# STRUCTURAL ASSESSMENT AND SCANTLINGS OF TRADITIONAL SMALL CRAFTS

**J-B R G Souppez,** Aston University, UK

## SUMMARY

The scantlings of traditional wooden crafts often originate from the extensive experience of designers and boatbuilders. With the contemporary regain of interest for historical replicas and timber construction, and the ever-critical necessity to minimise displacement, a compromise between the original scantlings and modern structural assessment must be struck. The latter heavily relies on rules-based design, driven by formal regulations, though a number of empirical methods also exist. Consequently, to assess the comparative structural requirements between traditional small crafts, empirical methods and regulatory requirements, case studies will be undertaken on small crafts. Ultimately, the results showcase the differences between original specifications, the recommendation of simplified methods, and modern rules, with the latter allowing for weight savings.

## 1. INTRODUCTION

Small crafts have heavily influenced the development of humanity, with evidence dating back to as early as the 6$^{th}$ millennium BC [1]. Throughout the vast majority of this time, the design and construction were unregulated, and relied on trial and error. Some of these errors remain particularly famous, such as the tragic capsize and sinking of the Swedish warship Vasa [2] in 1628, highlighting the vital need for sufficient stability and lowering the vertical centre of gravity.

The concept of pleasure craft is very recent, with the first instances being recorded during the 19$^{th}$ century, ahead of the two waves of development experienced in the 20$^{th}$ century [3] by the recreational small craft industry.

Firstly, the 1930s benefited from the fast improvements in engine power, lower weight and more accessible cost, following World War I and the progresses made in the automotive industry. Furthermore, as all pleasure industries, small crafts were made more popular thanks to the introduction of paid holiday throughout Europe. At this time, vessels remain small (8/9 m), primarily wooden runabouts, and able to reach 30 knots [3].

Later on, the 1960s witnessed the second wave of development in small crafts. Thanks to the emerging use of composites, large scale production increases, with bigger and faster vessels, now featuring accommodation. Once again, this was supported by the social developments and longer paid holiday across Europe.

Still, small leisure crafts remained unregulated. Larger vessels had seen the birth of SOLAS (Safety Of Life At Sea) in 1914 [4], following the sinking of the Titanic in 1912 [5]. But for small vessels, under 24 m in length, this would not come until the aftermath of the 1979 Fastnet Race [6], where the fleet was hit by a violent storm [7], leading to the loss of 15 yachtsmen, 75 capsizes and 5 sinkings. This triggering event highlighted the vital need for strict regulation on small pleasure crafts, including the stability and structure of vessels.

In time, this led to the Recreational Craft Directive, originally approved in 1994 [8], and prompted the development of numerous supporting standards, including the ISO 12217 [9] for stability, and the ISO 12215 [10] for scantlings.

More recently, the revised Recreational Craft Directive (RCD II) [11] resulted in renewed supporting ISO standards. Of particular interest to this paper are the developments made in the structural regulations [12], covering sailing [13], power [14] and commercial crafts [15]. Despite some limitation for modern wooden boats [16], historical crafts fall under a special regime.

Indeed, as stated in the RCD II [11]:

*"This Directive shall not apply to […] original historical watercraft and individual replicas thereof designed before 1950, built predominantly with the original materials and labelled as such by the manufacturer."*

In this instance, the compliance is assumed on the basis of the success of historical designs. However, with the regain of interest for modern replicas [17], new designs inspired by historical ones [18], and the application of modern yacht design techniques to historic crafts [19], the compatibility of historical scantlings with modern rules and regulations has become of interest. Consequently, this paper will investigate the compliance of scantlings from historical crafts in light of the latest structural regulations, namely the ISO 12215-5:2019 [20], through the case studies of two small vessels. In additional, empirical methods for wooden boat scantlings will also be applied for comparison purposes.

## 2. METHODS

Three methods will be employed for scantlings determination; two empirical ones, and a formal regulation.

