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New Insights into Voith Schneider Tractor Tug Capability

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The emerging use of tanker escort in restricted waters requires tugs that are capable of rendering effective retarding and steering assistance to large ships operating in the 6 to 12 knot speed range. This paper presents findings from a coordinated program of model tests, computer simulations and full scale trials which have yielded new insights into the capabilities of Voith Schneider propelled tractor tugs. The emergency assist capabilities are shown as speed-dependent contours of the vector assist force in the coordinates of the assisted vessel. For tractor tugs the capabilities increase with speed. Simulations of tug assisted tanker maneuvers at 10 knots show that the tractor tug is more effective than a conventional tug in controlling the behavior of a disabled tanker.

Introduction

THE UNFORTUNATE grounding of the *Exxon Valdez* has dramatically altered the climate for public processes involving industry regulators and other interested parties. The petroleum industry faces renewed and intensified demands to demonstrate the safety of their current operations and to obtain permits for increased activity. The sponsors of the research that forms the basis for this paper, ARCO Marine and Foss Maritime, have both recognized the need to consider the safety issues in petroleum transportation; and Foss Maritime has for many years provided cycloidal propeller tractor tug escort services to ARCO on the waters of northern Puget Sound (see Fig. 1).

Since 1975, Washington State law and federal regulation have mandated tug escort for loaded tankers operating on the waters of northern Puget Sound. Following the grounding of the *Exxon Valdez* there have been calls from several quarters for tug escort at other oil ports as well. In addition to the possibility of further federal requirements for tanker escort, the Oil Pollution Act of 1990 (OPA 90) has granted increased powers to states to regulate tanker operations on waters adjoining state coastlines. Several states, port districts, and other local authorities are currently in the process of determining whether or not to impose tanker escort regulations in their coastal waters.

In 1990 ARCO Marine and Foss Maritime commissioned The Glosten Associates to lead a broad program of research into the capability of escort tugs to render effective assistance to loaded tankers proceeding at speeds up to 12 knots. The research program embraced the following goals:

- Compare the escort assistance capabilities of Voith Schneider tractor tugs and conventional twin open screw propeller tugs.
- Evaluate the relative effectiveness and safety benefits derived from Voith Schneider tractor tug escorts and conventional tug escorts for tankers operating in Rosario Strait in northern Puget Sound (see Fig. 1).
- Develop the preliminary design for a new class of 7200 bhp Voith Schneider tractor tugs to operate in the escort service in northern Puget Sound.

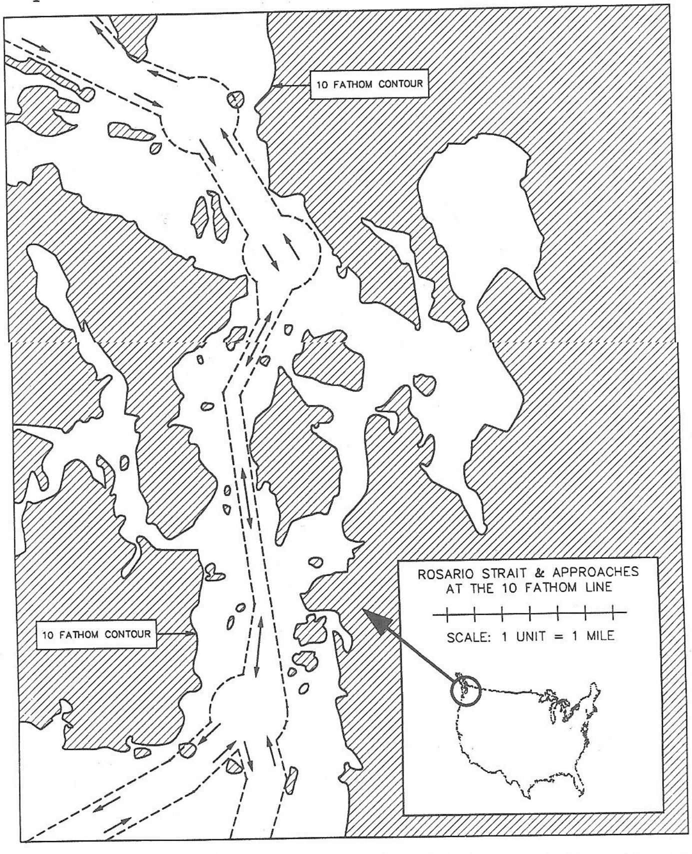

Fig. 1 Location map for Northern Puget Sound (enlargement shows Rosario Strait)

The preliminary design, developed as part of this research program, has now evolved into a contract design for a 7600 bhp Voith Schneider tractor tug. Tractor tugs of that design

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are currently under construction at Halter for Foss Maritime, with delivery of the first tug scheduled for the last quarter of 1993. However, this paper reports on studies of a 7200 bhp Voith Schneider propelled tractor tug.

Activities undertaken during the course of this research program included:

1. A literature survey of previous studies of tug assisted tanker maneuvers.
2. Inquiries and interviews at Voith Schneider GmbH and at major European model basins and maneuvering simulators to determine the status of pre-existing knowledge on tractor tug hydrodynamics.
3. Full-scale tug tanker trials between a loaded 70 000 dwt tanker, the *Arco Sag River,* and the 4000 bhp tractor tug *Arthur Foss*. These trials concentrated on assist maneuvers beginning from a tanker speed of 8 knots.
4. Development of the preliminary design of a new class of 7200 bhp Voith Schneider tractor tug.
5. Seakeeping and planar force model tests at MARIN (Maritime Research Institute Netherlands), of the new 7200 bhp tractor tug design.
6. Extensive computer simulations of emergency tug assistance to a loaded 125 000 dwt tanker operating in Rosario Strait. Simulations were conducted with both 7200 bhp conventional and 7200 bhp Voith Schneider tractor tugs.

The scope of this program of research was too broad to be properly reported in a single paper. Accordingly, we have chosen to focus the present paper on results derived from the planar force model tests of the Voith Schneider tractor tug. These results include: (1) new approaches to presenting tug capabilities; (2) comparisons of tractor tug and conventional tug capabilities; and (3) a limited presentation of results obtained from the computer simulation of the tracks of tankers assisted by tractor tugs.

Historical perspectives

Historically, tug performance has been characterized by singular scalar measures such as power, or bollard pull. Obviously, installed power does not differentiate in any way according to tug type, while bollard pull only differentiates performance at one speed (zero speed). A towrope pull versus speed diagram, such as that shown in Fig. 2 for 7200 bhp conventional and Voith Schneider tractor tugs, is useful for evaluating the performance of tugs in straight-ahead towing operations. From Fig. 2 the bollard pull, the free running speed and the speed with a tow having a known resistance curve can be determined.

Baer [1][4] added the vector diagrams of Fig. 3 to the naval architect's arsenal for comparing the performance of different tug types. These diagrams have represented the state of the art for describing tug performance for the past 20 years. Unfortunately, Baer's diagrams fail in two significant ways to address the modern needs for describing and comparing tug performance. First, they describe the performance only at zero speed. And, second, they present the bollard thrust capabilities in the coordinate system of the tug, *not* that of the assisted vessel!

Vector diagrams of bollard thrust may be adequate to the task of comparing tug capabilities for tasks such as berthing and unberthing operations, as well as very low speed assist duties, but such diagrams fall short of the task when assist operations must take place with substantial forward speed. As the diagrams in Fig. 3 are expressed in tug coordinates, they do provide some insight into the agility and handiness of the various tug types for close-in maneuvering, but they fail to convey the information most important to the owner of the ship requiring assistance: the assist forces that can be brought to bear on the assisted ship, in the coordinates of that ship! After all, that is what the shipowner is buying, isn't it—assist force in the coordinates of his ship?

