ON THE APPLICATIONS OF MODERN NAVAL ARCHITECTURE TECHNIQUES TO HISTORICAL CRAFTS

J-B R G SOUPPEZ, Southampton Solent University, UK.

SUMMARY

The Thames A Rater class had a predominant role in the popularisation of inland racing in the United Kingdom towards the end of the 19th century, and remains a historical racing class that owes its longevity to the progresses made in naval architecture and technology; the most emblematic example being the 43 feet tall carbon fibre rigs on the 27 feet centenary wooden hulls. Today, the class is a perfect illustration of the balance between historical conservation and modernisation. The design of a contemporary wooden Thames A Rater will be presented, aiming at retaining the spirit of tradition of the class, while incorporating the latest design evolutions, and complying with the current rules and regulations. Techniques such as computational fluid dynamics and parametric optimisation will be employed, leading to a significant increase in performance quantified thanks to a velocity prediction programme, thus demonstrating the applications of modern naval architecture techniques to historical crafts.

1. INTRODUCTION

To ascertain the role of modern naval architecture techniques in the conservation of traditional crafts, the design of a contemporary wooden Thames A Rater has been undertaken. This racing class appears particularly suited as its history reveals a tendency for evolution and modernisation in order to maintain the highest possible performance. The new design will make use of modern design tools, such as computational fluid dynamics, parametric optimisation and vortex lattice method, as well as consideration for the present regulations inherent to small crafts. The improvements in performance of the new A Rater will be compared to the original one thanks to the use of a velocity prediction programme, in order to demonstrate the positive impact of modern naval architecture techniques.

2. HISTORICAL BACKGROUND

2.1 THAMES SAILING CLUB

Created in 1870, the Thames Sailing Club (TSC) is the second oldest inland sailing club in Britain. The success of the first years of racing quickly highlighted two major issues: boats of highly diverse performance were competing together and no racing rules were applied. Despite those two constraints, the Thames Sailing Club became so important that in 1887, Queen Victoria herself awarded the Thames Champions Cup. This particular event revealed the potential of inland sailing events, and called for a prompt remedy to previously mentioned issues. The following year saw the creation of the Sailing Boat Association (SBA) that established racing rules, and introduced a handicap system, based on the popular Dixon Kemp's rating formula, dating 1880 [1]:

$$Rating = \frac{Lwl \times SA}{6000} \qquad \textit{Eq. 1}$$

In which:

Lwl	Waterline length.	ft
SA	Sail area.	ft^2

This gave birth to the term '*Rater*', defining yachts designed under this particular rule; a One-Rater rating 1, a Half-Rater rating 0.5, etc. Later, a class gathering boats rating from 0.8 to 1 was created: the A Rater class.

2.2 THAMES A RATER

Towards the end of the 19th century, the design of inland racing yachts is generally defined as a '*skimming dish*', a philosophy that reached a plateau with the A Rater's fleet [2]. Out of the 13 original A Raters still racing today, twelve were built between 1898 and 1911 and the last one post WWI in 1922. The majority of the A Raters were designed by Alfred Burgoine and Linton Hope, each having a radically different approach to the rating rule that only accounts for the waterline length and the sail area.

Burgoine's yachts are characterized by a large sail area, the counterpart being a shorter waterline length. While the latter restricts the speed for a given Froude number, the larger sail area will offer a more powerful boat that therefore has to be made wider to increase form stability and the ability to carry sail. On the other hand, Hope favoured a longer waterline and narrower beam, and consequently a smaller sail area as dictated by the rating rule. The opposition of those two design philosophies is illustrated in Table 1, comparing two original A Raters, namely *Ulva* (1898) and *Scamp* (1902), respectively designed by Burgoine and Hope.

Yacht	Lwl (m)	Bwl (m)	SA (m²)	Rating
Ulva	4.80	2.15	35.00	0.99
Scamp	5.15	1.66	33.00	1.00

Table 1: *Burgoine and Hope designs comparison.*

The radically opposed specifications led to distinctive performances, the Hope's yachts being better suited to upwind sailing while the Burgoine's ones sailed faster downwind.

2.3 CHEATING THE RULE

Looking at the various attempts to *cheat* the A Rater class rules provides some insights into the critical design areas to be improved; in this case the waterline length, the stability and the mast weight.

Firstly, the work of William Froude published a few decades before the A Raters [3, 4] identified the waterline length as the main speed restricting factor, hence the interest in a longer waterline length. For the typical resistance hump occurring at a Froude number of 0.33, Ulva would achieve 4.40 knots, while Scamp would reach 4.56 knots. As a result, some boats were fitted with rods and wires at each end. By winding up the wires, the yacht could artificially be sagged to offer a shorter waterline length when measured. The wires would then be loosened when racing, thus extending the actual waterline length.

Secondly, stability is a major factor for such a light displacement craft carrying a large sail area. Some of the main innovations with regard to stability have been experimented on Vagabond, designed in 1907 by Hope. The ancestor of the trapeze was named the *'bell rope'*: a crew, the *'bell boy'*, holding onto a rope attached at the top of the mast could stand to windward, as depicted in Figure 1, thus increasing the righting moment.

Figure 1: *The 'bell boy' and the 'bell rope' [2].*

Once made illegal, Vagabond was fitted with sliding seats (see Figure 2), with the same effect of increasing the righting moment, and the same fate of being banned.

Figure 2: *Sliding seats on Vagabond [2].*

Finally, removable top masts were introduced to minimise the heeling moment in high winds. While this practice was prohibited, the masts would undergo several improvements in the future.

2.4 EVOLUTION

While the hulls and appendages have been untouched since the beginning of the 20th century, the rig and sails have significantly evolved. Originally designed as a low aspect ratio gaff rigs, the masts evolved from bamboo to the current carbon fibre, via solid and hollow wooden spars as well as aluminium. With the improving mast technology, higher spans could be achieved, and the A Raters are now famous for their impressive 43 feet (13.1m) tall rigs, depicted in Figure 3.

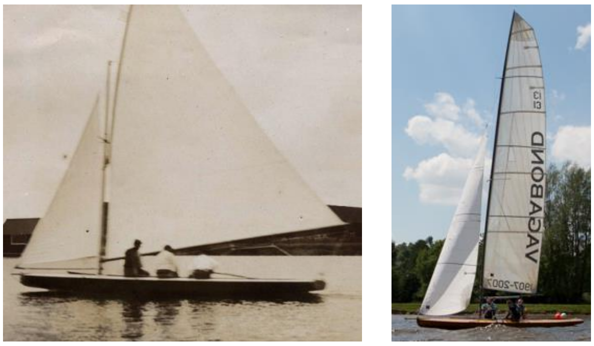

Figure 3: *Rig in 1907 (left) [2] and 2014 (right) [5].*

One of the downsides of the early gaff rigs was the eccentric location of the centre of effort of the sails downwind, requiring tremendous efforts from the helmsman to keep the boat on course in the narrow waterways. Remains of this behaviour can be seen today with some of the original tillers, clearly made for the helmsman to hold onto it firmly, as shown in Figure 4.

Figure 4: *The bracing tiller of Ulva [6].*

Along with the masts, cotton sails have been replaced with more advanced materials. Those innovations contributed to the success of the A Rater class, and so did the Glass Reinforced Plastic (GRP) technology that sparked a regain of interest in the class in the late 1970s.

