Designing the Next Generation of Small Pleasure and Commercial Powerboats with the Latest ISO 12215-5 for Hull Construction and Scantlings

Jean-Baptiste R. G. Souppez, Solent University, UK.

ABSTRACT

The revised ISO 12215-5 published in 2019 will govern the structural design of small crafts for the forthcoming decade. With an extended scope, applicable up to 24 m Load Line length and now encapsulating commercial crafts, the next generation of powerboats will be heavily influenced by this new regulation, and possibilities it offers. Furthermore, a wide range of improvements and new considerations have been incorporated to reflect the ever-evolving capabilities in structural design, analysis and production, particularly for composite vessels. This paper aims to provide the designers and builders of powerboats with an insight into the technical background and practical applications of the new regulation for the structural design of small recreational and commercial powercrafts.

NOMENCLATURE

For the purpose of this paper, the following nomenclature applies, as defined in the ISO 8666 (ISO, 2016) and ISO 12215 (ISO, 2019) were appropriate.

A_{D}	Design area (mm^2).
b	Short unsupported dimension of a panel (mm).
B_{C}	Chine beam at 0.4 L_{WL} (m).
B_{T}	Chine beam at transom (m).
Cb/b	Transverse camber of a curved panel (%).
Cl/l	Longitudinal camber of a curved panel (%).
C_{OB}	Power factor.
g	Acceleration due to gravity (m.s^{-2}).
$H_{1/3}$	Significant wave height (m).
k_{2b}	Panel aspect ratio coefficient for bending moment.
k_{AM}	Assessment method factor.
k_{BB}	Boat building factor.
k_{C}	Curvature correction factor for plating.
k_{DC}	Design category factor.
k_{DYN1}	Dynamic load factor.
k_{L}	Longitudinal pressure distribution factor.
k_{R}	Structural component and craft type factor.
l	Long unsupported dimension of a panel (mm).
L_{H}	Hull length (m).
L_{WL}	Length on waterline (m).
M_{db}	Design bending moment in the b direction (N.mm.mm^{-1}).
m_{LDC}	Maximum loaded displacement (kg).
M_{MAX}	Maximum bending moment (N.mm).
m_{ST}	Mass of an outboard engine (kg).
P	Pressure (kN.m^{-2}).
P_{TOT}	Total engine power (kW).
SM_{MIN}	Minimum section modulus per unit width (mm^3.mm^{-1}).
t	Thickness (mm)
V_{R}	Recommended reduced speed (kts).
x	Longitudinal position (m).
$\beta_{0.4}$	Deadrise angle at 0.4 L_{WL} (°).
β_{T}	Deadrise angle at transom (°).
σ_{DES}	Design stress (N.mm^{-2}).
CLT	Classical Lamination Theory.
FEM	Finite Element Methods.
FRP	Fibre Reinforced Plastics.
GRP	Glass Reinforced Plastics.
IMO	International Maritime Organization.
ISO	International Organization for Standardization.
RCD	Recreational Craft Directive.
SRM	Simplified Regression Method.

1. INTRODUCTION

The first record of a powerboat dates back to the 148ft vessel Pyroscaphe, trialled in France in 1783. Nevertheless, over a century would pass before the larger scale development of recreational powercrafts, occurring during two key decades of the XXth century. First, the 1930s strongly benefited from the improvements in internal combustion engines in terms of power, mass and affordability following the first World War and the progresses in the automotive industry. Furthermore, the social movements of this decade led to paid holidays, and thus a new attractive recreational sector. Wooden runabouts were the craft of choice at this point, with planning boats of length typically inferior to 9m but achieving speeds in excess of 30 knots. Secondly, the 1960s marked a turning point in the pleasure craft industry. Here again, the significantly better engines coupled with additional paid holidays played a role, but the key factor now allowing production scales previously unachievable is the advent of Fibre Reinforced Plastics (FRP). Larger vessels, in the region of 12m, with increased performance and internal accommodation below deck now became standard, with fast and high-volume production.

The next historical event of tremendous importance for the small craft industry was the tragedy of the 1979 Fastnet yacht race. The storm that hit the fleet of 303 sailing yachts caused over 75 vessels to capsize, 5 to sink, and 15 casualties amongst the sailors. This incident highlighted the relative absence of design rules governing recreational boats, and prompted the development of the Recreational Craft Directive (RCD), originally published as a European directive in 1994, later amended in 2003, and more recently, the RCD II was promulgated in 2013. These directives were accompanied with a range of international ISO standards aiming to ensure the safety of small crafts, and covering design aspects such as structure, stability, or man overboard prevention and recovery. Interestingly, historical vessels and individual replicas designed before 1950, primarily constructed from the original materials would be exempt from the RCD II (Alessio et al., 2016), whereas a traditional design with a modern construction method would be within the scope (Souppez, 2016).

The hull construction and scantlings of pleasure crafts of hull length ranging from 2.5 to 24 m is governed by the ISO 12215 series, with part 5 covering the design pressures for monohulls, design stresses and scantlings determination. Its 2008 version (ISO, 2008) stood for over a decade, during which the industry saw many advances, from design analysis to production methods. Consequently, the 2019 revision of the standard aims to provide an update that will be more in line with current design and manufacturing practices, while also making significant changes to its scope, such as covering commercial crafts as well.

