Advanced Viscous Flow Computation Method for Unsteady Ship-Ship Interactions

Prof. Hamn-Ching Chen
Texas A&M University

Dr. Woei-Min Lin
Science Applications International Corporation

Dr. Wei-Yuan Hwang
U.S. Merchant Marine Academy

Passing Vessel Issues Workshop
Portland, Oregon
October 29 - 30, 2003

Presentation Overview

- Background
- Highlight of the Chimera RANS Method
- Ship-Ship Interaction Validation Studies
  - Experimental and numerical set up
  - Result comparisons
- Related Applications
  - Passing ship effects on a moored vessel
  - Berthing operations
  - Floating pier and multiple-vessel interactions including mooring and fender effects
- Concluding Remarks

Background

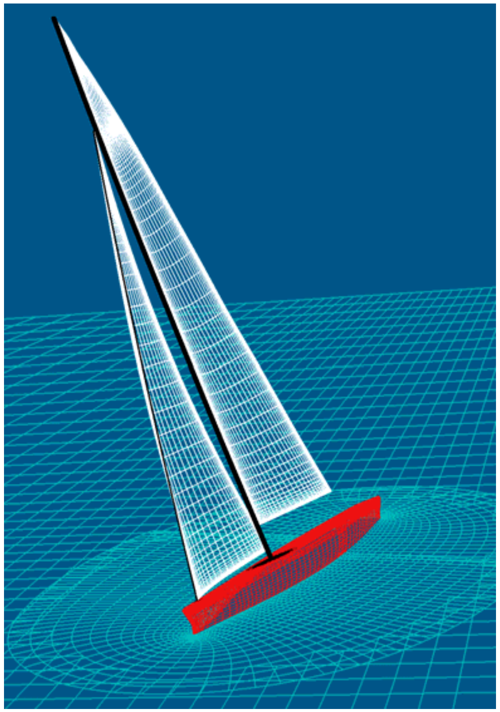
- Ship-ship interaction and ship operation in a channel are important problems for safety and economical reasons
- Traditionally, these problems have been approached using experimental means, prior experiences, or simplified theoretical and computational methods
- Advanced viscous flow computational fluid dynamic (CFD) methods offers a new possibility to study these problems in a more physics-based manner
- To use CFD effectively, we need to address the issue of:
  - Choice of the methods: RANS, LES, DNS
  - Validity of the “models”: turbulence models, etc.
  - Complexity of grid generation
  - Validation
  - Computation speed

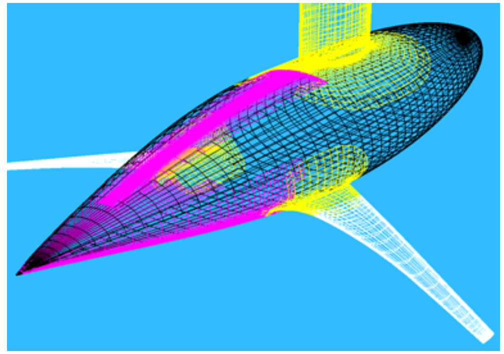
The Chimera RANS Method

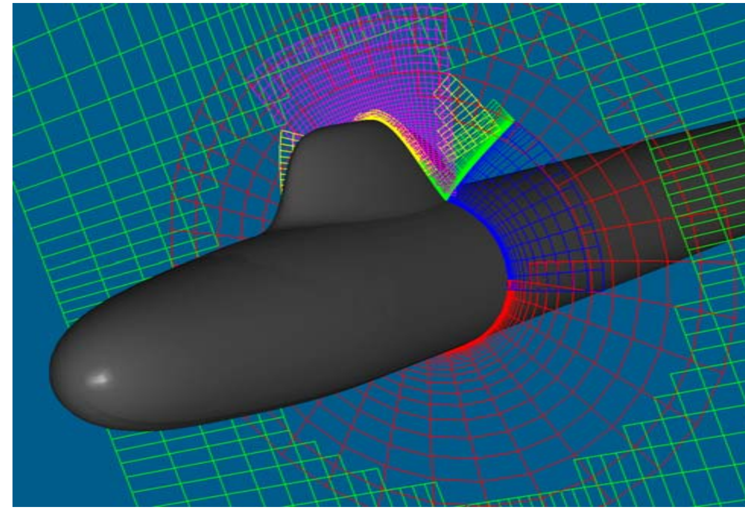
- **Unsteady Reynolds-Averaged Navier-Stokes Equations**
  – Curvilinear, moving coordinate system
  – Finite-analytic method for transport equations
  – Two-layer (near-wall) k-ε eddy viscosity models
  – Near-wall second-moment closure models
  – Linear and nonlinear free-surface effects
  – Specified motions or solving equations of motions for body dynamics

