Photo: KOTUG / Fotostudio Rijnmond Robert Nagelkerke

Figure 1.7 Azimuth tractor tugs (53 tonnes bollard pull) of the KOTUG towing company towing an oil rig. Depending on the port, harbour tugs should also be able to handle offshore equipment, barges, floating cranes and so on.

These activities also demand a specific type and size of tug, as well as specific manoeuvrability, equipment and towing methods, as is the case with tugs that have to operate, for example, at SPMs, F(P)SOs or at oil rigs.

1.2.5 Assisting method in use

The method of assistance used by tugs will depend on:

- Port, jetty, terminal layout and/or offshore installation.
- Types of ship.
- Environmental conditions.
- Navigational complexity of river, channels and port approach.
- Whether bridges and locks have to be passed.
- Often on tradition.

The type of tug used is largely dependent on the assisting method. Tugs have to meet, as far as possible, the requirements related to the assisting method. The assisting method may also depend on the availability of mooring boats. When no mooring boats are available a ship has to be brought up very close to the berth or even alongside to be able to pass the mooring lines. In these circumstances tugs should be able to push at the ship's side.

1.2.6 Available experience

Pilots and tug captains are accustomed to the assisting methods used in the port and to the types of tugs in the port. They have built up their experience with these tugs and with the tug's crews. They know the advantages and the shortcomings of their tugs and are thus able to anticipate. Changing over to a new system or to a new type of tug may be associated with difficulties, will take time and should be weighed carefully. Training and instruction will be needed, especially when the type of tug and the way it operates is totally different from the existing system. A well planned changeover to the new system will be necessary. All this should be taken into account when considering the introduction of a new tug type or assisting method.

1.2.7 Safety requirements

Tug assistance always includes risks for the tug and her crew. These risks can be minimised by good training and by a well designed and equipped tug. The type of tug also influences the level of safety. Depending on the type of port, the environmental conditions, the ships assisted, the assisting methods and the port regulations, the safety requirements may differ by port. On the other hand tug owners should require, regardless of the port situation, the highest level of safety, which could dictate a certain type of tug and tug equipment.

1.2.8 Summary

No port is the same. Many factors influence the choice of type of tug, such as local customs, environmental

conditions, water depth, type of ships using the port and escort requirements. These factors can differ enormously by port and so will affect the type of harbour tugs. Requirements for harbour tugs that have to operate at offshore installations may be an additional factor to be taken into account. It should be noted that the factors mentioned not only influence the type of tug needed, but also the assisting method used and that method has, in turn, a strong relation with the type of tug.

An overview of the factors influencing the operational requirements for tugs is given in the table at the end of this chapter.

1.3 Types of tug

The factors mentioned above have resulted in the use of different types of tug all over the world. At present mainly the following types are used:

- Single screw tugs.
- Twin screw tugs.
- Tractor type tugs.
- Tugs with azimuth propellers aft.

Single and twin screw tug types are generally well known. To increase towing power, many of them are fitted with nozzles. They may be equipped with fixed or variable pitch propellers. In some cases, to improve their manoeuvrability a bow thruster or, in particular on single screw tugs, a 360° steerable and often retractable bow thruster is installed, which also increases the towing force.

Tractor types of tug have propellers under the forebody of the tug. These propellers may be Voith-propellers or 360° steerable azimuth propellers.

Tugs with azimuth propellers aft resemble twin screw tugs. However, because of the 360° steerable thrusters they are much more manoeuvrable.

The different tug types are discussed in more detail in Chapter 2.

1.4 Assisting methods

Depending on local experience and circumstances the following assisting methods or combinations of these methods are mainly used:

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

When towing on a line, the towline is made fast at the bow or stern of the assisted ship. The tugs operate at a distance from the ship's bow and stern on a towline length normally at least one and half times the tug's length.

Depending on the assistance required, local situation and type of tugs used, tugs operating at the ship's side can be made fast with one, two or three lines. Different methods are used, such as the push-pull method, whereby the tug usually is made fast with one line. Alongside towing is another method. Tugs are then securely lashed alongside the ship with a minimum of three lines.

The different assisting methods are discussed in Chapter 3.

Photo: Smit International

Figure 1.8 Conventional twin screw tugs of 27 tons bollard pull towing on a line

1.5 Conclusion

It is clear that no port is the same with respect to tug requirements. Port layouts differ, as do the types of ship frequenting the port, the environmental conditions, local traditions and consequently the types of tug and the assisting methods.

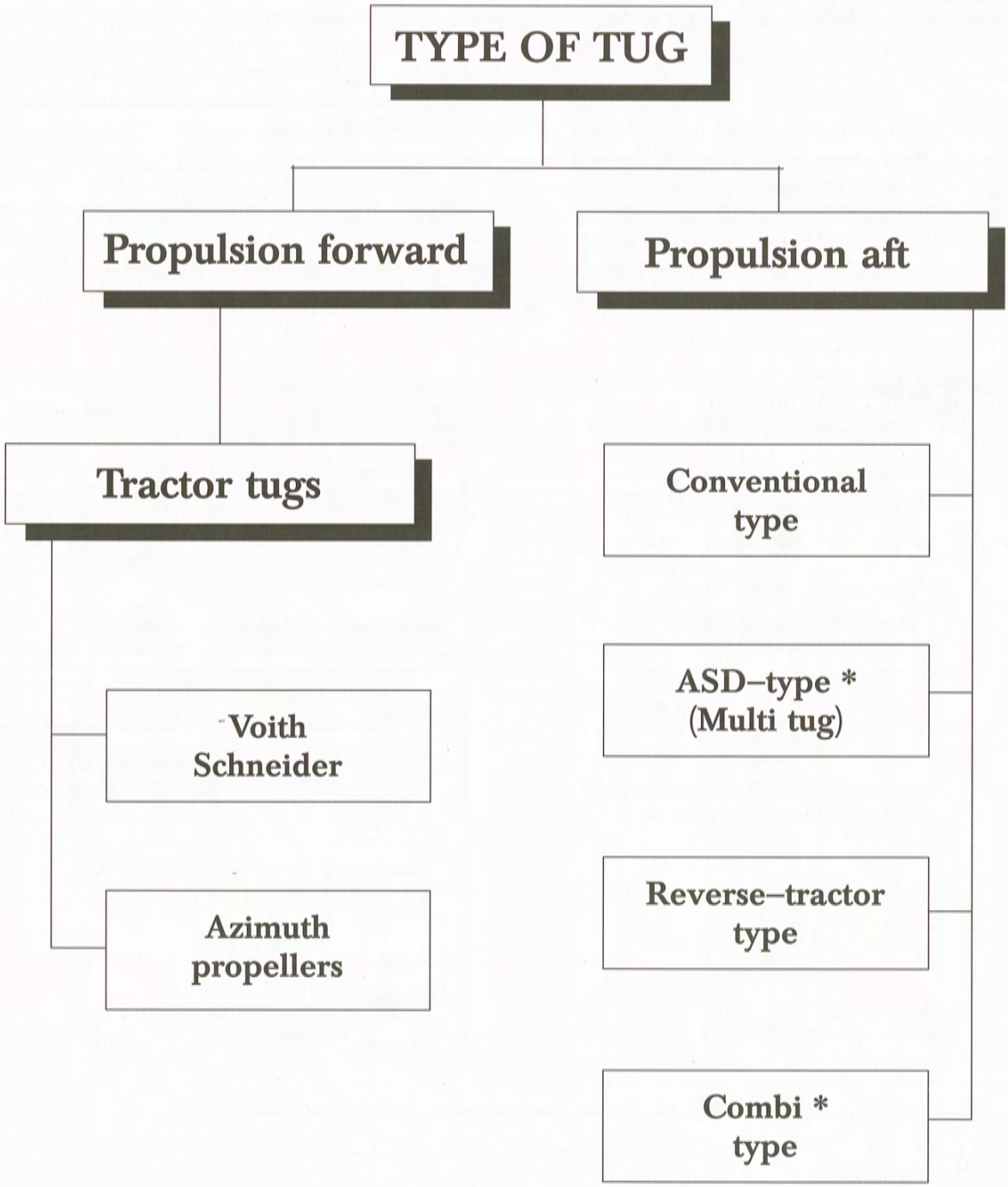
When a new tug is needed a simple answer to the question "which type of tug and/or which towing method is most suitable for the port" cannot easily be given. Too many factors play a role. It takes reliable research, weighing all the advantages and disadvantages against each other, in order to establish the requirements for the most suitable tug for the port. Most important is not only what forces have to be considered but how, when and under what conditions and circumstances, such as ship's speed, confinement, environmental conditions and underkeel clearance. This is the way more and more modern ports and/or tug companies work nowadays. The outcome may be a tractor type with azimuth propellers or Voith-propulsion or even a conventional type of tug. Escorting of tankers will set additional requirements.

On the other hand tug owners want to operate as few different types of tug as possible and prefer that the available types are put into action as frequently as possible. Harbour tugs should, therefore, be as versatile as possible.

Factors influencing harbour tug choice

Passage/ Berth	Environmental Conditions	Types of Ship	Other Services required	Assisting Methods	Existing Tugs	Available Experience	Safety of Tugs	Financial Aspects
Sea/Approach	Swell	General cargo ships	Offshore installations	Towing on a line	Conventional single screw	Tug type experience	Tug type	Budget
River	Waves	Container vessels	Barges	Push-pull	Conventional twin screw	Assisting methods experience	Port/ State regulations	Tug price
Channel	Wind	Car carriers	Floating cranes	Alongside towing	Tractor tugs VS		Classification regulations	Operating costs
Water depth	Current	Ro-ro ships	Dockyards	Escorting	Tractor tugs Azimuth		Environmental conditions	
Locks/Bridges	Ice	Tankers/ VLCCs	Escorting		ASD tugs			
Jetties in open sea	Fog	Gas tankers			Reverse tractor tugs			
Jetties in protected water		Bulk carriers			SDMs (Ship Docking Modules)			
Harbour basins		Ferries						
Terminals		Passenger ships						
River berths								
Mooring buoys								
Mooring boats								

Figure 1.9 Harbour tugs – factors influencing choice



* Tugs that can operate as a conventional tug and as a reverse (tractor-) tug

Note:

- The ROTOR tug discussed in par. 10.1.1 is in fact a tractor tug with a dynamic skeg, being a third thruster.
- The SDM (Ship Docking Module) discussed in the same paragraph does not belong to any of the categories mentioned above.

Figure 2.1 Main types of harbour tug

Chapter TWO

TYPES OF HARBOUR TUG

2.1 Classification of harbour tug types

TUG TYPES ARE NAMED AFTER THEIR MAIN CHARACTERISTICS, i.e. the type of propulsion, propulsion manufacturer, location of propulsion or steering system. Names include conventional tugs, Voith-Schneider tugs, Z-peller tugs, Kort nozzle tugs and tractor tugs, amongst others. There is no uniform naming system in use and this can be confusing. For example, when talking about a Z-peller tug, what is meant? Is this a tug with azimuth propellers forward or with azimuth propellers aft? The difference does not seem so great, but considering tug performance while rendering assistance, it is. After all, that is what tugs are used for – to render assistance. As will be seen later, it is better to classify tugs according to their location of propulsion and towing point. It makes things easier to understand.