2.5 MODERN DAYS

The A Rater class is one of the rare racing classes that survived after World War II, but with the last wooden A Rater dating from 1922, the number of boats was becoming smaller and smaller over time. In 1978, a female mould tool of *Ulva* was made, and new GRP hulls were built, thus ensuring the future of the class. Around this time also came into place a change in the rules: no new design would be allowed, any new A Rater would have to be an exact replica of an original one; as stated by the Thames A Rater class rule [7] and further discussed in Section 3.1. In addition, to stop the *arms race* resulting from the new composite manufacturing, a minimum class weight was imposed.

The early 2010s saw the appearance of the first full carbon boats, fitted with a new deck inspired from the 5o5 class, and thus moving away from the traditional designs; the latest A Rater built is pictured in Figure 5.

Figure 5: *The latest A Rater built [5].*

The challenge set is to design the next generation of wooden A Raters, marrying performance with tradition.

2.6 DESIGN BRIEF

The design brief aimed to involve as many stakeholders as possible, thus considering the requirements of the client, shipyard, and sailor's feedback. All agreed to an aesthetically pleasing wooden yacht, with classic lines to carry the historical legacy of the A Rater class, with however a stronger emphasis on improved performance.

Additional considerations originated from the environmental constraints. Due to the specific area of operation of the craft, namely the Norfolk Broads, as opposed to the Thames, requirements for the maximum draft and bridge heights had to be taken into account [8]. Furthermore, the Thames A Rater class rule requirements [7], detailed in Section 3.1, were incorporated.

Finally, in terms of the regulatory framework, the boat being aimed at the European market, it is to comply with the Recreational Craft Directive (RCD). As a consequence of the move to the RCD II [9] in January 2017, the yacht was designed to the newer regulation, and in accordance with the relevant ISO standards.

2.7 CONCLUSIONS

The historical Thames A Rater class is a significant part of England's inland racing history, and is still a vibrant class nowadays, primarily thanks to the compromise between tradition and evolution. The acceptance of the design and technology progresses made in rig and sails allowed the A Rater class to carry its legacy through time. And this is the objective for the new design: a high performance craft building on the latest design and technology, while preserving the spirit of tradition of the class; thus utilising modern naval architecture techniques to support the conservation of a historical class.

3. HULL DESIGN

3.1 CLASS RULE

The Thames A Rater class rules [7] specifies the requirements for a craft to meet the one design rule. This ranges from a minimum lightship weight of 750 lbs (340kg), to a maximum mast height from the sheerline of 43ft, and a sail area of 350 ft^2 (32.51m^2). But the primary design constraint is given by rule D2 [7]:

"D2 New Yachts

A new hull will only be considered to be an A class rater hull if it is an exact replica of an existing Rater as defined above, taken from either an existing hull, or original lines, subject in both cases to a tolerance of one and one half inches."

While some linesplans are still in existence, owners are very protective of those. The linesplan of an original Thames A Rater is therefore to be found in the public domain in order to provide the basis of the new yacht. The only publicly available linesplan is featured in the 11th edition of *Dixon's Kemp manual of yacht and boat sailing* [60], reviewed by Linton Hope, who added the linesplan of the Thames A Rater *Scamp*.

3.2 MODELLING SCAMP

Designed in 1902, *Scamp* has always been a successful boat, and being one of the original Thames A Rater, it qualifies as an exact replica of an existing A Rater and will therefore be adopted as the basis hull of the new design.

3.2 (a) Taking the Lines

When dealing with one of the last drawings of an historic craft, the priority is to ensure the integrity of the document and avoid any form of damage to it. With this is mind, the state-of-the-art facilities available at the British Library have been utilised to obtain a digital copy of the linesplan, as shown in Figure 6.

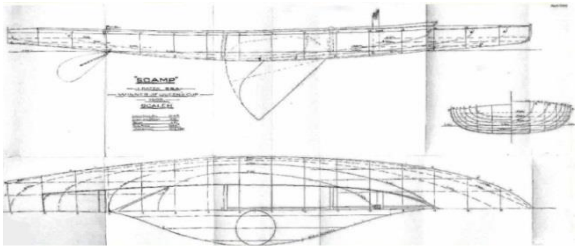

Figure 6: *Original linesplan of Scamp (1902) [10].*

Unfortunately, the drawing was slightly distorted due to the folds and the deformation due to aging. While it constitutes a good graphical representation, it does not allow for an accurate enough modelling of the boat.

As a result, the lines were manually taken off by physical measurements of all the offsets to the closest 1/64th of an inch (accuracy of ± 1/128th of an inch). The lines were taken solely from the body plan. Indeed, since the body plan was drawn over a small area, it had been less affected by distortion and aging or folds compared to the half-breadth and profile view extending the full length of the plan.

3.2 (b) 2D Drawing

The table of offsets realised was then scaled up to full size, converted from imperial to metric, and numerically lofted using computer aided design (CAD). This process enabled to redraw the 2D linesplan, ensuring an exact replica is achieved, as shown in Figure 7.

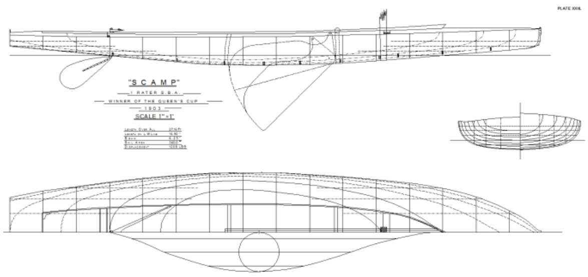

Figure 7: *Replica of the Scamp linesplan.*

Note that this linesplan is an exact replica of the original one, reproducing every detail, even where discrepancies have been noticed, as it is the case with the centreboard, later discussed in Section 4.2 (a).

3.2 (c) 3D Modelling

Scamp was then modelled in 3 dimensions, in a process very similar to the one of traditional boatbuilding. First, the stations are positioned along the length of the craft; a surface is then lofted along those stations with a specified accuracy of 0.01 mm. The process can be observed in Figure 8.

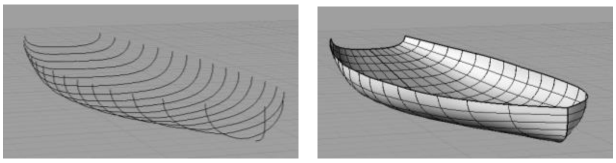

Figure 8: *3D modelling of Scamp.*

The hull surface then allows to ascertain the hydrostatics.

3.2 (d) Hydrostatics

The hydrostatics of the 3D model have been compared to those determined from the replica of the 2D linesplan using Simpson's rule. The results in Table 2 reveal a very accurate modelling, with an average 0.46% difference, well within the uncertainty inherent to each method.

Parameter	Linesplan	3D Model	Diff.	Diff. (%)
LOA (m)	8.28	8.28	0.000	0.00%
Lwl (m)	5.15	5.17	0.019	0.37%
BOA (m)	1.90	1.90	0.000	0.00%
Bwl (m)	1.66	1.64	-0.020	-1.20%
Tc (m)	0.16	0.16	-0.002	-1.25%
F (m)	0.31	0.31	0.000	0.00%
Disp. (m^3)	0.548	0.545	-0.003	0.00%
Awp (m^2)	6.58	6.60	0.020	0.30%
LCB (m)	2.84	2.80	-0.043	-1.53%
LCF (m)	2.81	2.78	-0.033	-1.16%
Cb	0.40	0.40	-0.003	-0.71%
Cp	0.59	0.59	-0.006	-1.04%
Cm	0.68	0.68	0.002	0.34%

Table 2: *Hydrostatics comparison.*

An exact replica of *Scamp* has therefore been achieved, thus complying with the class rule, which does however allow a one and a half inches (31.8mm) building tolerance [7]. Due to the reliability of modern wood construction, and the new boat being cold-moulded, part of that tolerance will be utilised to modify and improve the hull design while still meeting the rule.