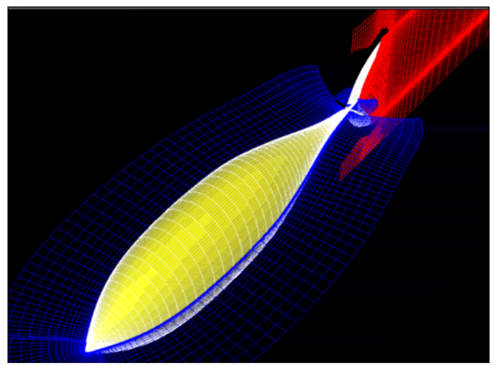
- **Chimera Domain Decomposition Method**
  – Embedding, overlapping, or matching boundary-fitted grids
  – Select the most suitable grid structure for each computational block
  – Local grid refinement to achieve maximum accuracy and efficiency
  – Relative motions between different grid blocks
  – Streamlined grid generation process
  – Automatic grid generation for minor design modifications or different operating conditions

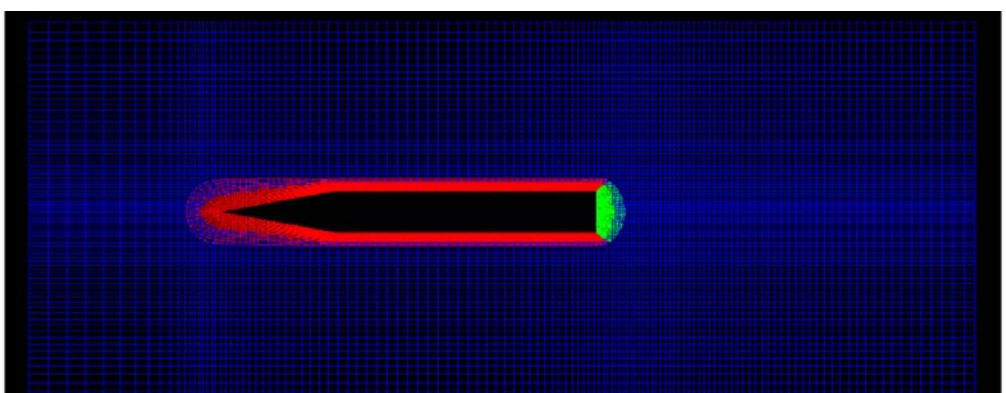
Examples of Chimera Grids

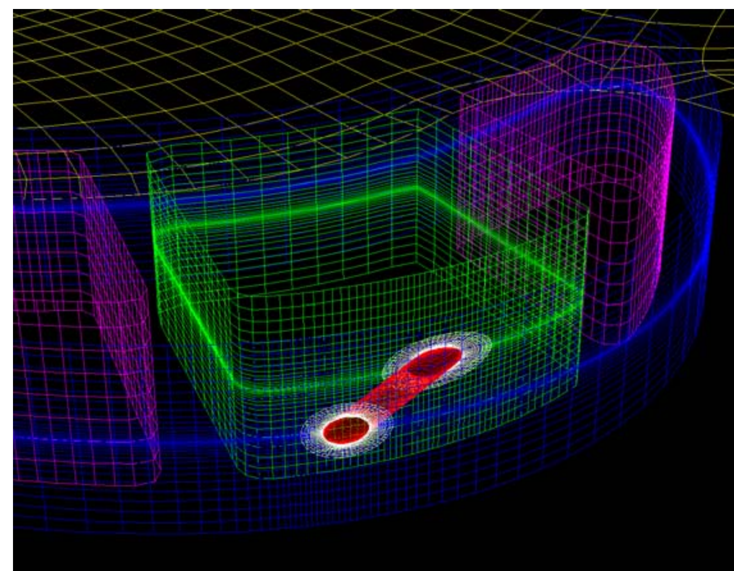










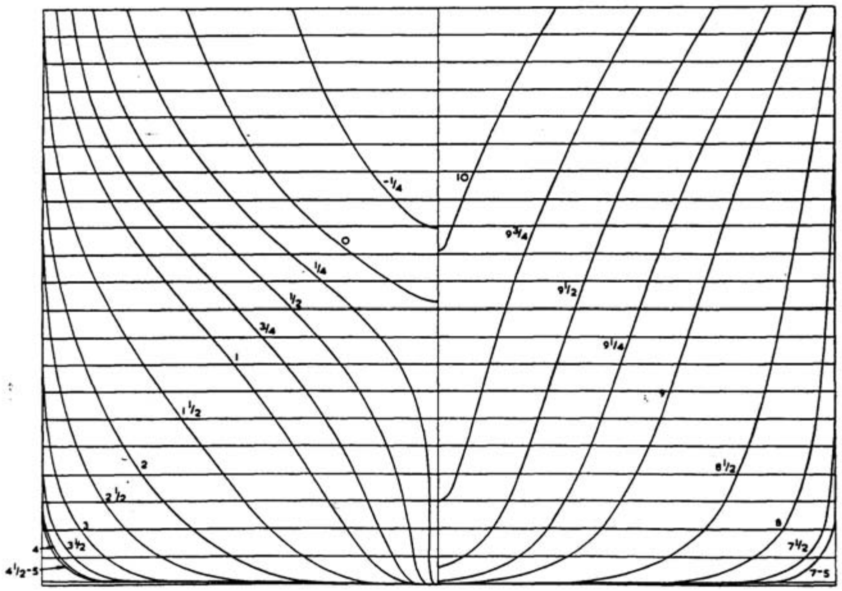


Validation Studies – Experimental Setup

- Experiments were carried out by Dr. Ian Dand and the results were reported in 1981
