THE LIFE PLATFORM: LEVERAGING A VIRTUOUS CIRCLE DESIGN

M. Magherini; **A. Meredith Hardy**, **A. Thoumazeau and J. Roy;** Lateral Naval Architects, UK

SUMMARY

The end of 2018 saw the delivery of the motor yacht Bravo Eugenia. She is built by Oceanco based on the LIFE platform developed in collaboration with Lateral Naval Architects. This study defines the LIFE platform (i.e. Long, Innovative, Fuel efficient, Eco conscious) its key features and outlines its fundamental design pillars. The relative merits of main parameters are assessed against a typical similar sized yacht by use of baseline fleet data. LIFE's low weight in relation to length and reduced powering requirements combined with a hybrid propulsion system result in a virtuous circle at which the centre is the single tier engine room. The benefits of the single tier layout such as the higher flexibility in designing the accommodation spaces and the improved balance between technical and luxury areas are outlined. In this context, various designers' LIFE platform interpretations are provided as examples for discussion. The LIFE hybrid propulsion system is presented and the various modes of operations for which the hybrid system is conceived are discussed.

NOMENCLATURE AND ABBREVIATIONS

Δ	Displacement [t]
B/ BOA	Beam Overall [m]
CE	Admiralty Coefficient
CPP	Controllable Pitch Propellers
C_R	Residuary Resistance Coefficient
$DISPV_{1.025}$	Volumetric Displacement in seawater
EPM	Electric Propulsion Motor
ER	Engine Room
F_N	Froude Number
GM	Metacentric Height [m]
GT	Gross Tonnage
Hs	Significant Wave Height [m]
L/ LOA	Length Overall [m]
LWL	Length Waterline [m]
ME	Main Engines
NT	Net Tonnage
P_S	Shaft Power [kW]
RMS	Root Mean Square
TBO	Time Between Overhauls
Tp	Roll Period

1. INTRODUCTION

Traditional motor yacht design often begins with the conception of interior layouts, or an exterior profile. Following the development of these, the naval architect is left to determine the resulting gross tonnage and optimise a hull and propulsion package around the intended design.

Sailing yacht design requires a different approach. Given that the available power is limited by the size of the sail plan, the heeling moment and the natural forces available, a holistic approach is required. Whilst length may also be fixed, the sailing yacht naval architect needs to pay far more attention in reducing the weight in relation to length, so naturally the GT of sailing yachts is far lower than that of a comparable sized motor yacht. A design that performs well will need to have a balanced approach between volume and weight compatible with performance of the chosen length.

This is in contrast with motor yacht design where the designer's role is usually separated from the naval architect, with the former exerting greater influence over the GT. The naval architect is left to optimise where possible, but ultimately if more speed is desired, it is generally a case of selecting bigger engines.

The LIFE platform (i.e. Long, Innovative, Fuel efficient, Eco conscious) delivers a design that operates in a virtuous circle: less volume, less weight, less power, less technical space, in turn reinforcing the need for a lower overall gross tonnage and afford a better balance of technical and luxury space on-board.

In the frame of this analysis, it is worth highlighting that the LIFE design platform is not a pre-engineered hull of fixed dimensions and characteristics. LIFE is rather a technical platform; a defined solution space within a feasible range of dimensions that leverages a naval architecture philosophy and a group of technologies upon which a fully custom design can be developed.

2. LIFE PLATFORM DNA

Inspired by the more holistic and performance orientated approach that is evident in sailing yacht design methodology, LIFE platform is conceived upon 2 key naval architecture fundamentals:

- Weight in relation to length – for any given weight increasing length is favourable (high length-displacement ratio)
- Speed in relation to length – for any given speed increasing length is favourable (lower F_N).

Some modern motor yachts operate at high $LWL/\Delta^{(1/3)}$ ratio (extended length, aluminium structure combined with lightweight interiors). However, the critical difference is that typically other designs have used the high-level hydrodynamic performance to increase top speed, whereas the LIFE platform uses it to reduce engine size. It is worth highlighting that LIFE platform DNA is based on a steel hull, aluminium superstructure and no use of particular lightweight materials. I.e. it is the architecture of the platform, not the use of expensive materials and outfit that bring the benefits discussed.

Recent studies on yacht operational profiles [1, 2] have concurred that motor yachts statistically spend only 2% of their total sailing time at top speed. This seems to unveil the likelihood of selected top speeds of most displacement motor yachts to be a vanity choice rather than being based upon true operational demands.

Following this approach, the LIFE platform top speed is kept within the lower range of similar GT yachts whilst increasing the L (i.e. decreasing F_N rather than keeping it constant by increasing speed). Whereas typical large displacement yachts will be operating between a $F_N = 0.34 – 0.36$, LIFE's selected top speed gives a $F_N \leq 0.32$. This results in the yacht operating in a less steep area of the resistance curve avoiding excessive additional power requirement for a small increase in top speed. This contributes greatly in reducing overall power.

The initial LIFE platform range of dimensions are shown below. The LOA is for a plumb/vertical style bow. Raked bows will see higher LOA possible:

- LOA = 102 - 112m
- Gross Tonnage = 2950 – 3400
- Top Speed = 19 knots

Figure 1 (at the end of this paper) allows for a comparison of the LIFE platform LOA and GT against existing motor yacht vessels. For this analysis, reference is made to fleet statistics about LOA and GT known from previous projects and publicly available data.

