Allrounder 360 Tug

AR360T

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All-Rounder 360 Tug *(*AR360T*)* – an innovative design

The main stream tug designs focuses on omni-directional thrusters to manoeuvre the tug towards the right position to tow the ship in and out of port. Although these omni-directional thrusters facilitate manoeuvring, they also have certain downsides including high cost and less propulsion efficiency. Further, the high cost is not only limited to the capital cost, but also higher maintenance cost of the thrusters. The AR360T offers an interesting alternative, by turning the whole tug's hull independent of the towline by means of a 360 degree towing carriage system equipped with a Towing Winch/Quick Release. Hereby the tug's propulsion can remain conventional robust and long lasting by applying well proven shaft lines at the stern of the tug. The towing ring offers all around capability by instant changing towing over the bow, to sideward, to the stern. Hereby safe assistance at higher speed can be achieved and continued operation in adverse weather conditions.

The AR360T is a further development of the carrousel technology offering an operational and cost effective tug with true All-Rounder capabilities. Within 25 m length (Lpp) a practical, robust and safe multi-purpose tug is created featuring enhanced assistances in port area and interregional towing operations of e.g. barges.

Because of the special technology and design, the AR360T has the same capabilities as an Azimut Stern Drive (ASD) tug but with much less capital expenditure and operational costs. The sales price for an All-Rounder 360 tug will be 20-30% less than for an ASD tug with the same ton bollard pull. The operational costs will be 30-35% less (fuel etc), as well as lower maintenance costs.

Another advantage is that the All-Rounder Tug cannot capsize under towline load.

The AR360T technology is covered by patents.

MORAN IRON WORKS

Available Designs

The following All-Rounder 360 Tug designs are available:

- 2409 AR360T up to 30-32T BP (towing ring with carriage and quick release system)
- 2409 AR360T up to 40-42T BP (towing ring with carriage and quick release system)
- 2410 AR360T up to 45-62T BP (towing ring with carriage and compact winch system)

The 2812 AR360T (up to 90T BP) design will be available soon.

Advantages

- ❖ The AR360T combines a towing ring with conventional shaft FPP and **offers an attractive economic alternative, both regarding building and operational cost**

- ❖ The AR360T offers two clear operational advantages of **all around flexibility** and **large hydrodynamic forces**

- ❖ Use of hydrodynamic forces instead of propulsion **reduces fuel consumption, pollution and engine running hours**

- ❖ **Less yearly repair and maintenance costs** and **longer economic life** of the tug itself due to less mechanical wear on propulsion system

- ❖ The **large stability effect** of the towing ring enables to locate the towing point near the center of lateral resistance. This in return enables to control the tug's heading safely independent of towline load variations

- ❖ The towing ring allows to **control the bow tug safely**, whilst using the full steering and braking potential

- ❖ Due to bow-first sailing and the **large stability safety margin**, the towing operations can even be performed at higher sailing speed, in adverse weather and wave conditions and high current conditions

- ❖ The AR360T **offers more effectiveness with less investment**. The use of the large hydrodynamic forces may even lead to a **reduction of the number of tugs** to be used for assistance

- ❖ Together with increasing escorting speed, the hydrodynamic lift forces of the tug increase, thereby **enabling safe operations at higher speeds**

- ❖ A bow AR360T offers, **in contrast to an ASD,** at sailing speed **effective steering forces, increased rate of turn and reduced path width** of the assisted vessel, thereby facilitating **controlled operations in narrow port areas**

- ❖ **The combination of a bow and stern** AR360T offers at sailing speed the **most effective steering and braking forces combination** for ship assistance

- ❖ **Capsizing** due to towline forces **is prevented** by the towing ring **enhancing the safety**

ALL-*Rounder 360 Tug*

The ALL-Rounder 360 Tug (AR360T) is a further development of the carrousel technology offering a operational and cost effective tug with true All Rounder capabilities. Within 24 m length (Lpp) a practical, robust and safe tug is created for safe and enhanced assistances in port and coastal areas.

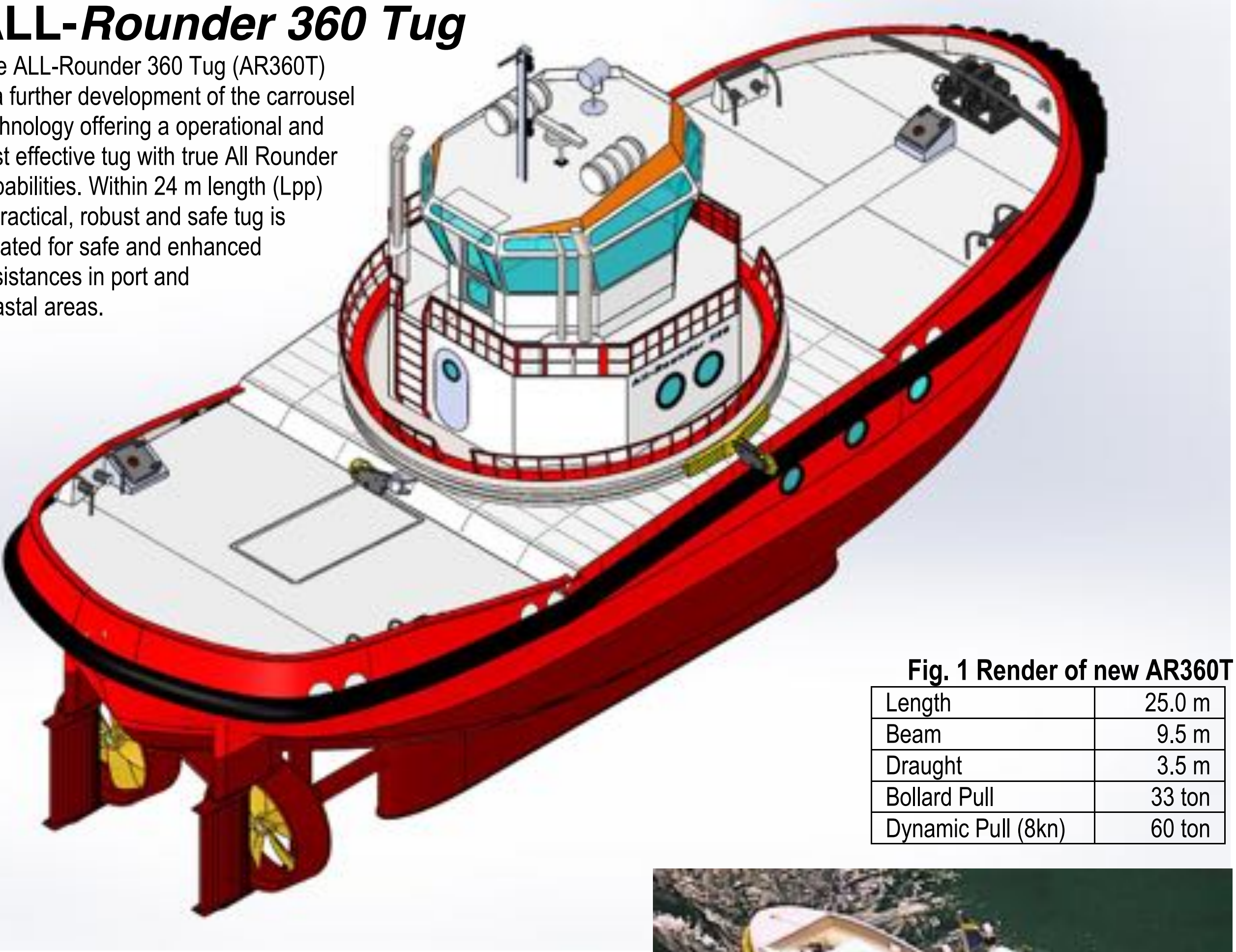


Fig. 1 Render of new AR360T

Length	25.0 m
Beam	9.5 m
Draught	3.5 m
Bollard Pull	33 ton
Dynamic Pull (8kn)	60 ton

1. Introduction AR360T

The main stream tug designs focuses on ever increasing power and bollard pull; in contrast, the AR360T focuses on a niche market of numerous smaller ports (with large currents) world-wide. These ports require practical, robust and safe operations with a highly operational and cost effective tug.
Sadly even today several small tugs still capsize, therefore safety is integrated in this design by the towing ring technology, which lowers the heeling arm effectively and prevents the tug from capsizing by external towline forces. Robust and long lasting propulsion is achieved by applying well proven shaft lines at the stern of the tug.
The towing ring offers all around capability by instant changing towing over the bow, to sideward, to the stern.

2. Stability and Safety

The design is based on the carrousel technology as developed for many years by IMC and Multraship and extensively tested and validated first on model scale at Delft University of Technology in the Netherlands (Fig. 2). After successful completion of the model tests, the real size 27 m long tug Multratug 12, was converted into the first carrousel tug (Fig. 3). The Dutch Maritime Research Institute MARIN has performed test trials with the MT 12 showing the potential of carrousel to prevent the tug from capsizing even under large heeling forces by towlines in sideward direction.

Fig. 2 Scale model at Delft University of Technology in the Netherlands (≈ 60 ton)

Fig. 3 Real size Multratug 12 extensively tested and demonstrated in Port of Rotterdam (up to 100 ton)

On model scale dynamic forces near 60 tons were measured and in real size forces even up to 100 ton, showing the large potential of dynamic forces primarily based on hull forces only.

Following these successful tests, Multratug has ordered in 2015 two large 70 ton BP new building Carrousel Rave Tugs from Damen (Fig 4), reviving this interesting technology (**www.novatug.nl**). The design has changed from the conventional shaft propulsion in the Multratug 12 to high tech Voith propulsion systems, one in the bow and one in the stern. This propulsion system offers superb manouvrability but at high building and operational cost.

Fig. 4 First Carrousel Rave Tug in operation in 2018 (Tugspotters)

2.1 Towing ring radial support effectiveness

The towing ring is a mechanical rail support moving the attachment point of the towline not only sidewards, but with increasing heeling angle downwards, thereby effectively preventing **capsizing** of the tug by towline forces.
The radial support is not only applied in various towing hooks, but also in the carrousel, the Mampaey DOT system (**www.mampaey.com**) and in the AR360T. The general functioning is explained schematically in Fig 5.

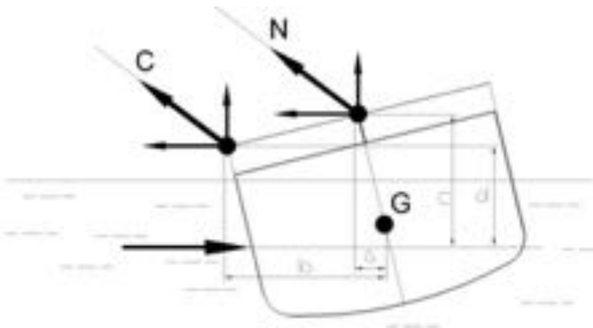


Fig. 5 The effect of a radial support (C) and normal attachment (N)

For the new AR360T, the stability has been analyzed with the towing ring for various loading conditions of the tug. Fig. 6 shows the stability lever and in addition the heeling lever; in case of a centre attachment (conventional) the nearly horizontal orange line and in case of the towing ring attachment the rapidly sloping down blue line. The intersection in design condition and 60 ton sideward load occurs at approx 20° heeling angle for the towing ring and 32° for the centre attachment. In addition, the stability area is significant higher. More information see "Tug Stability" by Hensen & Van der Laan.

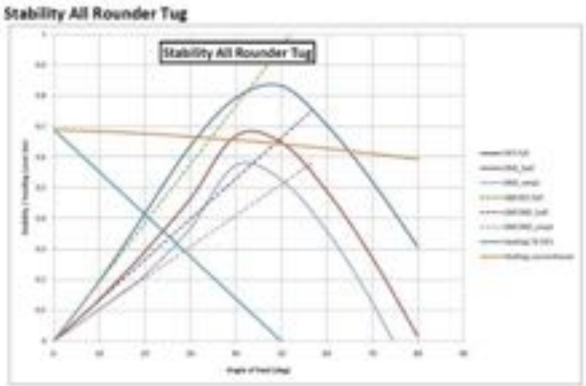


Fig. 6 Stability diagram AR360T for 60 Ton pull

Fig. 7 Stability diagram AR360T for 60 Ton pull @ 20 deg heel

In Fig. 7 above the corresponding heeling is shown from the stern side. This heeling angle is very similar for sailing yachts and offers a stable platform for towing operation.

2.2 Quick Release system

The towing ring system carriage is equipped with a quick release system which can be operated reliably by radio control or manual action. Hereby the tug master can at any moment release the towline connection.
In contrast to conventional tugs, quick release is no longer needed to limit extensive heeling, since the towing ring will prevent large heeling angles. However, there are still operational conditions, which may require quick release.

2.3 Safety improvements

The design offers not only the towing ring to reduce the heeling lever, but also improves the stability performance by adding large buoyancy of the hull, adding several transverse full watertight bulkheads, moving all watertight doors and tank piping to the centerline and applying SaferVents with crossed engine room inlet pipes. By this complete safety package, the tug will not flood even with extreme heeling angles up to 90°.
The large buoyancy of the hull and forward area offers good sea keeping performance in adverse weather conditions, extending the scope to beyond coastal borders.

