A Reassessment of Wind Speeds used for Intact Stability Analysis

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ABSTRACT

The intact stability of maritime surface vessels (ships, boats, landing craft, *etc*.) should be as-sessed for the most extreme environment that they are designed for or limited to operate in: namely the nominal and gust wind speeds and associated wave height and wave frequency profile.

The IMO and naval weather criteria apply to ocean going vessels but each use different wind speeds. The IMO criterion uses a single nominal wind speed (26 ms^{-1}) and a small gust factor ($\sqrt{1.5}$ = 1.225) for all assessed vessels, irrespective of operational environment or expectations. The naval weather criteria uses different gust wind speeds for different operational expectations, with most significantly higher than the IMO gust wind speed. Yet these criteria are intended to assess the suit-ability of vessels for essentially similar operational expectations.

This paper revisits the basis of the wind speeds used for stability analysis. A range of standard-ized wind speeds for different types of operational service is proposed.

Keywords: *Stability, Wind Speed,*

NOMENCLATURE

t	time interval, in sec
V_{avg}	average or nominal wind speed at 10 m height, in ms^{-1}
V_{gust}	gust wind speed at 10 m height, in ms^{-1}
V_Z	wind speed at height z, in ms^{-1}
V_{ref}	reference wind speed at height z_{ref}, in ms^{-1}
WSR_{600}	wind speed ratio based on an average over 600 seconds (10 minutes)
WSR_{3600}	wind speed ratio based on an average over 3600 seconds (1 hour)
z	height above the surface, in m
z_{ref}	reference height, in m
α	exponent

1. INTRODUCTION

Ship stability knowledge and practise has developed over the centuries much as other branches of engineering have, starting with trial and error, progressing to rules of thumb and then, relatively recently, introducing and developing analysis based on more rigorous application of scientific principles. Unlike other branches of engineering such as structural analysis, the ‘science’ of ship stability has not progressed much beyond the beginnings of scientific principles. Empirical relationships and heuristic information are heavily relied upon in developing criteria. In the main only still water characteristics are used to assess transverse stability in extreme environments. The use of seakeeping and manoeuvring characteristics in an extreme seaway to simulate and predict ship behaviour, such as broaching, that could lead to capsize has only in recent decades been actively explored.

Existing stability criteria are based on the still water characteristics of the vessel, incorporating various factors to account for operation in severe environments. Some, such as the basic IMO criteria, require nominated characteristics of the righting arm curve, including minimum areas under the GZ curve and minimum GM values. These were based on early work, such as that of Rahola (1939). This type of criteria that have been derived empirically are strictly only valid for the data set and the environments used in their derivation. However these criteria have been extended to many vessel types and sizes not in the original data set, and to environments markedly different than those original environments.

Weather criteria have been introduced in more recent decades that attempt to include the effects of wind and waves as overturning forces to be resisted. In these criteria, wave effects are usually introduced to the still-water righting moment curve by a ‘roll-back’ angle. Wind effects are introduced by a wind heeling moment/lever function, generally based on the upright wind heeling moment.

There are a number of different factors that contribute to a stability criterion, wind speed being one. Especially important are the hidden factors and cause/effect mechanisms that drive how the criteria actually works (e.g. different wind/heel relationships, how much of the buoyant structure is considered, roll back from nominal or gust equilibrium). The easiest example is probably the area ratio (refer to Figure 1): the naval criteria (DDS079, 1975) uses a $\cos^2$ relationship for the wind moment/lever with ship heel, requiring $A1/A2 \geq 1.40$, whereas the IMO criterion (IMO2008, 2009) uses a constant wind moment/lever relationship, requiring $A1/A2 \geq 1.00$.

The IMO wind speed (and wave age part of the roll back formulation) are intended to be an "average" between the height of a tornado (high winds, young, steep developing seas) and the aftermath (lower winds, more fully developed seas). So the criterion coefficients somehow relate this average environment to both the height of the tornado and the environment in its aftermath. What is actually being modelled here has become clouded, with wind speed used as a tuning factor.

