Concept Design and Testing of a Proposed 100-tonne Escort Rotor Tug

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The following article is abridged from a paper describing the design development and model testing of a new generation of high-performance Escort Rotor Tug, designed by Robert Allan Ltd. for Kooren Shipbuilding and Trading B.V.

Since its introduction in 1999, the 'Rotor tug' concept has proven itself in a number of ports and offshore activities. In 2002 new designs were further developed and refined for this triple-drive tug concept. The most important change was moving the aft thruster and the aft towing point closer together. By placing the aft towing point exactly above the aft thruster, the tug is made even more suitable for assisting large seagoing vessels, and positioning an azimuthing thruster directly below the towing point offers the tug unequalled manoeuvring characteristics.

Fourteen Rotor tugs have been built by Kooren Shipbuilding & Trading B.V. (KST B.V.) and their excellent performance, combined with the current market demand for ever more powerful tugs, prompted the company in 2005 to design a 'next generation' of Rotor tug. The new 'Escort-class Rotor Tug' is a product of the collaboration between KST B.V. of Holland and Robert Allan Ltd., the Canadian naval architectural firm known for its recent designs and hull shapes for advanced high-performance tugs.

The principal factors leading to the development of high-powered tugs with bollard pull in the 80-120 tonnes range have included: assistance of large, high-windage vessels such as containerships, LNG carriers, VLCCs, ro-ro vessels, tankers, ferries, etc; cost reductions for tug services by using fewer tugs for the same operation (less crew, less maintenance, etc.); the capability for tugs to apply significant forces during extreme escorting, towing, assisting or salvaging operations which are very dependent on tug size as well as power.

In addition, such high-powered and therefore expensive tugs can be cost-effective for universal applications when all the performance parameters related to power and size can be used with maximum efficiency and minimum idle time.

OWNER REQUIREMENTS

1. Operations

The new generation of very large containerships and the rapid increase in number of LNG transport ships both require stronger and more manoeuvrable tugs with 80-100 tonnes bollard pulls at low speeds, especially for port operations. Rotor tugs fit these requirements to advantage, especially in confined ports. However, tugs that assist oil and gas carriers must also be able to escort these ships with a required steering force of up to 140-150 tonnes at 10 knots. Existing Rotor tug designs do not suit these escort operations. Kooren S&T required a new multipurpose tug that would combine escort and Rotor tug characteristics to perform the following operations:

- Ship assistance, harbour duties, escorting in confined spaces, vessel berthing, etc. for VLCCs and LNG tankers (offshore/inshore of FPSOs), large bulk-carriers and the latest generation of containerships.
- Escort of large oil and LNG tankers through confined passages and open sea.
- Ocean towing.
- Fire-fighting and oil-spill response.