First, the method proposed by Gerr [21] will be applied. Derived for the study of existing vessels, it offers a very simple approach to structural sizes for small crafts, with each component being related to a function of the overall size of the vessel, termed scantling number, $Sn$, and defined as:

$$Sn_{Gerr} = \frac{LOA \times BOA \times D}{28.32} \quad (1)$$

Where:

| | |
|---|---|
| $LOA$ | Length overall (m) |
| $BOA$ | Beam overall (m) |
| $D$ | Depth of hull (m) |

Then, the method developed by MacNaughton [22] will be featured. It also expresses the required size of structural components as a function of a single input, related to the size of the vessel, also termed scantling numeral, but this time defined as the cube root of the displacement of the vessel (in imperial units):

$$Sn_{MacNaughton} = \sqrt[3]{\nabla} \quad (2)$$

Where:

| | |
|---|---|
| $\nabla$ | Displacement ($ft^3$) |

Lastly, the ISO 12215-5:2019 [20] will be applied. It is to be noted that the standard is only recognized for modern timber construction (namely strip planking, cold moulded, or a combination of both, as well as plywood), but not traditional techniques, such as carvel planking.

However, the method will be applied in this instance, as the underpinning theory remain very simple (namely assumption that a panel may be approximated as a built-in be under uniformly distributed load), despite being intended for modern construction. It should also be noted that it has been suggested cold moulded structures would be best analysed in a similar manner as composite laminates [23], i.e. in a ply-by-ply analysis, as opposed to a quasi-isotropic one.

## 3. CASE STUDIES

### 3.1 THAMES A RATER

The historical Thames A Rater class saw its birth in the late 19th century [24], and while the vessels still feature the same original wooden hulls [25], significant technological advances have been made over the years to keep the class competitive [26]. This led to a number of recent studies [19, 27, 28] focussed on performance optimisation, as well as characterisation of original designs, such as *Scamp*, a 1902 Linton Hope design, reproduced from the original linesplan [29], and presented in Figure 1.

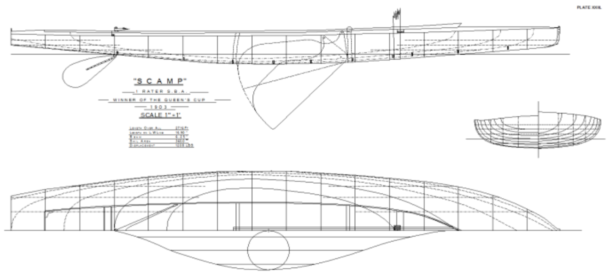

***Figure 1:*** *Replica of the Scamp linesplan [29].*

The modern developments in rig and sail designs, added onto the original timber hulls, can be seen in Figure 2, comparing the A Rater *Vagabond* over 100 years apart.

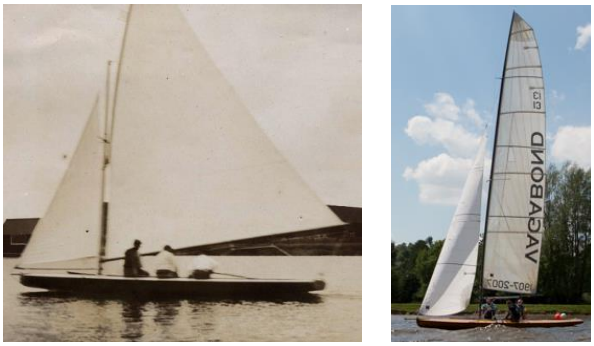

***Figure 2:*** *Rig in 1907 (left) [28] and 2014 (right) [28].*

### 3.2 DARK HARBOR 17.5

Designed in 1908 by B. B. Crowninshield [30], the Dark Harbor 17.5 is a traditional day sailor, with well documented plans and scantlings [31], and depicted in Figure 3 and Figure 4. The design has also benefited from recent interest with the aim of developing a modern replica [17, 32], shown in Figure 5, better suited to today's market, while also incorporating a more advanced construction method.

As such, it would no longer fall under the pre-1950 exemption in terms of regulatory compliance, hence the interest in the required scantlings for this vessel under current rules.