3.3 DESIGN MODIFICATIONS

3.3 (a) Design Tolerances

In order to establish how much of the tolerance can be allocated to modify the design, the accuracy lost in modelling the hull from the original linesplan must be evaluated, and building tolerances must be estimated.

By taking the lines off, the accuracy was maximised compared to simply drawing over the top of the linesplan that has been distorted over time. As a result, the replica of the linesplan can be considered as accurate as the measurement tolerance, i.e. 1/128th of an inch (0.20mm), which translates into 1/128th of a foot (2.38mm) full size. To this must be added the 3D modelling accuracy of 0.01mm, giving a total uncertainty of 2.39 mm.

While a high standard of manufacturing can be expected, it is important to allow for slight building inaccuracies, such as the lofting of the station moulds, the natural expansions and contractions of the wood, and the possibility of a human error. An overall margin of 3/8th of an inch (9.53mm) has therefore been allocated to the construction, leaving 19.88mm to modify the hull shape. This value has been rounded up to 20mm, thus decreasing the building tolerance to 9.41mm.

The 20mm margin offers an opportunity to improve the hull design. It is to be noted that, while the overall one and a half inches tolerance will be respected, it is in practice quite hard to enforce this aspect of the class rule. Indeed, while some physical dimensions such as the length and breadth of the boat can physically be measured, a change in curvature in the middle of a section cannot however be clearly identified. This is supported by the International Towing Tank Conference (ITTC) standard for towing tank models manufacturing [11], where a tolerance is allowed for the length, breadth and depth of the model, while other deviations of the hull shape from the intended geometry are neglected due to the impracticalities of comparing the two.

3.3 (b) Empirical Resistance Model

The 20mm allocated to design modification will aim at improving the hull shape by reducing its resistance thanks to parametric optimisation based on the Delft Systematic Yacht Hull Series (DSYHS) [12].

The DSYHS offers regression equations that enable to assess the resistance of a yacht from its principal dimensions. The two main drag components of a bare hull are namely the frictional and the residuary resistance.

At low Froude numbers (slow speeds), the frictional resistance is the major component, and is dependent on the wetted surface area of the hull (and inherent roughness). At higher Froude numbers, the residuary resistance becomes the primary drag component. In this instance, efforts have been focussed on decreasing the resistance at high Froude numbers due to the high speeds and planing ability of the A Raters.

The upright hull residuary resistance Rrh is given by [12]:

$$\frac{Rrh}{\nabla c \times \rho \times g} = a_0 + \left(a_1 \times \frac{LCB_{fpp}}{Lwl} + a_2 \times Cp + a_3 \times \frac{\nabla c^{2/3}}{Aw} + a_4 \times \frac{Bwl}{Lwl} + a_5 \times \frac{LCB_{fpp}}{LCF_{fpp}} + a_6 \times \frac{Bwl}{Tc} + a_7 \times Cm\right) \times \frac{\nabla c^{1/3}}{Lwl} \qquad \text{Eq. 2}$$

In which:

Rrh	Residuary resistance.	N
∇c	Canoe body displacement.	m^3
ρ	Water density.	$kg.m^{-3}$
g	Acceleration due to gravity.	$m.s^{-2}$
LCB_{fpp}	LCB location from the FPP.	m
Lwl	Waterline length.	m
Cp	Prismatic coefficient.	-
Aw	Waterplane area.	m^2
Bwl	Waterline beam.	m
LCF_{fpp}	LCF location from the FPP.	m
Tc	Canoe body draft.	m
Cm	Midship area coefficient.	-
a_0 to a_7	Regression coefficients.	-

3.3 (c) Parametric Optimisation

Thanks to the DSYHS, the most influent parameters on the resistance can be identified. However, the regression coefficients (a_0 to a_7 in Eq. 2) have a varying influence between displacement mode and semi-displacement mode; the sailing regime transition occurring around a Froude number of 0.45 [13].

The hull of the original *Scamp* has therefore been modified based on parametric optimisation to reduce the resistance at higher Froude numbers. The objective was reached with an average 3% reduction in overall resistance in a fully loaded condition (replicating the sailing displacement) past a Froude number of 0.45, as illustrated in Figure 9.

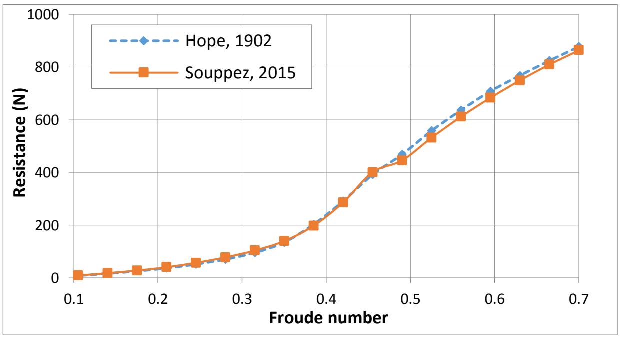

Figure 9: *Resistance comparison.*

The reduction is visible with the sudden discontinuity in the resistance curve occurring at a Froude number of 0.45. A similar resistance decrease was also observed at all sailing heel angles.

3.3 (d) Modified Scamp

The main modifications realised using the 20mm margin include an extended overall length and breadth, to respectively increase the Froude number and form stability. The angle of the bottom of the boat with the waterline being so acute, an additional 20mm of overall length resulted in an impressive 160mm increase in waterline length.

The draft has been shortened to provide a shallower and flatter craft; effectively increasing the values of the midship and prismatic coefficients, desirable for the purpose of the parametric optimisation and planing capabilities.

The modifications induced a 6.19% increase in wetted surface area, which implies a slight increase in frictional drag, largely over-compensated by the resistance reduction at higher Froude number. The comparison between the original Hope design and the modified *Scamp* is summarized in Table 3.

Parameter	Hope	Souppez	Diff. (%)
Length over all (m)	8.28	8.30	0.24%
Length on waterline (m)	5.46	5.62	2.93%
Beam over all (m)	1.90	1.92	1.05%
Beam on waterline (m)	1.67	1.70	1.80%
Canoe body draft (m)	0.185	0.166	-10.27%
Displacement (m^3)	0.652	0.652	0.00%
Midship coefficient	0.734	0.762	3.81%
Prismatic coefficient	0.528	0.546	3.41%
Wetted surface area (m^2)	7.112	7.552	6.19%
Waterplane area (m^2)	6.887	7.330	6.43%

Table 3: *Original and new Scamp design comparison.*

3.4 CONCLUSIONS

The original linesplan of an existing Thames A Rater has been considered for the new design, thus complying with the class rule. *Scamp* was accurately redrawn in 2D and then converted to 3D. By accounting for the modelling uncertainties and estimating the building tolerance required, a 20mm margin has been employed to improve the hull shape. Thanks to parametric optimisation, the resistance at high Froude numbers was reduced by 3%, and enhancements in terms of hydrostatics and stability have been achieved, giving the final hull design for the new A Rater.

No further work has been conducted on refining the hull with other methods, such as computational fluid dynamics (CFD). Indeed, a large amount of time would be required to only provide very minor improvements. Instead, the work has been focussed on the appendages design: since the centreboard and rudder do not have to be replicas, they offer a great opportunity to elaborate the hydrodynamics and will concentrate the majority of the development efforts.

