Modelling and Simulation of Marine Surface Vessel Dynamics

(Module 10: Software and Rapid Model Prototyping)

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THE UNIVERSITY OF NEWCASTLE AUSTRALIA

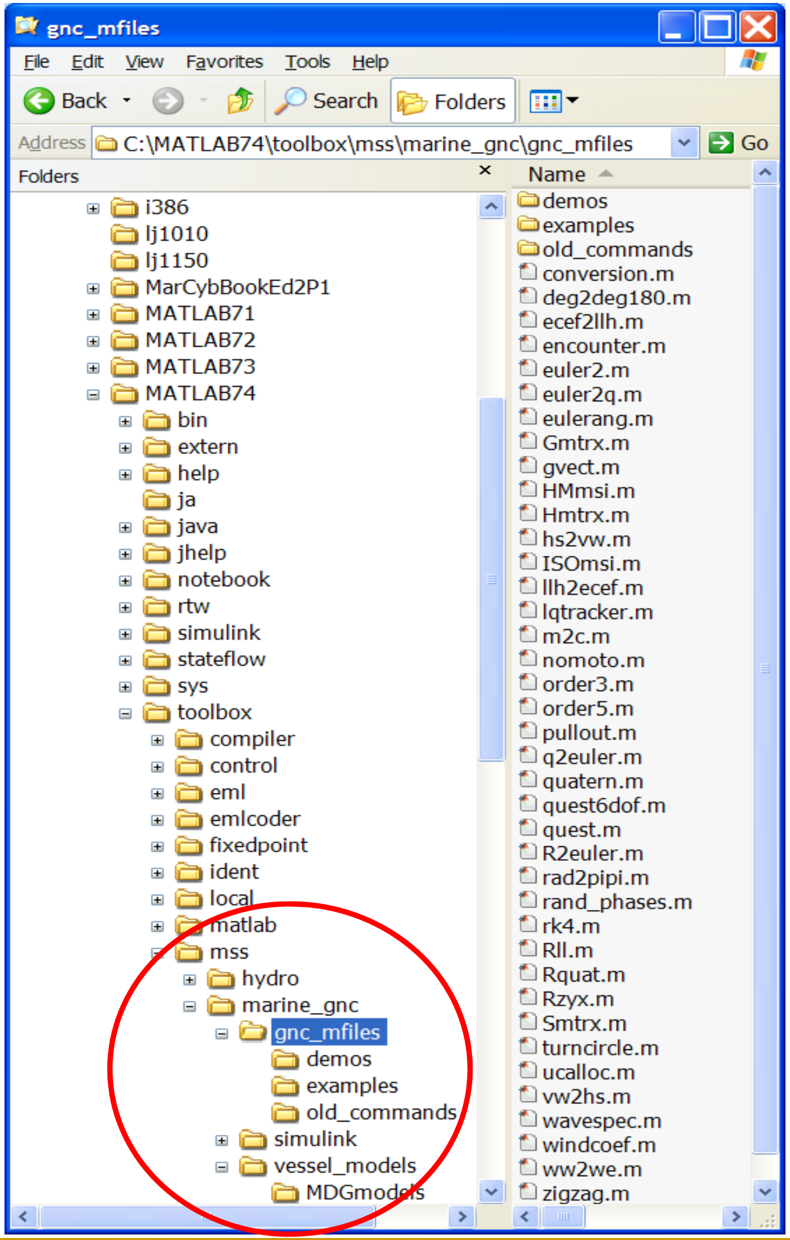
NTNU

Det skapende universitet

MSS – Marine Systems Simulator

- **GNC Toolbox** (m-file library and Simulink blocks)
  Used in T. I. Fossen (2002). Marine Control Systems

- **Hydro** (m-file library for hydrodynamic post-processing of hydrodynamic data + Simulink blocks for time-domain simulation of vessel responses in 6 DOF).
  Part of new book - worked examples - design of ship simulation models based on ship drawings
  T. Perez and T. I. Fossen (in progress)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hydro
marine_gnc
gnc_mfiles
demos
examples
old_commands
simulink
vessel_models
MDGmodels
demos
examples
old_commands
conversion.m
deg2deg180.m
ecef2llh.m
encounter.m
euler2.m
euler2q.m
eulerang.m
Gmtrx.m
gvect.m
HMmsi.m
Hmtrx.m
hs2vw.m
ISOmsi.m
llh2ecef.m
lqtracker.m
m2c.m
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order5.m
pullout.m
q2euler.m
quatern.m
quest6dof.m
quest.m
R2euler.m
rad2pipi.m
rand_phases.m
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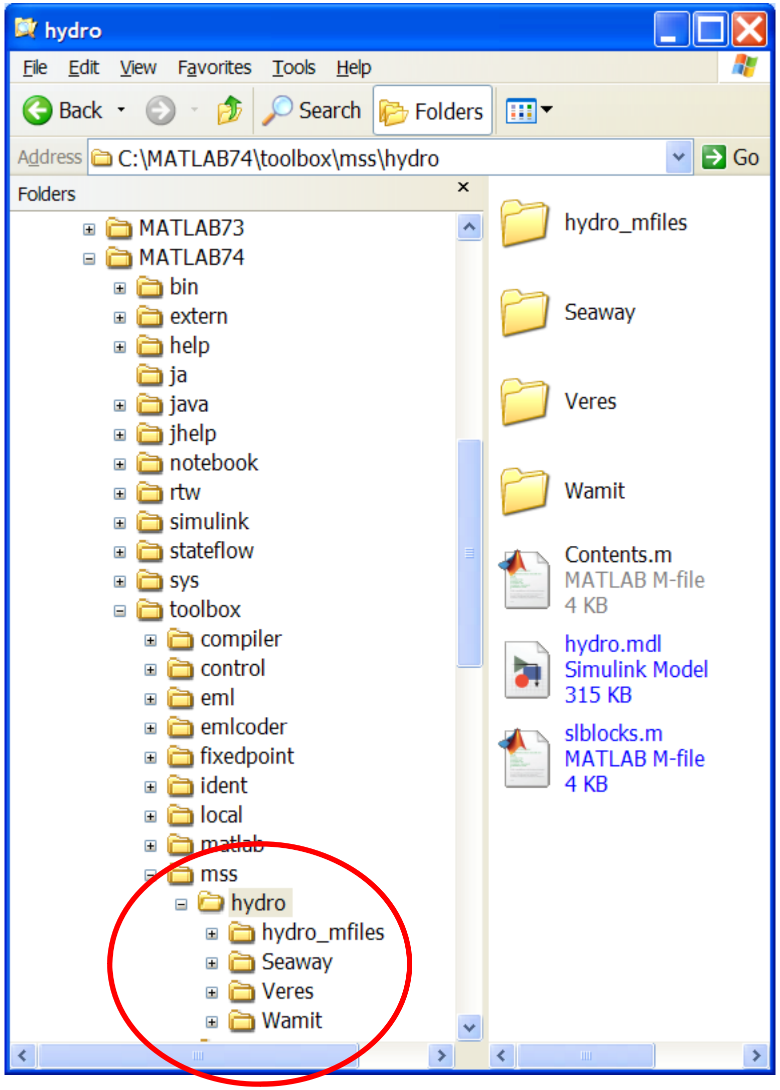
ww2we.m
zigzag.m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fixedpoint
ident
local
matlab
mss
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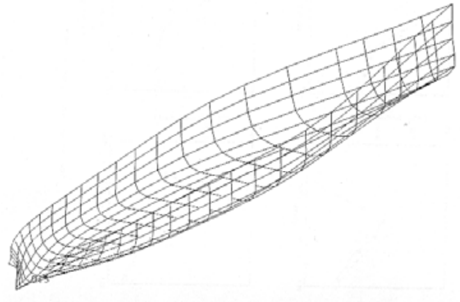
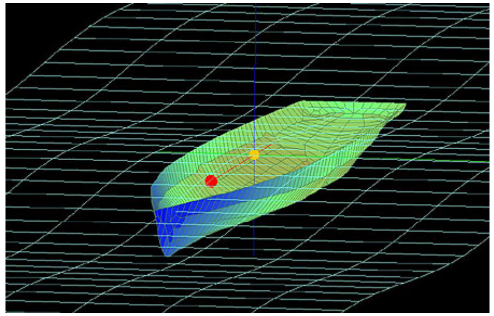
hydro_mfiles
Seaway
Veres
Wamit
hydro_mfiles
Seaway
Veres
Wamit
Contents.m
MATLAB M-file
4 KB
hydro.mdl
Simulink Model
315 KB
slblocks.m
MATLAB M-file
4 KB

