Pontoon Vessel Passenger Crowding Stability Criteria Study

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Abstract

Recent Subchapter S stability submittals for pontoon vessels to the Marine Safety Center raised concerns that the current stability criteria in 46 Code of Federal Regulations, Subchapter S for passenger crowding was not conservative with regard to pontoon vessels due to the large deck area available to passengers and the righting arm characteristics that are unique to pontoon vessels. As a result, MSC conducted an initial investigation to assess the adequacy of Subchapter S stability in this regard. Research of other stability standards and stability comparisons of pontoon vessels, catamarans, and mono-hulls has lead to the development of the below proposed method to apply Subchapter S stability criteria to pontoon vessel hull forms.

Background

The Pontoon Simplified Stability Test (PSST) is the most widely-preferred method of evaluating pontoon vessel stability. Established in the 1960's, the PSST is relatively inexpensive to perform and requires no technical engineering analysis. The PSST has long been considered to produce conservative results, however recent Marine Safety Center analysis has shown that it is only conservative in relation to the intact stability criteria in 46 CFR Subchapter S under certain circumstances such as no trim and less than 50% pontoon submergence, where it results in lower allowable passenger loads. As an alternative to the PSST, an inclining experiment (or deadweight survey with a conservative VCG) may be conducted on the vessel with stability calculations submitted to the Marine Safety Center showing compliance with the stability requirements of 46 CFR Subchapter S. Due to the higher relative cost of performing a stability test, the vast majority of vessel owners opt to conduct the PSST. Recently, stability calculations were submitted based on an inclining experiment conducted on a traditionally shaped pontoon boat, whose owner sought to increase the vessel's passenger count. The results of these calculations raised serious concerns about some of the assumptions that have historically been made when applying Subchapter S to these vessels, making it apparent that additional consideration must be given when evaluating pontoon vessel stability against Subchapter S.

<u>History of current regulations</u>: Stability requirements for passenger vessels originated in the 1940's, using a minimum GM criterion which is now known as the weather criteria in 46 CFR 170.170, reference (a). This early work was based on studies of typical ships in service at that time which included Liberty Ships and T-2 Tankers. These vessels were considered to have "usual hull form." Their stability was characterized by large freeboards, small beam-to-depth (B/D) ratios, and a center of gravity located near the center of the buoyant hull envelope. GM was an effective stability metric for these types of vessels, and the need for stability standards for passenger vessels resulted in the introduction in 1958 of the passenger heel GM criteria for all vessels, now 46 CFR 171.050, reference (b). Because stability evaluation methods continued to improve and vessel hull forms evolved, additional criteria were added for designs of "vessels of unusual form." A broad Shoal GM correction was temporarily applied to calculations in the 1950's and 1960's to account for vessels with hard chines, shallow drafts, and large B/D ratios. Additional GM modifications were applied to Offshore Supply Vessel (OSV) type vessels in MMT Note 4-64, reference (c), which considered earlier work done by J. Rahola, reference (d). In 1973, the USCG recognized an international standard based on Rahola's work, and published a modified righting energy criteria in NVIC 3-73, reference (e). This NVIC was to be used as an alternative for vessels of unusual design or special service. These standards, as well the US Navy DDS-079-1-d(6), reference (f), stability design criterion were incorporated into what is

now 46 CFR 170.173, criterion for vessels of unusual proportion and form (righting energy criteria). The key benefit to righting energy based stability criteria, when compared with the GM criterion, is that righting energy more accurately accounts for the stability characteristics of the vessel beyond initial angles of heel. The units of ft-degrees (area under the righting arm curve) allows for effective comparison of vessel stability between hull forms, such as comparing mono-hull vessels to multi-hull vessels. For a more detailed discussion of the above, reference the Marine Safety Manual, Volume IV, Chapter 6.E.20.

Currently, pontoon vessels under 65' in length are required to either conduct a PSST, or meet three subchapter S intact stability criteria: the weather criteria, passenger heel, and criterion for vessels of unusual proportion and form. Additionally, 46 CFR 178.340 states that all pontoon vessels with more than two hulls or with decks more than six inches above the pontoons must meet a stability standard acceptable to the Commanding Officer, Marine Safety Center. Pontoon vessels have historically been limited to Protected Waters on their stability letters due solely to structural concerns. Scantling dimensions and lack of internal structure typically prevent pontoon vessels from meeting a structural standard required by 46 CFR 177.300. As a result, structural approval for restricted routes is granted by the OCMI's as local policy dictates.