4. APPENDAGES

4.1 COMPUTATIONAL FLUID DYNAMICS

4.1 (a) Modelling and Simplifications

CFD has been employed to provide an initial comparison of a range of planforms for both the centreboard and rudder. The modelling has been heavily simplified: the presence of the hull and free surface and inherent impact on the appendages have been neglected. The appendage tested is therefore modelled alone in a domain of water; this is motivated by the restricted computational power available. All simulations have been performed with a Reynolds-Averaged Navier-Stokes Equations (RANSE) solver.

Since the structural and manufacturing constraints are not known at this stage, the appendages have been treated as thin flat plates. Indeed, the actual section will have to consider the structural requirements, thus dictating the thickness/chord ratio.

4.1 (b) Governing equations

The steady state analysis performed is to satisfy both the continuity (conservation of mass) and the momentum (conservation of linear momentum) equations, respectively given by:

$$\nabla.(\rho\langle u_k\rangle) = 0 \qquad \textit{Eq. 3}$$

And:

$$\nabla.(\rho\langle u_k\rangle\langle u_k\rangle) = -\nabla\langle p\rangle + \nabla.\overline{\tau_k} + \rho\vec{g} \qquad \textit{Eq. 4}$$

Where:

$$\overline{\tau_k} = \mu_{eff}\left(\nabla\langle u_k\rangle + (\nabla\langle u_k\rangle)^T - \frac{2}{3}\mu_{eff}\nabla.\langle u_k\rangle I\right) \qquad \textit{Eq. 5}$$

The k-ε turbulence model [14] has been chosen as it is an industry standard and has been extensively studied [15]. For the purpose of this analysis, a typical turbulence intensity I_T of 5% has been considered. The model is governed by two equations, the turbulence kinetic energy and energy dissipation rate:

$$\nabla.((\langle u_k\rangle\rho k) = \nabla.\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\nabla.k\right] + G_k \qquad \textit{Eq.6}$$

And:

$$\frac{\partial(\rho\varepsilon\langle u_k\rangle)}{\partial x_k} = \frac{\partial}{\partial x_k}\left(\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial\varepsilon}{x_k}\right) + C_{\varepsilon 1}\frac{\varepsilon}{k}G_k - C_{\varepsilon 2}\frac{\varepsilon^2}{k} \qquad \textit{Eq. 7}$$

Where:

$$G_k = \tau_{ik}\frac{\partial\langle u_i\rangle}{\partial x_k} \qquad \sigma_k = 1.00$$

$$\sigma_\varepsilon = 1.3$$

$$\nu_T = C_\mu\frac{k^2}{\varepsilon} \qquad C_{\varepsilon 1} = 1.44$$

$$C_\mu = 0.09 \qquad C_{\varepsilon 2} = 1.92$$

4.1 (c) Domain Size

The domain size, normally expressed in terms of boat length L has been kept relatively small to minimise computation time. The dimensions are: 2L long (0.5L upstream, 1.5L downstream), 0.5L wide, and 0.5L deep. Investigations into wider and deeper domains proved not to impact the results, suggesting that the selected domain is wide and deep enough to avoid blockage issues.

4.1 (d) Mesh

An unstructured mesh was adopted as it is easier and faster to create [15]. In addition, inflation layers have been built around the surface of the appendage to better capture the boundary layer and inherent viscous components.

To maximise accuracy while minimizing computational resources, a mesh convergence study has been conducted; results are shown in Figure 10.

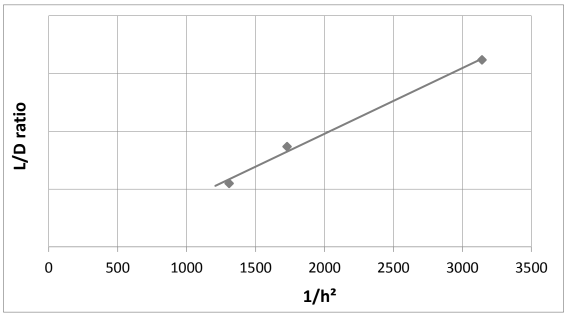

Figure 10: *Convergence study.*

The results reveal the second order nature of the solver (straight line achieved for $1/h^2$), and suggest that the region of monolithic convergence has been reached.

4.1 (e) Error Estimation

The discretization error and grid convergence index (GCI) have been evaluated following the Richardson extrapolation procedure and the Roach and Celik error estimation [16]. The results are summarized in Table 4.

Discretization Error Results						
r_{21}	r_{32}	p	F^{12}_{ext}	e^{21}_{a}	e^{21}_{ext}	GCI^{21}
1.35	1.35	2.58	10.25	0.29%	0.25%	0.32%

Table 4: *Discretization error.*

The negligible errors demonstrate the level of accuracy achieved with the finer mesh; no further refinement appears to be necessary. Indeed, a finer mesh would not significantly increase the accuracy, but induce a tremendous increment in solving time.

4.1 (f) Boundary Conditions

The boundary conditions set are described in Table 5.

Boundary	Applied Condition
Upstream end	Inlet, specified U velocity.
Downstream end	Outlet, specified U velocity.
Surrounding walls	No slip, smooth walls, U velocity.
Centreboard	No slip, smooth wall, stationary.

Table 5: *Boundary conditions.*

4.1 (g) Applications

In order to provide an initial comparison between a range of planforms using a RANSE solver, the problem had to be simplified due to the limited computational resources available. The method presented in this section will be applied to the centreboard and rudder design, respectively tackled in Section 4.2 and Section 4.3.

4.2 CENTREBOARD

4.2 (a) Design Discrepancy

The linesplan of *Scamp* offers two illustrations of the centreboard: one lowered under the hull (*centreboard 1*), and one retracted inside (*centreboard 2*). Careful analysis of the drawing revealed that those two centreboards are not identical, as depicted in Figure 11.

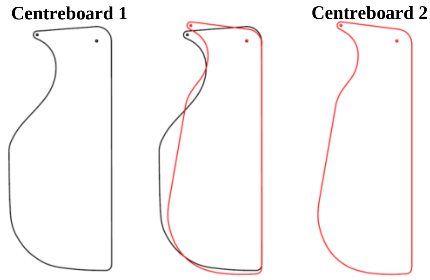

Figure 11: *Centreboards discrepancy.*

This difference is too extreme to simply result from a deformation of the plan, and is assumed to be a drawing error. Whilst it is impossible to know with certainty which one is the intended planform and which one is the mistake, two arguments would suggest that *centreboard 1* is the original design.

Firstly, *centreboard 1* is drawn as a solid thick line in the lowered position, where the centreboard is to operate. Conversely, *centreboard 2* is a thin dotted line that would typically be drawn as a rotation of the lower one, and therefore prone to a drawing mistake.

In addition, the choice of the appendages area was often taken as a percentage of the sail area; an approach still employed by many designers today.

Centreboard 1 represents 2.30% of the sail area, which when added to the rudder area gives a total 3.00%, both round numbers suggesting they are the intended proportions. Conversely, *centreboard 2* has an area equal to 2.12% of the sail area, as summarised in Table 6.

Appendage	Area (m²)	% of Sail Area
Centreboard 1	0.76	2.30%
Centreboard 2	0.70	2.12%
Rudder	0.23	0.70%

Table 6: *Appendage areas.*

There is therefore evidence to suggest *centreboard 1* is the intended planform, but no certainty, hence both centreboard designs will be considered and analysed.