Adopted in this paper is the premise that inputs (especially wind and wave effects) should be treated in as rigorous and realistic a manner as possible and then any criterion relationship coefficients tuned to give results that match experimental and real life data. This approach has the following advantages:

- Inputs can be investigated generally in isolation without hidden factors clouding results, allowing for better treatments over time.
- Criteria can be developed from established engineering principles largely independent of the inputs. Over time this could allow for better criteria to be developed.
- Inputs can be varied to allow for different environments in a logical and transparent manner.

The treatment of wind, particularly developing a standardised set of wind speeds for stability analyses, is the subject of this paper.

2. WIND CHARACTERISTICS

2.1 Wind Velocity Profile

The average or nominal wind does not have the same wind speed at all heights above the earth surface. Near the surface, friction and surface roughness affect the strength or speed of the wind. This is the ‘constant shear’ region, which extends to about 100 m above the surface. Within this region the variation in wind speed over the ocean is commonly approximated by (e.g. McTaggart and Savage, 1994, EM 1110-2-1100, 2002):

$$V_Z = V_{ref}\left(\frac{z}{z_{ref}}\right)^{\alpha} \quad (1)$$

The value of α varies from 0.1 to 0.4 depending on surface roughness. McTaggart and Savage (1994) reported that α varies from 0.12 to 0.14 for stormy ocean conditions. A common value for α is 0.13 (≈ 1/7.5).

The international meteorological community has standardized on reporting wind speeds at a 10 m height above the surface. Historically, this height was not always used and measurements of opportunity, such as ship’s anemometers, could be at any height. When comparing wind speeds from different sources, conversion to a common baseline height (10 m) using equation (1) may be necessary.

2.2 Wind Gusts

The long term average wind speed is used in wave growth models and is usually the nominal wind speed reported by the local weather bureau. In Australia, and generally internationally, the 10-minute maximum sustained wind speed average, at 10 meters height, is used as the nominal wind speed.

The spatial distribution of packets of wind blowing in a particular direction with a relatively constant wind speed is seemingly random in nature. A time history at a particular point will provide various statistics about the wind, such as the average and standard deviations of wind speed and direction, and so on. Unlike ocean waves, which can be viewed in an analogous manner, the wind statistics can quickly change, and there is a need to take statistics over limited time intervals. Durst (1960) established a relationship for gust wind speeds for different durations based on analysis of winds over open and flat terrain.

For a 1-hour (3600-seconds) average maximum sustained wind speed, the Durst wind speed ratio for winds of smaller duration is given by (EM 1110-2-1100 2002):

$$WSR_{3600}(t) = 1.277 + 0.296\tanh\left(0.9\log_{10}\left(\frac{45}{t}\right)\right) \quad (2)$$

If the wind speed ratio for a different return period, say 10-minutes (600-seconds), is calculated, it is a simple matter to obtain the wind speed ratio relative to that new return period:

$$WSR_{600}(t) = \frac{WSR_{3600}(t)}{WSR_{3600}(600)} \quad (3)$$

The wind speed ratios based on 1-hour, 10-minute and 1-minute average maximum sustained wind speeds are plotted in Figure 1. The gust ratio for a 5-sec gust duration when com-

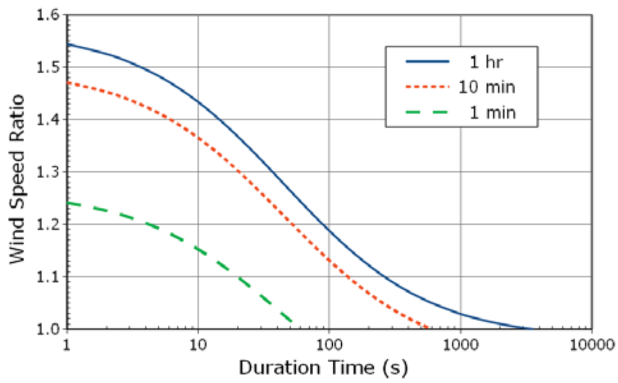

Figure 1 Wind speed ratio for 1 hour, 10 minute and 1 minute averaging periods

pared to the 10-min average is 1.4122, very close to $\sqrt{2} = 1.4142$.

