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# Innovation in Tug Design

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## SYNOPSIS

Wärtsilä's experienced vessel designers are looking into the future possibilities for tug design. Experience and analysis of the tug and offshore markets provide inspiration for developments in hull design and powering concepts. This paper incorporates broad input from the market peak of 2006-08, *SAFETUG, ITS* and *Tugnology,* and references from owners will be utilised. The unique position of Wärtsilä as ship designer and equipment manufacturer facilitates thorough systems integration. This optimisation of operability, operational efficiency and service intervals improves the environmental footprint of the industry.

## INTRODUCTION

There is nothing new about towing vessels – or is there? A quick look into history reveals that in the early 19th century, barges were towed by horses walking along the canals.

In 1842, the first steam engine tug was built. However, it took another 90 years to see the first diesel engine-driven tug, this being L Smit & Co's ***Zwarte Zee III***.

Thereafter, the speed of tug developments accelerated and various innovative designs led to where the industry is today:

- In 1999, Ton Kooren won the Dutch Innovation Award with his Rotor tug design, which was presented at *ITS 2000* in Jersey;
- In 2000, Damen and Smit presented the Damen 3210 that was to be the start of the successful ASD series from Damen;
- In 2002, in Bilbao, the carousel tug, with turning tow point under the wheel house, showed delegates the escort possibilities on model scale and MARIN introduced their plans for the SAFETUG JIP. Wärtsilä presented its latest developments – packages with Wärtsilä four-stroke engines and their recently acquired Lips Compact thrusters. Robert Allan stated the case for compact tugs, which was picked up immediately by Damen Shipyards who presented the building of ASD 2411 in China in Miami in 2004. During that same conference, PSA and Robert Allan presented the Z-tech – a tug design that incorporates the finest characteristics of both tractor style and ASD style tug;
- In 2006, Lamnalco presented the general market approach for LNG-terminal tugs, with very strict requirements and high bollard pulls up to 100 tonnes per vessel. During the Wärtsilä-sponsored tug parade, the history of tug boats sailed beside the Wilhelmina Quay, starting with an old steam tug and followed by the latest designs by Svitzer, Smit, Adsteam, Iskes and Kooren;
- In 2008, in Singapore, Green Wednesday showed a clear trend for tugs that are more environmentally friendly. This trend was followed up during *Tugnology '09* in Amsterdam, clearly showing the very low, high load running hours of a tug. Thanks to a few innovations and an active market approach, Voith is also penetrating the market again with its tug design based on the highly manoeuvrable Voith Schneider propulsion system.

Not only have the designs become more and more innovative, but there is a strong trend for larger sizes and higher bollard pulls.

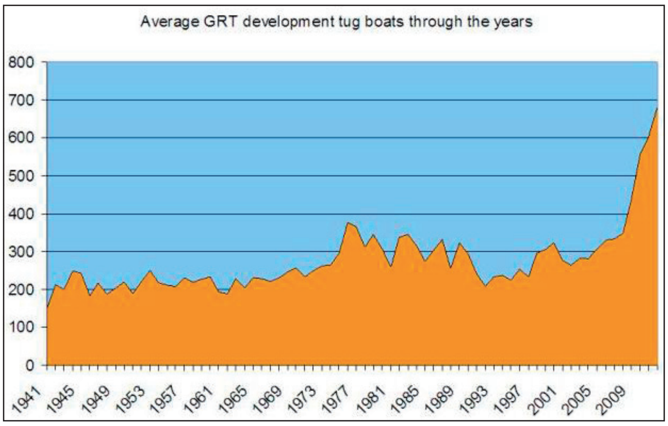



*Figure 1: The evolution of gross registered tonnage for tug boats from 1940 to 2010.*

Over the years, Wärtsilä has supported many innovative designs by supplying the appropriate engines and propulsion systems, in close co-operation with the designers, owners and yards.

When entering the ship design business in 2009, Wärtsilä sought to offer competitive solutions that would lead to better total efficiency, improved environmental performance, and reduced life cycle costs for its customers. This expansion is in line with Wärtsilä's strategy and strengthens its position as a total solutions provider striving to be the most valued partner for its customers.

W TUG solutions bring together the company's ship design and ship power expertise and aim to design a tug to meet tomorrow's environmental and economic requirements. This new Wärtsilä concept for tugs responds to the tightening of global environmental regulations and guidelines: both a challenge and an opportunity for Wärtsilä.

The 'Energy, Environment, Economy' sign crystallises our philosophy and works as a reminder of what Wärtsilä stands for. W TUG priorities are placed on performance parameters like reliability, efficiency, support and cost.


*Figure 2: Wärtsilä's philosophy.*

*Figure 3: W TUG in action.*

## DESIGN BRIEF

The standard of today's modern tugs results from experience gained over many years by designers, owners, yards, equipment suppliers and classification societies. Recognising this key aspect, the W TUG project solicited valuable comments from several tug operators and equipment suppliers throughout the process. Knowledge gained from joint industry projects, like SAFETUG, has also been implemented. Vessel performance, ease of production, ease of maintenance and safety were selected as being the key factors in developing a vessel compliant with tomorrow's environmental and economic requirements.