4.2 (b) Area

The planform area can lead to a large loss of performance if too little or too much is provided, respectively resulting in high leeway angle and added frictional resistance. In this case, one option could be to keep the original design area (2.30%). Alternatively, an empirical estimate can be calculated [17]:

$$\frac{KA}{SA} = 0.039 \times \frac{Tk}{LOA} + C \qquad \textit{Eq. 8}$$

In which:

KA/SA	Keel/sail area ratio.	%
Tk	Keel draft.	m
LOA	Length overall.	m
C	0.018 for racing yachts.	-

In this case, a 2.51% ratio is obtained.

Finally, a more advanced method [18] based on the area required when coming out of a tack in light winds has been applied. A keel area of 2.27% of the sail area has been ascertained, i.e. very close to the original 2.30%. The later value has therefore been conserved.

4.2 (c) Comparative Study

Having established the keel area (2.30% or 0.76m²), and based on the draft restriction of the area of operation [8], a range of possible designs have been investigated, based on the setup outlined in Section 4.1. Indeed, the class rule does not specify that the appendages have to be replicas of the original, thus allowing for hydrodynamic improvements. The centreboard designs considered are briefly described in Table 7 and illustrated in Figure 12.

Design	Characteristics
Scamp 1	Centreboard 1 [10].
Scamp 2	Centreboard 2 (see 4.2 (a)) [10].
Sorceress	L. Hope design for *Sorceress* [10].
Semi-Elliptic	Elliptical loading (cf. Spitfire wings).
Rectangular	Easiest to manufacture.
Inverted	Increased ballast lever (cf. *Australia II*).
Stewart	Stewart modern A Rater design [19].
Scow	Found on modern scows (cf. *E-Scow*).
45% Taper	Hydrodynamic optimum taper ratio [20]
20° Swept	Popular dinghy design [20].

Table 7: *Centreboard designs.*

Figure 12: *Centreboard designs investigated.*

The analysis has been performed at 15° of heel and 5° of leeway, for speeds of 1, 2, 3, 4 and 5 m/s, representative of typical sailing conditions.

4.2 (d) Results

The deltas (change) in lift/drag ratio compared to the original centreboard (Scamp 1), are shown in Figure 13.

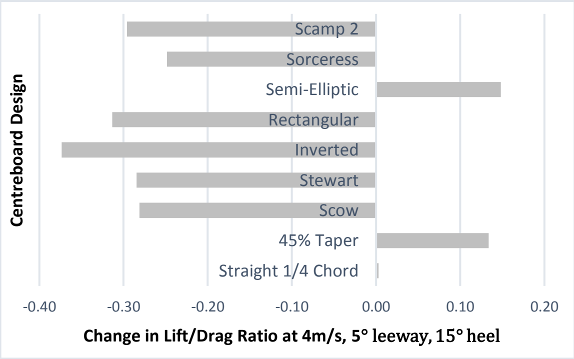

Figure 13: *Centreboards delta in Lift/Drag ratio.*

The overall design ranking is as expected: the semi-elliptic and 45% taper ratio, both promoting elliptical spanwise loading, proved to be the most efficients, especially at low speeds, due to a large reduction in tip vortex. The better hydrodynamic performance of the semi-elliptic centreboard constitutes a 1.8% improvement in terms of lift/drag ratio compared to the original.

4.2 (e) Section

The foil section of yachts are generally NACA 00 series, due to their better hydrodynamic performance, with a higher lift/drag ratio and a delayed stall angle compared to NACA 63, 64, and 65 series. A closer analysis revealed further advantages of the NACA 00 series.

Indeed, as detailed in Table 8, a NACA 00 series has the highest sectional area coefficient. Consequently, the ballast/WSA ratio will be the highest, meaning a lower wetted area and frictional resistance for a given volume.

Moreover, the section modulus/WSA ratio is also the highest, hence for a given structural requirement, a NACA 00 will again have a lower wetted area and thus less drag.

Section	Area Coeff.	Ballast/WSA	SM_T/WSA
NACA 0012	0.676	100%	100%
NACA 63 012	0.659	97.65%	95.19%
NACA 64 012	0.628	92.90%	86.30%
NACA 65 012	0.644	95.29%	90.79%

Table 8: *NACA series comparison.*

The thickness/chord ratio was dictated by the structural constraints from the ISO 12215-9 [26] and varies from the root to the tip due to the decreasing bending moment, with an average value of 7.2%.

4.2 (f) Conclusions

Based on the hydrodynamic analysis, the semi-elliptic centreboard appears to be the most efficient, and will therefore be the proposed design. In addition, due to its geometrical properties, the centreboard offers one of the highest centres of lateral resistance, thus decreasing the heeling arm, contributing to an improved stability. A NACA 00 section has been chosen and an average 7.2% thickness/chord ratio was defined based on the structural analysis.

4.3 RUDDER

4.3 (a) Area

As per the centreboard, the rudder area is generally expressed as a ratio of the sail area. For small yachts, 1.5% is usually advised [20]. This value however appears to be excessive for the A Rater *Scamp*, having less than half the area suggested.

Comparing the appendages of *Sorceress* (1894) and *Scamp* (1902), both designed by Linton Hope, showed that both the rudder and centreboard areas had been decreased, suggesting that only a minimum area is required. As a result, the original rudder area of 0.23m², or 0.70% of the sail area, will be kept. The rudder planform will however be redesigned.

4.3 (b) Comparative Study

Using the same CFD approach as for the centreboard, various rudder planforms will be investigated; aiming at increasing the rudder aspect ratio to improve the hydrodynamic performance. The ten designs testd are depicted in Figure 14 and characterised in Table 9.

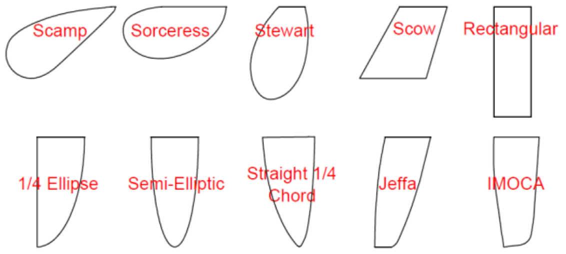

Figure 14: *Rudder designs investigated.*

Design	Characteristics
Scamp	Original *Scamp* rudder [10]
Sorceress	L. Hope design for *Sorceress* [10].
Stewart	Stewart modern A Rater design [19].
Scow	Found on modern scows (cf. *E-Scow*).
Rectangular	Easiest to manufacture
1/4 Ellipse	Popular hydrodynamic design [20].
Semi-Elliptic	Elliptical spanwise loading.
Straight 1/4 chord	Popular hydrodynamic design [20].
Jeffa	Typical modern cruiser/racer design.
IMOCA	Typical modern fast racing design.

Table 9: *Rudder designs.*

4.3 (c) Results

The analysis has been performed at 15° of heel and 5° of leeway, for speeds of 1, 2, 3, 4 and 5 m/s, as per the centreboard, with however different results due to the change in aspect ratio. The differences in lift/drag ratio compared to the original rudder (Scamp) are shown in Figure 15.

