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The Concept Design and Testing of a Proposed 100 Tonne BP Escort Rotor Tug

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SYNOPSIS: Robert Allan Ltd was tasked in late 2005 with the development of a new generation of high-performance Rotor tug for Kooren Shipbuilding and Trading BV, which was to have 100-tonne bollard pull, and all the favourable performance features of the previous generation of Rotor tugs, but with enhancements for improved escort and offshore operations. This paper describes the design challenges presented, the solutions developed, and the extensive model testing programme undertaken to verify the general performance and escort towing capabilities of the design.

1 INTRODUCTION

This paper describes 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 BV.

These new tugs will have all the favourable performance features of the prior generation of Rotor tugs, but with additional enhancements for open ocean operations, a more extreme escort capability, and the capacity to safely handle the new generation of larger ships currently appearing in the world's major ports.

The Rotor tug concept, since its introduction in 1999, has proven itself in a number of ports and offshore activities. In 2002 it was decided to further develop this triple-drive tug concept. New designs were developed and in consultation with experienced captains, a number of refinements were made to the original design.

The most important change was the placement of the aft thruster and the aft towing point towards each other. By placing the aft towing point exactly above the aft thruster, the tug is even more suitable for assisting large seagoing vessels. The positioning of an azimuthing thruster directly below the towing point offers the tug unequalled manoeuvring characteristics.

Four new Rotor tugs with this modification were built and have fulfilled the owner's expectations. At this moment, 10 Rotor tugs with bollard pull ranging from 45 to 80 tonnes have been/are being built, and more are pending.

Based on the excellent performance of the existing Rotor tugs, which have been confirmed by full scale tests with the first Rotor tugs (RT Magic Class) combined with the current market demand for ever more powerful tugs, it was decided in 2005 to design a new Escort Class Rotor Tug in cooperation with Robert Allan Ltd.

The designs and hull shapes of recent advanced high-performance tugs designed by Robert Allan Ltd were decisive in the owner selecting this Canadian firm as their naval architect for the next generation of Rotor tug.

The following are the principal factors leading to the development of high-powered tugs with bollard pull in the range from 80 tonnes to 120 tonnes:

- Assistance of the large, high-windage vessels such as containerships, LNG carriers, VLCCs, Ro-Ro vessels, tankers, ferries, etc;
- Objectives of reducing the cost of tug services by using fewer tugs for the same operation (less crew, less maintenance, etc);
- Capability of applying significant forces in extreme situations when escorting, towing, assistance or salvage, which are very dependent on tug size as well as power.

Such highly-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.

A review of the current worldwide demand of tug operators for new tug designs shows a strong tendency for universalism or multi-functioning. The high demand for such versatile tugs as the new RAstar Class or the success of unique high-performance VSP escort tugs such as Velox, also developed by Robert Allan Ltd, confirms this tendency.

2 OWNER'S REQUIREMENTS

2.1 OPERATIONS

The introduction of a new generation of very large containerships requires stronger and more manoeuvrable tugs with pulls at low speeds of 80 to 100 tonnes especially for port operations. Similarly, the rapid increase of LNG transport requires tugs with equal performance. Rotor tugs are very suitable to fulfill these requirements, and offer some unique advantages, especially in confined ports.

Tugs that assist oil and gas carriers must also be able to escort these vessels, with a required steering force up to 140 to 150 tonnes at 10 knots. For these operations, the existing Rotor tug designs are not suitable. In order to serve both markets with one tug, Kooren Shipbuilding and Trading BV has tried to create a new multipurpose tug with combined escort and Rotor tug characteristics.

The new tug must be able to perform the following operations:

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

The required operations are very diverse, and hence require quite different tug characteristics, some of which are contradictory. In particular, low-speed assist operations and high-speed escort operations do not generally match well with respect to tug characteristics.

2.2 PERFORMANCE

The following were the initial design objectives and restrictions for the new tug:

- The vessel must be equipped with a Rotor tug propulsion configuration for good low speed assisting capability and manoeuvrability;
- The tug must be able to generate a minimum 140 tonnes steering force at a speed of 10 knots;
- The draft is restricted to 7.3m and the length is ideally approximately 35m with a maximum of 38m in order to be suitable for port operations;
- Free-running speed, minimum 14 knots;
- Side-stepping speed of approximately 6 knots;
- Bollard pull of 100 tonnes;
- Fire-fighting capabilities according to Fi-Fi Class 1;
- Oil recovery capability;
- The tug must have good sea-keeping capability in heavy seas up to 5m significant wave height.