3. Robust Shaft Line Propulsion

Many modern tugs are equipped with omni directional thrusters, enabling to change the propulsion direction rapidly in the required direction. Although this solution offers ease of control, the mechanical drawbacks are often neglected, ranging from power loss in upper and lower gear box, smaller prop diameters to reduce torque and purchasing cost and the rapidly increasing maintenance cost with running hours. And the vulnerability when touching underwater objects.

For smaller ports world-wide, in general with less well defined hydrographic data and with a wide range of debris floating in or below the waterline, a straight shaft line propulsion offers the most cost effective propulsion: A robust solution with high pull efficiency and long running hours combined with limited maintenance.

Further standard fixed pitch propellers are used for optimal robustness and prevention of (oil) leakages in potential environmental areas. The AR360T has two relative large propellers aft protected behind a strong skeg extending forward of the propeller. The skegs form a robust structures to protect the propellers form underwater obstacles.

4. All rounder capabilities

The towing ring structure is integrated in the whole tug design offering a functional extension to the operational performance, whilst maintaining a general all round purpose tug, see figure 8.

Fig. 8 Towing ring structure on AR360T

Accommodation size for longer voyages.

The arrangement of the towing ring sloping down from the forecastle deck downwards to the aft deck enables to create a large accommodation space in the forecastle area, a (traditional) drawback of carrousel designs.

New hull shape

The specially designed hull shape has been extensively tested in model tests enabling a highly manouvrable performance during dynamic towing operations and also enabling a relative high free sailing speed. The two large parallel skegs form an integral part of the hull and increase the dynamic sideward force.

The hull shape allows full controlled dynamic towing sailing up to 60 tonf at angles up to 20° with relative low longitudinal resistance.

Compared to other conventional tug shapes, the hull lines offer a relative large displacement and large bunker capacities with a low free sailing resistance.

Docking on own skegs

The two parallel skegs have sufficient strength to dock the vessel on a straight docking floor and also offer a robust protection of the aft propellers/nozzles when sailing ahead.

Cooling system in integrated inside skegs and safely protected from external damages.

Safe Deck Use

Around the deckhouse a circular pathway is situated to allow easy and safe movements of the crew to either sides. The pathway includes double openings at forward and aft end near centerline. The whole bow and aft deck is along the edges protected with a standard bulwark with rounded top cover.

Maintenance considerations

The engine room is spacious and between both main engines spaced is reserved towards the aft deck to lift a complete main engine out for repairs/reconditioning. Hereby the tug can rapidly continue its operation.

The tug is fitted with twin engine / propulsion / rudder systems and offers a full redundant system to guarantee continued operation.

5. Ship assistance performance

Assistance of ships can be divided into two separate operations: 1) Low speed assistance typically in range 0 - 4 knots and 2) Medium speed assistance typically between 5 - 8 knots.

5.1 Low speed assistance 0 - 4 kn

This operation focuses typically on berthing and turning inside port. Speed is low and tugs operate in push - pull operation. The force is primarily generated by propeller thrust only without dynamic forces.

The AR360T can offer both push operations with heavy bow fendering and pull from the towing ring. For quick change, the AR360T can reverse the thrust and pull astern, however, at a small loss of propulsion efficiency for reverse flow through nozzles. To maximize thrust, the AR360T has to change the heading 180° and use the full forward bollard pull. Please note that in this condition the AR360T offers full BP in contrast to typical ASD tugs, which loose efficiency when pulling astern under their hull.

5.2 Medium speed assistance 5 - 8 kn

This operation focuses typically on sailing into and out of the port including canal/river areas. Speed is medium and tugs sail along the ship and offer temporary pull assistance for braking and for steering in sharp curves. In addition, tugs may be used as constant brake over longer distance to offer better steering performance of the ship by its own rudder. The force is primarily generated by a combination of propeller thrust and dynamic hull/skeg forces.

The AR360T offers the optimal solution for this type of operation. The towing ring offers a large operational extension to the dynamic performance of the tug. The major force components are shown in figure 9 below:

A schematic overview of the various possible positions and force directions when assisting a ship is shown below. Two typical examples, one for aft tug in figure 10, second for bow tug in figure 11:

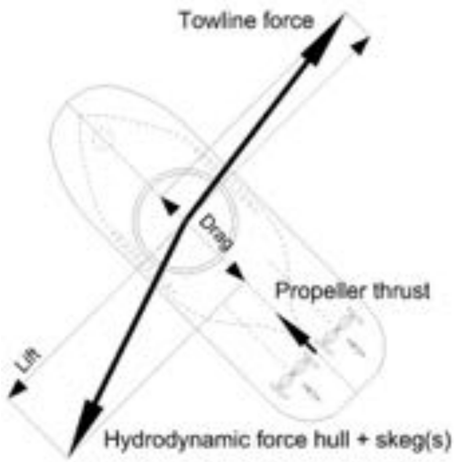


Fig. 9 Force balance for AR360T in indirect mode

Aft tug sails bow first with towing wire over bow (A):

- In position (A) the tug can select to use forward thrust or reverse thrust (sketched).
- As alternative to engine thrust, the hull dynamic drag force can be used by turning the hull rectangular to the flow (wire over side) (B). Thereby saving fuel and offering an environmental advantage.
- To steer/pull the ship, the tug sails along outer circle forward and starts pulling the ship, (wire over stern) (D).
- In various positions (B-D) the outer propeller rotation may be reversed, whilst the inner propellers delivers thrust astern along the rudder. Hereby proper control of the whole manouvre is achieved.

Bow tug sails bow first with towing wire over stern (G):

- To brake the ship at higher speeds, the tug sails along outer circle aft and the hull is turned rectangular to the flow, dragging alongside the ship (wire over bow/side) (H). Thereby taking advantage of the hydrodynamic drag forces.
- To brake the ship at lower speeds, the tug may reverse and sails backward braking with full bollard pull ahead (wire over stern).

Please note that the combined steering / braking performance of a AR360T bow tug is significant higher than a comparable sized ASD or tractor tug.

The hydrodynamic design of the hull enables the following dynamic assistance forces
At 8 knots speed : approx 60 ton (2x Bollard Pull)
At 6 knots speed : approx 35 ton

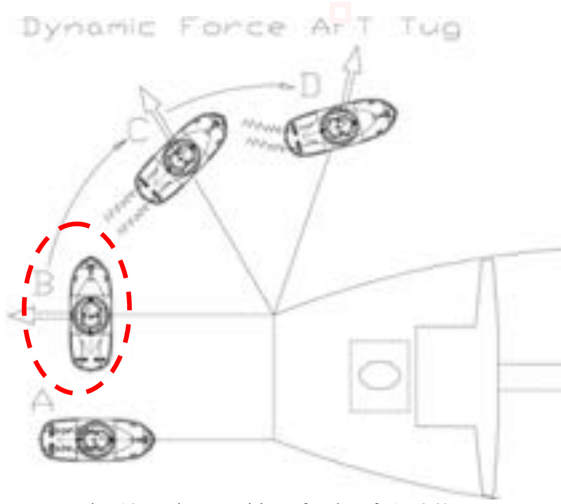


Fig. 10 Various positions for the aft AR360T

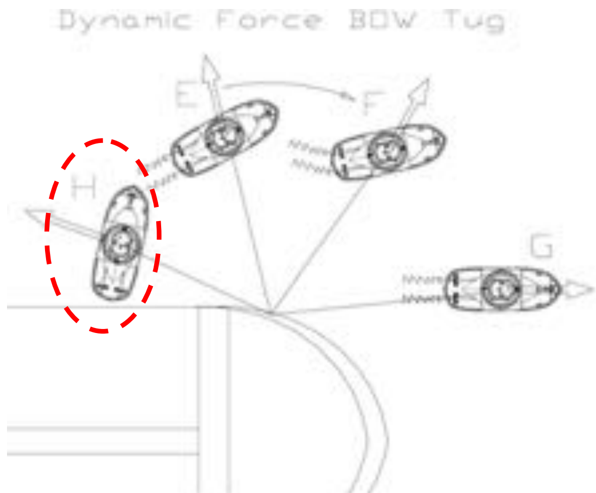


Fig. 11 Various positions for the bow AR360T

5.3 Twin operation at bow and stern

When two AR360T tugs are used, one at the bow and one at the stern, a medium size cargo ship can be safely guided in and out of port. The increased dynamic forces improve the manouvring with shorter curves and shorter stopping distances, enabling the primary aim of the operator:

***Safe assistance at higher speed and continued operation in adverse weather conditions*.**

Depending on the selected sailing path, the bow tug needs to select one of the sides of the ship in advance, preferably on the inner curvature side to both brake and steer the bow. The aft tug is free to select one of the sides and can easily and rapidly change to the other side. If positioned on the opposite side of the bow tug, the aft tug can speed up the rate of turn by doubling the turning moment in the planned curve. If positioned on the same side, the tug can ensure double braking capacity.
In case of an unplanned event when changing of the course to the opposite side is required, the aft tug has to perform the steering performance only, leaving the bow tug sailing parallel in a straight line without pull force.

Optimal use of both tugs requires proper training and good communication with pilot and each other.

6. Economic evaluation

Building cost

The tug design is based on a standard conventional twin shaft tug, as built for many years world-wide. The hull design is easy to build with multi chined developable plate surfaces with large curvatures. This will allow easy assembly without the need of plate shaping during production. The main structural elements are based on plate material without stiffener profiles.

Compared to a conventional tug, the only small additional cost is formed by the towing ring with carriage.
A modern thruster tug (either ASD/ tractor or ROTOR tug) involves significant additional cost based on:

- larger main engine due to power / propulsion losses in thruster (a thruster tug will require typically 5% more installed power for the same BP than a shaft driven conventional tug)
- the complex and expensive thruster units
- the long shaft drive train
- the sloped engine mounting

Considering these above factors, the AR360T will offer a building cost reduction in the range of 15 – 25 % compared to a standard ASD design with basic outfitting (without additional outfitting items as FiFi, cranes etc).

Operational cost

The use of hydrodynamic forces instead of / in addition to propulsion power offers a sharp reduction in operational cost due to lower fuel consumption and shorter running hours.

Further the direct shaft driven propulsion offers a higher propulsion efficiency, smaller main engines and less fuel consumption.

Resulting in significant lower environmental pollution.

Further the proven conventional shaft technology results in longer maintenance intervals and lower maintenance cost.

And finally, the towing ring carriages consists of sealed roller bearings with long maintenance intervals.

Due to the protected location of the propulsion, the likelihood of ground contact is less and the sturdy construction can take significant impacts before damaging, in contrast to relative weak and exposed thruster structures, with high risk of oil leakages.

7 Conclusions

- The AR360T is a further development of the carrousel towing technology in an improved practical tug design with All Rounder capabilities.
- The AR360T combines a towing ring with conventional shaft FPP and offers an attractive economic alternative, both regarding building and operational cost.
- The AR360T offers two clear operational advantages of all around flexibility and large hydrodynamic forces.
- Use of hydrodynamic forces instead of propulsion reduces fuel consumption, pollution and engine running hours.
- Capsizing due to towline forces is prevented by the towing ring enhancing the safety.
- The large stability effect of the towing ring enables to locate the towing point near the center of lateral resistance. This in return enables to control the tug's heading safely independent of towline load variations.
- The towing ring allows to control the bow tug safely, whilst using the full steering and braking potential.
- Due to bow-first sailing and the large stability safety margin, the towing operations can even be performed at higher sailing speed, in adverse weather and wave conditions and high current conditions.
- The AR360T offers more effectiveness with less investment. The use of the large hydrodynamic forces may even lead to a reduction of the number of tugs.
- Together with increasing escorting speed, the hydrodynamic lift forces of the tug increase, thereby enabling safe operations at higher speeds.