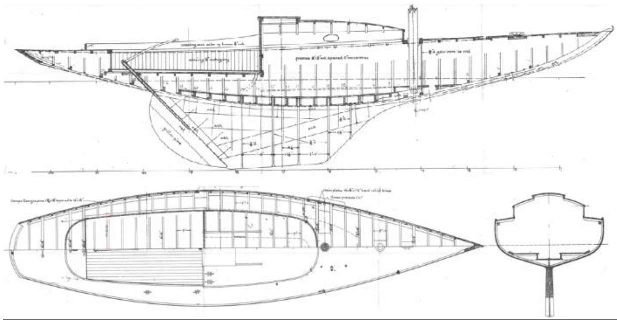

***Figure 3:*** *Structure of the Dark Harbor 17.5 [31].*

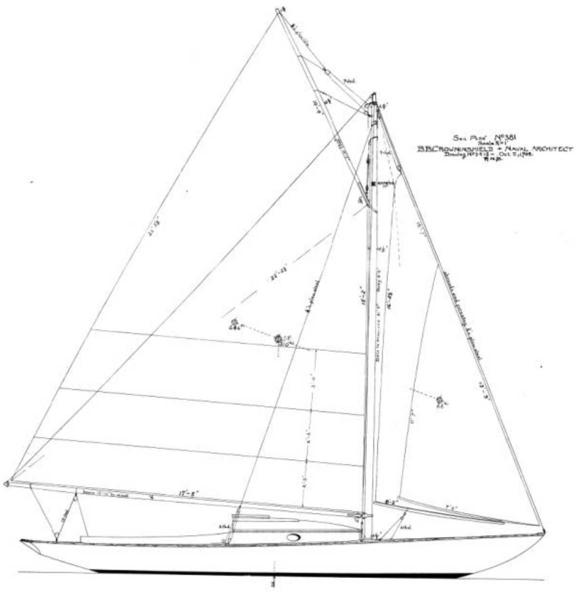

***Figure 4:*** *Sail plan of the Dark Harbor 17.5 [31].*

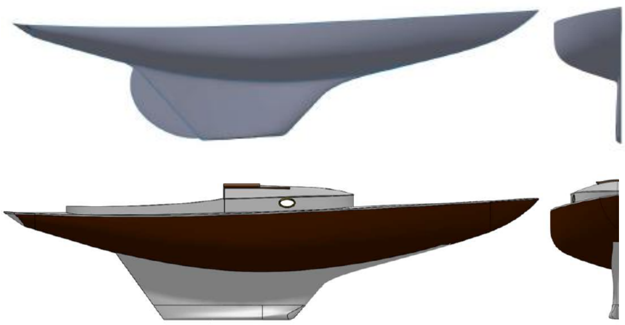

***Figure 5:*** *Original Dark Harbor 17.5 (top) [31] and modern replica (bottom) [32].*

### 3.4 HYDROSTATICS AND SCANTLINGS

For the case studies under consideration, the main hydrostatics, together with the resulting scantling numbers (in accordance with both Gerr's [21] and MacNaughton's [22] definitions) are presented in Table 1.

It should be noted that, although both labelled 'scantling numbers', there is no relationship between these two quantities across both empirical methods. Consequently, the quantitative differences in their values are of no importance at this stage.

***Table 1:*** *Main hydrostatics and scantlings numbers.*

| Parameter | A Rater (Scamp) | Dark Harbor 17.5 |
|---|---|---|
| LOA (m) | 8.28 | 7.92 |
| Lwl (m) | 5.17 | 5.34 |
| BOA (m) | 1.90 | 1.91 |
| Bwl (m) | 1.64 | 1.84 |
| D | 0.47 | 0.86 |
| $\nabla$ (m$^3$) | 0.548 | 1.513 |
| $\nabla$ (ft$^3$) | 19.35 | 53.43 |
| $SN_{Gerr}$ | 0.26 | 0.46 |
| $SN_{MacNaughton}$ | 6.45 | 17.81 |

## 4. RESULTS

Empirical methods typically suffer from a number of limitations; these include:

- An absence of consideration for the timber species considered, and therefore the mechanical properties of the material.
- There is no allowance for the design pressure applied to the craft, which would vary with the vessel's speed, but also operating profile (eg: inland versus offshore craft).
- The actual geometry of the panel, in terms of its size and curvature, are not accounted for.