Naming tugs this way there are only two main classifications, which can be grouped as follows:

a) **Tugs with their propulsion aft and towing point near midships. These are basically conventional types of tug.**

This category includes all normal conventional types such as single screw and twin screw tugs.

b) **Tugs with their towing point aft and propulsion forward of midships. These are tractor tugs.**

In this category are:

- Tractor tugs with Voith propulsion.
- Tractor tugs with azimuth propellers.

There are intermediate types of tug that can be classified either as conventional or tractor tugs, depending on the way they operate. These are:

- Reverse-tractor or pusher tugs – tugs with azimuth propellers aft and towing point forward, built to operate mainly over the tug's bow, as can be seen for example in Japan, Hong Kong and Taiwan. Tractor tugs normally work with their towing point – the tug's stern – towards the ship and their propellers – near the tug's bow – away from the ship. Reverse-tractor tugs operate in the same way regarding the towing point and the propellers, consequently the tug itself lies in the reverse direction.
- Azimuth Stern Drive (ASD) tugs. These are multi-purpose tugs with azimuth propellers aft which are built to operate over the tug's bow as a reverse-tractor tug as well as over the tug's stern like a conventional tug. Most ASD-tugs have a towing winch forward and one on the after deck while some have simply a towing hook instead of a towing winch aft. Because an ASD-tug can operate as a reverse-tractor tug, it is often mentioned together with reverse-tractor tugs. Although the term ASD-tug is frequently used, it is not such a good name, because reverse-tractor tugs also have azimuth propulsion under the stern. Multi-tug is a better name.
- Modified older tugs with a 360° steerable bow thruster (combi-tugs) and equipped with an additional towing point at the after end of the tug. These tugs can operate as a normal conventional tug or like a tractor tug when using their aftermost towing point.

So the following types of tug can be seen, all belonging to one or both of the above groups:

- Conventional tugs.
- Tractor tugs with azimuth propellers or Voith propulsion.
- ASD-tugs.
- Reverse-tractor tugs.
- Combi-tugs.

The table in figure 2.1 gives an overview of the classification of harbour tugs.

There are, of course, many differences in construction, hull design, propulsion and rudder configuration and so on within each tug type. The different types of tug are therefore discussed in more detail starting with some general aspects regarding tug performance and safety of operations.

2.2 Important general requirements for good tug performance

For good harbour tug safety and performance, the following factors are important:

2.2.1 Tug performance and safety

Response time

Harbour tugs should have a short response time and their manoeuvrability should be such that the tug can react in a minimum of time. It is therefore important that measures are taken to increase the manoeuvrability of harbour tugs and shorten their response time.

Not only is a short response time required when assisting a vessel, but also for making fast. Due to ever decreasing numbers in a ship's crew, the time taken to make tugs fast is increasing. Thus the requirement for tugs regarding fast and easy handling of towing equipment becomes an element of increasing importance in order to improve their response time.

Effectiveness and safety of operations

It is not only manoeuvrability, but also bollard pull and underwater shape that make a tug effective and therefore suitable for the job. For example, large container vessels with containers stacked six high on deck need powerful tugs in case of strong winds. When a ship is underway at speed, loss of tug's effectiveness due to the ship's speed and/or towing direction should be as small as possible. The effectiveness and safety of a tug is also related to factors such as the tug's stability and suitability of towing equipment.

Required manoeuvring space

The manoeuvring space required by assisting tugs should, depending on the situation, be as small as possible. This can be achieved by good tug manoeuvrability, limited tug dimensions and proper towing equipment.

Other practical aspects of importance for good tug performance and safety of operations are as follows:

2.2.2 Wheelhouse construction and layout

Visibility

A tug's wheelhouse should be placed and constructed such that, at his manoeuvring station, the tug captain has a good view of the tug's fore and aft ends and tug sides. He must also have a good view of:

- The towline and towing equipment.
- The working deck.
- Contact areas between tug and ship.
- The assisted ship.
- Other assisting tug boats.
- The direction of operation.

This requires a field of view at the manoeuvring station(s) as unobstructed as possible, with an angle of view as close as possible to 360°.

The Hong Kong Salvage & Towage Co. Ltd.

Figure 2.2 Pusher tug 'Lam Tong' (l.o.a 26·1m, beam 8·5m, bp 43T) with a cockpit wheelhouse. She has vertical and horizontal heavy duty fendering with water lubrication at the bow plus vertical stern and horizontal side fender systems

In addition to the all round view, well designed wheelhouses also have small windows that face upwards, which is important when making fast to vessels with a high forecastle, stern or freeboard. On some modern tugs very small wheelhouses are constructed with large windows and a nearly 360° view.

Manoeuvring stations

When making fast to a vessel and while assisting, a tug captain should be able, in one glance from his manoeuvring station, to see the most essential information available from outside, without jumping from side to side in his wheelhouse and without getting painful legs, neck or back. The essential outside information comes from:

a) The towline(s) – their direction and tension.
b) The assisted ship: such as relative heading and speed, distance off and the way the assisted ship reacts to the applied tug forces. When pushing, essential information also comes from the contact area between tug and ship.
c) The combined ship/tug direction of movement with regard to channel or fairway boundaries, other traffic and nearby berths and banks.

Depending on the type of tug and the assisting method in use, this essential information may come from totally different or even opposite directions. The directions may change during one and the same trip and are dependent, in any case, on the assisting method. In a reverse-tractor tug, which is assisting from over the tug's bow, nearly all the essential outside information comes from forward and should be available in one outside look from the manoeuvring station. This can be achieved with one forward facing station. If the manoeuvring station is well planned, the tug captain may have an unobstructed view in the working direction, even from a seated position, of the winch, working deck, bow and side fenders and the assisted ship.

For all other types of tug and/or other assisting methods the visibility requirements may be totally different. For instance, a tractor tug used for push-pull operations works over the stern. Then an aft facing manoeuvring panel is needed. When the same tug is free sailing a forward facing manoeuvring panel is required. Depending on the wheelhouse construction, a central manoeuvring panel for this type of tug could be useful, capable of being operated in both directions, forward and aft. On other tugs more manoeuvring panels may be required, of course, depending on the wheelhouse size and construction. Some harbour tugs even have three manoeuvring panels facing forward and one facing aft. Care should be taken in order that reliable change-over between manoeuvring panels is possible without the risk of failures or mistakes.

Controls at the manoeuvring panels should be arranged such that they can be operated in a logical way in relation to the tug's direction of movement. Pushing a lever down and away in the direction the tug captain is facing should result in an increase of movement in that direction. Turning a wheel or moving a joystick to the left should turn the tug in that direction, regardless of whether the direction of movement is ahead or astern. Any illogical way of control or complexity in control easily leads to human control failures, particularly when under tension.

It is clear that the wheelhouse layout and the number, location and orientation of manoeuvring panels depend largely on the type of tug and the usual assisting method and should be carefully considered, also taking into account the optimum view needed from the manoeuvring station when coming alongside a ship or berth. Modern tugs sometimes have one central manoeuvring panel in an optimal designed small wheelhouse, like a kind of cockpit.

At the manoeuvring stations the captain should also have a good view of his instruments, including the radar. Communication and quick release systems, which will be discussed later on, should be within hand reach at all manoeuvring panels. Towing winch control from the wheelhouse is also recommended for harbour tugs. The towline length can then always be adjusted when required without calling a man to the towing winch. The number of crew members on modern harbour tugs is very limited nowadays.

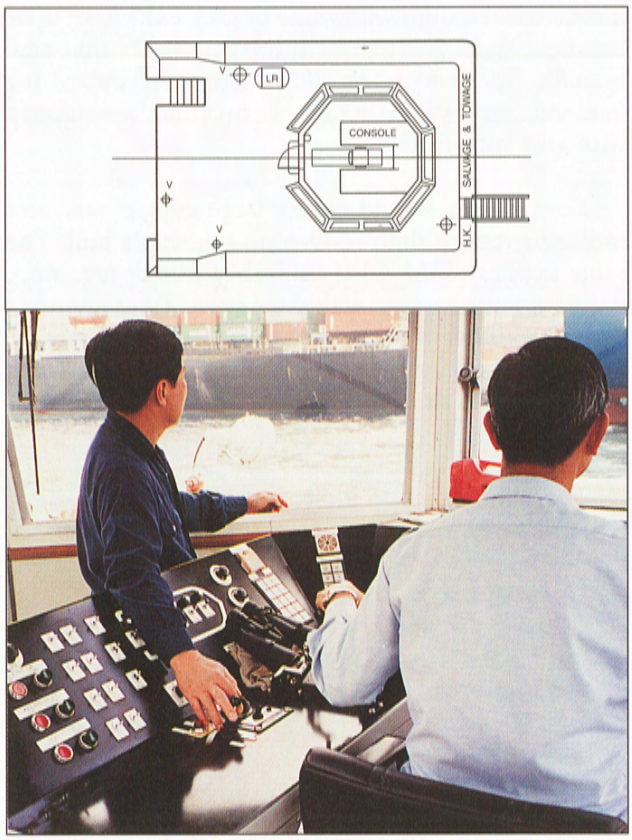


Photo: Author

Figure 2.3 Plan of the navigation bridge deck and view of the wheelhouse of a modern Hong Kong pusher tug. The captain is handling the propeller controls and the mate the towing winch

Communication

Good co-operation between the pilot and tug captain is a basic requirement for safe and efficient shiphandling with tugs. Such co-operation is only possible with good procedures and efficiently working communication systems. Radio communication systems on board tugs should therefore be reliable. A double VHF set is recommended.

2.2.3 Tug superstructure and underwater design

Tugs regularly have to work near a ship's bow or stern, where the flare and overhang are often fairly pronounced. It is necessary, therefore, that the tug's superstructure is located well inboard of the deck edge, so that risk of tug damage can be avoided as much as possible when working near the ship's bow or stern or when the vessel or tug is rolling when alongside a ship.

Underwater design of the tug should be such that the propulsion units will not hit the ship's hull when the tug is rolling alongside. In this regard harbour tugs have to assist all kind of vessels, including submarines in some ports. Tug propellers may hit the submarine hull when a tug is required to come alongside for assistance or for bringing the pilot on board. In that case single screw harbour tugs were usually best.

2.2.4 Fendering

Tugs should be equipped with good fendering. Appropriate fendering protects both the assisted ship and tug from damage and decreases the tendency to slide along the ship's hull when the tug is pushing at an angle to the ship's hull. Fenders are constructed of rubber or synthetic rubber products. Beyond the mechanical requirements of load versus deflection and energy absorption, which is given in curves, attachment methods and structural limits, consideration should also be given to the material used in the fender. The material used should have good resistance to polluted water, ozone, UV radiation and high and low temperatures.

The following factors are of importance in the choice of a tug's bow and/or stern fendering:

- The way the tug is assisting vessels, for instance towing on a line or push-pull, and whether the tug will push by the stern and/or by the bow.
- The size and engine power of the tug which are important factors for the horizontal load and kinetic energy transmitted during contact and pushing.
- Size of contact area.
- The type and size of vessels to be handled e.g. ships with large bow flare and/or overhanging stern. Tugs

pushing near the bow or stern of these ships may need extra fendering on top of the bow to prevent damage to tug or ship.
- The environmental conditions such as waves and swell. These conditions will give rise to additional forces in the fendering, for which it must be able to compensate.
- The tug's bow and stern construction.