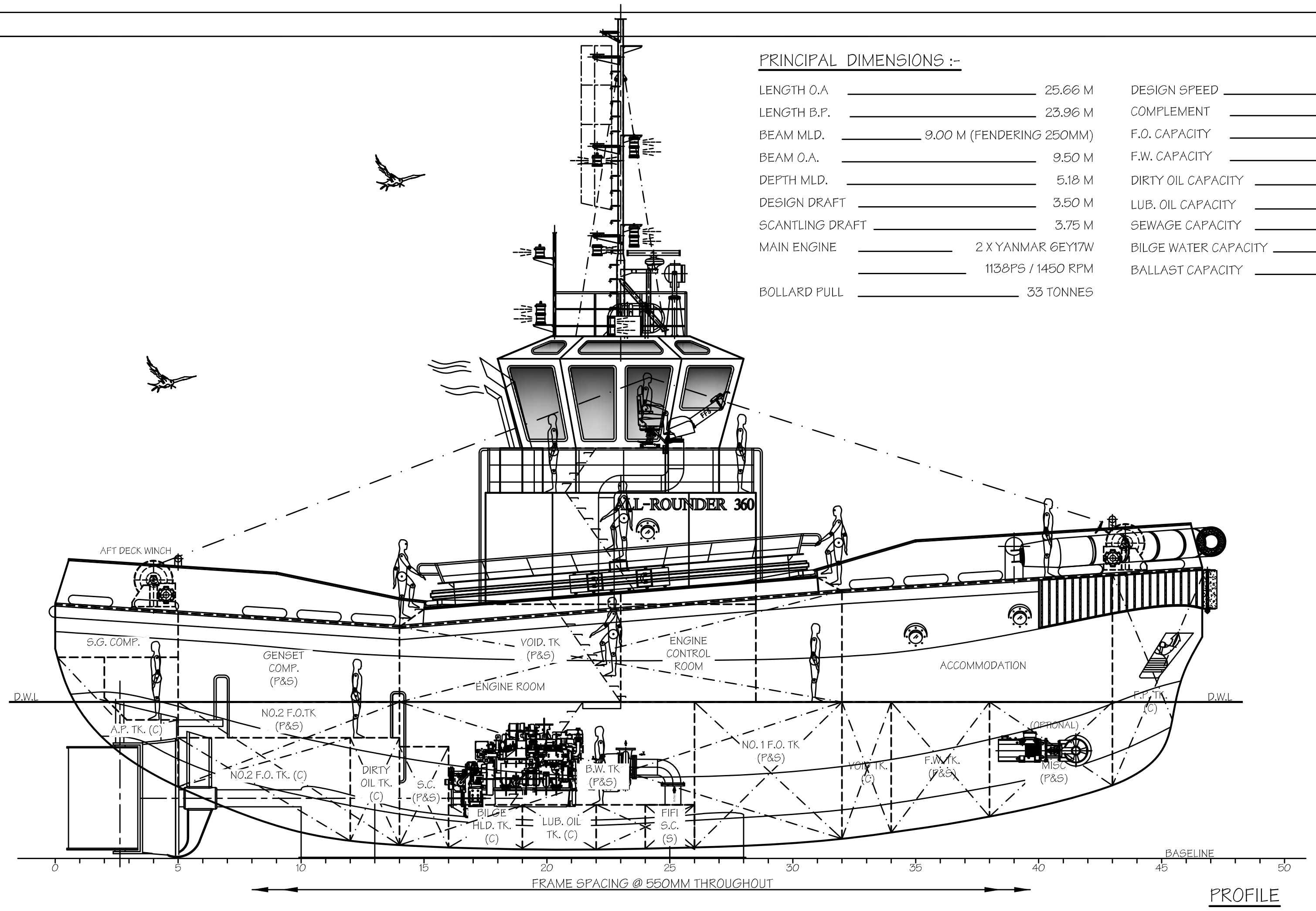
8 General particulars

AR 360 T 24 09		
Length pp	23.750	m
Length oa	25.000	m
Breadth mld	9.000	m
Breadth oa	9.500	m
Depth midship	5.180	m
Draft (des)	3.500	m
Draft (sct)	3.750	m
Displacement (des)	410	Ton
Main Engines (2x)	Yanmar 6EY17W IMO Tier II	
Power Rating (2x)	1,138 PS @ 1,450 rpm	
Gear Boxes	Reintjes WAF 665L 5.95 : 1	
Propellers FPP	2200 mm Rice Thrust Nozzles	
Rudders	High Lift Fishtail A-symm	
Bollard Pull	33	ton
Dynamic Pull @ 8 kn	60	ton
Speed	13	kn

PRINCIPAL DIMENSIONS :-

LENGTH O.A	25.66 M
LENGTH B.P.	23.96 M
BEAM MLD.	9.00 M (FENDERING 250MM)
BEAM O.A.	9.50 M
DEPTH MLD.	5.18 M
DESIGN DRAFT	3.50 M
SCANTLING DRAFT	3.75 M
MAIN ENGINE	2 X YANMAR 6EY17W
	1138PS / 1450 RPM
BOLLARD PULL	33 TONNES

DESIGN SPEED	13 KNOTS
COMPLEMENT	9 CREWS
F.O. CAPACITY	ABT. 118.2 M^3
F.W. CAPACITY	ABT. 36.5 M^3
DIRTY OIL CAPACITY	ABT. 4.4 M^3
LUB. OIL CAPACITY	ABT. 3.6 M^3
SEWAGE CAPACITY	ABT. 3.5 M^3
BILGE WATER CAPACITY	ABT. 3.5 M^3
BALLAST CAPACITY	ABT. 73.3 M^3



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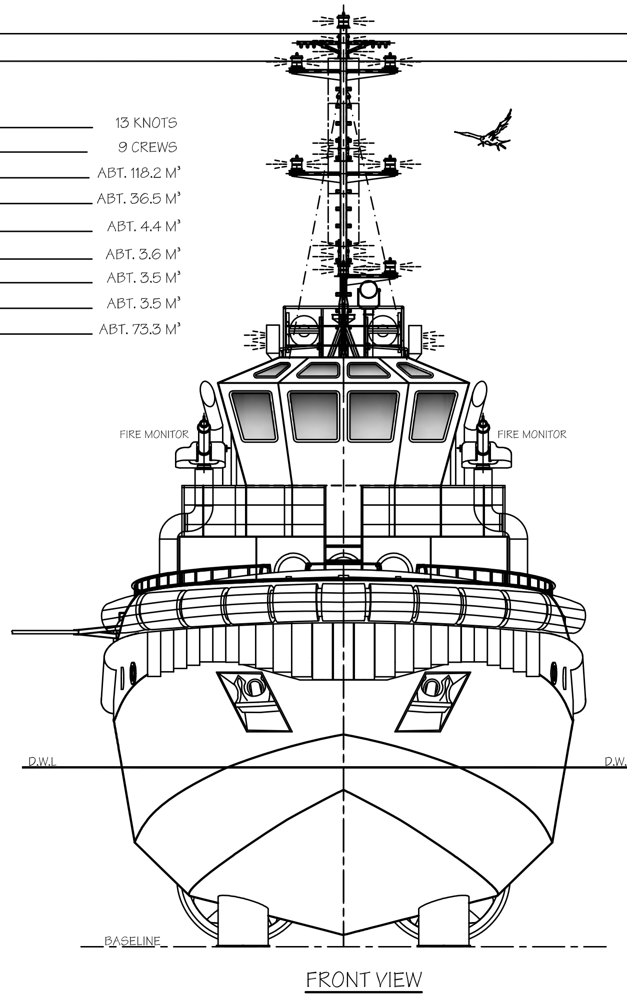
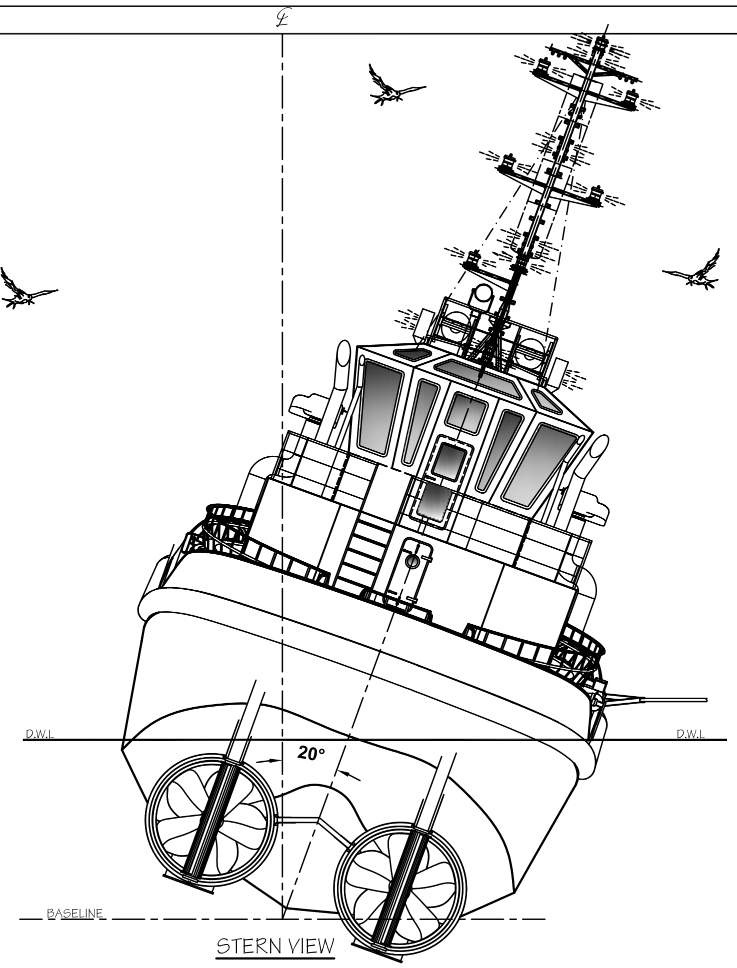
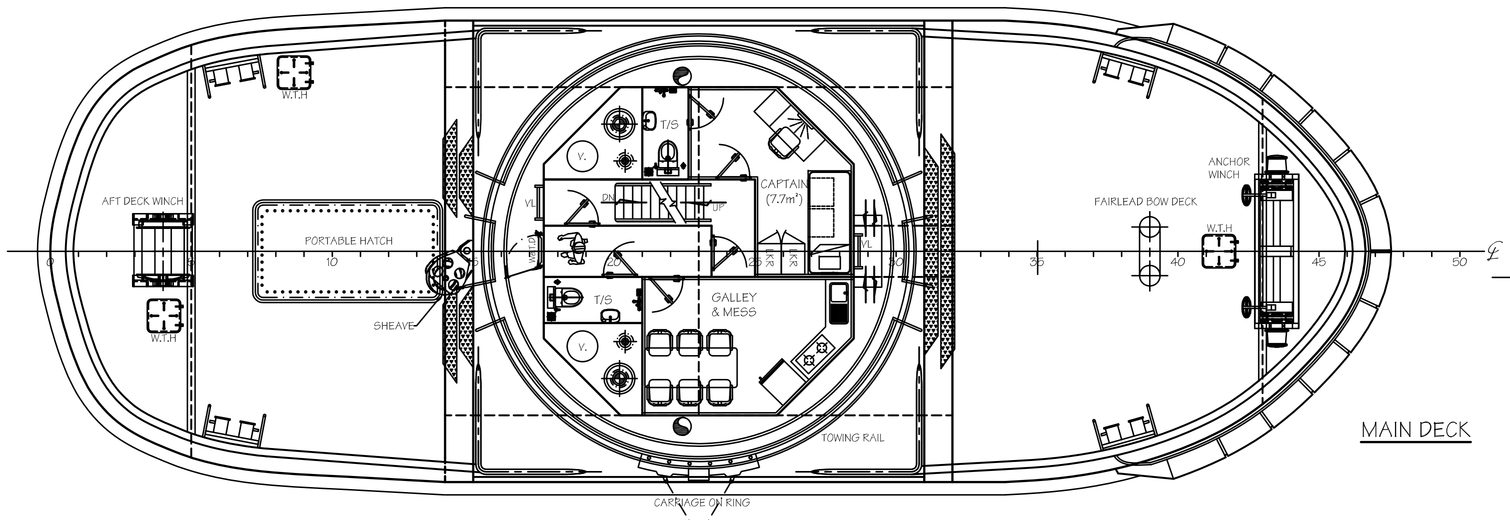