First, the motivations and background behind the revision will be introduced. Then, the major changes to the scope and applicability of the regulation will be highlighted, before tackling the range of additional considerations featuring in the new standard. Subsequently, the specificities inherent to commercial crafts will be presented. Eventually, some formal notes on the use and interpretation of the published regulations will be provided.

2. MOTIVATIONS FOR THE REVISION

All ISO standards undergo a periodic revision process to ensure they remain current, suitable, and adjust to our fast-changing industries. The revisions of the ISO 12215 were however significant in light of the progresses made in structural design and analysis methods, as well as more advanced manufacturing processes. External organizations also dictated new elements to be brought into the scope. For instance, despite the 2008 version being clearly not applicable to commercial vessels, regulations such as the Brown Code or MGN 280 (M) (MCA, 2004) referred to this ISO standard for the structure of commercial vessels such as pilot boats, which was originally never intended to cover, thus leading to the development of a workboat annex for commercial crafts in the 2019 version.

Furthermore, the decade of practical application and users feedback suggested a number of possible improvements and pointed out some flaws, such as:

- Large panels, especially sandwich ones, tended to be penalized, and were also handicapped in terms of attached platting. Moreover, the applicability of the stiffness-based deflection criterion for sandwich panels and stiffener was questioned.

- While single curvature effect was accounted for (as in Class Rules), small crafts often feature large curvatures in both directions, thus accounting for double curvature effects would be welcomed.
- Higher freeboard vessels appeared to be at a disadvantage compared to low freeboard ones.
- More refined analysis methods for quasi-isotropic single skin laminates made of chopped strand mat and woven roving should be provided.
- A loophole whereby the simplified analysis for single skin gave lower structural requirements than the more advanced ply-by-ply analysis was noticed, and rightly perceived as unfair, penalizing the users employing a more advanced method with reduced uncertainty.
- Numerical analysis methods, such as Finite Element Methods (FEM) being more commonly available and utilized, should be offered as a mean to demonstrate structural compliance.
- With the increasing performance and development in comfort and shock-mitigating equipment, and with the inclusion of commercial crafts, acceleration in excess of 6 g should be considered.

With a strong emphasis on upgrading the revised standard to widen the range of structural analysis methods, it was also important not to rule out the simplified and practical ones, intended for smaller yards. Moreover, the ambition was to provide a smooth transition from one version to the other, thus ensuring consistency in the structural requirements, so that vessels comfortably passing the 2008 version would still meet the 2019 one.

3. REDEFINED SCOPE

3.1 Maximum Length

Twenty-four meters is a key threshold in the regulatory framework; however, issues arise from the inconsistence of its definition. Indeed, the RCD II (European Parliament, 2013) and ISO standards are applicable only up to a hull length (L_{H}) of 24 m. On the other hand, the following regulations (IMO, Class Society, etc…) start at 24 m Load Line length (IMO, 2003), defined as the greatest of 96% of the waterline length (L_{WL}) at 85% of the moulded depth, or the length from the front of the stem to the rudder stock axis. Consequently, it is common for vessel with large overhangs be above the 24 m hull length, but below Load Line definition, thus falling into a regulatory *no man's land*. This is a critical issue that remains unsolved. In order to provide a step towards resolving this discrepancy, the scope of the 2019 revision will extend up to 24 m Load Line length. It is to be noted that, at present, this has only been adopted for the revised ISO 12215, and not for other standards or the RCD II. It is however hoped this will provide a precedent that will, in time, lead to a more harmonious definition of 24 m across regulatory bodies.

3.2 Workboats and Commercial Crafts

The increasing recognition of the ISO 12215-5 by several countries as relevant to commercial vessels, despite the standard clearly not being intended to do so, led to the addition of workboats as part of the new version, eventually taking the form of a dedicated annex, namely Annex J (Souppez, 2018). This prompted further extension of the scope in terms of accelerations and maximum speeds, to better reflect the mode of operation of commercial vessels. These are sub-categorized in three groups, charter, light duty and heavy duty, each with specific requirement, as later detailed in Section 5.

4. ADDITIONAL CONSIDERATIONS

Besides the widened scope, a range of new considerations and associated coefficients have been introduced (Souppez & Ridley, 2017), with the most influential ones presented in the following subsections. Given the predominant use of composites for small crafts, and the inherent variety in materials and production technologies, several improvements have been solely dedicated to composite structures (Souppez, 2018).

4.1 Applicable Methods

To broaden the range of methods available to the industry in analysing composite structure, and to account for the more common use of advanced calculations and numerical methods, six methods can now be employed to determine the scantlings:

1. Simplified method: based on a simple thickness equation for quasi-isotropic Glass Reinforced Plastics (GRP) single skin.
2. Enhanced method: ply-by-ply analysis for quasi-isotropic GRP.
3. Developed method: application of Classical Laminate Theory (CLT) to all FRP structures.
4. Direct test: relying on mechanical testing, primarily intended for FRP.
5. FEM: finite element methods using the ISO design pressures and properties, also mostly aimed at FRP.
6. Drop test: applicable to vessels less than 6 m hull length.