2.3 CAPACITIES

The following capacities were required:

- Fuel oil capacity sufficient for seven days' operation at 85 per cent of maximum power, or a minimum 200m^3;
- Freshwater minimum: 30m^3;
- Total volume of lube oil and hydraulic oil: 6m^3;
- Recovered oil capacity of approximately 200 m^3;
- Oil boom on reels; total of 500m;
- Accommodation for a crew of eight persons, all in single cabins, and each with en suite toilet and shower facilities;
- One double drum escort/towing winch aft, with synthetic hawser of 300m and steel towline of 1,000m;
- One single drum, line-handling winch forward, with synthetic hawser of 300m.

3 DESIGN APPROACH AND LIMITATIONS

3.1 DESIGN APPROACH

In commencing this design, it was immediately evident that a number of compromises must be made in order to best satisfy the owner's demands, which sometimes conflict.

The main limits of the overall design came from the operational environment. Length and draft were both constrained. The crew, endurance and capacity requirements created limits for the space and volume design. All these limits are further discussed below.

3.2 OPERATIONAL DESIGN REQUIREMENTS AND LIMITATIONS

The tug had to be designed for the five main operations listed above. Each of these operations require the individual qualities described in the following subsections:

3.2.1 SHIP ASSISTANCE

- High manoeuvrability in confined spaces;
- Capability of force application pulling on the hawser or pushing through the fender;
- Ability to work with hawser over both the bow and the stern. This required installation of two winches;
- Capability of low speed operations (2 to 4 knots) combined with high thrust.

These qualities were achieved by the development of the Rotor tug concept where high manoeuvrability is achieved by three propulsion units placed in a triangle. This triple-drive configuration can apply thrust in any horizontal direction without rotation of the tug, but by rotation of the thrust.

The tug by itself does not need to be rotated in the direction of the force application. This capability is very important in the narrow canals or locks where the transverse steering force must be applied to the assisted vessel but the tug is restricted in its manoeuvres because of the canal limitations. The Rotor tug applies the force 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.

Figure 1 shows the typical forces acting during rotoring, when bow first and stern first.

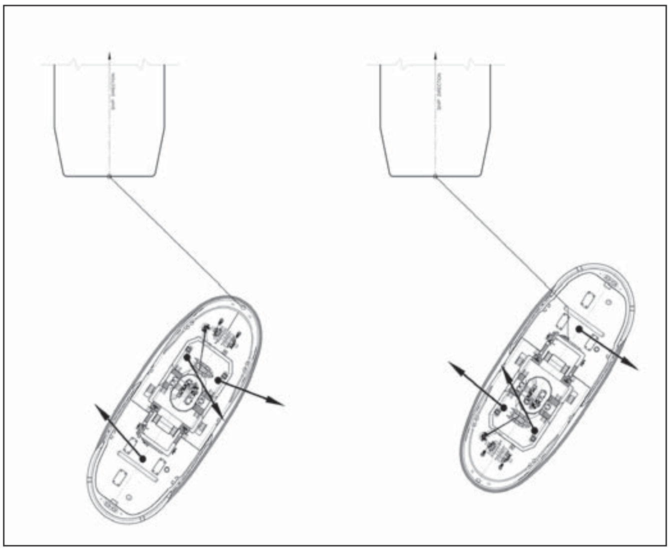

Figure 1: Thrust forces during rotoring for bow first and stern first.

For maximum effectiveness, rotoring requires a hull with minimum appendages and minimum lateral area. Minimum overall length also is an advantage. The preferred position of the aft towing point is exactly above the aft thruster.

3.2.2 LONG RANGE ESCORT

- High speed;
- Good seakeeping;
- Creation of maximum possible indirect steering force;
- Capability of creating high braking forces;
- A very high standard of stability.

It was proven that a Rotor tug is able to perform indirect escort mode operations at high speed during full scale trials with *RT Magic* in 1999. Figure 2 and Figure 3 are photos from escort trials both stern first and bow first respectively. However, the capacities of this size of tug are not sufficient for competing with purpose-built high performance escort tugs.