- Two model ships, one tanker (own ship) and one cargo liner (passing ship), moving on parallel course in a towing tank
- Head-on encounter and overtaking encounter cases with different speeds and separation distances
- Shallow water with different bottom clearances
- Measurements include sinkage, trim, sway force, and yaw moment on the own ship
- Curve-fitting technique was developed to fit the data into a modified sine function format

Validation Studies – Hull Forms and Motions

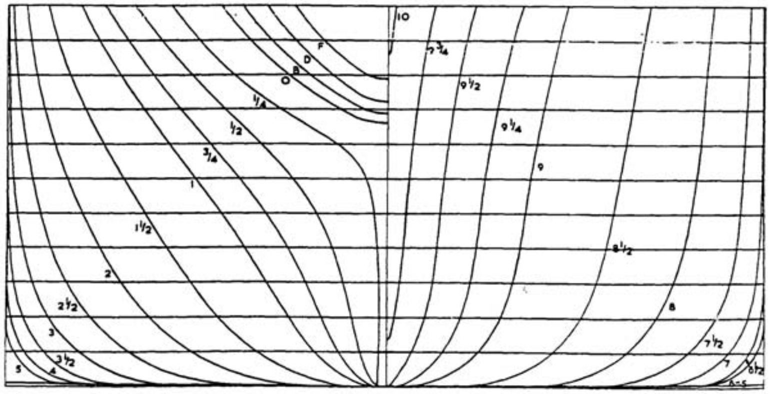
Model 5233 (own ship)



Tanker

- Instrumented for measurement
- Attached to carriage (tank centerline)
- Equipped with propeller and rudder
- Restrained in surge, sway, and yaw

Model 5232 (passing ship)