Figure 4 shows the assist forces resolved into both tug coordinates and ship coordinates. The components of the assist force in ship coordinates consist of a longitudinal force component, which may be either a towing force or a retarding (braking) force, and a transverse force component, which, depending on where it is applied upon the length of the assisted ship, may either move the ship sideways or turn the ship. In general we may regard the transverse component of the assist force as a steering force, especially when the assisted ship has forward speed.

It is instructive to consider the form that the vector diagrams of Fig. 3 would assume if they were transformed to express the bollard assist force capability in assisted vessel coordinates. They would assume the very simple form of a circle with radius equal to the bollard pull. Such a diagram would express the idea that, at zero speed, each tug could

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[4] Number in brackets indicates Reference at end of paper.

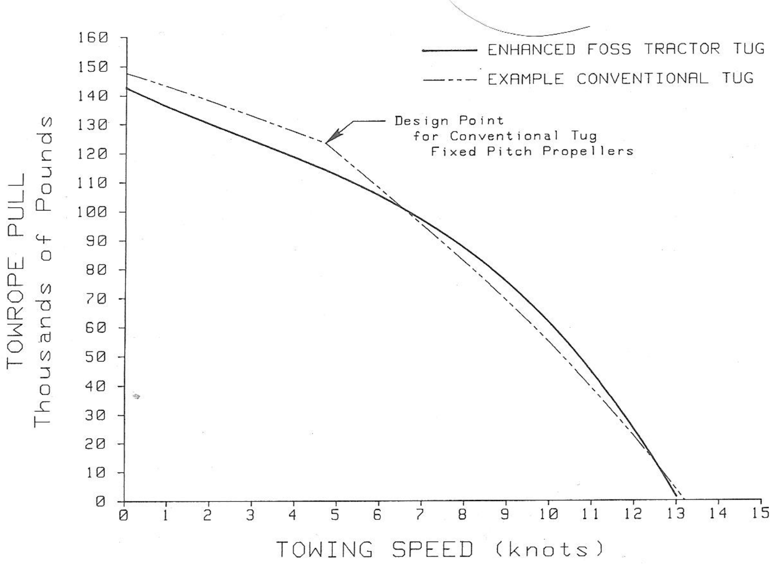

Fig. 2 Towrope pull versus speed

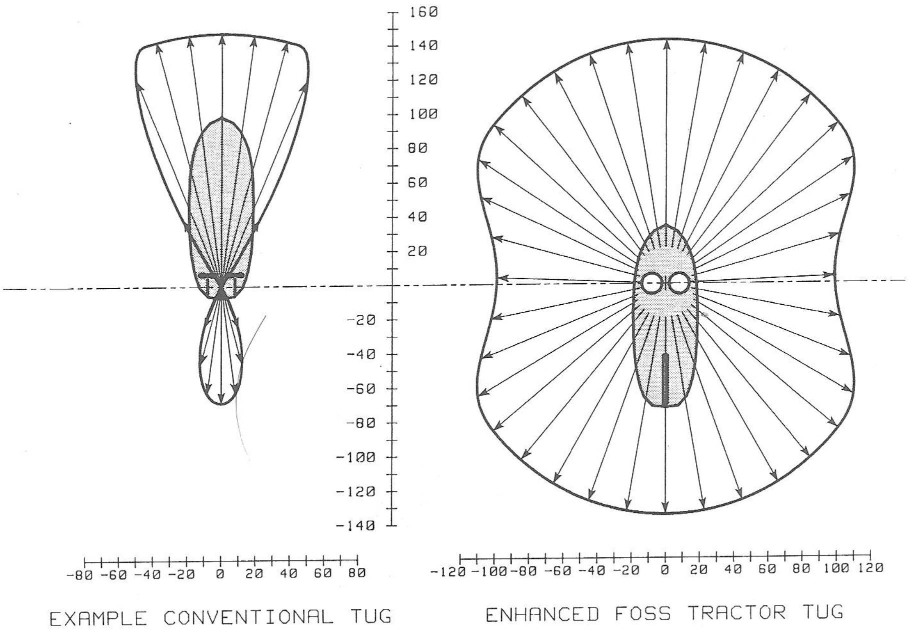

Fig. 3 Vector diagrams of bollard thrust

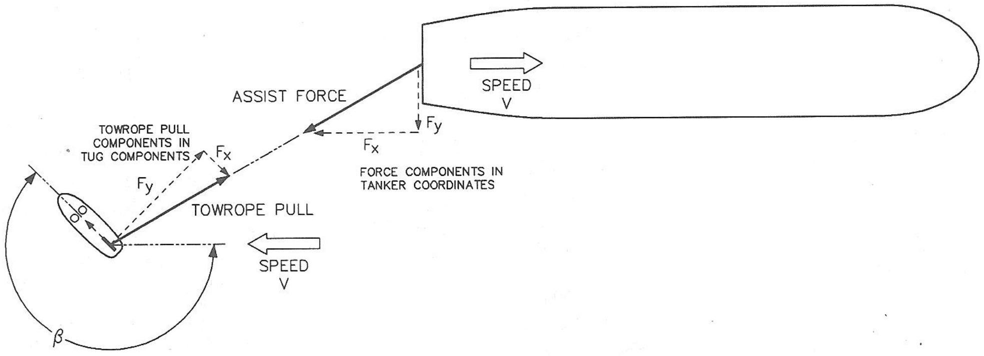

Fig. 4 Assist forces resolved in ship and tug coordinates

position itself so that it could apply its full bollard pull capability in any desired direction.

The relatively new requirement that tugs perform tanker escort duties places new demands on tugs (and on the naval architect attempting to assess the capabilities of various tugs, and tug types, to satisfy these new demands). The authorities who have mandated these tanker escorts clearly are acting in the belief that the tugs can render effective emergency assistance to a tanker that is proceeding at speeds up to 10 knots in restricted waters. This means that we must determine the assist forces that the tug can generate, in tanker coordinates, at all speeds of advance—from zero to perhaps as much as 12 knots. Our review in 1990 of the technical literature and discussions with European model basins and maneuvering simulators led us to conclude that the technical basis did not exist for determining these assist force capability diagrams. Accordingly, a model test program was devised to generate the basic data from which these capabilities could be developed.

Planar force model tests

Planar force tests were performed at MARIN with a captive model of the 7200 bhp Voith Schneider tractor tug design. The model was free to heave (sinkage), pitch (trim) and roll (heel), but was constrained in surge, sway and yaw. Horizontal plane forces (F_x, F_y) and moments (M_z) were measured and resolved to the towing point. The towing forces were applied at the elevation of the tow point so that the heeling behavior was correctly modeled. The heel angle was measured during the tests. Figure 5 is a photo of the model during these planar force tests. A complete program of tests was performed on the appended model, both with and without active model Voith Schneider propellers.

During the tests of the appended hull without model propellers, the propeller wells were plugged to produce a fair hull. Tests were conducted at speeds of 2, 6, 10 and 12 knots, and drift angles, β, of 0, 10, 20, 30, 50, 70, 90, 110, 130, 150, 160, 170 and 180 degrees. A drift angle of 0 deg corresponds to normal ahead operation, while a drift angle of 180 deg corresponds to operations skeg-end first. Many typical tractor tug operations in the indirect mode take place at drift angles on the order of 150 to 160 deg. Tests near β = 90 deg were not conducted at speeds above 6 knots, due to excessive heel angles.

