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Damen ATD Tug 2412 Twin Fin Concept

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SYNOPSIS

Since 1927, Damen has had a reputation for building compact tugs and workboats. As technology has developed and the size and scale of towage operations have increased, customer requirements have also changed. This has resulted in demands for greater power and even more compact vessels to attend ships manoeuvring in and out of port. At the same time, the towage industry is being forced to reduce capital expenditure and lower operational costs in order to remain competitive. The demands for higher power within a small vessel, along with lower initial and operational costs, all contribute to an on-going search for more efficient use of power within confined physical boundaries.

With the development of the ASD 2411 (presented at *ITS 2002*) the design for the first compact but high-powered harbour tug was presented. Now, eight years later, more than 50 have been delivered worldwide: evidence of serious market interest in the compact tug concept. However, with a minimal length over beam ratio, directional stability becomes a challenge, especially in the case of a compact tractor drive tug.

This paper describes the development of the new Twin Fin tractor tug design, and the results of the model test programme. The objective was to achieve perfect manoeuvring performance and at the same time perfect course stability. The single skeg ATD Tug 2412 was already a remarkable success and now the new Twin Fin configuration is set to make the new tractor tug industry benchmark.

DAMEN AS COMPACT TUG BUILDER

The ATD Tug 2412, similar to the Damen ASD Tug 2411, has been developed as a compact tug with a bollard pull of up to 65 tonnes. The compact tug is not a new phenomenon for the company, as in the 1970s, the Stan Tug 1, a 700hp twin-screw, 15m length, one-man operated tug, was introduced.

Figure 1: ATD Tug 2412 escorting.

Figure 2: Stan Tug1 – standard compact tug built in 1970 with 700hp.

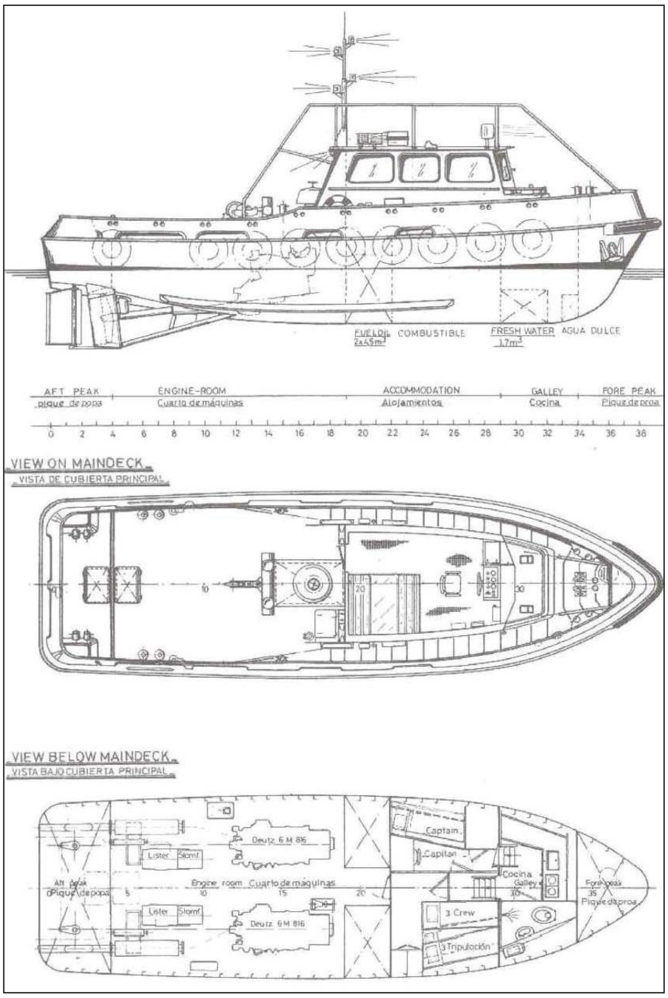


Figure 3: GA drawing – Stan Tug 1.

This tug has been progressively developed into the present day Stan Tug 1606, with a length of 16m and 1200hp. More than 250 units of this 16m tug have been built since 1970 and are now successfully operating with dredging companies, harbour authorities and tugboat owners for general towing and ship assist services. The most striking characteristic of the latest generation of these vessels is the power installed, which in this Series exceeds much larger vessels providing the same service.

DAMEN STANDARD SERIES

For several decades the company has been well known for its series-built, standard, Stan Tug range – compact conventional tugs with twin fixed pitch propellers in nozzles and a high bollard pull.

In 2002, the ASD Tug 2411 was introduced, with a total installed power of 4,200kW and a bollard pull of 67 tonnes. Other more recent compact tugs in the ASD Tug range are the ASD Tug 2009, with a length of 21m and 2,600hp, and the ASD Tug 2310, with a length of 23m and 4,000hp.