The W TUG 60 design targets typical harbour duties. Compact size, high manoeuvrability, and fire-fighting capability are required for this tug with a bollard pull of 60 tonnes and 12.5 knots trial speed. The total cost should be within reach of all operators, including those in areas with low margins such as developing markets. Accommodation is specified for seven crew.

The design brief for the W TUG 80 requires safe operation in exposed areas such as offshore terminals. Escorting at high speed, push-pull operations and coastal towing are also typical tasks. This calls for a highly manoeuvrable vessel with good sea-keeping characteristics. The vessel also needs fire-fighting capability, the ability to operate 200nm from the coast and a relocation range of 4,000nm. Bollard pull capacity is 80 tonnes and the trial speed is 14kn. The coastal aspect requires accommodation for eight crew.

## THE W TUG STANDARD

The W TUG 60 has one basic outfit level suitable for its intended harbour operations. There is a towing winch on the foredeck and a towing hook on the aft deck. Fire-fighting monitors are located atop the wheelhouse. The specification allows for medium-speed Wärtsilä 9L20 engines or high-speed alternatives.

The W TUG 80 has a basic and an elaborate deck outfit option. The basic version includes a foredeck winch, intended for towing and escorting duties, with towing pins on the bow. A second towing winch is located on the aft deck together with a deck crane and capstan. In the extended outfit a stern roller, towing pins, towing hook and tugger winch complement the basic fit-out. Fire-fighting equipment is located atop the wheelhouse.

The engine configuration comprises two alternatives. The first is the conventional twin medium-speed engine configuration with Wärtsilä 8L26 engines. The alternative is an advanced hybrid version, with twin Wärtsilä 9L20 main engines and a single Wärtsilä 6L20 generating set connected to the thrusters by means of an electrical power intake. More details on this hybrid version are presented later in this article.

*Figures 4 and 5* showing the GA drawings for W TUG 60 (basic version) preliminary layout and W TUG 80 (basic version) final layout, can be seen at the end of the paper.

| Main parameters: | W TUG 60 | W TUG 80 |
|---|---|---|
| Length over all | 29.5m | 35.0m |
| Max breadth | 11.8m | 14.0m |
| Depth hull (excl skeg) | 5.6m | 6.4m |
| Draft below skeg | 5.4m | 6.5m |

In the following part of this article we will focus on two key elements – optimisation of both the hull and the hybrid machinery.

*Figure 6: W TUG 80 illustration, the escort tug solution.*

## DESIGNING WITH CFD

Several types of CFD (computational fluid dynamics) are used in parallel during the design process. Panel methods are used to analyse ship motions, whilst hull resistance is investigated by means of the RANS method. By utilising CFD, model test results can be predicted with close to 90 per cent accuracy. The optimisation of hull shapes and appendages thus starts well before model building and tank testing. This saves time and the combination of methods provides greater understanding of the flow phenomena around the hull and appendages. During the optimisation process, many different configurations are analysed in different operating conditions. CFD calculations often allow unique, colourful views on the vessel.