Nondimensional hull force coefficients were determined from the tests of the appended hull without propellers. These coefficients included:

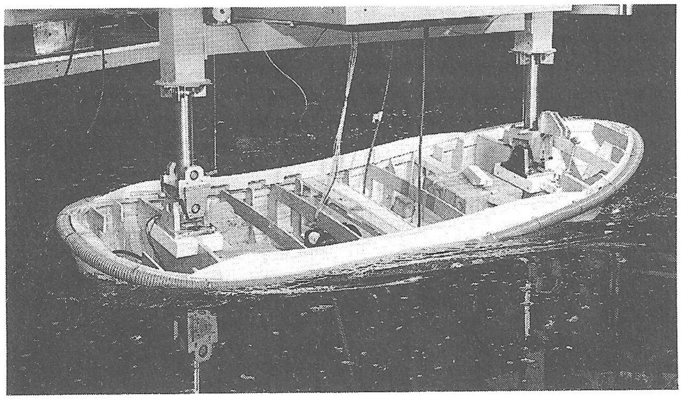

Fig. 5 Photo of model during planar force tests

$C_x(\beta)$ for longitudinal component of force in tug coordinates
$C_y(\beta)$ for transverse component of force in tug coordinates
$C_M(\beta)$ for moment about a vertical axis through tow point
$C_H(\beta)$ for vertical center of pressure on hull (below still waterline)

The elevation of the vertical center of pressure was derived on the basis of the metacentric height, GM_T; the measured heel angle, $\phi(\beta)$; and the measured transverse force, $F_y(\beta)$.

The data points determined for these nondimensional coefficients during the test program were used to generate interpolating polynomials, with the drift angle β as the independent variable. Simple interpolation is used for intermediate speeds since the nondimensional coefficients show very little speed dependence.

During the tests with operating model Voith Schneider propellers, the propeller torque and rpm were measured. Propeller pitch amplitude is set in the model Voith Schneider propellers by internal cam races. Pitch amplitudes of 100% ($P/D = 0.80$) and 80% ($P/D = 0.64$) were tested. Pitch direction was adjusted by rotating the propellers in the model. Equilibrium is established when the total net moment about a vertical axis through the tow point is zero. For each combination of drift angle, pitch amplitude and pitch direction, a series of propeller revolutions was tested to bracket the propeller thrust corresponding to equilibrium. Subsequently, the rpm, torque and power corresponding to equilibrium were established by interpolation.

In actual operation the Voith Schneider propellers are usually operated at constant rpm and the transverse component of pitch is adjusted to bring about equilibrium. The approach used during the model tests, where rpm was varied rather than pitch, was necessary because the pitch of the model propellers is not so easily varied, and then can be varied only in discrete increments.

In general this test method was very successful. In a few instances it was not possible to reduce the rpm sufficiently to bracket the equilibrium condition. This could have been corrected had tests been conducted with very low pitch amplitudes, but there was no provision for such tests in the program. The inability to achieve equilibrium in these few cases was not a major problem since the cases in question were very nearly in equilibrium without any propeller thrust, and it was clear both that the low values of thrust could be achieved and that the propeller flow was not going to significantly alter the overall flow.

Tests were conducted with operating model propellers in the direct mode for straight-ahead towing and self-propulsion, and also for the direct mode retarding maneuver. Tests were conducted with operating model propellers in the indirect mode at the following combinations of speed and drift angle:

SPEED, knots	DRIFT ANGLE, deg
6	137
8	140
10	152
12	160

These drift angles for each speed were selected on the basis of advance simulations.

The most significant finding from these planar force tests was that the hydrodynamic interaction was small between the flow around the hull and the propeller-induced flow. This means that good engineering estimates of performance can be generated by using the hull force coefficients, and equilibrium may be established by determining the required lateral thrust component from the Voith Schneider propellers. The longitudinal component (in tug coordinates) of propeller thrust does not disturb the equilibrium condition.

Simulation of tractor tug assist forces

The two principal findings of the planar force model tests were: (1) the nondimensional hull force coefficients, $C_x(\beta)$, $C_y(\beta)$, $C_M(\beta)$, and $C_H(\beta)$; and (2) the determination that the hydrodynamic interaction between the hull flow and the propeller flow was small. These findings form a sufficient basis for the development of a simulator for the behavior and performance of a Voith Schneider propelled tractor tug. They also tend to confirm advice received from Voith Schneider GmbH during our 1990 fact finding mission.

Equilibrium conditions must be established in the horizontal plane and in a vertical plane situated transversely in the tug. Figure 6 shows the freebody diagram for horizontal plane and Fig. 7 the freebody diagram for the vertical plane.

The condition for equilibrium in the horizontal plane is, as previously mentioned, that the moments about the tow point sum to zero. In the vertical plane the heel angle will increase until the roll restoring moment equals the heeling moment. The hull force acts at an elevation established by the coefficient $C_H(\beta)$ and the propeller forces are assumed to act at the middle of the propeller blade span.

Simulations were run for assisted vessel speeds of 2, 4, 6, 8, 10 and 12 knots. At each speed every drift angle between 0 and 180 deg was investigated, in increments of 1 deg. At each speed and drift angle the nominal longitudinal component of Voith Schneider propeller pitch was set at values ranging from −100% to +100% in increments of 10% (corresponding to Voith "lever" settings from −10 to +10 in unit steps).

For each case the required transverse component of Voith Schneider propeller thrust was determined from the horizontal plane equilibrium equations. The transverse component of Voith Schneider propeller pitch was determined from the required transverse thrust. If necessary, the longitudinal component of pitch was reduced in accordance with advice received from the manufacturer. Through this procedure all horizontal plane forces are established. The heeling moment is then determined and the heel angle for equilibrium can be computed.

Each case was subject to three constraints:

1. Acceptable cases must not exceed the Voith Schneider propeller thrust capability or power limits.
2. The heel angle for acceptable cases must not exceed that heel angle that brings water over the deck edge.
3. The towline lead in acceptable cases must not intersect the tug superstructure.