From Vessel Body Plan to MSS





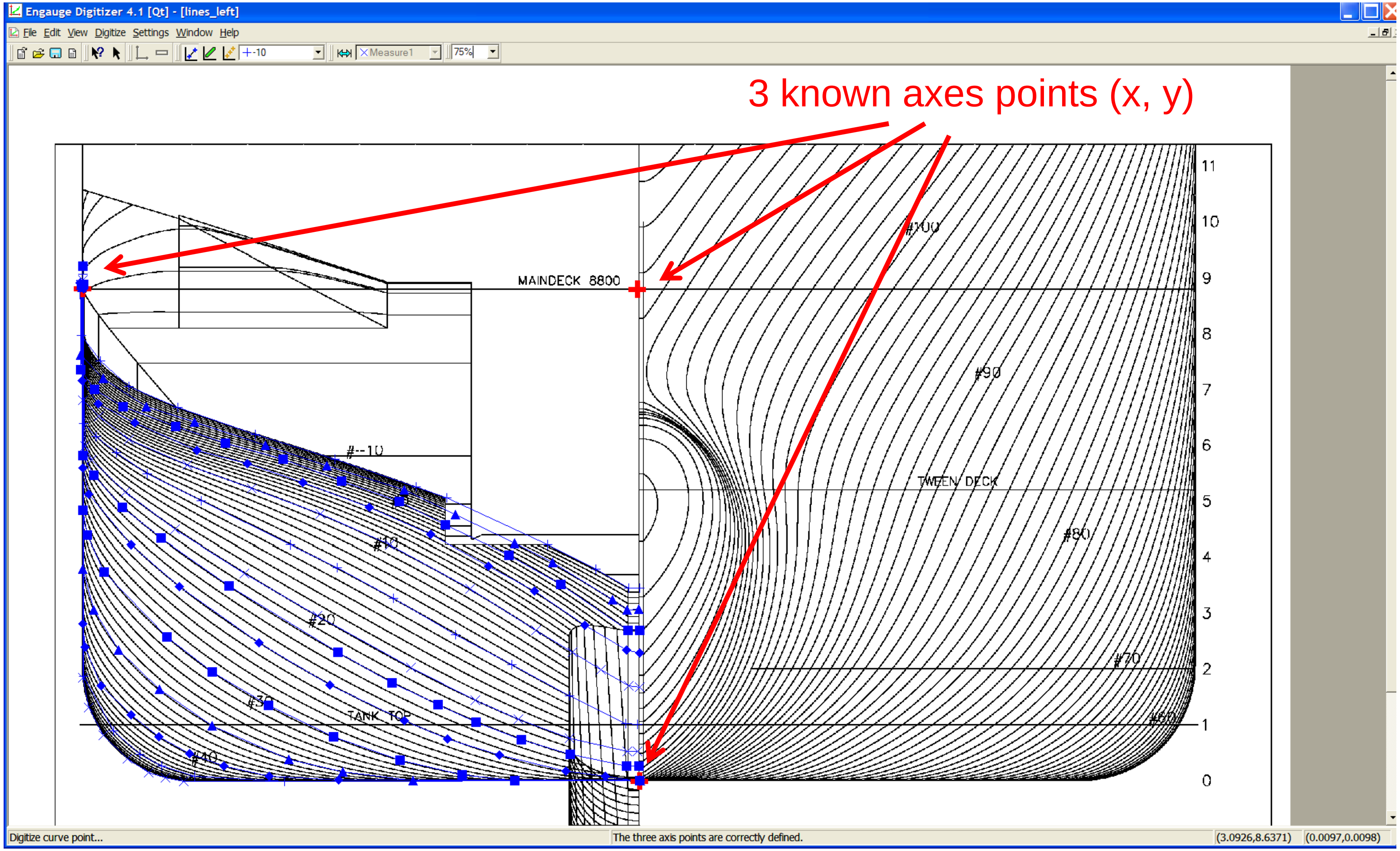
1. Body plan (general arrangement)
- Drawing can be scanned and digitalized manually
- Geometry file: AutoCad, ShipX, Wamit, Napa, etc.

2. Hydrodynamic Configuration and Computations
- SW: Wamit, Shipx (VERES), Octopus (SEAWAY) etc.
- Computes:
  - Frequency-dependent added mass and potential damping
  - Restoring forces
  - Froude-Krylov and diffraction forces (1st-order wave loads)
  - Wave drift (2nd-order wave loads)
  - Viscous roll damping (Ikeda damping etc.)

3. Post-Processing (MSS Hydro)
- Computes state-space models for frequency-dependent hydrodynamics
- Add viscous damping like linear skin friction, ITTC drag, cross-flow drag
- Add nonlinear maneuvering coefficients

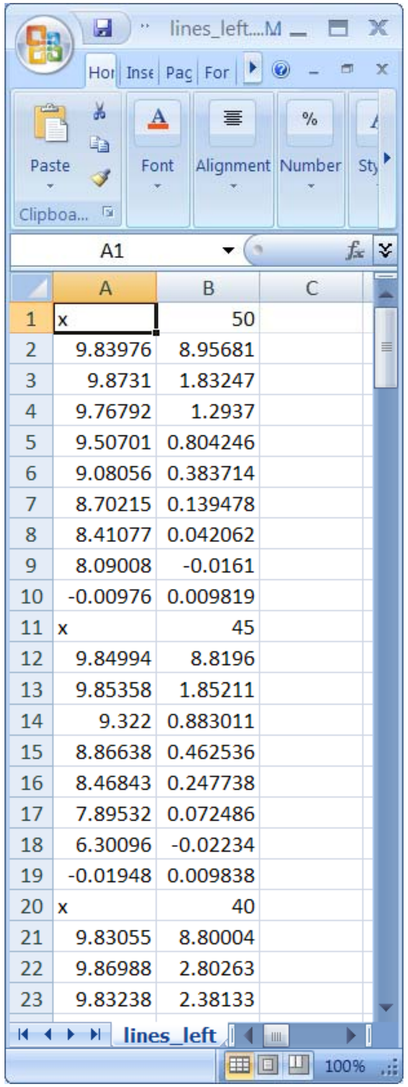
4. Simulink Vessel Simulator (MSS Hydro)
- 6 DOF real-time simulation of vessel position, velocity, and acceleration + wind, current, and wave generators.
- For a floating vessel the resulting model will be described by 100-200 ODEs. Wave load data for different speeds and headings (0-360 deg) are also included.