The success of the compact series has provided an extra stimulant to the development of new compact tractor tugs. Consequently, the ATD 2909 with 2,900hp and the ATD 2412 with 5,700hp have been developed in recent years.

Figure 4: ASD Tug 2411 with 1,200m^3 Fi-Fi.

TOWING METHODS AND TUG OPERATIONS

Methods of assistance provided by tugs in ports around the world differ due to local conditions, specific geography and traditional methods. In addition, the following factors play a role in tug choice:

- Tug assistance methods already in use;
- Present tugs have available experience;
- Safety requirements;
- Port developments.

Figure 5: ASD Tug 2810 operating at a ship's side.

Other important factors are the type of ships to be assisted, such as LNG carriers, bulk carriers, oil tankers, container vessels, car carriers, ro-ro ships etc. The following types of tugs are available:

- Twin screw Stan Tug Series;
- Twin screw ASD Tug Series;
- Twin screw ATD Tug Series;
- Twin Voith VTD Tug Series.

The following assistance methods, or a combination of these methods are most common:

- Tugs towing on line;
- Tugs operating at a ship's side.

Figure 6: ASD Tug 2411 towing on line.

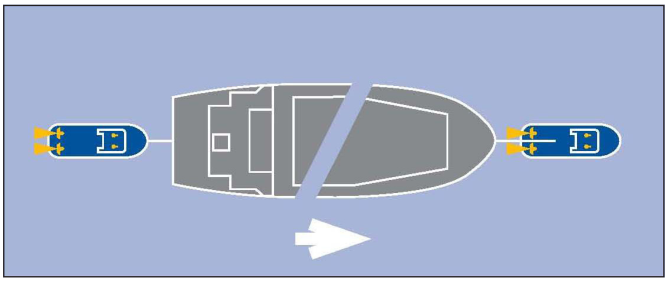


Figure 7: ASD tug manoeuvring manual illustration 23, normal style, commonly used by ASD tugs. Tugs towing on line.

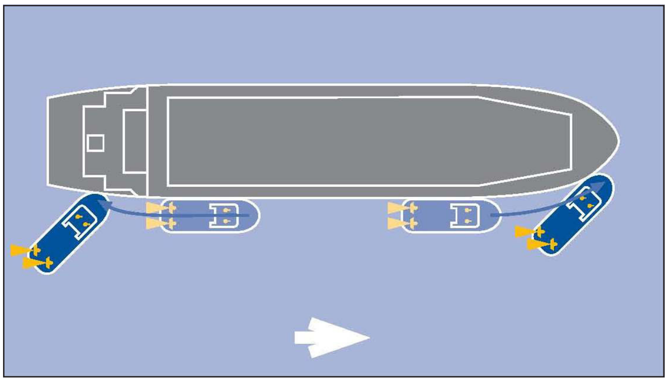


Figure 8: ASD tug manoeuvring manual illustration 28, pushing under an overhanging bow or stern. When vessel's speed is more than 3 knots, go to the flat area of the vessel's side and move from there under the overhanging bow (or stern), keeping constant contact. This is the safest method. Tugs operating at ship's side.

Figure 9: ATD Tug 2412 towing on line.

Tugs towing on a line are made fast at the bow and astern of the assisted ship. Tugs operate at a distance of a ship's bow and astern normally 1.5 times the tug's length. The performance of ASD tugs, ATD tugs, VTD tugs and conventional Stan tugs when towing on a line were calculated using the TugSim simulation program.

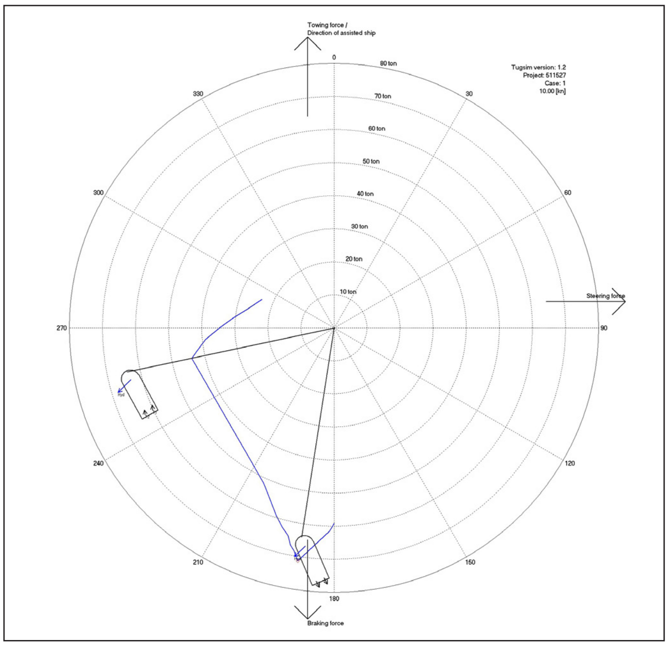


Figure 10: TugSim tug assist diagram 10 knots.