Focussing on the top end of the LIFE platform size and to demonstrate the interesting proportions of the design, it can be seen that:

- a typical 112m yacht has approximately a GT of 4900; this is 1500 more than the LIFE platform.
- a typical 3400 GT yacht has a LOA of approximately 95m. This is 17m shorter than the LIFE platform.

LIFE is designed with lower GT/LOA ratio compared against typical fleet vessels. Typical $LWL/\Delta^{(1/3)}$ values for displacement motor yachts in the range of 80-120m are shown in Figure 2: LIFE platform operates at higher ratios, resulting in a significant decrease in resistance.

Having stretched a typical design in length, whilst maintaining GT, the result is a reduced profile area but also a decreased BOA, which in turn leads to further lower resistance driving down the size of required propulsion machinery. This further improves weight in relation to length.

This is the tipping point: the design effectively enters in a virtuous circle of reducing power and weight.

From this analysis, it is evident that a basis for comparison needs to be addressed.

3. BASIS OF COMPARISON: GT

In the evaluation of commercial vessels, it is common to refer to the GT value (or NT) as one of the key design parameters for the prospective owner / operator in order to demonstrate size and cargo capacity. Similarly, it can be argued that in the evaluation of a yacht, in addition to the subjective aesthetic considerations, the GT should be considered equally as a defining factor for the owner ensuring a set level of luxury area for enjoyment. The paradigm shift for assessing the relative merits of the LIFE platform against other vessels is to conduct a comparative analysis against similar GT vessels.

4. BENEFITS OF MAIN PARTICULARS

In the following sections, this paper compares the relative merits of the LIFE platform main particulars against a typical vessel at identical GT of 3400. In this context, the baseline motor yacht main particulars are determined by statistical data of existing large yachts. A trendline is used to represent yachts of typical proportions and form. As previously shown, the LOA would be 95m.

The baseline 95m vessel is initially developed from an existing selected motor yacht where the main particulars and performance are known to the Authors, and close to the target values for comparison. Next, the vessel is scaled using the following assumption:

- L, B, and T are slightly increased to match target GT according to trend fleet data [3]
- Half load displacement has been scaled by the difference in GT when considering the powering
- Internal and external deck areas were scaled according to both L*B ratio and GT ratio of the selected candidate vessel. The more conservative values were chosen for comparison.

In the frame of the comparative analysis (Sections 4.1 (a), 4.3, and in Chapter 6) the LIFE design point is set at LOA=110m with GT=3400. This design point was selected as mature data was available within the Lateral office for a design of this size for comparison purposes.

4.1 RESISTANCE AND POWERING

The application of the Admiralty Coefficient (CE) against Speed Coefficient is regarded as a valid benchmarking system in assessing hydrodynamic performance of hull forms.

Admiralty Coefficient and Speed Coefficient are respectively defined as:

$$CE = \frac{0.7477 * V^3[knots](DISV_{1.025})^{\frac{2}{3}}[m^3]}{PE[kW]};$$

$$Speed\ Coefficient\ = \frac{V\ [knots]}{DISPV_{1.025}^{\frac{1}{6}}}.$$

CE seems to compare lines plans on a fairer basis rather than strictly looking at other coefficients (such as C_R): vessels with high CE achieve high hydrodynamic performance (i.e. less power required to reach a given speed * displacement product).

Figure 3 shows comparison of LIFE platform CE against other displacement hull forms of more typical main dimensions achieving various level of optimisation.

Based on the CE comparison, it is evident that LIFE's main particulars result in a high level of hydrodynamic performance.

4.1 (a) Fuel Consumption

LIFE's low resistance reduces the amount of fuel required to achieve a target range against fleet typical values.

Figure 4 reports the fuel consumption of the LIFE platform against a typical 95m motor yacht: 30% fuel reduction is achievable across the speed range.

It is worth highlighting that comparison is made for diesel mechanical propulsion trains: LIFE is conceived with a hybrid propulsion system (described in Chapter 5), hence further fuel saving in the low speed range (i.e. non-optimal engine rpm/MCR) are also achievable.

For the same range, the resultant reduced tankage and fuel oil deadweight further contributes to the virtuous circle with reduced displacement.

4.2 SEAKEEPING

The inherent DNA of the LIFE platform and resultant main dimensions, low profile shape and VCG can have a valuable effect on the seakeeping behaviours of the yacht.

Underway, the long LWL and deep forefoot provide good seakeeping performance in terms of reducing pitch motions and accelerations in large head seas.

The low beam provides opportunities for a low GM value compared to typical fleet values. During design a GM in the region of 1.3 – 1.6m was targeted. Low GM results in longer natural roll periods and tender motions (reduced roll acceleration). When coupled with an effective stabilisation system to reduce roll amplitude a high level of comfort can be achieved. However, this exercise of reduced GM is limited by compliance with regulatory stability requirements.

No single parameter can be used to define seakeeping performance of a specific design. However, it is common practice on yachts to benchmark the stabilised roll performance with absolute roll angle at zero speed in resonant beam waves against existing fleet data.

In setting a comparative analysis, a candidate reference motor yacht was selected based on similar natural roll periods and low GM. Experimental tests with scaled models on both LIFE platform and the reference yacht were conducted at MARIN (Maritime Research Institute Netherlands); hence, a high level comparative analysis can be undertaken.

Vessels	**Tp [sec]**	**GM [m]**	**Fins**	**Area [m²]**
LIFE	9.2	1.56	2x	21.7
Ref. yacht	9.5	1.36	4x	26.0

Table 1: [LIFE main seakeeping particulars against selected reference vessel].

