COMPARATIVE PERFORMANCE PREDICTION OF HISTORICAL THAMES A RATER CLASS DESIGNS

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SUMMARY

The Thames A-Rater fleet is a unique class both in appearance and in its combination of historic and modern technologies. With high aspect ratio, carbon fibre rigs fitted onto wooden hulls, many of which have survived two World Wars, the class is a demonstration of the evolution of sailing technology. In more recent decades, various attempts have been made to expand the class with new composite boats. However, due to the strict rules issued by the class association, new hulls must be exact replicas of existing A-Raters, with a 1.5 inch tolerance. Furthermore, as only one linesplan exists in the public domain, the expansion of the fleet is extremely limited.

Consequently, in order to ensure the conservation of some of these historic designs, the lines of several vessels were taken off and used to create accurate linesplan and 3D models. The comparative performance of the various crafts was then assessed through a Velocity Prediction Programme, focused on the specific environmental conditions of the vessels' main operating area, eventually ascertaining the hull with the best racing potential by design.

1. INTRODUCTION

Advances in naval architecture theory and inherent technology has allowed to take a closer and more refined approach to the analysis of historical crafts. The intention is not only to widen the knowledge of past designs, but also to ensure their conservation. This particular paper focuses on the British Thames A Rater class, with the ambition to contribute to the conservation of these historic designs, as well as identify the best performing one, to further promote the revival and growth of the class.

Firstly, the history underpinning the Thames A Rater class will be introduced, with a strong focus on the novelty and innovations that this atypical racing class has provided for over a century. Then, two methods of conservations will be presented, namely modelling hulls from either original linesplan, or by taking the lines off existing vessels. In both cases, the final product is a table of offsets, allowing for an accurate 3D model to be made. Finally, the performance of the various hulls fitted with identical rig, sails and appendages will be ascertained using a velocity prediction programme (VPP), thus identifying the fastest design.

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, with Hope's yachts being better suited to upwind sailing while 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 member, 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].*

After the *'bell rope'* was 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 and aluminium spars. 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.

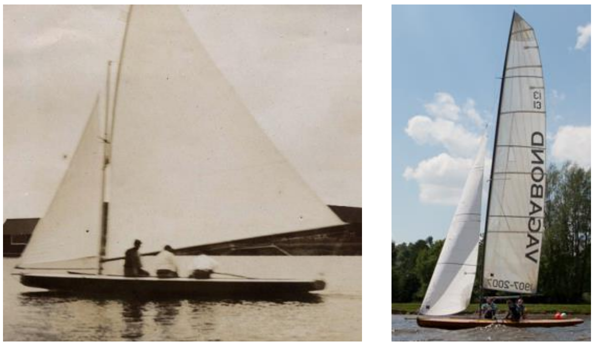

Figure 3: *Rig in 1907 (left) [2] and 2014 (right) [5].*

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 evolution of 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 renewed 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 a change in rules also took palce: no new design would be allowed, and 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 to have been built is pictured in Figure 5.

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

2.6 DEVELOPMENT AND GROWTH

The current challenge is to provide a new opportunity for the Thames A Rater class to grow and develop its racing fleet. In order to support this ambition, a number of linesplan for existing vessels will be gathered, and converted into 3D models. This will either be based on existing linesplan, as detailed in Section 3, or by taking the lines off existing vessels, as presented in Section 4. From the database of designs, the most efficient hull leading to the fastest boat of the water will be identified. This will then be adopted as the base hull for the next generation of Thames A Raters.

3. LINESPLANS CONSERVATION

3.1 ORIGINAL LINESPLAN LOFTING

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 ($32.51 m^2$). 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 therefore has 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* [8], reviewed by Linton Hope, who added the linesplan of the Thames A Rater *Scamp*.

3.2 TAKING THE LINES

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.

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.

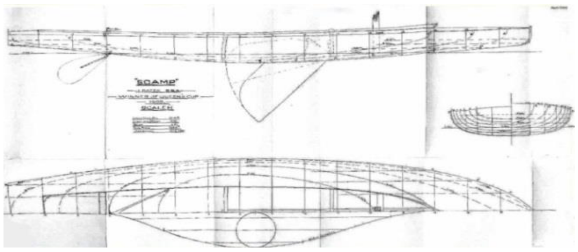

Figure 6: *Original linesplan of Scamp (1902) [8].*

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.