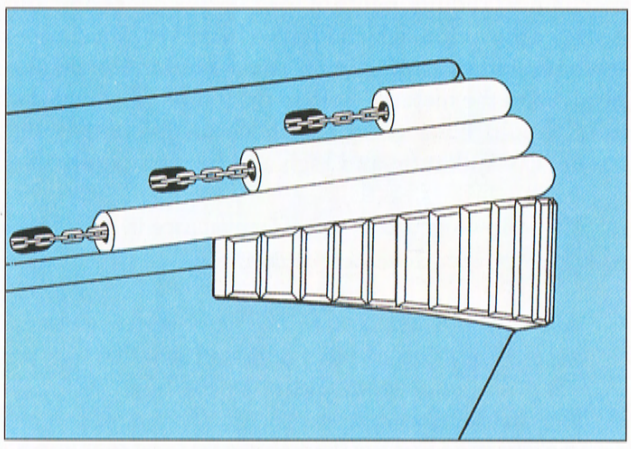
Tug fendering varies enormously. One frequently used fender system is the extruded profile type. Extruded fenders are produced in different lengths and in a wide variety of profiles and sizes. They can have a hollow D-shape profile, can be rectangular, cylindrical or solid, can be precurved to fit the tug bow or stern, be chamfered or drilled. Extruded fenders are very flexible from the point of view of design. Extrusion is a manufacturing method whereby uncured rubber is forced through a die to produce the required profile and then the lengths of formed rubber are vulcanised.

Moulded modular or block fender systems offer many of the advantages of extruded fenders and, in addition, allow for secure attachment and ease of repair since with this type individual blocks can be replaced.

Weldable fenders with steel backings are yet another fender type, used when very secure attachment is required.

A tug's bow and/or stern can be equipped with horizontal fendering, for instance extruded fenders of cylindrical profile, or with vertical block fendering. A combination of these types is often used. Block fenders can easily be replaced when damaged, and for fenders on bow and stern which are intensively used, basic vertical block fendering is very suitable.

Other types of fendering include those made of reinforced truck or aircraft tyres which are cut to a specific size and compressed onto steel supporting rods. This fender type, made in the USA, is suitable for bow fenders, stern fenders and side fenders. There is one specific type which has a large absorption ability and is very soft, thus having a large contact area and 'sticking ability' when under load.



Royal Bakker Rubber, The Netherlands

Figure 2.4 Typical fender arrangement for a tug pushing under swell conditions and/or at flaring parts of a vessel, consisting of vertically installed moulded blocks and horizontal hollow cylinders of extruded rubber

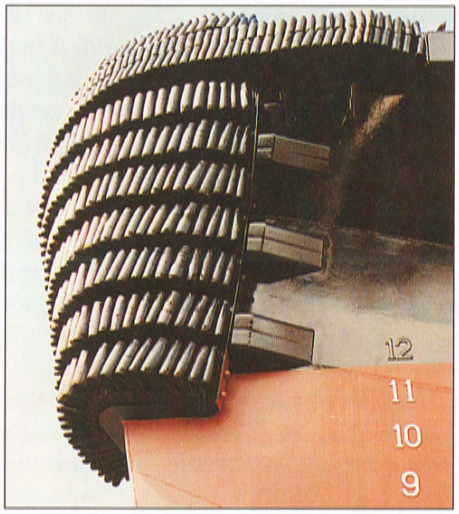


Photo: Schuyler Rubber Co. Inc., USA

Figure 2.5 Bow fender made of reinforced truck tyres

Tugs may also be fitted with foam-filled or pneumatic fenders, especially when working in exposed areas. Sometimes 'non-marking' fenders are required, for instance when ships with white or grey hulls have to be handled, such as cruise or navy vessels. In that case manilla rope fenders, in addition to the standard tug fendering, may still be used or the tugs may be equipped with grey rubber fendering.

Bow fenders should have a large contact area and radius to reduce the pressure on the ship's hull. The same applies to the stern fenders of tractor-tugs since these tugs are pushing with their stern. Tyres are often used in addition to bow and stern fenders to protect the fenders and enlarge the contact area and are often used along tug sides since they can easily be replaced when damaged.

The following is an indication of some permissible hull pressures, which vary by ship's type and size:

General cargo ships of 20,000 dwt and less	400–700 kN/m²
Oil tankers of more than 60,000 dwt	< 350 kN/m²
VLCCs	150–200 kN/m²
Container ships:	
3rd generation	< 300 kN/m²
4th generation	< 250 kN/m²
5th and 6th generation (Superpost Panamax)	< 200 kN/m²

Gas carriers (LNG/LPG)
and **Bulk carriers** < 200 kN/m^2

Fender material should have a large coefficient of friction in order to keep the bow or stern in position when the tug is pushing under an angle to the ship's hull. Sliding along the ship's hull, tug berth or alongside other tugs, and rolling and pitching along the ship's side due to waves will easily damage tug fenders. To avoid early damage of the fendering, as for instance the side fendering, or where no grip is required, fenders can be used with a low friction coefficient or can have a top layer of UHMW polyethylene, which has an extremely

Photo: Author

Figure 2.6 Tyres used in addition to vertical bow fendering

low friction coefficient. The coefficient of friction of rubber to steel is approximately 0·8. The friction force $F = c \times P$, where P is the impact force of the tug and c the friction coefficient. UHMW polyethylene has a friction coefficient of 0·15.

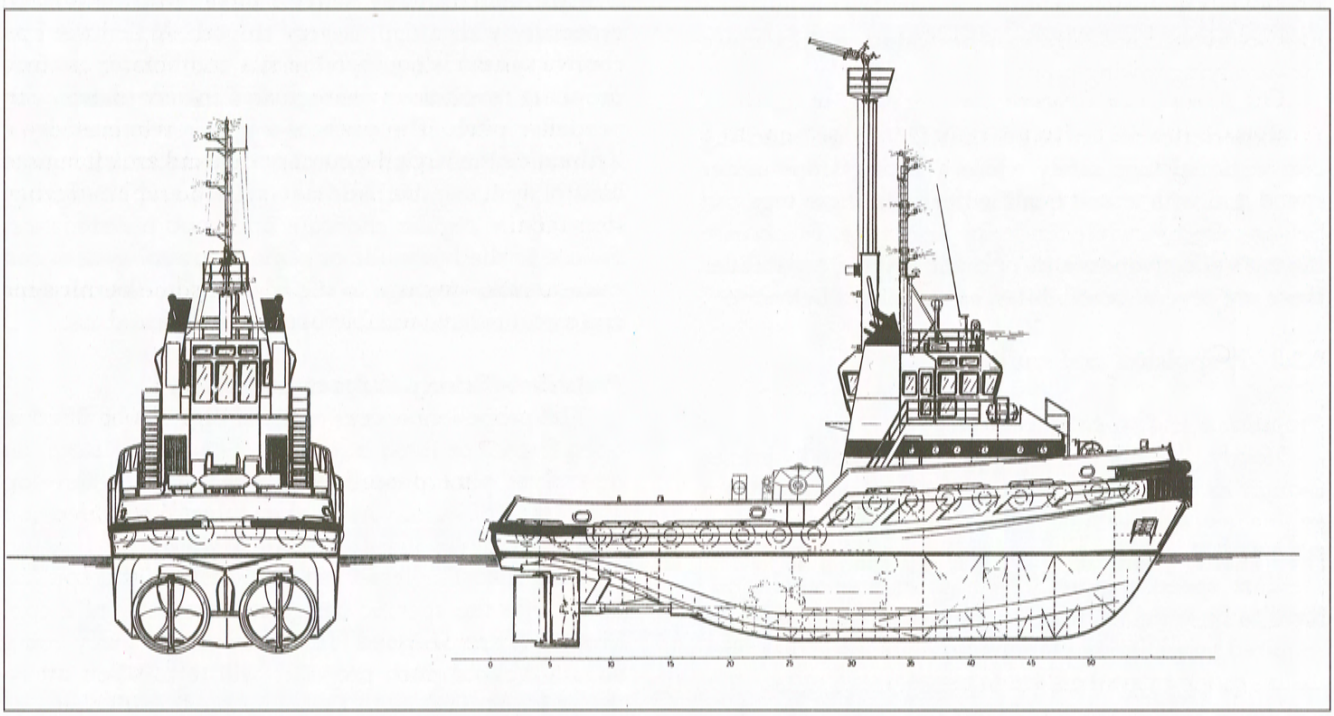
Specific types of fenders can be provided with water lubrication to reduce the friction between tug and ship and so prevent damage and wear, especially when pushing against a slab-sided ship in swell conditions. This type of fendering can, for instance, be found on tugs in the port of Hong Kong (see photo of the reverse-tractor tug *Lam Tong* – figure 2.2).

The height of a tug's fendering above water level is a factor to be considered. When pushing under an angle at a ship's side while the ship has headway or sternway, the hydrodynamic forces on the tug create a list. It is evident that the higher the bow fender above the water the larger the resulting heeling moment will be.

Harbour tugs assisting submarines may also have underwater fendering to avoid contact damage to the submarine's hull. In addition, an ASD or reverse-tractor tug's hull may be expanded with fendered steel sponsons on the quarters to ensure that the nozzles of the tug's azimuth propellers never come in contact with the submarine being assisted, the so-called 'propulsion unit protective sponsons'.

Further relevant information for harbour tug design in general and for ASD-tug design in particular can be found in 'Designers' Checklist No 1. Azimuth Stern Drive Tugs (ASD)' (see References).

Suitable and reliable towing equipment is also important for good harbour tug performance and safe working. This is dealt with in Chapter 7.



Damen Shipyards, The Netherlands

Figure 2.7 Conventional twin screw tug – type Stan Tug 2909. L.o.a. 29·6m, beam 9·3m, bp depending on installed engine power: 30-60 tons

2.3 Conventional types of tug

2.3.1 General

The largest number of tugs still belong to this type. They can be seen all over the world and are still built in large numbers. Conventional tugs are used for push-pull assistance, alongside towing and in particular, in European ports, for towing on a line.

There is a large variety of conventional tugs. The most simple one is a single screw tug with a single plate rudder. Mainly due to the location of the towing point, the tugs have limitations regarding performance and safety. When towing on a line the main risk is of girting. A towing winch with a quick release mechanism lowers this risk. The same applies to a quick release towing hook, if it works under the extreme condition of girting, which is not always the case. The astern power of conventional tugs is generally low. When making fast near the bow of a ship, interaction forces between the ship and the tug should be allowed for, which can better be done with tugs that can produce good side thrust, such as tractor-tugs. Girting and interaction are dealt with in Chapters 4 and 6.

The towing point of these tugs generally lies about 0·45 x LWL from aft, although shorter distances may be found. The aft towing point on American conventional tugs lies further aft, which allows the opportunity to extend the deckhouse further aft. A more aft placed towing point limits the tug's effectiveness when towing on a line at speed but this way of towing is not normal practice in the USA.

In USA ports where tugs are used for towing on a line, conventional tugs can be found with a more forward lying towing point.

Experience is an important factor in handling conventional tugs safely while assisting ships under speed and with a well qualified captain these tugs can be very effective while rendering assistance. To increase the tug's effectiveness and/or manoeuvring capabilities there are several possibilities, as explained below.

2.3.2 Propulsion and rudders

Propulsion and propeller control

Nearly all tugs are equipped with diesel engines though an occasional old harbour tug with a steam engine may still be found somewhere outside a maritime museum. Diesel engines on harbour tugs are high or medium speed engines. The high engine revolutions have to be brought down by reduction gearing to the required propeller revolutions. To reverse the propeller thrust, different systems are in use.