4.1.1 Simplified Method

The simplified method provides a basic equation for the strength-driven plating thickness, assuming a built-in beam (aspect ratio greater than 2) of span b, under a uniformly distributed load P. In those condition, the design stress can be found as the ratio of the maximum bending moment and the minimum section modulus per unit width; mathematically:

$$\sigma_{\mathrm{DES}} = \frac{M_{\mathrm{MAX}}}{SM_{\mathrm{MIN}}} = \frac{6\ P\ b^2}{12\ t^2} \qquad (1)$$

Solving for the plate thickness yields:

$$t = b\sqrt{\frac{0.5\ P}{\sigma_{\mathrm{DES}}}} \qquad (2)$$

Which is then implemented with a single curvature coefficient k_c and a unit conversion factor of 1000 to give the ISO thickness requirement for quasi-isotropic GRP, metal and laminated wood as:

$$t = b\ k_{\mathrm{c}}\sqrt{\frac{P \times k_{2\mathrm{b}}}{1000 \times \sigma_{\mathrm{DES}}}} \qquad (3)$$

In which:

t	Thickness in mm.
b	Short side of the panel in mm.
k_C	Curvature coefficient.
P	Pressure in kN.m^{-2}.
$k_{2\mathrm{b}}$	Panel aspect ratio coefficient for bending moment.
σ_{DES}	Design stress in N.mm^{-2}.

A similar set of assumption is made in order to develop the simplified requirements for stiffeners.

4.1.2 Enhanced Method

The enhanced method consists of a ply-by-ply analysis for quasi-isotropic and orthotropic materials, considering shear force and bending moment in both directions of the plates, and accounting for double curvature. While the simplified method is only applicable for GRP, the enhanced method is intended for FRP, thus allowing more advanced materials, such as carbon and aramid, to be analyzed.

4.1.3 Developed Method

Extending the limitations of the enhanced method to all type of laminates (including non-balanced ones), the developed method relies on the principles of CLT. This extends the ply-by-ply analysis, considering stress and strain in both directions, typically using the Tsai-Hill (Tsai, 1968) or Tsai-Wu (Tsai & Wu, 1971) criterion. This difference is the primary reason for the enhanced method having a lower assessment method factor, as later discussed in Section 4.2. Note that CLT software users should ensure inner skin wrinkling and core shear stress are checked.

As an alternative to CLT, a Simplified Regression Method (SRM) was developed, primarily aimed for boat builders or design offices not confident with CLT or unable to afford a CLT software. This offers a more practical and less numerical approach, although its application would be limited to balanced laminates, generally combining biaxial and quadraxial fabrics.

4.1.4 Direct Test

Rather than assuming the mechanical properties of a laminate as defined by the ISO 12215-5 and associated design assessment methods, mechanical testing can be conducted to demonstrate that the bending moment and shear force of a panel or stiffener (with its attached plating) comply with the regulatory requirements.

The recommended test standards for each mechanical property are indicated below:

- Tensile properties: ISO 527-4 (ISO, 1997), ISO 527-5 (ISO, 2009)
- Flexural properties: ISO 178 (ISO, 2010)
- Compressive properties: ISO 14126 (ISO, 1999)
- In-plane shear properties: ISO 14129 (ISO, 1997)
- Interlaminar shear stress: ISO 14130 (ISO, 1997)
- Through-thickness tensile properties: ASTM D7291 (ASTM, 2015)

Should there not be an international standard for a given mechanical property, a recognized national regulation can be utilized as an alternative. It is also to be noted that compressive properties under the ISO 14126 (ISO, 1999) have proven to be difficult to ascertain, especially for unidirectional, that generally buckles as a result of the imposed test sample size, as opposed to failing in pure compression. It can therefore be seen relevant to assess this particular property using a four-point bending test, conducted under the ASTM D6272 standard (ASTM, 2017), and providing the sample failure occurs between the two load points on the upper face.

As it is common practice in structural testing, a minimum of 5 samples per property tested should be used, and the retained value should be the lesser of 90% of the mean, or the mean minus two standard deviations. The design values are then taken as $0.5 \times k_{\mathrm{BB}}$ of the assessed value, *i.e.* applying a factor of safety of 2, and a consideration for the boat building quality factor, as later tackled in Section 4.3.

4.1.5 Finite Element Methods

Perhaps one of the most eagerly anticipated by industry, but also one of the most controversial addition to the revised standard is the use of FEM. Indeed, with the increasing computational power available and improving affordability of the software, designers now turn to FEM for a more realistic 3D analysis of structures.

Nevertheless, it is recommended good practice to compare the results of FEM with those of the enhanced method, and a technical explanation would be required should the FEM results appear to be considerably lower than those of the developed method. Indeed, the FEM analysis should be conducted using the ISO design pressures and relevant material properties, consequently vast discrepancies between FEM and the enhanced methods would not be expected.

4.1.6 Drop Test

Despite the novel considerations made for double curvature, discussed in Section 4.6, the effect on very small boats (hull length lesser than 6 m) cannot be properly quantified. Hence, the physical drop test is deemed a suitable method to demonstrate structural compliance. This is applicable only to FRP and non-reinforced plastics, where the thicknesses cannot be easily and reliably assessed, and where the large deflections are not covered under the ISO 12215-5. The drop test is also a very practical way to ensure compliance, and has therefore been employed primarily by boat builders, and as part of a self-certification process most typically.

4.2 Assessment Method Factor

Building on the industry's feedback and evidence of a loophole providing less advanced methods with lower requirements, the introduction of the assessment factor (k_{AM}) aims to remedy this issue. The intention is to handicap cruder methods, and promote the use of more advanced ones, as reflected in the values of the coefficient shown in Table 1.