Figure 2: Rotor tug **Magic** *in the escort mode when stern first.*

Figure 3: Rotor tug **Magic** *in the escort mode when bow first.*

For a modern escort tug, the required steering force can be in the range of 130 to 150 tonnes at a speed of 10 knots. Due to the limitations placed on the size and power of the tug, this level of steering force could not be achieved by the drive thrust alone, but must be generated by the thrusters and by an additional hydrodynamic force. The hydrodynamic force is 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 per cent to 20 per cent of LWL towards midship.

3.2.3 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 finally, reliable and durable towing gear, suitably located for the towing functions.

3.2.4 FIRE-FIGHTING AND SPILL RESPONSE

Fire-fighting and spill response capabilities do not necessarily require a special tug configuration, but there are obvious impacts on machinery space arrangements, and in the case of spill response both special onboard equipment requirements and frequently suitable tankage and associated fittings for recovered oil.

All of the operational requirements described above can coexist, but they can frequently contradict each other. A balanced design approach that includes careful analysis, calculations, tank tests, elements of optimisation and a review of the other relevant design experience enables the creation of a complete new technical design solution with minimal contradictions.

A comprehensive design process was involved in defining this new tug, with numerous iterations between designer and owners in order to achieve the best possible final design solution. The following describe some of the more salient aspects of the design process, and the resulting solutions.

4 CONCEPT DESIGN SOLUTION

4.1 HULL FORM

A unique hull form was developed for the new escort Rotor tug, incorporating some of the features developed and refined by Robert Allan Ltd in previous successful escort tugs. The new Rotor tug hull has the following characteristics:

4.1.1 DOUBLE ENDED HULL

The need for a hull to operate in both escort and towing modes demands a form that is capable of working equally well in both directions. Higher steering forces will be developed with the stern forward. The proposed hull has approximately similar speed when sailing bow first and stern first.

4.1.2 SPONSONS

The unique sponsoned hull form developed by Robert Allan Ltd and used in several successful escort tugs to date was also proposed for the new Rotor tug. This shape increases stability when transverse forces are applied from towing or escorting. This feature also creates a narrower waterline and increases L/B, important to achieving high speed. The sponsons also significantly reduce roll motions and accelerations in a seaway.

4.1.3 BULBOUS BOW

The high speed requirement on a limited overall length limit demanded a special approach to the hull design. The objective was to create a longer submerged hull, with sharper waterline entry and reduced wake generation characteristic; hence a bow with a bulbous shape was proposed.

4.1.4 HULL SURFACE GEOMETRY

Both ends of the hull have V-shaped frames with flare for good seakeeping and green water minimisation. The stern has a deep flare that creates a physical extension of the skeg in full load conditions. The hull was developed with double chines at midships and sharp chines at the stern. The chines create some addition to the steering force and act positively for reduction of motions. The bow is raised and incorporates both V-shaped frames and flare to minimise wetness and spray forward, and to improve seakeeping motions and increase the speed in heavy seas.

4.2 SKEG AND STRUTS

One of the major features of this new design is the skeg, fitted aft (at the single thruster end). In a VSP or a Z-drive tractor tug, this skeg is a major contributor to the steering force development. The requirements for rotoring and escorting however result in a direct contradiction: in one case minimal skeg area is required, in the other maximum area is required.

However, the presence of the third Z-drive also prevents the fitting of a large skeg. The skeg has to be fitted in the limited space between the aft end of the hull and the aft Z-drive.

A number of alternatives were considered, and in the final analysis a vertically retractable skeg was selected as the final design solution.

The hull has two more appendages, the forward and aft struts, both of which were designed for vessel support and Z-drive protection when docking. The aft strut is used as a guide and support for the retractable skeg.

In order to comply with the requirement to generate a steering force not less than 140 tonnes the design team considered a number of new solutions. These included a flap attached to the skeg and a 'pulling' Z-drive unit, with the suction side positioned close to the flap edge.

Later the tank tests showed that the level of the required steering force could be easily achieved and exceeded without the flap installation and without pulling type aft Z-drive. The flap and pulling Z-drive were eliminated from the design because of unclear benefits and possible future construction and operational problems.

4.3 ESCORT/TOWING STAPLE

In order to minimise heeling forces and improve escort steering capacity, a staple with an A-shape, with a large slot in the lower section and a towing chock in upper part was proposed.