Issue: Two key shortcomings were identified in applying the Subchapter S criteria to pontoon vessels. These include:

1. *Passenger crowding in various conditions of trim*. Subchapter S independently addresses passenger heel and trim. Under certain loading conditions, a pontoon vessel can meet the passenger heel (171.050) and righting energy (170.173) criteria but capsize during possible passenger crowding scenarios, i.e., all passengers shift to the extreme beam at 2 ft^2 per person. This phenomenon is largely the result of high passenger fractions, which is a term developed by the Marine Safety Center and defined as the ratio of passenger load to total vessel displacement. While passenger fractions on typical monohull small passenger vessels reviewed by the Marine Safety Center average 11% and typically range from 5 – 15%, passenger fractions of over 40% are common to pontoon vessels. Therefore, small shifts in the center of the passenger load result in larger trim and heeling moments than experienced by monohull vessels of similar dimension and displacement. Passenger crowding is especially a concern for pontoon boats because their typically open decks may allow for unobstructed movement of passengers athwartship, fore, and aft, such as a group photo or movement to avoid weather. Of particular concern is the fact that such shifts in personnel can induce enough moment to capsize the vessel even when at all stop or tied to a pier. This scenario, though possible, is not a normal operating condition which explains why pontoon vessels aren't capsizing on a regular basis. However, situations such as group photos or personnel crowding to observe an event do happen on these vessels from time to time and the regulations do not adequately account for such crowing conditions.

2. *Small amounts of righting energy associated with high initial GM*. Pontoon vessels are inherently stable for small angles of heel, but have righting arm curves (RAC) that are very different from other similar mono-hull vessels. The large values of GM at initial angles of heel allow a pontoon vessel to pass the 171.050 ("passenger heel") criteria for extremely high passenger counts. The passenger heel criterion is a minimum GM requirement that never anticipated the typical pontoon vessel RAC. Enclosure (1) demonstrates the effects of a pontoon vessel's righting arm curve resulting from longitudinal crowding. As trim or heel angles on pontoon vessels increase, the initial slope of the righting arm curve stays relatively steep;

however, the area under the curve is reduced significantly. As noted above, the regulation was intended for rounded chine monohull vessels whose typical RACs corresponded to large areas under the RA curve (righting energy, or RE). In the case of pontoon vessels, there may be adequate initial GM for high passenger counts but relatively low righting energy.

Similar Standards: Before determining the means to appropriately address the issues listed above, the Marine Safety Center reviewed several similar standards to establish threshold limits for passenger density and resulting righting energy requirements. References (a) through (n) contain recognized standards relating to allowable area measurements for passenger crowding and residual stability criteria after disturbing forces are applied to a vessel. These references provided a spectrum of limits currently in practice across a broad range of regulatory bodies, both maritime related and not. In all cases, the passenger density requirements (square feet per person) were much more conservative than the 6.67 ft^2 per person that the Marine Safety Center extrapolated from the existing passenger heel criteria in 171.050[1].

Analysis

Methodology: The Marine Safety Center conducted a detailed intact stability analysis of numerous certificated small passenger vessels to determine the impact of passenger crowding. Several passenger crowding conditions were examined for each vessel. It was assumed that passengers were crowded to the accessible extremes forward, aft, transverse, and at each quarter of the deck area available to passengers. Obstructions within the passenger area (seating, stanchions, gear boxes, etc.) were neglected to simulate unrestricted movement of passengers. Passengers were crowded at densities ranging from 10 ft^2 per person down to 1 ft^2 per person. For each of these crowding scenarios, the righting energy to the angle of maximum righting arm was recorded. Plots of passenger crowding density vs. righting energy to maximum righting arm are provided in enclosures (2) through (4). This analysis determined the following for each vessel type:

1. *Mono-hulls*: A total of 10 mono-hulls were analyzed, with different geometries and ranging in size from 67 to 133 feet. Each vessel operates on either protected or partially protected waters and carries a stability letter issued by the Marine Safety Center. For those on partially protected waters, the maximum passenger count for protected waters was used for the analysis. In all cases, the vessels displayed greater than 5 ft-degrees of RE to max righting arm at a passenger density of 5 ft^2 per person. In all but two cases these vessels exhibited greater than 2 ft-degrees at a passenger density of 2 ft^2 per person. The transverse passenger shift was the limiting configuration in every case examined.