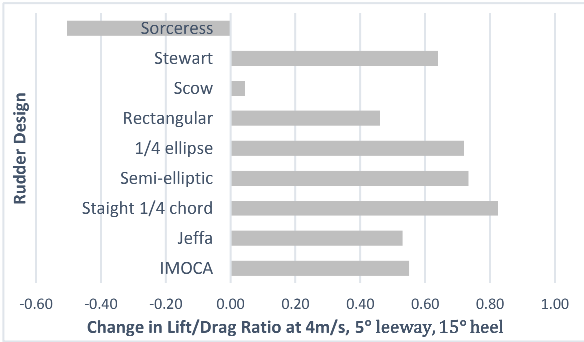

Figure 15: *Rudders delta in Lift/Drag ratio.*

The straight ¼ chord rudder appears to provide more lift and less drag than the other planforms tested, and led to a 10.5% improvement compared to the original. Those results are supported by tests realised for a rudder angle of 15° (close to stall), where the straight ¼ chord also proved to be the most efficient, as it provides a significant decrease in tip vortex compared to the original *Scamp* rudder.

4.3 (d) Section

A NACA 00 series has been selected due its higher stall angle compared to other NACA series. A thin foil would have minimum drag but a low stall angle. Conversely, a thick foil would delay stall, but increase the drag.

A 12% thickness/chord ratio is often seen as a good compromise, and was adopted in this case. Moreover, the chosen section also proved to be structurally suitable and able to accommodate the rudder stock diameter required to satisfy the ISO 12215-8 [25].

4.3 (e) Conclusions

Following a comparative CFD analysis, a straight ¼ chord line rudder configuration has been selected, with a standard NACA 0012 foil section.

4.4 CONCLUSIONS

A basic CFD setup has be used to contrast a range of planforms for both the centreboard and rudder, aiming at a maximum lift developed for a minimum drag. A semi-elliptic planform was therefore chosen for the centreboard, while a straight ¼ chord proved to be the most efficient rudder. The new centreboard and rudder improved the lift/drag ratio by 1.8% and 10.5% respectively compared to the original design. However, further considerations such as the location of the appendages will be required to achieve a better balance between the aerodynamic centre of effort of the sails and the hydrodynamic centre of lateral resistance of the appendages, detailed in Section 6.2 (b).

5. COCKPIT DESIGN

5.1 INTRODUCTION

The design of a practical, polyvalent, and safe cockpit is a major requirement for open boats. The three main cockpit design philosophies are depicted in Figure 16, and are namely:

- A narrow rectangular cockpit, such as the original *Scamp* (left).
- A slightly wider cockpit running parallel to the sheer (centre).
- A very wide cockpit (right).

Figure 16: *Cockpit design philosophies [7].*

The pros and cons will be highlighted in order to find a compromise, with considerations for downflooding, ergonomics and anthropometrics.

5.2 SIDE DECK WIDTH

5.2 (a) Downflooding Angle

The foremost consideration inherent to the downflooding angle is the width of the side decks, and resulting width of the cockpit. On original A Raters such as *Scamp*, the governing factor was avoiding water intake when heeling over or capsizing. The angle at which water gets inside the cockpit is known as the downflooding angle. As presented in Figure 17, the downflooding angle of *Scamp* is just above 90°, thus coherent with a safe design to avoid water intake, and potentially sinking the boat when capsizing.

Nowadays, the buoyancy aid imposed by the A Rater class rule [7] prevents sinkage, leading to much more open cockpits. This allows more space for manoeuvers, and the crew can provide an increased righting moment without having to hike yet since they are sitting further out. The drawback is an earlier water intake, potentially within operating heeling angles, which would handicap the performance of the boat.

The proposed design offers a good compromise, with a 350mm wide side deck, which allows both a comfortable and efficient position of the crew, while retaining a high downflooding angle of 48°, thus satisfying the relevant ISO regulation [21], as demonstrated in Figure 17.

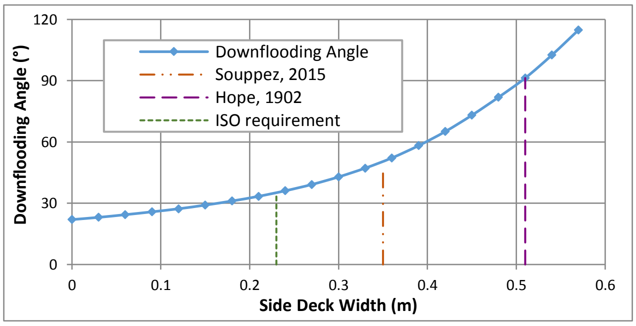

Figure 17: *Downflooding angle.*

5.2 (b) Ergonomics and Anthropometrics

Another decisive factor, unfortunately rarely incorporated in deciding upon the width of the side deck is the location of the sailor's back-knee. Consequently, both ergonomics and anthropometrics have been taken into account, respectively defined as the science of designing spaces and environments and the study and measurements of human proportions.

From a comfort point on view, any edge resting on the back-knee when hiking is particularly painful, and the position cannot be sustained for prolonged amount of time. Furthermore, experiments realized on improving hiking positions [22] revealed that the shorter the back-knee/sheer distance, the more efficient and comfortable the hiking is.

With the proposed cockpit, the sheer lies just above the back-knee when fully hiked, for a prolonged and efficient contribution to the righting moment. Plus, the inner edge of the cockpit will also lie just above the back-knee of a crew seeking support on the centreboard case.

The width of the cockpit and resulting side decks width have therefore been fixed based on both downflooding angle and comfortable hiking. The length of the deck however is governed by a different factor.

5.3 DECK LENGTH

Longitudinal strength is a likely issue for a yacht such as the A Rater, as confirmed by the ISO 12215-6 guidance [23]. Thus the deck offers a significant structural contribution not to be neglected. Indeed, considering the entire boat as a beam, the deck is located away from the neutral axis, hence its predominant contribution.

On the one hand, a small open space has been retained in front of the mast in order to provide a convenient location to store excess ropes or gear, without it overcrowding the cockpit.

On the other hand, the aft deck has been extended forward of the rudder stock; this will also provide a stronger support point for the top rudder bearing, thus improving the steering comfort.

However, the deck cannot be fully closed, as it must provide sufficient space for the crew to perform manoeuvres. Furthermore, the mass of the crew constitutes a large proportion of the overall weight; a large cockpit offering a wide range of longitudinal positions for the crew will therefore improve the sailing equilibrium. To encourage this, the compartments of the cockpit have been redefined.

5.4 COMPARTMENTS

The cockpit of the original *Scamp* is divided into three main areas, one for each crew. The helmsman has the largest, while the forward crew is confined into a very small space. This is in contradiction with a typical race crew organization, where the helmsman would remain mostly static, while the two other crew would be in charge of the balance. It is therefore crucial to have the ability to move forward and aft so that the longitudinal balance of the yacht can be adjusted, particularly to promote planing.

The new cockpit is only composed of two compartments: the aft one dedicated to the helmsman, and a spacious forward one for the two crew members. As a result, the sailors can move further forward and further aft, while still having all control lines in close proximity.

The definition of the compartments is primarily dictated by the location of the two main structural bulkheads. The first one, in way of the mast, has to withstand the mast, shrouds, and centreboard loads. The second one, separating the two main cockpit areas, supports the aft end of the centerplate case, the mainsheet, traveller and running backstays.

5.5 CONCLUSIONS

Starting from the original cockpit, an improved version has been designed, with a smaller side deck width to provide a more comfortable hiking position, while retaining a high downflooding angle. In addition, the overall length of the cockpit has been decreased for structural purposes, the actual usable volume has however been greatly increased. Finally, a new layout has been created, offering a larger compartment for the two forward crew members. A graphical comparison of the original and new cockpit designs is presented in Figure 18.