Digitizing the Ship Lines using a Drawing



Export to Table of Offsets

The digitized ship sections are exported to Excel in two columns (xz-plan) from Digitizer



	A	B	C
1	x	50	
2	9.83976	8.95681	
3	9.8731	1.83247	
4	9.76792	1.2937	
5	9.50701	0.804246	
6	9.08056	0.383714	
7	8.70215	0.139478	
8	8.41077	0.042062	
9	8.09008	-0.0161	
10	-0.00976	0.009819	
11	x	45	
12	9.84994	8.8196	
13	9.85358	1.85211	
14	9.322	0.883011	
15	8.86638	0.462536	
16	8.46843	0.247738	
17	7.89532	0.072486	
18	6.30096	-0.02234	
19	-0.01948	0.009838	
20	x	40	
21	9.83055	8.80004	
22	9.86988	2.80263	
23	9.83238	2.38133	

The VERES geometry file format looks as follows:

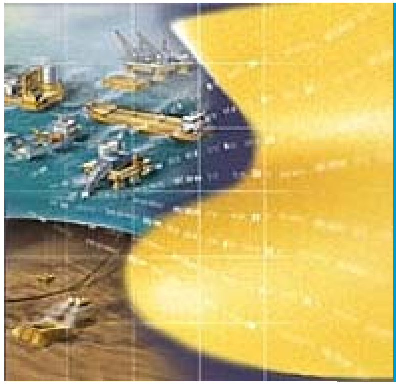
```
Text string 1
Text string 2
Text string 3
Text string 4
LPP (i.e. the value of Lpp, NEW IN VERES VERSION 4!)
Section_number
X-position
Number_of_points
y(Section_number,1)                 z(Section_number,1)
y(Section_number,2)                 z(Section_number,2)
      .                                   .
      .                                   .
y(Section_number,Number_of_points)  z(Section_number,Number_of_points)
Next_section_number
      .
```

Example: S175 container ship.

```
VERES Geometry file
Demo
S-175 Container Ship,
Basic design, Draught = 9.5 m.
175.0
    1
-87.500
   15
0.280   11.000
0.110   10.000
0.100    9.000
0.200    8.000
0.350    7.000
0.560    6.000
0.820    5.000
1.100    4.000
1.320    3.000
1.340    2.000
```

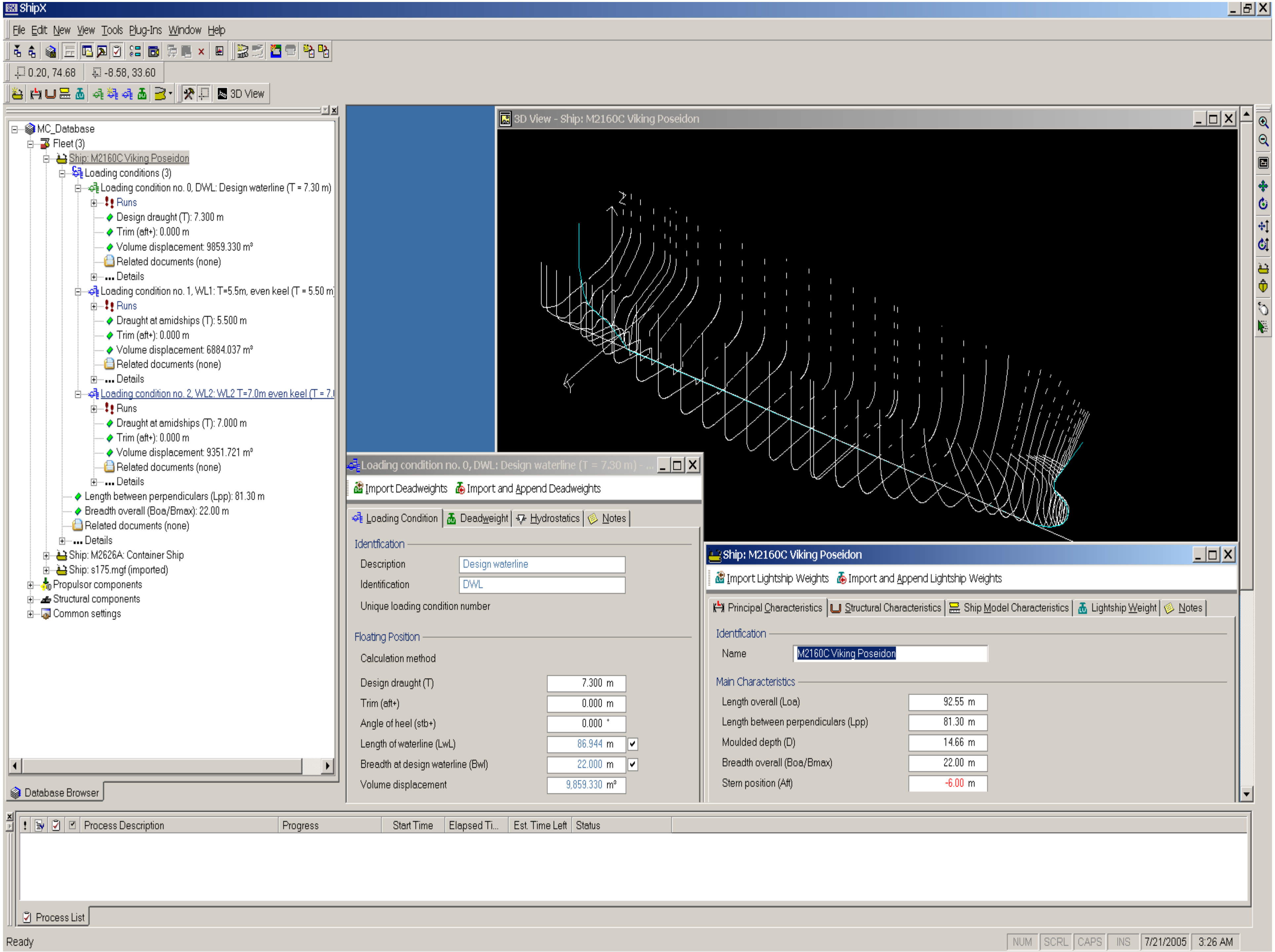
Ascii file: S175.mgf

ShipX (VERES) by MARINTEK



MARINTEK - the Norwegian Marine Technology Research Institute - does research and development in the maritime sector for industry and the public sector. The Institute develops and verifies technological solutions for the shipping and maritime equipment industries and for offshore petroleum production.

VERES - **VEssel RESponse program** is a **Strip Theory Program** which calculates wave-induced loads on and motions of mono-hulls and barges in deep to very shallow water. The program is based on the famous paper by **Salvesen**, **Tuck** and **Faltinsen** (1970). *Ship Motions and Sea Loads*. Trans. SNAME.


ShipX
File Edit New View Tools Plug-Ins Window Help
0.20, 74.68
-8.58, 33.60
3D View
MC_Database
Fleet (3)
Ship: M2160C Viking Poseidon
Loading conditions (3)
Loading condition no. 0, DWL: Design waterline (T = 7.30 m)
Runs
Design draught (T): 7.300 m
Trim (aft+): 0.000 m
Volume displacement: 9859.330 m³
Related documents (none)
Details
Loading condition no. 1, WL1: T=5.5m, even keel (T = 5.50 m)
Runs
Draught at amidships (T): 5.500 m
Trim (aft+): 0.000 m
Volume displacement: 6884.037 m³
Related documents (none)
Details
Loading condition no. 2, WL2: WL2 T=7.0m even keel (T = 7.
Runs
Draught at amidships (T): 7.000 m
Trim (aft+): 0.000 m
Volume displacement: 9351.721 m³
Related documents (none)
Details
Length between perpendiculars (Lpp): 81.30 m
Breadth overall (Boa/Bmax): 22.00 m
Related documents (none)
Details
Ship: M2626A: Container Ship
Ship: s175.mgf (imported)
Propulsor components
Structural components
Common settings
Database Browser
3D View - Ship: M2160C Viking Poseidon
Loading condition no. 0, DWL: Design waterline (T = 7.30 m) - ...
Import Deadweights
Import and Append Deadweights
Loading Condition
Deadweight
Hydrostatics
Notes
Identfication
Description
Design waterline
Identification
DWL
Unique loading condition number
Floating Position
Calculation method
Design draught (T)
7.300 m
Trim (aft+)
0.000 m
Angle of heel (stb+)
0.000 °
Length of waterline (LwL)
86.944 m
Breadth at design waterline (Bwl)
22.000 m
Volume displacement
9,859.330 m³
Ship: M2160C Viking Poseidon
Import Lightship Weights
Import and Append Lightship Weights
Principal Characteristics
Structural Characteristics
Ship Model Characteristics
Lightship Weight
Notes
Identfication
Name
M2160C Viking Poseidon
Main Characteristics
Length overall (Loa)
92.55 m
Length between perpendiculars (Lpp)
81.30 m
Moulded depth (D)
14.66 m
Breadth overall (Boa/Bmax)
22.00 m
Stern position (Aft)
-6.00 m
Process Description
Progress
Start Time
Elapsed Ti...
Est. Time Left
Status
Process List
Ready
NUM
SCRL
CAPS
INS
7/21/2005
3:26 AM

