

## A note on mathematical modelling of tugs



## Tug types

Based on an extensive development program FORCE Technology has developed several mathematical models of various tug types, including

- ▶ ASD
- ▶ VSP
- ▶ Rotor
- ▶ Conventional twin-screw



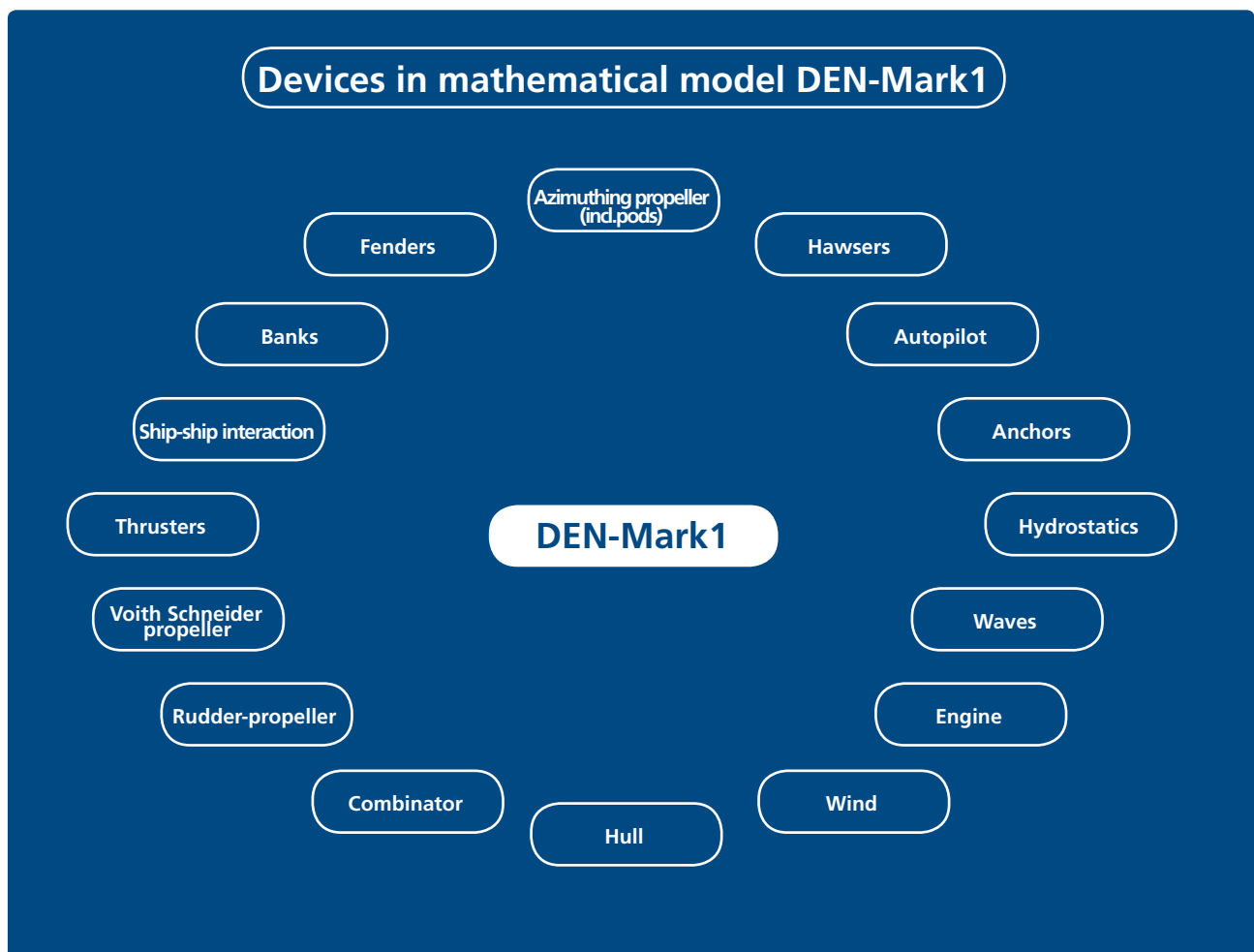
## Modelled effects

The mathematical model DEN-Mark1 consists of several modules (devices) as can be seen on the below figure.