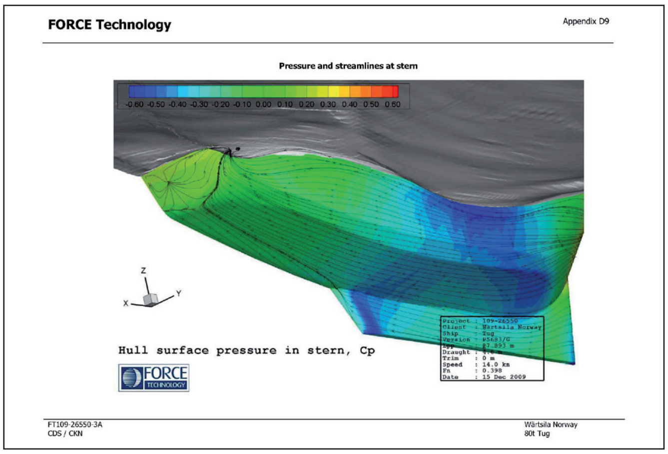



*Figure 7: CFD investigation of the flow along the hull during free sailing.*

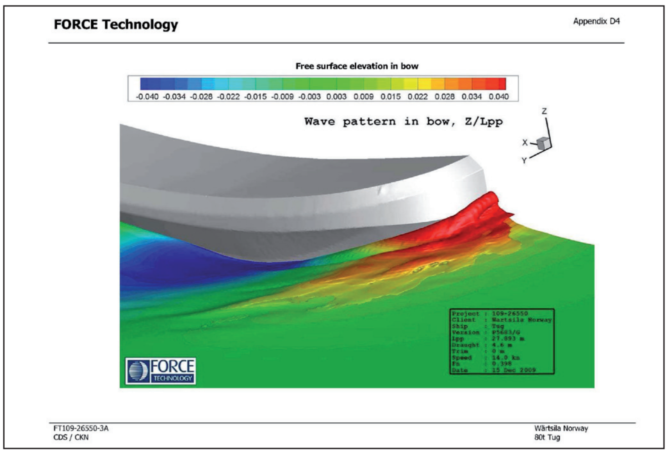



*Figure 8: CFD investigation of the wave pattern on the bow of the hull.*

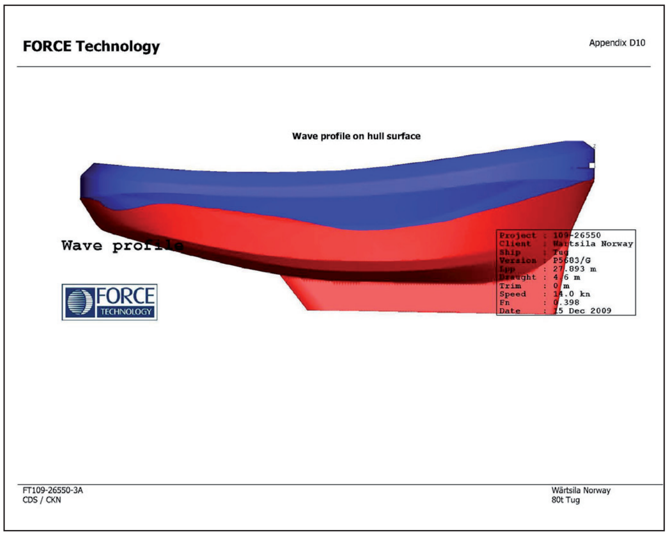



*Figure 9: CFD investigation of the wave profile on the W TUG 80 hull.*

CFD investigation goes hand-in-hand with comprehensive model testing, including towing, self propulsion (forward and aft), escorting, bollard pull and manoeuvring tests. Pitch and roll characteristics will be confirmed, as required by the design brief, for operating the W TUG 80 in exposed sea areas. The model tests are essentially the confirmation of the results obtained by CFD.

## MACHINERY OPTIMISATION

### Today's tug

Typically, tugs operate at an average engine loading of 20 per cent for around 2,000 hours per year. The maximum bollard pull (100 per cent power) is seldom used despite it being a design driver. Although the exact operating profiles differ between harbours, this trend is confirmed by key players in the market. Such low actual engine loading is far removed from the design condition of most engines. Ideally tugs should thus be optimised for both low power and the full engine rating.

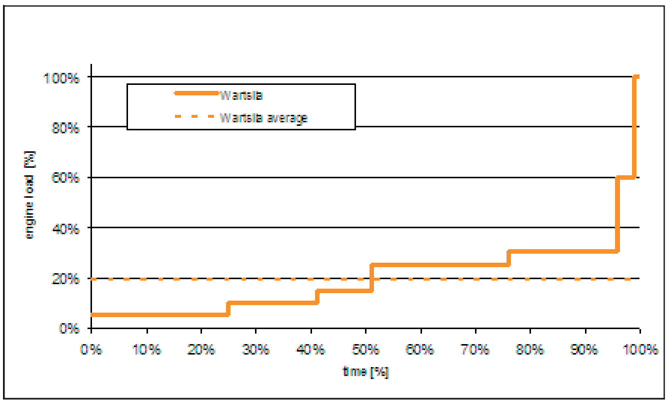



*Figure 10: Operating profile relative to engine load.*

Average loading is only part of the story. When assisting another vessel, power availability is just as important since full power may be required at a moment's notice. At the other extreme, engine load during transit is very stable and predictable.

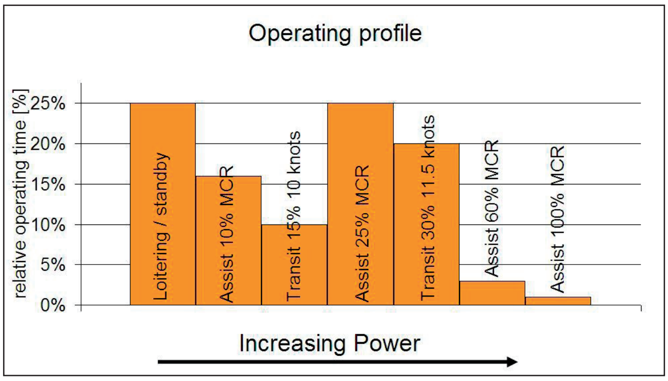



*Figure 11: Operating profile split into operating conditions.*

Reliability, power availability and investment considerations have resulted in straightforward diesel-mechanical installations. These continue to serve the industry well, but can be improved upon from environmental and efficiency perspectives.