In more recent years there have been many studies of wind gustiness, especially in hurricanes, each arriving at different gust factors. One example is the gust model developed by the Engineering Sciences Data Unit, ESDU. Vickery and Skerlj (2005) presented data indicating that the ESDU gust model, using a roughness of 0.03m, gave the best fit to available data, though the Durst model also gave a fit close to this preferred ESDU model. Limited data indicated that gust factors at sea are a little lower than over land by an average factor of 0.95, Vickery and Skerlj (2005). A later analysis by Vickery et al. (2007) presented a comparison of the ESDU gust model to available data, this time based on a 1-minute nominal period, reproduced as Figure 2. Overlaid on this figure (dashed line) is the Durst model for 1-minute nominal wind speeds. The Durst model appears to give better predictions for gusts longer than 3 seconds. Also, converting to 10-minute nominal winds would result in 15-20% higher gust factors.

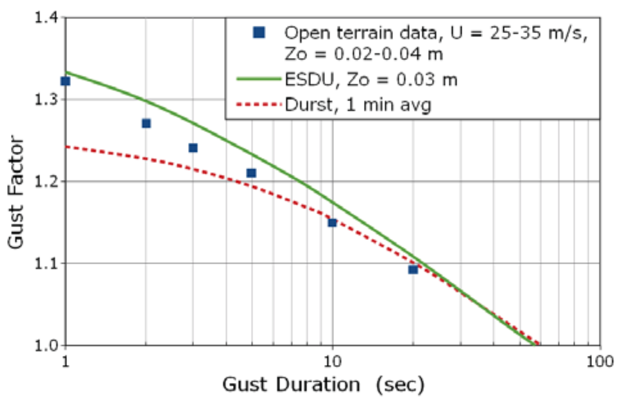

Figure 2 Comparison of the ESDU model to gust data, adapted from Vickery et al. (2007)

The ESDU model is somewhat complicated to apply, whereas the Durst model is relatively simple. Noting that the two give fairly similar results and that the Durst model dates from the 1960s when wind speeds for stability analysis were selected, the Durst model is adopted for this paper.

2.3 Tropical Cyclone Scales

There are a number of schemes for categorising the severity of tropical cyclones. A summary of the various scales used throughout the world as given by Tropical Cyclone Scales (2013) is:

- Atlantic Ocean and East Pacific Ocean - characterised by the United States developed Saffir-Simpson Hurricane Scale, which is based on 1-minute maximum sustained wind speeds.
- West Pacific Ocean, Northern Hemisphere monitored by the Japan Meteorological Agency's Regional Specialized Meteorological Centre (RSMC). The typhoon intensity scale is based on 10-minute maximum sustained wind speed.
- North Indian Ocean - monitored by the India Meteorological Department's Regional Specialized Meteorological Centre in New Delhi, India. The cyclonic storm scale is based on a 3-minute averaging period to determine sustained wind speeds.
- South-Western Indian Ocean - monitored by Météo-France which runs the Regional Specialized Meteorological Centre in La Reunion. The tropical cyclone scale is based on a 10-minute average maximum sustained winds.
- South Pacific Ocean and South-Eastern Indian Ocean - monitored by either the Australian Bureau of Meteorology and/or the Regional Specialized Meteorological Centre in Nadi, Fiji. Both warning centres use the Australian tropical cyclone intensity scale, which is based on 10-minute maximum sustained wind speed combined with estimated maximum wind gusts, which are a further 30-40% stronger.

It can be seen that there are a number of different scales used to characterise tropical cyclones, potentially making comparisons erroneous.

Table 1 Beaufort wind scale, adapted from Tropical Cyclone Scales (2010)