3.3 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 the redrawing of the 2D linesplan, ensuring an exact replica is achieved, as shown in Figure 7.

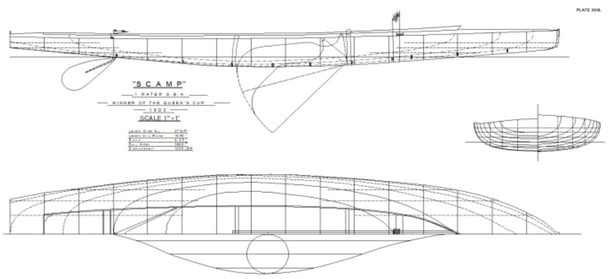

Figure 7: *Replica of the Scamp linesplan [9].*

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.

3.4 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.

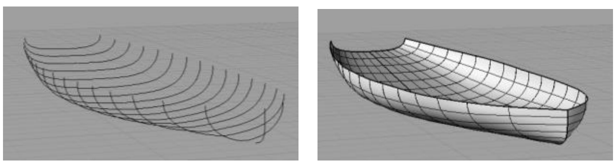

Figure 8: *3D modelling of Scamp.*

The hull surface then allows to ascertain the hydrostatics, compared to the expected values derived from the linesplan, in order to ensure the accuracy of the modeling process, and thus compliance with the strict tolerance of the class rule.

3.5 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%
Disp. (m^3)	0.548	0.545	-0.003	0.00%
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%

Table 2: *Hydrostatics comparison.*

An exact replica of *Scamp* has therefore been achieved, thus complying with the class rule.

4. HULL MODELLING

4.1 HULL MEASUREMENTS

To satisfy the primary ambition of this project, namely to preserve the Thames A Rater designs, a method for producing a table of offsets from hand measurements was applied.

A right-angled triangle jig was designed and built from metal and wood with horizontal shelves at 50mm vertical intervals, as shown in Figure 9.

Figure 9: *Rig used to take offsets from hull*

Measurements were made to a high degree of accuracy, ensuring it was perfectly level and square. The hull was first measured for its overall length, breadth and depth. The length of the vessel was then separated into 10 equally spaced stations and the jig was lined up at right angles to the centreline of the vessel at each station. The height of the jig was adjusted so that the top shelf lined up with the sheer line, the jig was levelled and the distance from the centreline to a known point on the jig was measured and recorded. The distance from the known point to the sheer line was then recorded with a meter rule to an accuracy of ±0.5mm. This procedure was then repeated on all the shelves down from the sheer line and finally the canoe body depth at the station was measured. The procedure was performed for all the stations down the length of the boat. The same method was also used to measure some of the aesthetic features of the hull such as the reverse raked transom and the bow curvature. Ultimately, a detailed table of offsets was produced, as illustrated for the boat *Spindrift* in Table 3.

Station	Sheer	Waterlines								canoe body line
		1	2	3	4	5	6	7	8	
0	0.276	0.258	0.218	0.181	0.139	0.091				-0.050
1	0.588	0.562	0.522	0.475	0.429	0.367	0.289			-0.095
2	0.806	0.788	0.754	0.723	0.682	0.629	0.565	0.446	0.253	-0.162
3	0.940	0.920	0.896	0.870	0.838	0.792	0.719	0.625	0.476	-0.190
4	1.027	1.012	0.992	0.969	0.944	0.909	0.848	0.776	0.632	-0.210
5	1.080	1.064	1.042	1.025	0.993	0.968	0.904	0.782	0.608	-0.195
6	1.107	1.084	1.065	1.041	1.009	0.970	0.915	0.819	0.614	-0.190
7	1.059	1.048	1.024	0.995	0.954	0.894	0.801	0.613		-0.117
8	0.944	0.933	0.898	0.860	0.790	0.668	0.409			-0.075
9	0.788	0.773	0.717	0.640	0.476					0.000
10	0.587	0.557	0.481	0.333						0.065
T	0.423	0.367	0.209							0.115

Table 3: *Example of table of offsets for Thames A Rater*

4.2 POINT CLOUD MEDELLING

The table of offsets collected from the hull measurements was formatted and imported into a hull modelling software. The station spacing, and vessel base line was defined. The result is a point cloud for the half-hull of the vessel, depicted in Figure 10.