## Tomorrow's tug

### *Hybrid*

The simultaneous optimisation of both low and high power output is possible with a hybrid machinery configuration. Such a configuration has been applied to many vessel types, such as offshore supply vessels from which the proven technology has been borrowed. The final configuration applied for the W TUG is shown in *Figure 12* with both mechanical and electrical power trains. The electrical input is simply mounted on the reverse side of the thruster as per existing dual input installations. The target for this hybrid is to be able to transit on a single engine in diesel-electric mode, and then supplement this with the mechanical engines when in assist mode. The sizing of the engines thus starts from the bollard pull requirement, resistance curve, and the electrical load balance. The aim is to optimise the resistance curve and equipment efficiency for the same transit operating speed. A key operator concern is to be able to get out of the way of an assisted vessel in case of a black-out on the tug. This intrinsic failsafe of mechanically-driven vessels is taken into account in the hybrid. In fact a second, purely electrical fail-safe is introduced in case of a mechanical failure.

The Wärtsilä 9L20 engines are mechanically coupled to the CS300 thruster units by means of a shaft. The components in the blue box are the heart of the hybrid. The electrical power intake (PTI) and frequency drive unit take electrical power from the Wärtsilä 6L20 generating set and the small harbour generating set. The PTIs can be used to run the thrusters independently in a pure electrical mode, or to boost the mechanically supplied power. The batteries in the red box can be added to create a completely silent electrical operating mode.

*Figure 13* showing the GA drawing for the W TUG 80 (hybrid version) can be seen at the end of the paper.

An indication of where savings can be achieved is shown in the overall energy consumption for electrical and propulsive needs in *Figure 14*.

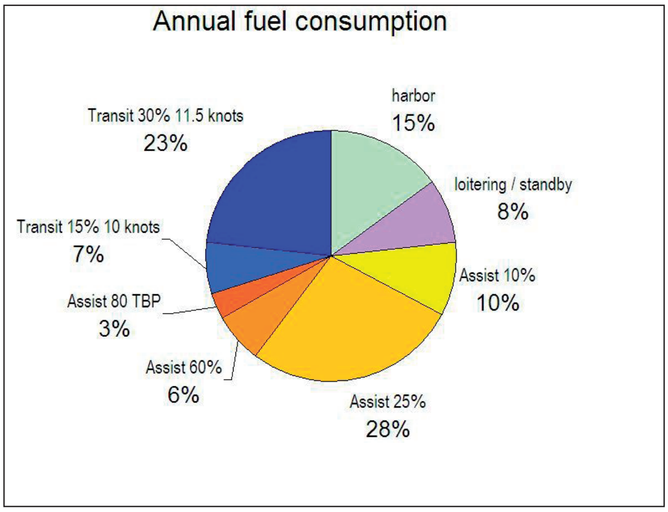



*Figure 14: Energy consumption per operating condition.*

Transit between the berth and the area of assist represents almost a third of all energy consumption. The main engines operate at less than 30% in this condition is an indication of the improved potential. Increasing the engine load does not result in a significant speed increase, but merely generates excessive waves

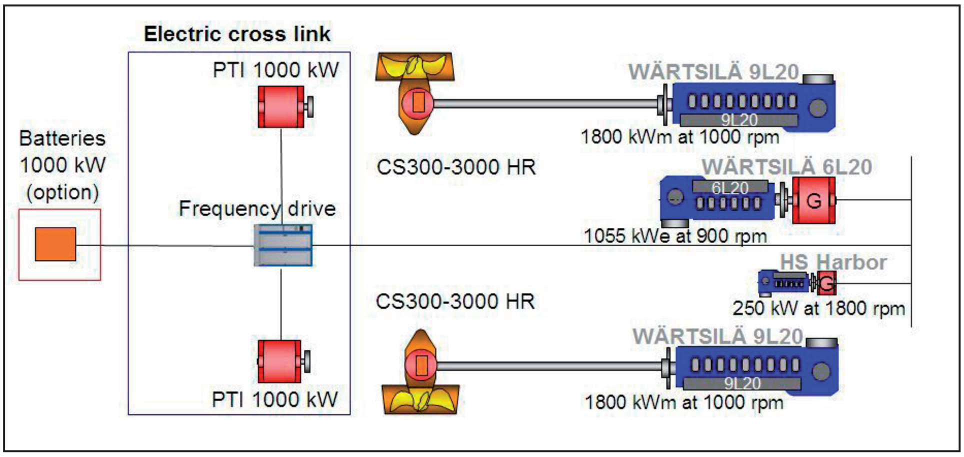



*Figure 12: Hybrid machinery configuration.*

Loitering, with the engines mostly idling, is typically an inefficient operating condition. At least part of the eight per cent energy consumption should be salvageable. Perhaps surprisingly, the harbour power requirements contribute 15 per cent to total energy consumption. This is not because of the high power demand, but is due to the large amount of time spent in the harbour. Typically one of the harbour sets is always running at high rev/min and at relatively low loads during much of its life.