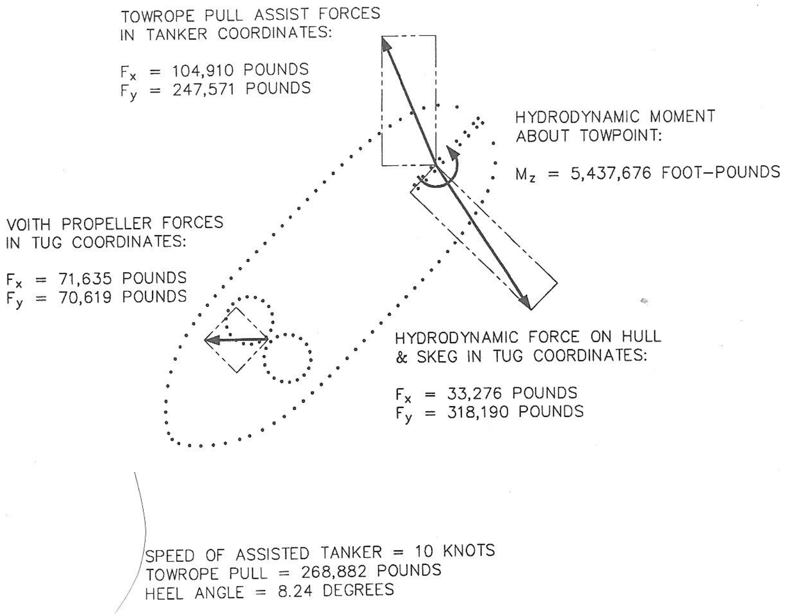

Fig. 6 Horizontal plane freebody diagram for Voith Schneider tractor tug

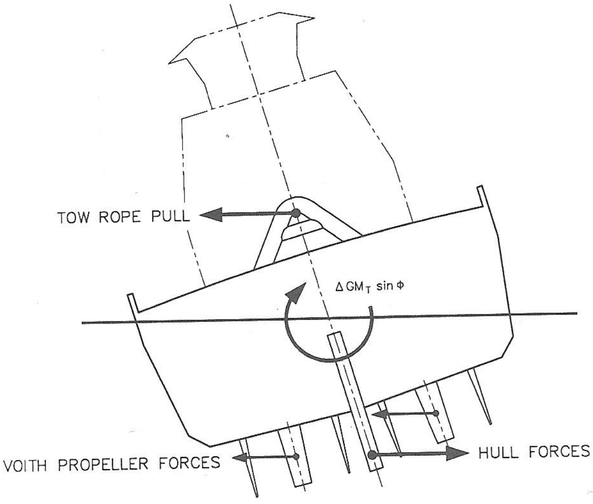

Fig. 7 Vertical plane freebody diagram for Voith Schneider tractor tug

The simulation model for Voith Schneider propeller thrust capability is too complex to present in this paper. The propeller thrust capability model provides an estimate of the x- and y-components of tandem propeller thrust (in tug coordinates), given: (1) the magnitude of the uniform inflow velocity (i.e., the tanker speed in the present instance); (2) the direction of the uniform inflow velocity vector in tug coordinates (i.e., the angle β); (3) the Voith lever setting; and (4) the Voith wheel setting. The propeller performance model was developed from data provided by the manufacturer and measurements taken during the model tests at MARIN.

The heel angle that brings water over the deck edge was established by observation during the planar force tests.

Cases where the towline intersected the tug superstructure occurred during some indirect mode maneuvers at low and intermediate speed values where the heel angle does not first intervene as a limit. In general, for any case where the towline intersected the superstructure there was a corresponding viable direct mode case which would generate larger assist forces.

Figure 8 shows a typical scatter plot showing all the viable assist cases for a simulation at 9 knots. Similar scatter plots were generated at speeds of 2, 4, 6, 8, 10 and 12 knots. The scatter diagram is plotted in the coordinates of the assisted ship and is symmetric about the longitudinal force axis. Each point indicates a combination of longitudinal and transverse components of assist force which it is possible to achieve.

Analysis of simulated assist forces

Interior points were eliminated from each scatter diagram (e.g., Fig. 8) to arrive at a set of points lying very near to the boundary of the assist force space, as shown in Fig. 9.

Figure 10 shows assist force contours for a 7200 bhp Voith Schneider tractor tug at speeds of 0, 2, 4, 6, 8, 10 and 12 knots. The forward towing force, $+F_x$, is greatest at $\theta = 0$ deg (12 o'clock). The forward towing force is seen to decrease with increasing speed, as also depicted in Fig. 2.

All of the points in the sector $90 < \theta < 270$ deg (i.e., between 3 o'clock and 9 o'clock) contain some element of retarding (braking) force. For speeds below 6 knots the greatest retarding force is to be found at $\theta = 180$ deg (6 o'clock), but for speeds of 6 knots and above, the greatest retarding force is found in combination with some lateral force. At 12 knots the maximum retarding force is found at approximately $\theta = 140$ and $\theta = 220$ deg (approximately 0440 and 0720 hr).

At zero speed the greatest lateral force (steering force) is found at $\theta = 90$ and $\theta = 270$ deg (3 o'clock and 9 o'clock), as would be expected. As the speed increases, the greatest steer-

Table 1 Stopping of 125 000 dwt tanker following loss of power at 10 knots

	Time to stop, min	Total Headreach, ft
7200 bhp VSP tractor	15.3	7400
7200 bhp open wheel	29.2	12600
Tanker unassisted	83.3	30400

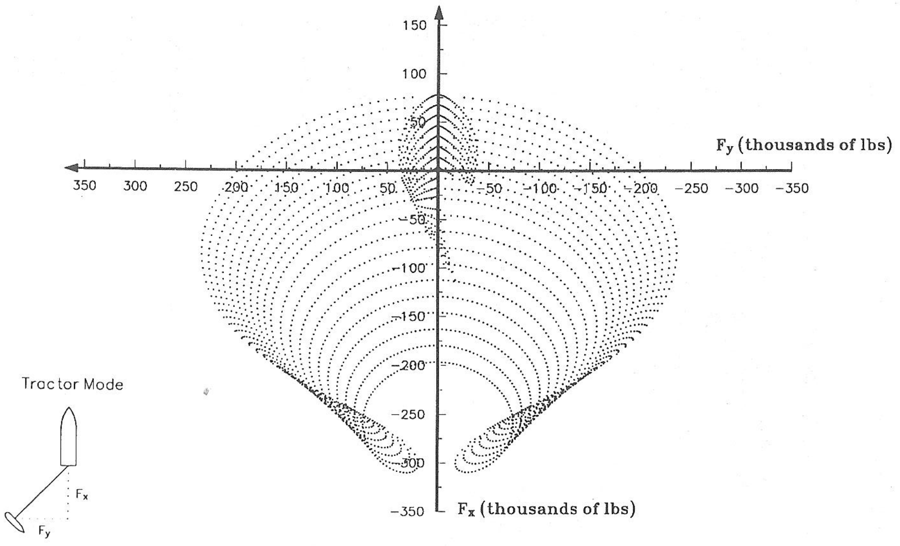

Fig. 8 Example scatter diagram of simulated assist forces. Raw data for assist force capability in tanker coordinates. Enhanced Foss tractor tug: 7200 bhp; number of data points = 3032; speed = 9 knots

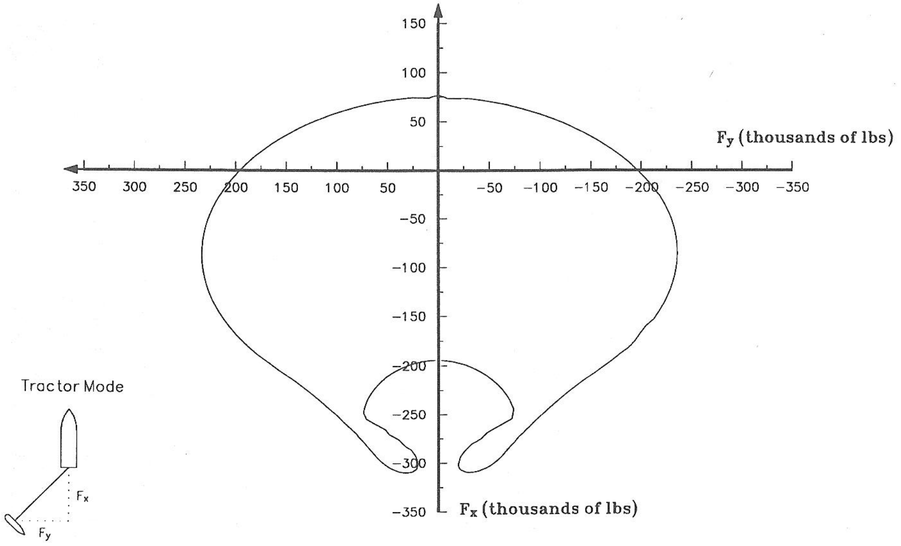

Fig. 9 Example showing points selected on boundary of assist force space. Assist force capability in tanker coordinates. Enhanced Foss tractor tug: 7200 bhp (—); speed = 9 knots