The benefit of this rather extreme staple geometry is an additional 30 tonnes of steering force. The force diagram for both an upright and inclined tug with this staple configuration is shown in Figure 4.

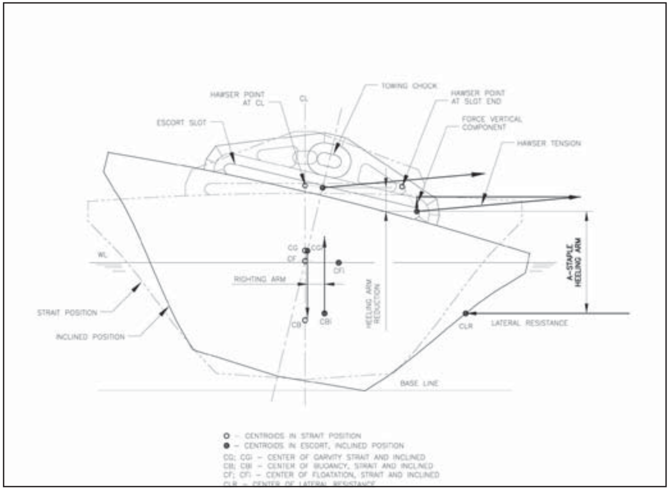

Figure 4: Escort/towing staple.

4.4 TOWING ARRANGEMENT

The combination of a steel wire tow rope and a synthetic hawser deployed from the same winch presents significant challenges. Any area in contact with steel towing wire will be abraded and thus it will inflict serious damage to the expensive synthetic hawser used for escort and ship-handling operations. It is therefore essential to separate the contact areas for these tow line types. In the new Rotor tug, the 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. None of these surfaces can be in contact with the steel tow wire.

The SWR towline uses the upper staple chock as a fairlead and then is deployed through a stern towing chock located under the cylindrical fender in the transom. Access to the towing chock is arranged by the short towing trunk.

The design must satisfy the towline pull stability criteria that limits the heeling moment resulting from application of bollard pull at a heeling lever (distance between centre of the propeller and tow staple). It is difficult to fulfill these criteria for a high-powered tug with 100 tonnes of bollard pull, relatively high staple on the deck and Z-drives located under the hull bottom. The low aft towing chock eliminates this problem. The towing arrangement with escort and towing line separation is shown in Figure 5.

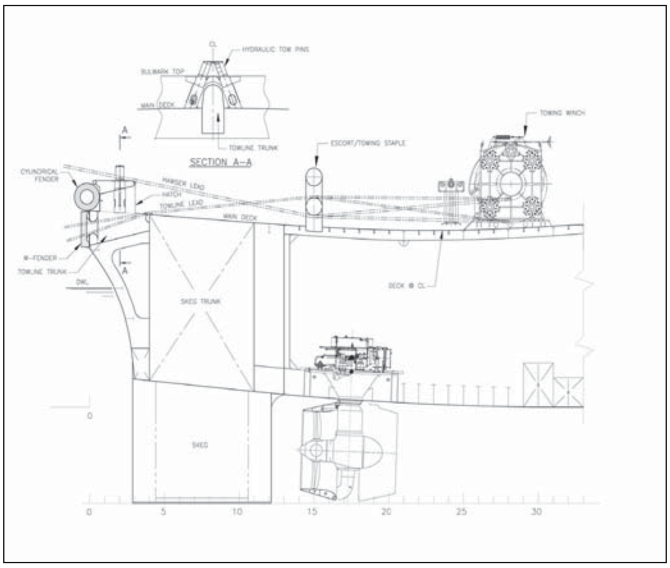

Figure 5: Towing arrangement.

4.5 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 2.6m because of draft. Schottel SRP 1515 CP units were selected. High-speed CAT 3516B diesel engines of 2,000kW at 1,600 rev/min were selected because of their relative small size and low weight.

5 MODEL TEST PROGRAMME

Due to the numerous challenges presented by the design and the combination of unique performance objectives, it was decided at an early stage in the design process to perform a comprehensive series of model tests of the new design.