The performance graph shows an ASD tug towing on a line at 10kn. The main objective of the graphs is to show the maximum steering and braking forces that can be achieved in indirect and combination mode. Tug stability, freeboard and height of towing point have a considerable influence on the maximum achievable towing forces. Limiting factors are engine torque and heel angle.

Figure 11: Compact ASD and ATD Tugs have high side thrust.

For operations such as push-pull and for operations at the ship's side, these tugs have almost equal power astern and ahead and can apply thrust in any direction. For conventional tugs, with fixed pitch propellers in nozzles, the maximum astern thrust is about 60 per cent of the ahead thrust (see also *Tug Use in Port* by Capt Henk Hensen).

DESIGN DEVELOPMENT OF TWIN FIN CONCEPT

The ATD Tug 2412 has unconventional main dimensional ratios – an L/B ratio of 1.89 and a B/T ratio of 3.75 (*see Figure 12*). The resistance of a tug with such short L/B ratio is hard to determine by the empirical method. Using CFD to accurately predict the resistance in such a breaking wave is also not possible. Therefore, the powering and resistance curves are quantified using model tests. In addition to the powering and resistance tests, several manoeuvring tests were also carried out.

An observation from full-scale trials and model scale trials was that the tug had to be steered (when sailing ahead) with about 5-10 degrees of azimuth angle and allowing a drift of 3-5 degrees. This phenomenon was determined using Dieudonné tests at model and at full scale (*see Figure 13*). Sailing astern showed the tug as directionally stable. We determined this peculiar steering behaviour whilst sailing ahead as reverse stable.

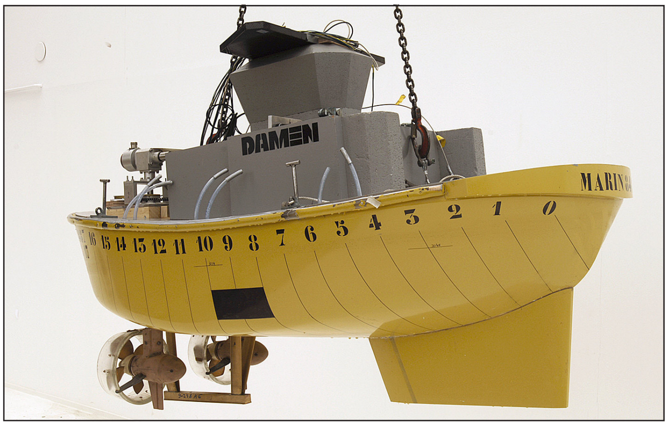


Figure 12: ATD Tug 2412 with a conventional skeg.

Opportunities to improve on this peculiar steering behaviour when sailing ahead were sighted and a study initiated to further enhance the design.

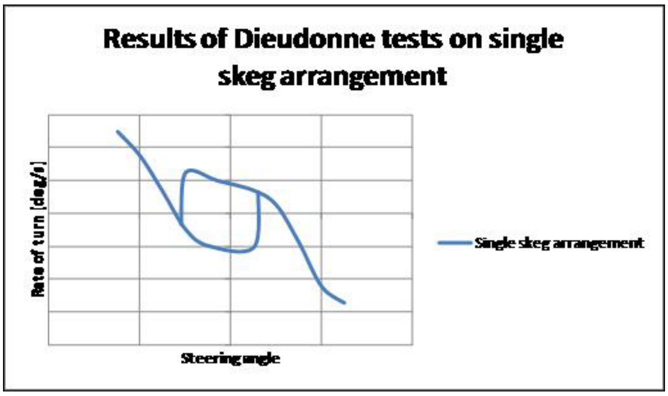


Figure 13: Dieudonné results for a conventional skeg arrangement.

The aim of the design enhancement is to reduce the azimuth angle and drift when sailing straight ahead and increase the 'ease' of steering without degrading the turning ability too much. The sailing characteristics, neither in seaway nor in the wake of an escorted vessel, should be negatively influenced by the design modification.

The turning ability and directional instability of this tractor tug are rather complex. The 'yaw balance' between the applied steering and propulsion forces (action forces), the damping forces (reaction forces) on the hull depending on the yaw and drift and the mutual interaction phenomena are to be considered. To better understand this, the following aspects are highlighted:

1. The occurring phenomenon is typical for all tractor tugs, but it is more pronounced in ATDs with a short L/B ratio;
2. Interactions between the thrusters and the skeg. Given their location and magnitude, the interactions are large and sensitive to the manoeuvring motions, azimuth angles and speeds. One of the hypotheses is that the skeg generates an opposing steering force due to its location in the propeller races at small azimuth angles. This is an explanation for the fact the tug turns to the opposite direction than expected;
3. Working lever of the steering force. The steering force has a certain 'working' lever with respect to the reaction forces on the hull. The force times the lever delivers the steering moment for the yaw motion. If we simplify the complex pressure distribution on the hull as a force vector than this force vector has its centre of effort in the front half of the hull, say at about 30 per cent L_{PP} aft of the F_{PP}. In a tractor tug design the location of the thrusters are very close to the same spot, making the working lever small or even inverse.
4. Balance of the damping forces on the hull as function of drift and yaw motions. A skeg surface aft increases damping, reducing turning ability and increasing directional stability.