The route to the propeller is different in the case of mechanical and electric transmission. The efficiency comparison has thus been performed based on fuel consumption per kW of power delivered to the thruster, thus taking the full chain of efficiencies into account. This provides an interesting insight into the relative performance of different power sources, including batteries, high-speed engines and medium-speed engines. At the low loads at which tugs operate, a 20 per cent difference in fuel oil consumption can be found between the best and worst configurations. The same method can be used for optimising an emissions profile.

Besides selecting engines with low specific fuel oil consumption in the relevant operating areas, a lot can be gained or lost in the combination of propeller rpm and propeller pitch. The combination of rev/min and pitch over the operating range is generally referred to as the 'combinator'. Low thrust requirements can be achieved with high rev/min/low pitch or low rev/min/high pitch. The latter is typically more efficient for the same thrust when using a nozzle, but is limited by the minimum rev/min requirements of diesel engines.

Electric motors allow operation at extremely low rotation rates. Electrically driving the main propulsion at low loads is thus used to benefit hydrodynamic efficiency and to reduce mechanical losses in the gears and bearings. Such hydrodynamic efficiency improvements more than offset the losses introduced within the electrical system in several operating conditions. The capability of stopping the propellers altogether improves efficiency even further.

The hybrid solution presented is the result of comparing many different installations. It achieves an efficiency improvement of just over 10 per cent compared to a conventional twin medium-speed engine tug by optimising the integrated system. This efficiency improvement is evenly spread out over all operating conditions, bar the harbour and loitering/standby conditions. This even spread is an indication of the low sensitivity of the hybrid configuration to the exact operating profile.

In the loitering/standby operating condition, the savings can be up to 50 per cent depending on the interval at which propulsion power is required. If harbour power is sourced from the harbour generating set, then no significant savings can be achieved. Reducing the harbour generating set size to the point where it could not satisfy total on-board demand was not considered an option. Alternatively, the power required in harbour can be sourced from shore. Depending on the type of shore based power plants in use, this could provide a further efficiency and emissions improvement.

Even if the maximum bollard pull rating is rarely used, it needs to be available instantaneously during ship assist operations. To achieve this response, all equipment required to reach the vessel's bollard pull rating is running during the assist mode. This, unfortunately, means some of the equipment is still operating at low loading to meet harbour safety requirements. The presented savings in the assist mode are, therefore, conservative.

### *Controls*

The strong demand for, and limited availability of, skilled crew has resulted in a reduction in crew size. Many operators are running their vessels with only three crew members, while the industry is discussing the implications of two-man crews.

With crew size in mind, the hybrid machinery must be easy to use. The tug master simply requires his attention in order to safely perform the vessel assistance task at hand. The applied user interface has, therefore, been designed to only require input that comes naturally to the tug master. He can recognise whether his vessel is in transit or about to assist another vessel, for example. Selection of these operations-related conditions by the tug master allow the vessel controls to optimise the machinery configuration for optimal efficiency and emissions.

It should be noted that the changeover between operating conditions is not required during peak activity levels, but solely at moments when the tug master can devote a small amount of his attention to it. Such a simple user interface is essential to materialising the calculated improvements.

Behind the user interface, the controls also provide the intelligence. For the selected operating condition, certain engines are brought online in keeping with the power requirements normally expected in that operating condition. The thruster control levers function as normal, triggering the normal power and steering commands. Handling of the vessel is thus not affected.

In case the power demand signal is higher than the power available, the tug master is prompted to switch to a higher level of power availability. Similar prompts occur in case of a sub-optimal system configuration for an extended period of time. Note that such a prompt will not interfere with vessel assist operations when the tug master needs his full attention.

### *Fuel oil consumption and emissions*

Introducing the hybrid for the presented operating profile reduces fuel consumption by just over 10 per cent compared to the conventional twin medium-speed engine set up. $CO_2$ and $SO_x$ emissions are directly related to fuel consumption and are reduced by the same amount. $NO_x$ emissions reduce by just over 12 per cent as a result of the improved engine operating points made possible by the hybrid concept. In case a shore power connection is used for harbour power requirements, an additional 15 per cent of the reference vessel's energy consumption can be transferred to land-based power plants where exhaust after-treatment is easier to implement.

