Possibilities of representing the ship-tug cooperation in the free model tests

Jacek Nowicki,
Foundation for Safety of Navigation and Environment Protection

Abstract

Model tests of ship manoeuvring in ports and in other restricted waters require the tug forces and moments to be taken into account. As the additional tug forceRhol can be relatively easily allowed for with reasonable approximation in a computer simulation system, the free model tests require more complicated methods. This paper contains a review of the methods used in the Experimental Centre in Ilawa and then in the Foundation for Safety of Navigation and Environment Protection in order to represent the ship-tug cooperation in the free model tests.

Keywords: *ship-tug cooperation, free model tests, ship manoeuvring*

A bit of history

It is assumed that the first ship with a mechanical propulsion system intended for towing was „Charlotte Dundas" launched in 1801 in Great Britain (Fig. 1). In the next year, towing of two 70-ton barges in the Forth of Clyde waters near Glasgow showed that even the biggest ships might be safely towed inside restricted port water areas by other ships and not by rowboats with 10 oarsmen as it had been practiced before. That event was the beginning of a new type of specialist ship - tug and new method of manoeuvring by means of tugs.

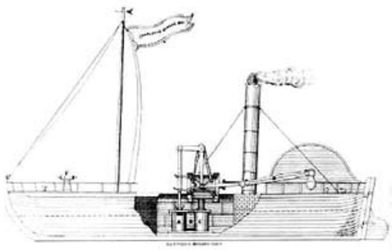

Fig. 1 *- Plan of the steamship „Charlotte Dundas" launched in 1801*

The idea of aiding the ship manoeuvres in ports by tugs spread quickly, particularly in view of quick increase of ship size, development of the mechanical propulsion systems and confined port space in those days. For instance, in 1828 an old side-wheeler was converted into a tug in New York. It probably looked similar to a dozen years younger ship presented in Fig. 2. In 1850 in New York the first tug with a screw propeller was launched. Its name was „Sampson" and it cost its owner USD 4500.

Fig. 2 *- Side-wheeler „Norwich" in the port of New York, built in 1836 and converted into a tug in 1842*

The following years are characterised by fast development of tugs, constructed then in accordance with individual designs. The ships of those times were mainly ocean-going clippers and single-screw vessels of increasing dimensions and limited manoeuvring capability, requiring the assistance

Fig. 3 *- Single-screw tug with steam engine built in 1890 in the United States. Port of New York*

of tugs during entering and leaving ports. Fig. 3 shows a tug at the end of 19th century.

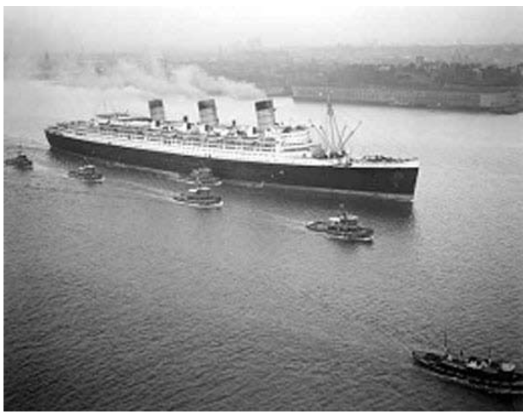

Fig. 4 *- Tugs assisting Queen Mary in the 1930s*

The development of steam engines is reflected in the increased towing power, twin-screw tugs are built with the Kort-nozzle propellers. Manoeuvrability of such tugs is much better than those with classical single-screw propulsion sy-

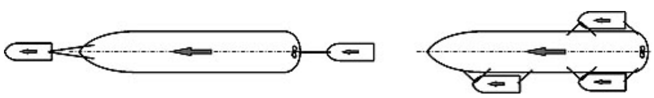

Fig. 5 - The difference between American and European method of the ship-tug cooperation

stem, which makes the cooperation with ship easier and safer. Nevertheless, the number of tugs necessary for handling the biggest ships increases and several are needed simultaneously to aid the large ocean passenger liners (Fig. 4).

There are also differences in the operating methods: Europe prefers tug on a towrope, USA develops a technique based on tug at the ship side (Fig. 5).