The interaction between a centre line skeg and the flow coming from the thrusters is indicated in *Figure 14a*. The phenomenon may be expected for every tractor tug, but for the present design, it is more pronounced, because of the short length and the powerful thrusters. In *Figure 14b*, the flow on one side of the skeg causes a lift force opposed to the lift that one expects from a skeg.

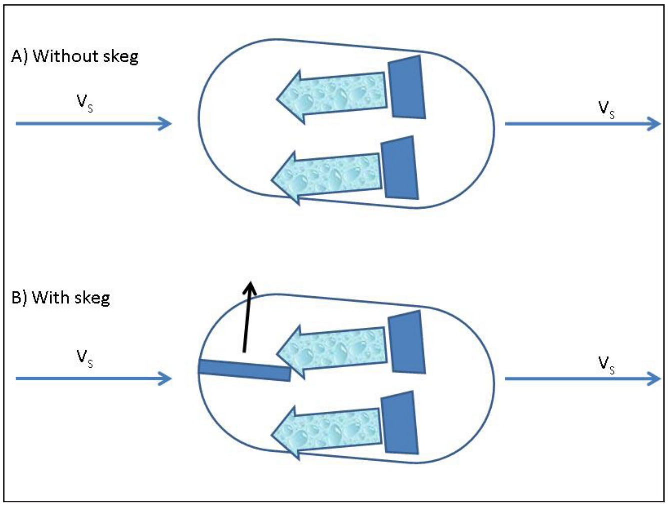


Figure 14: Illustration of effect of the skeg.

Figure 15: Twin Fin arrangement (high aspect ratio).

Figure 16: Single Fin arrangement (high aspect ratio).

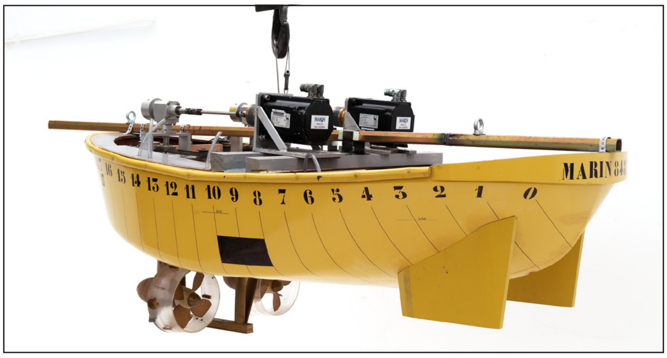


Figure 17: Twin Fin arrangement (low aspect ratio).

Figure 18: Twin Fin arrangement (medium aspect ratio).

The solution based on this hypothesis was to add high aspect ratio fins in the aftship, in line with the thrusters. Having said that, the size of the fins was not yet established. To quantify the recommended fin size, various alternative designs were tested and evaluated (*see Figures 15, 17* and *18*). A single fin arrangement (*see Figure 16*) was also one of the design alternatives, but this would obviously suffer the same interaction phenomenon as sketched in *Figure 14 (see page 4)*.
A number of these arrangements have been tested in MARIN's seakeeping and manoeuvring basin, which is one of its seven hydrodynamic testing facilities.
The unique size of this basin is perfect for performing Dieudonné tests. The facilities around the basin allowed for a quick modification of skegs in between tests (*see Figure 19*).

Figure 19: Skeg modifications between test series.

The results of a selected set of tests are given in *Figure 20*. These results demonstrate that the large centre line skeg yields a reverse stable behaviour, including the phenomenon of *Figure 14 (page 4)*. The Twin Fin arrangements (of which two of them are presented in the figure), showed a nearly conventional directional stability. In addition, the turning velocity at higher rudder angles increased as well, which demonstrated that the Twin Fin gives a somewhat higher turning ability.