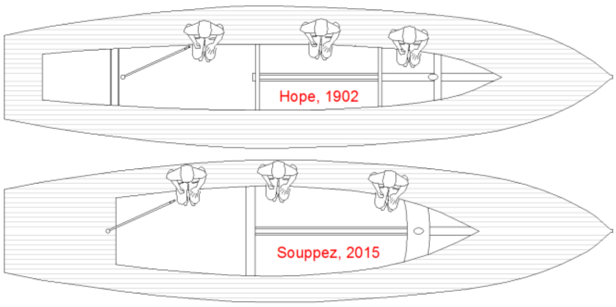

Figure 18: *Cockpit layout comparison.*

6. DESIGN EVALUATION

6.1 COMPLIANCE

The vessel was designed for the RCD II, taking into account the relevant harmonised ISO standards. All requirements have been satisfied for category C, inshore, rather than category D, inland. This is primarily motivated by the extreme nature of the Thames A Rater, thus providing an additional factor of safety; but also to extend the vessel's programme to inshore sailing, thus widening the area of operation.

6.1 (a) Structural Design

In order to fit with the shipyard's production technology and retain a wooden hull while having a light, strong and durable boat, a cold-moulded hull has been designed. The final hull is made of three layers of 2.5mm African mahogany (*khaya anthotheca*) veneers, the outer one running fore and aft to conserve a traditional look, and sheathed with an E-glass DB 300 for a see-though finish. Douglas fir (*pseudotsuga menziesii*) longitudinal stiffeners and plywood frames and bulkheads complete the hull shell structure.

The scantlings of the vessels have been checked and proven to comply with the ISO 12215-5 [24] for the hull, also considering the global load case recommended in the ISO 12215-6 [23]. Furthermore, the rudder and centreboard and inherent supporting structures have been demonstrated to meet the requirements of the ISO 12215-8 [25] and ISO 12215-9 [26] respectively.

6.1 (b) Stability

As a sailing vessel of hull length greater than 6m, the Thames A Rater is to comply with the ISO 12217-2 [21]. Although compliance can be demonstrated in this case by a capsize recovery test only, at a design stage and in order to ensure compliance with category C, requirements such as downflooding opening and heights, wind stiffness and flotation requirements have been considered.

6.2 PERFORMANCE

6.2 (a) Sails

Vortex lattice method (VLM) was employed for the design of the sails, with particular attention to minimising the vortices created. Furthermore, to maximise the aerodynamic efficiency of the jib, a flatter foredeck was implemented, thus reducing the gap between the foredeck and foot of the jib to a value much lower than the current A Raters. The effect is a 6% reduction in drag and a 4% improvement in lift [20].

Finally, two reefs were added based on the velocity prediction programme (VPP) detailed in Section 6.2 (c), representing respectively 75% and 45% of the full main sail area. Those particular values have been chosen to give the best performance to the new A Rater in a wider range of weather conditions.

6.2 (b) Balance

Absolutely critical to achieve a performance yacht, balance between the hydrodynamic forces applied at the centre of lateral resistance (CLR) and the aerodynamic forces acting through the centre of effort (CE) of the sails must be achieved. However, good balance does not consist in a perfect equilibrium where no rudder angle is needed; a slight weather helm is preferred. Indeed, a small amount of weather helm makes the yacht safer in gusts as it lifts up into the wind, thus depowering the sails. Furthermore, it provides good feedback to the helmsman. Finally, weather helm means the rudder side force acts together with the centreboard side force.

However, locating the CLR and CE is a complex problem. In this case, the centre of lateral resistance was assessed using the method proposed by Delft [27, 28], while the centre of effort was considered as the geometric centre of area of the sails; a common assumption, mostly valid for small and moderate angles of heel [29]. The relative position of the CE in front of the CLR, known as the lead, is typically expressed as a percentage of the waterline length (Lwl). In this instance, a 7% lead was considered, at the upper end of the range suggested by the literature for fractional sloops [17, 20]; this is justified by the beamy design coupled with a high aspect ratio rig. Furthermore, should the lead prove to be unsuitable during sea trials, it is always easier to move the CE back (by raking the mast for instance), than bringing it forward. Consequently, greater lead values are seen as safer.

6.2 (c) Velocity Prediction Programme

The planing abilities of the Thames A Rater are not particularly well modelled in most commercially available VPP software; hence the creation of a six degrees of freedom VPP with the addition of planing behaviour by adapting Savitsky's planing theory for flat plates [30, 31]. The hydrodynamic resistance was calculated in accordance with the Delft Systematic Yacht Hull Series [32], and the aerodynamic forces are based on the Offshore Racing Congress coefficients [33].

The VPP created was first used to assess the performance of the original *Scamp*, and later compare it with the proposed design. The results in 4, 8, 12 and 16 knots of true wind speed (TWS) are presented in Figure 20.

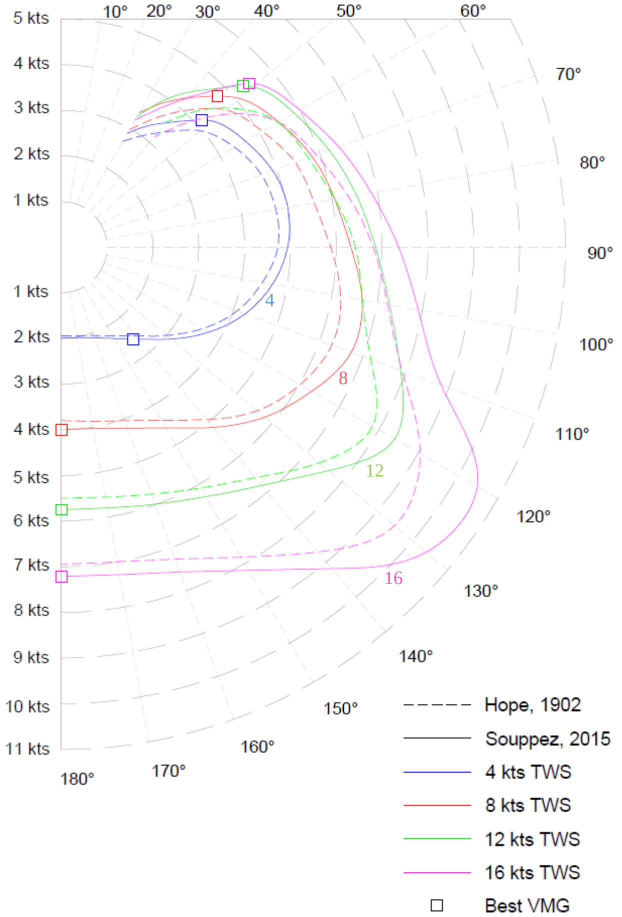

Figure 20: *VPP results comparison.*

The new design appears to be faster than the original one, both upwind and downwind. Indeed, in addition to the lower hydrodynamic resistance and higher drive force, additional factors contributed to the large increase in performance.

Firstly, the reefed mainsail, higher CLR location, added form stability and more efficient hiking led to a faster boat upwind, especially in stronger winds as the crew can fully handle the yacht. Downwind, the flatter hull shape combined with the ability for the crew to move longitudinally thanks to the new cockpit layout enhances the planing capabilities, that can be seen between 110º and 130º of true wind angle at the higher wind speeds, where the gains in speed are the most significant. Finally, the increase in speed is much smaller dead-downwind, where the stability, longitudinal balance and high aspect ratio foils have very little impact on the sailing.