There are therefore flaws in empirical methods, which do however benefit from a level of simplicity far greater than that of regulatory requirements, and thus often found their use restricted to the very early stages of the design. Furthermore, no technical background is provided for these methods. Ultimately, this yields very inconsistent results, that widely diverge from the actual scantlings of the vessels, as presented in Table 2.

***Table 2:*** *Comparison of the main scantlings.*

| Method | Scantling | A Rater (Scamp) | Dark Harbor 17.5 |
|---|---|---|---|
| **Gerr** | Planking thickness (mm) | 11.0 | 13.8 |
| | Square frame (mm) | 20.3 | 25.5 |
| | Frame spacing (mm) | 179.2 | 208.7 |
| **Mac Naughton** | Planking thickness (mm) | 24.6 | 67.9 |
| | Square frame (mm) | 41.0 | 113.1 |
| | Frame spacing (mm) | 245.7 | 678.6 |
| **Actual** | Planking thickness (mm) | 7.9 | 19.1 |
| | Square frame (mm) | 12.7 | 22.2 |
| | Frame spacing (mm) | 152.4 | 203.2 |

In comparison, the ISO 12215-5 [20] addresses the major limitations of the empirical methods. Firstly, the planking thickness is derived from a simplified structural analysis, assuming the panel as a built-in beam under uniformly distributed load, thereby providing some technical background. The plating thickness under this small craft regulation is given by Equation 3:

$$t = b \times k_c \times \sqrt{\frac{P \times k_{2b}}{1000 \times \sigma_d}} \tag{3}$$

Where:

| | |
|---|---|
| $t$ | Thickness (mm) |
| $b$ | Panel's short side (mm) |
| $k_c$ | Curvature coefficient (-) |
| $P$ | Pressure (kN/m$^2$) |
| $k_{2b}$ | Aspect ratio correction factor (-) |
| $\sigma_d$ | Design stress (N/mm$^2$) |

While more complex in its formulation, and requiring a higher number of inputs, this equation accounts for:

- The panel's geometry, in terms of its physical size ($b$), curvature ($k_c$) in both the longitudinal and transversal directions, and aspect ratio ($k_{2b}$).
- The pressure (P), which varies with multiple factors, including the design category of the vessel (inland, inshore, offshore and ocean), and the longitudinal position along the length of the vessel.
- The mechanical properties of the actual timber species considered, and building on a wealth of previous research for various timbers [33, 34, 35, 36, 37, 38].

While a strict comparison cannot be undertaken between all methods, the application of regulatory rules to traditional craft consistently yields far lower structural requirements, whether for the planking or framing. This is supported by the number of recent investigations into modern replicas and novel structural designs, that routinely achieved structural weight savings [17, 19, 28].

Despite the impossibility to generate like-for-like comparison between the actual scantlings, those advised by empirical methods, and those required by modern regulations, very clear results were yielded. With too many limitations, empirical method over-structure historical crafts (which may already be deemed over-structured by today's standards), particularly small inland/inshore ones. Conversely, vast weight savings can be achieved under the ISO 12215-5, which should therefore be considered, where applicable, even for historical crafts that may be exempt from regulatory compliance due to their design dating back prior to 1950 and constructed primarily as per the original vessel specifications.

## 5. CONCLUSIONS

This paper used two historical crafts, namely the Thames A Rater and the Dark Harbor 17.5, as case studies to comparatively assess the relevance of empirical scantlings methods and contemporary rules and regulations.

With vastly higher structural requirements, empirical methods may find there place in very early design stages, but did not prove suitable to determine the required size of structural components. These methods suffer from their simplicity, and do not allow to capture all the necessary aspects of a craft and its operation to yield relevant scantlings.