OCTOPUS SEAWAY by Amarcon

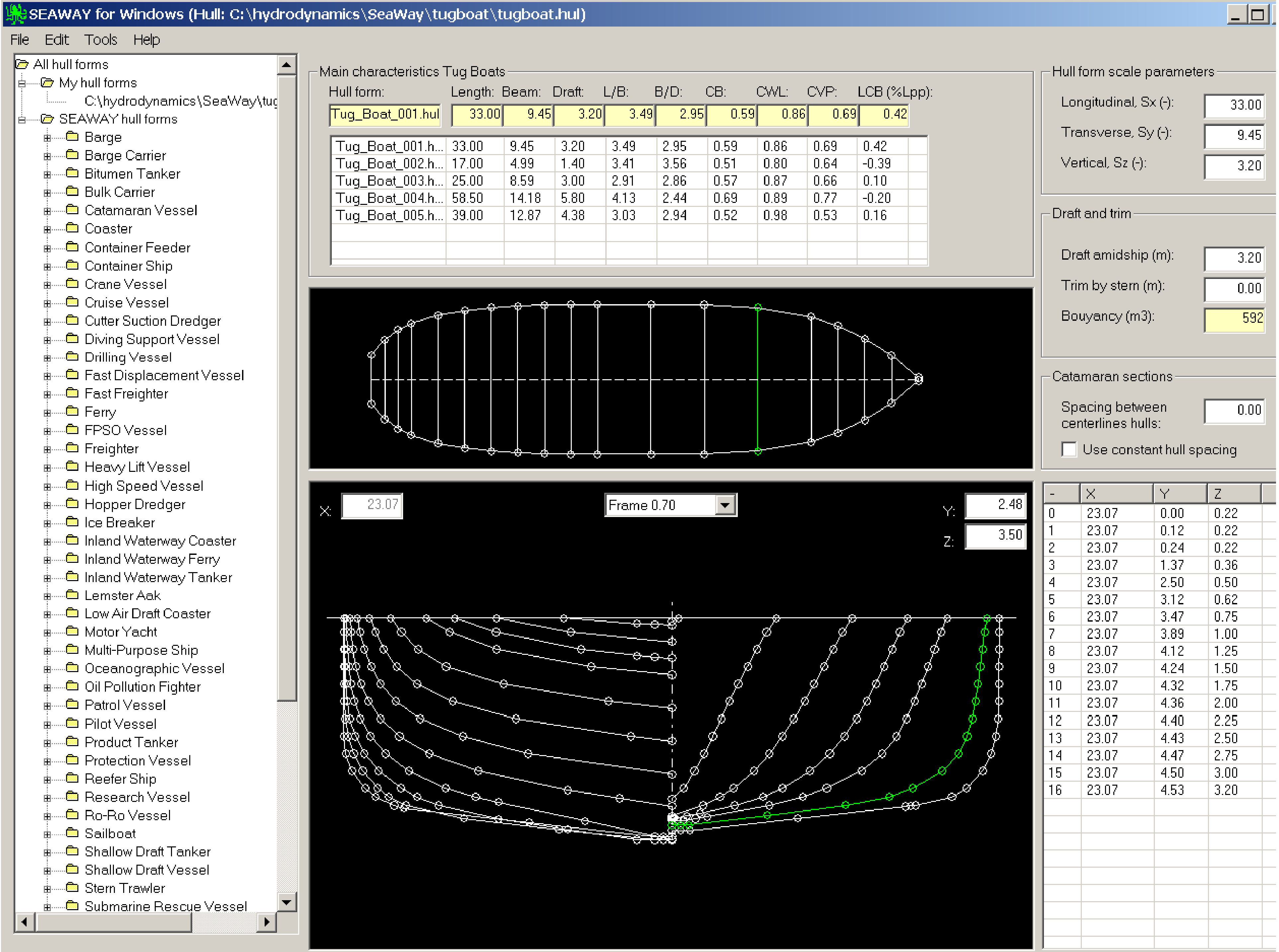
and AMARCON cooperate in further development of SEAWAY

The Maritime Research Institute Netherlands (MARIN) and AMARCON agree to cooperate in further development of SEAWAY. MARIN is an internationally recognized authority on hydrodynamics, involved in frontier breaking research programs for the maritime and offshore industries and navies.

SEAWAY is developed by Professor J.M.J. Journée at the Delft Univ. of Technology

SEAWAY is a **Strip Theory Program** to calculate wave-induced loads on and motions of mono-hulls and barges in deep to very shallow water. When not accounting for interaction effects between the hulls, also catamarans can be analyzed. Work of very acknowledged hydromechanic scientists (like Ursell, Tasai, Frank, Keil, Newman, Faltinsen, Ikeda, etc.) has been used, when developing this code.

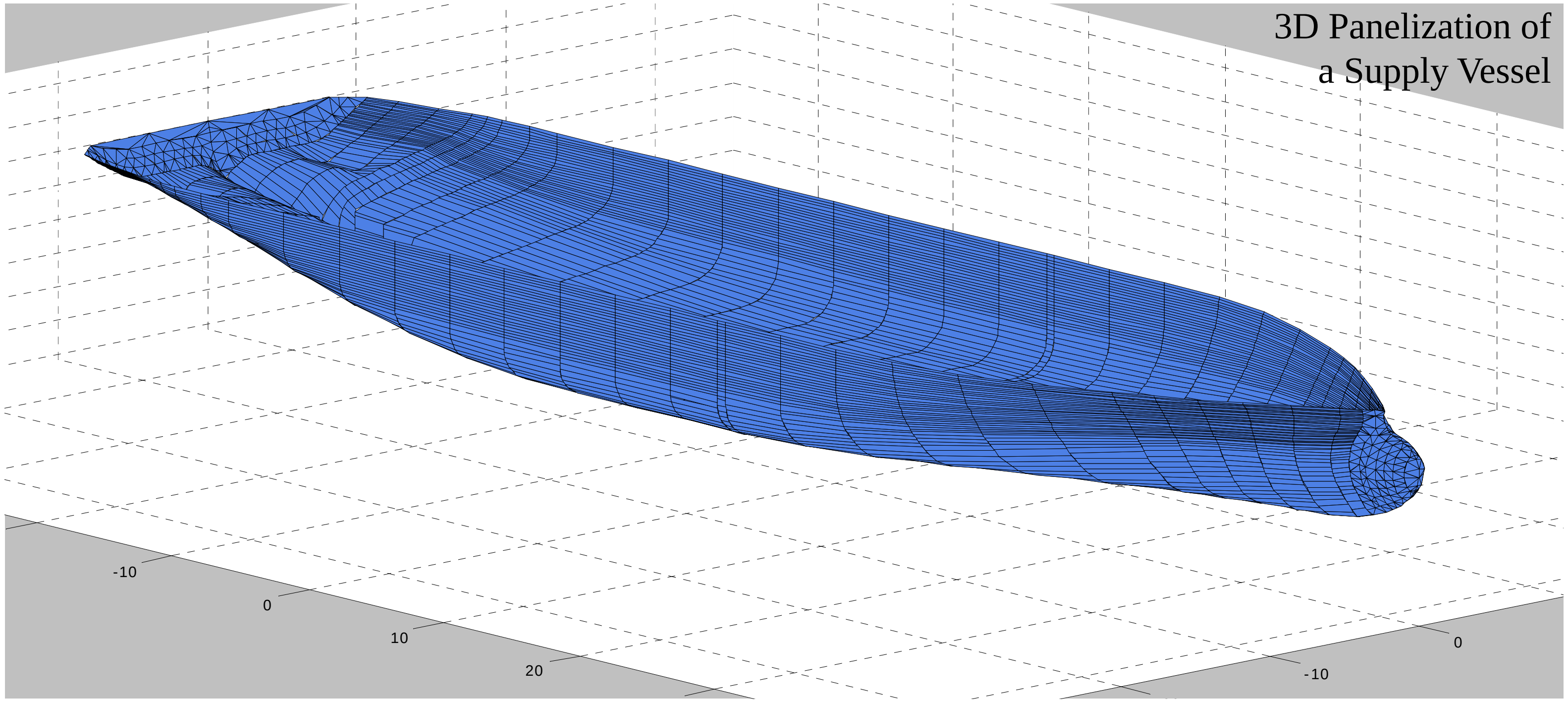
SEAWAY has extensively been verified and validated using other computer codes and experimental data.