Table 1: Values of k_{AM}.

Assessment Method	Value of k_{AM} for FRP
Method 1: Simplified	0.90
Method 2: Enhanced	0.95
Method 3: Developed	1
Method 4: Direct Test	1
Method 5: FEM	1
Method 6: Drop Test	n/a

The more advanced methods, namely the developed one, direct test and FEM, benefit from a value of 1. The enhanced method is slightly penalized to reflect the absence of the Tsai-Hill or Tsai-Wu criterion, with a value of 0.95. Finally, the simplified method based on basic beam theory is set at a value of 0.90, which should prevent its thickness to be lower than the other methods.

4.3 Boat Building Quality Factor

The build quality is of primary importance on the final mechanical properties of composite materials, hence a build quality coefficient (k_{BB}) has been developed. The aim is to reward both the higher manufacturing qualities and higher manufacturing processes, and consequently to penalize the mechanical properties for less advanced manufacturing methods.

Indeed, the mechanical properties of composites are heavily driven by the production, with the fiber weight fraction having a strong impact on the properties, while advanced quality control to minimize contamination, voids, dry patches and other defects should be enforced. The building qualities are classified as low, high and tested, with the characteristics and k_{BB} values presented in Table 2.

Table 2: Values of k_{BB}.

Quality	Builder Characteristics	Value of k_{BB}	
		Hand Laid	Infused / Prepreg
Low	No measurement or checking of fiber weight fraction. The volume fraction is taken as the ISO default value.	0.75	0.8
High	Measured fiber weight fraction resulting from a range of representative laminates, and high-quality control.	0.95	1
Tested	Mechanical properties of the laminates are tested and high-quality control.	1	1

This also represents an incentive to upgrade production techniques from hand laid to infused for instance. In addition to the increase in mechanical properties and faster production times, infusion has strongly developed over the last decade for health and safety reasons. Indeed, although still debated, the role of styrene as a human carcinogen was recognized in 2011 (Gardiner, 2011). Infusion therefore provides a sensible alternative for polyester and vinylester yards, enabling to trap and extract the styrene, thus protecting the workforce's health.

Finally, a further improvement from the previous version is a clarification regarding how often the quality control and tests should be realized, which has now been fixed at a minimum of once a year. While manufacturers would be encouraged to conduct this as often as possible, this requirement is intended not to be too much of a burden for yards, particularly small ones with limited volume production.

4.4 Longitudinal Pressure Distribution Factor

The longitudinal pressure distribution coefficient (k_{L}) has been modified, following industry feedback, to reduce the requirements in the aft section, but also extended beyond the aft perpendicular ($x/L_{\mathrm{WL}} = 0$), and the forward perpendicular ($x/L_{\mathrm{WL}} = 1$). A comparison of the longitudinal pressure distribution coefficients at accelerations of 3 g and 6 g is depicted in Figure 1.

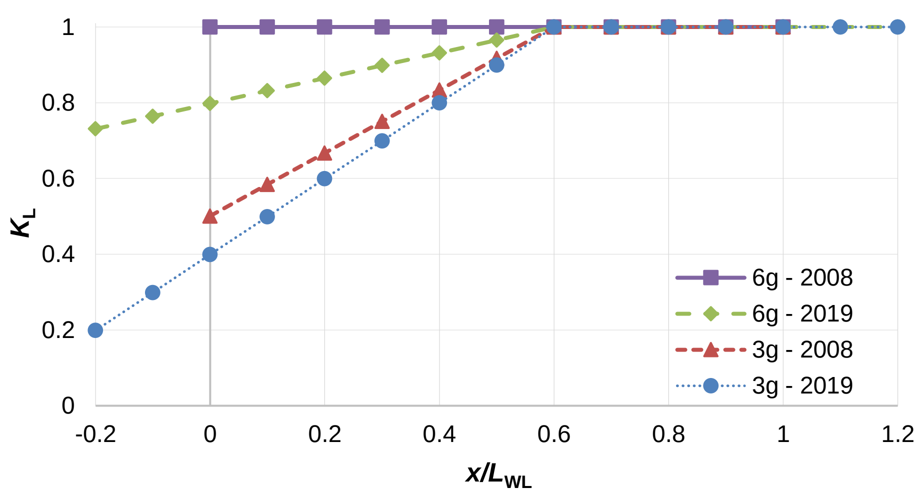

Figure 1: Comparison of the values of k_{L}.

While the pressure remained constant aft of the aft perpendicular in the previous version, the revised standard will consider a more realistic decrease in pressure over the aft overhang. Moreover, coupled with the new definition for natural stiffeners on round bilge hulls, presented in the following section, the reduced pressure will allow to lighten the structure.

4.5 Natural Stiffeners for Round Bilge Hulls

Natural stiffeners for hard chine sections have long been established, and featured in the previous version of the ISO 12215-5. In the newer version, a criterion for natural stiffeners on round bilge is introduced. Two definition for natural stiffeners are provided, one for circular center panels, typically found in a forward section, and one for curved sections, more representative of a middle to aft section.

4.5.1 Circular Centre Panel

Where a circle can be inscribed in the center bottom panel, it may be considered as a natural stiffener provided the chord length between tangent points is greater than 80% of the radius of the circle; this is shown in Figure 2.