In these devices we model the different hydrodynamic and mechanical effects on the ship. For tugs there are some effects that are especially important, namely:

- ▶ basic hydrodynamics
- ▶ thruster-thruster interaction
- ▶ propeller wash
- ▶ environmental forces
- ▶ thrust loss in waves
- ▶ ship-ship interaction
- ▶ fender forces

These effects are described on the following pages.





*Tug training in full-mission tug simulator*



*Svitzer Mars (ASD)*



*Kurtama 3 (VSP)*



PMM test with ASD tug in FORCE Technology's towing tank

## Basic hydrodynamics

The basic hydrodynamic effects include:

- ▶ resistance, damping and added mass forces
- ▶ propulsion and propeller-hull interaction

The hydrodynamics are based on captive model tests and Planar Motion Tests (PMM) and tuned against escort forces from free-sailing model tests.

## Thruster-thruster interaction

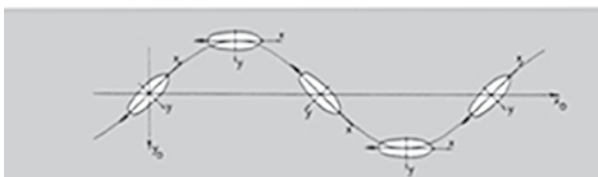
Thruster-thruster interaction is the effect of the slipstream of an azimuthing thruster influencing other thrusters.

Degradation of each thruster is determined by evaluation of the resulting inflow velocity, which is used in the table look-up of propeller forces.

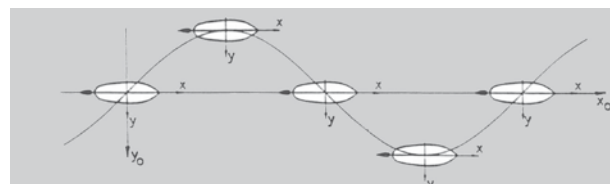
The model takes into account:

- ▶ thruster location
- ▶ thruster direction
- ▶ propeller loading
- ▶ ship speed

The thruster-thruster interaction model has been validated against model test data.



Pure yaw motion



Pure sway motion

Dynamic modes in PMM tests



*PMM test with ASD tug in FORCE Technology's towing tank*

## Propeller wash

The mathematical model includes the effect of propeller wash from the assisted ship hitting the tug.

The model depends on ship speed i.e. there is a larger wash effect in the bollard pull situation.

The actual thrust of the propeller is converted into local velocity using a simplified slipstream model, added in a similar way as current (see next page).



*Escort test with ASD tug in FORCE Technology's towing tank*

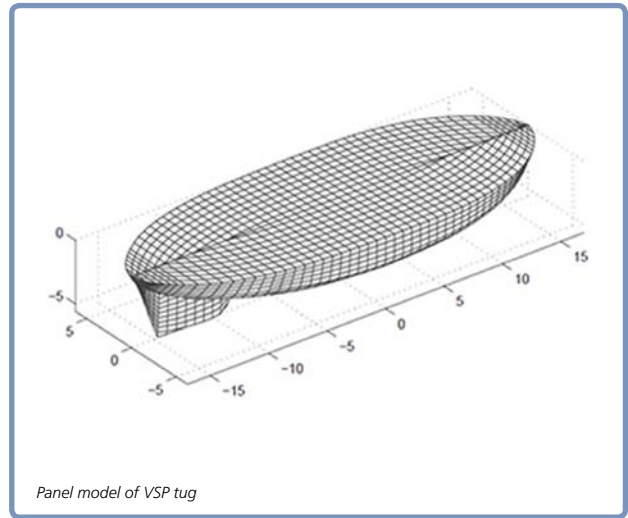
## Environmental forces

Environmental forces include wind, current and wave loads.