The direct-reversing system is the oldest and can still be found on some conventional tugs. The engine has to be started on ahead and on astern. On some tugs engines can be controlled from the wheelhouse, while on others it still has to be done by an engineer. The number of manoeuvres is limited by the volume of starting air available. The response time from ahead to astern and back differs by tug and by the direct-reversing handling system fitted.

Diesel-electric propulsion systems can still be found in some harbour tugs. The diesel engine(s) drives electric generators which in turn drive electric motors. These electric motors drive the propeller. This system is easily controllable from the wheelhouse. It has the large advantage that it can deliver any propeller shaft speed ahead and astern without delay. The system is expensive, though. It has high initial costs and higher maintenance expenses compared to other systems.

Most common nowadays on harbour tugs are high and medium speed diesel engines with reduction gears and pneumatic-hydraulic couplings. (See References for 'Operational benefits of high-speed electronic diesel engines'). Other types of couplings can be used. On tugs with fixed propellers the propeller thrust is reversed by means of a reverse-reduction gear, while on tugs with controllable pitch propellers (cpp) thrust is reversed by changing the propeller pitch. Torque problems may arise when a fixed pitch propeller is reversed at high tug speeds. These problems can be reduced or overcome by proper design (= the correct combination of engine, propeller and gear) and tuning of the whole propulsion system. Shaft brakes are used, depending on engine and propeller type.

Engine revolutions and propeller pitch are remotely controlled from the wheelhouse. Manoeuvring, especially with a cpp, is very smooth. When the cpp control system is equipped with a combinator control, propeller revolutions are regulated in accordance with propeller pitch. The pitch of a cpp is regulated by a hydraulic system. Cpp control systems, including remote control systems, the hydraulic system and emergency stop require regular checkups and good maintenance. Failure in the hydraulic or remote control system can cause serious damage to tug, ships or berths. Modern cpp systems have reliable backup systems.

Propeller efficiency and manoeuvrability

The propellers of conventional tugs can be fitted in open frames or fitted in nozzles. Going full astern, an open fixed pitch propeller will – in general – develop about 60% of its maximum ahead thrust. An open cpp going astern develops some 40 to 45% of maximum ahead thrust. The lesser efficiency astern of a cpp has to do with the specific design and working of a cpp. Propellers are designed for maximum efficiency going ahead. A fixed pitch propeller will turn, when astern thrust is required, with the same pitch in the reverse direction as on ahead. The propeller blades of a standard cpp have a smaller width near the hub and therefore,

when the blades are set for ahead, a larger forward pitch angle than near the tip of the propeller. When the blades are turned for astern thrust, the lower part of the blades will consequently have a smaller pitch than the top of the blades, which results in less efficiency going astern compared to a fixed pitch propeller.

Nozzles increase thrust and consequently bollard pull significantly. Mr. Ludwig Kort, an aerodynamicist, designed the first nozzles as far back as 1927. The first one was introduced into service in 1932 and was originally designed to protect canal banks from propeller wash. The effect of a nozzle is most pronounced with high propeller loads at low speeds. Harbour tugs have to perform in that way. Nozzles increase thrust by 15-25% in towing and pushing conditions.

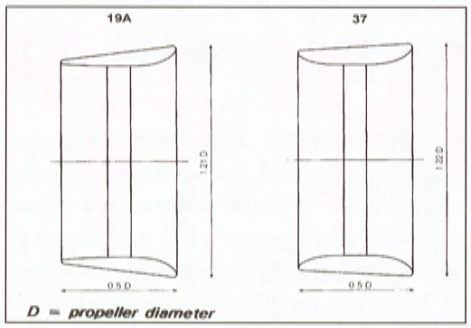


Figure 2.8 Two generally used nozzle types 19A and 37

Lips, The Netherlands

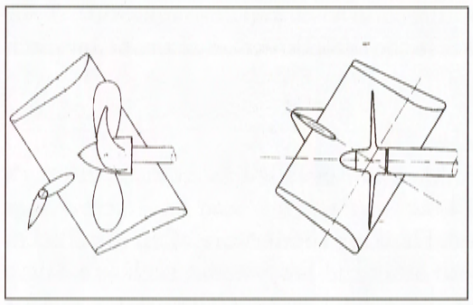


Figure 2.9 Steering nozzles, one with a moveable flap the other with a fixed fin

Willi Becker, Ingenieurbüro, Germany

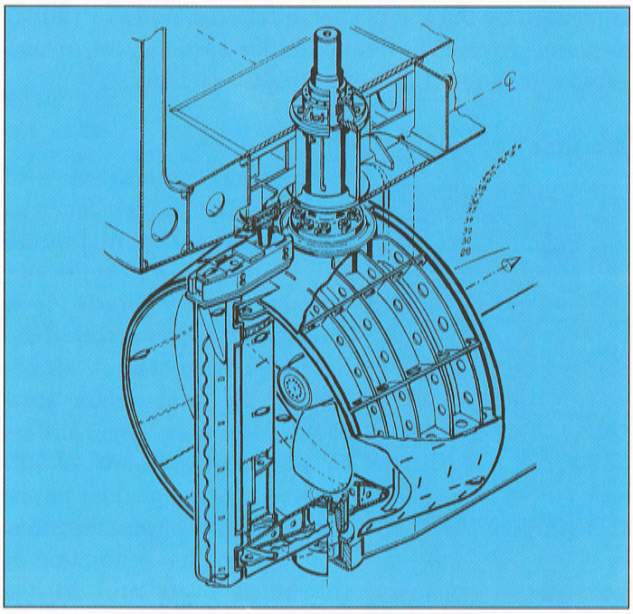
Various types of nozzles (figure 2.8) have been developed while research is still going on. Nozzle type 19A is very common because of its cost-effective design and is typical for ahead thrust requirements. Nozzle type 37, a 'backing nozzle', has been developed to give better efficiency going astern, which results in only a little less efficiency going ahead. The same applies to the Hannan Ring Nozzle, which is a normal type 19A nozzle with slots cut in at the after end giving good astern thrust – about 70% of the ahead value with fixed pitch propellers and special blades and 60-65% with ordinary blades. Nozzle type 37 is a type of nozzle often used for conventional harbour tugs.

Conventional tugs with controllable pitch propellers in nozzles (nozzle type 37) achieve, when pulling astern, about 45% of maximum ahead bollard pull, while this figure is about 65% for tugs equipped with fixed pitch propellers and the same type of nozzles. With a specific propeller design a much higher value can be reached for astern performance of controllable pitch propellers, but then ahead efficiency will be lower.

Note:

The 19A nozzle, and several variations more or less on this design, are used for azimuth thrusters, either with fixed or with controllable pitch propellers, because astern thrust is achieved by turning the nozzle.

A nozzle seen on several tugs with azimuth propulsion is the Nautican nozzle, which is the same as the Lips HR (=high efficiency) nozzle. Ahead efficiency of this nozzle is higher than of nozzle type 19A and 37, approximately 8% in bollard pull conditions, while astern performance of the Nautican nozzle is better than of nozzle type 19A, but not better than of nozzle type 37. As said, astern performance is not relevant for tugs with azimuth thrusters.



Willi Becker, Ingenieurbüro, Germany

Figure 2.10 Construction of a steerable nozzle with moveable flap

Nozzles increase the efficiency of the propeller but decrease steering capabilities. The fitting of a nozzle is equivalent to increasing the lateral area of skegs. Special rudder systems are therefore often used.

Nozzles can be also be steerable. Their manoeuvring performance is superior to normal rudder arrangements. Rudder angles of no more than 25° - 30° are used due to the greater side thrust. A tug's manoeuvrability when going astern with a nozzle rudder system is very good. When going astern the tug will swing to port or starboard depending on the direction of the steering nozzle. A vertical fin or a movable flap may be fitted at the end of the steering nozzle. (see figures 2.g and 2.10).

Some twin screw tugs have two independently controlled steerable nozzles, so increasing the tug's manoeuvrability further.

Conventional tugs can be single screw, twin screw and even triple screw, e.g. the USA harbour tug *Scott T. Slatten.* Manoeuvrability of twin and triple screw tugs will, in general, be better than of single screw tugs.

In general tugs are equipped with balanced, semi-balanced or spade rudders. By far most tugs have balanced rudders. Single plate rudders are also still used. With the spade, balanced or semi-balanced rudder the leading edge of the rudder extends forward of the rudder shaft. This, together with the shape of the rudder, results in higher propeller efficiency and a lower steering couple, so a smaller steering gear can be used. Spade rudders are hanging free, are not attached to a heel, and are consequently more stoutly constructed than a balanced rudder. Single plate rudders decrease propeller efficiency, need a higher steering couple and consequently a larger steering gear.

The manoeuvrability of conventional tugs can be increased by the use of specific rudder types or rudder systems. Several different rudder systems are in use, often in combination with nozzles, such as:

Movable flap-rudders

Photo: Heinz Hinze, Germany

Figure 2.11
Fixed nozzle with a moveable flap rudder

There are several types of movable flap rudders, such as Becker, Barke, Ulstein, Jastram and Promac Stuwa. At the end of the rudder blade is a movable flap, controlled by linkage, comprising about 20-30% of the total rudder area. Maximum helm angle differs by type and is about 40-50°. Each type of flap rudder has its own specific characteristics. The flap angle is a function of the helm angle and with a Becker rudder, for instance, it will be about three times the main rudder angle for the lower range and decreasing to a factor of two for the upper range rudder angles. Maximum lift, which is achieved at a rudder angle of approximately 30°, is increased by 60-70% compared with a conventional rudder of the same shape, size and area. Sideways thrust ranges up to 50% of ahead thrust. At maximum rudder angle the propeller stream will, depending on rudder size and balance, be diverted approximately 90°. At speed the vessel can turn very quickly and speed will drop fast. When dead in the water the vessel can nearly turn on the spot. Performance of the rudder when the tug has speed astern is about the same as that of an unflapped rudder. Tugs may have more than one movable flap rudder behind a nozzle.

Schilling rudders

Schilling rudders can also be found on tugs e.g. the new tug *Sayyaf* at Abu Dhabi. Schilling Monovec rudders have no movable parts. Horizontal slip stream guide plates are fitted at the top and bottom of the rudder. The rudder itself has a high lift blade profile with a wedge profile, so-called 'fishtail', at the end of the rudder blade. The rudder develops 30-40% more lift compared to a conventional rudder and maximum lift is obtained at a rudder angle of approximately 40°. The rudder can be used up to 70° angle and at this angle the propeller slipstream is thus deflected 90° and works more like a side thruster. When moving astern the rudder is more effective than normal rudders. With a Schilling Monovec rudder, turning on the spot is almost possible while speed is dropping very fast.

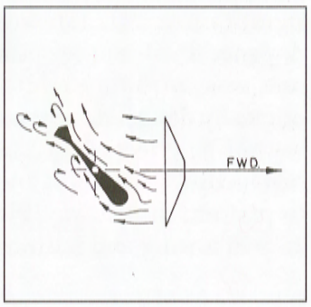


Figure 2.12
Schilling rudder

Two Schilling rudders, called Schilling VecTwin, can be used behind a propeller and make the vessel very manoeuvrable. Each rudder has a separate steering gear. The rudders can be turned by joystick a maximum of 105° outboard and 40° inboard. A maximum side thrust of 70% of ahead thrust can be achieved. Depending on the two rudder angles, it allows the degree of thrust from a conventionally mounted propeller to be controlled and the thrust direction vectored through 360°. Thus the need to reverse the shaft direction or propeller pitch is eliminated.