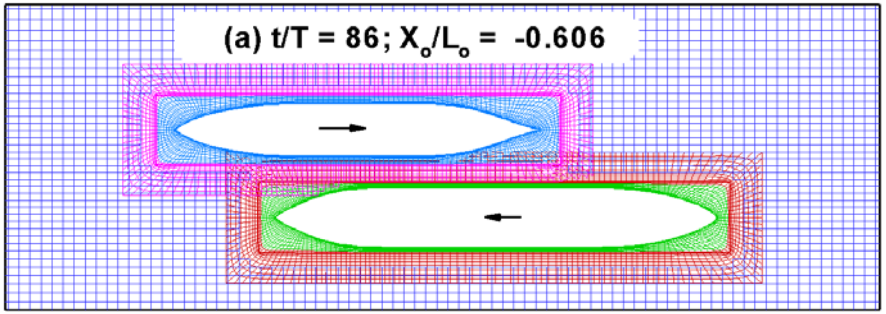
Single-screw cargo liner

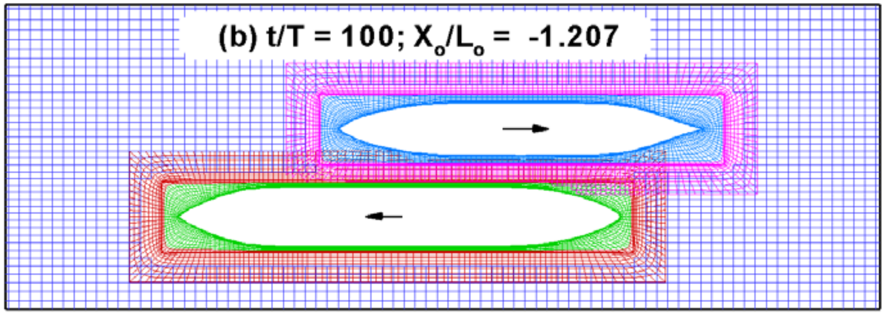
- No measurement equipments
- Running on a track
- Equipped with propeller and rudder
- Restrained in sway and yaw

CFD Validation – Numerical Setup

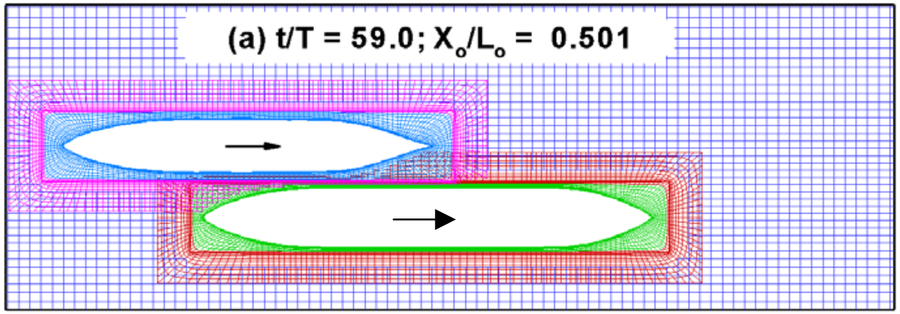
<u>Chimera domain decomposition</u>
7 computational grid blocks
811,587 volume grid points
29,895 free surface grid points

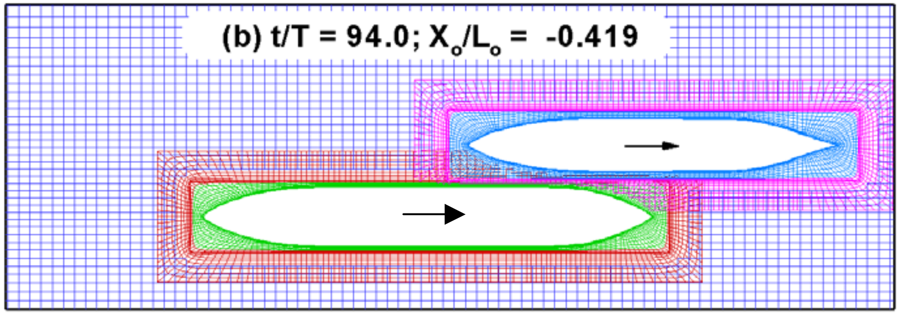
Head-On Encounter Cases





Overtaking Cases





Validation Studies – Differences in Setup

Differences between experimental and numerical setup:

- The forward speed of the ships were assumed to be constant (except the initial ramp start) in the numerical calculations, while the actual speed of the ship models might not be constant in the experiments, as reported in Dand (1981), due to increase of resistance while one ship passes another.
- The ship acceleration during ramp start produced strong pressure waves that may cause some initial oscillations in the forces.
- The motions of the ship models in the numerical calculations were constrained (include sinkage and trim in some cases), while the test model was allowed to heave, pitch, and roll.
- The tank walls were assumed to be perfectly reflective in the simulations.
- The physical test models were equipped with rudder and propeller. Dand (1977) showed that the effects of rudder and propeller are recognizable although not overwhelming.