<table>
<tr><th colspan="6">Wind</th><th colspan="3">Tropical Cyclone Scales</th></tr>
<tr><th rowspan="2">Beaufort</th><th rowspan="2">Description</th><th colspan="2">Upper Wind Speed</th><th colspan="2">Potential 5 sec Gust</th><th rowspan="2">US</th><th rowspan="2">Japan</th><th rowspan="2">AU</th></tr>
<tr><th>Knots</th><th>m/s</th><th>Knots</th><th>m/s</th></tr>
<tr><td>6</td><td>Strong Breeze</td><td>27</td><td>13.9</td><td>38</td><td>19.6</td><td rowspan="2">Tropical Depression</td><td rowspan="2">Tropical Depression</td><td rowspan="2">Tropical Depression</td></tr>
<tr><td>7</td><td>Near Gale</td><td>33</td><td>17.0</td><td>47</td><td>24.0</td></tr>
<tr><td>8</td><td>Gale</td><td>40</td><td>20.6</td><td>56</td><td>29.1</td><td rowspan="3">Tropical Storm</td><td rowspan="2">Tropical Storm</td><td rowspan="2">Cat 1 Tropical Cyclone</td></tr>
<tr><td>9</td><td>Strong Gale</td><td>47</td><td>24.2</td><td>66</td><td>34.1</td></tr>
<tr><td>10</td><td>Storm</td><td>55</td><td>28.3</td><td>78</td><td>40.0</td><td rowspan="2">Severe Tropical Storm</td><td rowspan="2">Cat 2 Tropical Cyclone</td></tr>
<tr><td>11</td><td>Violent Storm</td><td>63</td><td>32.4</td><td>89</td><td>45.8</td><td rowspan="2">Cat 1 Hurricane</td></tr>
<tr><td>12</td><td rowspan="7">Hurricane</td><td>71</td><td>36.5</td><td>100</td><td>51.6</td><td rowspan="7">Typhoon</td><td rowspan="2">Cat 3 Severe Tropical Cyclone</td></tr>
<tr><td>13</td><td>80</td><td>41.2</td><td>113</td><td>58.1</td><td>Cat 2 Hurricane</td></tr>
<tr><td>14</td><td>89</td><td>45.8</td><td>126</td><td>64.7</td><td rowspan="2">Cat 3 Hurricane</td><td rowspan="2">Cat 4 Severe Tropical Cyclone</td></tr>
<tr><td>15</td><td>99</td><td>50.9</td><td>140</td><td>71.9</td></tr>
<tr><td>16</td><td>109</td><td>56.1</td><td>154</td><td>79.2</td><td rowspan="2">Cat 4 Hurricane</td><td rowspan="3">Cat 5 Severe Tropical Cyclone</td></tr>
<tr><td>17</td><td>118</td><td>60.7</td><td>167</td><td>85.7</td></tr>
<tr><td>+</td><td></td><td></td><td></td><td></td><td>Cat 5 Hurricane</td></tr>
</table>

The Beaufort wind scale is used to categorize wind speed and, in the absence of reliable instrumentation, is often used to report wind speed. Wind speeds used in the Beaufort scale reflect the standard 10-minute average at 10-metres height. The Beaufort Scale is typically defined to Beaufort 12. It was extended to Beaufort 17 in 1944, intended for special cases, such as tropical cyclones (Met Office, 2010).

The tropical cyclone scales of interest are the US Saffir-Simpson scale and the Japanese scale, as they have been influential on wind speed selection used in stability analyses, and, for the authors, the Australian tropical cyclone scale. These tropical cyclone scales have been compared to the Beaufort scale in Table 1, using the Durst relationship to convert US 1-minute sustained wind speed to 10-minute sustained wind speeds. This illustrates the differences between the tropical cyclone scales. Of note is that the US hurricane categories start at Beaufort 11 and the Japanese typhoon category (which is subdivided for internal use) starts at Beaufort 12.

3. WIND SPEEDS

3.1 IMO

The IMO uses a wind speed of 26 ms^{-1} (50.5 knots) as the nominal wind speed in its weather criterion, with a gust factor (GF) of 1.225 ($\sqrt{1.5}$) to give a gust wind speed of 31.8 ms^{-1} (61.9 knots). The nominal wind speed is equivalent to a mid Beaufort 10 wind. Noting that the gust heeling lever governs the weather criterion, using the 5-second gust factor of 1.412 equates the IMO gust wind of 31.8 ms^{-1} to a nominal wind speed of 22.5 ms^{-1} (43.8 knots), which is mid Beaufort 9. For vessels expected to avoid the worst weather and that can use weather routing to do so, mid Beaufort 9 represents fairly severe weather - but it is certainly not the worst that could be encountered. Not all vessels, whether or not they are using weather routing, can successfully avoid the worst weather.

According to Yamagata (1959), the selection of 26 ms^{-1} was an average between the maximum winds of a tropical cyclone (called a typhoon by the Japanese) and the more steady winds in the immediate aftermath. This also made allowance for wave age—waves tend to be younger and therefore steeper in short duration winds compared to the more fully developed waves that occur with time. However, an examination of the actual data presented, especially Table III of Yamagata (1959) (adapted as Table 2 here), would suggest a higher value.