Flanking rudders

Flanking rudders are installed in front of the tug's propeller and both single screw and twin screw tugs may be so fitted. Flanking rudders are often installed in conjunction with other rudder systems, such as a single rudder behind the propeller or a Towmaster rudder system and are especially used in conjunction with fixed nozzles. In general there are two flanking rudders situated before the propeller nozzle. The flanking rudders are operated by separate controls and enhance steering performance when moving astern or when towing astern on a towline from the tug's bow. When going ahead they are kept amidships.

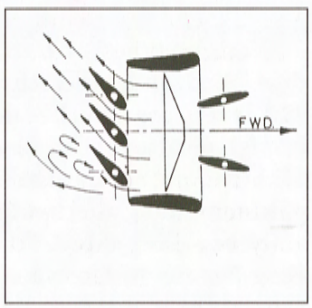


Figure 2.13 Shutter rudder system with a fixed nozzle and two flanking rudders

Towmaster system

The Towmaster rudder system is a shutter rudder type used in conjunction with fixed nozzles. It consists of several rudders mounted behind and sometimes also ahead (flanking rudders) of each nozzle. Behind the nozzle are normally three and ahead of the nozzle two

rudders. Rudder angles are possible up to 60°. The Towmaster system provides good thrust and steering characteristics ahead and astern at the expense of increased complexity. Astern thrust can be more than 70% of ahead thrust. Even recently built tugs are still equipped with this system, such as tugs of the Kuwait Oil Company, the tug *Al-Hawtah* of the Saudi Arabian Oil Co., tug *Pegasus* of the Mobil Refinery, Port Stanvac, Australia and the tug *Neeltje P* and her sister tugs of Terminales Maracaibo, Venezuela. The Michigan Vane Wheel used on some tugs in the USA is a comparable system, with several high aspect ratio rudders, e.g. three, behind a fixed nozzle; the same applies to the Nautican High Aspect Ratio Triple Rudder system.

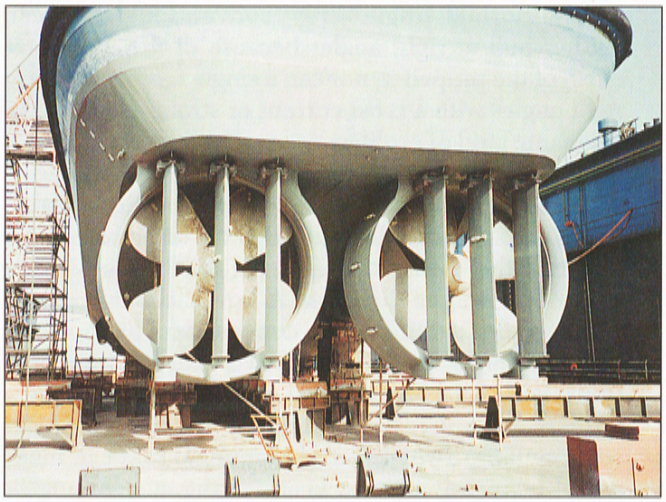


Photo: Damen Shipyards, The Netherlands

Figure 2.14 Towmaster rudder system of tug 'Hazam'. L.o.a. 38m, beam 11m, Bp 70 tons ahead and 50 tons astern

Other systems

Besides the rudder systems mentioned above, many other systems exist, such as different types of fishtail rudders and the previously mentioned triple screw tug *Scott T. Allen* with her three rudders, of which the centre rudder can be operated independently from the outboard rudders.

Bow thruster

Conventional harbour tugs are sometimes equipped with a tunnel bow thruster. The effectiveness of a tunnel thruster is not high when the tug has speed ahead. With only two knots speed the effectiveness of the bow thruster may already be reduced by 50%. Seagoing harbour tugs operating in port areas as well as at sea for offshore work often have a bow thruster, which enables them to keep position better near oil platforms.

Conventional tugs may be equipped with a (retractable) 360° steerable bow thruster. These bow thrusters are much more effective and can operate in any direction. Tugs with this kind of bow thruster are the previously mentioned combi-tugs.

2.3.3 Manoeuvring conventional tugs

Single screw tugs

Three aspects are important in manoeuvring a normal single screw conventional tug:

- The aft location of the rudder and propulsion.
- The transverse effect of the propeller when turning for astern.
- The low astern power.

When ahead thrust is applied with port or starboard helm, the tug's stern moves in a direction opposite to the intended direction of turn due to the aft location of the propeller and rudder. This contrasts with tractor tugs where the steering forces are applied in the direction of turn. This is a subject further dealt with in Chapter 6 when discussing interaction effects between tug and ship.

Turning on the spot, or nearly on the spot, is only possible with the previously mentioned high lift rudders. No sideways movement of a single screw tug is possible, not even with high lift rudders, though sideways movement is possible with high lift rudders in conjunction with a bow thruster.

The transverse effect or 'paddle wheel effect' is caused by the propeller wash hitting the stern at right angles when the propeller is turning for astern. Nearly all single screw tugs have a right handed propeller, which means a clockwise turning propeller going ahead in case of a fixed pitch propeller and an anti-clockwise turning propeller in case of a controllable pitch propeller. When the propeller is set for astern, propeller wash hits the tug's stern on the starboard side and the stern moves to port – consequently the bow turns to starboard. The more sternway the tug has the more effective the rudder is and it may even be possible to bring the tug onto a straight course by applying rudder. The paddle wheel effect together with the low astern power results in poor performance going astern in single screw tugs.

When moving astern a tug's stern can be controlled when the tug is equipped with a steering nozzle or with Towmaster or flanking rudders. Steering nozzles or flanking rudders can be set for the direction the stern has to move.

Twin screw tugs

Twin (or triple) screw tugs are much more manoeuvrable than single screw tugs. They can turn on the spot without making headway and can easily manoeuvre straight astern. Turning can be done by reversing one propeller and setting the other for ahead while applying helm in the intended direction.

Propellers of twin screw tugs, whether controllable or fixed pitch, are often inward turning except on tugs designed to operate in ice conditions. The advantage of in-turning propellers is higher propeller efficiency. A disadvantage with fixed pitch propellers is the larger

turning diameter, because the starboard propeller is left handed and the port one is right handed. When using the propellers as a couple, the transverse effect of the screws opposes the turn.

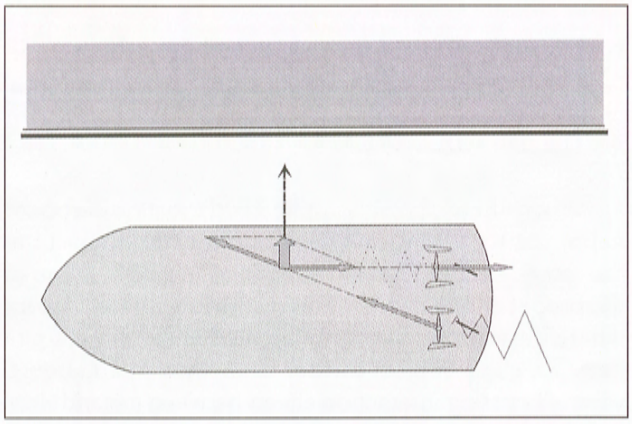


Figure 2.15 Twin screw tug moving sideways to starboard, also called flanking, by setting the port engine on ahead and starboard engine on astern while applying port helm. In the case of in-turning fixed pitch propellers the transverse thrust of the inner propeller will enlarge the side thrust to starboard

With inward turning fixed pitch propellers a tug can move sideways (see figure 2.15), so-called 'flanking'. When the tug has to move sideways to starboard, one would think of setting the starboard propeller to ahead and the port propeller to astern. This works only when the tug is equipped with a bow thruster. However, without a bow thruster this propeller setting does not move the whole tug sideways, but only the stern to starboard. By setting the propellers in the opposite way, with the starboard propeller astern, the port propeller ahead and the rudder to port, the tug will move sideways to starboard without gathering headway, depending on trim, wind and current influence. The transverse effect of the inner propeller will enhance the side thrust.

2.3.4 Conventional tugs in shiphandling

Conventional tugs are used for all methods of tug assistance but are not equally suitable for all methods. When assisting a vessel under speed a conventional tug is effective when towing on a line but as a stern tug, owing to the location of the towing point, it has severe limitations. When the ship has more than approximately three knots headway the after tug can only assist at one side of the ship and cannot shift to the other side nor is it able to control the speed of the assisted ship. The towing point being near midships implies a risk of girting.

When towing on a line, conventional tugs are not suitable to changing over, while the towline is still fastened, to pushing at the ship's side. This might be desirable, for instance, on arrival at a berth. For a quick change-over from pulling to pushing and vice versa while the towline is still fastened the conventional tug would have to push with the stern. The manoeuvre itself is already difficult unless the tug is equipped with a bow thruster or if it is a twin screw tug. However, when pushing with the stern the tug's propellers are so close to the ship's hull that the interrupted water flow towards the propellers will result in low propeller efficiency. In addition, the stern fendering of conventional tugs are normally not designed for pushing with the stern. In such a situation it is better to release the tug from the bow or stern in order to be able to push at the ship's side.

For tug operations at the ship's side a normal conventional tug can push but it is not the most efficient one for pulling on a tug's bow line, due to the limited astern power. Specific rudder configurations, such as the Towmaster system for example, will increase astern thrust. Normal single screw conventional tugs can neither pull at right angles because of the transverse effect of the propeller, nor can a single screw tug pull at right angles with a cross current or strong cross winds. The same kind of problem arises when the assisted ship is moving ahead or astern while the tugs are pulling. It will then be impossible to stay pulling at right angles. Additional measures should then be taken, such as a line from the stern of the tug to the ship to keep the tug in the best pulling direction. A bow thruster does not improve the situation as the conventional tug operates while pulling with the tug's bow headed towards the ship's hull. Steering nozzles, Towmaster and flanking rudders make it easier to keep the tug at right angles when pulling. Twin screw conventional tugs can make use of their propellers to keep the tug at right angles, although this will be at the expense of loss of effectiveness.

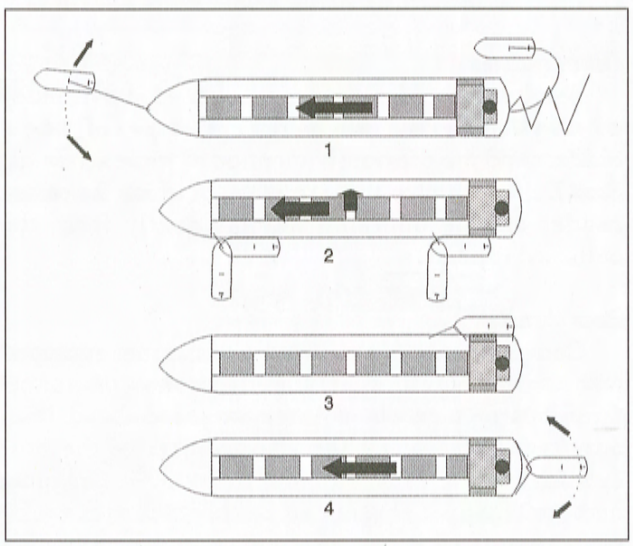


Figure 2.16 Some assisting methods with conventional tugs

The capabilities and limitations of conventional tugs in relation to other tug types are discussed in Chapter 4. Some assisting methods with conventional tugs are shown in figure 2.16.