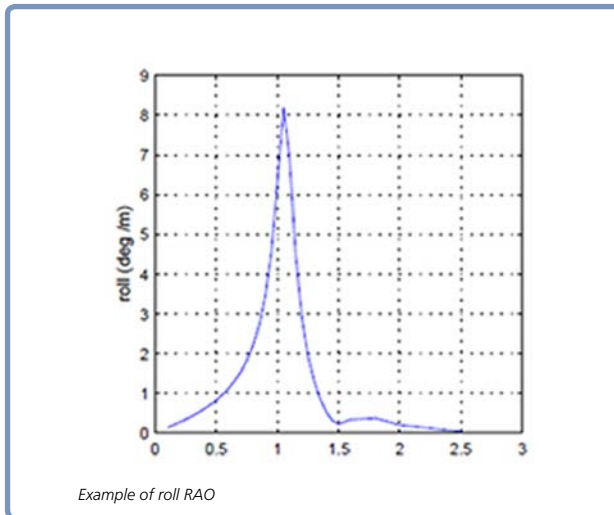
**Wind loads** are based on our database of wind tunnel test results.

**Current loads** are calculated by adding contribution to local speed through water in 20 points along hull, using tables of hydrodynamic forces in hull device.

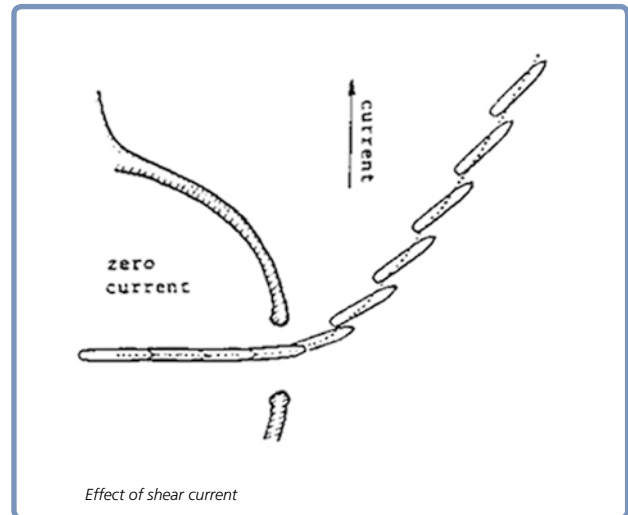
**Wave loads** are calculated for actual hull by in-house developed 3D-panel code OMEGA, giving 1st order forces (responses), 2nd order forces (drift) and damping due to wave radiation (hull memory). Roll damping is determined by empirical methods and tuned against model test data.



Panel model of VSP tug



Example of roll RAO



Effect of shear current



Full-mission tug simulator, 360° view.

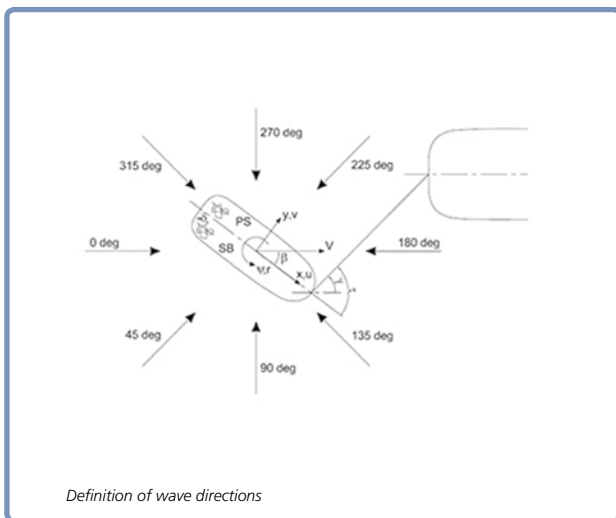
## 5. Thrust loss in waves

Tugs experience reduced propeller performance due to ventilation when working in waves. In the mathematical model this degradation function is determined by:

- ▶ wave height
- ▶ wave period
- ▶ relative wave direction
- ▶ propeller loading
- ▶ ship speed

In this way the model covers both the bollard pull and the escort situation.