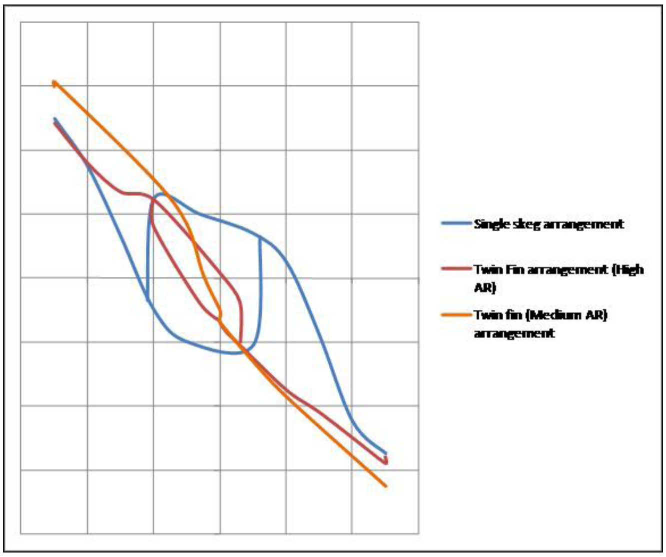


Figure 20: Results of Dieudonné tests for Twin Fin arrangements.

The observed complex hydrodynamic phenomenon was explained and the hypothesis was proved. In co-operation between engineers at both companies, a good solution was found. The Twin Fin configuration enables a directionally stable compact tractor tug with perfect steering behaviour both sailing ahead and astern. Based on the model tests, the best Twin Fin arrangement could be selected. Damen has an application for a patent to all countries in Europe as well as countries outside Europe for the Twin Fin design.

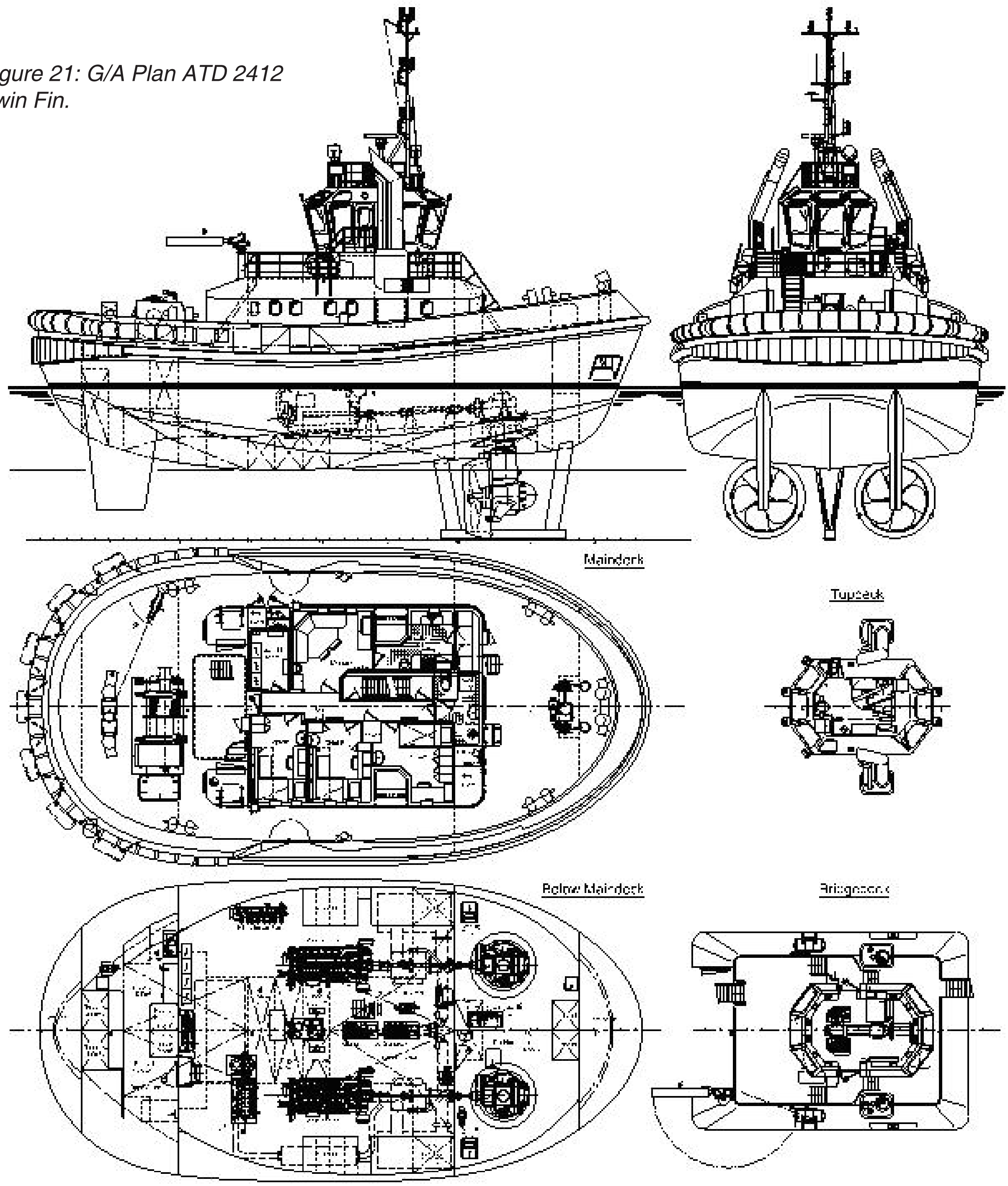
DESIGN ATD TUG 2412 TWIN FIN

The new design of the Twin Fin is the result of careful market research and product development work carried out to develop a compact tractor tug. The aim was to produce a very compact economical harbour tug with a good performance suitable for ship handling in small harbours, confined dock systems and locks.