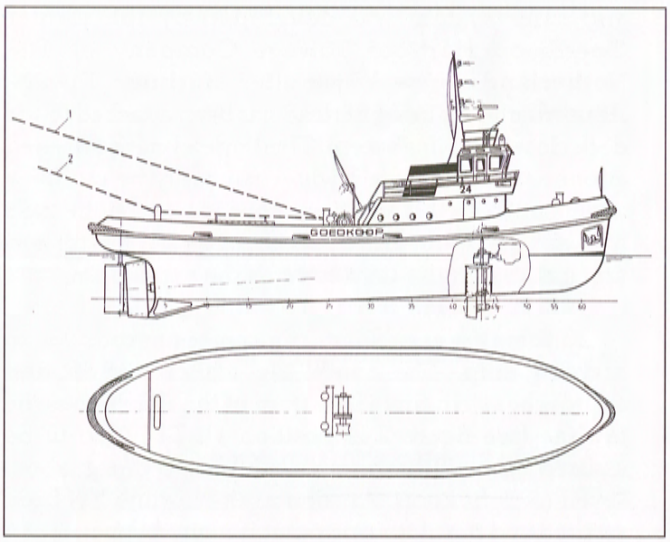


Figure 2.17 Combi-tug 'Petronella J. Goedkoop' of Wijsmuller Harbour Towage Amsterdam. L.o.a. 28·5m, beam 6·9m. Main engine 900 bhp. One cpp in fixed nozzle and twin rudders. Retractable 360° steerable bow thruster of 420bhp, type Aquamaster UL 316/2600. Bollard pull of main engine 15t. Bollard pull main engine + bow thruster 20t. Maximum speed ahead 11·9 knots, astern 10·2 knots when using both main engine and bow thruster. The tug is equipped with a special fairlead at the stern and a towing winch. Line '1' shows the tow line in its 'normal' position and '2' the tow line passing through the fairlead

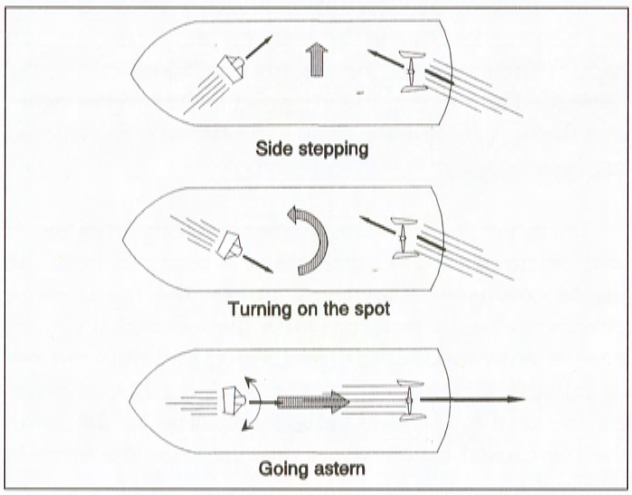


Figure 2.18 Free sailing manoeuvres with a combi-tug

2.4 Combi-Tugs

2.4.1 Designing and manoeuvring combi-tugs

As discussed above, the manoeuvrability of single screw conventional tugs can be improved by the use of high lift rudders. However, the disadvantage of many single screw tugs without steerable nozzles, Towmaster system and/or flanking rudders, is that moving straight astern is hardly possible and no single screw tug can move sideways unless fitted with a tunnel bow thruster in combination with high lift rudders. The astern power of single screw tugs is also low, unless the tug is equipped with a special rudder and/or propeller arrangement which increases propeller efficiency.

By installing a conventional single screw tug with a 360° steerable bow thruster, also called azimuth bow thruster, these disadvantages can be overcome. Tugs equipped with such a bow thruster are the so-called combi-tugs. The first combi-tugs appeared in the early 1960s. A tug equipped with this type of bow thruster can, with the aid of the main propulsion and the bow thruster, turn on the spot, sail straight astern at a fair speed and move sideways as well (see figure 2.18). Setting this type of bow thruster in the same direction as the propulsion also gives additional bollard pull ahead and astern and increases maximum speed. In most cases this type of bow thruster is equipped with a nozzle and can be of retractable or fixed type. An azimuth bow thruster with a nozzle propeller below the keel, in contrast to a tunnel bow thruster, achieves high efficiency in any direction even when the tug is moving quickly. This provides an additional increase in the tug's manoeuvrability.

As an example, an azimuth bow thruster of 400 hp can increase the top speed of a tug of 27 metres length and engine power of 1500 bhp by half a knot. With just the bow thruster working a speed of about five knots can be achieved. The towing force of the tug is increased by five tonnes if the main propulsion and the bow thruster work in the same direction. This is all in addition to better manoeuvrability.

For older tugs this is a satisfactory and inexpensive way of improving manoeuvrability and bollard pull. As examples of converted tugs, at Amsterdam, The Netherlands, some older tugs have been converted to combi-tugs and at San Pedro, California, USA, the tug *San Pedro* (now *Pacific Combi*) has been converted into a combi-tug with a similar conversion to the tug *Point Gilbert* and *Flying Phantom* of Cory Towage (now Wijsmuller Marine) in the UK. The *San Pedro* has been equipped with a 600 bhp bow thruster, which has increased the tug's bollard pull by 40%, from 25 to 35 tons and has improved the manoeuvring capabilities. Moran Towing Company, USA, revitalised its fleet of single screw tugs by installing retractable azimuth bow thrusters and a large fairlead aft. New tugs are also equipped with azimuth bow thrusters, all of them of the retractable type.

If the azimuth bow thruster is not in use it causes extra resistance. This is one of the reasons for making the bow thruster retractable. In shallow waters a retractable type is necessary. Care is required in using the azimuth bow thruster when underkeel clearance is small and it should be retracted in good time. A good working alarm system when the water depth is not sufficient for safe working of the bow thruster is strongly recommended.

2.4.2 Combi-tugs in shiphandling

Combi-tugs can tow on a line forward as well as aft. As a forward tug the combi-tug operates like a conventional tug, but has the advantage of increased maximum speed, manoeuvrability and bollard pull. Also, the risk of girting is reduced and response time is less due to the higher manoeuvrability.

As a stern tug combi-tugs can operate as a conventional tug at low speeds and can easily work over the tug's stern at higher speeds because of the azimuth bow thruster. However, since conventional tugs have their towing point approximately 0·45 x LWL from aft, working over the tug's stern needs an additional towing point near the stern to prevent girting, especially when the assisted ship has a higher speed. On conventional tugs the towing point can be moved aft by a gob rope, and on some tugs by a gob rope from a gob rope winch. The gob rope is then led from the winch through an eyelet or swivel fairlead at the tug's stern. At the free end of the wire is a large shackle which can be put around the towline. By heaving on the gob rope winch the towing point can thus be brought as far as possible aft.

This system is further explained in paragraph 7.2. A gob rope arrangement normally needs two persons on deck. With the reduced numbers in tug's crews a handier and safer system was developed by the former Goedkoop Harbour Towage Company of The Netherlands (now Wijsmuller Harbour Towage Amsterdam). A strong fairlead has been attached to the deck close to the tug's stern. This fairlead can be opened at one side so that the towline can easily be put in or taken out. With this additional towing point at the tug's after end the combi-tug can operate similarly to a tractor-tug, that is with the stern towards the assisted ship.

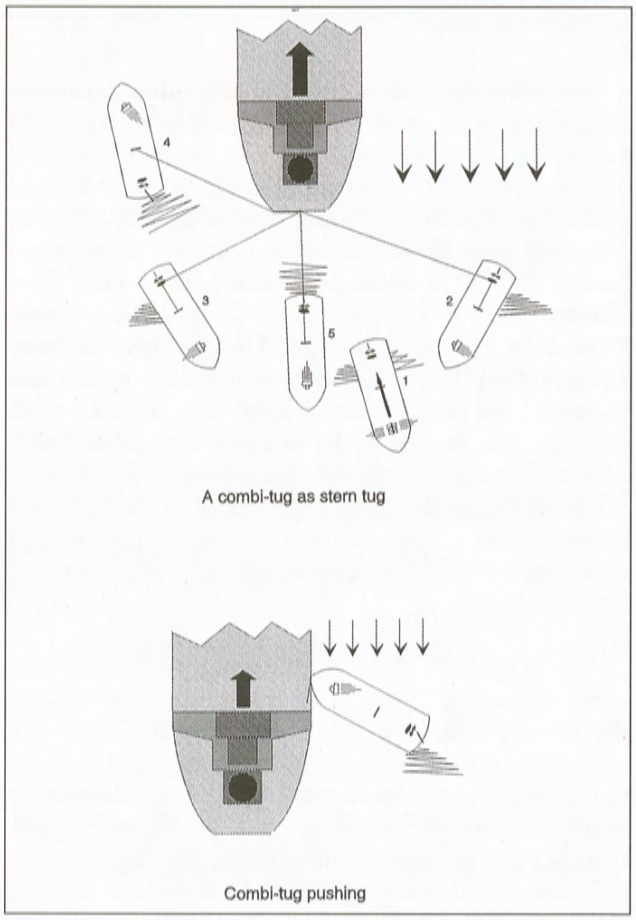


Figure 2.19 Some assisting methods with a combi-tug

To show the capabilities of a combi-tug consider an arriving ship. The combi-tug makes fast aft and approaches stern first to the stern of the ship to pass the towline (see figure 2.19 position 1). The ship to be assisted may still have rather a high speed, e.g. about seven to eight knots. As soon as the towline has been secured and the aft towing point is in use by means of a gob rope or fairlead, the combi-tug can control the vessel's speed (position 5) or assist in steering (positions 2 and 3). To reduce ship's speed, the tug's propulsion and the bow thruster will be set in the same direction to increase the tug's pulling force. Assisting steering is achieved by the tug sheering out to port or starboard with the main propulsion going astern and the bow thruster working sideways. In positions 2 and 3 the incoming water flow creates lift forces on the tug and consequently a force in the towline. When the ship's speed reduces, the effect of the tug in position 2 and 3 will become less due to the reduced lift forces. The gob rope is then released or the towline taken out of the fairlead. The original towing point is then in use again and the tug can operate again as a normal conventional tug (position 4).

In circumstances where there are strong cross winds and/or currents, and much effort is required from the tug to compensate for those forces, the tug is more effective when it proceeds with the assisted ship as a normal conventional tug (position 4) and thus can use its full ahead power. When required, the bow thruster can be used to increase bollard pull. The lift forces on the tug caused by the water flow increase the force in the towline.

If so required the tug can, even when the assisted ship has forward speed, shift to a position behind the ship's stern by using the gob rope or fairlead, bow thruster and main propulsion (position 4 $\longrightarrow$ 5). This can be done faster compared to a normal conventional tug. Conversely, moving from a position abaft the stern to a position moving with the assisted ship is, because of the bow thruster, possible at a somewhat higher speed than with a normal conventional tug.

It has been made clear that the advantages of a combi-tug are greatest when the tug operates as a stern tug on a line. For that reason this type of tug often assists during quite long passages as a stern tug for speed and steering control. The combi-tug can also be used at the ship's side, such as for push-pull operations.