The goal of the model test programme was both to test new proposed technical solutions for various features of the tug, and to verify that the overall performance objectives could be satisfied. The tests were conducted by FORCE Technology in Copenhagen during June and July 2006. The test programme was directed by Kim Henriksen, senior project manager, FORCE Technology and by Alan Reynolds, president, Offshore Research Ltd, acting on behalf of Robert Allan Ltd. The test programme included the following elements:

- Calm water tests for determining the speed-power characteristics of 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, bow first);
- Rotoring tests to define maximum steering forces at low speed with bow first;
- Seakeeping tests to define speed loss, accelerations and green water effects in three sea states.

5.1 THE FACILITIES AND THE MODEL

The tests were conducted in the FORCE Technology 240m x 12m x 5.4m towing tank. This facility is equipped with a double flap wave-maker at one end and a metallic beach at the other to absorb wave energy.

The main characteristics of the tug and model were as follows:

Parameter	Index	Ship	Model
Model scale	λ	1	12
Length overall (m)	LOA	37.00	3.084
Length waterline (m)	LWL	34.13	2.244
Breadth, maximum (m)	B	14.00	1.167
Draught (design) (m)	TF	4.0	0.333
Draught aft (design) (m)	TA	4.0	0.333
Volume (m^3)	Disp.	1,062	0.615
Metacentric height (m)	GM	2.2	0.183

Prior to building the scale model, a hull lines evaluation report with speed and power estimates was provided by FORCE Technology. This was based on a CFD calculation and in-house experience with similar vessels.

The model was run at the design draft of 4.0m for most of the tests. Results were also obtained at a second draft of 3.7m during the still water and sea-keeping tests. The model is shown in Figure 6. Figure 7 shows the aft end of the model with Z-drive, skeg and flap.

Figure 6: The model for tank tests.

Figure 7: Aft end of the model with Z-drive, skeg and flap.

5.2 STILL WATER PERFORMANCE

The still water performance tests used the standard FORCE Technology arrangement with the model located under the carriage. For the resistance measurement a force gauge was connected through a steel rod to the model. Z-drives were modelled around the standard FORCE drives which allow measurements of propeller thrust and torque, nozzle thrust and total Z-drive thrust.

The following test results were obtained:

Resistance tests

- The resistance was lower than estimated in the initial lines evaluation report;
- At 14 knots ahead, the bow strut increased the bare hull resistance by 12.1 per cent and the skeg increased the bare hull resistance by another 4.4 per cent;
- At 14 knots astern, the bow strut increased the bare hull resistance by 8.4 per cent and the skeg increased the bare hull resistance by another 2.6 per cent;
- The bare hull resistance astern was 36 per cent higher than the resistance ahead.

Self-propulsion tests

- At the design speed of 14 knots ahead, the forward power was 1,275kW/shaft and the aft power was 1,135kW, making a total of 3,685kW;
- At 14 knots astern the forward power was 1,679kW/shaft and the aft power was 1,333kW, making a total of 4,691kW;
- A speed exceeding 15 knots was achieved with the proposed power of 6,270kW.

Bollard pull tests

- The pitch setting for the bollard pull was at P/D = 1.16. During bollard pull tests ahead, the forward thrusters were rotated 15 degrees (thrust jet outwards from ship CL), to minimise interference at the single aft thruster. For bollard pull astern, all three thrusters were parallel to CL;
- Maximum total bollard pull at the power of 6,270kW was 101.6 tonnes ahead and 98.0 tonnes astern.

Side-stepping tests

Free sailing tests were conducted to determine the side stepping speed without skeg, with skeg retracted and with 25° flap. Power was set on the aft Z-drive while the forward Z-drives were adjusted to balance the heading at 90 degrees. The upstream Z-drive was at a fixed azimuth angle of 80 degrees while starboard Z-drive was used to keep a relatively straight course.

Results were scaled directly from measured torque and propeller revolutions without frictional resistance corrections. This approach was chosen because the flow is very turbulent and therefore does not scale with the friction line. However, as some of the resistance might be pure friction this might lead to a slightly pessimistic result.

As there were two thrusters at the bow and only one at the stern, the power was reduced at the bow in order for the vessel to sidestep without yawing. The sidestepping speed without skeg was 6.3 knots. With retracted skeg and 25 degrees flap the sidestepping speed reduced to 5.8 knots.