2. *Catamarans:* Five catamaran hulls were analyzed during the process, each with recent stability letters from the Marine Safety Center. As protected route catamarans are rare, the sample included vessels that were authorized partially protected and exposed routes. Each vessel displayed more than adequate righting energy at every passenger density. While it may be

[1] The 6.67 ft^2 per person density was derived from the passenger heel criteria in 171.050 based on assumptions that passenger count for the vessel is maximized at 10 ft^2 per person based on deck area criteria listed in 176.113. For passenger heel, the regulations assume that 2/3 of the passengers shift from the vessel's centerline to a distance halfway between the centerline and beam. Assuming a rectangular shaped deck area accessible to passengers, as it the case with most pontoon vessels, the average density for all passengers equates to 6.67 ft^2 per person under the passenger heel criteria.

anticipated that catamaran hull forms would display properties similar to pontoon vessels, catamarans typically have characteristics such as deeper hulls that provide more buoyant volume, no tumblehome, greater lightship displacements due to increased scantling requirements, short passenger deck areas, and buoyant volume in the cross structure between the hulls. In combination, these physical differences significantly impact the stability of the vessel in a positive manner.

3. *Pontoon Vessels:* Five pontoon hulls were analyzed. Two of these vessels received stability letters from the Marine Safety Center after approved stability tests. Two others were denied stability letters by the Marine Safety Center due to passenger crowding concerns. The fifth vessel was modeled in two loading conditions of 25 passengers at 140 lbs per passenger and at 168 lbs per passenger. The two vessels with valid stability letters displayed ample righting energy at all conditions of crowding. The two other vessels reviewed by the Marine Safety Center had just over 5 ft-degrees of righting energy when crowded at 5 ft^2 per person, but nearly capsized at 2 ft^2 per person. The fifth hull model capsized when loaded with 168 lbs per passengers at a passenger density of 5 ft^2 per person and when loaded with 140 lbs per passenger at a density of 3 ft^2 per person. When compared with the curves for catamarans and mono-hulls, the slope for acceptable pontoon vessels is typically much flatter.

For each of the vessels listed above, the slope of the density versus righting energy to max curve is heavily dependent on factors such as vessel geometry, passenger fraction, and deck area available to passengers. As a result, a single criteria such as 5 ft-degrees at a crowding density of 5 ft^2 per person or 2 ft-degrees at a density of 2 ft^2 per person would not be sufficient as vessels with very steep or very flat sloped curves could pass one criteria, but not the other. Enclosure (5) provides a scatter plot of passenger crowding density versus righting energy for all 20 vessels analyzed to illustrate these cases. A datum, formed by plotting a straight line that intersects the points of 5 ft-degrees RE vs. 5 ft^2 per person and 2 ft-degrees RE vs. 2 ft^2 per person was plotted in on Enclosure (5). It was noted that most vessels had characteristics that placed them above this datum.

Findings/Recommendations

Passenger crowding and residual righting energy are key to applying Subchapter S to pontoon vessels. This analysis shows value in developing criteria based on two crowding scenarios.

1. *For expected passenger crowding conditions*: At a passenger crowding density of 5 ft^2 per person, it is recommended that a vessel have at least 5 ft-degrees of righting energy to the angle of maximum righting arm. A density of 5 ft^2 per person adequately represents a typical passenger crowding scenario (i.e. passengers moving to one side of the vessel to look at an item of interest). A righting energy of 5 ft-degrees would sufficiently counteract the dynamic forces (wind & waves) for operations on a Protected Route.

2. *For extreme passenger crowding cases* where passengers are temporarily shifted or moved to a tight group: At a passenger crowding density of 2 ft^2 per person, it is recommended that a vessel have at least 2 ft-degrees of righting energy to the angle of maximum righting arm. This extreme case represents the maximum feasible crowding on a vessel based on precedent