The model is based on model test data



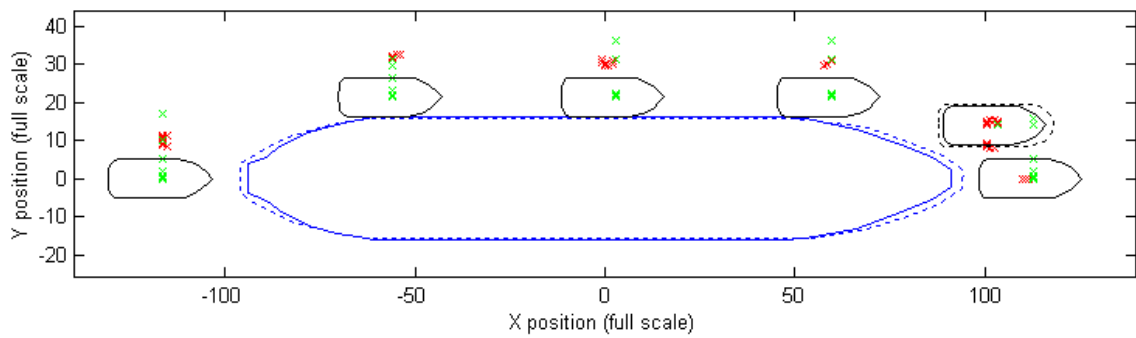
Escort test with ASD tug in waves in FORCE Technology's towing tank.

## Ship-ship interaction

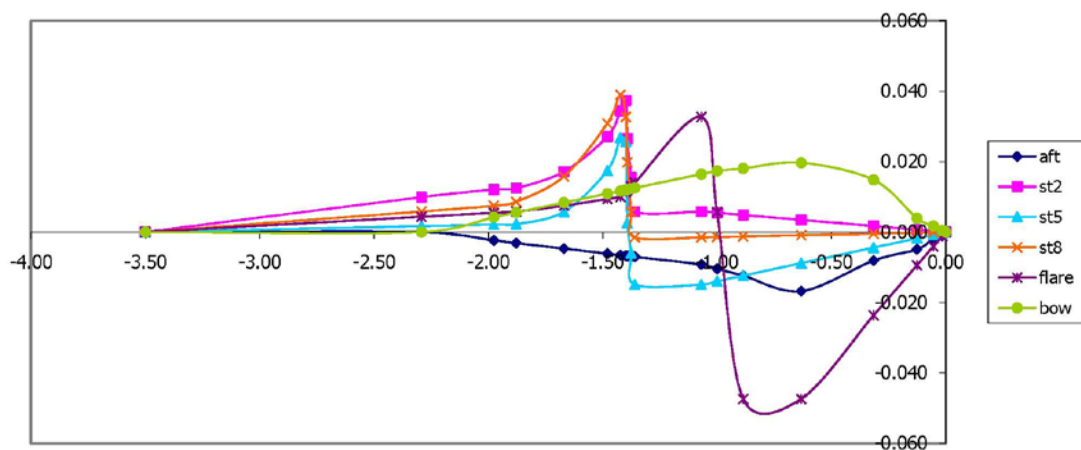
The ship-ship interaction effect is related to the presence of a pressure field when operating in the vicinity of an assisted ship at speed. This effect gives contribution to forces and moment on the tug depending on:

- ▶ relative location and
- ▶ relative direction
- ▶ speed
- ▶ water depth

The ship-ship interaction model is based on extensive model tests in our towing tanks.