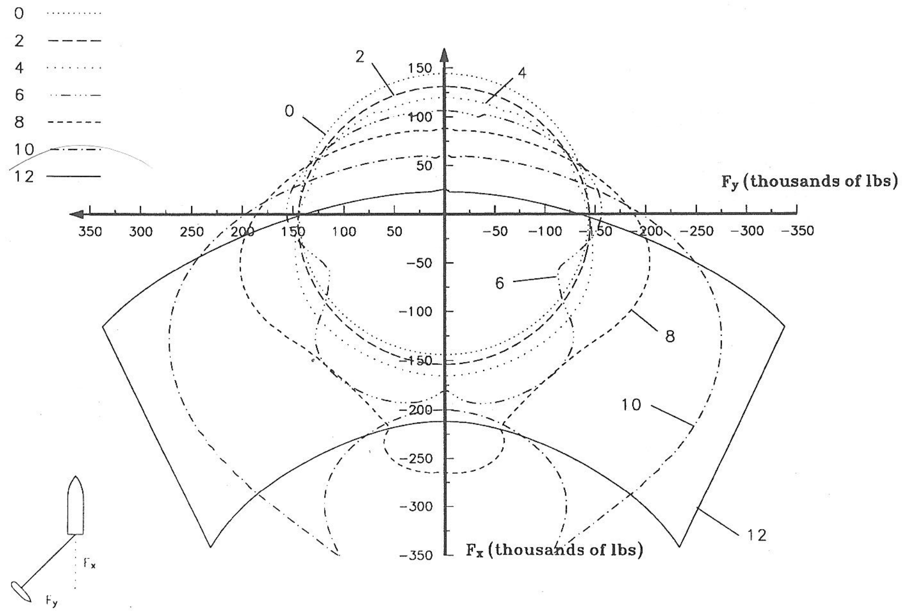

Fig. 10 Assist force contours for a 7200 bhp tractor tug. Assist force capability in tanker coordinates. Enhanced Foss tractor tug: 7200 bhp; speeds = 0, 2, 4, 6, 8, 10, 12 knots

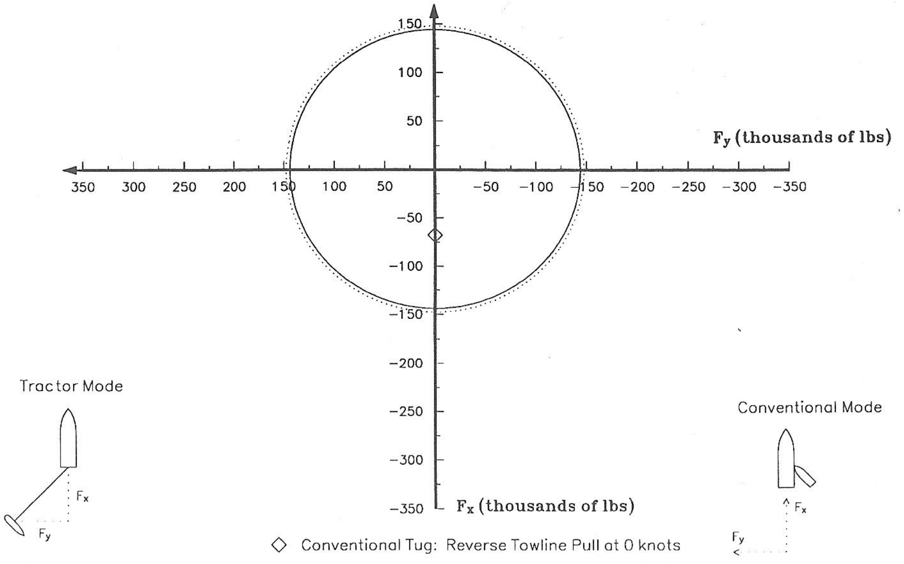

Fig. 11 Assist force contours for 7200 bhp tugs at 0 knots. Assist force capability in tanker coordinates. Enhanced Foss tractor tug: 7200 bhp (—). Conventional twin-screw open wheel tug: 7200 bhp (······); speed = 0 knots

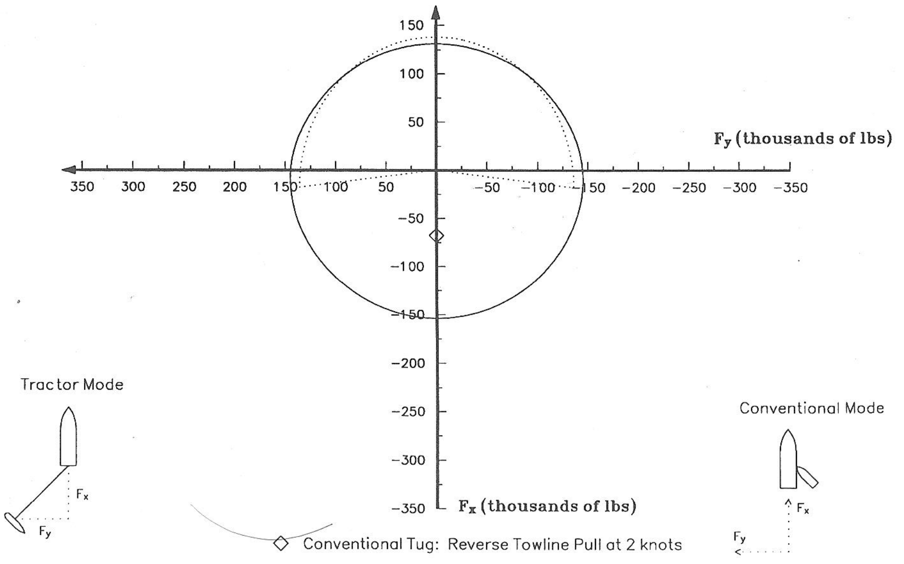

Fig. 12 Assist force contours for 7200 bhp tugs at 2 knots. Assist force capability in tanker coordinates. Enhanced Foss tractor tug: 7200 bhp (—). Conventional twin-screw open wheel tug: 7200 bhp (······); speed = 2 knots

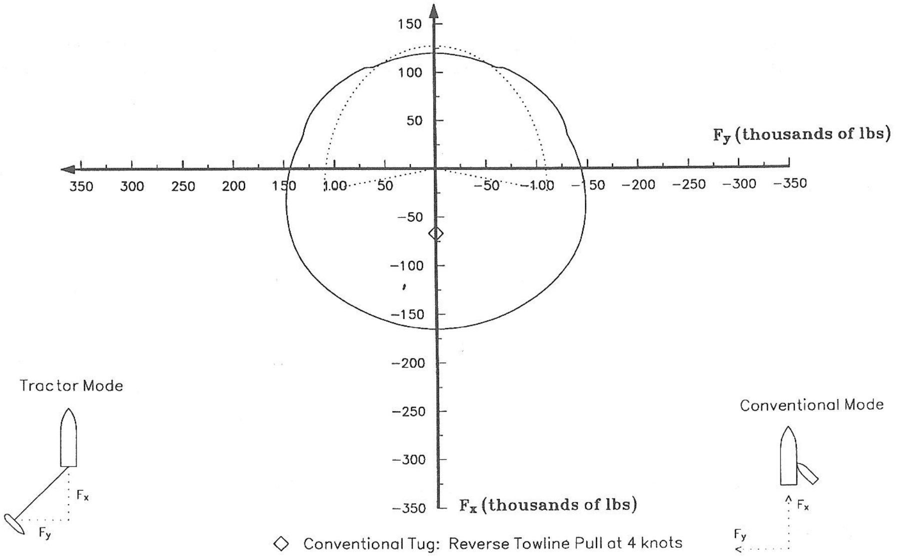

Fig. 13 Assist force contours for 7200 bhp tugs at 4 knots. Assist force capability in tanker coordinates. Enhanced Foss tractor tug: 7200 bhp (—). Conventional twin-screw open wheel tug: 7200 bhp (······); speed = 4 knots