Validation Studies – Cases Studied

Case 1: Velocity Study

h/To=1.19, Yo/Bo=1.59

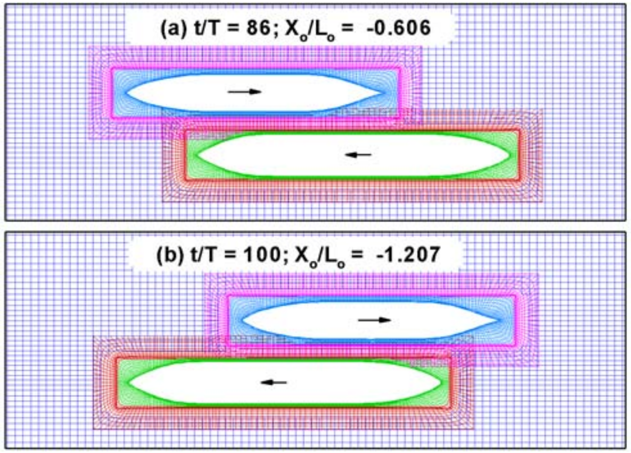
Case	Fno	Fnp	Fnr
1.1	0.128	-0.427	0.555
1.2	0.172	-0.430	0.602
1.3	0.250	-0.421	0.671
1.4	0.329	-0.401	0.731
1.5	0.369	-0.422	0.791

