis that results in the least favorable condition with respect to the pass/fail criteria. However, range of stability is the first failing regulatory criteria for SEACOR POWER as demonstrated in this analysis. Each of the failing range of stability criteria cases for SEACOR POWER is affected by fading stability and the failing cases all occur with wind directions very near the bow or stern where righting energy is much higher than other inclination directions. Additionally, failures of the range of stability criteria can be "mitigated by sufficient righting energy" as described in CG-ENG-2's letter. Range of stability is not considered for intact stability in the ABS MODU Rules. It is therefore not clear if range of stability criteria results in a reasonable critical axis.

The location point for heeling and righting moment application in the regulations and ABS MODU Rules is not the same. In some cases, this could cause the comparison of these moments to be invalid if the center of buoyancy and center of resistance are significantly separated (the distance of separation that is significant is not known). However, neither regulation nor ABS MODU Rules provide guidance on when separation between center of buoyancy and center of resistance becomes critical.

8.8. Regulatory criteria wind speeds are not appropriate operational guidance

46 CFR 134.170 requires that a liftboat Operating Manual list "designed limits" for wind and waves. 46 CFR Part 174's regulatory wind speeds are used explicitly and without context as operational guidance within SEACOR POWER's Marine Operations Manual and on the vessel's Certificate of Inspection. These regulatory wind speeds are listed in Part 174 as 70 knot “severe-storm” and 60 knots “normal condition of operation afloat” for restricted liftboats and they are used for stability calculations that only consider static response in still-water (no motion of the vessel and no waves) to establish minimum safety characteristics. These regulatory wind speeds are engineering benchmarks that do not represent actual operational conditions which are combinations of wind and wave magnitude, direction, and encounter time in a dynamic setting.

9. References

1 Santen, J.A. van, "Problems met in stability calculation of offshore rigs and how to deal with them," Proceedings of the 13th International Ship Stability Workshop, 2013

2 Breuer, J.A. and K. Sjölund, "Steepest Descent Method. Resolving and Old Problem," Proceedings of the 10th International Conference on Stability of Ships and Ocean Vehicles, 2009.

3 Santen, J.A., "The use of energy build up to identify the most critical heeling axis direction for stability calculations for floating offshore structures, review of various methods," Proceedings of the 10th International Conference on Stability of Ships and Ocean Vehicles, 2009

4 Breuer, J.A. and K. Sjölund, "Orthogonal Tipping in Conventional Offshore Stability Evaluations," Proceedings of the 9th International Conference on Stability of Ships and Ocean Vehicles, 2006.

10. Appendices

A. GHS Output with MSC Hydrostatic Model Notes

B. GHS Output with MSC Model Departure and Casualty Condition Details

C. GHS Output from MSC Model with Operating VCGs and 60 knot Winds

D. GHS Output from MSC Model with Storm Survival VCGs and 70 knot Winds

E. GHS Output from MSC Model with Damaged Conditions and 50 knot Winds (Rev. 1)