Table 2 reports RMS for roll angle at different Hs in the beam sea zero speed condition (irregular waves). Both models are fitted with bilge keels, and have identical stabiliser suppliers and systems.

Hs	**LIFE**	**Reference vessel**
[m]	**RMS Roll [deg]**	**RMS Roll [deg]**
0.5	0.29	0.25
1	0.71	0.65
1.5	1.58	1.40

Table 2: [RMS Roll comparison with active fins].

It can be seen that despite the smaller fins, and also the higher test GM, the LIFE platform achieves results close to the reference yacht.

The low block coefficient of the hull form and round bilges does have the advantage that 2x stabilisers can be positioned close to midships (where they are most effective) rather than 4x stabilisers positioned fore and aft. The smaller fins also reduce resistance and power, further enhancing the virtuous circle philosophy.

4.3 EXTERIOR DECK AREAS

Scaling the deck areas following the assumptions stated at the beginning of this chapter, allows for direct comparison at constant GT.

Parameters	LIFE	Baseline 95m
GT	3400	3400
LOA [m]	110.0	95.0
External deck area [m^2]	1008	853

Table 3: [External deck area comparison between LIFE against typical 95m MY].

The baseline 95m motor yacht external deck area is 155m^2 less (approximately 16% decrease) than the LIFE platform's areas. This can be beneficial in cases where space for outside living, or compliant helipads is of particular interest to owners.

5. HYBRID SYSTEM

On top of an efficient hull form and reduced powering requirements, the LIFE platform benefits from a hybrid propulsion system powering a twin shaft train fitted with controllable pitch propellers (CPP).

A hybrid system by definition uses a combination of different energy sources or propulsion devices.

LIFE presents a diesel electric hybrid system also including batteries, which is designed around a direct drive main engine, coupled to an electric motor by dual input gearbox (see Figure 5). The electric motor can operate as both a motor and a shaft generator.

Typical advantages of hybrid system against a typical diesel mechanical system are:

- Operational flexibility for control of the yacht;
- Potential to operate with the lowest fuel use and carbon emissions;
- Reduced total installed power of prime movers;
- Maximised TBO (Time Between Overhaul) by maintaining the best loading on equipment;
- Flexible arrangement of main propulsion and power components allows for low profile machinery spaces;
- Single tier engine room is feasible (detailed in next chapter).

On the other hand, typical disadvantages compared to a traditional yacht propulsion system to consider are:

- Increased system complexity.
- More machinery volume required (at same P_S).

5.1 BATTERIES

At the time of writing, it has been demonstrated [4] that the current most practical use of batteries on board large yachts is found for peak shaving and for electrical load management which is a highly effective method of delivering reductions in generator sizing. In addition, optimum generator loading can be achieved across a wide range of operating conditions with increased security of electrical power supply.

The size and weight of batteries required to achieve this on the LIFE platform is consistent with the overall philosophy of the virtuous circle design.

As battery energy density and performance improves, increased periods of "battery only power" and "battery only propulsion" can be expected on future LIFE platform designs.

5.2 MODES OF OPERATIONS

The key benefits of employing a hybrid system consists in combining the advantages of both diesel-electric and diesel mechanical systems.

The following are typical modes of operation for diesel electric hybrid systems. All these factors need to be carefully considered alongside the yachts likely operating profile.

5.2 (a) Slow speed

The mode will run with electric propulsion (only generators & EPM operating). Speeds of around 11-12 knots are possible.

This mode allows generators to be optimally loaded. Main engines are switched off avoiding poor low loading. Very low level of noise and vibration is produced; all the exhaust emissions are routed to the mast via soot filters avoiding black marks and cleaning.

5.2 (b) Eco Cruise speed

The main engines are running with the electric motors operating as shaft generators (i.e as a PTO system). All the generators are switched off to reduce wear and maintenance and increase their TBO.

As the main engines are supplying both the propulsion and hotel power, the load is sufficient that they can be made to work at their optimum efficiency. This can be ensured by adjusting the propeller combinator curve to suit engine performance.

5.3 (c) Fast Cruise speed

At high cruise speeds, the system can operate in a traditional diesel-mechanical mode (ME only for propulsion, generators for hotel load).

5.3 (d) Boost speed

For boost speed, all the installed power of the main engines and generators is being used to deliver the top speed. The system will operate as a diesel electric and diesel mechanical system combined (a boost is provided to the shafts from the generators via the EPM).

6. SINGLE TIER ENGINE ROOM

The virtuous circle (high $L/\Delta^{(1/3)}$ ratio, moderate powering requirements, hybrid propulsion) results in the ability to select a lower main engine block series, which in turn means a significant reduction in the vertical height required in main machinery spaces.

Following this philosophy unveils the centre of the virtuous circle: a single tier engine room. Where conventional designs of similar GT would employ a twin-deck engine room, LIFE platform is able to utilise a single tier design.

For instance, typical motor yachts of this size could employ MTU 4000 series or equivalent engines, whereas LIFE only needs to utilise the 2000 series which is significantly smaller and lighter.

Main engine dimensions (length*width*height) for both LIFE and the reference vessel are reported in Table 4: ME length and height are significantly reduced compared to higher engine block series.

Parameters	LIFE	Baseline 95m
GT	3400	3400
LOA [m]	110.0	95.0
ME [mm]	2260*1320*1460	4040*1470*2440
Luxury area [m^2]	903	805

Table 4: [Comparison LIFE against baseline 95m MY].