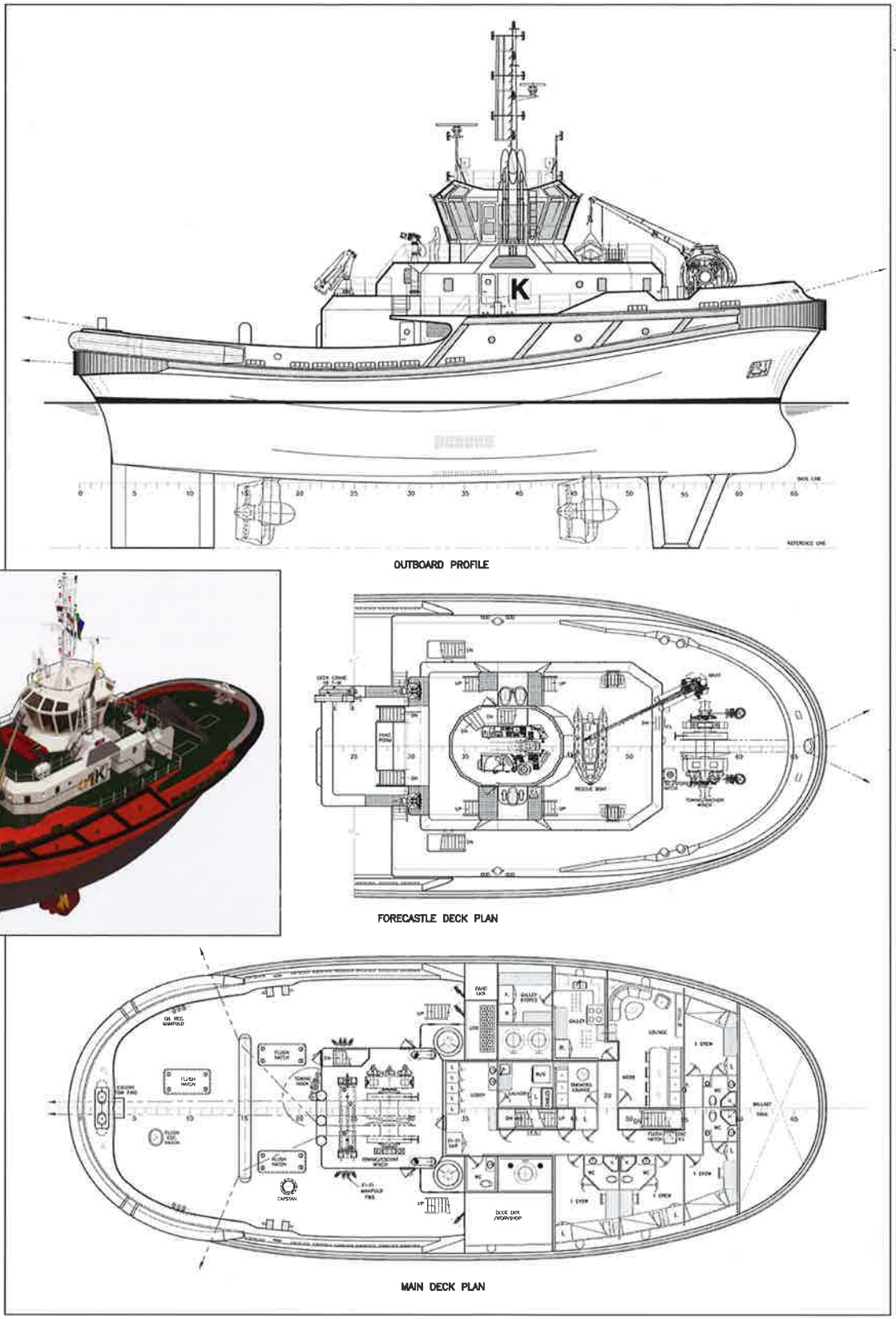
These operations are quite diverse and require quite different (and some contradictory) tug characteristics, particularly the capabilities for both low-speed assist and high-speed escort operations.

2. Performance

The new tug required the following initial design objectives and restrictions:

- Rotor tug propulsion configuration for low speed ship assist and manoeuvrability.
- For port operations, a length of approximately 35 metres (38 metres max) and draft restricted to 7.3 metres.

Courtesy Robert Allan Ltd



The general arrangement for a new Escort Rotor Tug design developed by Kooren Shipbuilding and Trading B.V. and Robert Allan Ltd. The design incorporates all the best characteristics of the previous generation of Rotor tugs and includes new capabilities as an extreme offshore escort and long-range ocean towing tug.

- A minimum of 140 tonnes steering force at a speed of 10 knots.
- Bollard pull of 100 tonnes.
- Free-running speed, minimum 14 knots.
- Side-stepping speed of approximately 6 knots.
- Fire-fighting capabilities meeting Fi-Fi Class 1.
- Oil recovery capability.
- Sea-keeping ability in high seas up to 5 meters significant wave height.

3. Capacities

The following capacities were required for the tug:

- Fuel oil sufficient for 7 days operation at 85% of maximum power, or a minimum 200 m3.
- Freshwater, minimum 30 m3.
- Lube and hydraulic oil, 6 m3.
- Recovered oil capacity of approximately 200 m3.
- Oil boom of 500 metres total length.
- Accommodation for a crew of eight, all with single cabins c/w en suite toilet and shower.
- Aft double-drum escort/towing winch with 300 metres synthetic hawser and 1,000 metres steel towline capacities; a forward single drum, line-handling winch with 300 metres synthetic hawser capacity.

CONCEPT DESIGN APPROACH

A number of compromises were required to best satisfy the owners' sometimes conflicting demands. The operational environment constrained both length and draft, while the crew, endurance and capacity requirements combined to limit space and volume.