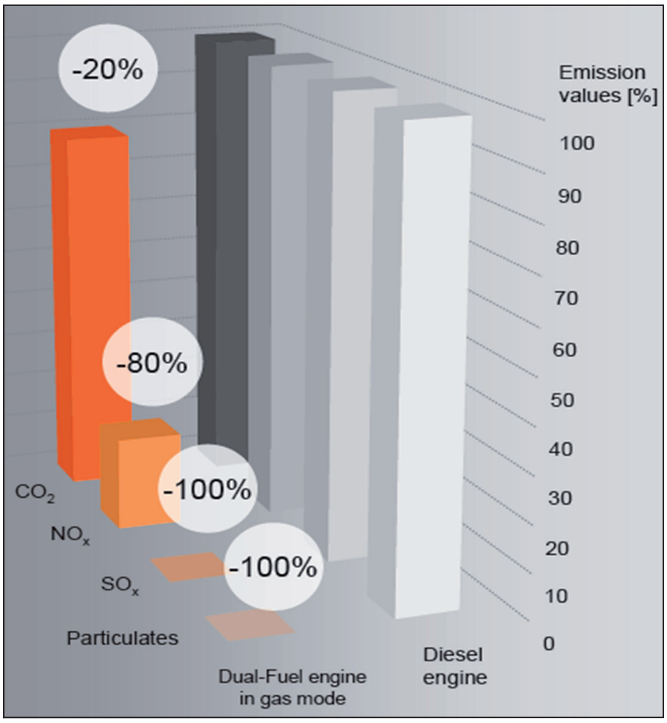



*Figure 15: Emission values of dual-fuel engine in gas mode and diesel engine.*

### *Future*

Batteries, dual-fuel engines, and fuel cells allow further emission and efficiency improvements. Even more advanced hybrid tugs can be expected in the near future.

## CONCLUSION

At Wärtsilä, we believe that emission regulations require the re-design of many existing vessel types. This is especially true for vessels operating in the proximity of large population centres, as is the case with tugs in ports. The steadily decreasing cost and high reliability of available technology indicate that the marine sector is ready for more advanced solutions. The economic viability of these complex solutions typically results from an integrated approach, from vessel design to equipment selection and on-site support for the shipyard and owner.

Wärtsilä's approach is to be the single point of contact during the design, building, and even operational phases, thus providing the W TUG customer assurance that this advanced vessel solution is supported at every stage of its lifecycle.