Close co-operation between Damen Sales, Damen Tugs & Workboats project office, Central Engineering and Damen Research resulted in a completely new design with the promise of high bollard pull, excellent manoeuvrability and considerable stability. During the development stage, everything possible was done to ensure that the final result would be a low cost, effective standard design, suitable for series production.

Essential basic design criteria includes good visibility from the wheelhouse, good handling characteristics, safe working conditions and ease of maintenance. All

Figure 21: G/A Plan ATD 2412 Twin Fin.



of the basic requirements are achieved by adopting a shorter but wider hull design, with an overall length of 24.74m, a maximum beam of 12.63m and a draft of 5.80m. The choice of hull form is based on previous experience with tractor tugs such as the Tractor Tug 3010 and tank testing at MARIN. The vessel has a round bilge hull with twin azimuthing thruster propulsion in the fore ship. In combination with the new Twin Fin design these provide the tug with excellent manoeuvrability and directional stability.

For a small vessel, the Twin Fin has a remarkably spacious layout. Considerable attention has been paid to providing adequate deck space and a safe working environment for the crew. A similar approach has been applied in the wheelhouse and engine room. The attention to detail is self-evident. The entire bulwark and superstructure is fully enclosed; simplifying maintenance and adding considerably to the strength of the vessel. Mooring bitts are situated on the inside of the bulwarks forward, aft and amidships and an 'H' style towing bitt is installed fore and aft.

An enclosed central filling station is located on the fore deck, housing all the major filling pipes and ventilation pipes. In all other respects the decks have been kept free of any unnecessary projections likely to cause falls or accidents. Such details give the vessel a simple but modern appearance. The raised forward deck is reduced in size, only the anchor winch for two anchors and the forward towing bitt and mooring bitts are fitted. The aft deck has a low flat sheer creating a spacious, relatively flat and safe working area, the main towing winch with a split drum, towing bitts and the towing hook are fitted on the aft deck. For normal towing operations the Twin Fin works as a tractor tug and for push-pull operations the hull is more rounded in the aft ship and shaped as an ASD tug. For that reason navigation lights are installed for sailing in both directions. The profile of the vessel is as low as practically possible to facilitate assistance to highly flared ships in narrow locks and docks.

MAIN DESIGN CHARACTERISTICS

The following are the basic design criteria for the new ATD Tug 2412 Twin Fin design *(see Figure 21 opposite)*:

- Bollard pull maximum 70 tonnes;
- Tonnage < 300 GT;
- Length approx 24m;
- Two-man crew design;
- Stability criteria according BV, design IMO, US Coast Guard, RMRS;
- Design conditions; 35 degrees C sea water, maximum outside air 45 degrees C and minimum -5 degrees C;
- Tank capacity 100m³;
- Main engines two Caterpillar 3516C TA HD/D Tier 2 compliant, total power 4,200kW at 1,600 rev/min;
- Azimuth thrusters Roll-Royce US 255, propeller diameter 2,600mm.

During the design process all of the following matters were addressed:

- Hull design, including full scale testing and calculations for structural strengths, fatigue, hull frequencies and wave profile;
- Optimisation of propulsion system;
- Noise level, speed and bollard pull performance.

The result of all the work invested in the design has resulted in a compact and very powerful harbour tug, with clean lines and many of the distinctive features in common with its sister ships in the Series.

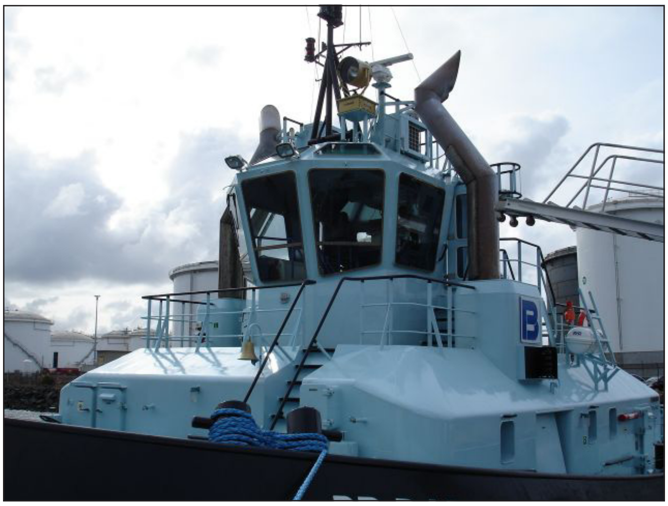


Figure 22: Superstructure with rounded corners.