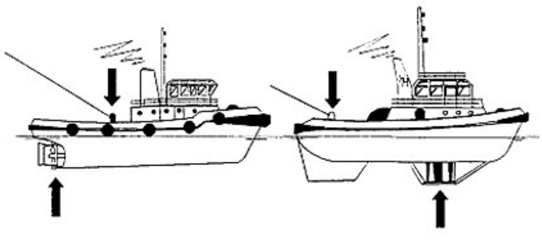

Fig. 6 - Conventional tug and tractor - different points of propulsion acting upon the tug hull

However, a real revolution is made by introduction of new types of propellers: the Voith-Schneider propeller or various types of a propulsion column under the hull. Tugs with propeller placed before the centre of towing pull are called tractors (Fig. 5 and 6). They have good manoeuvring capability and allow to use new methods in the ship-tug cooperation. The towing power is also increasing.

The threat to the natural environment that an oil spill carries caused the development of a new class of tugs - escort tugs. They are very effective and relatively fast (10-12 knots). This is necessary in order to be able to assist large tankers for tens of miles in their trips in restricted waters (in straits and among rocky islands). Escort tugs improve the ship manoeuvrability, they become also a „sheet anchor" in case of the propulsion or steering system breakdown. The requirement of escorting the ships carrying hazardous cargo is becoming a rule. The operating method of an escort tug is shown in Fig. 7 and 8.

Fig. 7 - Tug in escorting operation. The marked ship steering force is generated by the tug skeg

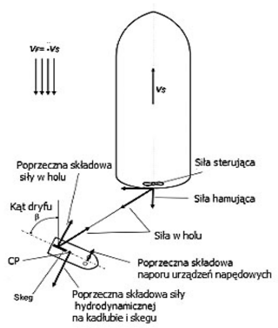

Fig. 8 - Force distribution on an escort tug during assisting a ship, in the indirect assistance method

The steering forces at the maximum tug speed may reach a value of 140-150 tons.

Manoeuvrability tests with free models

Free model tests are carried out on a lake, pond or in other sufficiently large water space. The water depth usually corresponds to the deep water conditions as it is extremely difficult to find a large natural shallow water area.

Nowadays, the aim of tests is to determine the ship manoeuvrability characteristics, although in many centres the open water resistance and propulsion as well as seagoing quality tests have been carried out for long years. Also the non-conventional units: hovercraft, hydrofoils etc., were often tested in the open water conditions, as they were too big to be tested in typical towing tanks.

A part of the ship manoeuvrability tests involves manoeuvres in restricted water areas, mainly in ports and port approaches. The aim is to verify a given port and waterway configuration from the point of view of navigation safety. In such case the cooperation of ship with tugs, particularly a large ship manoeuvring in heavy weather conditions, is of essential importance. It is not possible, even for units very well equipped with additional steering devices, to manoeuvre on their own in ports and fairways. Therefore, the quality of tests will to a large extent depend on the reliability of representation of the cooperation with tugs, including also the interaction between tugs and the hull.

Representation of the cooperation with tugs

From the manoeuvring point of view, a tug means an additional force controlling the ship movement, applied to the hull through the towrope or the point of contact between the tug hull and ship hull. It should be performed in a way ensuring maximum effectiveness of the manoeuvre. The tug impact force depends on the tug type, propulsion system configuration and to some extent on the quality of it's crew. The effective steering force will also be a function of the relative tug position, motion parameters and usually is much smaller than the tug bollard pull.

The first free tests in the Experimental Centre in Ilawa, aimed at the verification of a port water area layout, were carried out in 1975. They pertained to the Northern Port in Gdansk, which was built in a 1:24 scale on the Lipowa island. The port water area and a substantial part of the approach fairway had the depth adequate to the adopted scale. That provided proper depth of water under the keel and the hydrodynamic reactions on the ship hull. The tug and the number of units cooperating with the ship turned out to be a problem. Simple calculation of the necessary pull force for a 7^{o} B wind and the assumed water depth yielded the number of 4. As the cost of purchase of the tug model remote control devices exceeded the financial resources of the project, a simple method of the tug impact simulation was applied.