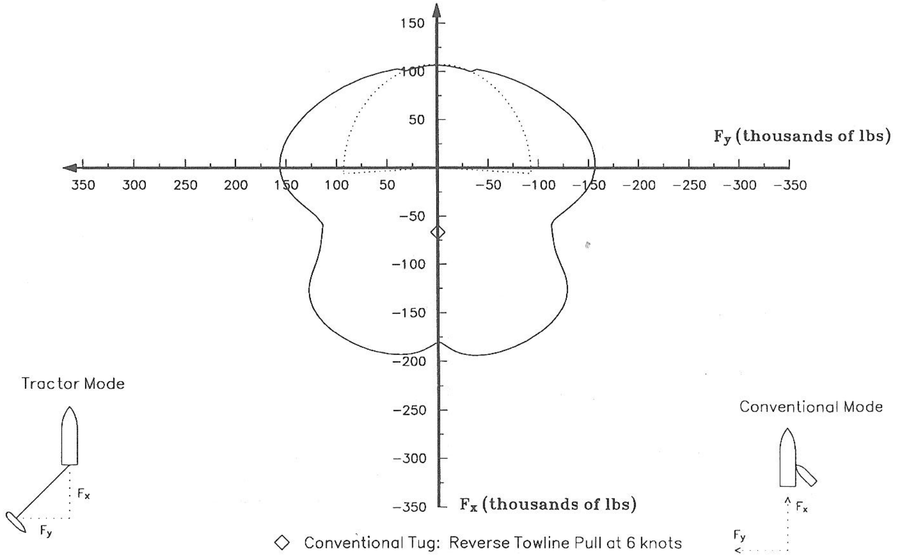

Fig. 14 Assist force contours for 7200 bhp tugs at 6 knots. Assist force capability in tanker coordinates. Enhanced Foss tractor tug: 7200 bhp (—). Conventional twin-screw open wheel tug: 7200 bhp (······); speed = 6 knots

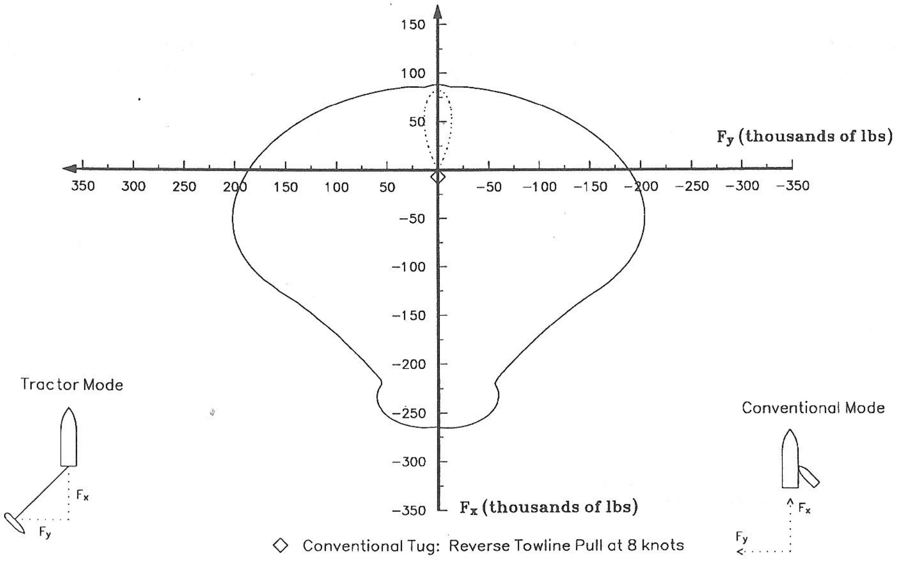

Fig. 15 Assist force contours for 7200 bhp tugs at 8 knots. Assist force capability in tanker coordinates. Enhanced Foss tractor tug: 7200 bhp (—). Conventional twin-screw open wheel tug: 7200 bhp (······); speed = 8 knots

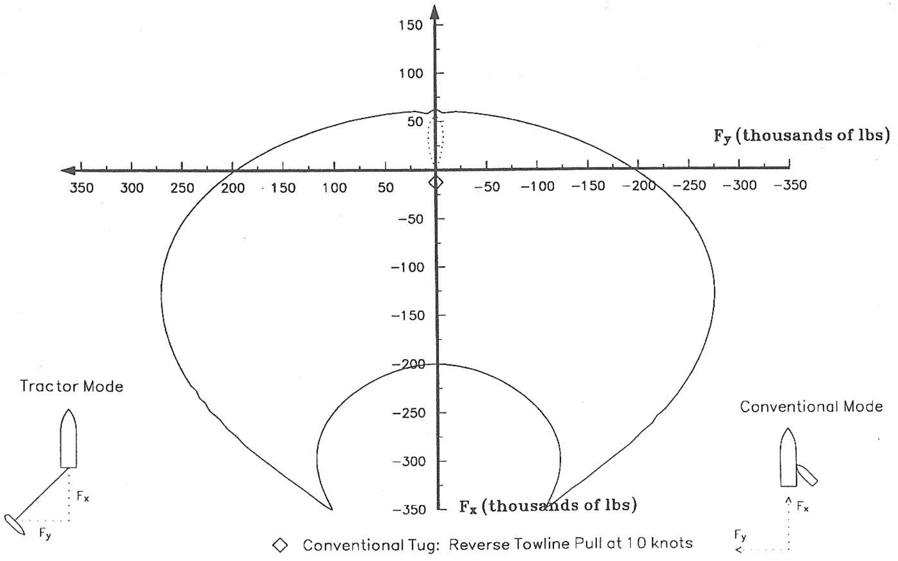

Fig. 16 Assist force contours for 7200 bhp tugs at 10 knots. Assist force capability in tanker coordinates. Enhanced Foss tractor tug: 7200 bhp (—). Conventional twin-screw open wheel tug: 7200 bhp (······); speed = 10 knots

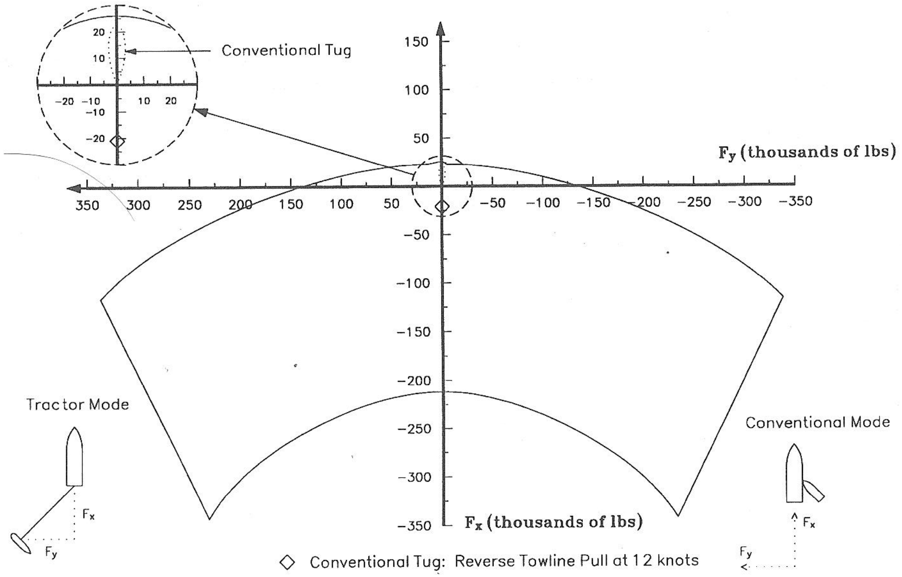

Fig. 17 Assist force contours for 7200 bhp tugs at 12 knots. Assist force capability in tanker coordinates. Enhanced Foss tractor tug: 7200 bhp (—). Conventional twin-screw open wheel tug: 7200 bhp (······); speed = 12 knots