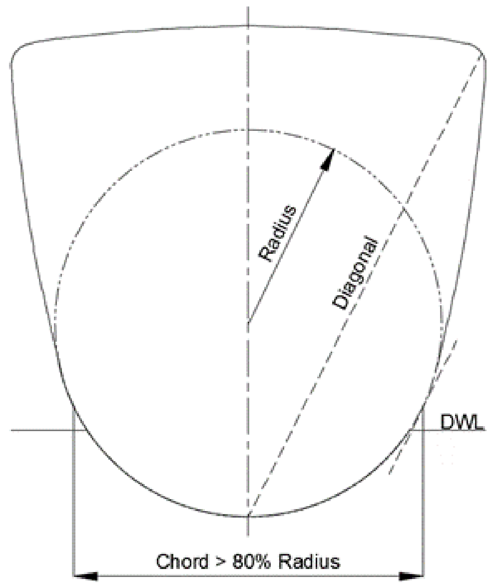

Figure 2: Natural stiffener criterion for circular center panel.

4.5.2 Curved Panel

For curved panel, a circle that represents the shape of the hull (see Figure 3) shall be defined and connected to the hull at the tangent point with a line parallel to the diagonal between the centerline and deck edge. Under those conditions, a natural stiffener maybe be defined, provided the following are satisfied:

- The radius of the circle is lesser than or equal to 40% of the length of the diagonal.
- The intersection with the hull is greater than 80% of the radius of the circle.

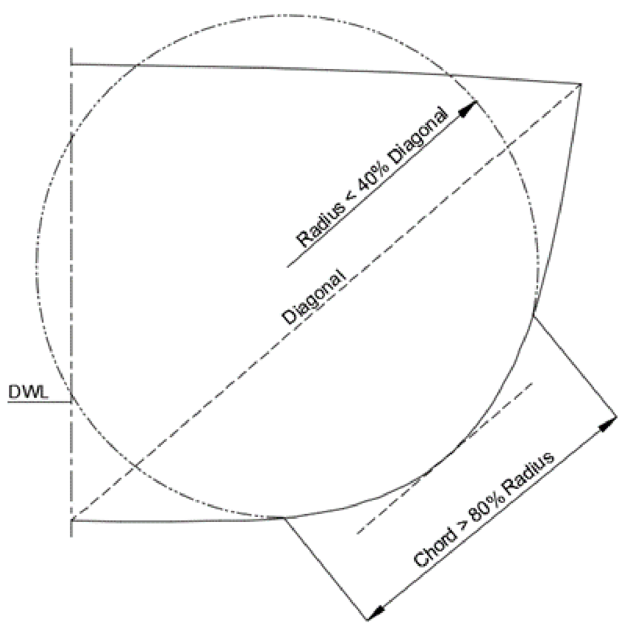

Figure 3: Natural stiffener criterion for curved panel.

4.6 Double Curvature

Single curvature has long been considered (Hildebrand, 1991), and features in all class regulations. In addition, it has been acknowledged that the double curvature of small crafts would also have a strong impact, although this was never quantitatively ascertained, and could only be demonstrated via the use of a drop test for very small vessel ($L_{\mathrm{H}} < 6\ m$).

It was therefore sensible for a small craft regulation such as ISO to introduce a correction factor for double curvature; this represents one of the novelties of the revised standard. Indeed, building on Timoshenko's theory of shells and plates (Timoshenko, 1959) and after FEM validation, a curvature correction for up to 22.5% camber in the transverse direction and 10% camber in the longitudinal direction was implemented. It is to be noted that the 22.5% camber in the transverse direction extends further than the original 18% maximum in the previous version, which appears more consistent with other class rules.

The values of the curvature coefficient factor (k_{C}) for a range of transverse curvatures (Cb/b) and longitudinal curvatures (Cl/l) can be found in Figure 4, and compared to the single curvature coefficient of the 2008 version.

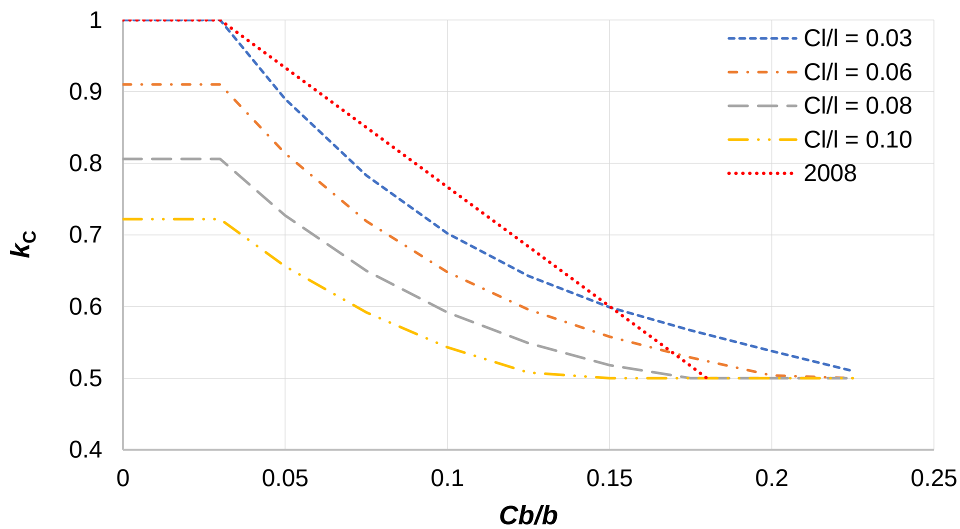

Figure 4: Curvature correction coefficients.