On the other hand, thanks to the lower structural requirements of the ISO 12215-5, weight savings could be achieved on historical crafts. This is particularly important, as the fit out of these vessels in modern days tends to be far heavier than originally, due to the addition of engine, batteries, life-saving equipment, etc…

Remembering that crafts designed before 1950s and built in accordance with the original scantlings are exempt of regulatory compliance, this paper demonstrates that there is a strong benefit in complying with modern standards. Consequently, it would be advised to investigate this option, which may also provide further consumer confidence in the reliability of the vessel.

## 6. REFERENCES


[1] CRTER, R., 'Boat Remains and Maritime Trade in the Persian Gulf During the Sixth and Fifth Millennia BC', *Antiquity*, vol 80(307), pp 52-63, 2006.

[2] KESSLER, E. H., BIERLY, P. E & GOPALAKRISHNAN, S., 'Vasa Syndrome: Insights from a 17$^{th}$-Century New-Product Disaster', *Academy of Management Perspectives*, vol 15, no 3, 2001.

[3] ISSC COMMITTEE V.8, 'Yacht Design', *Proceedings of the 18$^{th}$ International Ship and Offshore Structures Congress*, 2012.

[4] WHEELER, E. P., 'International Conference of Safety of Life at Sea', *The American Journal of International Law*, vol 8, no 4, 1914.

[5] CONRAD, J. 'Some Reflexions, Seamanlike and Otherwise, on the Loss of the Titanic', *The English Review 1908-1937*, vol 11, 1912.

[6] O'DONNERL, B., 'The Fastnet Race 1979', *British Medical Journal*, vol. 281, 1980.

[7] ADLARD COLES, K., ‘The Fastnet Storm of 1979’, *The Journal of Navigation*, vol 33, issue 2, 1980.

[8] EUROPEAN PARLIAMENT, ‘Directive 1994/25/EC on Recreational Craft’, *Official Journal of the European Union*, 1994.

[9] INTERNATIONAL ORGANISATION FOR STANDARDIZATION, ‘BS EN ISO 12217 - Small Craft - Stability and Bouyancy Assessment and Categorization’, *International Organisation for Standardization*, 2015.

[10] INTERNATIONAL ORGANISATION FOR STANDARDIZATION, ‘BS EN ISO 12215 - Small Craft - Hull Construction and Scantlings’, *International Organisation for Standardization*, 2019.

[11] EUROPEAN PARLIAMENT, ‘Directive 2013/53/EU on Recreational Craft and Personal Watercraft’, *Official Journal of the European Union*, 2013.

[12] SOUPPEZ, J.-B. R. G. & RIDLEY, J., 'The Revisions of the BS EN ISO 12215', *Marine Sector Showcase* - Composite UK, Southampton, UK, 2017.

[13] 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.

[14] SOUPPEZ, J.-B. R. G., 'Designing the Next Generation of Small Pleasure and Commercial Powerboats with the Latest ISO 12215-5 for Hull Construction and Scantlings', *1st SNAME / IBEX Symposium*, Tampa, Florida, US, 2019.

[15] SOUPPEZ, J.-B. R. G., 'Structural Analysis of Composite Search and Rescue Vessels under the New BS EN ISO 12215-5'. *SURV9 - Surveillance, Search and Rescue Craft*, The Royal Institution of Naval Architects, London, UK, pp 1-4, 2018.

[16] SOUPPEZ, J.-B. R. G., 'Timber Construction: an Experimental Assessment of the Strength of Scarf Joints and the Effectiveness of Various Adhesives for Laminated Wood', *Historic Ships, The Royal Institution of Naval Architects*, London, UK, 2020.

[17] 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, The Royal Institution of Naval Architects*, pp 121-127, London, UK, 2016.

[18] LINDEN, V. & SOUPPEZ, J.-B. R. G., 'Sailing towards Sustainable Trading with Wooden Cargo Schooner', In the Proceedings of the *British Conference of Undergraduate Research*, Sheffield, 2018.

[19] SOUPPEZ, J. B. R. G., ‘On the Applications of Modern Naval Architecture Techniques to Historical Crafts’, *Historic Ships, The Royal Institution of Naval Architects*, pp 1-15, London, UK, 2016.