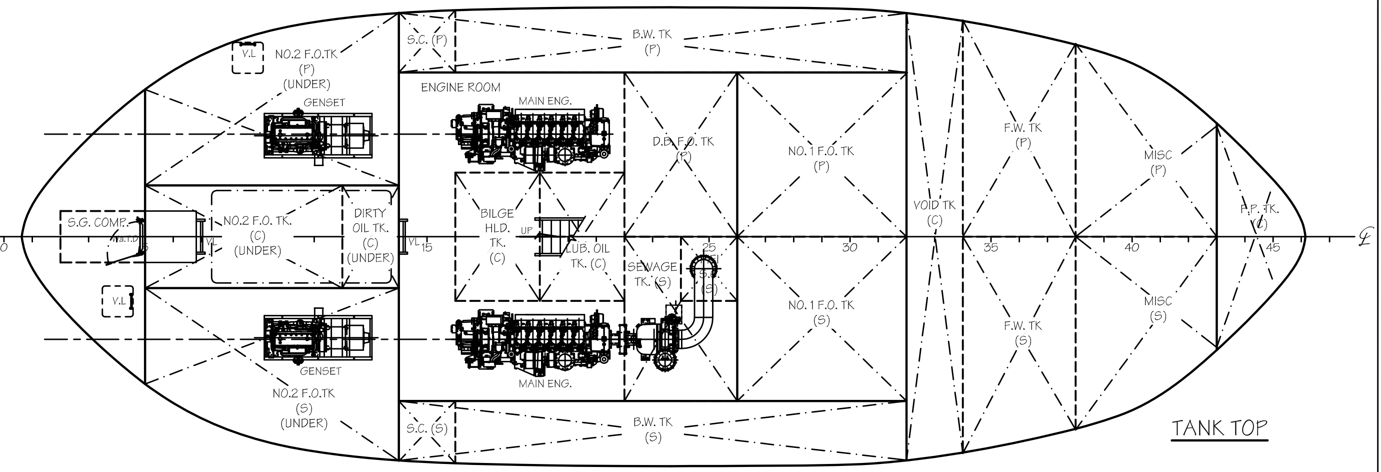
FRONT VIEW



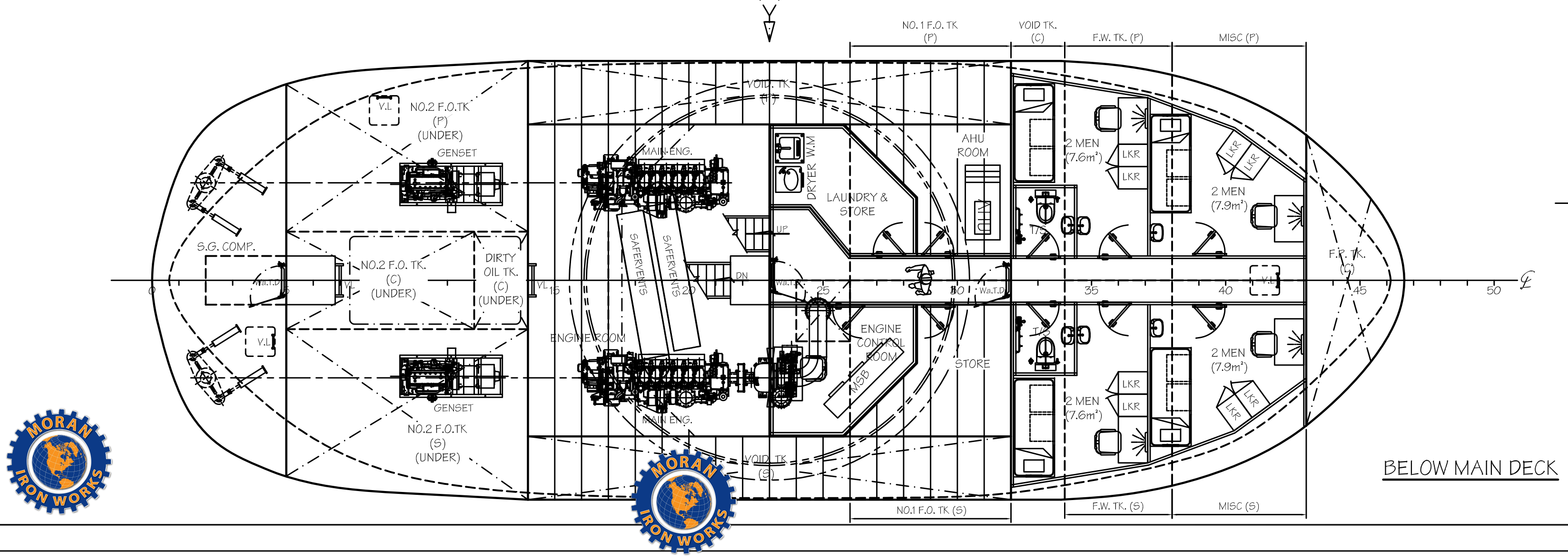
STERN VIEW



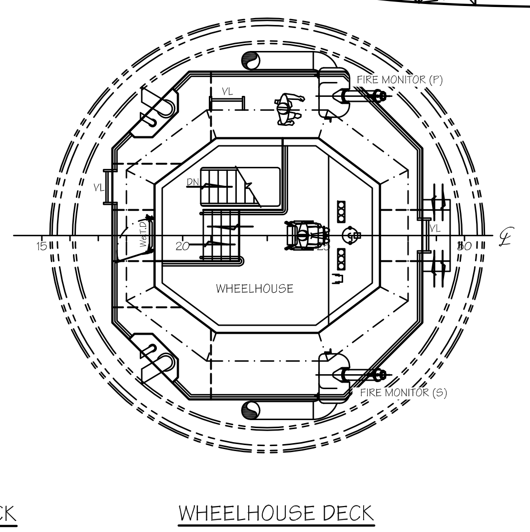
MAIN DECK



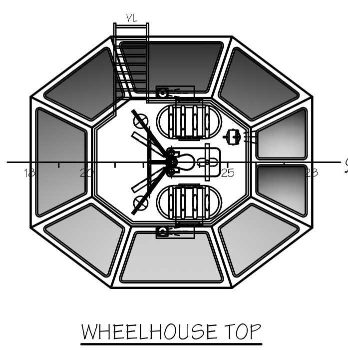
TANK TOP



BELOW MAIN DECK



WHEELHOUSE DECK



WHEELHOUSE TOP

REV.	DESCRIPTION	BY	DATE

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IN COLLABORATION WITH:
NVS MARITIME CONSULTANCY SDN. BHD.

PROJECT:
24M 360 ALLROUNDER TUG

CLIENT:			HULL/PROJECT NO :	SCALE:
-			-	1:75
DRAWN BY	KONG	14 DEC 17	DRAWING NO :	REV.
CHECKED BY	PETER TAY	14 DEC 17	NE688A-GA	RPf

TITLE:
GENERAL ARRANGEMENT

PRINCIPAL DIMENSIONS :-

LENGTH O.A	25.66 M
LENGTH B.P.	23.96 M
BEAM MLD.	9.00 M (FENDERING 250MM)
BEAM O.A.	9.50 M
DEPTH MLD.	5.18 M
DESIGN DRAFT	3.50 M
SCANTLING DRAFT	3.75 M
MAIN ENGINE	2 X YANMAR 12AYM-WET
	1659PS @ 1900RPM
BOLLARD PULL	40 TONNES
DESIGN SPEED	13 KNOTS
COMPLEMENT	9 CREWS
F.O. CAPACITY	ABT. 118.2 M^3
F.W. CAPACITY	ABT. 36.5 M^3
DIRTY OIL CAPACITY	ABT. 4.4 M^3
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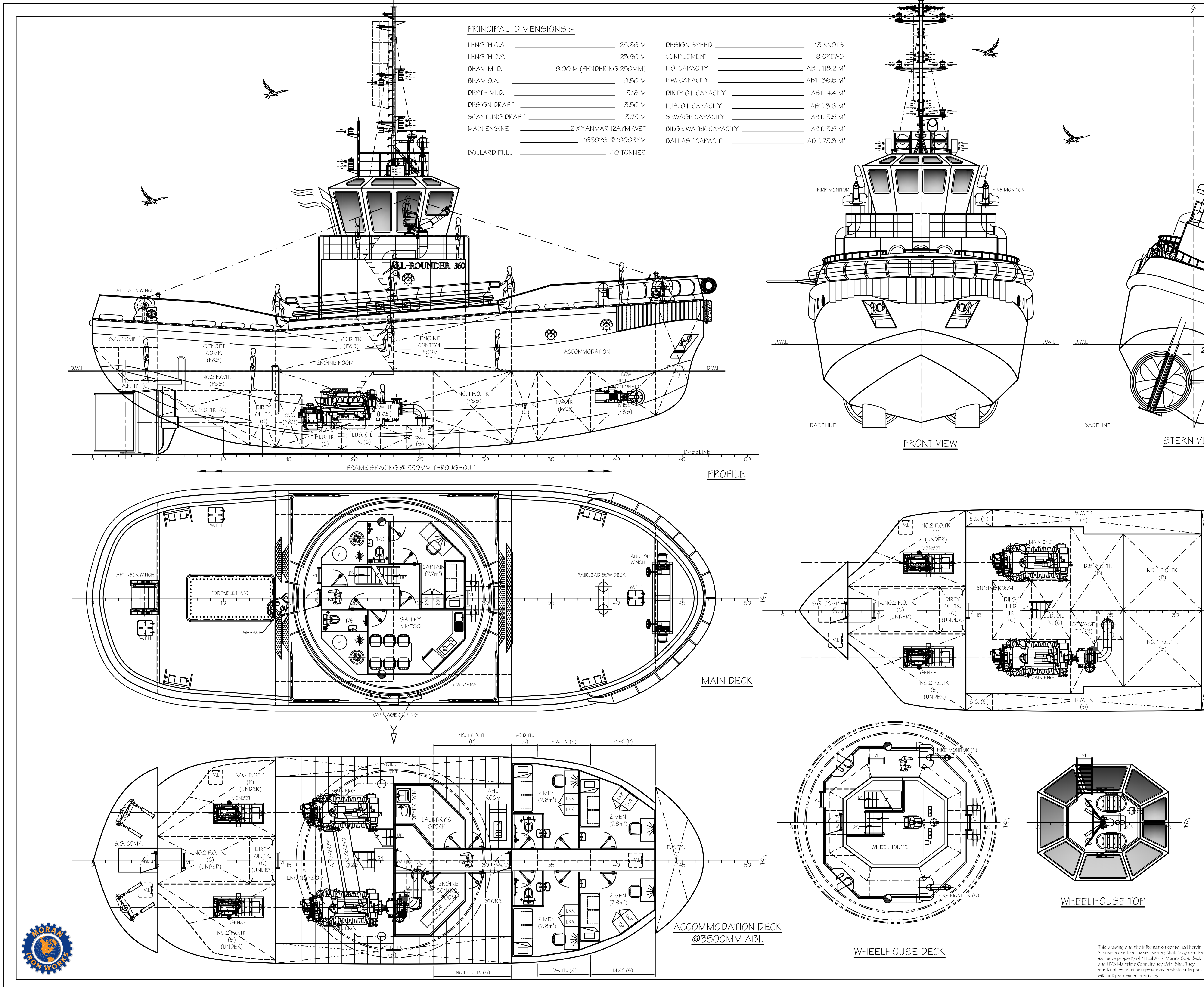

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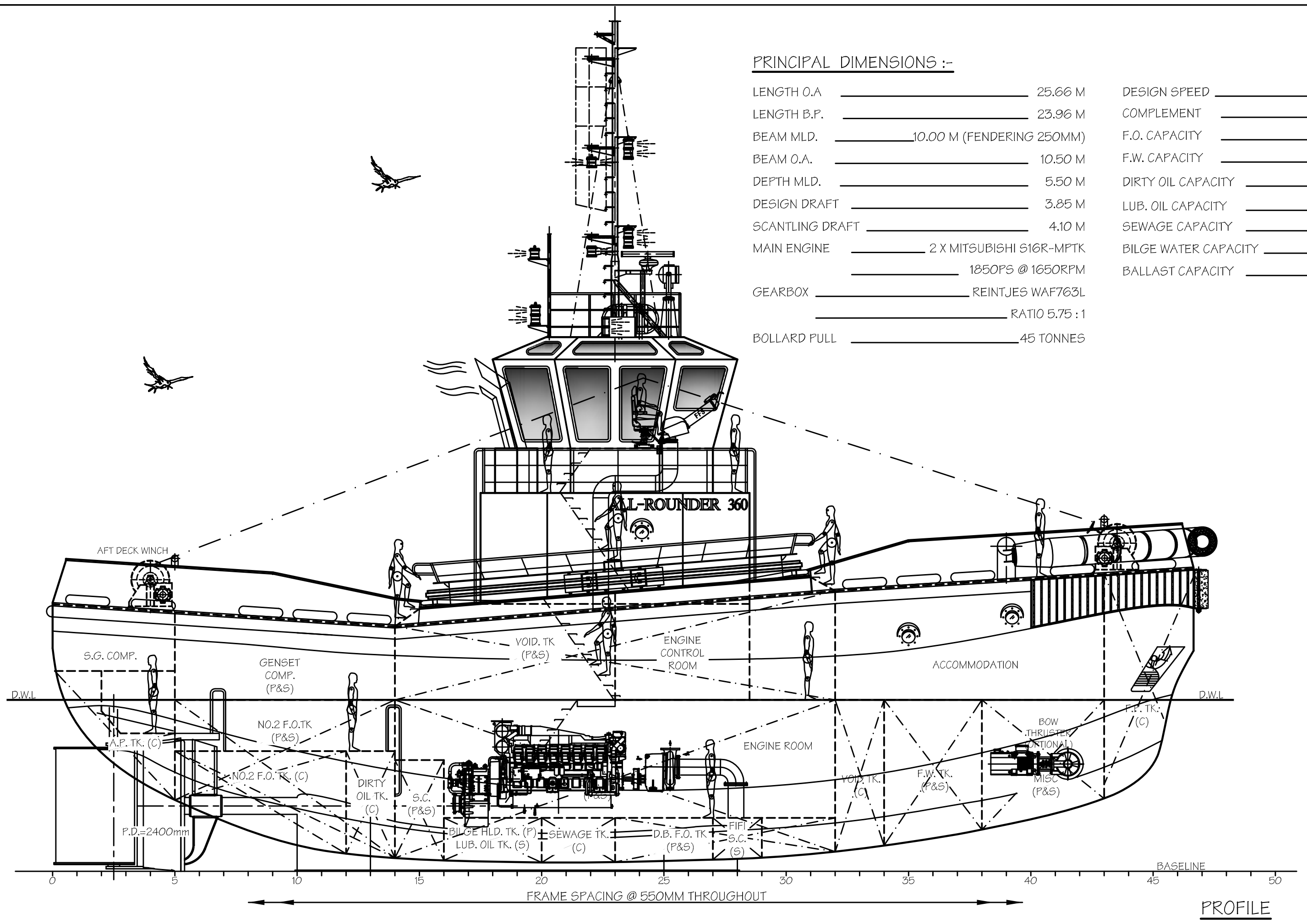
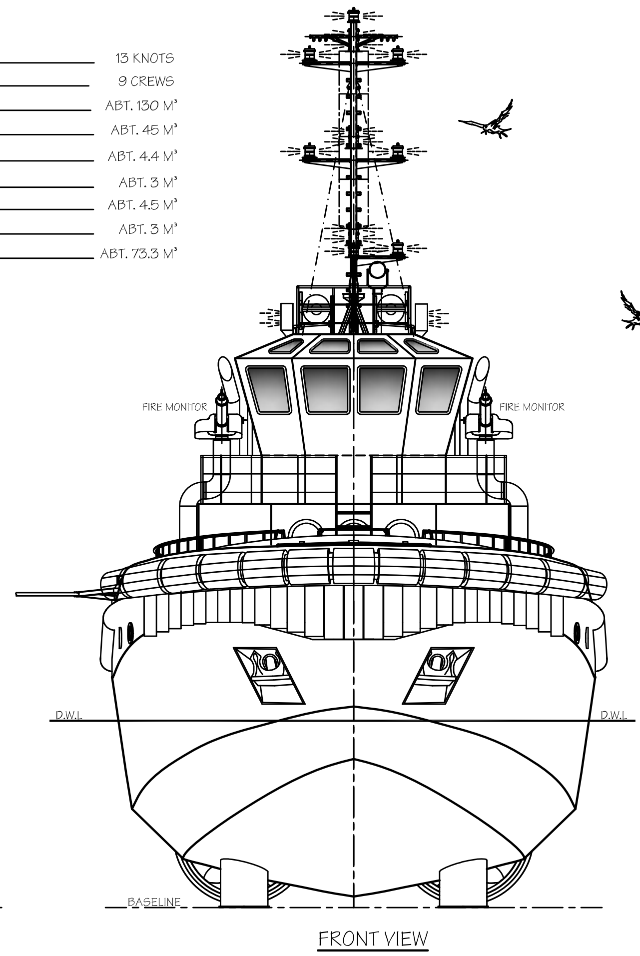