Table 2 Nominal wind environments, adapted from Yamagata (1959)

Event	Avg Trailing Wind Speed (ms^{-1})	Max Wind Speed At Centre (ms^{-1})	Application
Barometric Gradient	10		Smooth waters
Front	15		Inshore
Low	15	32	Offshore
Typhoon	20	50	Ocean going

Comparing Table 1 with Table 2, the maximum wind speeds of Table 2 could possibly be gust wind speeds. The question then is what gust ratio to apply.

Yamagata (1959) provided data, reproduced as Figure 3 here, that showed gust factors ranged from 1.0 to 1.7 with an average of 1.23 (≈ √1.5). At higher wind speeds, above about 30 ms^{-1}, the maximum gust factor was 1.3. The average value was adopted, taken as √1.5 (= 1.225).

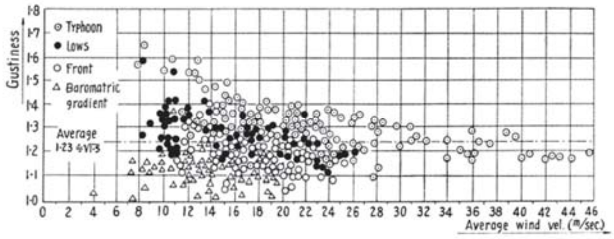

Figure 3 Wind gustiness, from Yamagata (1959)

The variation of wind speed with location from the peak of a tropical cyclone through to the trailing wind was simplified (Yamagata, 1959). This simplification was similar to Figure 4 (the bottom line is the Yamagata simplification, apparently using the data from Table 2, though how this was effected is not immediately apparent). The maximum wind speed adopted was about 32 ms^{-1}. From Table 2, this is the maximum wind velocity for a low pressure system. If the value of 50 ms^{-1} from Table 2 is taken as a gust wind speed, using a gust factor of 1.225 (the gust factor assumed by the Japanese) gives a nominal wind speed of 40.8 ms^{-1}. Alternatively, using a gust factor of 1.412 (the gust factor from Durst) gives a nominal wind speed of 35.4 ms^{-1}. Neither matches the 32 ms^{-1} that was used.

Taking the data of Table 2 as the intended values, a number of different analyses can be performed. Assuming that the typhoon maximum wind speed is a gust wind speed and the gust factor of 1.225 applies, the average and gust wind speeds of the central or tropical cyclone zone should have been calculated as:

$$\begin{aligned} V_{avg} &= \frac{\left(\frac{50}{1.225}+20\right)}{2} \\ &= 30.4 \quad ms^{-1} \\ V_{gust} &= 1.225 \times 30.4 \\ &= 37.2 \quad ms^{-1} \end{aligned} \tag{4}$$

If the 5-second gust factor of 1.412 was used instead, the respective wind speeds would be:

$$\begin{aligned} V_{avg} &= \frac{\left(\dfrac{50}{1.412} + 20\right)}{2} \\ &= 27.7 \quad ms^{-1} \\ V_{gust} &= 1.412 \times 30.4 \\ &= 39.1 \quad ms^{-1} \end{aligned} \tag{5}$$

This second result is close to the top of Beaufort 10 (nominal to 28.3 ms^{-1}, gusts to approximately 40.0 ms^{-1}). This suggests that Beaufort 10 is a more realistic wind definition for vessels intended for unlimited operation at sea, though still avoiding centres of severe tropical disturbance.

Figure 4 shows the result when applying different gust factors (GF) to the specified maximum wind speed at the centre of a typhoon of 50.0 ms^{-1}.

Applying the same method and the 5-second gust factor of 1.412, the respective wind speeds for a low pressure system would be:

$$\begin{aligned} V_{avg} &= \frac{\left(\dfrac{32}{1.412} + 15\right)}{2} \\ &= 18.8 \quad ms^{-1} \\ V_{gust} &= 1.412 \times 18.8 \\ &= 26.5 \quad ms^{-1} \end{aligned} \tag{6}$$

This last result is the middle of Beaufort 8 (nominal to 20.6 ms^{-1}, gusts to approximately 29.1 ms^{-1}). This suggests that Beaufort 8 is more appropriate for vessels that must avoid the worst weather. Such vessels would need ready access to refuge.