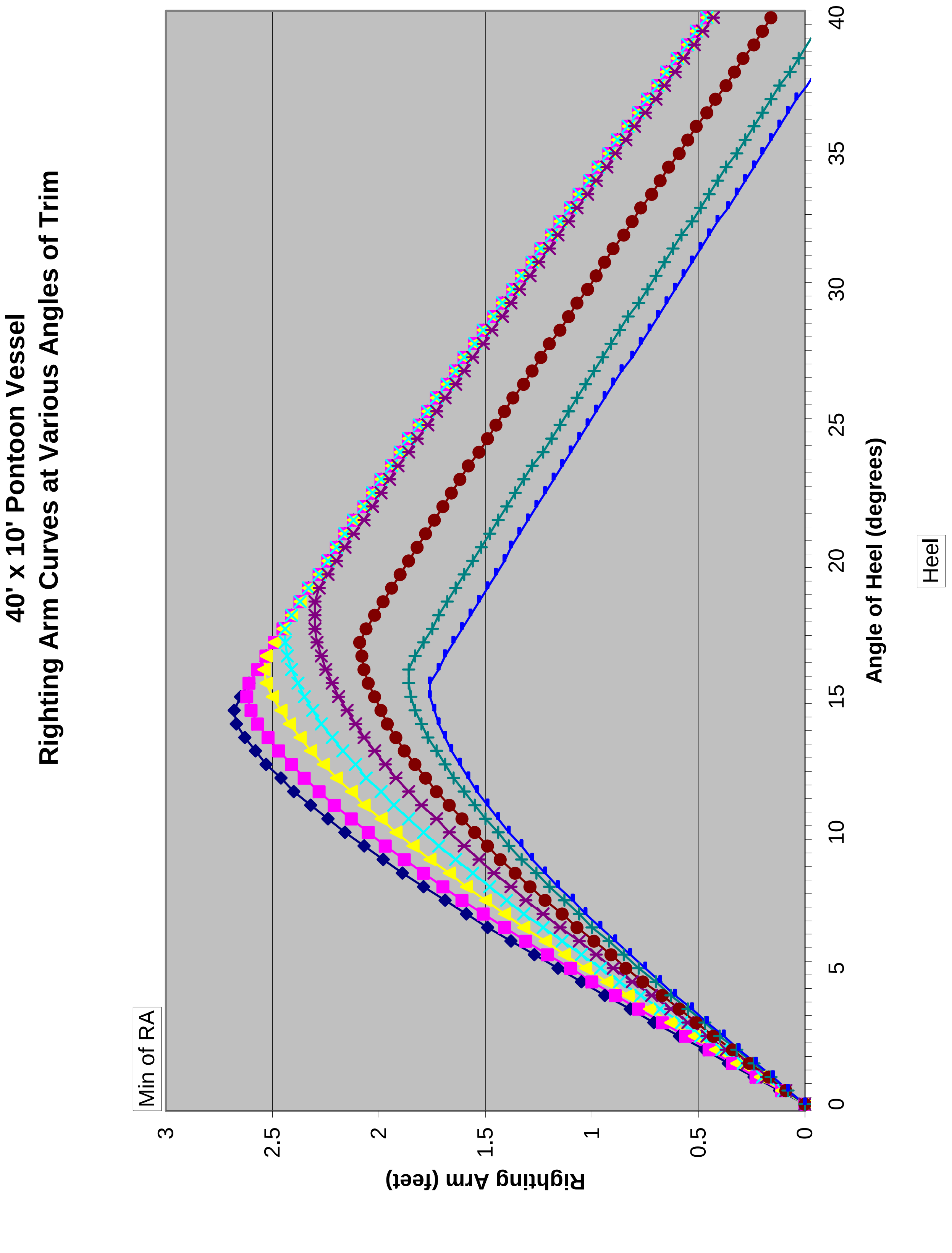
established in reference (i) and ensures that the vessel remains upright with at least a marginal amount of righting energy.