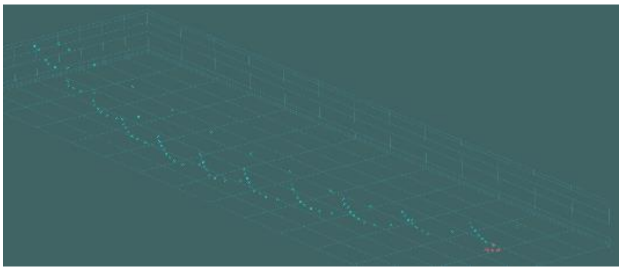

Figure 10: *Point cloud achieved from the table of offsets.*

4.3 GENERATING SURFACE

An editable surface was then generated, with a web of control points related to the markers, aiming for close proximity. Using handmade adjustments of control points, the surface was then minorly altered to bring it as close to the markers as possible and increase the degree of accuracy of the model to well within the required 1.5 inch required by the class rule. The final faired 3D model for *Spindrift* can be seen in Figure 11. The same process was repeated for *Dainty Too*. The resulting linesplans for *Scamp* introduced in Section 3 and those of *Spindrift* and *Dainty Too* can be found in the Appendices.

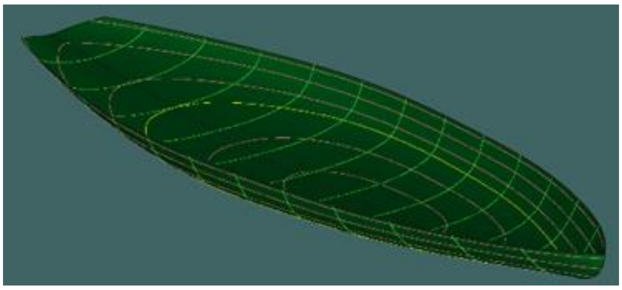

Figure 11: *Surface Generated and fitted to point cloud*

5. VELOCITY PREDICTION PROGRAM

5.1 TECHNICAL BACKGROUND

At a design stage, the performance of sailing yachts can be assessed by way of a velocity prediction programme. In this particular instance, a three degrees of freedom VPP was conducted, achieving equilibrium for the surge, sway and roll.

The hydrodynamic resistance model was based on the Delft Systematic Yacht Hull Series (DSYHS) [10], with all the Rater hulls fitting within the series. The aerodynamic model, based on Hazen coefficients [11], allowed to quantify the sail forces, and in turn the drive force, sail side force, and heeling moment. The boat speed, leeway angle and heel angle required for equilibrium can then be ascertained, thus providing the theoretical optimum boat speed for each vessel at given points of sails in given wind conditions.

To ensure that the ideal hull design, from a performance perspective, is identified, only the hulls were varied for the comparative performance assessment. The rig, sails and appendages were all kept constant for the various historical hull designs.

5.2 RIG, SAILS AND APPENDAGES

A set of foils and spars were designed to be used in the VPP. Each hull would be tested with these appendages under the same wind speeds and directions, isolating the hull shape as the only changing factor between each test. The performances of each design could then be accurately analysed and compared.

The largest allowable sail area written into the Rater Association Rules was chosen and several existing sail sets were compared to determine the best foresail area to mainsail area ratio. The sizing of the spars and rigging was determined using The Nordic Boat Standard [12].

The rudder and centreboard were designed with a straight quarter-chord semi elliptical shape to encourage elliptical spanwise loading, reducing the induced drag from the appendages. Multiple symmetrical airfoil sections were tested to determine the most efficient shape at the angles of attack experienced when the vessel is underway.

5.3 WEATHER CONDITIONS

The Thames A-Rater sails on the upper regions of the River Thames throughout the year and , during this time they experience a wide variety of conditions, with wind speeds ranging from 0 to gusts in excess of 30 knots. In order to better refine and target the VPP to the most typical sailing conditions, a weather study was conducted looking at the wind speeds experienced by the Raters during one of their main racing events, namely Bourne End Week, over the last 9 years. The results of the weather study are summarised in Table 4.