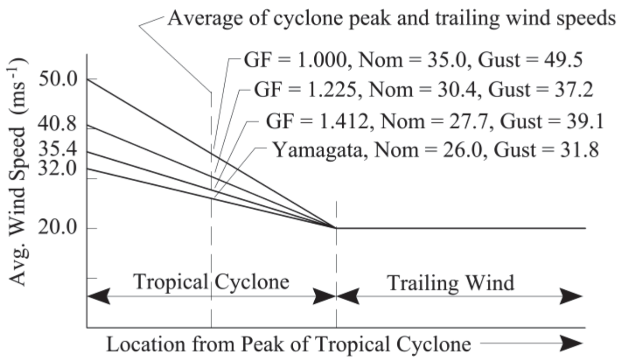

Figure 4 Simplified typhoon wind velocity, adapted from Yamagata (1959)

3.2 Naval

There is no actual historical evidence available for the development of the naval criteria wind speeds. The likely rationale for their selection can be deduced once the different tropical cyclone scales employed by different authorities are considered.

The defining event for formulating USN intact stability, Typhoon Cobra in 1944 (also known as Halsey's Typhoon), was described as Force 12 with average winds 50 to 75 knots and gusts as high as 120 knots. Brown and Deybach (1998) reported that the USN identified 100 knots as a reasonable wind velocity for ship survival in tropical storms. DDS 079-1 (1975) specified wind speeds for various service categories as:

- Ocean and Coastwise:
  - 100 knots - Ships which must be expected to weather the full force of tropical cyclones.
  - 80 knots - Ships which will be expected to avoid centres of tropical disturbance; and
- Coastwise:
  - 60 knots - Vessels which will be recalled to protected anchorages if winds over Force 8 are expected.

A number of observations can be made about the USN categories:

- 100 knots is the 5-second gust speed for Beaufort 12. It seems reasonable to assume that, for this service category, a gust factor of about 1.5, rounded to a neat result, was applied to a nominal wind of Beaufort 12.

- 80 knots is close to the 5-second gust speed for Beaufort 10 - refer to Table 1. Under the US system, this is the strongest Beaufort wind not categorized as a hurricane and 80 knots applies to ships expected to avoid centres of tropical disturbance. It seems reasonable to assume that, for this service category, a gust factor of about 1.5, rounded to a neat result, was applied to a nominal wind of Beaufort 10.
- Beaufort 8 has a nominal wind speed to 40 knots. 60 knots is 1.5 times the nominal wind speed. It seems reasonable to assume that a gust factor of about 1.5, rounded to a neat result, was applied.
- The USN categories are essentially for ocean voyaging ships (100 and 80 knots wind speed) and for limited range vessels (60 knots) able to return easily to shelter. The latter category could include ship's boats which would not operate in severe environments and which could return to the parent ship.

3.3 NSCV

The Australian National Standard for Commercial Vessels (NSCV, 2002) defined environments deemed suitable for domestic operations. The wind environments were presented as Beaufort wind speeds and gust pressures, with a formula to convert pressures to equivalent wind speeds. Using this formula revealed a wide range of gust factors, ranging from 1.3 for the ocean going categories to 1.76 for a protected waters category.

In the Australian context, it is desirable to use the NSCV categories where possible as most vessels available commercially in Australia would have been assessed against the NSCV. This can best be done by matching gusting wind pressures, which are used for analysis in the NSCV.

4. STANDARD WIND SPEEDS

The reanalysis of the original Japanese data presented in Yamagata (1959), the interpretation of the naval wind speeds presented in DDS 079-1 (1975) and inclusion of the NSCV categories strongly suggest the wind speeds defined in Table 3 for a range of service categories should apply. The wind speeds prescribed are nominal or average wind speeds. A gust factor of around 1.4 is recommended to derive the gust or design wind speed typically used in quasi-static analyses. This would most easily be arranged by doubling the nominal wind heeling moment (equivalent to a gust factor of $\sqrt{2} = 1.414$).

This paper developed the wind speeds recommended for offshore and ocean-going vessels. Table 3 also presents recommended wind speeds for operation of limited duration offshore (coastal) and in more protected areas. These were developed by Hayes (2014) and are appropriate for the Australian context. Other jurisdictions will possibly need to vary from these suggestions to suit local conditions.