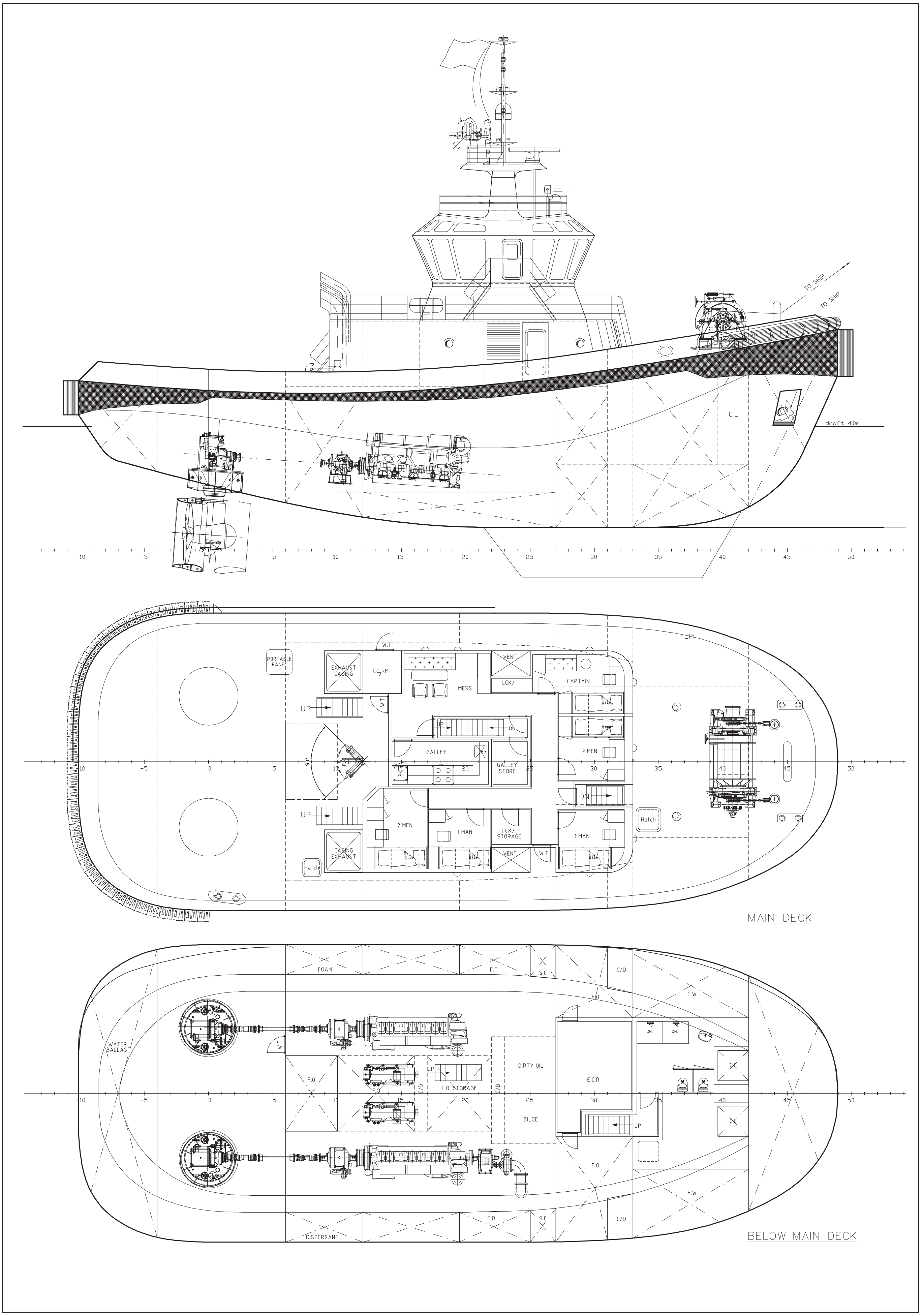



*Figure 4: GA for W Tug 60 (basic version) preliminary layout.*

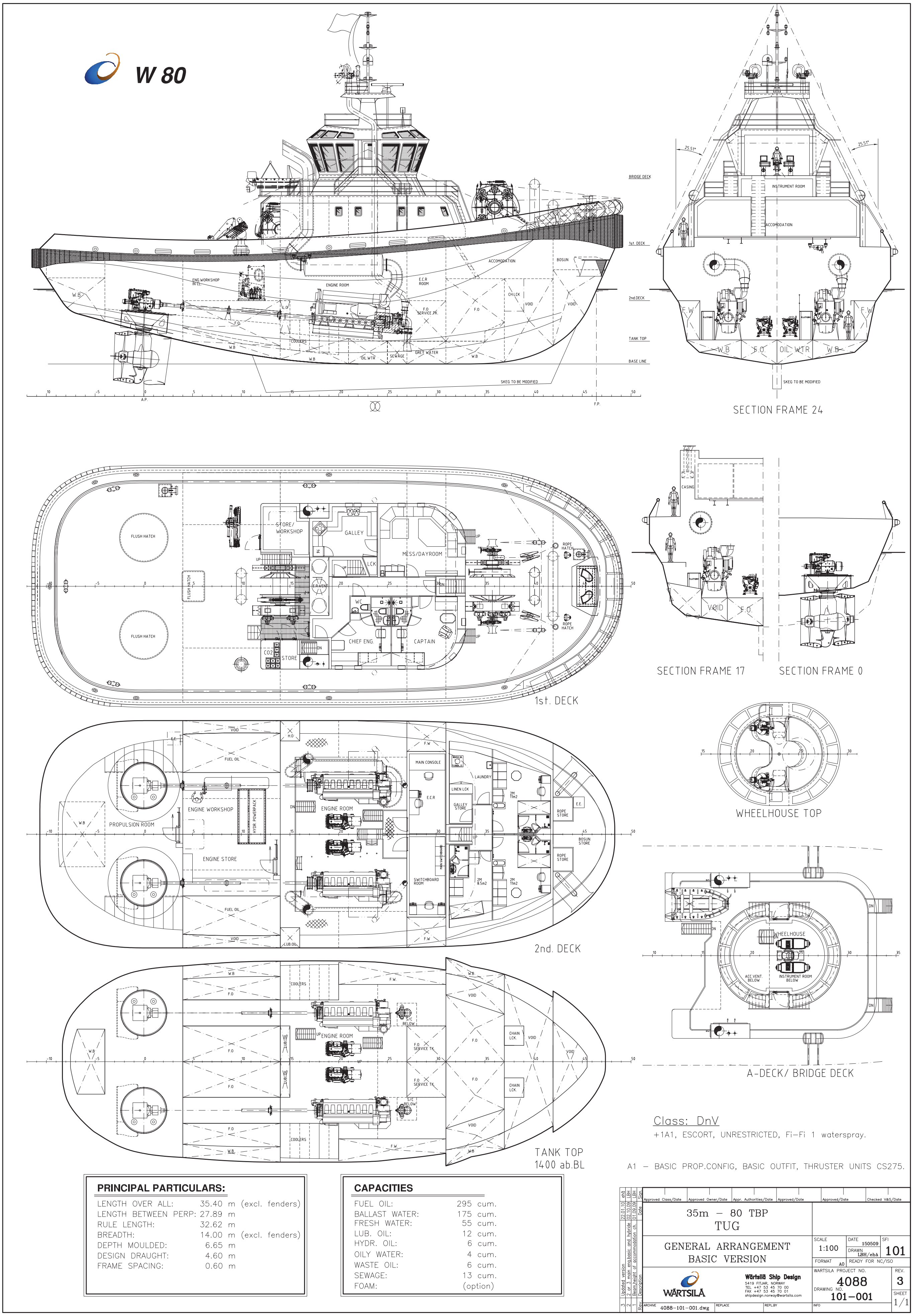
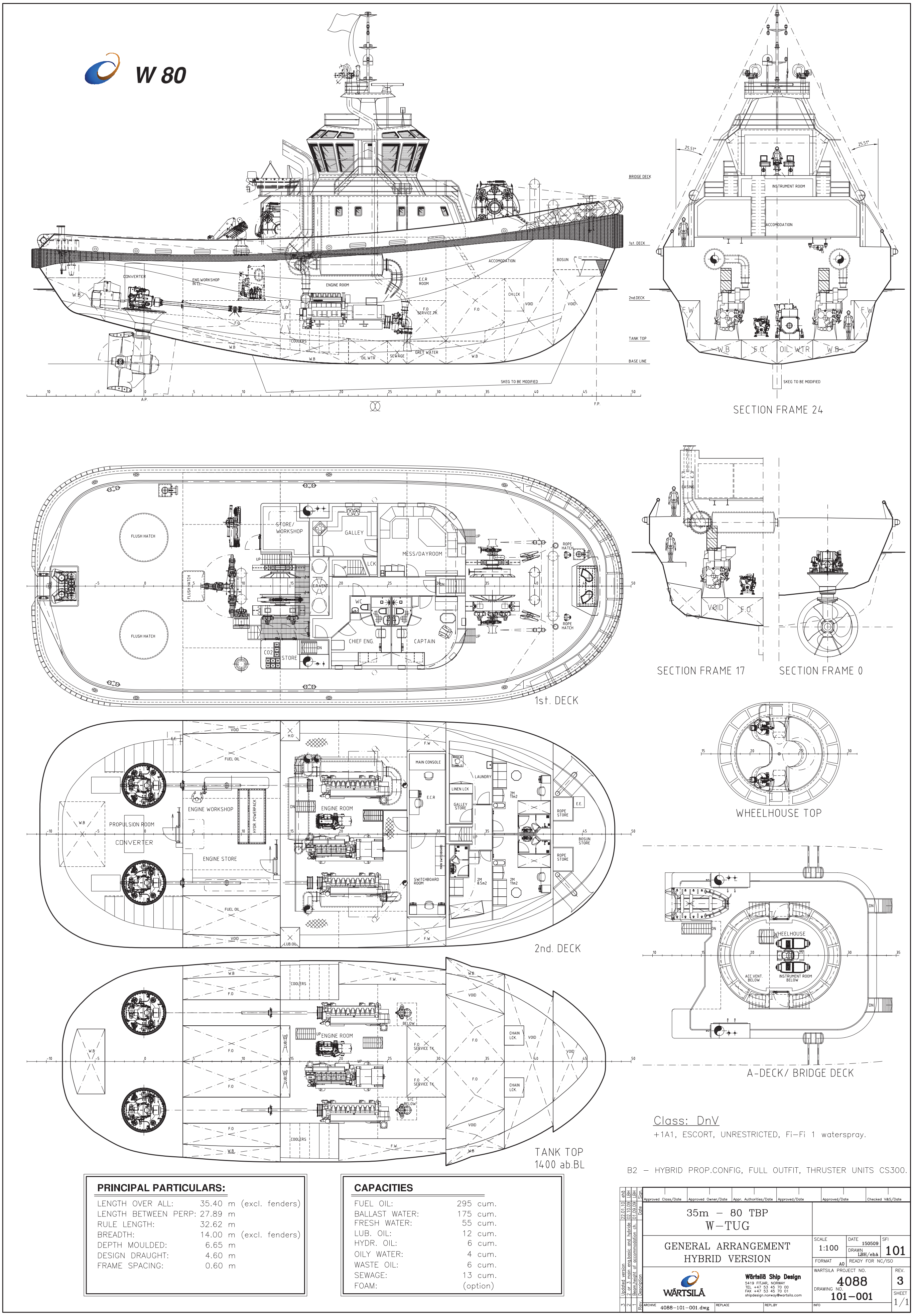



*Figure 5: GA for W Tug 80 (basic version) final layout.*




**PRINCIPAL PARTICULARS:**

| | |
|---|---|
| LENGTH OVER ALL: | 35.40 m (excl. fenders) |
| LENGTH BETWEEN PERP: | 27.89 m |
| RULE LENGTH: | 32.62 m |
| BREADTH: | 14.00 m (excl. fenders) |
| DEPTH MOULDED: | 6.65 m |
| DESIGN DRAUGHT: | 4.60 m |
| FRAME SPACING: | 0.60 m |

**CAPACITIES**

| | |
|---|---|
| FUEL OIL: | 295 cum. |
| BALLAST WATER: | 175 cum. |
| FRESH WATER: | 55 cum. |
| LUB. OIL: | 12 cum. |
| HYDR. OIL: | 6 cum. |
| OILY WATER: | 4 cum. |
| WASTE OIL: | 6 cum. |
| SEWAGE: | 13 cum. |
| FOAM: | (option) |

*Figure 13: GA for the W TUG 80 (hybrid version).*