Operational Design Requirements and Limitations

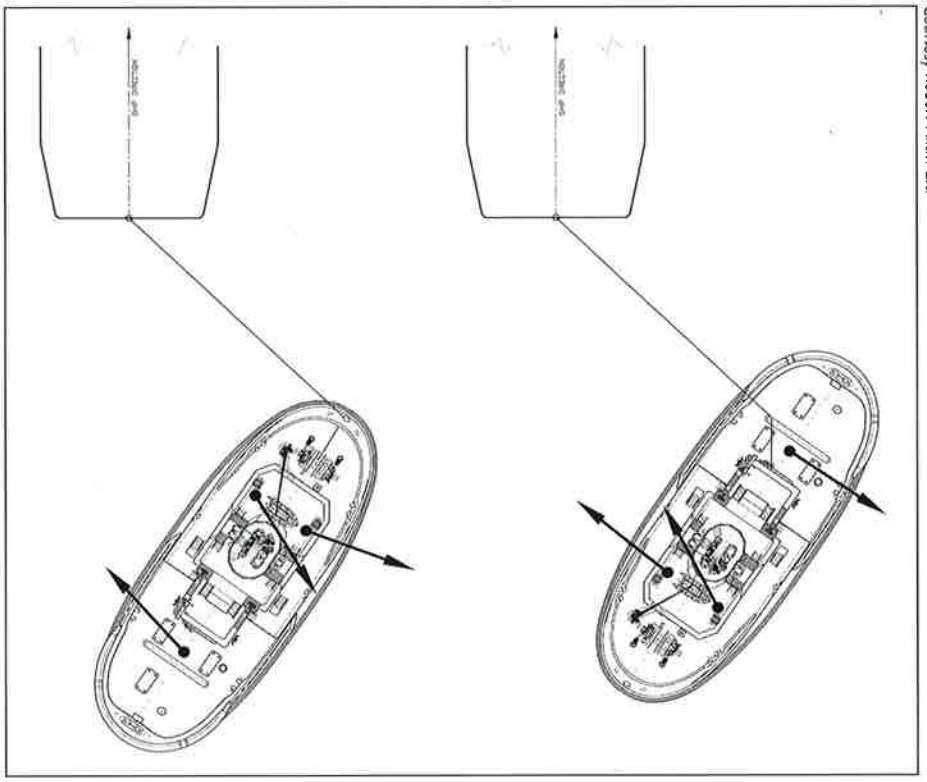
1. Ship Assistance

Ship assistance requires: high manoeuvrability in confined spaces; application of force by pulling on the hawser or pushing through the fender; two hawser winches to work over both bow and stern; low speed operations (2 to 4 knots) combined with high thrust. The manoeuvrability was achieved with the Rotor tug's triple-drive triangle configuration which can apply thrust in any horizontal direction. The tug does not need to be rotated in the direction of the force application, instead the thrust is rotated. The tug applies transverse steering forces to the assisted vessel when the tug is restricted in its manoeuvres, as in narrow canals or locks. Rotor tug force is applied using a manoeuvre termed 'rotoring' which positions the tug in a space which is often not much wider than the beam of the assisted vessel, and

where the thrust is directed in almost any direction without affecting the yaw angle of the tug (see Figure 1). For maximum effectiveness, rotoring requires a hull with minimum appendages and minimum lateral area. Minimum overall length is also an advantage. The preferred position of the aft towing point is exactly above the aft thruster.

2. Long Range Escort

The requirements for a high performance escort tug include high speed, good seakeeping, creation of the maximum possible indirect steering force, the capability for high braking forces and very high stability. Full scale trials with the RT MAGIC in 1999 (see photo on page 26) proved a Rotor tug can perform indirect escort mode operations at high speed but capabilities of a tug this size are insufficient to compete with purpose-built escort tugs.



Courtesy Robert Allan Ltd

Figure 1: Thrust forces generated during 'rotoring', bow first and stern first.

Courtesy Robert Allan Ltd

The Rotor tug RT MAGIC in the escort mode, running bow first.

Modern escort tugs require steering forces in the 130-150 tonnes range at a speed of 10 knots. The limitations placed on the size and power of the new tug meant this level of steering force – not achievable by drive thrust alone – must be generated by the thrusters combined with an additional hydrodynamic force (usually the main component of the force in indirect mode). Maximum longitudinal lateral area of the hull helps create these steering and braking forces. The tow point must also be as low as possible and should be located 15% to 20% of LWL towards midship.