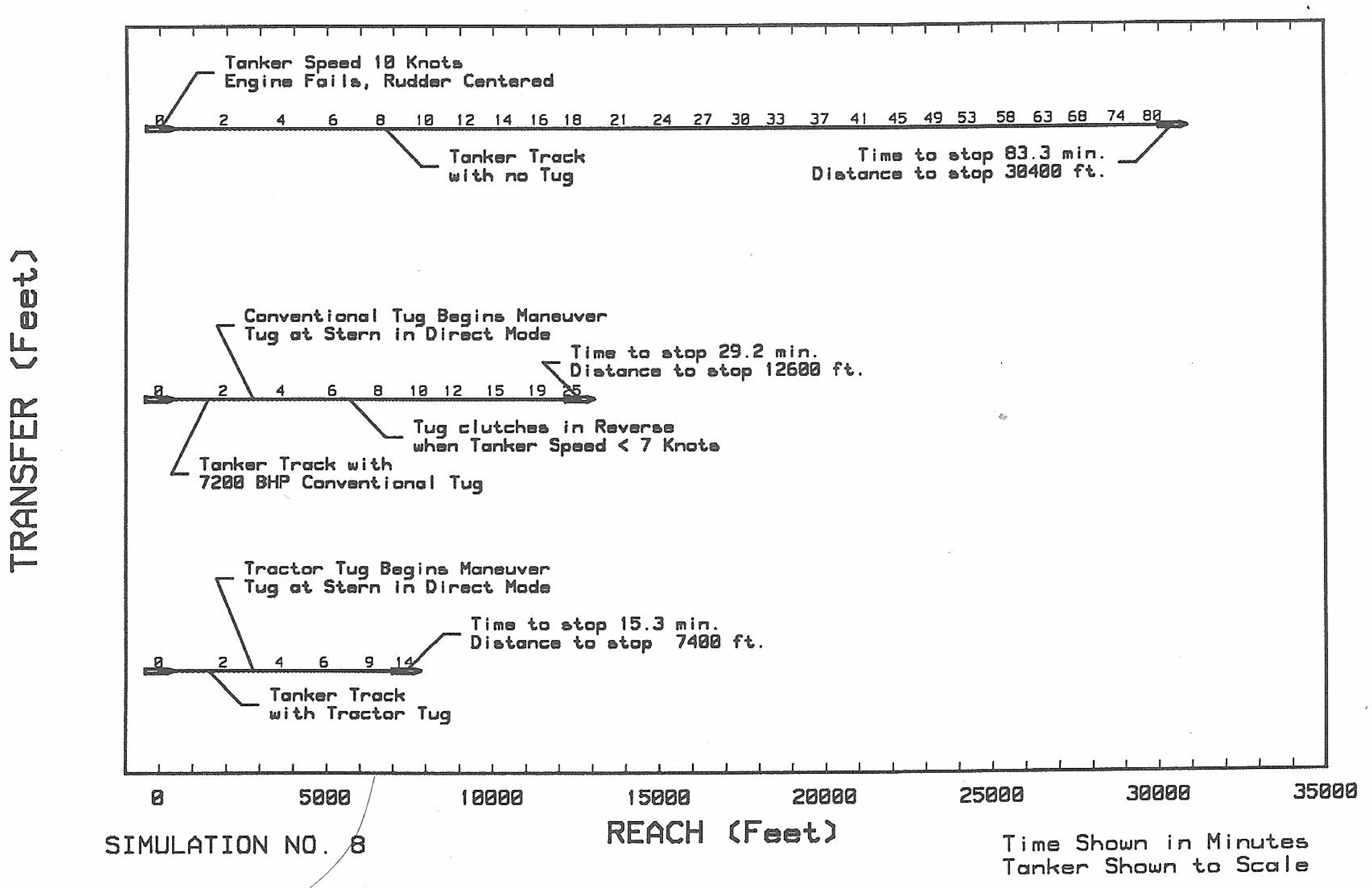

Fig. 18 Maneuvering simulation of stopping 125 000 dwt tanker following loss of power at initial speed of 10 knots

Table 2 Turning 125 000 dwt tanker 90 deg to port following steering failure with rudder 35 deg to starboard at 10 knots

	Tanker Conditions when Tug Is Engaged					Tanker Conditions at End of Maneuver				
	Time, min	Speed, knots	Reach, ft	Transfer, ft	Heading, deg	Time, min	Speed, knots	Reach, ft	Transfer, ft	Heading, deg
7200 bhp VSP tractor	3.0	8.04	2762	−183	110.0	11.2	1.75	7068	−477	0.0
7200 bhp open wheel	4.0	6.88	3519	−429	124.2	20.5	1.38	7774	−4798	0.0
Tanker unassisted	−0−	10.0	−0−	−0−	90.0	23.3	−1.72	3445	−5636	270.0