PROFILE

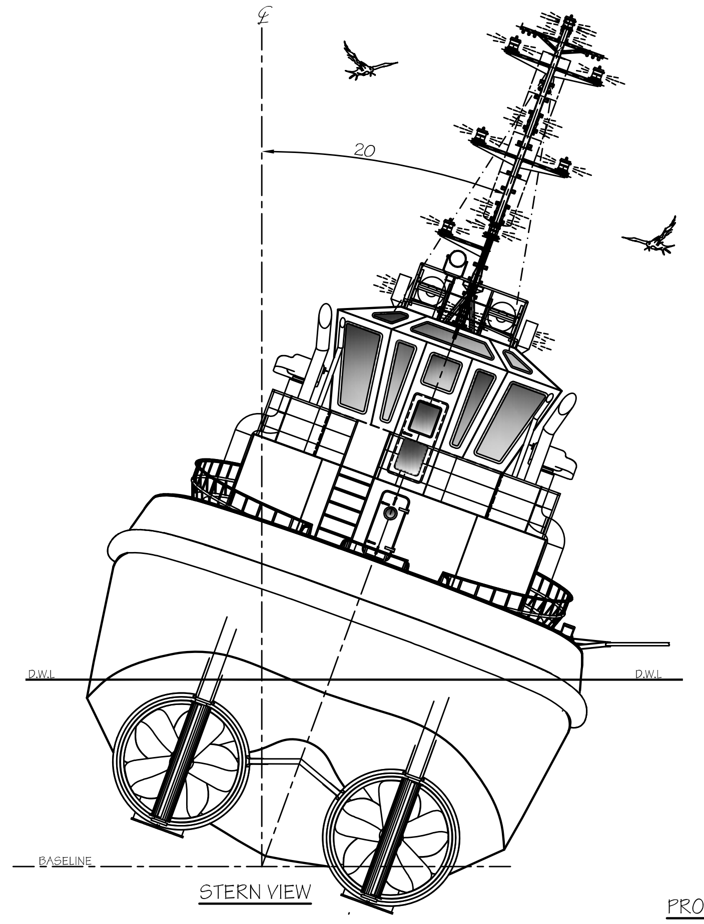
PRINCIPAL DIMENSIONS :-

LENGTH O.A	25.66 M
LENGTH B.P.	23.96 M
BEAM MLD.	10.00 M (FENDERING 250MM)
BEAM O.A.	10.50 M
DEPTH MLD.	5.50 M
DESIGN DRAFT	3.85 M
SCANTLING DRAFT	4.10 M
MAIN ENGINE	2 X MITSUBISHI S16R-MPTK
	1850PS @ 1650RPM
GEARBOX	REINTJES WAF763L
	RATIO 5.75 : 1
BOLLARD PULL	45 TONNES

DESIGN SPEED	13 KNOTS
COMPLEMENT	9 CREWS
F.O. CAPACITY	ABT. 130 M^3
F.W. CAPACITY	ABT. 45 M^3
DIRTY OIL CAPACITY	ABT. 4.4 M^3
LUB. OIL CAPACITY	ABT. 3 M^3
SEWAGE CAPACITY	ABT. 4.5 M^3
BILGE WATER CAPACITY	ABT. 3 M^3
BALLAST CAPACITY	ABT. 73.3 M^3