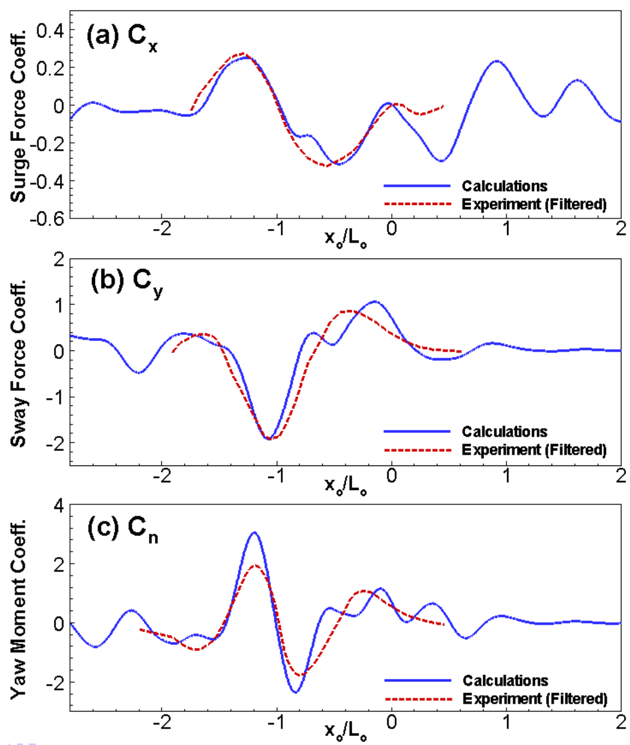
Case 2: Separation Distance

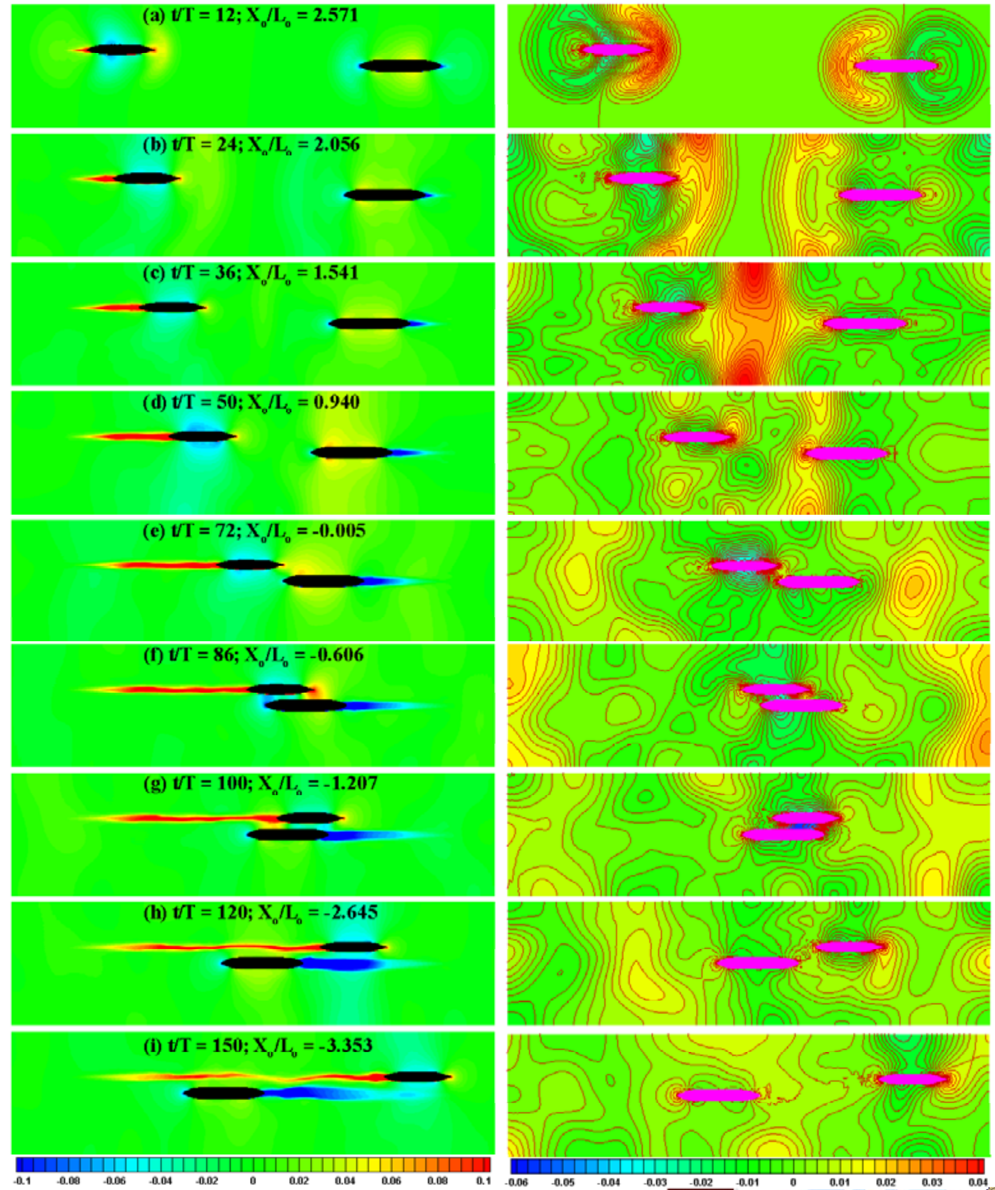
h/To=1.19, Fno=0.250
Fnp=-0.421, Fnr=-0.671