[20] INTERNATIONAL ORGANISATION FOR STANDARDIZATION, ‘BS EN ISO 12215-5:2019 - Small Craft - Hull Construction and Scantlings. Part 5: Design Pressures for Monohulls, Design Stresses, Scantlings Determination’, *International Organisation for Standardization*, 2019.

[21] GERR, D., ‘The Elements of Boat Strength’, *International Marine, McGraw-Hill*, 1999.

[22] MACNAUGHTON YACHT DEIGNS, ‘Scantling Rules’, *MacNaughton Yacht Designs*, 2010.

[23] LOSCOMBE, R., ‘Structural Design Considerations for Laminated Wood Yachts’, *International Conference on the Modern Yacht*, Portsmouth, UK, 1998.

[24] LAITY, M., ‘Thames Clubs’, *Classic Boats,* 2001.

[25] LAITY, M., ‘Bell Boy’, *Classic Boats*, 2007.

[26] THAMES SAILING CLUB, ‘The Thames A Rater Association Rules’, *Thames Sailing Club*, 2007.

[27] SOUPPEZ, J.-B. R. G., ‘Design and Production of a Wooden Thames A-Rater Class Sailing Yacht’, *Master Thesis, The University of Auckland*, 2015.

[28] THOMAS, J. & SOUPPEZ, J.-B. R. G. ‘Comparative Performance Prediction of Historical Thames A Rater Class Designs’, *Historic Ships, The Royal Institution of Naval Architects*, pp 67-76, London, UK, 2018.

[29] KEMP, D., ‘Dixon Kemp’s Manual of Yacht and Boat Sailing and Yacht Architecture. New and Eleventh Edition. Edited by B. Heckstall-Smith and Linton Hope’, *Horace Cox, London*, 1913.

[30] CROWNINSHIELD, B. B., 'Dark Harbor 17½', *Dark Harbor Design Plan,* 1908.

[31] WOODEN BOATS, '25'10" Sloop, Dark Harbour 17½', *Wooden Boats,* undated.

[32] ALESSIO, L. G., 'Redesign of a Classic Sailboat with FEA Investigation of the Plate Curvature', *Master Thesis*, 2017.

[33] US GOVERNMENT, 'Design of Wood Aircraft Structure,'A*nc-18 Bulletin,* 1951

[34] STARTLING PUBLISHING CO, 'Encyclopedia of Wood', *Startling Publishing Co,* 1989.

[35] PRINCESS RISBOROUGH LABORATORY, 'The Strength Properties of Timber in Metric Units', *Building Research Establishment,* 1978.

[36] BRITISH STANDARDS, 'BS EN 408:1995, Timber Structures - Structural Timber and Glued Laminated Timber - Determination of Some Physical and Mechanical Properties', *British Standards,* 1995.

[37] BRITISH STANDARDS, 'BS EN 1995-1-1:2004, EUROCODE 5, Design of Timber Structures, Plus TRADA Guidance Document N° 3', *British Standards*, 2004.

[38] DENSCH, H. E. & DINWOODIE, J. M., 'Timber - Structure, Properties, Conversion and Use', 7th edition, *MacMillan Presss Ltd*, 1996.

## 7. AUTHORS BIOGRAPHY

Jean-Baptiste R. G. Souppez is the Senior Teaching Fellow in Mechanical Engineering and Design at Aston University. As the UK Principal Expert in Small Craft Structures, he is in charge of representing the interest of the British marine industry in the development of international structural regulations (ISO12215) while also overseeing all small craft regulatory developments on behalf of the Institute of Marine Science, Engineering and Technology (IMarEST). He is also the Deputy Editor-in-Chief of the Society of Naval Architects & Marine Engineers (SNAME) Journal of Sailing Technology. His research in fluid dynamics features a wide range of experimental methods supporting his cutting-edge expertise in hydrofoils and award-winning work on the aerodynamics of downwind racing yachts sails. He contributes to the international Erasmus Mundus Master in Advanced Design in Ship and Offshore Structures (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, supervising post-graduate researchers and enabling established professionals to achieve Chartered Engineer (CEng) status through the IMarEST.