5.3 ESCORT TESTS – ASTERN

All escort tests were performed with a free-running model which is very similar to full-scale escorting. This relies on the setting of the propeller revolutions and azimuth angle for each of the three Z-drives in order to achieve the maximum steering force. All astern escort tests were performed at a staple position of 17.5 per cent of LWL from AP, except for the staple location optimisation tests.

Flap variation tests

For these tests the model was equipped with a skeg with a trailing edge flap. The flap angle was tested in a 0° and 25° setting at four speeds. The aft thruster was set in a constant azimuth angle of 160°. The forward thrusters were run in parallel both for azimuth angle and propeller revolutions.

Some 25° of flap angle increased the steering force by 4.5 per cent at 10 knots. However the required steering force of 140 tonnes was easily achieved without the flap, hence it was determined that the additional mechanical complexity of this device was not warranted in the final design.

Staple location optimisation tests

In order to determine the optimum staple position, escort towing tests were performed with the staple position moved to positions corresponding to 12.5 per cent, 17.5 per cent, 22.5 per cent and 25 per cent of LWL from AP. All staple positions were placed 3.05m from centreline and 6.35m above baseline. Staple points were adjusted corresponding to deck shear.

The results of the maximum steering force at 10 knots for different staple positions are shown below:

Staple (Position)	Zero Flap (Tonnes)	25° Flap (Tonnes)	Increase (%)
12.5%	142	147	3.5
17.5%	156	163	4.5
22.5%	175	178	1.7
25%	175	174	-0.6

At the staple position of 25 per cent the model was harder to control without having any gain in steering force. At 22.5 per cent position a relative large increase in steering force was achieved but with a narrower range in thruster/yaw angles.

Force tests with skeg removed

The escort operations of the tug were tested with the skeg completely removed from the model. Thruster configuration was all pushing. The results of the maximum steering force tests in this mode are shown below:

Speed (knots)	Zero Flap (Tonnes)	No Skeg (Tonnes)	Skeg Force (Tonnes)
6	95	81	14
8	127	93	34
10	156	109	47
12	185	121	64

From the above results it can be seen that the hull and the Z-drives provide 70 per cent of the maximum steering force at 10 knots and the skeg provides 30 per cent.

Escorting in waves

The variation of steering and braking forces in waves was a critical performance criteria. The model and Z-drive configuration was set up similar to the flap variation tests. The results are shown below:

Speed (knots)	F_s - Still Water (Tonnes)	F_s - 3 m Waves (Tonnes)	Increase (%)	Hawser Force (Tonnes)
6	95	81	14	109
8	127	93	34	142
10	156	109	47	179

The average steering force increased in 3m Hs waves by 5 per cent at 10 knots.

5.4 ESCORT/ROTORING TESTS – BOW FIRST

The skeg was retracted and the flap placed at the 0° position during the bow first tests. The towing point was located at the centreline, 35m forward of the AP.

Rotoring tests

The goal of the rotoring test was to determine the maximum steering force for operation at low speeds of 2 to 4 knots.

The forward Z-drives were fixed at azimuth angles of 80 degrees and 100 degrees to minimise interaction with the aft drive unit. Different combinations of towline and yaw angle were achieved by adjusting the azimuth angle and the propeller revolutions of the aft Z-drive. The maximum steering forces achieved during rotoring are shown below.

Speed (knots)	Zero Flap (Tonnes)
2	38
4	42

Escort bow first tests

The same model was used as for the rotoring tests except for one additional series, which was conducted with the bare hull. It was found that the aft Z-drive was not able to produce enough thrust to create much yaw angle. Therefore the aft Z-drive was fixed at 50 degrees, while the azimuth angles of the forward Z-drives were varied. The results of the bow first maximum steering force tests are summarised below:

Speed (knots)	Zero Flap Astern (tonnes)	Bow First (tonnes)	Percentage (%)
6	95	64	67
8	127	76	60
10	156	86	55
10	156	91	58

At 10 knots, escorting in a bow first mode produces about 55 per cent of the maximum steering developed in the astern mode. Removing the skeg entirely increased the maximum steering force by 5.8 per cent.

5.5 SEA-KEEPING TESTS

The model was tested in 3 JONSWAP wave conditions as follows:

Wave ID	Spectrum	Hs (m)	Tp (s)
Wave 1	JONSWAP	1.5	6.0
Wave 2	JONSWAP	3.0	8.0
Wave 3	JONSWAP	5.0	10.0

The reference coordinate system used for analysing the results is shown in Figure 8.