Moreover, Table 4 shows internal luxury areas for the baseline motor yacht compared to the life platform. The single tier engine room results in a more optimal use of luxury space giving approximately an extra 100 square meters compared to a twin tier engine room vessel of same GT.

Figure 6 shows an artistic impression of the hybrid system and the single tier ER. The highlighted volume indicates the area gained for accommodation spaces at Lower Deck level. At such location, it is unusual for typical yachts of this size to have luxury space: this creates design opportunities that are covered in Chapter 7.

7. LIFE PLATFORM DESIGN ASPECTS

The virtuous circle established in the LIFE platform DNA results in some key recognisable design features:

- Stretched length gives sporty/ slender/ light yacht look rather than a traditional voluminous superyacht;
- Single tier engine room gives higher flexibility of internal spaces, as such:
  - Lower deck offers more accommodation spaces, (guests or crew) against similar GT vessels;
  - Circulation between aft areas (e.g. beach club) and mid-ship is improved (e.g. main stairwell / access to crew areas).

The following sections report a variety of LIFE platform interpretations by various yacht designers.

7.1 BRAVO EUGENIA: NUVOLARI LENARD INTERPRETATION

Bravo Eugenia, is the first delivered vessel conceived from the LIFE platform [see Figure 7]. She is at the higher design size range of platform and was recently presented with the Technology and Innovation award at the 2019 Yacht Club Monaco's La Belle Class Explorer award [5].

On Bravo Eugenia, six guest cabins are located at lower deck level above the single tier engine room. As such, guests are next to the aft beach lounge/ gym, SPA areas and water toys garage. Circulation and guest experience around the vessel are enhanced.

7.2 BALANCE: SINOT INTERPRETATION

Balance [Figure 8] was presented during Monaco Yacht Show 2018.

The 4 guest cabins above the single tier engine room at Lower Deck gives easy access to the Laguna lounge/ cinema theatre, the gym /SPA and to the water toys in the aft areas of the vessel.

Two VIP cabins are situated at the Main Deck with the deck above being reserved to Owner.

7.3 VIRTUS: MC PHERSON INTERPRETATION

With L = 102m, and 5 decks, Virtus motor yacht [Figure 9] is at the lower range of the LIFE Platform dimensions both in terms of length overall and GT ($\leq$3000).

All six guest suits are located at lower deck above the single tier engine room, granting proximity to the aft beach club/ cinema area. Owner's area is at Bridge Deck within this configuration.

8. CONCLUSIONS

This paper analyses the merits of a motor yacht platform designed by following a holistic approach.

As is often the case, it is Authors' opinion that major innovations succeed by leveraging existing technologies in a novel combination.

It is arguable that, in recent years, other superyachts have been designed and built by targeting low volume, and a light weight against length approach; however, the enhanced level of hydrodynamic performance has been typically exploited to fulfil the constant seek of higher top speeds.

On the contrary, the LIFE platform's key achievement consists in the unique combination of leveraging first naval architecture principles whilst taking a pragmatic approach to operational profiles. As such, this paper demonstrates how the LIFE platform can achieve a significantly lower level of fuel consumption compared to a typical superyacht fleet vessel whilst also offering more luxury/ accommodation space as well as external deck space. This is done without the need for aluminium hull construction of light weight interiors.

LIFE's virtuous circle has been analysed and comparisons made against a baseline motor yacht are shown. Following this, with the aim of summarising the key features of a LIFE platform design, the following pillars are identified:

- Optimised main particulars to increase length-displacement ratio whilst keeping a moderate Froude Number at top speed;
- Hybrid propulsion system;
- Single tier engine room.

This study shows that these key features respectively result in:

- Higher hydrodynamic performance (i.e. less power required to reach a given speed * displacement product);
- Operation flexibility and potential for low fuel use and carbon emissions with maximised machinery TBO;
- Optimised use of luxury space compared to a typical double tier engine room by creation of additional accommodation space in an unusual location.

The inherent DNA and approach of the platform results in outcomes which are synonymous with an Eco Conscious design. Although not the topic of this paper, it is worth to note that the platform is also configured with large waste heat recovery systems on the generators, IMO Emissions Tier III compliance (prior to the implementation date requirement) as well as other green technologies.

The current study does not address practical aspects of adopting hybrid propulsion systems (i.e. system commissioning and integration, required higher crew technical skills to operate the system correctly, etc.) This will be motivation for future work on the subject.

9. REFERENCES

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10. AUTHORS BIOGRAPHY

Matteo Magherini (CEng, MRINA) holds the position of Naval Architect/ Business Developer Coordinator at Lateral Naval Architects. He currently works in a number of yacht projects from initial development to engineering phase. He is also involved in the provision of wider company consultancy services and business strategies.

Alex Meredith Hardy (MEng, MRINA) holds the position of Principal Naval Architect at Lateral Naval Architects. In this role he looks after the naval architect team and capabilities of the company. He was involved in the development of the LIFE platform since the inception of the project.

Adrien Thoumazeau holds the position of Senior Naval Architect/ Research and Development Coordinator at Lateral Naval Architects. He is involved in wide range of yacht projects from concept design stages through to the detail design stages as well as coordinating innovation. The development of the LIFE platform was one of the first projects he worked on at this company.

James Roy (CEng, MRINA) is the Managing Director of Lateral Naval Architects. James has overall responsibility for a talented, multi skilled and multinational team of engineers who, whilst concurrently engineering multiple new build and refit projects are applying knowledge, insight an lateral thinking in the development of new technical platforms enabling the superyacht design community to develop every more creative and iconic yachts. James holds a Bachelor of Engineering with First Class Honours in Yacht and Powercraft Design and has 23 years' experience in the naval architecture and engineering of specialised vessels.