3. Ocean Towing

Safe ocean towing requires a unique combination of the following: adequate sustained thrust, especially in a seaway; adequate endurance; good seakeeping in a wide range of conditions; safe working decks for the crew, and; reliable, durable towing gear suitably located for the towing functions.

4. Fire-Fighting & Oil Spill Response

While not requiring a special tug configuration, fire-fighting and oil spill response capabilities have obvious impacts on machinery space arrangements. Spill response requires specialized on-board equipment and, frequently, recovered oil tankage with associated fittings.

CONCEPT DESIGN SOLUTIONS

All of the operational requirements described above can coexist even though they frequently contradict each other. A balanced design approach that includes careful analysis, calculations, tank tests, elements of optimization and a review of relevant design experience produces a new and complete technical design solution with minimal contradictions. The following describe some of the more salient aspects of the comprehensive design process, and resulting solutions, for the new Escort Rotor Tug.

Unique Hull Form

The hull form incorporates characteristics developed in other successful Robert Allan Ltd escort tugs.

- **A double-ended hull** for operations in both directions during escort and towing modes. Higher steering forces will be developed with the stern forward and similar speeds are achievable with both bow first and stern first.
- **Sponsons** provide increased stability when transverse forces are applied during towing or escorting plus a narrower waterline (important to achieving high speed) and significant reductions in roll motions and accelerations in a seaway.
- **A bulbous bow** was proposed for a longer submerged hull with sharper waterline entry to achieve higher speed (and lower wake generation) on the tug's limited overall length.
- **The hull surface geometry** includes V-shaped frames at both hull ends to provide flare for good seakeeping and green water minimization. Deep stern flare creates a physical extension of the skeg in full-load conditions. The chines (double at midships; sharp at the stern) add to the steering force and act to reduce motions. In heavy seas the raised, flared bow minimizes wetness on deck and increases seakeeping and speed.

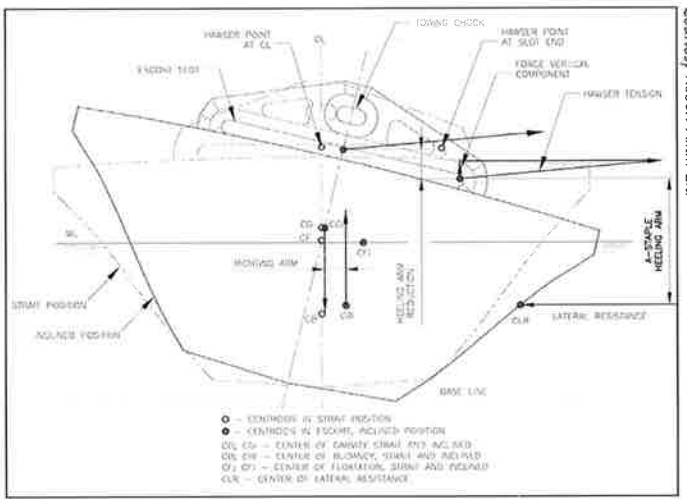
Skeg and Struts

A major feature of the new Escort Rotor Tug design is the skeg fitted at the aft/single-thruster end. In a Voith cycloidal drive or a Z-drive tractor tug this skeg is a major contributor to steering force development. However, the requirements for rotoring and escorting contradict; the former requires minimal skeg area, the latter requires maximum skeg area. The presence of the third Z-drive also requires the skeg to be fitted in the limited space between the aft end of the hull and the aft Z-drive. As the final design solution, a vertically-retractable skeg was selected for the new tug.

Two more appendages, the forward and aft struts, provide vessel support and Z-drive protection when docking. The aft strut also forms a guide and support for the retractable skeg. The requirement to generate a steering force not less than 140 tonnes resulted in new design solutions including a flap attached to the skeg and a 'pulling' Z-drive unit with the suction side positioned close to the flap edge. Tank tests showed that these could be eliminated.

Escort/Towing Staple

A staple with an 'A' shape minimizes heeling forces and improves escort steering capacity. The staple has a large slot in the lower section and a towing chock in its upper part. This rather extreme staple geometry provides an additional 30 tonnes of steering force (see Figure 2).