When operating at the ship's side, a combi-tug has many of the disadvantages of a normal conventional tug. The combi-tug can either push with the bow or with the stern. When pushing with the bow while the ship has some speed, the bow thruster can be helpful to keep the tug's bow in position and prevent sliding along the ship's hull. The bow thruster will also give an additional transverse pushing force (see figure 2.19). When pushing with the stern, the effectiveness of the tug is reduced due to the restricted water flow towards the propeller and it is more difficult to bring or hold the tug at right angles to the ship's hull when the ship has some speed, due to the low power of the bow thruster. In particular, when working over the tug's bow, pulling effectiveness at speed is low.

2.5 Tractor-tugs with cycloidal propellers

2.5.1 Design

Tractor tugs have their propulsion under the forebody. Those with a vertical blade system, or cycloidal propulsion system, are the so-called Voith-Schneider or Voith tugs (VS tugs). The first vertical axis propeller, similar to the Voith Schneider propulsion system, was developed in the early 1920s by Professor Kirsten of the Aeronautical Engineering Faculty at the University of Washington in Seattle, USA. Tugs with Voith Schneider propulsion system appeared in the 1920s and 1930s. In the 1950s Wolfgang Bear of the Voith Company designed a shiphandling tug with the cycloidal propulsion under the tug's forebody and the towing gear on the aft deck. Many limitations of conventional tugs were overcome by the introduction of this totally new concept, which was called a Voith Water Tractor.

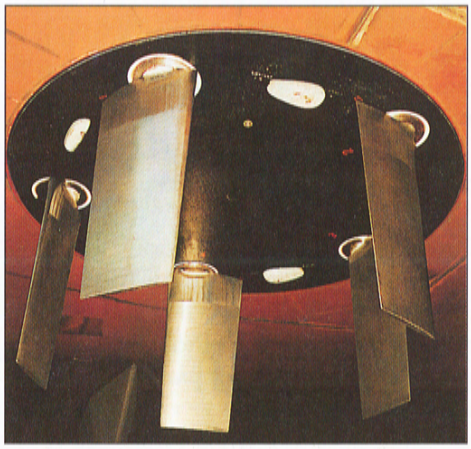


Figure 2.21
Propeller blades of a VS tug

Photo: J. M. Voith GmbH, Germany

The cycloidal propulsion system is, in fact, a kind of controllable pitch propeller (see the side-view of Voith tractor tug, figure 2.20). The engine works at constant rpm and magnitude of thrust and the thrust direction is regulated from the wheelhouse. Different engine rpm settings can be selected. Full engine rpm is required when full towing or pushing power is required or at high free sailing speeds. In other situations lower rpm settings can be used. The VS propulsion system for tugs consists of two units with vertical propeller blades whose pitch and thrust direction can be regulated uniformly through 360° without delay. The protection plate (2) protects the propeller blades and works like a nozzle, thus increasing propeller efficiency. During docking the tug stands on these protection plates and on the skeg (4).

The large skeg is typical for tractor tugs and in particular for VS tractor tugs. It gives course stability and brings the centre of hydrodynamic pressure further aft, which is advantageous to both safety and towing performance when towing on a line, especially towing performance when operating as an after tug at higher speeds.

The towing winch (6) is located aft of midships. It may also be just a towing hook. The towing point, a large fairlead or towing staple (7), through which the towing line

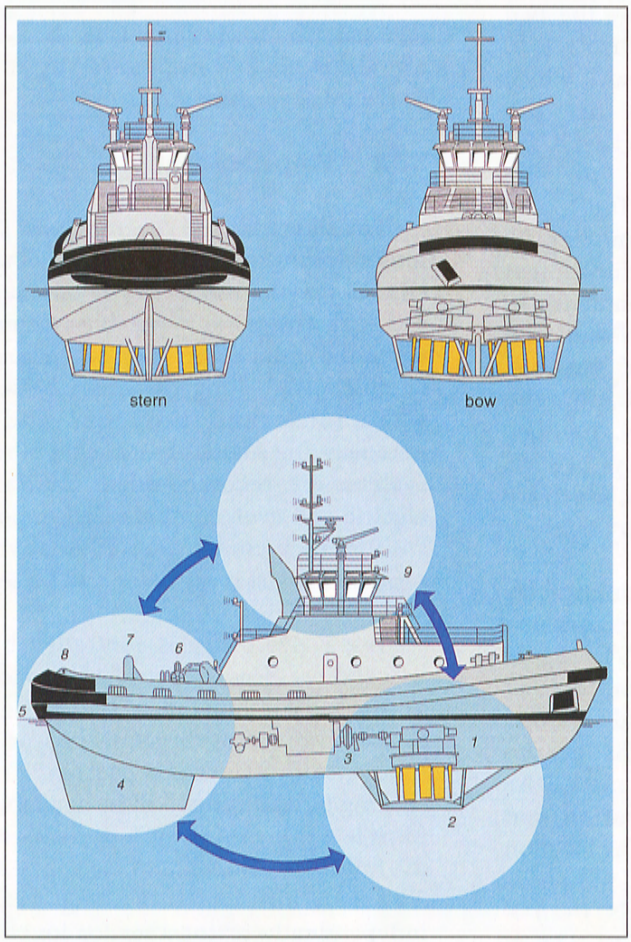


Figure 2.20
Voith tractor tug

Note: A second towing point is only fitted in a small number of VS tugs, and is discussed further in Chapters 4 and 9

1 Voith-Schneider propeller

2 Propeller guard plate

3 Voith turbo coupling

4 Skeg

5 Fender

6 Towing winch

7 Towing staple

8 Second towing position

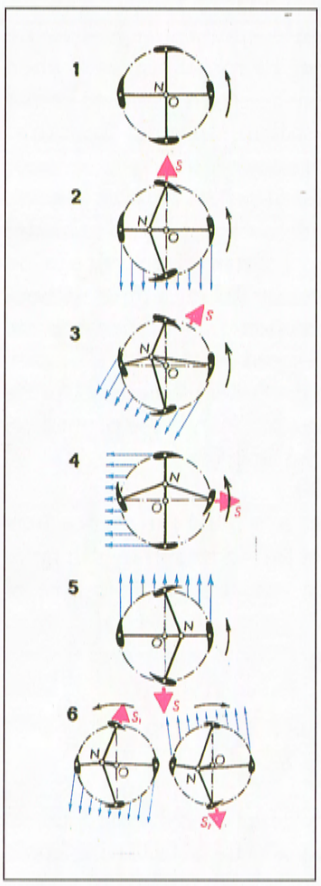
9 Wheelhouse

J. M. Voith GmbH, Germany

passes, lies far aft and usually exactly above the middle of the skeg. The hull is relatively wide and flat to provide sufficient space for the two propulsion units. VS tugs have heavy duty fendering (5), especially at the stern, because when pushing, the tugs push with the stern.

Most modern tugs have small wheelhouses with optimal visibility. The same applies to modern VS-tugs, like the one shown in figure 2.20. The small and optimum wheelhouse (9) often has one central manoeuvring panel for propeller control.

The principle of a cycloidal VS propeller is shown in figure 2.22. Links leading to the steering centre N are fitted to the vertical propeller blades. The steering centre N can be moved out of the centre O by two hydraulic cylinders. One hydraulic cylinder works in the longitudinal direction and the other one in the transverse direction. The propeller blades create a thrust in a direction depending on the location of the steering centre N. In sketch 1 there is no thrust; the propellers are 'idling'. In sketch 2 the steering centre is moved by one hydraulic cylinder to port. This offset location of the steering centre N results in forward thrust. In sketch 3 the steering point N is moved by the two hydraulic cylinders to port and forward, which gives thrust in the indicated direction S. So, the thrust can be regulated for any direction by moving N. The nominal direction of thrust is perpendicular to the line O-N and the magnitude of thrust is proportional to the distance O-N. In tugs, there are always two VS propeller units, which are installed side by side.



J. M. Voith GmbH, Germany

Figure 2.22 Principle of Voith propulsion

The maximum draft, including the propulsion units, of a VS tug is relatively larger than that of conventional tugs, due to the weight of the propulsion units, the propeller location and dimensions. The location of the propulsion units is approximately 0·25 – 0·30 x LWL from forward. The towing point lies 0·1 – 0·2 x LWL from aft, although this may differ by tug depending on operational requirements.

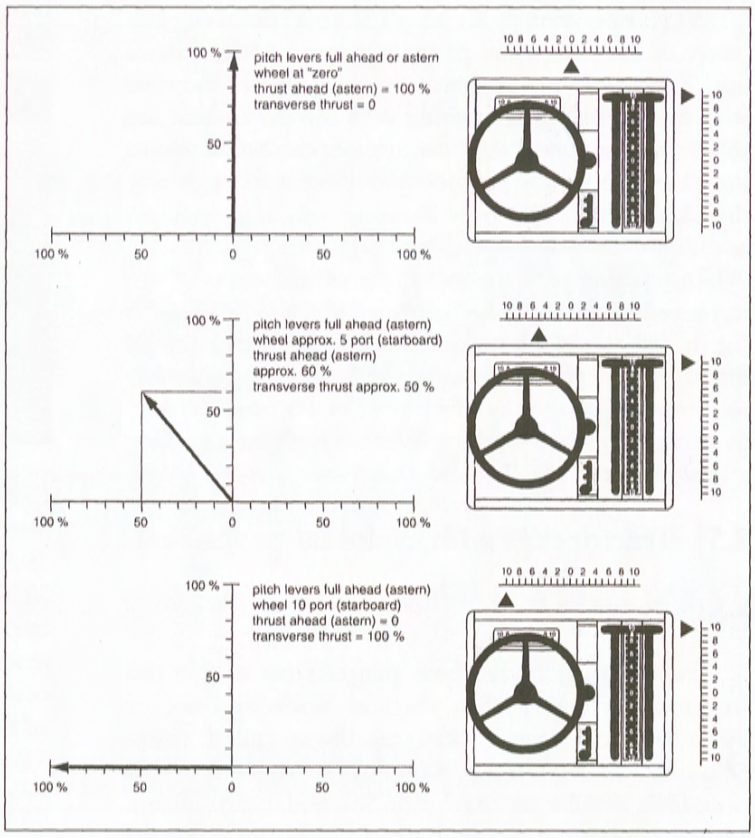


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Figure 2.23 Propeller control of VS tugs

2.5.2 Propeller control

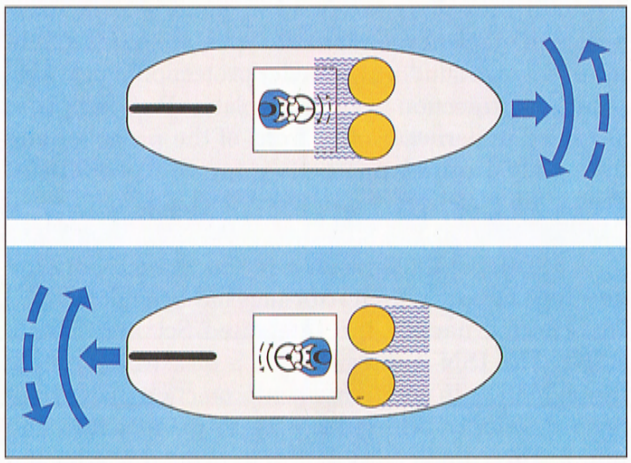
The direction and magnitude of propeller thrust is remotely controlled from the wheelhouse. The remote control may be mechanically operated by a push-pull rod gear. This is a very reliable system for tugs and best when the distance between wheelhouse and propeller is short. With long distances between the bridge/wheelhouse and propeller and when several manoeuvring stands are installed other remote control systems are recommended. Hydraulic, pneumatic, electric and even computerised remote controls, even with joystick control, are alternative solutions. How propeller thrust is regulated can be seen in figure 2.23.