Case	Yo/Bo
2.1	1.10
2.2	1.30
2.3	1.60

CFD Validation: Head-On Encounter





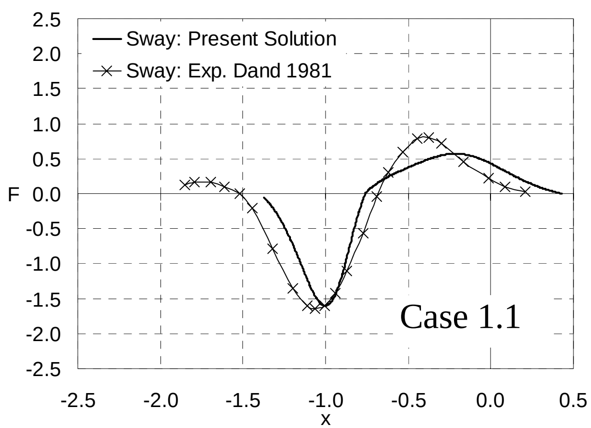


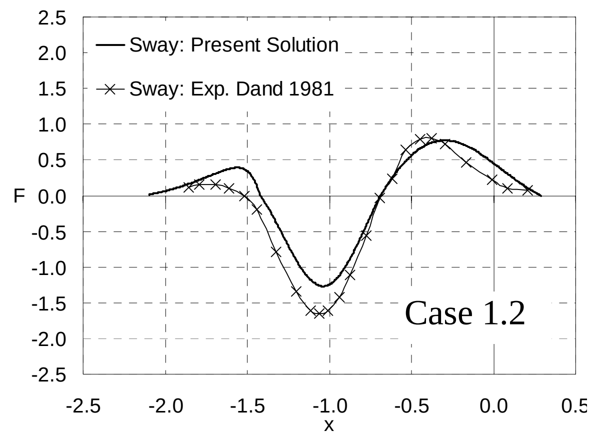
BAC

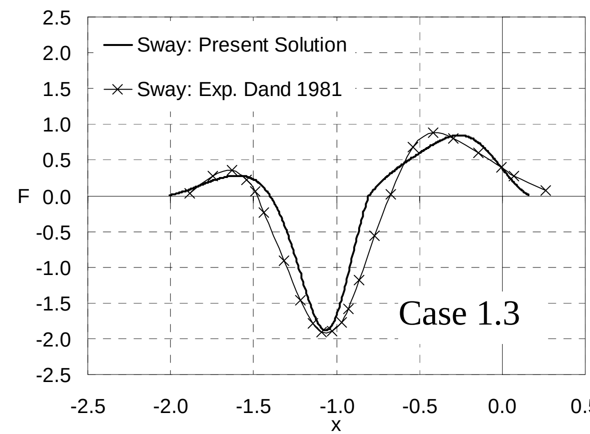
An Employee-Owned Company

CFD Validation – Velocity Study

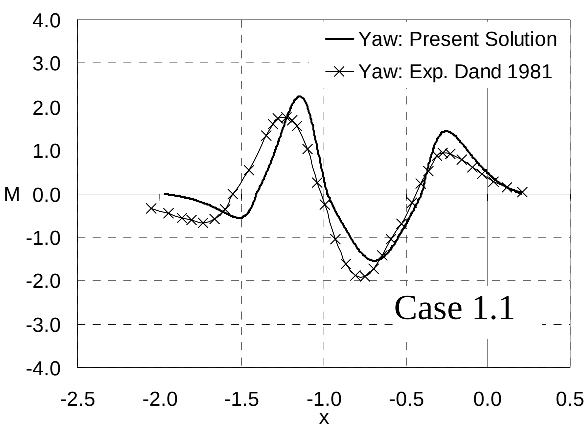
Sway Force