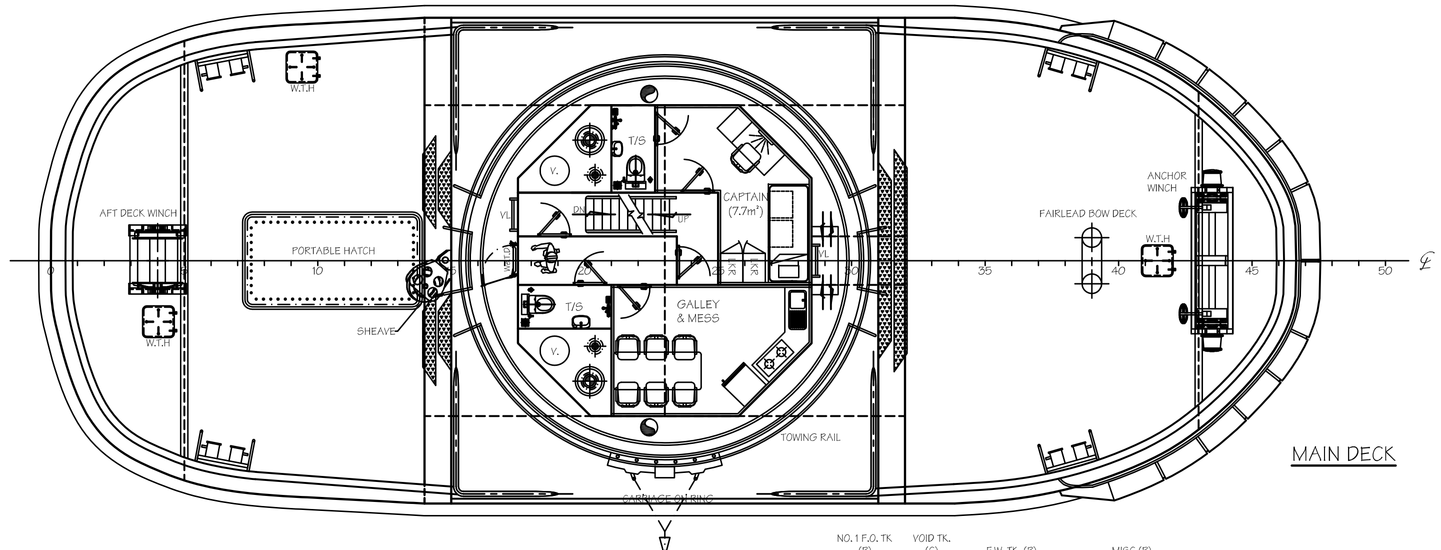


FRONT VIEW

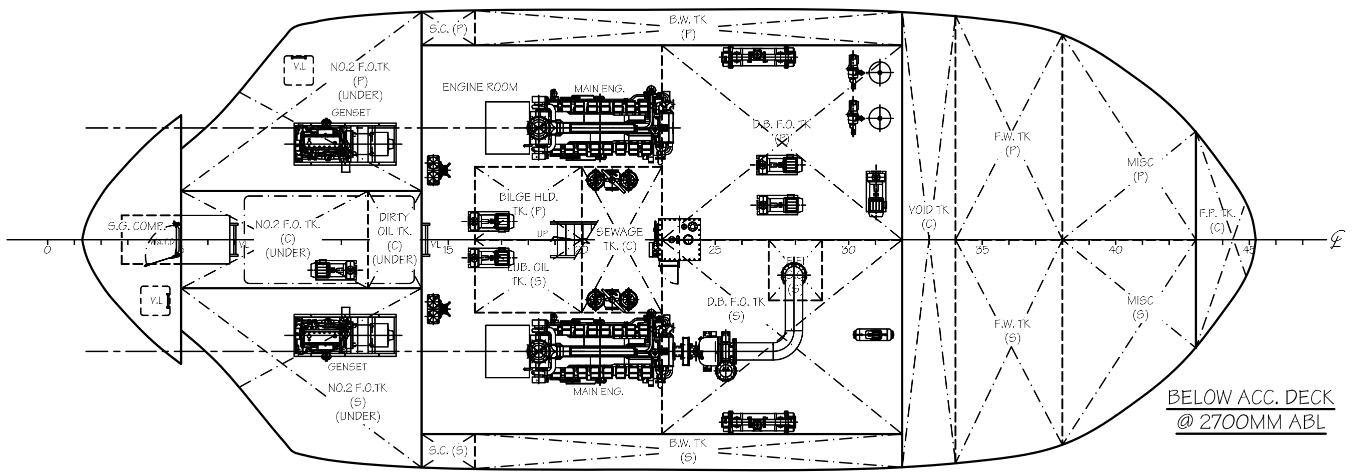


STERN VIEW

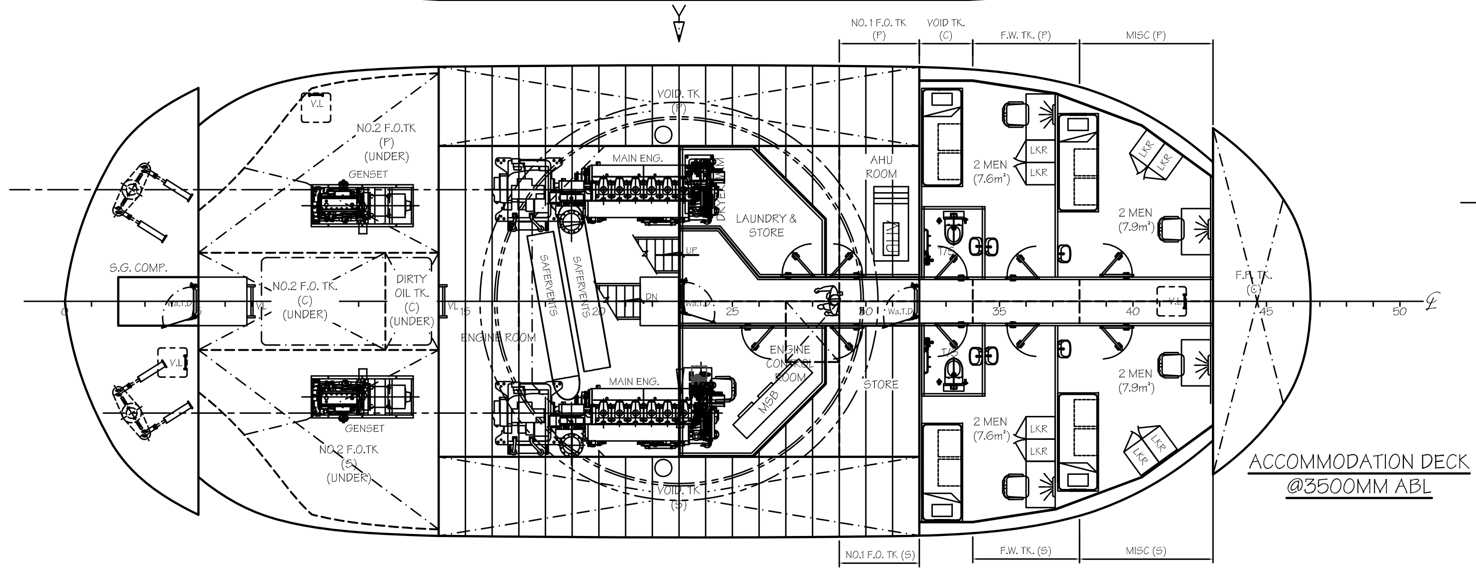
PROFILE



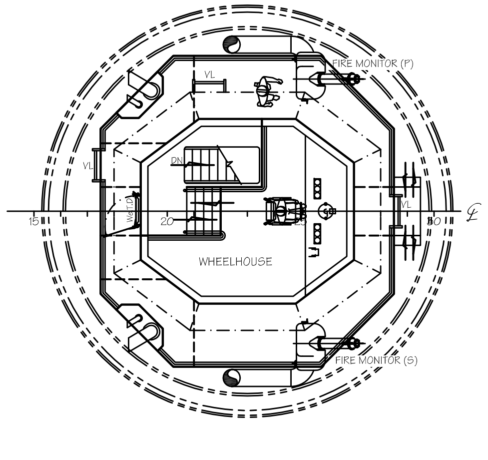
MAIN DECK



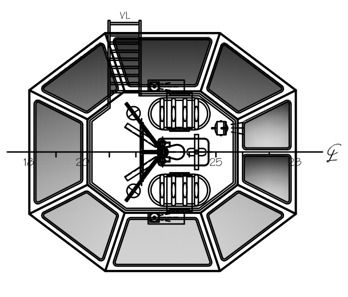
BELOW ACC. DECK @ 2700MM ABL



ACCOMMODATION DECK @3500MM ABL



WHEELHOUSE DECK



WHEELHOUSE TOP

REV.	DESCRIPTION	BY	DATE

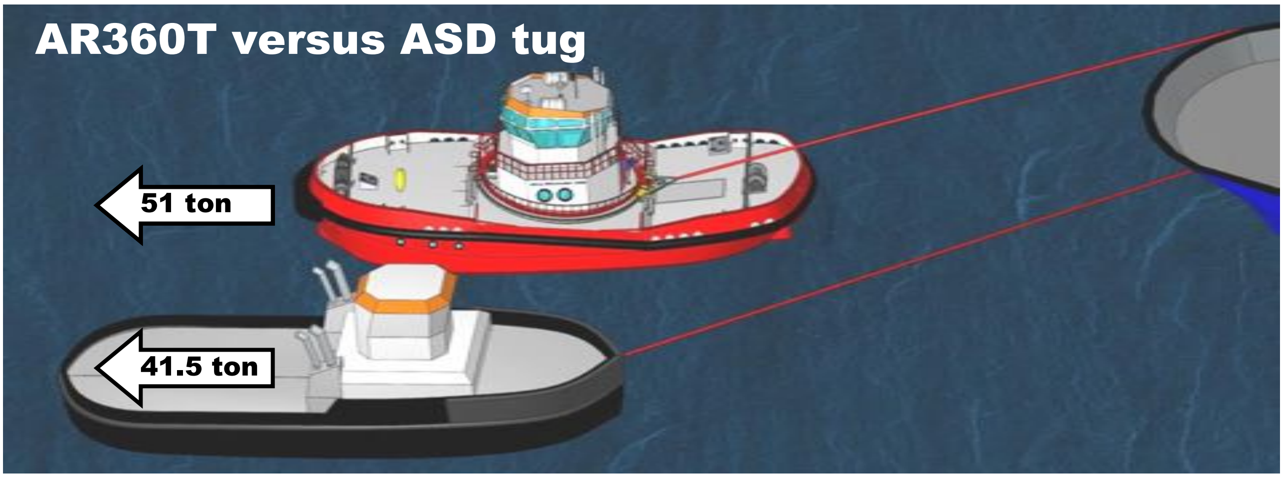
Naval Arch Marine Sdn. Bhd.
MARINE DESIGN & CADCAM CONSULTANTS
No.77, 1st Floor, Lorong Sungai Merah 2C, 96000 Sibu
Sarawak, Malaysia
TEL: 084-326467 E-MAIL: petertay@navalarch.com.my FAX: 084-327467

IN COLLABORATION WITH:
NVS MARITIME CONSULTANCY SDN. BHD.

PROJECT:
24M 360 ALLROUNDER TUG (2410)

CLIENT:			HULL/PROJECT NO :	SCALE:
-			-	1:80
DRAWN BY	KONG	26 JULY 18	DRAWING NO :	REV.
CHECKED BY	PETER TAY	26 JULY 18	NE757B-GA	R0

TITLE:
GENERAL ARRANGEMENT



Performance	AR360T	ASD
Same Engine Power (hp)	3750	3750
Dia prop (m)	2.4	2.2
BP ahead (ton) °	**51**	**45**
BP astern (ton)	34-37	40-43
Dynamic Pull (ton) °°	90	55

° AR360T uses shaft driven large size propellers with higher efficieny and lower losses in drive shaft / gears.
°° Dynamic pull is related to dynamic pull in indirect mode. Value depends largely on hull shape / design and assistance speed.

Low speed assistance 0 - 4 kn (static)

Typically involving berthing and turning inside port. Speed is low and tugs operate in push - pull operation. The force is primarily generated by propeller thrust without dynamic forces. Depending on assistance space, the AR360T may need to reverse, whilst an ASD can keep pulling astern.

Comparison with ASD:
The AR360T offers 6 ton higher BP ahead, and 6 ton lower BP astern. AR360T may need slightly more time (< 30 sec) to reposition for towing when reversing.

Medium speed assistance 5 - 8 kn (dynamic)

Typically involving sailing into and out of the port including canal/river areas. Speed is medium and tugs sail along the ship and offer temporary pull assistance for braking and for steering in sharp curves. The force is generated by a combination of propeller thrust and dynamic hull / skeg forces.

When assisting a ship, the various positions and generated forces of the AR360T are shown for the aft tug in figure 1 and for the bow tug in figure 2:

Aft tug sails bow first with towing wire over bow (A):

- In position (A) the tug can select to use forward thrust or reverse thrust (sketched).
- As alternative to engine thrust, the hull dynamic drag force can be used by turning the hull rectangular to the flow (wire over side) (B). Thereby saving fuel and offering an environmental advantage.
- To steer/pull the ship, the tug sails along outer circle forward and starts pulling the ship, (wire over stern) (D).
- In various positions (B-D) the outer propeller rotation may be reversed, whilst the inner propellers delivers thrust astern along the rudder. Hereby proper control of the whole manouvre is achieved.

The AR360T combines lower investment and higher efficiency than an ASD type with the same Bollard Pull.

Bow tug sails bow first with towing wire over stern (G):

- To brake the ship at higher speeds, the tug sails along outer circle aft and the hull is turned rectangular to the flow, dragging alongside the ship (wire over bow/side) (H). Thereby taking advantage of the hydrodynamic drag forces.
- To brake the ship at lower speeds, the tug reverses and sails backward braking with full bollard pull ahead (wire over stern).

The hydrodynamic design of the hull enables the following dynamic forces of approx 90 tons @ 8 - 9 kn speed.

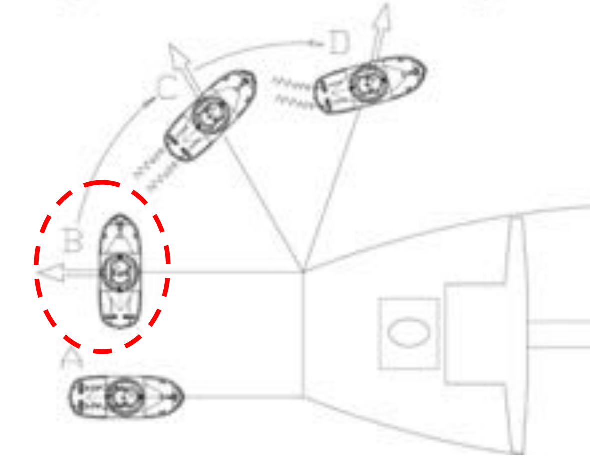


Fig. 1 Various positions for the aft AR360T

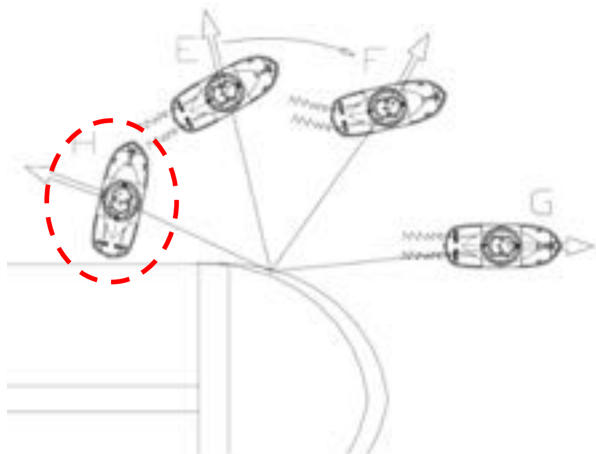
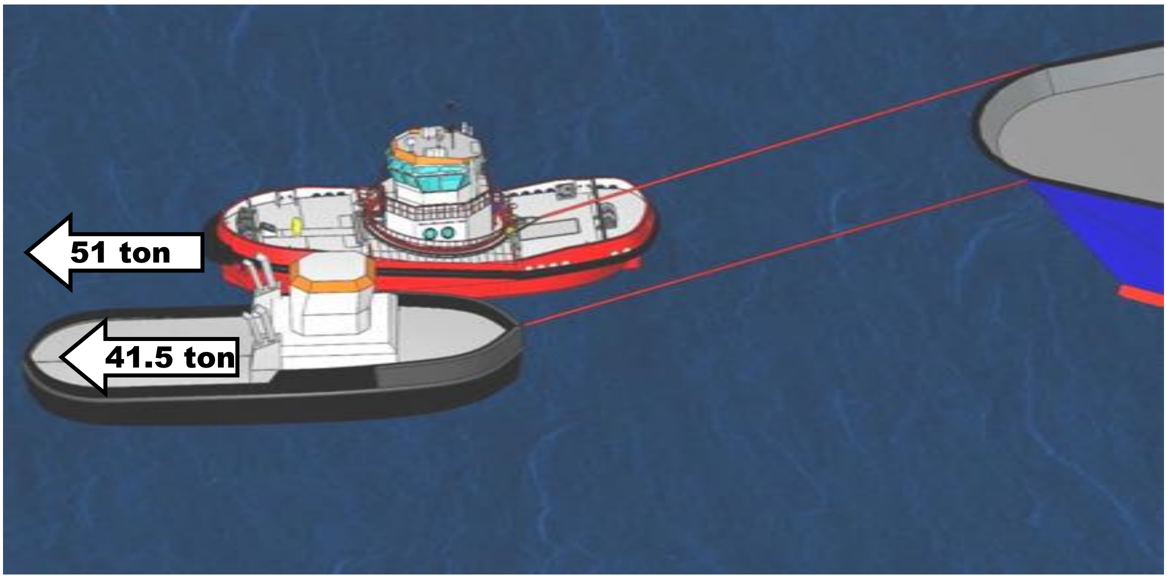


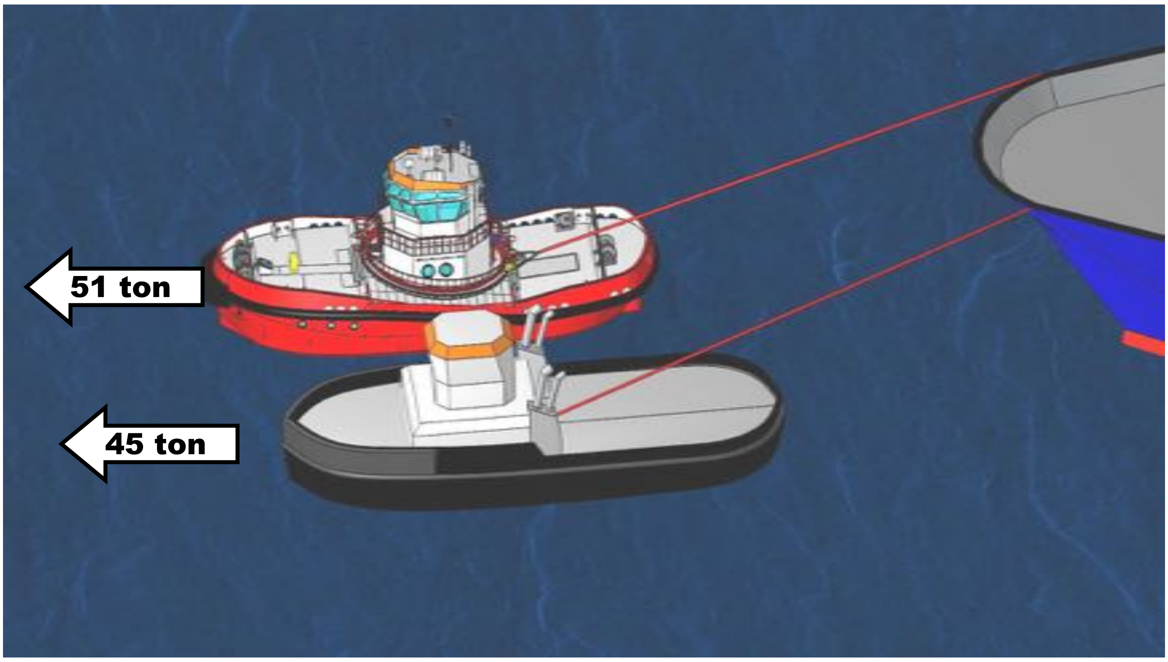
Fig. 2 Various positions for the bow AR360T

Comparison with ASD:
The AR360T offers significant higher dynamic pull force with less fuel consumption. Further, the AR360T can operate over the whole circle range including position 'B' and 'H', which are difficult / impossible to handle for an ASD.

What engine power is right comparison?
In order to make a proper comparison, the pull force of both the AR360T and the ASD should be compared in detail. When applying the same installed engines and power rate, there is a significant difference in operational BP.