Transverse thrust is controlled by the wheel and longitudinal thrust is controlled by pitch levers. So thrust setting is a combination of transverse and longitudinal thrust. Transverse direction has priority. When full transverse thrust is used (wheel hard to port or starboard) no longitudinal thrust will be available, even when the pitch levers are set in pitch position. It can be seen that the full 100% thrust cannot be applied in any direction. The two units of a VS tug can be controlled independently or together for longitudinal thrust but only controlled together for transverse thrust.

2.5.3 Manoeuvring

VS tractor-tugs are highly manoeuvrable, can turn on the spot, deliver a high amount of thrust in any direction and sail straight astern at high speed. Astern thrust is nearly equal to ahead thrust. Many of the disadvantages of conventional – especially single screw – tugs, such as low astern power, no or low side thrust and in some situations transverse effect of the propeller, do not apply to VS tugs. Because it is possible to apply side thrust tractor tugs are also safer when making fast near the ship's bow and interaction forces can be better compensated.

Sailing ahead as well as astern is easily achieved by use of the wheel, as shown in figure 2.24. Turning on the spot can be done by setting the wheel hard to port



J. M. Voith GmbH, Germany

Figure 2.24 A VS tug sailing ahead and astern

or starboard. A VS tug can be moved sideways e.g. to port. The port pitch lever is set for ahead and the starboard for astern, while turning the wheel to port. The turning moment of the propellers is eliminated by the action of the wheel and the tug moves sideways. Propeller effectiveness is less on astern therefore ahead pitch should be set somewhat lower than astern pitch.

VS tug propulsion produces little wash, which is invaluable when skimming oil and, for example, when working with full thrust close to deep loaded lighters as can be the case in narrow harbour basins.

The full bow of tractor-tugs and the flat and wide hull bottoms which are necessary to create sufficient room for the propulsion units adversely affect their sea keeping behaviour. According to the experience of some VS tug captains, so do the bottom plates of the VS propulsion units in rough sea conditions.

A number of VS-tugs, particularly those used for escorting, are designed such that they better meet the demands of operating 'skeg-first'. This, however, does not alter the basic principles of the tractor tug.

2.5.4 VS tugs in shiphandling

VS tugs are used for towing on a line and for operations like push-pull (see figure 2.25). For towing and pushing operations the maximum longitudinal pitch is limited (to approximately pitch 8 for towing/pulling and pitch 9 for pushing) to avoid overloading the engine. In push-pull operations the disadvantages of conventional tugs of having low astern power and/or not being able to pull at right angles to the ship do not apply to VS tugs. As already mentioned, VS tugs have nearly equal power astern and ahead and can apply thrust in any direction.

While towing on a line a VS tug forward or aft can change to pushing without releasing the towline, which is very handy while approaching the berth (see figure 2.25, situation 3). The forward tug can change to a

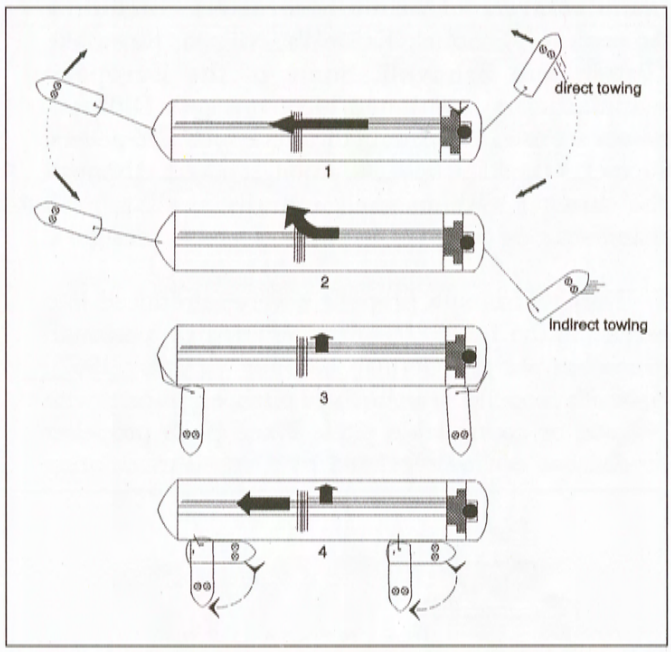


Figure 2.25 Some assisting methods with a tractor tug

pushing position at a ship's speed up to approximately two knots. A towing winch is always useful with this kind of operation in order to control the length of the towline and to enhance safety.

VS tugs can also make fast directly to a ship's side as push-pull tugs (see figure 2.25, situation 4) approaching the ship either stern or bow first. Ship's speed should then not be more than about five knots. Although VS tugs are not the most effective type of tug as a forward tug towing on a line for a ship under speed, due to performance restrictions imposed by the location of the towing point, they are very suitable as after tug for course and speed control. Course control can then be carried out with ships having headway and, contrary to what is possible with conventional tugs, to starboard as well as to port.

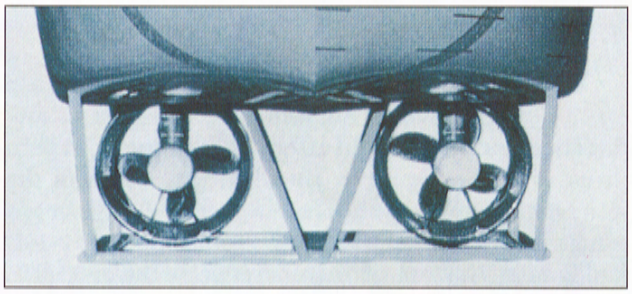
Course control is carried out at higher speeds by the indirect method (see figure 2.25, situation 2), making use of the hydrodynamic forces on the tug's hull, or at lower speeds by the direct method (see figure 2.25, situation 1). Forces in the indirect method can be far higher than the tug's bollard pull. When braking forces are required, pitch levers should be adjusted to ship's speed to avoid overloading the engine and a minimum of wheel should be used. The different manoeuvres that can be carried out with a VS tug are shown in the manoeuvring manual of J.M. Voith GmbH.

2.6 Tractor tugs with azimuth propellers

2.6.1 Design

Tractor tugs with azimuth propellers have two 360° steerable thrusters under the forebody. There are several manufacturers of azimuth thrusters, including Aquamaster, Schottel, KaMeWa, Niigata, Kawasaki, Ulstein and Brunvoll. Some of the European manufacturers mentioned have merged. Different names are used for azimuth thrusters, such as Z-pellers, Rexpellers and Duckpellers, amongst others. Although the thruster systems are generally similar, each manufacturing company has its own specific design.

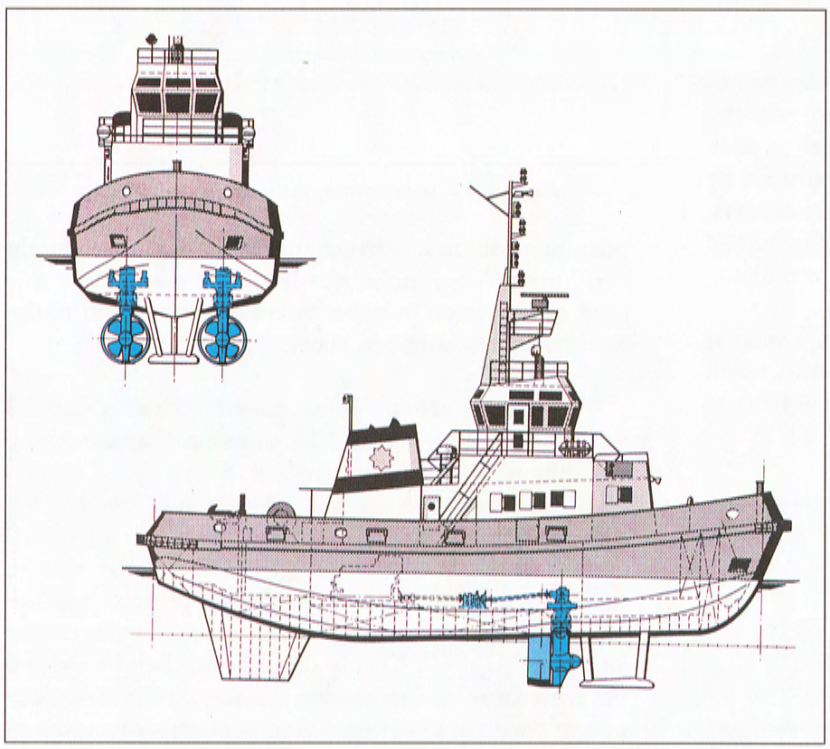
The first azimuth propellers were introduced into service in the 1960s. The first tug fitted with azimuth propellers was the German harbour tug *Janus* (1967). Azimuth propellers can be fixed pitch, e.g. mostly with Niigata, or controllable pitch. Fixed pitch propeller revolutions can be regulated by a speed modulating clutch, which enables the propeller speed to be controlled in a stepless manner from zero up to maximum. This more or less eliminates the need for controllable pitch propellers and is much less expensive. Azimuth propellers are fitted in nozzles to increase propeller efficiency, (for nozzle types, see par. 2.3.2) In the event of grounding, propeller protection is provided either by protection or docking plates. Docking plates are fitted underneath or in front of the propeller and give only limited protection for the propellers. Protection plates serve also when docking.



Schottel-Werft, Germany

Figure 2.27 Integrated Schottel nozzles with open protective frames, decreasing a tug's maximum draft by approximately 0·5m without affecting the tug's performance

As thrusters underneath a tug increase its draft, a new type of nozzle for tractor-tugs has been developed by Schottel, namely the Integrated Schottel Nozzle (ISN). The ISN is integrated in a disk which rotates through 360°. In addition, open protection plates have been developed which are easy to manufacture and install. This combined system of integrated nozzles and open protection plates decreases the draft by 0·5 m, does not affect the propulsion and bollard pull data more than a normal docking plate and gives optimal propeller protection in the event of grounding.



Schottel, The Netherlands

Figure 2.26 Azimuth tractor tug 'Fairplay V'. L.o.a. 26·7m, beam 8·8m, bp 29t. In front of the thrusters is the docking plate

The basic design of the tug itself does not differ much from VS tractor tugs. The displacement of a VS tug is more than that of a comparable azimuth tractor tug of the same engine power, due to the higher weight of the VS propulsion systems and to the requirements for more stiffening due to the wider hull openings for the VS units. An azimuth tractor tug of the same dimensions and engine power will therefore have less hull draft.

Towing point location is generally similar to that in VS tugs. The skeg is sometimes smaller and the location of the towing point is often less strictly related to the location of the skeg as with VS tractor tugs. The towing point lies approximately 0·1 x LWL from aft and the propellers are fitted at 0·30 – 0·35 x LWL from forward. A smaller distance is found, 0·25 x LWL for instance, on some Italian tractor-tugs at Genoa, Italy. Thrusters