SEAWAY for Windows (Hull: C:\hydrodynamics\SeaWay\tugboat\tugboat.hul)
File
Edit
Tools
Help
All hull forms
My hull forms
C:\hydrodynamics\SeaWay\tug
SEAWAY hull forms
Barge
Barge Carrier
Bitumen Tanker
Bulk Carrier
Catamaran Vessel
Coaster
Container Feeder
Container Ship
Crane Vessel
Cruise Vessel
Cutter Suction Dredger
Diving Support Vessel
Drilling Vessel
Fast Displacement Vessel
Fast Freighter
Ferry
FPSO Vessel
Freighter
Heavy Lift Vessel
High Speed Vessel
Hopper Dredger
Ice Breaker
Inland Waterway Coaster
Inland Waterway Ferry
Inland Waterway Tanker
Lemster Aak
Low Air Draft Coaster
Motor Yacht
Multi-Purpose Ship
Oceanographic Vessel
Oil Pollution Fighter
Patrol Vessel
Pilot Vessel
Product Tanker
Protection Vessel
Reefer Ship
Research Vessel
Ro-Ro Vessel
Sailboat
Shallow Draft Tanker
Shallow Draft Vessel
Stern Trawler
Submarine Rescue Vessel
Main characteristics Tug Boats
Hull form: Length: Beam: Draft: L/B: B/D: CB: CWL: CVP: LCB (%Lpp):
Tug_Boat_001.hul 33.00 9.45 3.20 3.49 2.95 0.59 0.86 0.69 0.42
Tug_Boat_001.h... 33.00 9.45 3.20 3.49 2.95 0.59 0.86 0.69 0.42
Tug_Boat_002.h... 17.00 4.99 1.40 3.41 3.56 0.51 0.80 0.64 -0.39
Tug_Boat_003.h... 25.00 8.59 3.00 2.91 2.86 0.57 0.87 0.66 0.10
Tug_Boat_004.h... 58.50 14.18 5.80 4.13 2.44 0.69 0.89 0.77 -0.20
Tug_Boat_005.h... 39.00 12.87 4.38 3.03 2.94 0.52 0.98 0.53 0.16
Hull form scale parameters
Longitudinal, Sx (-): 33.00
Transverse, Sy (-): 9.45
Vertical, Sz (-): 3.20
Draft and trim
Draft amidship (m): 3.20
Trim by stern (m): 0.00
Bouyancy (m3): 592
Catamaran sections
Spacing between centerlines hulls: 0.00
Use constant hull spacing
X: 23.07
Frame 0.70
Y: 2.48
Z: 3.50
- X Y Z
0 23.07 0.00 0.22
1 23.07 0.12 0.22
2 23.07 0.24 0.22
3 23.07 1.37 0.36
4 23.07 2.50 0.50
5 23.07 3.12 0.62
6 23.07 3.47 0.75
7 23.07 3.89 1.00
8 23.07 4.12 1.25
9 23.07 4.24 1.50
10 23.07 4.32 1.75
11 23.07 4.36 2.00
12 23.07 4.40 2.25
13 23.07 4.43 2.50
14 23.07 4.47 2.75
15 23.07 4.50 3.00
16 23.07 4.53 3.20

WAMIT (Vers. 6.3) by WAMIT INC.

WAMIT® is the most advanced set of tools available for analyzing wave interactions with offshore platforms and other structures or vessels.

WAMIT® was developed by **Professor Newman** and coworkers at **MIT** in 1987, and it has gained widespread recognition for its ability to analyze the complex structures with a high degree of accuracy and efficiency.



Over the past 20 years WAMIT has been licensed to more than 90 industrial and research organizations worldwide.

File Formats – Ship Geometry

It is possible to convert data file formats between the programs:

- SEAWAY table of offset file: *.out
- VERES table of offset file: *.mgf
- WAMIT geometry file (panels) *.gdf

SEAWAY has an **add-in** for export to VERES *.out + WAMIT panel generation.

VERES can import CAD/CAM data (NAPA etc.) + **add-in** for WAMIT panel generation.

WAMIT only reads it panel data in *.gdf form. You can generate these in SEAWAY and VERES or buy a CAD/CAM program like MULTISURF to generate WAMIT geometry files.

Hydrodynamic Methods (MSS Hydro)

- Frequency-Dependent Hydrodynamic Added Mass, Potential Damping, and Restoring Forces:
  Computed using: WAMIT, ShipX (VERES), or Octopus SEAWAY

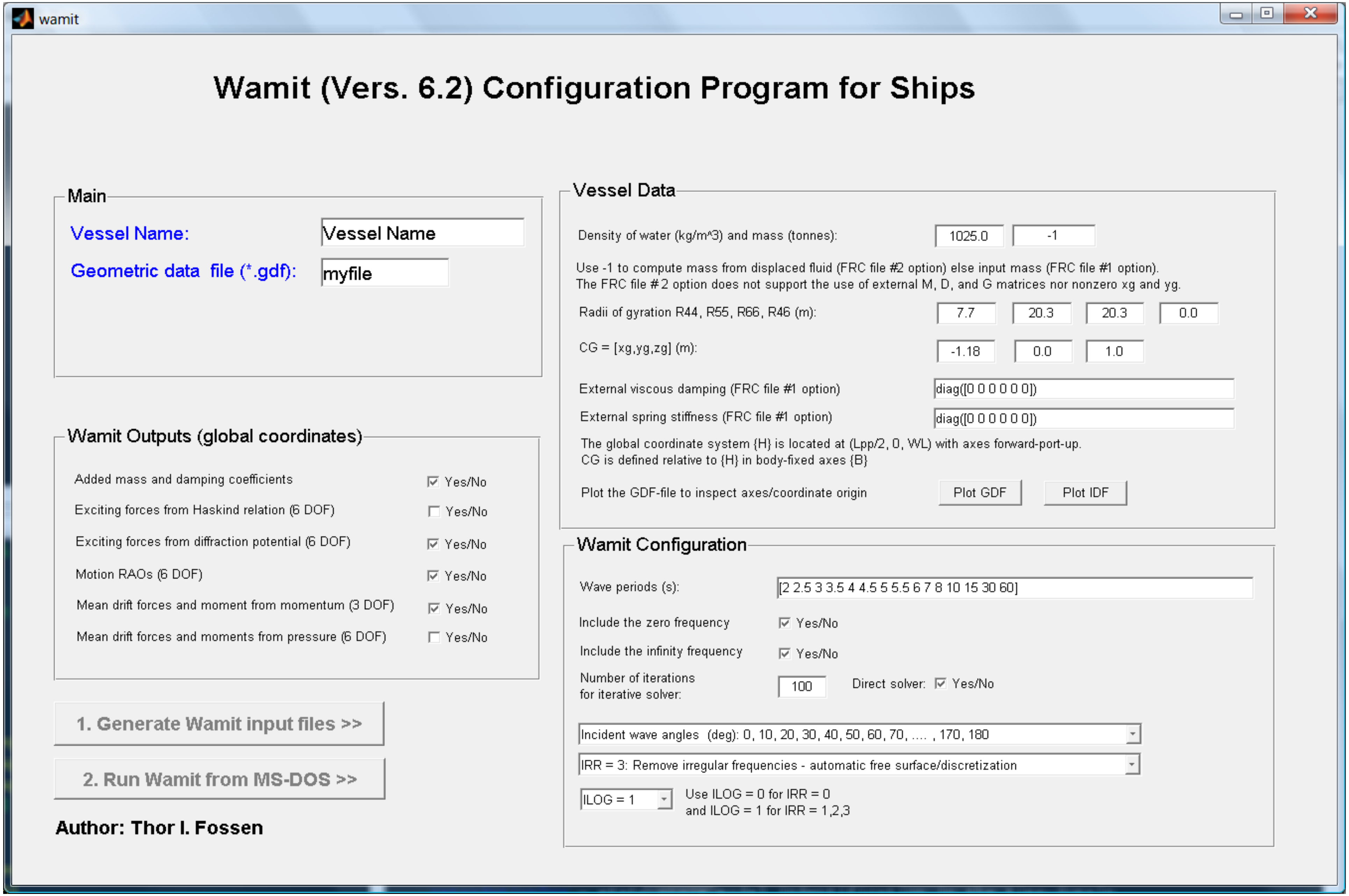
- Nonlinear Viscous Damping and Current Loads:
  - ✓ ITTC quadratic drag formulation/ added resistance in surge (includes current)
  - ✓ Nonlinear cross-flow drag in sway and yaw (includes currents)
  - ✓ Munk moment in yaw from potential coefficients
  - ✓ Higher order nonlinear damping terms in heave, roll, and pitch (manually added)
  - ✓ Maneuvering coefficients (manually added)