6.3 CONCLUSIONS

The proposed design has been shown to comply with the requirements for category C for both stability and structure. Furthermore, the VPP created allowed to demonstrate and quantify the benefits of the modern naval architecture techniques employed to improve the performance of the A Rater.

7. CONCLUSIONS

The Thames A Rater class provides a fantastic insight into the history of British inland racing, but also represents an example of a traditional class that remains particularly attractive for racing. The Thames A Raters demonstrate the possibility of preserving their legacy while evolving with technology. The rig and sails being a perfect example, as well as the use of composites and contemporary construction methods.

Based on those observation, the modern design of Thames A Rater was undertaken. The new design is based on an existing linesplan, thus complying with the class rule requirements. However, the application of modern techniques such a computational fluid dynamics and parametric optimisation allowed to significantly improve the hydrodynamics of the hull. Ergonomics and anthropometrics have been considered to provide a cockpit layout more in line with today's racing crew organisation. Throughout the project, the rules and regulations, namely the RCD II and relevant ISO standards, have been applied, with particular emphasis on stability and scantlings. The more efficient sail plan, optimised thanks to vortex lattice method and additional considerations, such as the reduction of the gap between the foot of the jib and foredeck, resulted in a significant increase in performance, highlighted and quantified by the VPP. The new design allows to conserve a traditional appearance, yet making the boat more competitive.

There is therefore a place for modern naval architecture techniques, not only for the conservation of historical crafts, but also to ensure their sustainability through time, by offering additional performance and compliance with modern regulations, while retaining the original spirit of tradition.

8. REFERENCES

[1] LAITY, M., 'Thames Clubs', *Classic Boats,* 2001

[2] LAITY, M., 'Bell Boy', *Classic Boats,* 2007.

[3] FROUDE, W., 'Experiments of the surface friction experienced by a plane moving through water', *Report to the British Association for the Advancement of Science*, 1872.

[4] FROUDE, W., 'Report to the Lords Commissioners of the Admiralty on experiments for the determination of the frictional resistance of the water on a surface under various conditions', *Report to the British Association for the Advancement of Science*, 1874.

[5] UPPER THAMES SAILING CLUB, 'Upper Thames sailing club gallery', *Available online: http://bew.utsc.org.uk/*, 2015.

[6] PHILLIPS, M., 'Ulva', *Available online: http://www.tradboatrally.com*, 2005.

[7] THAMES SAILING CLUB, 'The Thames A Rater Association Rules', *Thames Sailing Club*, 2007.

[8] BROADS AUTHORITY, 'Norfolk and Suffolk Broads Act', *Available online: http://www.broads-authority.gov.uk/*, 1988.

[9] EUROPEAN PARLIAMENT, 'Directive 2013/53/EU', *Official Journal of the European Union*, 2013.

[10] 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.

[11] INTERNATIONAL TOWING TANK CONFERENCE, 'ITTC recommended procedures and guidelines: model manufacture, ship models', *23th International Towing Tank Conference*, 2002.

[12] KEUNING, J. A. and KATGERT, M., 'A bare hull resistance prediction method derived from the results of the delft systematic yacht hull series extended to higher speeds', *Delft University of Technology*, 2008.

[13] REMMLINGER, U., 'Bare hull resistance prediction based on the Delft Systematic Yacht Hull Series', *Ulirch Remmlinger*, 2014.

[14] LAUNDER, B. and SPALDING D., 'Mathematical models of turbulence', *Academic Press, London*, 1972.

[15] SOUPPEZ, J-B., 'On the use of unstructured meshes for free surface flow around a yacht hull', *The University of Auckland*, 2014.

[16] CELIK, I. B., 'Procedure for estimation and reporting of discretization error in CFD applications', *West Virginia University*, Undated.

[17] WALLIS, S., 'Marine craft design and development: keel and ballast', *Southampton Solent University*, 2011.

[18] SOUPPEZ J-B., 'Design and production of a one-off 32 feet wooden racing yacht dedicated to Southampton Solent University', *Southampton Solent University*, 2013.

[19] STEWART, J., 'The design of a Thames A Class Rater', *Southampton Solent University*, 2002.

[20] LARSSON, L. and ELIASSON, R., 'Principles of yacht design', *Adlard Coles Nautical, London*, 2007.

[21] INTERNATIONAL ORGANISATION FOR STANDARDISATION, 'BS EN ISO 12217-2:2015 - Small Craft – Stability and buoyancy assessment and categorization. Part 2: Sailing boats of hull length greater or equal to 6m', *International Organisation for Standardization*, 2015.

[22] LE DEROFF, J. Y. and LACHIKINE, P., 'Righting moment measurement on Laser class', *Ecole Nationale de Voile*, 2001.

[23] INTERNATIONAL ORGANISATION FOR STANDARDISATION, 'BS EN ISO 12215-6:2008 - Small Craft – Hull Construction and Scantlings. Part 6: Structural Arrangements and Details', *International Organisation for Standardization*, 2008.

[24] INTERNATIONAL ORGANISATION FOR STANDARDISATION, 'BS EN ISO 12215-5:2008+A1:2014 - Small Craft – Hull Construction and Scantlings. Part 5: Design Pressures for Monohulls, Design Stresses, Scantlings Determination', *International Organisation for Standardization*, 2014.

[25] INTERNATIONAL ORGANISATION FOR STANDARDISATION, 'BS EN ISO 12215-8:2009 - Small Craft – Hull Construction and Scantlings. Part 8: Rudders', *International Organisation for Standardization*, 2009.

[26] INTERNATIONAL ORGANISATION FOR STANDARDISATION, 'BS EN ISO 12215-9:2012 - Small Craft – Hull Construction and Scantlings. Part 9: Sailing Craft Appendages', *International Organisation for Standardization*, 2012.

[27] GERRITSMA, J. and KEUNING, J. A., 'Further experiments with keel-hull combinations', *SNAME First Tampa Bay Sailing Yacht Symposium*, 1986.

[28] KEUNING, J. A. and VERWERFT, B., 'A new method for prediction of the side force on keel and rudder of a sailing yacht based on the results of the Delft systematic yacht hull series', *The 19th Chesapeake sailing yacht symposium, Annapolis*, 2009.

[29] SOUPPEZ J-B., 'Upwind wind tunnel testing of the Stewart 34', *The University of Auckland*, 2014.

[30] SAVITSKY, D., 'Hydrodynamic design of planning hulls', *SMANE transactions*, 1964.

[31] SAVITSKY, D. and BROWN, W. P., 'Procedures for hydrodynamic evaluation of planning hulls in smooth and rough water', *Marine Technology*, 1976.

[32] KEUNING, J. A. and KATGERT, M., 'A bare hull resistance prediction method derived from the results of the delft systematic yacht hull series extended to higher speeds', *Delft University of Technology*, 2008.

[33] OFFSHORE RACING CONGRESS, 'ORC VPP Documentation', *Available online: http://www.orc.org*, 2013.

9. AUTHORS BIOGRAPHY

Jean-Baptiste R. G. Souppez holds the current position of Lecturer in Yacht Design and Composite Engineering at Southampton Solent University. He is responsible for delivering a number of units on the BEng (Hons) Yacht and Powercraft Design and BEng (Hons) Yacht Design and Production, and is a member of the ISO working group 18 (ISO 12215). He graduated from the BEng (Hons) in Yacht and Powercraft Design at Southampton Solent University, from the Diploma in Practical Boatbuilding at the International Boatbuilding Training College and from the MEngSt in Yacht Engineering at the University of Auckland.