Courtesy Robert Allan Ltd

Figure 2: The Escort Rotor Tug's escort/towing staple. This figure displays the force diagram for both an upright and inclined tug with this staple configuration.

Towing Arrangement

Steel wire rope (SWR) towline and synthetic escort/ship-handling hawser require separation as the SWR line abrades all areas and will damage the hawser. The towing arrangement with hawser and tow-line separation is seen in Figure 3 on page 28.

Propulsion Machinery

The main engines and Z-drives were selected in accordance with the required bollard pull and draft restrictions. The propeller diameters were limited to 2.6 metres because of draft. Schottel SRP 1515 CP Z-drive units were selected. High-speed Caterpillar 3516B diesel engines (2,000 kW at 1,600 rpm) were selected because of their relatively small size and low weight.

MODEL TEST PROGRAM

With the design's numerous challenges and the combination of unique performance objectives, comprehensive model tests were conducted in 2006 in the 240m x 12m x 5.4m towing tank at FORCE Technology in Copenhagen. The test program was directed by Mr. Kim Henriksen, Senior Project Manager, FORCE Technology and by Mr. Alan Reynolds, President, Offshore Research Ltd., acting on behalf of Robert Allan Ltd.

The test program included the following elements: calm water tests to determine the speed-power characteristics of

Courtesy Robert Allan Ltd

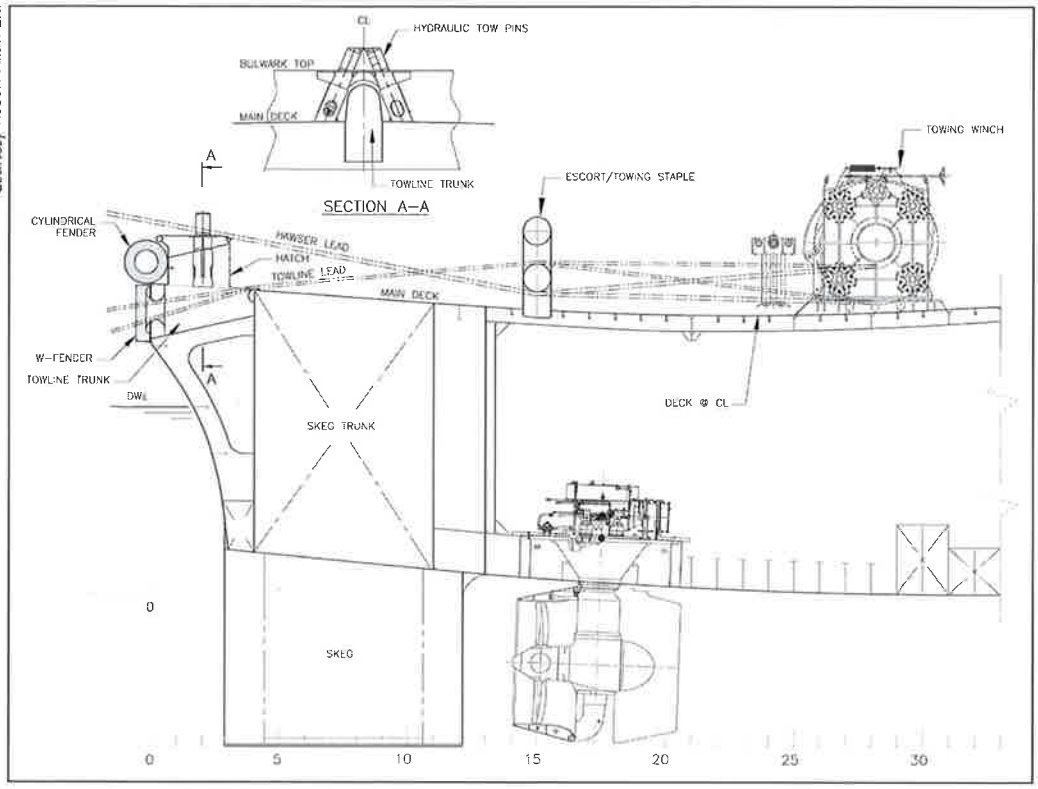


Figure 3: The tug's escort line acts above the bulwark and can slide along the staple slot and bulwark top and use the stern stainless steel escort tow pin set. The SWR towline uses the upper staple chock as a fairlead and then is deployed through a stern towing chock located under the transom's cylindrical fender. The low aft towing chock satisfies the towline pull stability criteria which limit the heeling moment resulting from application of bollard pull at a heeling lever (distance between centre of propeller and tow staple).