ASD astern offers 41.5 ton BP / AR360T ahead offers 51 ton BP = **22%** more power per HP



ASD ahead offers 45 ton BP / AR360T ahead offers 51 ton BP = **13 %** more power per HP

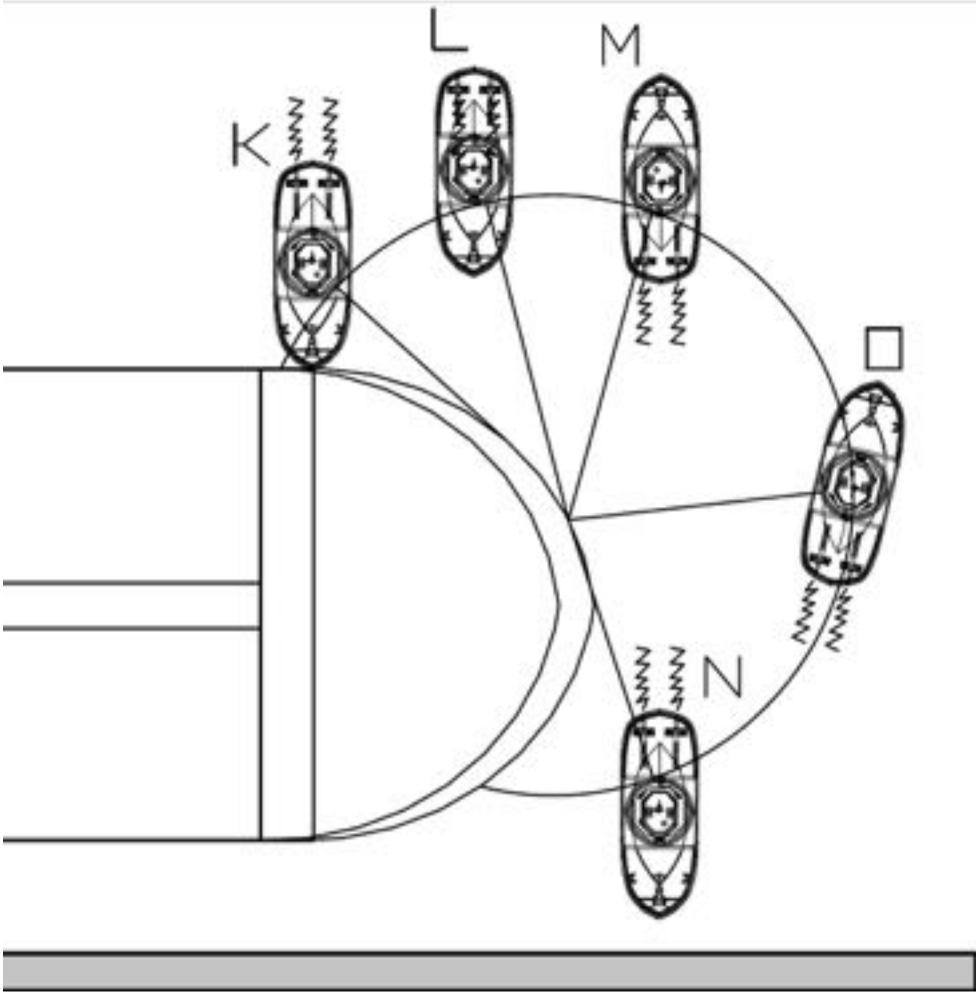
Jetty allows towing on a line
Above investigation is focused on a straight quay with standard push-pull operation. In case of an open jetty (oil/gas/chemical) the bow and stern tugs can operate on a line and rapidly change from pull towards the jetty into pull from the jetty and vice-versa. In this condition the AR360T continuously operates in ahead condition with instant reaction!

Explanation Push-Pull Operation

Additional information to the information sheet : Comparison Ship Assistance of AR360T versus ASD tug.

MOORING OF A SHIP

The picture shows a typical operation of an AR360T tug at the bow of a large ship when moving slowly towards the mooring location at the bottom (shaded area). In this example the connection between the tug and the ship is made via the PS bow fairlead. When the ship needs to move to the mooring location, the tug first takes position (N) at the SB side of the ship and uses the full BP over the stern to pull the ship slowly towards the quay. When the vessel comes close to the quay, the tug needs to move to the PS of the ship in position (L) or (M) to slow down the sideward speed of the vessel. And finally the tug needs to (very) slowly push the ship towards the quay in position (K). Possibly temporarily position (L) is needed to slow down the motion.



When sufficient space is available ahead of the ship, the tug can move relative quick from (N) to (M) by turning to PS and **with line tension** make the circle movement from (N) via (O) to position (M). If aft tug performs the same circle the axial ship components are balanced. This operation offers a controlled manouvre without slack towing line and can at any stage be interrupted or reversed. It can be performed with a conventional FPP propulsion installation, since reversing is not needed. Please note that the tug's hull can rotate independently of the towing line and the circular move can be performed rapidly with the hull in nearly longitudinal sailing direction, see position (O).
When less space is available ahead of the ship, the tug can move quickly astern from (N) to (L) by reversing the thrust and sailing in a straight line **without line tension** to position (L). Care should be taken that the towing line keeps free of the propulsion and that speed is properly controlled when line is tightened in (L). This operation has advantages of a CPP to quickly reverse thrust when manouvring.

The last Push-Pull operation is performed between (K) and (L). If (re)action time is considered crucial, a CPP installation offers rapid and controlled change from forward to reverse thrust and also offers direcly full thrust of each propeller to steer the tug by the lever between both propellers. Please note that position (K) should align with the prescribed tug contact areas of the ship and is without line tension.

In theory, turning the hull direction from (L) to (M) is possible, but will take some time and is therefore in general not practical.

In case of large ships, often more then 2 tugs are used and in that case one bow tug can be solely involved in the push operation (K) and the other bow tug solely in the pull operation. In that case the tug can take the (M) position which offers full thrust over the stern. But in some cases both tugs should operate parallel push and parallel pull and then position (K) and (L) are applicable.

Conclusion:
When operating an AR360T in Push-Pull operations, there is a time advantage for a CPP installation, especially in limited space. With a CPP installation the reaction time is similar to an ASD tug and no limitations are expected. Certain operations will probably even have a slight time advantage of the AR360T with CPP over an ASD with FPP.

UNMOORING OF A SHIP

Leaving the quay is a less complex operation; the tug should be in position (M) offering the full BP over the stern to pull the ship away from the quay. Further manouvring as discussed in the information sheet : Comparison Ship Assistance of AR360T versus ASD tug.pdf.

PS 1 : BP values of the AR360T
BP (see matrix in information sheet) is in condition (K), (M) and (N) BP ahead of 33 ton and in condition (L) BP astern of 25-27 ton. For a 45 ton BP tug values should be linearly adjusted.

PS 2 : Interesting increase of BP by zig-zag motions
Experience with the Multratug 12 has demonstrated that in position (M) turning the rudders temporarily to SB and back to PS results in the whole tug body creating a zig-zag motion. This operation offers a (significant) higher BP than pulling in a straight line due to the additional hydrodynamic force of the hull. Especially when pulling a ship sideward in shallow water this effect is considerable. (Same procedure is often performed by salvage tugs to enhance pull).

Advantages All-Rounder compared to twin screw tug

Main advantages

1) Safety against capsizing by towing ring

The towing ring moves the attachment point of the towing force towards the side and effectively prevents capsizing due to towline forces. This prevents:

- Total loss of vessel and crew (!)
- Risk for the assisted ship to collide / ground due to loss of tugboat assistance
- (Part) flooding of engine room with high reconditioning cost
- Long period of 'out-of-charter' after accident/incident
- Crew risk/incidents by dynamics / large heeling angles

2) Operational advantages by dynamic assistance

With increasing sailing speed of the assisted ship/barge, the effectiveness of conventional tugs reduces as conventional tugs generate only marginal dynamic forces and with increasing speed reduced propulsion power.

The AR360T offers at low speed propulsion force and with increasing speed also generates increasing dynamic forces. Hereby a safe and efficient assistance can be guaranteed with higher sailing speeds. Both bow and stern tug can assist with dynamic forces by steering or braking. This enables:

- Higher assistance speeds into and out of port due to tug sailing safe at high speed and offering instant braking and steering support
- Higher transit speeds between ports (e.g. for barges)

3) Change of towing direction (especially for aft tug)

A conventional stern tug can either connect over the stern (towline alongside) or over the bow. This however introduces a complex change of connection when assisting as stern tug. And a limited turning direction based on the chosen towline side.

The AR360T can easily change from towing direction by turning the hull under the towing ring without need for complex (dis)connection. When a ship is assisted over a longer route with certain narrower parts (e.g. bridge), the AR360T can easily adapt and turn in the requested direction.

4) Reduction of fuel consumption

During the assistance of a ship, often tugs are used with their propulsion system to tow the ship in the required direction. With the AR360T in addition to propulsion power, also the hydrodynamic forces can be used, thereby significantly reducing fuel consumption and engine maintenance.

Fuel savings depend on the specific application and can range up to 70% in case of assisting a ship over a longer distance by dynamic steering / braking performance with main engines only running idle.

5) Green impact

By using the dynamic steering/braking instead of engine power, not only fuel oil is saved, but also associated diesel emissions are reduced. And in case of potential accidents, not only the environmental impact of the tug loss should be considered, but also as a consequence of the failing towing assistance, the potential collision and/or grounding damage of the ship.

Further advantages AR360T

- **Efficient hull shape for free sailing speed**
  The hull design has been specially designed for low resistance and relative high speed. Hereby the tug has a rather high economical speed and also a high maximum speed.
- **Large buoyancy of hull effective towing operations even in wave conditions**
  Compared to a conventional tug, the freeboard is rather high and the hull accommodates large buoyancy volume. Hereby offering proper operations even in significant wave height.
- **Proper seagoing in adverse weather conditions**

The hull includes a large bow height and large buoyancy and a relative large freeboard. This offers good operations in in adverse weather condition. The twin large skegs offer effective anti-rolling performance.

- **Proper steering astern with main propulsion only**
  The propeller shafts positioned wide aside in combination with the specific hull shape enables to steer the tug astern by varying the engine power. Possibly enhanced by additional bow thruster.
- **Fully horizontal mounting and (de)installation of the whole propulsion system**
  To facilitate building, mounting, maintenance etc, the whole propulsion system is positioned horizontally inside the hull.
- **Main engines can be exchanged without cutting hull / sections.**
  The design includes a 'corridor' aftward from the engine room to the aft deck with a bolted deck cover to easily exchange engine parts or even a complete engine
- **Easy building/docking on skegs reduces time and handling**
  The two strong skegs are designed to dock the vessel on, thereby reducing the docking time and required handling of dock-blocks.
- **Propulsion and rudders safely protected by skegs**
  When sailing ahead, the strong skegs protect the propulsion (nozzle and propeller) and the rudder. Thereby preventing potential damage in areas with less navigational (up-to-date) data.
- **Good damage stability**
  The large compartmentation of the internal hull with various watertight bulkheads and the SaferVents in the engine room vents contribute to a good damage stability.
- **Large bunker capacity for longer towages**
  The hull is optimized for relative low resistance in combination with sufficient displacement. Therefore the tug can accommodate large bunkers for longer towage voyages.

Conclusion

The AR360T design enhances the towing assistance performance from a twin screw propulsion to an azimuth propulsion by a small investment of the carriage and towing ring.

AR360T Quick Reversing Explained IV

The AR360T tug is designed to pull in the ahead direction and rotates the towing ring in the corresponding direction towards the towed vessel. The propellers, nozzle and position aft are optimized for the highest propulsion efficiency pulling ahead. Therefore it is advantageous to turn the hull in the ahead position in order to achieve the highest thrust.
However, although in astern condition a less optimal thrust is available, a typical 70% of ahead thrust is still available.
When considering various operational assistances of the AR360T, one should note that the ahead condition is used in the large majority of the towing conditions. The astern condition is rarely used and, if used, primarily in combination with a short transition from one position to the other.

The same principle of different pull ahead and astern also applies to ASD tugs, although the difference between ahead and astern is smaller (range of 7-10%) as a result of the 180° rotation of the whole thruster. Although this loss astern is relative small, one should note that the majority of towing assistances with ASDs are performed in the less efficient astern condition!

In the paper 'AR360T Propulsion and Manoeuvring Explained' details are given on the special characteristics of the wide apart spaced main propellers offering a large steering moment both ahead and astern. Further enhanced by the large installed power, the rudders ahead and the hull effect astern.
As comparison: The AR360T offers a double steering moment by the main propellers only compared to a Damen 2408 tug.