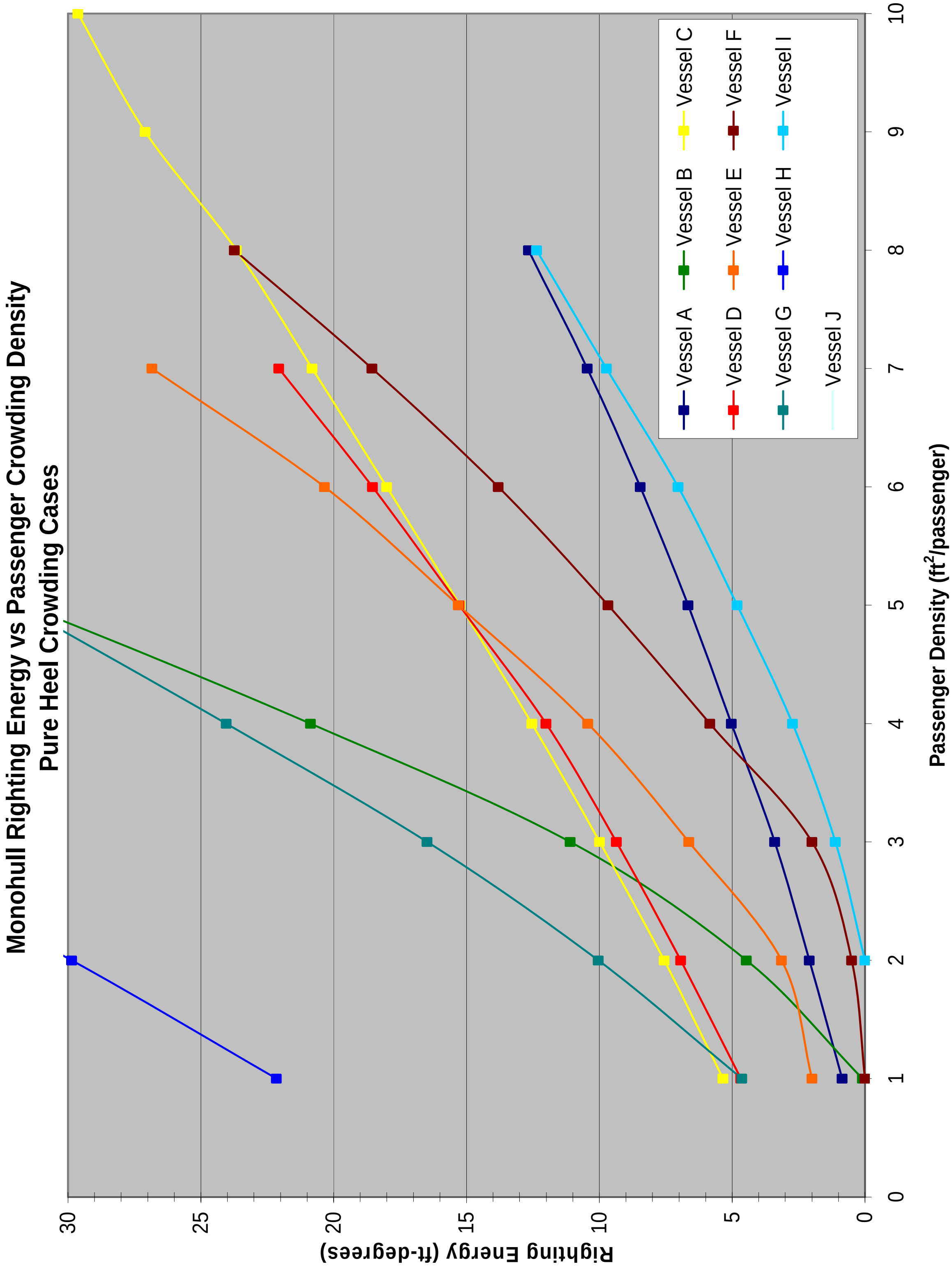
Conclusion

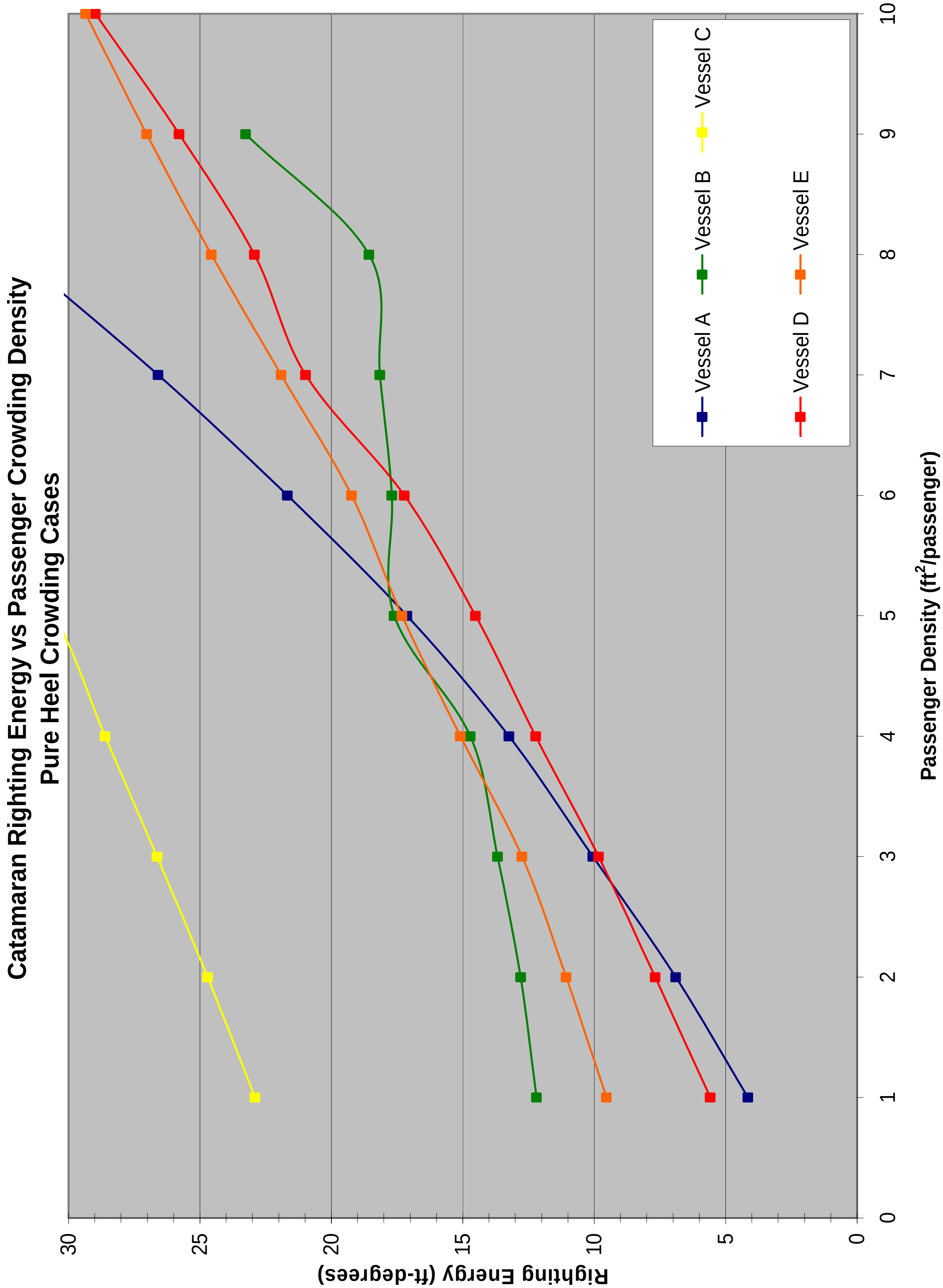
To ensure an adequate margin of safety in all loading conditions, in addition to satisfying 170.173(e)(2) [10 ft-degrees of righting energy with the passengers distributed about the centerline], pontoon vessels should have a minimum of 5 ft-degrees of righting energy to the angle