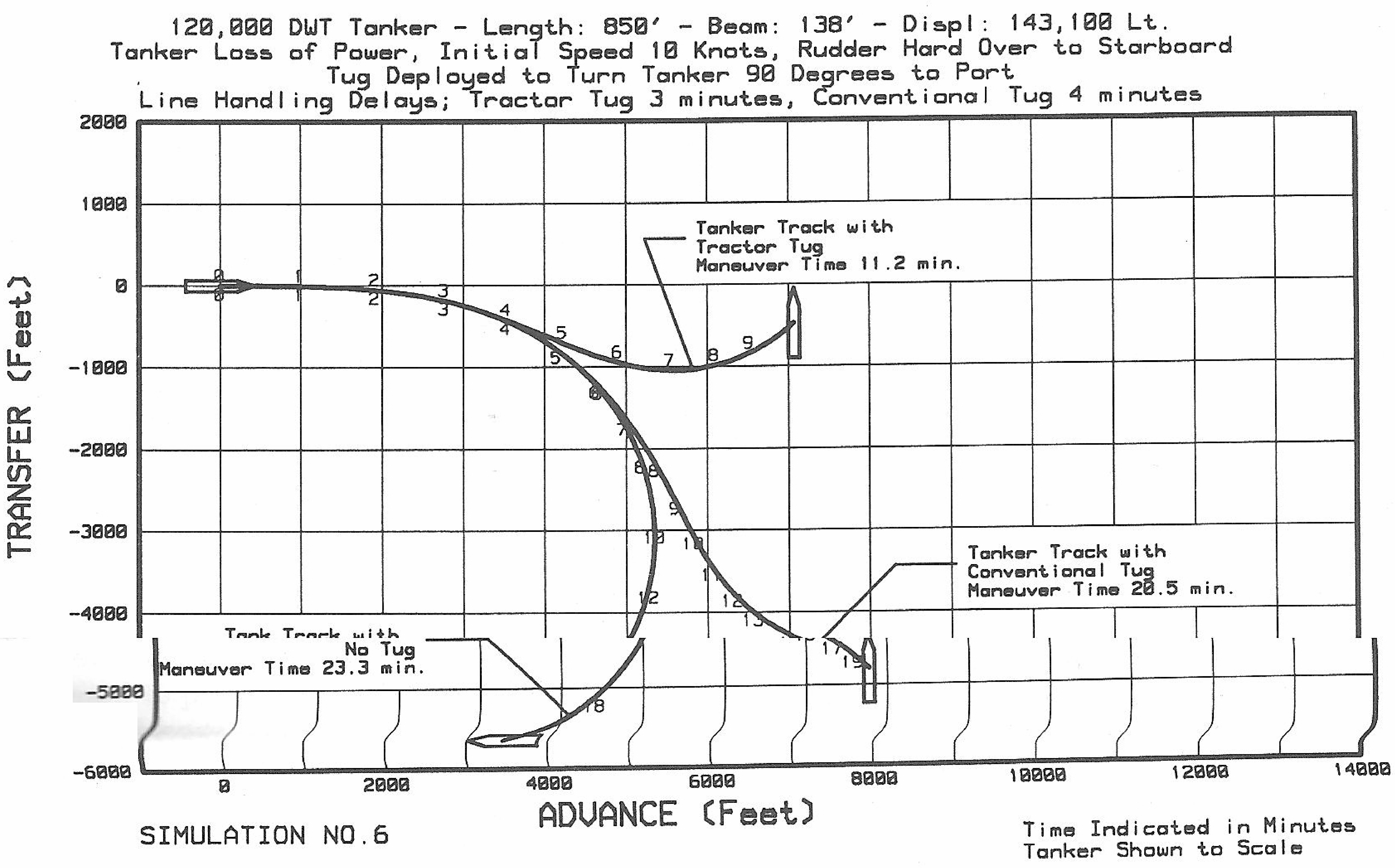

Fig. 19 Simulated tanker tracklines following rudder failure at 35 deg to starboard at 10 knots; 7200 bhp Voith tractor versus 7200 bhp conventional open wheel tug

ing force may be observed to shift its polar location to some considerable degree. First, at speeds of 2 and 4 knots it is seen to occur in combination with modest retarding forces. Then at 6 knots it is seen to occur in combination with some slight forward towing force (though steering forces of considerable magnitude are also available at 6 knots in combination with retarding forces or with no longitudinal force). And finally, at speeds of 8 knots and above, the maximum steering assist force is seen to occur in combination with moderate retarding forces.

By reasoning similar to that applied by Baer [1] to the vector diagram of bollard thrust (in tug coordinates) as shown in Fig. 3, the area in a given sector of these assist force contours, at a given speed, may be regarded as a measure of merit for certain types of activities. In particular, the area in the sector $90 < \theta < 270$ deg may be regarded as a measure of the capability of a tug to perform retarding (braking) assist duties for a large ship with forward speed and also as a measure of the capability to provide steering assistance.

As would be true for any tug, the capability in the forward sector, $0 < \theta < 90$ deg and $270 < \theta < 360$ deg, is equal to the capability in the aft sector $90 < \theta < 270$ deg at zero speed. What is remarkable about the Voith Schneider propelled tractor tug is the growth in aft sector capability with increasing speed. For speeds above 4 knots the capability of the Voith Schneider propelled tractor tug to provide retarding and steering assistance clearly exceeds its forward towing capability, and yet its forward towing capability is comparable to that of a conventional tug, as evinced by Fig. 2. Unlike forward sector towing capabilities, the capabilities of Voith Schneider propelled tractor tugs to provide retarding and steering forces actually increase, in absolute measure, with the forward speed of the assisted vessel.

Comparisons with conventional tug

Figures 11–17 show the assist force capability contours for the 7200 bhp Voith Schneider tractor tug discussed above, at speeds of 0, 2, 4, 6, 8, 10 and 12 knots respectively. Also shown in these figures, using dashed lines, is the corresponding estimated capability for a conventional 7200 bhp, twin-screw, fixed-pitch, open propeller tug. As shown in Fig. 2, the design point for the fixed-pitch propellers of this conventional 7200 bhp tug is about 4.7 knots.

The forward sector capabilities are seen to be similar up to a speed of about 4 knots. For speeds of 8 knots and above, the Voith Schneider propelled tractor tug has significantly greater assist force capabilities in the forward sector as well as in the aft sector. Except at zero speed (bollard condition) the Voith Schneider propelled tractor tug has significantly greater aft sector capability than a conventional tug of equal power. The steering force capability of the conventional tug is very limited at speeds of 8 knots and above. The retarding force capability of the conventional tug is limited, at speeds above 7.2 knots, to the drag of the hull with propellers locked by the shaft brakes. This is because the geared diesel drive is unable to clutch in and absorb the torque demand of the reversed fixed-pitch propellers at speeds above 7.2 knots.

These figures make it manifestly clear that a Voith Schneider propelled tractor tug is to be preferred over a comparably powered conventional tug when retarding or steering assist forces to a large vessel are desired, proceeding at speeds above about 2 knots. The tractor tug is seen to offer a greater range of towing and retarding forces, in combination with substantial steering forces, at all speeds. The tractor tug is revealed to be particularly capable of delivering combined steering and retarding forces. Thus the Voith Schneider propelled tractor tug excels at precisely those duties that are required of a tanker escort tug.

Simulations of tug-assisted tanker maneuvers

A large program of maneuvering simulation was undertaken using The Glosten Associates maneuvering simulator SHIPMAN. Comparisons were made between simulations and the full-scale trials of the 70 000 dwt tanker *Arco Sag River* and the 4000 bhp tractor tug *Arthur Foss*. Extensive simulations were made of 125 000 dwt tankers assisted by 7200 bhp conventional and tractor tugs. It is hoped that a full report on these simulations can be made in a future technical paper. Until then, the following two cases help to illustrate the suitability of Voith Schneider propelled tractor tugs to the tanker escort problem.

The first simulation is of stopping a 125 000 dwt tanker following loss of tanker power at 10 knots. The tractor tug stops the tanker in substantially less time and distance than the conventional tug, as detailed in Table 1 and illustrated in Fig. 18.

The second simulation concerns turning a tanker 90 deg to port, following a tanker steering failure with the rudder stuck at 35 deg to starboard. It is assumed that the tanker cuts its own power immediately upon recognizing the steering failure. Table 2 summarizes the results of this simulation and Fig. 19 illustrates the tracks of the unassisted tanker and those of the tanker with conventional or tractor tug assistance. The tractor tug is capable of limiting the transfer to little more than one tanker length, while the conventional tug assistance results in a trackline hardly better than that of the unassisted tanker.

Summary and conclusions

This paper presents a new method of describing and comparing tug assist capability. Two advantages are offered over previous approaches: the ability to examine tug assist capability with forward speed, and the presentation of tug assist forces in the coordinate system of the assisted vessel.

The results of model tests, full-scale trials and simulations have shown that Voith Schneider propelled tractor tugs are well suited to the stopping and steering assistance maneuvers required by tanker escort service. Tractor tugs are shown to be particularly effective at the higher speeds commonly encountered in escort service, which are precisely the conditions where conventional tugs are least effective in rendering retarding or steering assistance.

Future research goals include: (1) improving the Voith Schneider propeller thrust capability model; (2) mapping and understanding the various operating modes and domains internal to the Voith tractor tug capability diagrams; and (3) improving the assist capability models for conventional tugs.

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Reference

1 Baer, W., "Assessment of Tug Performance," Paper No. 4, First International Tug Conference, Thomas Reed and Company Ltd., London, 1970.