This paper describes quick reversing for :
1) Explanation of typical manoeuvre when changing from push to pull (NO current)
2) Explanation of typical manoeuvre when changing from push to pull (with 3 kn current)

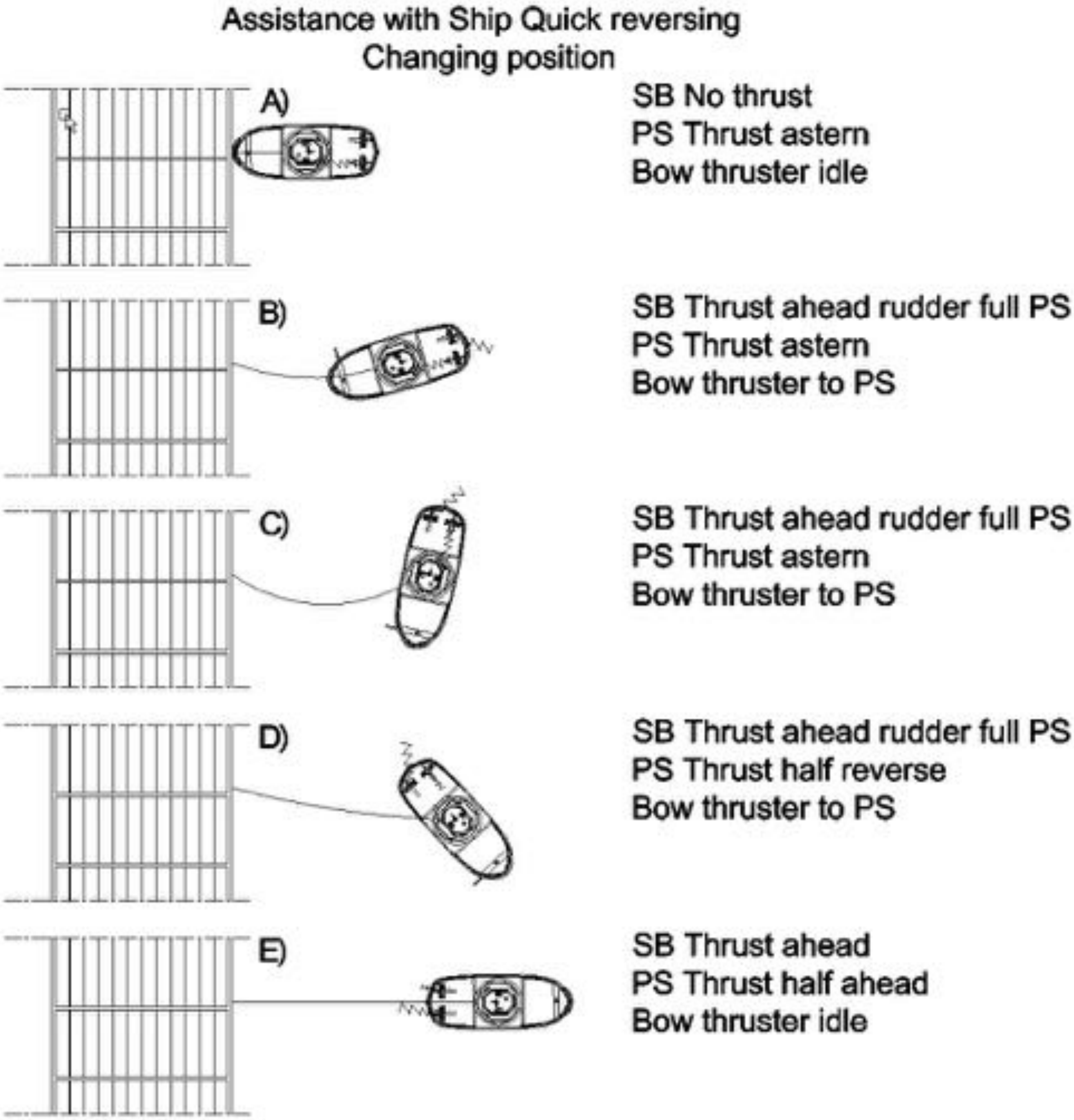
Both manoeuvres can be performed rapidly in a controlled way.

1) Explanation of typical manoeuvre when changing from push to pull (NO current)

To clarify the manoeuvre from push to pull, the manoeuvre is shown below in 5 steps. Starting with the tug in push position on the side of a ship, followed by reversing thrust of the PS engine, sailing astern and adding forward thrust of the SB engine with rudder full to PS. The whole operation supported by a powerful bow thruster pushing the bow to PS.

The motion from A) to E) does not only include a 180° rotation, but also a move from push to pull position and requires some typical 30 sec. This time frame is considered acceptable in the whole towing assistance. An ASD tug will also require time to move astern to the outer pull position, depending on type / powering some 15 sec will also be necessary.

The difference between an ASD and an AR360T tug in this operation is therefore less than 15 sec.



Note: Although the ahead condition of the AR360T is more efficient, intermediate push-pull changes can also be performed in the astern position, however, taking into account some 30% less BP available. There may be certain push-pull operations where the captain will evaluate which position is considered best. E.g. when pushing a vessel towards the quay, the final stopping by pulling 'back' requires less power than pushing towards the quay and could be performed in astern position.
In comparison with an ASD towing astern, the difference is only 20% less power.

2) Explanation of typical manoeuvre when changing from push to pull (3 kn current)

In addition to the previous description without current, please find below the situation with a 3 kn current from above. This situation is similar to the ship sailing at 3 kn speed in upward direction.

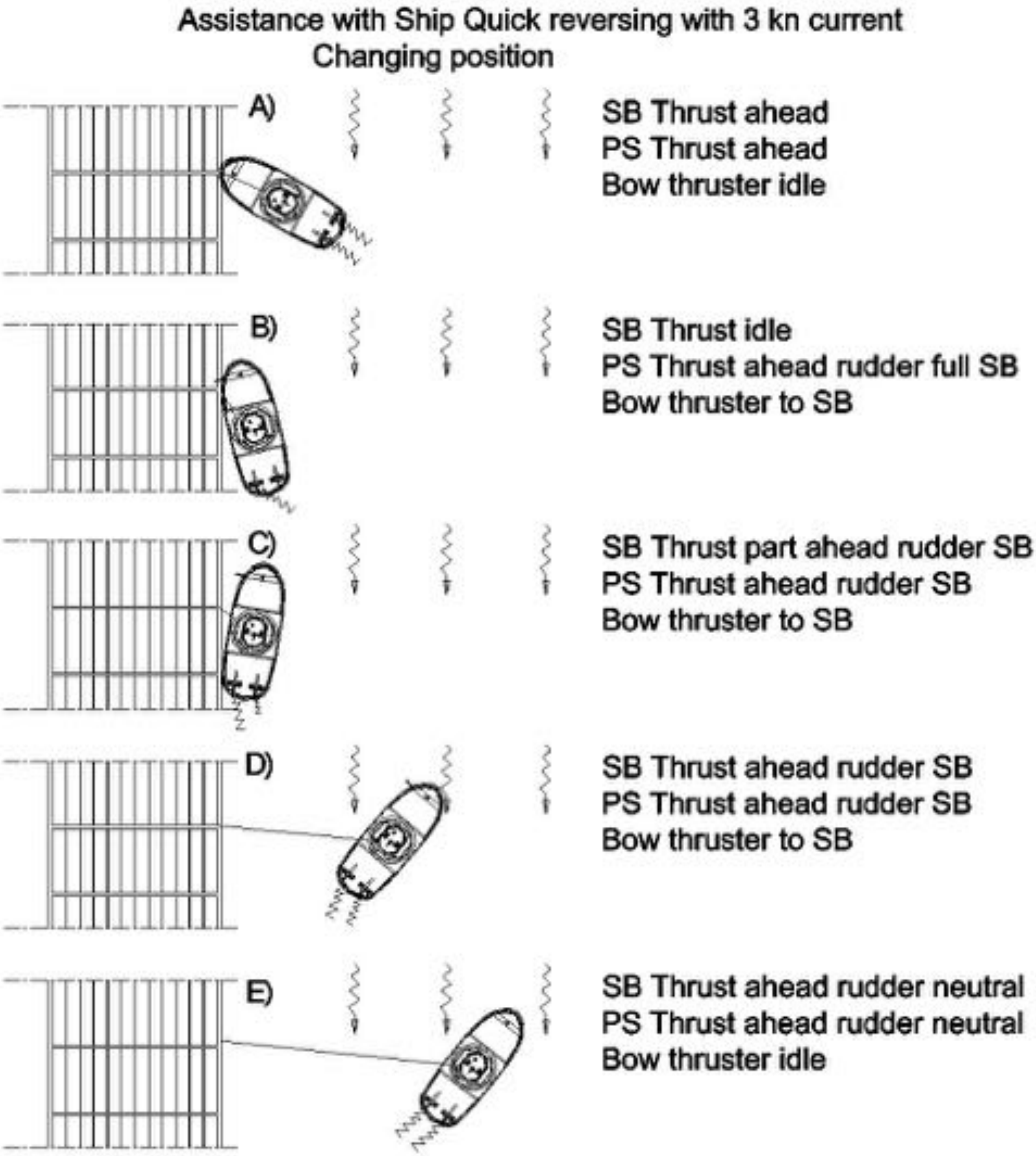
In the figure below the various steps are shown. In contrast to an ASD Tug, the heading of the AR360T hull does not need to be in line with the towline direction and this enables to use the hydrodynamic force of the tug's hull in addition to the propulsion force.

Please note that there is a slight reduction in manoeuvring time, compared to situation 1) because:

1) The main engines do not need to use the reverse gear (slow down, shaft brake, reversing, speed up)

2) The steering angle is significant less than 180°

The difference between an ASD and an AR360T tug in this operation is therefore in range of 10 - 15 sec.



Maintenance comparison matrix AR360T vs Thruster Tug

MAINTENANCE SCHEDULE

Main propulsion components	Installation Standard	2.5 year Survey	5 year Survey	7.5 years Survey	10 years Survey
AR360T conventional propulsion					
Main engines	Standard	Standard	Standard	Standard	Additional
Gear box	Standard	Standard	Standard	Standard	Standard
Reversing mechanism	Standard	Standard	Additional	Standard	Additional
Clutching mechanism	Standard	Standard	Additional	Standard	Additional
Main thrust bearing	Standard	Standard	Standard	Standard	Standard
Propeller shaft	Standard	Standard	Standard	Standard	Standard
Seals	Standard	Standard	Additional	Standard	Additional
Propeller	Standard	Standard	Standard	Standard	Additional
Propeller shaft supports	Standard	Standard	Standard	Standard	Standard
Nozzle	Standard	Standard	Standard	Standard	Standard
Steering machine	Standard	Standard	Standard	Standard	Additional
Rudder	Standard	Standard	Standard	Standard	Standard

Thruster Tug (ASD/ Tractor)	Installation Standard	2.5 year Survey	5 year Survey	7.5 years Survey	10 years Survey
Main engines	Standard	Standard	Standard	Standard	Additional
Shaft lines + cardan joints	Additional	Standard	Additional	Standard	Additional
Thruster upper gears	Standard	Standard	Standard	Standard	Additional
Thruster lower gears	Standard	Standard	Additional	Additional	Significant
Thruster seals	Standard	Standard	Additional	Standard	Additional
Thruster clutch	Standard	Standard	Additional	Standard	Additional
Thruster propeller	Standard	Standard	Standard	Standard	Additional
Thruster nozzle	Standard	Standard	Standard	Standard	Standard
Thruster main steering bearing	Standard	Standard	Additional	Standard	Additional
Thruster main steering machine	Standard	Standard	Standard	Standard	Additional

DAMAGE SCENARIO

	Object through prop			Grounding		
AR360T conventional propulsion	Minor	Medium	Large	Minor	Medium	Large
Main engines	Standard	Standard	Standard	Standard	Standard	Standard
Gear box	Standard	Standard	Additional	Standard	Standard	Standard
Reversing mechanism	Standard	Standard	Standard	Standard	Standard	Standard
Clutching mechanism	Standard	Standard	Additional	Standard	Standard	Additional
Main thrust bearing	Standard	Standard	Standard	Standard	Standard	Standard
Propeller shaft	Standard	Standard	Standard	Standard	Standard	Standard
Seals	Standard	Standard	Standard	Standard	Standard	Additional
Propeller	Standard	Additional	Additional	Standard	Additional	Significant
Propeller shaft supports	Standard	Standard	Standard	Standard	Standard	Additional
Nozzle	Standard	Standard	Standard	Standard	Additional	Significant
Steering machine	Standard	Standard	Standard	Standard	Standard	Additional
Rudder	Standard	Standard	Standard	Standard	Additional	Significant

	Object through prop			Grounding		
Thruster Tug (ASD/ Tractor)	Minor	Medium	Large	Minor	Medium	Large°
Main engines	Standard	Standard	Standard	Standard	Standard	Standard
Shaft lines + cardan joints	Standard	Standard	Additional	Standard	Additional	Additional
Thruster upper gears	Standard	Standard	Additional	Standard	Standard	Additional
Thruster lower gears	Additional	Additional	Significant	Additional	Significant	Significant
Thruster seals	Standard	Additional	Additional	Standard	Additional	Additional
Thruster clutch	Standard	Standard	Standard	Standard	Standard	Standard
Thruster propeller	Standard	Additional	Additional	Standard	Additional	Significant
Thruster nozzle	Standard	Standard	Standard	Standard	Additional	Significant
Thruster main steering bearing	Standard	Additional	Significant	Additional	Additional	Significant
Thruster main steering machine	Standard	Standard	Additional	Standard	Standard	Additional

° Loss of thruster

STANDARD WORK

ADDITIONAL WORK

SIGNIFICANT WORK

Note: Shore lay up time for repair will be longer for Thruster Tug versus AR360T meaning higher loss of operating revenue