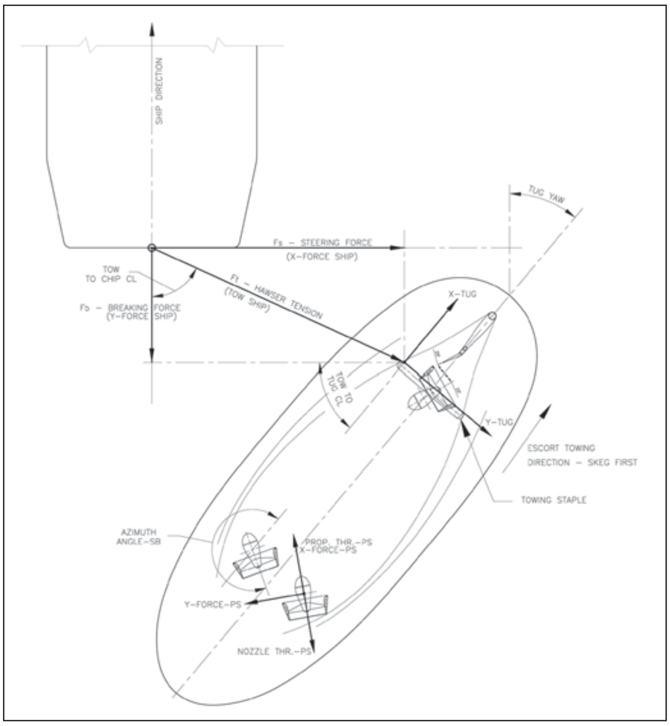

Figure 8: Reference coordinate system used for analysing the results.

For these tests the model was self-propelled and free sailing but restrained in yaw. The speed and power curves were directly calculated from measured propeller revolutions and torque. The speed loss was calculated as a speed difference at constant power consumption between speed/power curves in the corresponding sea state and the still water reference at 14 knots from the bow first tests.

The towing force (FD) and the wind resistance force were accounted for by correcting the measured torque and rpm values, at model self-propulsion point. The results of the speed loss tests are summarised below:

Condition	1.5m waves (knots)	3.0m waves (knots)	5.0m waves (knots)
Astern, 4.0m draught	0.30	0.5	0.3
Ahead, 4.0m draught	0.75	1.6	1.8
Astern, 3.7m draught	0.45	1.1	1.6
Ahead, 3.7m draught	0.40	0.5	1.5

The maximum significant sea-keeping accelerations and motions are summarised below:

Condition	Wave Height (metres)	Acceleration FP (g)	Acceleration AP (g)	Pitch (degrees °)	Heave (metres)
Astern, 4.0m draught	1.5	0.34	0.41	9.87	1.0
	3.0	0.72	0.64	17.78	3.3
	5.0	0.82	0.72	21.31	5.3
Ahead, 4.0m draught	1.5	0.32	0.13	5.47	1.2
	3.0	0.56	0.61	13.16	3.8
	5.0	0.70	0.72	16.03	6.4
Astern, 3.7m draught	1.5	0.38	0.43	10.08	0.9
	3.0	0.76	0.28	17.20	3.2
	5.0	0.87	0.32	21.12	6.5
Ahead, 3.7m draught	1.5	0.34	0.14	5.86	1.3
	3.0	0.60	0.23	12.45	3.5
	5.0	0.69	0.70	15.75	6.0