A weight equal to 90% of the tug bollard pull was suspended on a block fastened to a wooden tug hull model in the same scale as the ship model. The tug position was changed manually - „skippers" were employees of the then Division of

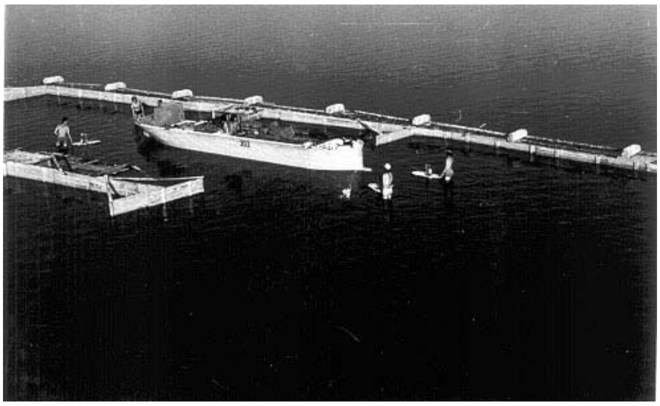

Fig. 9 - *Model tests aimed at the verification of port water area layout in the Northern Port in Gdansk, Ilawa 1975.*

Hydromechanics. Such solution prevented excessive towrope forces from appearing but did not allow to monitor the interaction between tug and ship. The trajectory was recorded by a photographic method - the ship position was registered, every fixed number of seconds, in the same frame. Fig. 9 presents that test methodology.

The following year, with the same methodology, verification was carried out of the shipyard basin configuration in the newly designed shipyard in Ustka. The maximum size of a ship to be hauled out from Ustka was determined as 400 000 DWT, the water depth map in the whole shipyard and port area was also maintained.

Later, the Ship Hydromechanics Division activity in the ship manoeuvrability field was more and more directed towards training in the ship manoeuvring. The first training models were built equipped with the tug operation simulation systems, good measurement instrumentation allowed to use them also for research work, which was a frequent case. „WARTA" - model of an LCC ship was built in 1980, „SZCZECIN" - a Panamax ship model in 1983 and „GDYNIA" - a Ro-ro ship model in 1987. The time of construction (end of the 1970s) was not good for execution of the tug operation simulator. The tug towing power was replaced by tubular rudders (thrusters) installed in the training-research model bow and stern at the points as close as possible to the centre of towing pull. Therefore, the tug impact force configuration was limited: perpendicular to the ship axis to PS or SB (see Fig. 11). This allowed to use a tug for pushing a ship to the quay or pulling from the quay, also turning a ship in the manoeuvring basin by two tugs could be relatively well simulated. Represented was the tug bollard pull, decreasing with the increasing model speed (like the tubular rudder thrust), also taken into account were some time constants, e.g. passage of the tug from one ship side to the opposite. In the „Warta" model the bow thruster could be rotated by an angle approximately equal to the operating angle of the bow tug on the towrope. It was a considerable step forward which made it possible to use a tug as assistance in the port approach fairway, in narrow passages etc.. A diagram of tug impact forces is shown in Fig. 10.

The increasing requirements regarding trainees as well as research orders connected with dimensioning of the port water areas have necessitated the design and implementation of a new generation of tug simulators. As before, the tug impact force is generated by the steering devices: thrusters or Schottel propellers with a 360° rotation capability, which significantly widens the scope of possible tug cooperation representations. However, the greatest qualitative improvement has been coupling of the tug simulator with GPS, sending precise information to the model about its position in relation to the surrounding objects (quay, shallow water spots etc.). That allows to generate virtual tug profiles changing their position in accordance with changes in the thrust generating device control settings. This is only a short step from using a simplified mathematical model representing the dynamics of a specific type of tug, including its interaction with the ship hull. Available are the towrope operating tugs or the ship side tugs (the American method), twin-screw or tractor type.