- Nonlinear Frequency-Dependent Damping in Roll due to Bilge Keels and Anti-Rolling Tanks:
  Can be computed in ShipX (VERES) and Octopus (SEAWAY)

- Frequency-Dependent Linear Viscous Damping in DOFs 1,2,6:
  Manually added using exponential decaying functions for skin friction

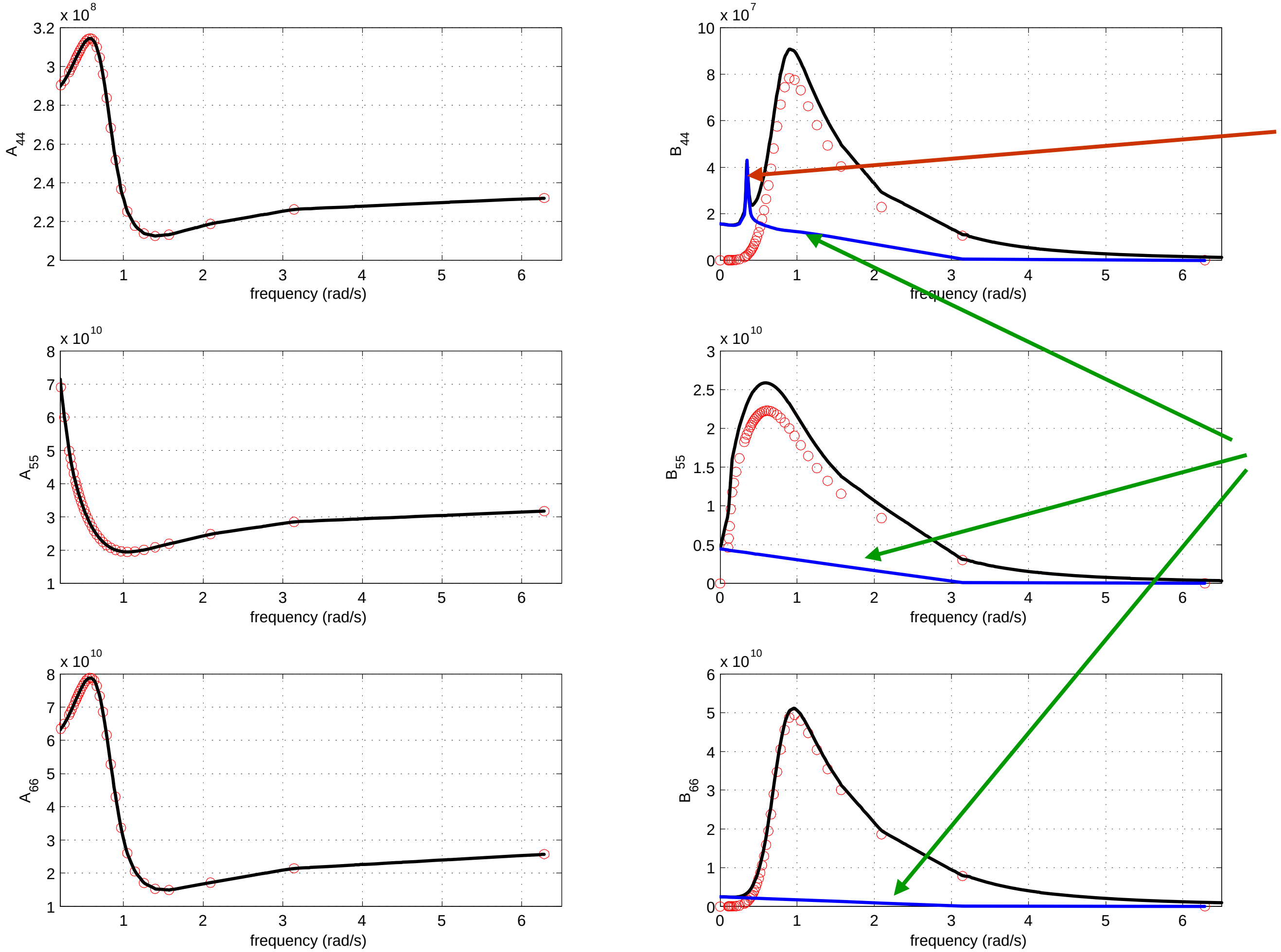
- Wave Loads:
  1st-order (Froude-Krylov and diffraction) and 2nd-order wave loads (wave drift) are computed using 2D/3D potential theory

- Wind Loads:
  Computed using wind coefficient tables


wamit
Wamit (Vers. 6.2) Configuration Program for Ships
Main
Vessel Name:
Vessel Name
Geometric data file (*.gdf):
myfile
Wamit Outputs (global coordinates)
Added mass and damping coefficients
Yes/No
Exciting forces from Haskind relation (6 DOF)
Yes/No
Exciting forces from diffraction potential (6 DOF)
Yes/No
Motion RAOs (6 DOF)
Yes/No
Mean drift forces and moment from momentum (3 DOF)
Yes/No
Mean drift forces and moments from pressure (6 DOF)
Yes/No
1. Generate Wamit input files >>
2. Run Wamit from MS-DOS >>
Author: Thor I. Fossen
Vessel Data
Density of water (kg/m^3) and mass (tonnes):
1025.0
-1
Use -1 to compute mass from displaced fluid (FRC file #2 option) else input mass (FRC file #1 option).
The FRC file #2 option does not support the use of external M, D, and G matrices nor nonzero xg and yg.
Radii of gyration R44, R55, R66, R46 (m):
7.7
20.3
20.3
0.0
CG = [xg,yg,zg] (m):
-1.18
0.0
1.0
External viscous damping (FRC file #1 option)
diag([0 0 0 0 0 0])
External spring stiffness (FRC file #1 option)
diag([0 0 0 0 0 0])
The global coordinate system {H} is located at (Lpp/2, 0, WL) with axes forward-port-up.
CG is defined relative to {H} in body-fixed axes {B}
Plot the GDF-file to inspect axes/coordinate origin
Plot GDF
Plot IDF
Wamit Configuration
Wave periods (s):
[2 2.5 3 3.5 4 4.5 5 5.5 6 7 8 10 15 30 60]
Include the zero frequency
Yes/No
Include the infinity frequency
Yes/No
Number of iterations
for iterative solver:
100
Direct solver:
Yes/No
Incident wave angles (deg): 0, 10, 20, 30, 40, 50, 60, 70, ... , 170, 180
IRR = 3: Remove irregular frequencies - automatic free surface/discretization
ILOG = 1
Use ILOG = 0 for IRR = 0
and ILOG = 1 for IRR = 1,2,3

Example: Adding Viscous Damping

Added mass A44, A55, A66 | Damping B44, B55, B66



Peak is due to IKEDA roll damping theory for bilge keels

Linear viscous skin friction (ramps)

Output (Ascii-files) from Hydrodynamic Codes

- **VERES**
  - *.re1 - motion RAOs
  - *.re2 - wave drift data
  - *.re7 - added mass, damping, restoring terms
  - *.re8 - force RAOs
  - *.hyd - hydrostatic data etc.
- **SeaWay**
  - *.out - all computed data and vessel configuration
- **WAMIT**
  - *.out - all computed data
  - *.pot - vessel configuration data

Postprocessing of the Hydrodynamic Data Files to the MSS vessel structure

- Extract necessary information from the ASCII files generated by the hydrodynamic code
- Scaling of data
- Change and translate coordinate frames for hydrodynamic coefficients, RAOs, transfer functions etc.
- Add viscous effects (hydrodynamic codes are non-viscous/potential theory)
- Process data for time-domain simulation

Notice that the *MSS vessel structure* is independent of the hydrodynamic code!