11. ACKNOWLEDGMENTS

The Authors wish to extend the merits of the LIFE platform development with Oceanco, especially the Project Development Team, and the MARIN (Maritime Research Institute Netherlands) Team.

LIFE platform is an example of a collaborative approach where the result exceeds the sum of the individual parts.

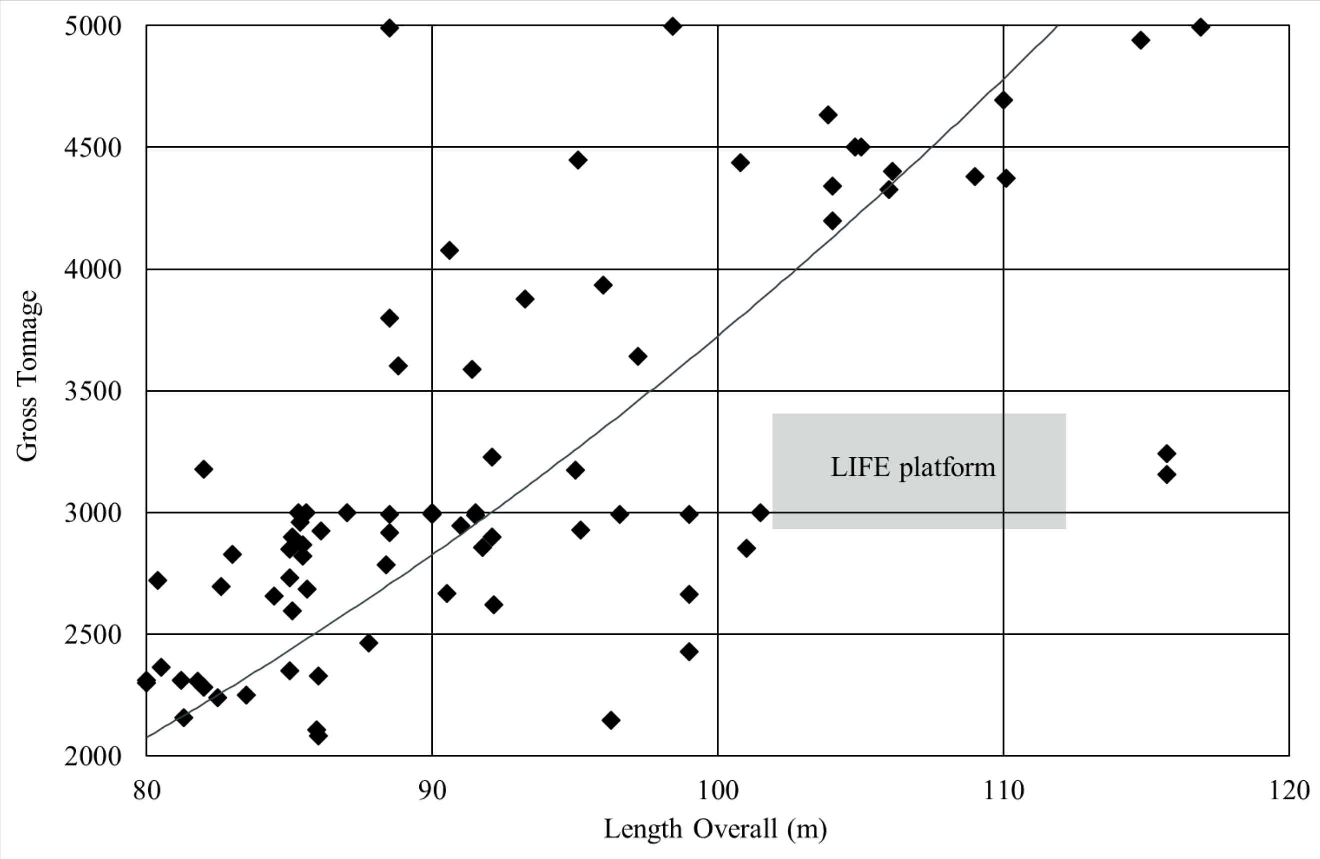

Figure 1: [GT vs LOA of existing yachts] [3].