In most cases, a much lower requirement will be achieved thanks to the lower values of k_{C}, the only exception being highly curved panels in the transverse direction with very little curvature in the longitudinal direction, that will see a slight increase compared to the previous standard

It is to be noted that the above values only apply for fully fixed panels; should this not be the case, the users should either employ FEM, or refer to the values provided by Timoshenko (1959) for other end fixities.

4.7 Analysis of Bulking Material

A number of bulking materials, whether resin-rich felts, syntactic foams, or thick fabrics, are very common in the production of leisure crafts. On the one hand, they can be used as a print-through barrier on lower level production. On the other hand, they can be employed as a thinner alternative to a core. This prompted further regulatory considerations in order for these materials to be analyzed properly. Indeed, as a print-though barrier, the bulking material would be considered as part of the laminate, thus working in both shear transmission and bending. Conversely, when used as a thin core, it would only be carrying shear. Care should therefore be taken by the designers or builders to clearly define whether the bulking material is considered part of the laminate or acting as a core.

5. WORKBOATS AND COMMERCIAL CRAFTS

5.1 Background

With the new extended scope to now include commercial vessels, a dedicated normative annex (Annex J) was developed, and distinguishes between three types of crafts, namely bareboat rental and charter, light duty workboat and heavy duty workboat. While all types are defined as commercial vessels, the distinction depends on the restrictions inherent to its usage and operating conditions. It must be noted that both military crafts and vessels operating in ice conditions are excluded, the intended crafts ranging from pilot boats and search and rescue, to crafts transport vessels for less than 12 passengers.

5.2 Types of crafts

5.2.1 Bareboat Rental and Charter

Rental and charter vessels do not have any environmental restriction with the exception of the design category they were conceived for, as defined in the RCD II in terms of Beaufort wind speed and significant wave height. As a commercial vessel, relevant maintenance and survey programs are to be implemented. Furthermore, the vessel is expected to be handle with 'good seamanship' by the user, and speed reduction when operating above category D should be considered.

5.2.2 Light Duty Workboats

A light duty workboat is expected to operate in category D, or up to category C restricted to Beaufort 5 and a significant wave height of 1 m. The operating conditions for light duty workboats should not include rough seas, and the crew should ensure the comfort of passengers is be paramount, leading to appropriate courses and speeds at sea, *i.e.* strong consideration for seakeeping in order to minimise passenger discomfort. Maintenance and surveying programs shall be undertaken as appropriate, based on the usage and weather conditions experimented.

5.2.3 Heavy Duty Workboats

Heavy duty workboats are characterized as operating from the upper end of category C, up to category A, however restricted to Beaufort 9 and 5 m significant wave height. In this case, it is assumed that, due to the operating profile of vessels such as search and rescue crafts, the course would not be altered and the speed would not be reduced, and the boat would experience rough seas routinely. Consequently, the 50 knots top speed has been lifted for this particular craft type, and accelerations up to 8 g may be considered on the structure. Such operation and accelerations would obviously require special seating to be provided to the crew in order to remain in full ability to manoeuvre the vessel and be comfortable, as well as imply additional structural requirements. Moreover, recommendations for a reduced speed based on sea conditions should be provided. Here again, a suitable maintenance and survey plan shall be implemented.

5.3 Specific Requirements and Speed Reduction

In all three cases, the owner's manual shall provide the appropriate definition of the commercial craft usage conditions, as well the relevant recommendations linked to the specific application. For charter vessels and light duty workboats, this is the only additional requirement incurred by Annex J. Heavy duty workboats however need to satisfy a number of extra criteria.

Firstly, as accelerations up to 8 g may be considered, only the first dynamic coefficient criterion (k_{DYN1}) should be used, and not taken greater than a value of 8.

Then, while unchanged for both metal and wooden, the factor of safety for FRP, sandwich core and bulking material has been raised from the standard 2 to 3. The change was deemed relevant as industry practice is to typically apply a factor of safety of 3 for static loads, and 1.5 for dynamic loads, the latter being rapidly absorbed by the structure. This is achieved by modifying the coefficients in the allowable direct and shear design stress for the materials. In addition, the recommended minimum thickness for single skin and sandwich becomes compulsory, with the addition of a 15% margin.

Finally, an equation is provided to suggest the suitable reduction in speed according to the significant wave height experienced:

$$V_{\mathrm{R}} = \sqrt{\frac{m_{\mathrm{LDC}}}{{B_{\mathrm{C}}}^2} \times \frac{3.125 k_{\mathrm{DYN1}} \times \sqrt{k_{\mathrm{DC}}}}{\left((50 - \beta_{0.4}) \times \left(\frac{H_{1/3}}{B_{\mathrm{C}}} + 0.084\right)\right)}} \tag{4}$$

In which:

V_{R}	Recommended reduced speed (kts).
m_{LDC}	Maximum loaded displacement (kg).
B_{C}	Chine beam (m) at 0.4 L_{WL}.
k_{DYN1}	Dynamic load factor.
k_{DC}	Design category factor.
$\beta_{0.4}$	Deadrise angle (°) at 0.4 L_{WL}.
$H_{1/3}$	Significant wave height (m).