Sketch of measured positions in model tests

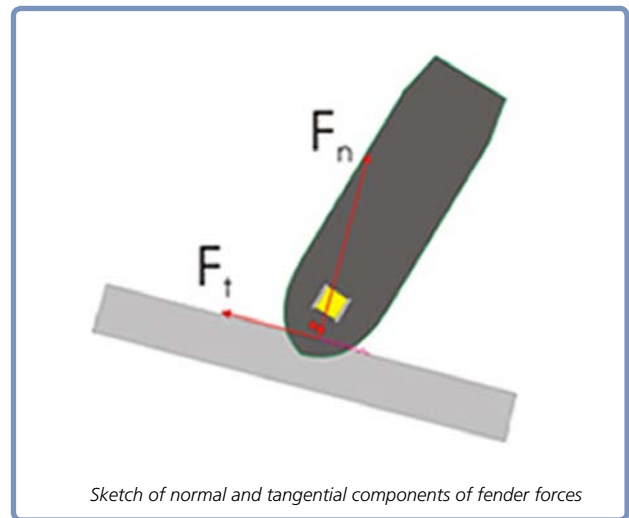
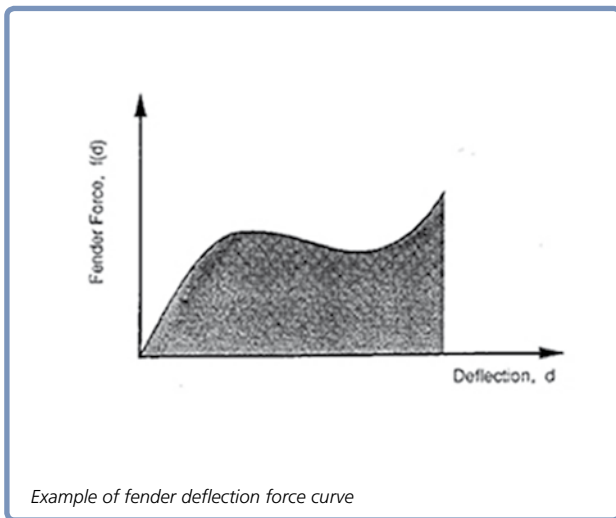


Example of measured data: interaction force as function of lateral distance at various positions

## Fender forces

The forces that occur when the tug is in contact with another ship are modelled based on the physics involved, where the following elements are taken into account:

- ▶ actual outline of ship at tug contact height
- ▶ break load of fender
- ▶ deflection force curve
- ▶ loss due to damping
- ▶ horizontal friction, both static and dynamic



*Visual image from FORCE Technology ship simulator*

## Hawser forces

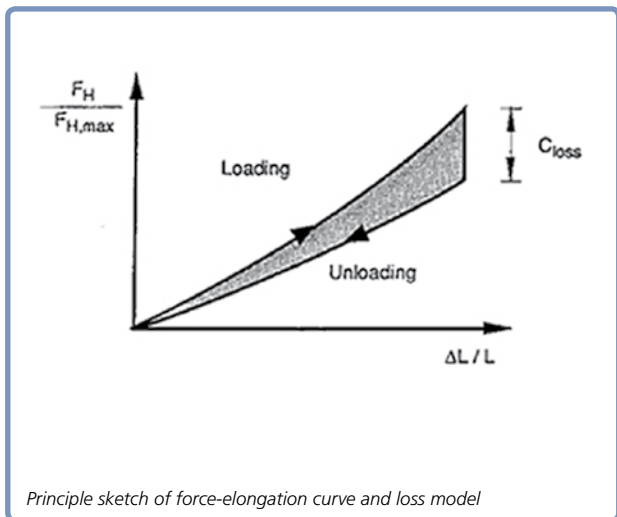
The model of the forces in the towline (hawser) includes the following:

- ▶ break load
- ▶ elongation force curve
- ▶ loss due to loading and unloading

The library of various towlines includes various types, such as nylon, ultraline and steeline, either new or used.