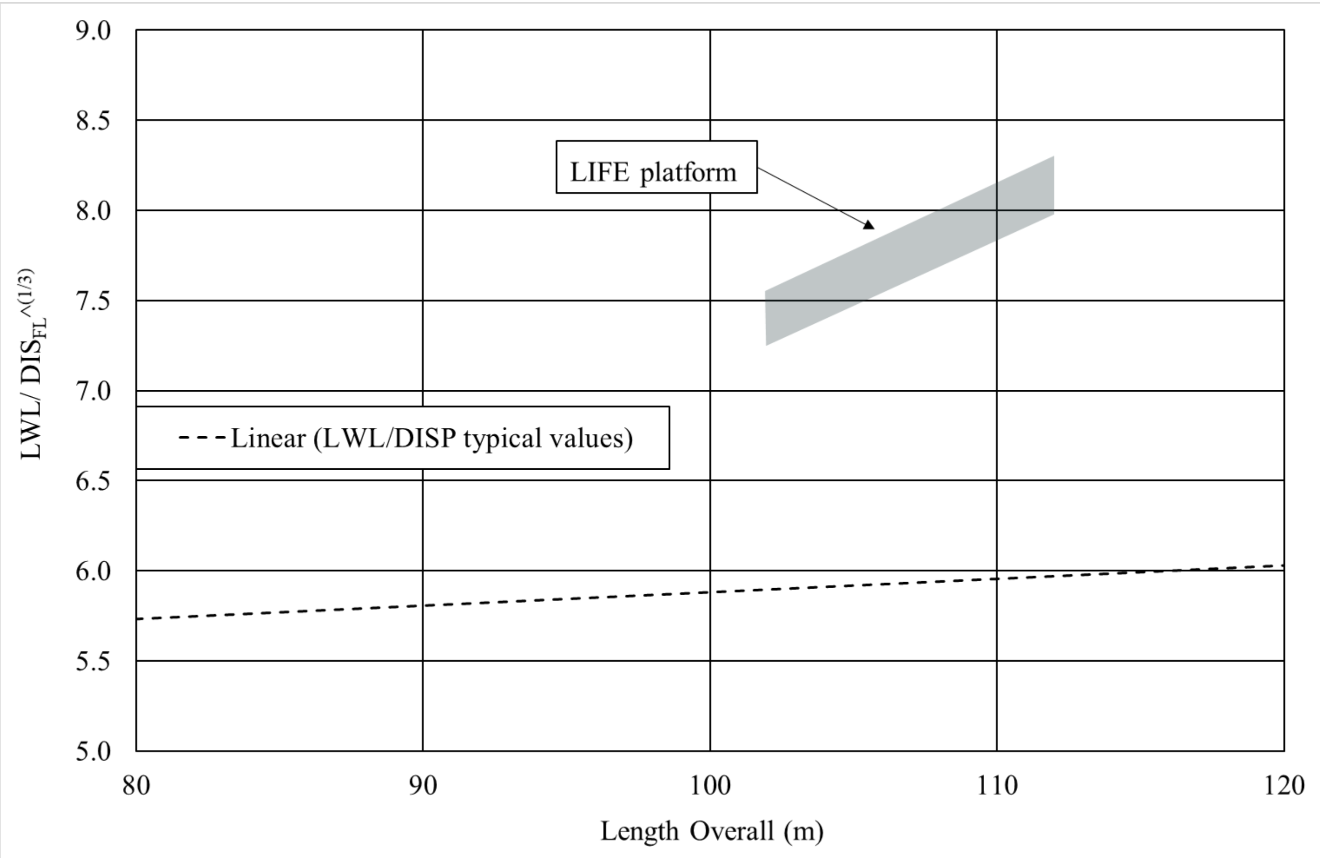

Figure 2: [LWL/$\Delta^{(1/3)}$ ratio at Full Load vs LOA compared to trend of existing yachts] [3].