6 FINAL DESIGN SOLUTION

6.1 DESIGN DECISIONS RESULTING FROM THE TANK TESTS

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

- The proposed double-ended hull shape showed good performance. The 14 knot speed requirement was exceeded both ahead and astern. A sidestepping speed of about 6 knots was also attained. The hull showed good sea-keeping and escort capabilities. The proposed hull form was therefore affirmed for the final design;
- The testing of different skeg configurations enabled a merit-based decision about the final design solution. A vertically retractable skeg of relatively small lateral area, but without a flap was chosen. Skeg retraction increases manoeuvrability and side-stepping speed during ship-assist operations. The benefits of the flap were not sufficient, and not fully confirmed by the limited tests, hence this device was eliminated from further consideration;
- The interesting tests of the skeg with flap and a closely-located 'pulling' Z-drive unit gave a surprisingly negative result. The flap is an additional mechanical device acting in heavy loaded conditions in the Z-drive stream and also vulnerable to damage. The tests showed approximately 4.5 per cent increase in steering force due to the flap and no positive influence from the closely located Z-drive. As the project requirements were fully satisfied without these complexities, the flap and the pulling Z-drive were also dropped from further consideration;
- The decision was made to keep the struts as protection and support at docking in spite of additional resistance. The specified speed was easily attained with the installed struts;
- The skeg/Z-drive combination aft works extremely effectively. The indirect steering force generated by this system was unexpectedly high;
- The staple location was fixed for the project at 22.5 per cent of WL length from the aft perpendicular. This position provides stable control of the vessel during escort operations and creates the maximum indirect steering force. The staple location at 22.5 per cent of WL length from the AP is the closest to the aft Z-drive, and thus also in the best position for rotoring;
- The model tests confirmed that the sea-keeping performance both bow first and stern first were excellent and in accordance with the designer's and owner's expectations;
- The speed loss was the same in the 3m and 5m JONSWAP sea states and was less than expected. The significant motions and accelerations were also very acceptable;
- When escorting in the astern indirect mode in 3m waves at 10 knots the steering force was about 5 per cent above the calm water value.

6.2 GENERAL ARRANGEMENT

The new Escort Rotor Tug 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. This tug is capable of fulfilling all five main operations requested by the owner with a high degree of efficiency in each mode. Figure 9 presents the general arrangement of the Escort Rotor Tug as finally defined.

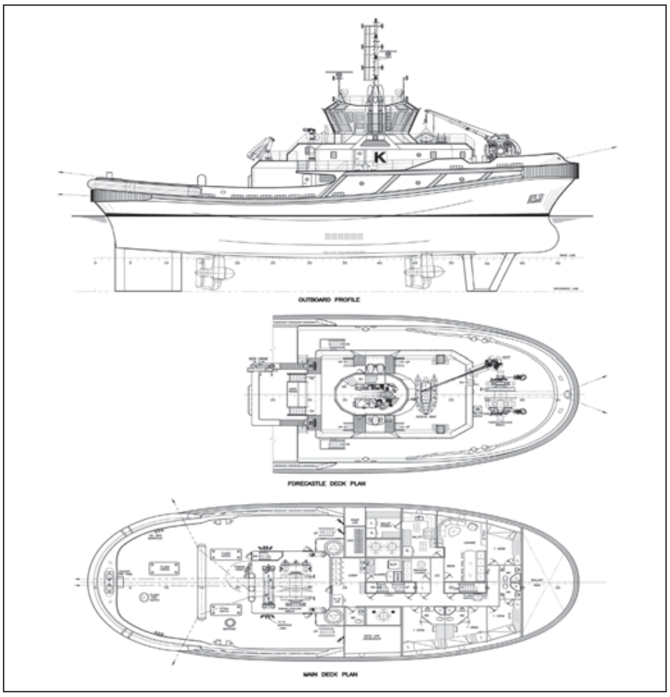

Figure 9: General Arrangement.

The final design has the following unique features and capabilities:

- Speed in excess of 14 knots in both directions;
- Capability of ship assistance (rotoring) from both ends;
- Sidestepping speed in excess of 6 knots;
- Capability of generating escort steering forces up to 165 tonnes in accordance with the DNV escort stability criteria;
- Retractable skeg that makes it possible to combine contradictory qualities required for rotoring with exceptional escort performance;
- System of escort steering force generation with contributions from both a passive skeg and the active Z-drive (instead of only passive skeg). This system allows a reduction in skeg size to approximately 50-60 per cent of that of a comparable tractor tug;
- Good sea-keeping in both directions;
- Large aft working deck with capability to accommodate up to 100 tonnes of deck cargo;
- 500m of oil booms stored on two reels in the hold;
- The highest standard of crew accommodation and facilities.

7 CONCLUSION

At the beginning of this project it was not at all clear that it would be possible to create the desired ‘universal tug’ with good balanced performance for ship assistance, escort and ocean towing because of some of the contradictory requirements. However, the combined experience of the designers and the owners, coupled with the results of the extensive and enlightening model test programme have resulted in a new, unique design which has proved that the Rotor tug concept can be applied to a very high-performance escort tug, with performance which exceeds all expectations.

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