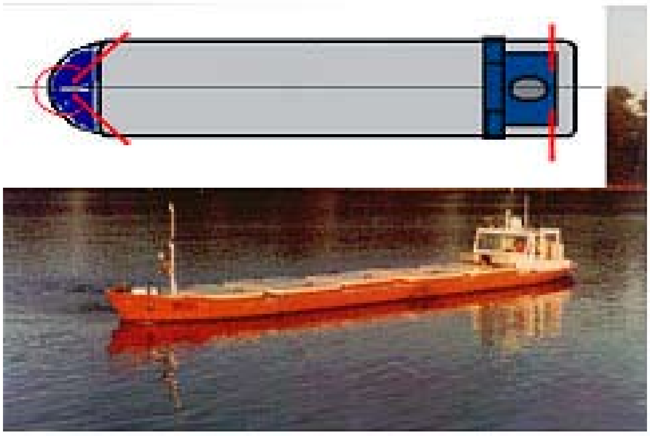

Fig. 10 - *The training and research model „Warta" equipped with the first tug cooperation simulators. State in 1983*

Fig. 11 - *Training model „Szczecin" equipped with a bow thruster and stern thruster. They had a tug operation simulation option*

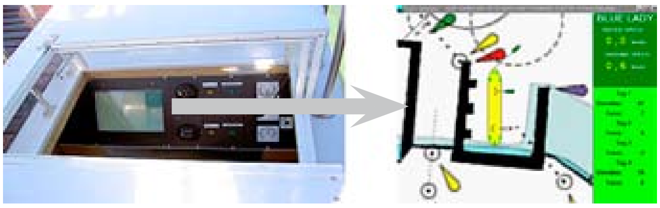

Fig. 12 - *Control panel of a tug simulator and a monitor screen with transitory tug positions*

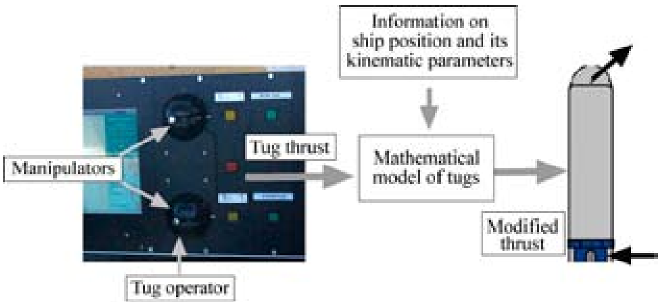

Fig. 13 - *Determining the thrust force of the steering devices representing the tug operation*

However, the steering device generated force limitations (mainly due to the Coanda effect) and some problems with manoeuvring in very shallow waters were the reasons for seeking different solutions allowing to implement all the aspects of the ship-tug cooperation. Particularly important appeared the escorting function, which in the indirect assistance method (see Fig. 8) requires considerably greater impact forces. After an analysis of methods used in Ilawa and abroad (remotely controlled tug models, fan generated force, additional propellers behind the hull on outriggers etc.) it was decided to use the simplest method: building of a manned tug model in the same scale as the big training and research models. Nowadays, escort tugs are even more than 50 m long and the analysis showed that a model could be built without significant outfit limitations. The tug model tests were carried out in 2005 and now work is

Fig. 14 - Escort tug of the BUKSER OG BERGING company and the escort tug model under construction in the Foundation workshop in Ilawa, May 2006

in progress on the hull and propulsion system. In the second half of 2006 the prototype will be put into operation in the Foundation Centre on Lake Slim. Fig. 14 below presents the original escort tug used as a reference solution in the propulsion and skeg positioning (skeg first). But the type of propulsion on the tug model is entirely different.

Calculations confirm a possibility of generating by the tug a force allowing to obtain the steering force of up to 150 tons on the training model. It is assumed that the value of forces generated on the tug model hull and skeg and transmitted through the towrope to the ship will be continuously monitored.

Summary

It is difficult these days to imagine a ship manoeuvring in restricted waters without assistance of tugs, in spite of the development of various additional steering devices. Many port administrations simply prohibit to use fully those devices in the vicinity of hydrotechnical structures, for safety reasons, e.g. during pushing a ship to the quay. Therefore, only tugs and their efficient and effective cooperation with the ship may secure safe navigation.

The research work and training should represent as fully as possible all the aspects of that cooperation, including the interaction between ship and tug. It seems that building a physical model of a tug operated by man, in spite of all the possible scale effect reservations, is a proper way of solving all the problems of the open water tug-assisted manoeuvring investigations.