of maximum righting arm for all possible passenger distribution loading conditions with an assumed passenger density of 5 ft^2 per person. Additionally, a pontoon vessel should have a minimum of 2 ft-degrees of righting energy to the angle of maximum righting arm with an assumed passenger density of 2 ft^2 per person.

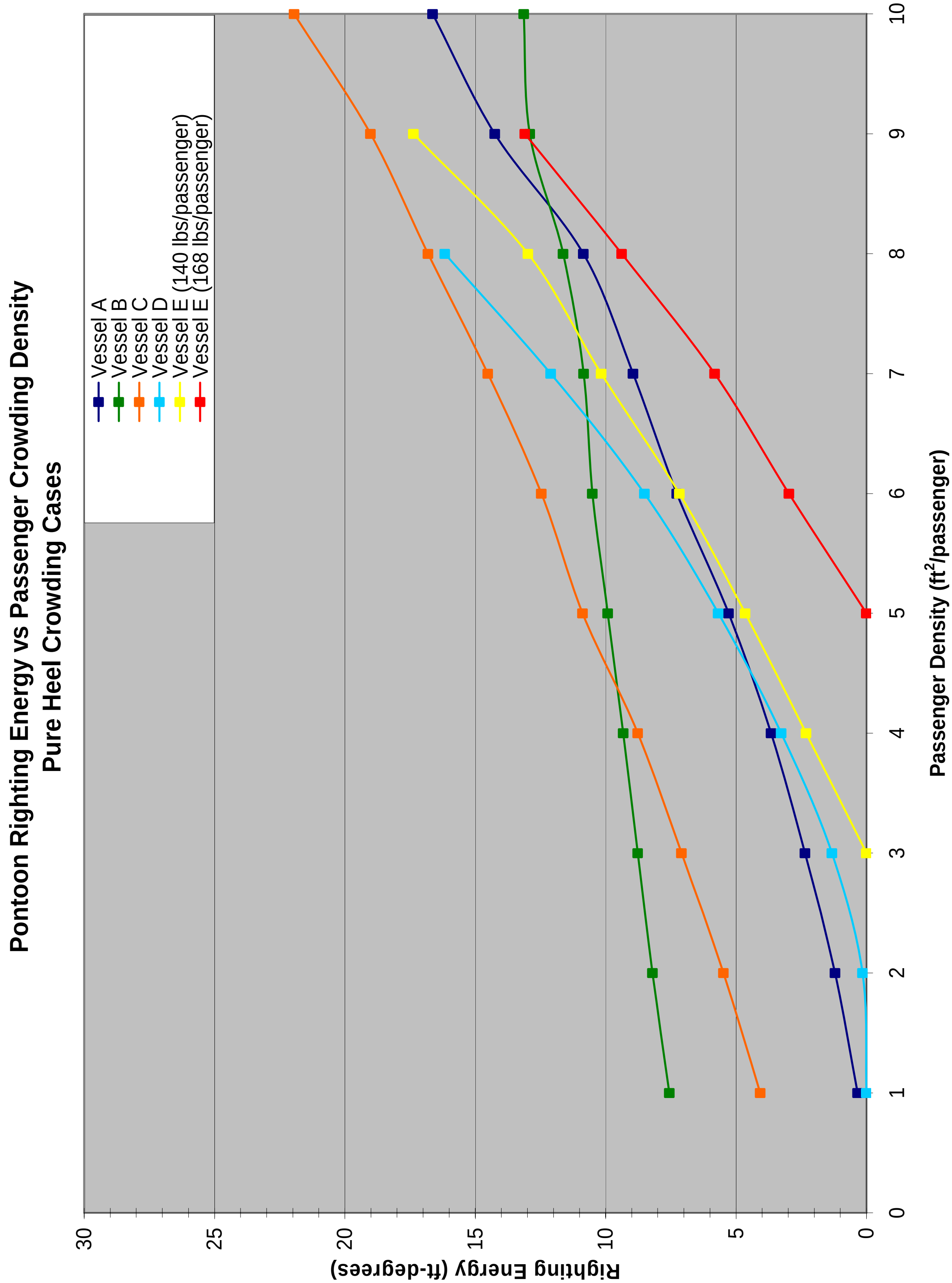
References:

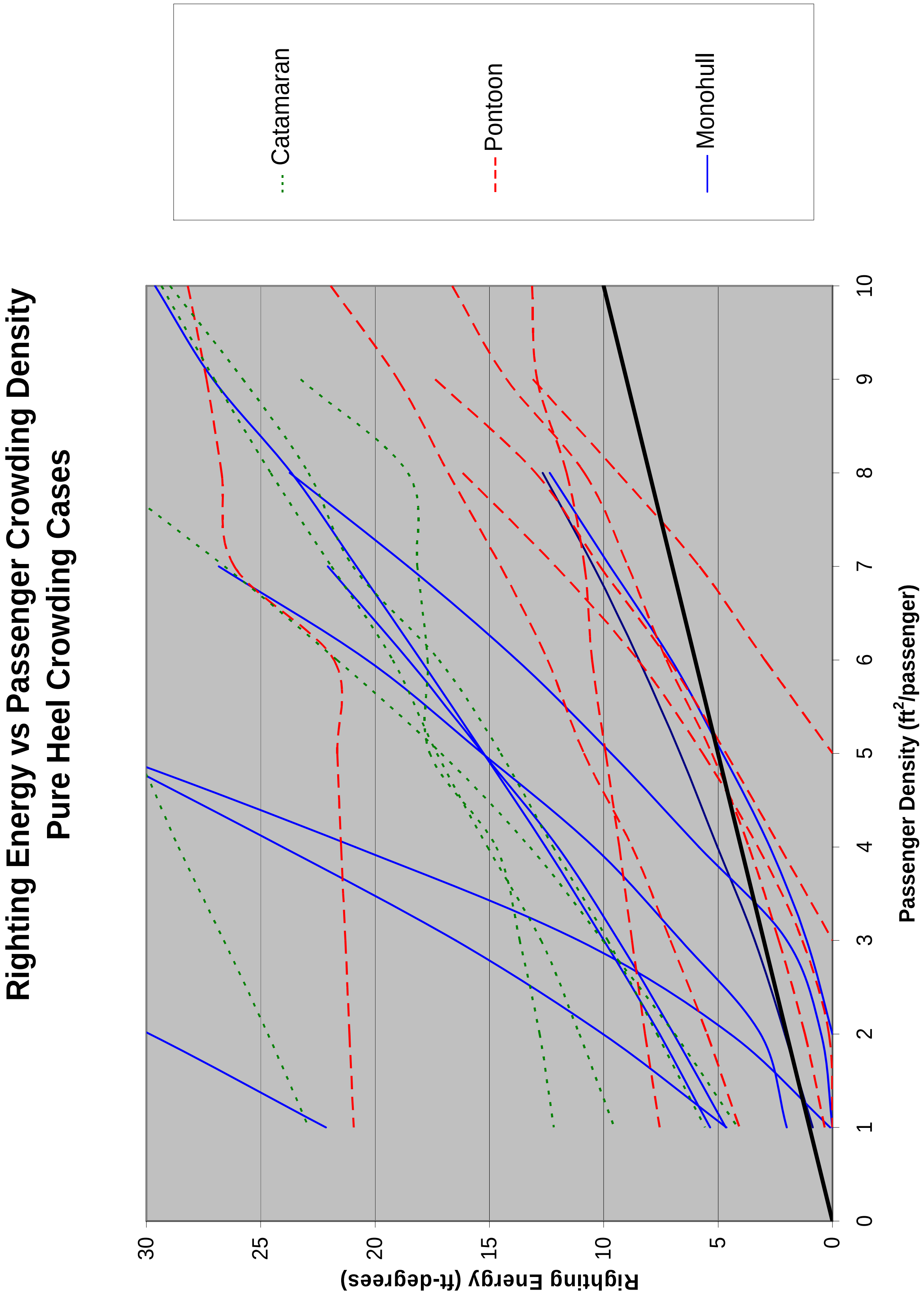
a. 46 CFR Subchapter S, 170.170, "Calculations required" (i.e. Weather criteria)
b. 46 CFR Subchapter S, 171.050, "Intact stability requirement for a mechanically propelled or a nonself-propelled vessel" (i.e. Passenger heel criteria)
c. MMT Note 4-64, OSV Stability
d. J. Rahola, "The Judging of the Stability of Ships and The Determination of the Minimum Amount of Stability," Helsinki, 1939 (Thesis for the Degree of Doctor of Technology).
e. NVIC 3-73 "Intact Stability Criteria for Passenger and Cargo Ships Under 100 Meters in Length"
f. Department of the Navy, Design Data Sheet DDC 079-1, Stability and Buoyancy of U.S. Naval Surface Ships
g. 46 CFR Subchapter T, part 177 "Construction and Arrangement"
h. USCG Regatta Criteria, Merchant Marine Technical (MMT-5), 1963 (not published)
i. ***Safety of Life at Sea***, Consolidated Edition, IMO, London, 2001, Chapter II-2, Regulation 28
j. NFPA 101, Life Safety Code, 2006, section 12.1.7.1.1.
k. 46 CFR 173.095, "Towline pull criterion"
l. 46 CFR 116.520(b)(1), "Emergency evacuation plan" (3 ft^2 per person for area of safe refuge)
m. Cooper, E., "Study on the U.S domestic Intact Stability and Subdivision Requirements for twin hull Pontoon Passenger Boats less than 65 feet in length", USCG (G-MSE-2) April, 28, 2005
n. Borlase, G. and Cooper, E.,"A Comparison of Regulations Evaluating the Stability of Pontoon Passenger Vessels", Society of Naval Architects and Marine Engineers Transactions 2006, Vol. 114