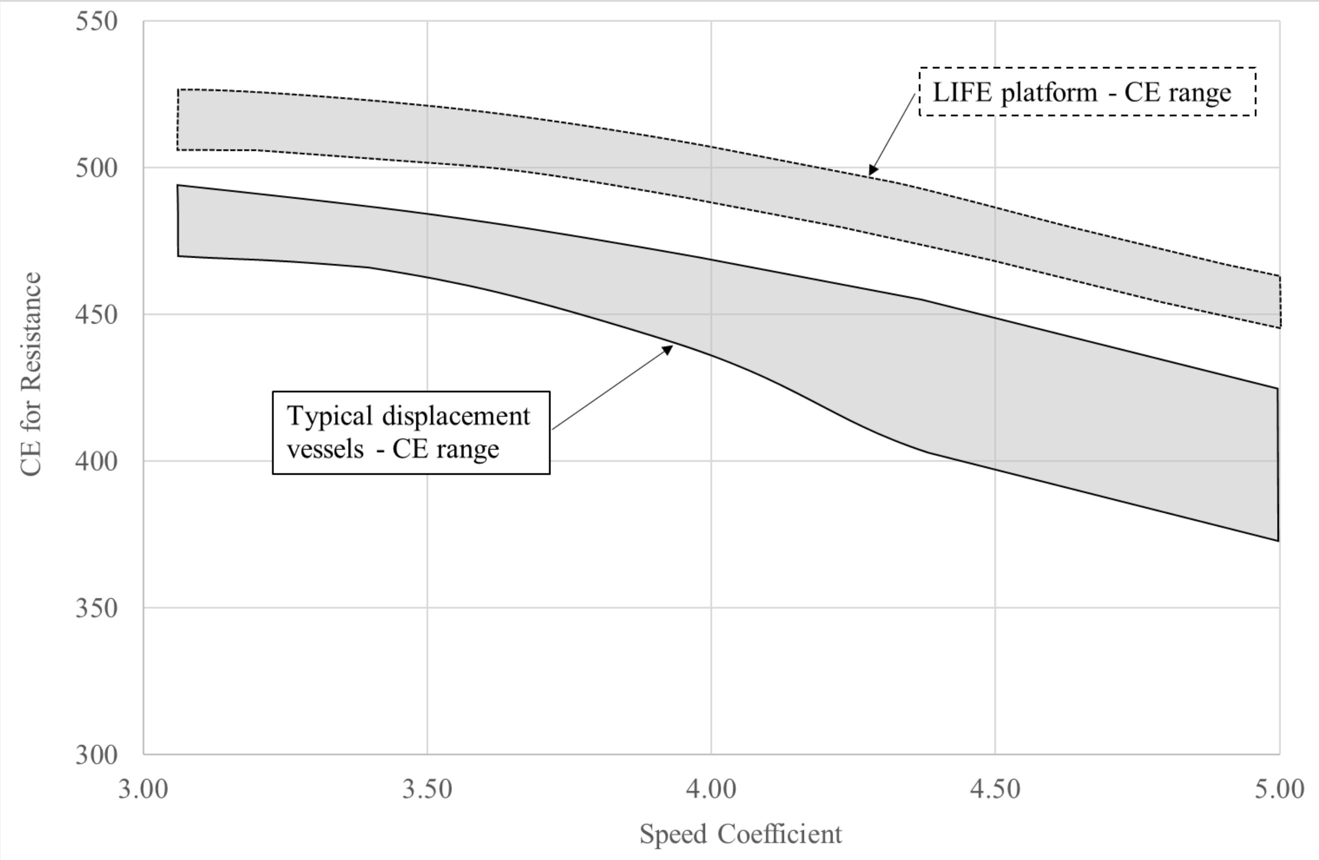

Figure 3: [LIFE platform CE comparison against other vessels].

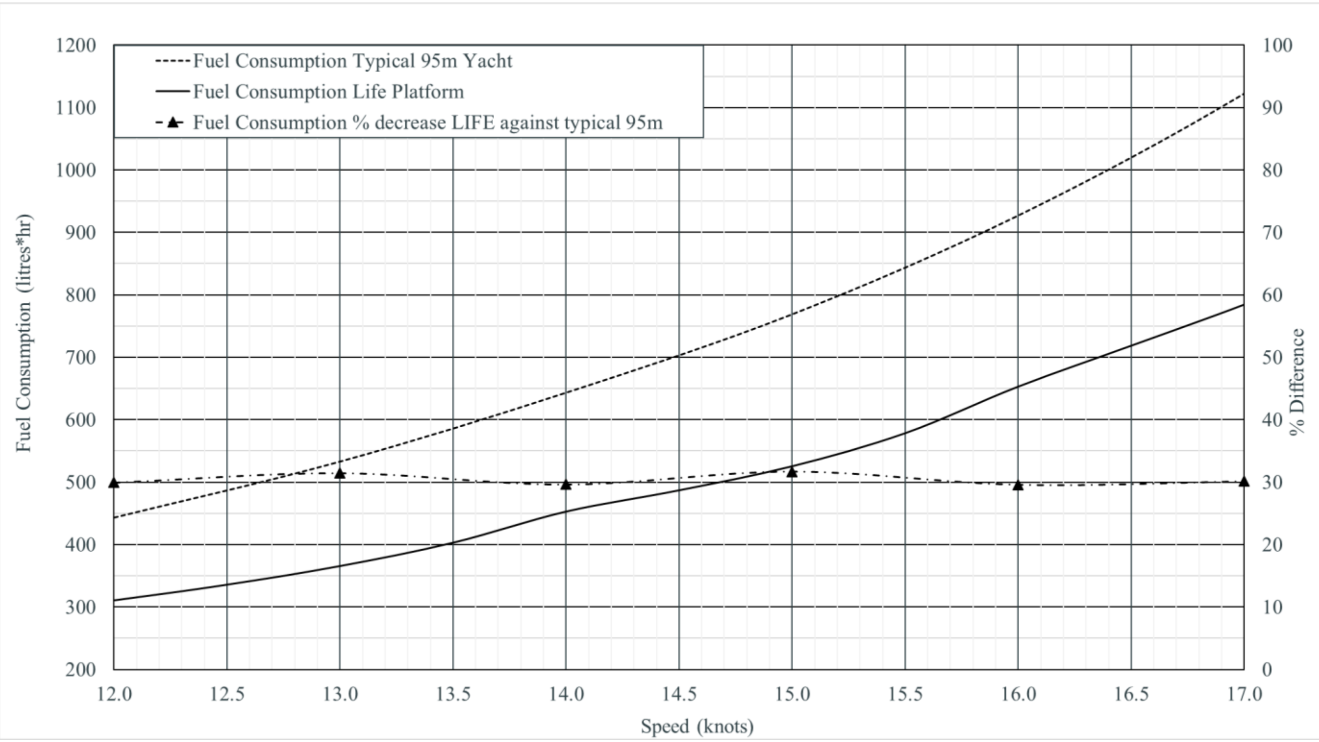

Figure 4: [LIFE platform fuel consumption against typical 95m MY].