6. FORMAL IMPROVEMENTS

The ISO 12215-5:2019, published by ISO features some typos as well as recommendations made by the working group for modifications, improvements and clarifications, that were however not accepted by the ISO secretariat (Dolto, 2019). The following points, to be read in conjunction with the standard, aim to address these and provide additional guidance to the users.

1. In Table 9, the following statement should be added to the note: *"This approach is based on usual practice which is not valid for panels with a large aspect ratio, i.e.* $l/b > 4$*. In case of large aspect ratio, the pressure and scantlings may be smaller than acceptable in term of safety, particularly for planning craft, unless* A_D *is taken* $= 4b^2 \times 10^{-6}$*."* Moreover, $k_{\mathrm{R}} = 1$ should only be considered for bottom (not side and deck) planing craft in planing mode.

2. In Table A.4, the equation for the bending moment in the b direction, M_{db} should read P^2 instead of P (note that the calculations presented in tables H.2 and H.4 are indeed correct, based on the accurate equation featuring the P^2).

3. In Table A.5, the formula for the simplified web shear area should read an s instead of a b.

4. In annex B, the design stress for unwelded aluminium should be the minimum of $0.6\sigma_u$ or $0.9\sigma_y$ unwelded (and not $0.6\sigma_{uw}$ or $0.9\sigma_{yw}$).

5. The values of interlaminar shear strength in Table C.5 should be treated with caution. It is based on Halpin-Tsai formulas that correspond to polyester laminates, and are computed in the last columns of the bottom part of Tables C9 and C10. These values (10 to 18 $\mathrm{N.mm^{-2}}$) are in line with that of polyester (15 $\mathrm{N.mm^{-2}}$) in Table H.5, but much lower than the values for epoxy (25 to 40+ $\mathrm{N.mm^{-2}}$), commonly quoted by manufacturer. In the absence of further research, the values will be too pessimistic for epoxy.

6. In Annex D section D.1.2, the assumptions should be labelled a) to c) and not d) to e).

7. In annex K, the equation for the power factor (C_{OB}) is incorrect, despite ISO being presented with the results of a relevant test campaign (VTT, 2016). The correct equation should read:

$$C_{\mathrm{OB}} = 0.43 \times (50 - \beta_{\mathrm{T}}) \times \frac{\sqrt{P_{\mathrm{TOT}}} \times {B_{\mathrm{T}}}^{2}}{{m_{\mathrm{ST}}}^{2/3}} \tag{5}$$

In which:

C_{OB} Power factor.
β_{T} Deadrise angle at transom (°).
P_{TOT} Total engine power (kW).
B_{T} Chine beam at transom (m).
m_{ST} Mass of an outboard engine (kg - and not g for grams and specified in the published standard).

7. CONCLUSIONS

Representing a logical development following from the historical expansion of the pleasure craft industry, rules and regulations have become a core element of yacht design and manufacturing. For the hull construction and scantlings of monohulls, the ISO 12215-5 has become an international reference, and its new 2019 revision is set to shape the design and manufacturing of small crafts for the next decade, with new inclusions, such as lengths up to 24 m Load Line and the addition of commercial vessels.

The new considerations brought into the standard to address user feedback and remain in line with recent industry developments, particularly centered around composite boats, have been presented. Moreover, the newly introduced types of commercial crafts and inherent requirements have been detailed. Lastly, important points regarding the revision that did not make it into the final published standard are provided for guidance.

At present, the scope of the RCD II and associated ISO standard does not consider hydrofoiling vessels in non-Archimedean mode. However, with the ever increasing use of foils in the marine industry, the aim of regulations to follow design evolution, and the recent progresses in understanding both the forces (Dewavrin & Souppez, 2018), and stability and performance (Souppez *et al.*, 2019) of hydrofoil-assisted crafts, these could be included as part of the small craft regulations in the future, to remain up-to-date with industry practices.

8. REFERENCES

Alessio, L. G., Souppez, J.-B. R. G. & Hage, A., "Design Evaluation and Alteration of the Dark Harbor 17.5: Case Study of a Modern Replica", *Historic Ships*, Royal Institution of Naval Architects, London, UK, 2016.

ASTM, "ASTM D7291 / D7291M - 15 - Standard Test Method for Through-Thickness "Flatwise" Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material", *ASTM International*, 2015.

ASTM "ASTM D6272 - 17 - Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials by Four-Point Bending", ASTM International, 2017.

Dewavrin, J. M. M.-A. & Souppez J.-B. R. G., "Experimental Investigation into Modern Hydrofoils-Assisted Monohulls: How Hydrodynamically Efficient are they?", *The International Journal of Small Craft Technology,* 160(B2):111-120, 2018. DOI: 10.3940/rina.ijsct.2018.b2.223

Dolto, G., "Errata / Improvement List in ISO 12215 Series", *WG18 Report*, 2019.

European Parliament, "Directive 2013/53/EU on Recreational Craft and Personal Watercraft", *Official Journal of the European Union*, 2013.

Gardiner, H., "Government Says 2 Common Materials Pose Risk of Cancer", *New York Times*, 11 June, 2011.

Hildebrand, M., "On the Bending and Transverse Shearing Behaviour of Curved Sandwich Panels", *Technical Research Centre of Finland*, 1991.

IMO, "International Convention on Load Lines", *International Maritime Organization*, 2003.