These include an all-welded steel hull of robust round bilge construction, using 12mm thick plate in the sides and bottom, a 15mm sheer strake, a heavy build construction for the pushing fender area in the aft ship and the rubber fender in the sides. A complete, very detailed production engineering package for the construction of the tugboats has been made using the *3D Nupas Cadmatic* software package.

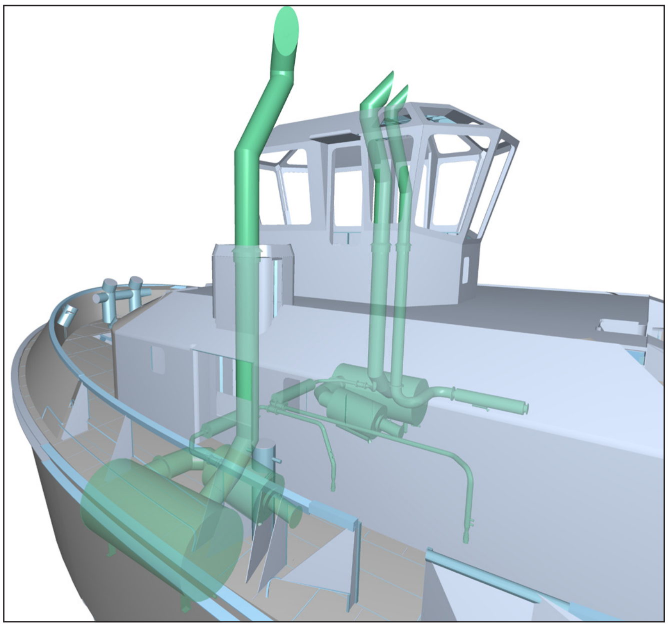


Figure 23: 3D drawing exhaust systems of main and auxiliary engines.

PROPULSION AND STEERING SYSTEM

At the heart of the Twin Fin is its remarkably spacious engine room. As standard the tug is powered by two Caterpillar 3516C HD TA/D main engines, each generating 2,100kW at 1,600rpm, a total power of 5,600bhp. The engines have electronically-controlled fuel injection systems and meet the requirements of EPA Tier 2 and IMO recommendations. Resilient engine mountings and flexible couplings reduce the transmission of vibration and noise throughout the vessel. A closed cooling system with box coolers designed for 35 degrees C sea water eliminate the need to treat sea water in the engine room. Two twin speed engine room ventilators supply 60,000m³/h of fresh air into the engine room. Large main engine exhaust silencers, designed for 45dBA reduction are mounted in the engine room and are heavily insulated to regulate noise and temperature.

Each main engine drives a Rolls-Royce US 255 fixed pitch fully steerable propulsion unit incorporating a built-in slipping clutch for slow speed manoeuvring and propeller speed control. The five-blade, fixed pitch propeller has a diameter of 2,600mm and the steering speed of the unit is approximately 2.5 rev/min. The propeller runs in a TK nozzle with stainless steel lining. The shaft line is designed as straight as possible, with a bow tooth coupling, a straight shaft bulkhead seal, shaft bearings and flexible coupling. The number of bearings has been kept to a minimum.

Electric power is generated by two Caterpillar C4.4 TA diesel powered alternators, each supplying 85kVA, 230/400v, 50Hz. Space is available in the engine room for a third diesel auxiliary engine or optional 600, 1,200 or 2,400m³/hr fire-fighting system. The monitoring and alarm system is designed for a two-man crew with full monitoring and alarm system in the wheelhouse and in the main deck switchboard room.

FENDERING SYSTEM

The comprehensive fendering arrangement is designed to protect the tug and its tow during a wide range of ship handling and other harbour operations. The push fender comprises a large cylindrical rubber hollow fender at the aft ship on main deck level, secured by high performance webbing. The cylindrical fender has a diameter of 800mm. The lower fender on the aft ship is formed by vertical W type block fenders, 480 x 300 mm, secured by galvanised steel pins. Block fenders in combination with cylindrical fenders offer excellent protection during push-pull operations. Hollow D-section rubber mouldings are fitted around the sides and the bow, size 300 x 300mm.

Figure 24: Heavy sausage, W and D fenders on bow, shoulders and sides.

TOWING GEAR

An ‘H’ style towing bitt of heavy construction designed for a safe working load of 150 tonnes with stainless steel integrated fairleads and a hydraulically-powered tow winch are installed on the aft deck for ship handling operations. The winch has a split drum with the ability to accommodate two towlines, one for daily operation and one as spare. The towline from the drum runs from the top of the winch, the maximum line pull is 36 tonnes and maximum line speed is 40m/min. The winch has a brake holding load of 150 tonnes. Each section on the drum can accommodate 150m of 80mm diameter high performance fibre towline. Hydraulic power for the towing winch is supplied by dual pumps, one mounted on each main engine. The winch has full remote control from the wheelhouse and local control from the aft deck.