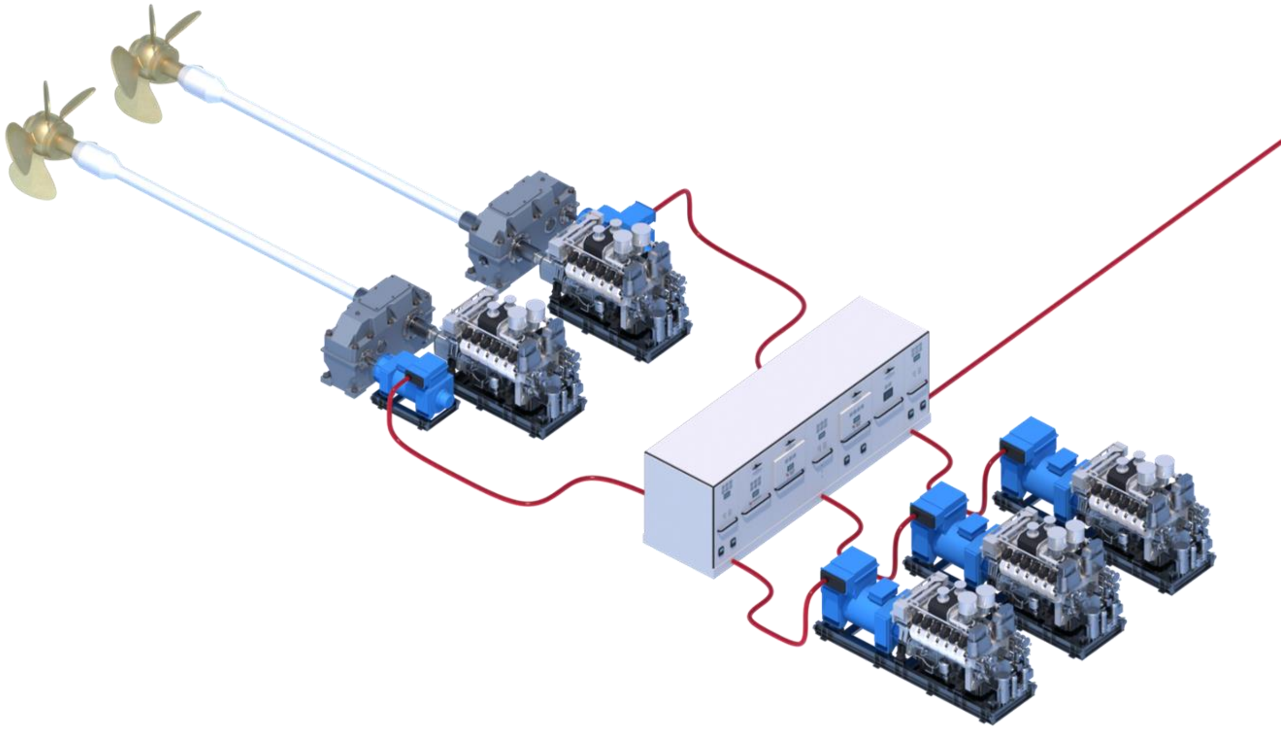

Figure 5: [Artistic schematic of typical diesel-electric hybrid system]

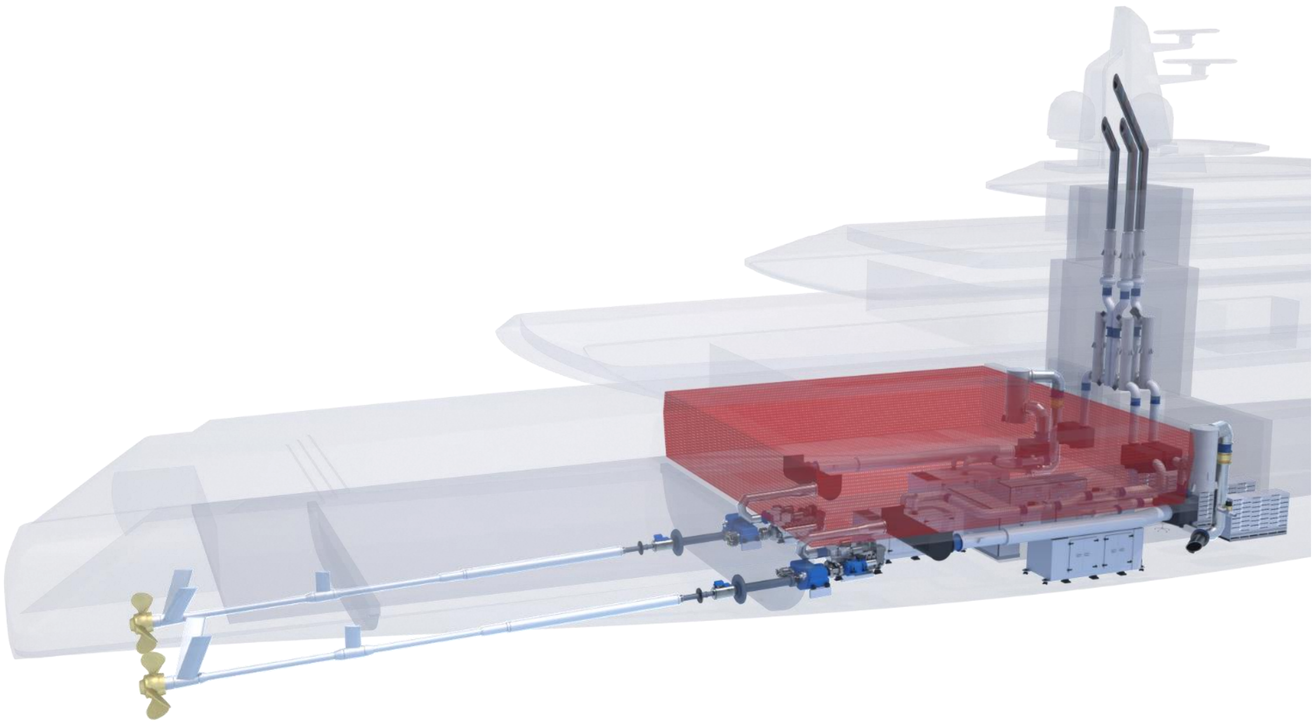

Figure 6: [Artistic impression of LIFE platform single tier engine room. Highlighted volume shows extra accommodation spaces at Lower Deck.]

Figure 7: [Bravo Eugenia (photo credit: Francisco Martinez)].

Figure 8: [102m Balance (rendering: Sinot Yacht Architecture & Design)].

Figure 9: [102m MY Virtus (rendering: Mc Pherson Yacht Design)].