Year	Day 1	Day 2	Day 3	Day 4	Day 5	Avg
2010	11.3	17.4	9.6	6.1	6.1	10.1
2011	14.8	13.0	10.4	9.6	9.6	11.5
2012	11.3	13.0	11.3	10.4	12.2	11.6
2013	9.6	7.8	16.5	6.1	7.8	9.6
2014	9.6	12.2	6.1	9.6	7.8	9.0
2015	9.6	8.7	8.7	9.6	10.4	9.4
2016	9.6	11.3	13.0	16.5	13.9	12.9
2017	14.8	4.3	6.1	13.9	4.3	8.7
2018	16.5	7.8	9.6	10.4	5.2	9.9

Table 4: *Weather study for past Bourne End Weeks: maximum steady wind speed (kts).*

5.4 PERFORMANCE ASSESSMENT

All three boats were tested in the VPP under the same conditions, particularly focussed between 8 to 12 knots, however with light wind speeds as well for the purpose of assessing the determining design factor affecting the performance. Indeed, three main factors are at play:

- A longer length on waterline implies a lower Froude number for a given speed, thus contributing to a reduction in the wave making drag.
- A wider beam provides better stability, keeping the spars and sails more upright, and offering the maximum sail area to the wind, while reducing the amount of wind spilling form the sails, thus increasing the vessels performance in higher winds.
- A reduced wetted surface area (WSA), i.e. the surface of the hull that is in contact with the water, minimises drag at low speeds.

The three boats used in the study were good examples of how the combinations of the aforementioned attributes, quantified in Table 5, can affect performance.

Yacht	Lwl (m)	Bwl (m)	Tc (m)	WSA (m^2)	Disp. (kg)
Scamp	5.15	1.66	0.16	7.13	650
Spindrift	5.76	1.85	0.15	7.70	650
Dainty Too	4.25	1.74	0.18	6.30	650

Table 5: *Main hydrostatics comparison.*

It is important to note that the results in Table 6 do not represent a definite comparison of the various boats on the water, as these vessels all have different rigs and crew, both significantly altering the performance of a racing dinghy. Instead, the intent is to assess, for a given rig and appendages, the hull design that would theoretically results in the optimum performance.

Fastest Hull	True Wind Speed (kts)					
TWA	2	4	6	8	10	12
32	Scp	Scp	Scp	Spdt	Spdt	Spdt
40	Scp	Scp	Scp	Scp	Spdt	Scp
45	Scp	Scp	Spdt	Scp	Spdt	Spdt
52	Scp	Scp	Spdt	Spdt	Spdt	Spdt
60	Scp	Scp	Spdt	Spdt	Spdt	Spdt
70	Scp	Scp	Spdt	Spdt	Spdt	Spdt
75	Scp	Scp	Spdt	Spdt	Scp	Spdt
80	Scp	Scp	Spdt	Spdt	Spdt	Spdt
90	Scp	Scp	Spdt	Spdt	Spdt	Spdt
100	Scp	Scp	Spdt	Spdt	Spdt	Spdt
110	Scp	Scp	Spdt	Spdt	Spdt	Spdt
120	Dto	Scp	Scp	Spdt	Spdt	Spdt
130	Dto	Scp	Scp	Spdt	Spdt	Spdt
135	Dto	Scp	Scp	Spdt	Spdt	Spdt
140	Dto	Scp	Scp	Scp	Spdt	Spdt
150	Dto	Scp	Scp	Scp	Spdt	Spdt
160	Dto	Scp	Scp	Scp	Scp	Spdt
165	Scp	Scp	Scp	Scp	Scp	Spdt
170	Scp	Scp	Scp	Scp	Scp	Spdt
180	Scp	Scp	Scp	Scp	Scp	Spdt

Table 6: *Comparative VPP results for Scamp (Scp), Spindrift (Spdt) and Dainty Too (Dto).*

The results depict a near perfect divide between *Scamp* and *Spindrift*. The former performs better in lighter winds thanks to its lowered wetter surface area, and larger wind angles where stability is not needed, as *Scamp* is narrower. As the wind speed increases, the friction drag's contribution to the total resistance decreases, and stability becomes more critical. Consequently, *Spindrift* would perform better in these conditions.