Figure 25: The winch is remote-controlled from the wheelhouse as well as local control on the main deck.

Load indication and towline length indication are included on the control panel, with control levers and a foot control on the winch panel. There is a disc-type, quick-release towing hook on the aft deck, safe working load 100 tonnes and hydraulically-operated towing pins fitted in the aft bulwark. Both towing hook and towing pins are remotely-controlled from the wheelhouse.

WHEELHOUSE LAYOUT

The wheelhouse is air-conditioned and heated and use of modern noise and vibration control measures has reduced the noise levels to 65dBA. The wheelhouse layout and arrangement of the exhaust piping ensures an excellent view all around from the captain’s chair. The wheelhouse has been designed and equipped to make two-man operation possible.

Figure 26: Large windows and shaped superstructure for optimal view.

The compact wheelhouse has many standard features including a functional and ergonomically-designed console layout. The standard vessel control consoles ensure all the essential propulsion system controls, winch controls, alarm panels and remote control Fi-Fi monitors are within easy reach. Foot controls are provided for some of the winch and VHF radio functions. A chart table with drawers is neatly incorporated in the layout. The wheelhouse is designed for navigation and communication equipment that meets GMDSS area A3.

Figure 27: All round view from the wheehouse.

ACCOMODATION

Accommodation on board the vessel is suitable for up to six persons. Two single cabins, both with an optional extra berth, and one double cabin are situated on the main deck along with the spacious galley and mess room, toilet and shower room.

The comfortable mess room is equipped with a TV and DVD player. Air-conditioning ensures that the temperature in the entire accommodation remains pleasant even under tropical conditions. The cabins are fitted out to a good but simple standard, using plywood and finishing with formica and anodised aluminium. Floating floors, thermal insulation, partitions and bulkheads of sandwich construction, and Dampa ceilings are used in the accommodation. That level of insulation, in combination with resiliently-mounted exhaust systems, main and auxiliary engines, and other equipment such as cooling water pumps, guarantee a low noise level in the wheelhouse and living areas.

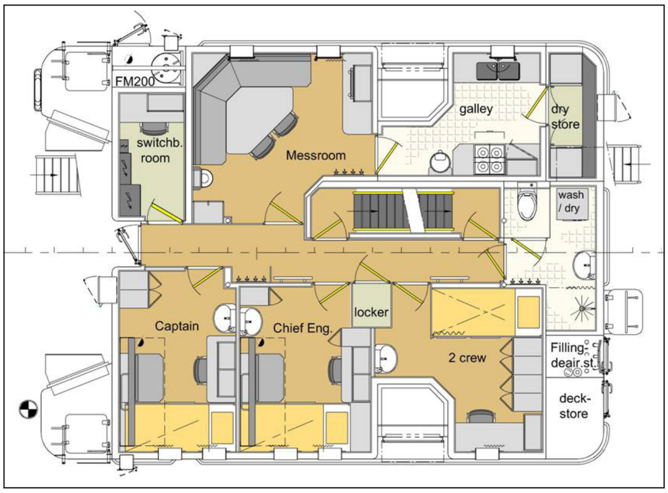


Figure 28: Layout ILO 2006 compliant accommodation.

The accommodation meets the requirements of International Labour Organisation 2006. Sufficient storage space is provided in accommodation areas such as rope, workshop, food, linen and deck stores.

Figures 29: General stores, deck stores, rope stores and workshop.

CONCLUSIONS

The first vessels in this new ATD tug class were subjected to extensive trials. At an early stage it became clear that the tug represented a major step forward.

During bollard pull trials the first vessel exceeded expectations, pulling 67 tonnes ahead. Maximum speeds of 12 knots ahead with an impressive 12 knots astern were recorded. The trials' captain reported that he considered the tug to be more than satisfactory. Stability was very good and sailing astern proved to be very easy – thanks to the hull design. When sailing ahead there was still room to improve directional stability and here the Twin Fin design provides an answer.

During the trial full-power turning circle tests the vessel remained very dry and was found to be extremely manoeuvrable. This has been proven in the daily ship handling operations of the ***PB Murray*** and ***PB Darling*** in the confined spaces of Sydney harbour. Under sailing conditions those on board reported that 'the tug is quiet and virtually free from vibration'. ***PB Murray*** and ***PB Darling*** have undoubtedly proven their worth in Sydney harbour, and the designers believe that this new design will be the ideal tug for small harbours and will open up a new market in large number of ports around the world.

Figure 30: Two ATD 2412 tugs at PB Towage mooring facility in Sydney Australia.

The authors wish to express their sincere thanks and appreciation to Jack Gaston for assisting us in writing a paper in English.