The winch is modelled by key parameters including:

- ▶ pull-in speed
- ▶ max pull force
- ▶ max brake force
- ▶ constant tension mode



Full-mission tug simulator at FORCE Technology

## Tuning and validation

The mathematical models of tugs at FORCE Technology have been tuned in cooperation with external tug masters from Svitzer, Voith and others.

The tuning includes validation tests covering free-sailing, bollard pull, connected and along-side manoeuvring. An extract from a validation sheet is shown below.

#	Name	Description	Parameter	Simulated values	Trial values
1	Speed	Straight ahead / astern at full power	Speed	ahead: 14.0 kn @ 100% rpm; astern: 13.9 kn @ 100% rpm	ahead: 14.0 kn @ 100% rpm; astern: 14.0 kn @ 100% rpm
			Time to reach max speed	ahead: 19 s @ 100% rpm; astern: 18 s @ 100% rpm	not available
2	Turning circle at speed	Turning circle started at steady full speed by commanding wheel pitch 8 on both units, completed at heading 360 deg	Turning diameter	ahead: 44 m from 14.0 kn, pitch 8; astern: 31 m from 14.0 kn, pitch 8	ahead: 32 m from 13 kn, pitch 8;(*) astern: 43 m from 13 kn, pitch 8
			Time to complete turn	ahead: 41 s from 14.0 kn, pitch 8; astern: 23 s from 14.0 kn, pitch 8	ahead: 39 s from 13 kn, pitch 8;(*) astern: 48 s from 13 kn, pitch 8
			Heel angle when steady	ahead: 7.3 deg; astern: 6.9 deg	not available
3	Turning on the spot	Turning circle started from zero speed by commanding speed pitch 0 and wheel pitch 10	Turning diameter	25 m @ pitch 10	< 1 ship length
			Time to complete turn	34 s @ pitch 10	51 s @ pitch 10
4	Crash stop	Stop manoeuvre performed by commanding full astern from full ahead (or visa versa)	Advance	ahead: 37 m @ pitch -10 to 10, 49 m @ pitch -9.5 to 6; astern: 40 m @ pitch 10 to -10, 47 m @ pitch 9.5 to -6	ahead: 36 m @ pitch -9.5 to 6; astern: 29 m @ pitch 9.5 to -6
			Time to stop	ahead: 9 s @ pitch -10 to 10, 13 s @ pitch -9.5 to 6; astern: 9 s @ pitch 10 to -10, 13 s @ pitch 9.5 to -6	ahead: 25 s @ pitch -9.5 to 6; astern: 21 s @ pitch 9.5 to -6
5	Bollard pull	Tug connected to land point, full ahead	Bollard pull	73-74 ton @ pitch 8	72 ton @ pitch 8 (max)
6	"Ready to work" manoeuvre	Tug still alongside LNG at zero speed. Tug then turns out stern 90 deg to be ready to work (push)	Time to reach new position	ab. 10 s @ LNG at zero speed	ab. 10-15 s
7	Change of position while connected at stern	Tug connect to stern of LNG at 4 kn in a position 40 deg on SB side rel. to LNG Tug then changes position to 50 deg on PS	Time to reach new position	ab. 50 s from PS 50 to SB 50	ab. 60 s
8	Bollard pull in waves	Tug connected to land point, full ahead in 2 m head waves	Bollard pull	74-78 ton @ pitch 8 using a 50 m line	72 ton ± ab. 5 ton @ pitch 8

Extract of validation sheet filled in for 34m VSP tug (ahead = VSP first; astern = fin first)

**Note:**

(\*) The trials for this tug were affected by strong current, which is assumed to be the reason for the unexpected relation between the measured turning circles ahead and astern.



**Further information**

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