MSS Hydro toolbox commands:

```
>> veres2vessel.m
>> wamit2vessel.m
>> seaway2vessel.m
```

MSS Hydro Vessel Structure

vessel.headings:	headings
vessel.velocities:	velocities
vessel.freqs:	frequencies (A and B matrices)
vessel.A(6,6,freqno,velno):	added mass matrix
vessel.B(6,6,freqno,velno):	damping matrix
vessel.C(6,6,freqno,velno):	spring stiffness matrix
vessel.MRB(6,6):	rigid-body mass matrix
vessel.driftfrc.	
amp(freqno,headno,velno):	wave drift force amplitudes
w(1,freqno):	circular wave frequencies
vessel.forceRAO.	
amp{1:6}(freqno,headno,velno):	wave excitation force amplitudes
phase{1:6}(freqno,headno,velno):	wave excitation force phases
w(1,freqno):	circular wave frequencies
vessel.motionRAO.	
amp{1:6}(freqno,headno,velno):	wave motion RAO amplitudes
phase{1:6}(freqno,headno,velno):	wave motion RAO phases
w(1,freqno):	circular wave frequencies

Vectorial Vessel Model Representation for Marine Vessels

From Robotics to Ship Modeling (Fossen 1991, PhD thesis)

Consider the classical robot manipulator model:

$$\mathbf{M}(\mathbf{q})\ddot{\mathbf{q}} + \mathbf{C}(\mathbf{q},\dot{\mathbf{q}})\mathbf{q} = \boldsymbol{\tau}$$

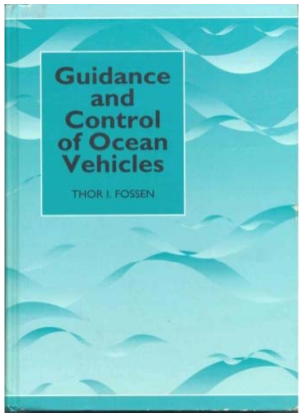
- $\mathbf{q}$ is a vector of joint angles
- $\boldsymbol{\tau}$ is a vector of torque
- M and C are the system inertia and Coriolis matrices

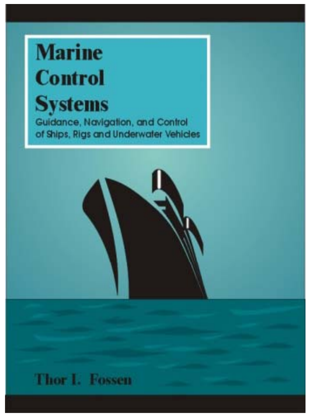
This model structure can be used as foundation to write the 6 DOF marine vessel equations of motion in a compact *vectorial* setting (Fossen 1994, 2002):

$$\dot{\boldsymbol{\eta}} = \mathbf{J}(\boldsymbol{\eta})\boldsymbol{\nu}$$

$$\mathbf{M}\dot{\boldsymbol{\nu}} + \mathbf{C}(\boldsymbol{\nu})\boldsymbol{\nu} + \mathbf{D}(\boldsymbol{\nu})\boldsymbol{\nu} + \mathbf{g}(\boldsymbol{\eta}) = \boldsymbol{\tau}$$

- body velocities: $\boldsymbol{\nu} = [u, v, w, p, q, r]^T$
- position and Euler angles: $\boldsymbol{\eta} = [x, y, z, \phi, \theta, \psi]^T$
- M, C and D denote the system inertia, Coriolis and damping matrices
- $\mathbf{g}$ is a vector of gravitational and buoyancy forces and moments



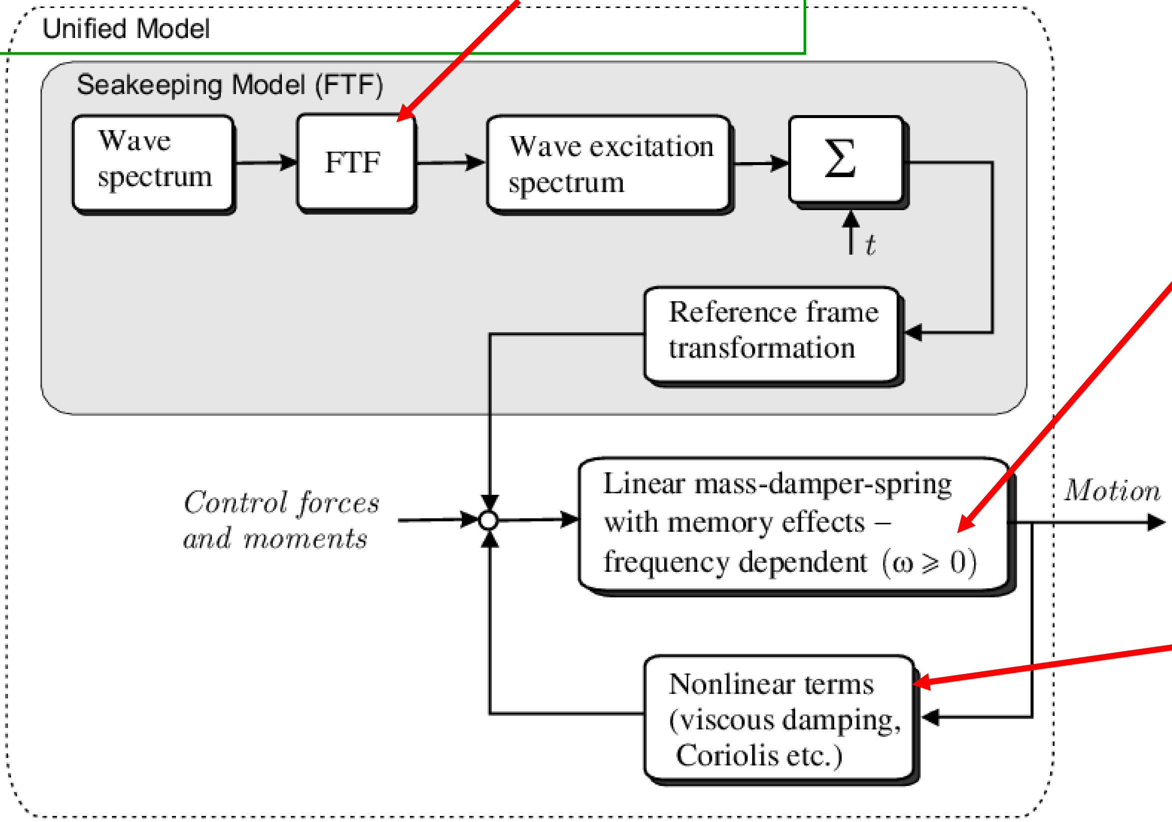


Unified Time-Domain Model for Different Speeds and Different Sea States

The *Force-Transfer-Functions* are computed using hydrodynamic SW e.g. WAMIT, VERES or SEAWAY

$$\dot{\boldsymbol{\eta}} = \mathbf{J}(\boldsymbol{\Theta})\boldsymbol{\nu}$$

$$\mathbf{M}\dot{\boldsymbol{\nu}} + \mathbf{C}_{RB}\boldsymbol{\nu} + \mathbf{D}\boldsymbol{\nu} + \mathbf{d}_n(\boldsymbol{\Theta},\boldsymbol{\nu}) + \boldsymbol{\mu} + \mathbf{g}(\boldsymbol{\eta}) = \boldsymbol{\tau}_{\mathrm{env}} + \boldsymbol{\tau}$$



$$\dot{\boldsymbol{\chi}} = \mathbf{A}_r\boldsymbol{\chi} + \mathbf{B}_r\delta\boldsymbol{\nu}, \qquad \boldsymbol{\chi}(0) = \mathbf{0}$$
$$\boldsymbol{\mu} = \mathbf{C}_r\boldsymbol{\chi} + \mathbf{D}_r\delta\boldsymbol{\nu}$$