Courtesy Robert Allan Ltd

the hull for bow first, stern first and sidestepping operations; bollard pull performance; added resistance of bow, strut and skeg appendages; indirect escort towing tests (stern first and bow first); rotoring tests to define maximum steering forces at low speed, bow first, and; seakeeping tests to define speed loss, accelerations and green water effects in three sea states.

[*Editor's note: Detailed results of the model testing program are not shown here due to space limitations but are available from the authors.*]

Courtesy Robert Allan Ltd

The 1/12th scale model of the Escort Rotor Tug for the tank tests (photo above). The inset photo shows the model's aft end with Z-drive, skeg and flap (which was eliminated after model tests). Main characteristics of the full-sized tug and model include (model characteristics in brackets, all measurements in metres):

Length overall: 37.00 (3.084) *Draft aft (design): 4.0 (0.333)*
Length waterline: 34.13 (2.244) *Volume (m3) Disp: 1,062 (0.615)*
Breadth maximum: 14.00 (1.167) *Metacentric height: 2.2 (0.183)*
Draft (design): 4.0 (0.333)

DESIGN SOLUTIONS

Based on the model test results, the following design solutions were fixed and confirmed:

Double-ended hull shape: the 14 knot speed requirement was exceeded both ahead and astern and the hull attained side-stepping speed of approximately 6 knots.

Skeg configuration: A vertically retractable skeg of relatively small lateral area and without a flap was chosen. Skeg retraction increases manoeuvrability and side-stepping speed during ship-assist operations. Tests of the skeg with a flap (see photos above) and a closely-located 'pulling' Z-drive unit yielded no sufficiently positive result. There was approximately 4.5% increase in steering force due to the flap and no positive influence from the 'pulling' Z-drive. Project requirements were fully satisfied without these two complexities (which are also susceptible to damage) so they were eliminated.

Skeg/Z-drive: This aft combination generated unexpectedly high indirect steering force.

Struts: Additional resistance is created by struts but specified speed was easily attained with them so the struts were retained for protection of the Z-drives and for docking support.

Staple: The staple location, fixed at 22.5% of WL length from the aft perpendicular, provides stable control during escort operations, creates the maximum indirect steering force, and is in the best position for rotoring when closest to the aft Z-drive.

Seakeeping & speed: The speed loss was equal in 3- and 5-metre JONSWAP sea states and was acceptable, as were significant motions and accelerations.

Escort steering force: When escorting in the astern indirect mode in 3-metre waves at 10 knots the steering force was approximately 5% above the calm water value.

FEATURES AND CAPABILITIES IN THE FINAL DESIGN

(See *General Arrangement* on page 23):

- Speed exceeds 14 knots in both directions.
- Ship assistance (rotoring) from both ends.
- Sidestepping speed exceeds 6 knots.
- Escort steering forces up to 165 tonnes (meets the DNV escort stability criteria).
- Retractable skeg combines rotoring with exceptional escort performance.
- Escort steering force generated by the combination of a passive skeg and an active Z-drive reduces skeg size to (approx) 50-60% of a comparable tractor tug.
- Good sea-keeping in both directions.
- Large aft working deck for cargo (up to 100 tonnes).
- Hold storage for 500 metres of oil booms on reels.
- Highest standard of crew facilities and accommodation.

CONCLUSION

Some of the project's contradictory requirements made it unclear if a 'universal tug' with good balanced performance for ship assistance, escort and ocean towing could be achieved. However, the combined experience of the designers and the owners, coupled with the results of the extensive and enlightening model test program, have resulted in a new unique design which has proven that the Rotor tug concept can be applied to a very high-performance escort tug with performance that exceeds all expectations. ◀

This article is an abridged version of the paper The Concept Design and Testing of a Proposed 100 Tonne Escort Rotor Tug *originally presented by Dr. Oscar Lisagor at Tugnology '07 in Southampton, England. This version is published by* Western Mariner *with permission from The ABR Company Ltd. which presents the* Tugnology *conferences in alternating years with their* International Tug & Salvage Conventions. *The complete paper in its original form includes the results of the model testing and is available from the authors.*