As for *Dainty Too*, despite a much smaller wetted surface area and reasonable beam, the boat suffers from too short a waterline length, implying it will sail at a much higher Froude number for a given boat speed. With the exception of specific downwind angles in extremely light winds, this design never outperforms the others.

Referring back to the weather study, wind speeds between 8 and 12 knots would be most common, and *Spindrift* has been shown to perform much better in those conditions achieving up to a knot of boat speed more than the next best hull. It would therefore be the recommended hull to be employed for the development and growth of the Thames A Rater Class.

Nevertheless, there are elements, such as the three A Rater crew hiking out to the full extent of their ability to keep the vessel flat that cannot be replicated in a computer programme such as a VPP.

6. CONCLUSIONS

Using different techniques, such as taking the lines off existing original linesplans, or performing measurements on existing hulls for the purpose of generating a point cloud of 3D models, the linesplan of three Thames A Rater have been conserved, namely *Scamp*, *Spindrift* and *Dainty Too*.

Furthermore, the three hull designs were combined with a standard rig and appendages to perform a velocity prediction, and assess their comparative performance in a range of conditions, representative of the typical racing weather that Thames A Raters are subject too. This demonstrated the importance of minimising the Froude number thanks to an increased length on waterline, as well as the better performance in light winds and downwind of *Scamp*, due to its lower wetted surface area and narrow beam. Conversely, upwind and as the true wind speed increases, *Spindrift*'s larger waterline beam and inherent stability led to a much faster yacht.

This study therefore provides ways of accurately reproducing historical designs for the purpose of historical conservation, as well as the application of modern naval architecture techniques, in this instance velocity prediction.

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8. AUTHORS BIOGRAPHY

Joseph E Thomas is a graduate of the BEng (Hons) Yacht and Powercraft Design at Solent University with a particular focus on performance sailing craft. He is an avide Thames A-Class Rater sailor. He has worked on refurbishment work for two vintage Thames A-Class Raters keeping them in a sailable seaworthy condition. His previous work with the class includes a dissertation designing a new Mahogany Thames A Rater and a presentation on his work given at the British Conference of undergraduate research.

Jean-Baptiste R. G. Souppez holds the position of 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. He contributes to the European Master in Integrated Advanced Ship Design (EMship+) as a Visiting Professor and Research Supervisor, and is also 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). 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.