For 6 DOF this model will typically be represented by 6 + 6 + 90 = 102 ODEs which are computed using hydrodynamic e.g. WAMIT, VERES or SEAWAY

These terms are found using experimental results/curve fitting or semi-empirical methods

Computing the Fluid Memory Effect State-Space Model

- Computes retardation functions in 6 DOF. These are fitted to a reduced-order state-space model.
- The state-space model can also be obtained by using curve-fitting in the frequency domain.

$$\dot{\boldsymbol{\chi}} = \mathbf{A}_r\boldsymbol{\chi} + \mathbf{B}_r\delta\boldsymbol{\nu}, \qquad \boldsymbol{\chi}(0) = \mathbf{0}$$
$$\boldsymbol{\mu} = \mathbf{C}_r\boldsymbol{\chi} + \mathbf{D}_r\delta\boldsymbol{\nu}$$

MSS Hydro toolbox command:

```
% vesselABC = vessel2ss(myship) computes the hydrodynamic coefficients,
% retardation functions and state-space model by loading myship.mat
% which must be generated using ShipX (VERES), Octopus SEAWAY or WAMIT.

>> vesselABC = vessel2ss('s175')
```

Matlab Case Study

\>> load supply1 – load MSS **vessel** structure

```
vessel =
         main: [1x1 struct]
          MRB: [6x6 double]
            A: [6x6x36 double]
            B: [6x6x36 double]
            C: [6x6x36 double]
         roll: [1x3x36 double]
        freqs: [1x36 double]
     headings: [1x19 double]
   velocities: 0
           Bv: [6x6x36 double]
          exp: [1x1 struct]
     forceRAO: [1x1 struct]
    motionRAO: [1x1 struct]
     driftfrc: [1x1 struct]
           LF: [1x1 struct]
```

\>> plotABC(vessel,mtrx,i,j,velno) plots added mass, damping, restoring

matrix element i,j versus frequency and speed

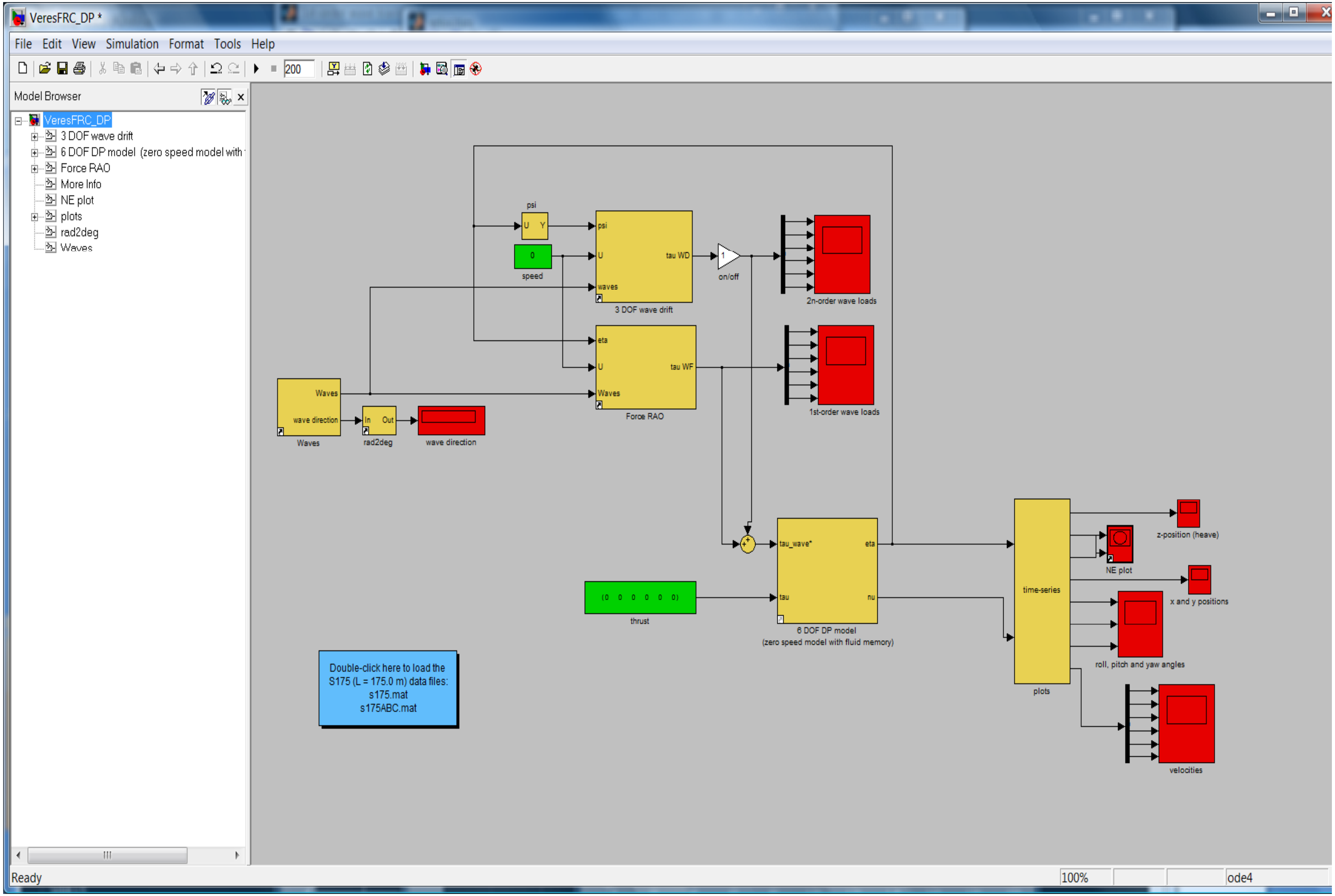
\>> plotABC(vessel,'A',4,4,1) added mass A44

\>> plotTF(vessel,type,x_axis,velno) plots the motion or force RAO transfer functions versus frequency

\>> plotTF(vessel,'motion','rads',1) rad/s

\>> plotTF(vessel,'force','s',1) period in sec.

\>> plotTF(vessel,'force','hz',1) 1/s


VeresFRC_DP *
File Edit View Simulation Format Tools Help
200
Model Browser
VeresFRC_DP
3 DOF wave drift
6 DOF DP model (zero speed model with
Force RAO
More Info
NE plot
plots
rad2deg
Waves
psi
speed
3 DOF wave drift
on/off
2n-order wave loads
Force RAO
1st-order wave loads
Waves
rad2deg
wave direction
thrust
6 DOF DP model
(zero speed model with fluid memory)
time-series
plots
z-position (heave)
NE plot
x and y positions
roll, pitch and yaw angles
velocities
Double-click here to load the
S175 (L = 175.0 m) data files:
s175.mat
s175ABC.mat
Ready
100%
ode4

FINALE

CAD/CAM

GA
Ship lines

Digitizer

Table of offset file

Veres
Seaway

Panel generator

WAMIT

Postprocessing of output files in MSS

Compute fluid memory effects and wave load transfer functions

Generate vessel structure

MSS vessel structure

Simulink
block diagram

Add control system

Time-series plot