40' x 10' Pontoon Vessel
Righting Arm Curves at Various Angles of Trim
Min of RA
Righting Arm (feet)
0
0.5
1
1.5
2
2.5
3
Angle of Heel (degrees)
0
5
10
15
20
25
30
35
40
Heel


Monohull Righting Energy vs Passenger Crowding Density
Pure Heel Crowding Cases
Righting Energy (ft-degrees)
Passenger Density (ft²/passenger)
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
9
10
Vessel A
Vessel B
Vessel C
Vessel D
Vessel E
Vessel F
Vessel G
Vessel H
Vessel I
Vessel J


Catamaran Righting Energy vs Passenger Crowding Density
Pure Heel Crowding Cases
Righting Energy (ft-degrees)
Passenger Density (ft^2/passenger)
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
9
10
Vessel A
Vessel B
Vessel C
Vessel D
Vessel E


Pontoon Righting Energy vs Passenger Crowding Density
Pure Heel Crowding Cases
Vessel A
Vessel B
Vessel C
Vessel D
Vessel E (140 lbs/passenger)
Vessel E (168 lbs/passenger)
Righting Energy (ft-degrees)
Passenger Density (ft²/passenger)
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
9
10


Righting Energy vs Passenger Crowding Density
Pure Heel Crowding Cases
Righting Energy (ft-degrees)
30
25
20
15
10
5
0
Passenger Density (ft²/passenger)
0
1
2
3
4
5
6
7
8
9
10
Catamaran
Pontoon
Monohull