9. APPENDICES

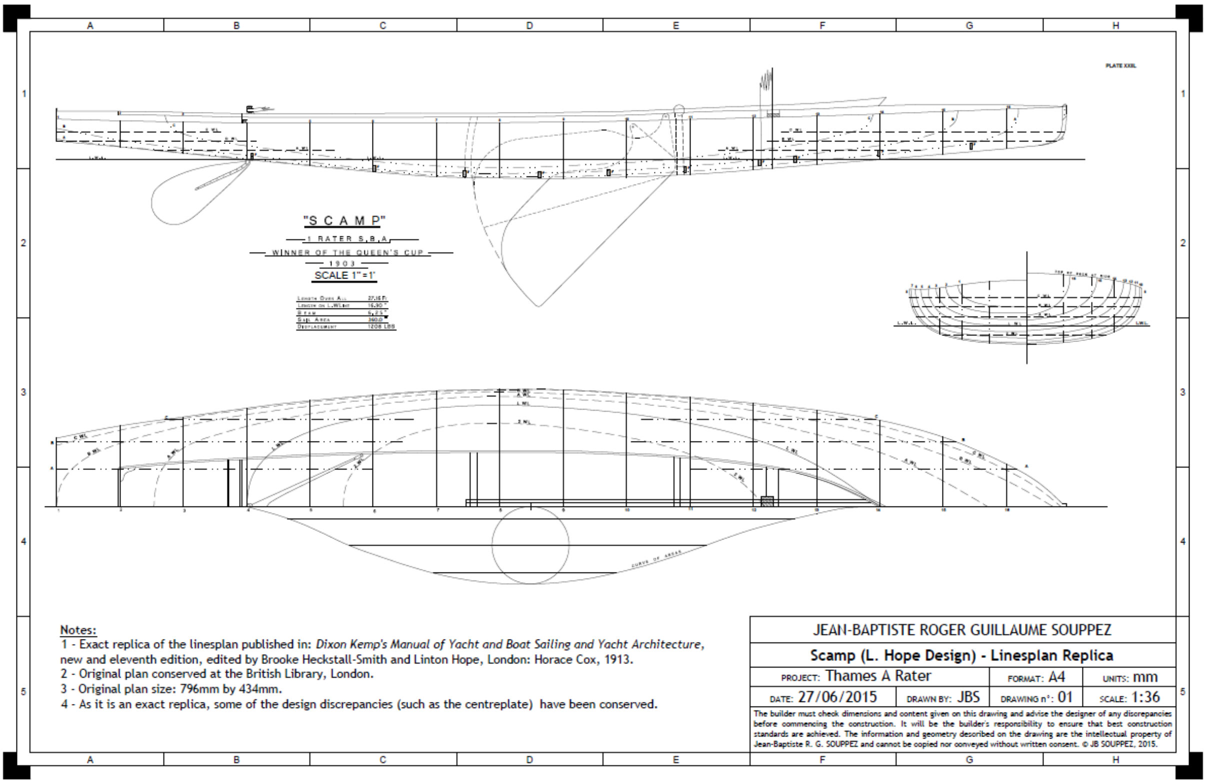

Figure 12: *Linesplan Replica for Scamp [13].*

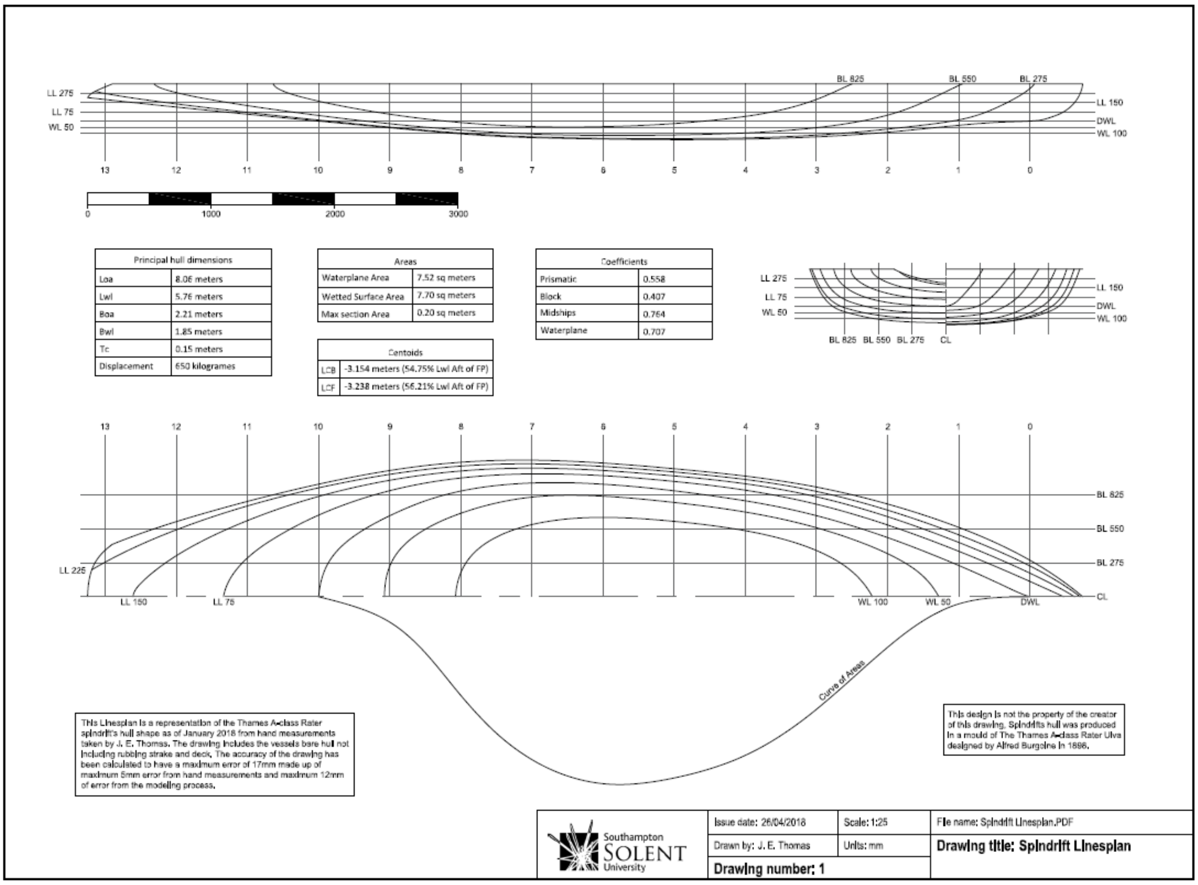