Associated wave heights have been shown in Table 3 for completeness. They were derived from basic wind/wave relationships (Hayes, 2014) and are not intended to be definitive.

It is useful to define a number of service categories for the purposes of setting the environments (and any other pertinent parameters) applicable to the intended uses of a vessel. A vessel intended to stay in position except in the most severe weather should clearly be assessed using a more severe environment to that for a vessel intended to coastal hop only when suitable weather presents itself. The service categories, once defined, would be applied to most vessels, selecting the most appropriate category for the intended service of the vessel. This allows for clear definitions that can be applied and understood across the fleet.

Table 3 Suggested standard environments

Service Category	Wind					Sig. Wave Height	NSCV Equivalent[4]		
	Nominal Speed[1]			Pressure[2]			Category	Pressure	Sig Wave Ht
				Nominal	Gust[3]				
	B'fort	Kts	m/s	Pa	Pa	m		Pa	m
Ocean Unlimited	12	71	37	987	1974	14.0	None		
Ocean Limited	10	55	28	592	1184	9.5	None		
Offshore	8	40	21	313	626	6.0	A / B	600	>6
Coastal	7	33	17	213	426	4.5	C	450	4.5
Inshore	6	27	14	143	285	2.5	D	360	2.5
Smooth Waters	6	27	14	143	285	0.6	E	300	0.6

Notes: 1. 10-minute average at 10 metres.
2. Based on flat plate, 500 Pa at 26 m/s.
3. Gust pressures 2 times the nominal pressure.
4. Data from NSCV (2002)

Suggested descriptions of the service categories are presented in Table 4. Note that in the naval context, a safe haven can include the parent ship and that the size of the environment and range from the safe haven, not geographical limits, are the important parameters. This could also apply in the commercial context.

Table 4 Suggested service categories

Service	Description	Weather & Sea Characteristics	Survival & Rescue Infrastructure
Ocean Unlimited	Fully independent operation at sea, able to hold station in all but extreme conditions, able to resume duties after conditions abate.	Severe tropical cyclone or equivalent, extreme winds and extreme seas.	Early rescue not likely. Probable extended period in survival mode.
Ocean Limited	Independent operations at sea, avoiding centres of severe tropical disturbance, able to resume duties when conditions abate.	Storm force weather or equivalent. Very high winds and very high seas.	Early rescue not likely. Probable extended period in survival mode.
Offshore	Independent operation within 200 nautical miles or 12 hours at cruising speed (whichever is less) of a safe haven. Return to safe haven if winds likely to exceed Beaufort 8.	Gale force weather and very rough seas.	Survival in moderate conditions or early location likely and within helicopter range for rescue.
Coastal	Restricted operations within 4 hours travel at cruising speed of a safe haven.	Near gale force weather and rough seas.	Survival in benign conditions or early rescue.
Inshore	Operates within specified geographical limits defined as 'partially smooth' or within 2 hours travel at cruising speed of a safe haven in an equivalent environment.	Strong winds and moderate seas.	Rescue facilities and/or shoreline nearby.
Smooth Waters	Operates within specified geographical limits defined as 'smooth' or within 1 hour travel at cruising speed of a safe haven in an equivalent environment.	Strong winds and operates only in small waves.	Rescue facilities and/or shoreline nearby.

The suggested service categories would apply to a majority of cases. Special purpose vessels, intended for very specific roles, environments and survival probabilities, could require very specific operational profiles and environments to be defined.

5. CONCLUSIONS

Reiterating, inputs to stability criteria (especially wind and wave effects) should be treated in as rigorous and realistic a manner as possible. Any criterion relationship coefficients should then be developed such that the results of applying the criteria match experimental and real life data – i.e. they are realistic predictors of safe vessels for the intended extreme environment.

A standardised set of wind speeds for stability analyses would mean that the use of wind speed becomes more transparent, with less opportunity to cloud how it shapes the criteria coefficients. How the criteria would then be developed to accommodate these standardised wind speeds is a different question to be answered by more research.

Wind speeds appropriate for general stability analyses have been developed and defined in terms of different service categories. Adopting these, or similar, wind speeds and service categories allows for stability analyses appropriate to the actual use of and operational limitations of different vessels and is encouraged.

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