ISO, "ISO 14129:1997 - Fibre-Reinforced Plastic Composites - Determination of the Inplane Shear Stress/Shear Strain Response, Including the Inplane Shear Modulus and Strength, by the Plus or Minus 45 Degree Tension Test Method", *International Organization for Standardization*, 1997.

ISO, "ISO 14130:1997 - Fibre-Reinforced Plastic Composites - Determination of Apparent Interlaminar Shear Strength by Short-Beam Method", *International Organization for Standardization*, 1997.

ISO, "ISO 527-4:1997 - Plastics - Determination of Tensile Properties - Part 4: Test Conditions for Isotropic and Orthotropic Fibre-Reinforced Plastic Composites", *International Organization for Standardization*, 1997.

ISO, "ISO 14126:1999 - Fibre-Reinforced Plastic Composites - Determination of Compressive Properties in the Inplane Direction", *International Organization for Standardization*, 1999.

ISO, "ISO 12215-5:2008 - Small Craft - Hull Construction and Scantlings - Part 5: Design Pressures for Monohulls, Design Stresses, Scantlings Determination", *International Organization for Standardization*, 2008.

ISO, "ISO 527-5:2009 - Plastics - Determination of Tensile Properties - Part 5: Test Conditions for Unidirectional Fibre-Reinforced Plastic Composites", *International Organization for Standardization*, 2009.

ISO, "ISO 178:2010 - Plastics - Determination of Flexural Properties", *International Organization for Standardization*, 2010.

ISO, "ISO 8666:2016 - Small Craft - Principal Data", *International Organization for Standardization*, 2016.

ISO, "ISO 12215-5:2019 - Small Craft - Hull Construction and Scantlings - Part 5: Design Pressures for Monohulls, Design Stresses, Scantlings Determination", *International Organization for Standardization*, 2019.

MCA, "MGN 280 (M) Small Vessels in Commercial Use for Sport or Pleasure, Workboats and Pilot Boats – Alternative Construction Standards", *Maritime and Coastguard Agency*, Southampton, UK, 2004.

Souppez, J.-B. R. G., "On the Applications of Modern Naval Architecture Techniques to Historical Crafts", *Historic Ships*, Royal Institution of Naval Architects, London, UK, 2016.

Souppez, J.-B. R. G., "Structural Design of High Performance Composite Sailing Yachts under the New BS EN ISO 12215-5", *Journal of Sailing Technology*, issue 2, pp. 1-18, 2018.

Souppez, J.-B. R. G., "Structural Analysis of Composite Search and Rescue Vessels under the New BS EN ISO 12215-5", *Surveillance, Search and Rescue Craft*, Royal Institution of Naval Architects, London, UK, 2018.

Souppez, J.-B. R. G., Dewavrin, J. M. M.-A., Gohier, F. & Borba Labi, G., "Hydrofoil Configurations for Sailing Superyachts: Hydrodynamics, Stability and Performance", *Design & Construction of Super & Mega Yachts*, Royal Institution of Naval Architects, Genoa, Italy, 2019.

Souppez, J.-B. R. G. & Ridley, J., "The Revisions of the BS EN ISO 12215". *Composite UK - Marine Sector Showcase*, Southampton, UK, 2017.

Timoshenko, S. P., "Theory of Plates and Shells", *McGraw-Hill*, 1959.

Tsai, S. W., “Strength Theories of Filamentary Structures. In: Fundamental Aspects of Fibre Reinforced Plastic Composites”, *Wiley-Interscience*, pp. 3-11, 1968.

Tsai, S. W. & Wu, E. M., “A General Theory of Strength for Anisotropic Materials”, *Journal of Composite Materials*, Volume 5, pp. 58-80, 1971.

VTT, “Guidelines for Commercial Crafts”, *VTT Expert Services LTD*, 2016.

9. DISCLAIMER

The views expressed in this paper are those of the author only and do not necessarily reflect those of the ISO/TC188/WG18. All information presented are for guidance only and do not replace compliance with the relevant regulatory framework and applicable requirements.

10. ABOUT THE AUTHOR

Jean-Baptiste R. G. Souppez is the Senior Lecturer in Yacht Design and Composite Engineering at Solent University, teaching on the prestigious *BEng (Hons) Yacht and Powercraft Design*, *BEng (Hons) Yacht Design and Production* and *MSc Superyacht Design,* and contributes the highly international Erasmus Mundus *Master in Integrated Advanced Ship Design* (EMship+) as a Visiting Professor and Research Supervisor at the University of Liege, while promoting professional development as an Associate Tutor for the MLA College (University of Plymouth), in partnership with the IMarEST, enabling established professionals to achieve higher academic qualifications and chartered engineer (CEng) status. He is also the Deputy Editor-in-Chief of the SNAME Journal of Sailing Technology, the world's leading peer-reviewed journal for sailing related research, and the UK Principal Expert in Small Craft Structures, in charge of representing the interests of the British Marine Industry in the development of international structural regulations (BS EN ISO 12215) thanks to his extensive knowledge of composites and structural design and analysis. His research in fluid dynamics features twisted flow wind tunnel, towing tank, wave and current flume, particle image velocimetry, laser doppler anemometry, and full-size instrumented testing, as well as a range of numerical methods, supporting his leading expertise in hydrofoils and award-winning work in downwind racing yacht sails.