Figure 13: *Linesplan Replica for Spindrift.*

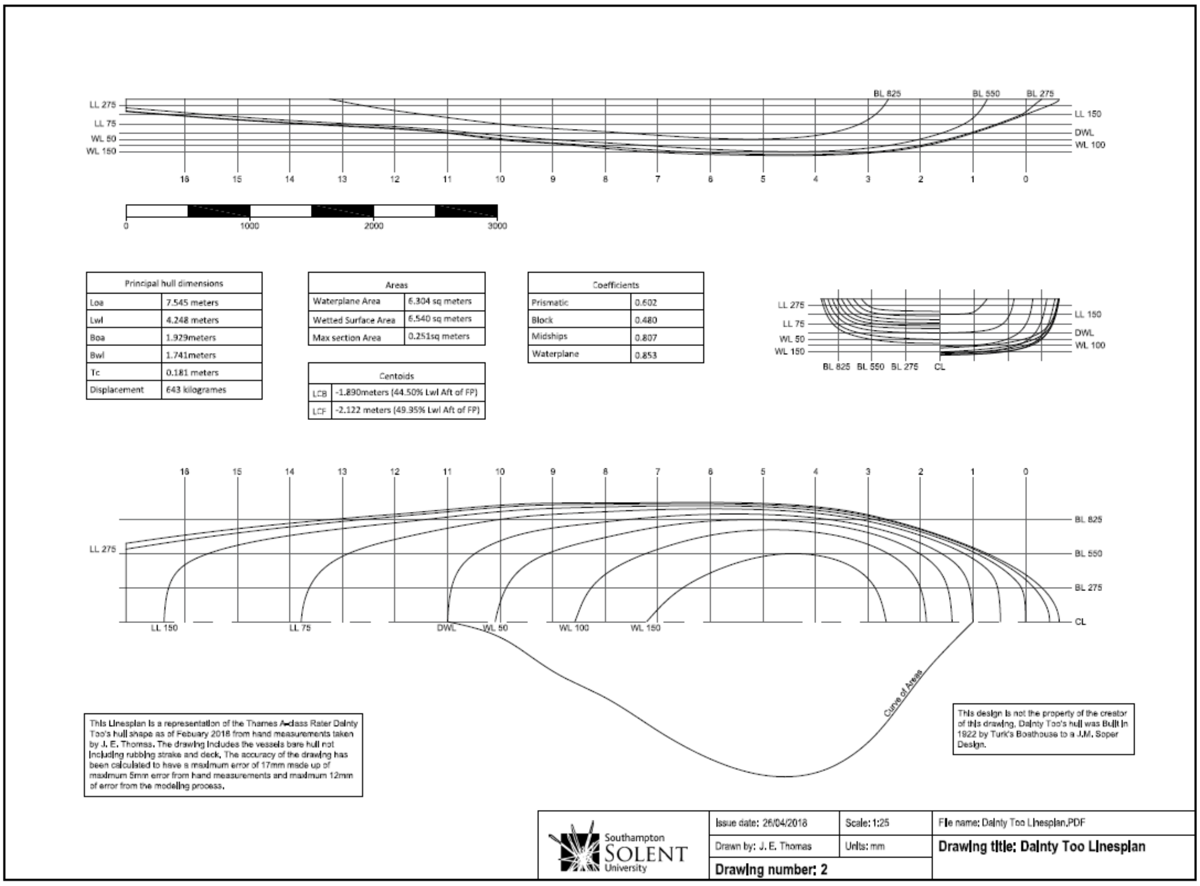

Figure 14: *Linesplan Replica for Dainty Too.*