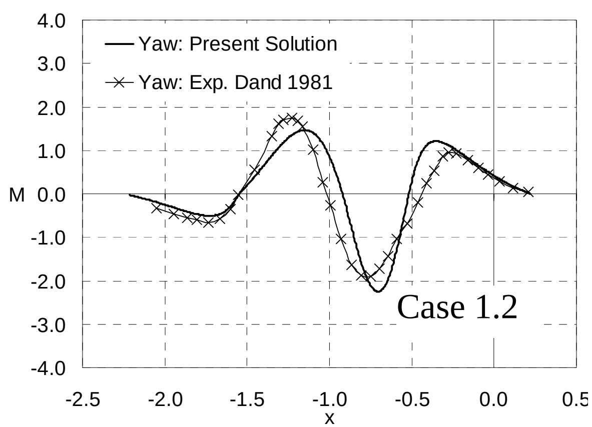


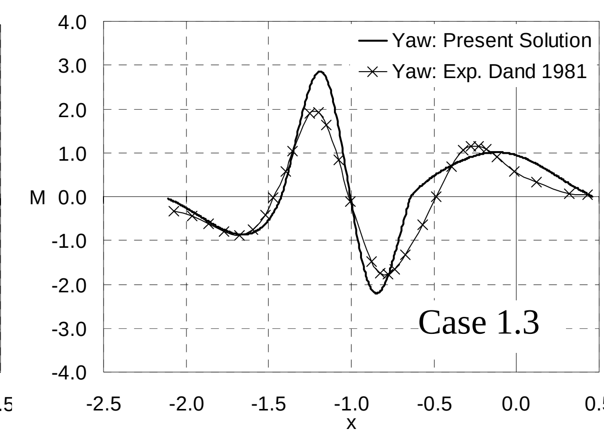




Yaw Moment

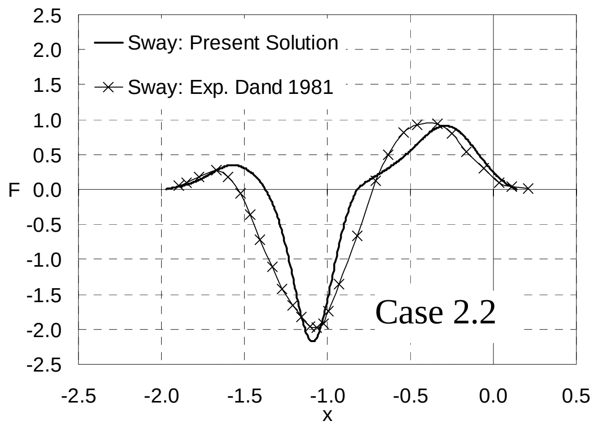


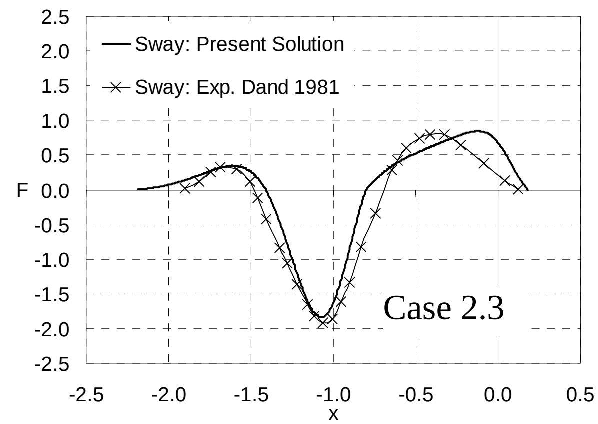




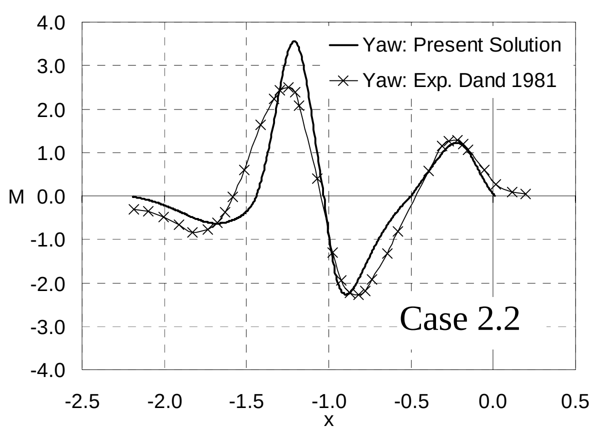
CFD Validation – Separation Distance

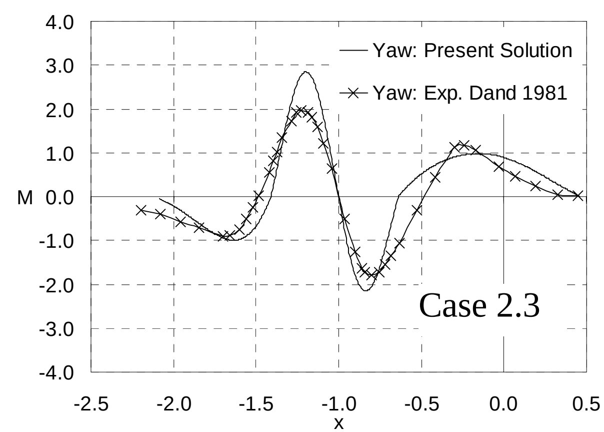
Sway Force



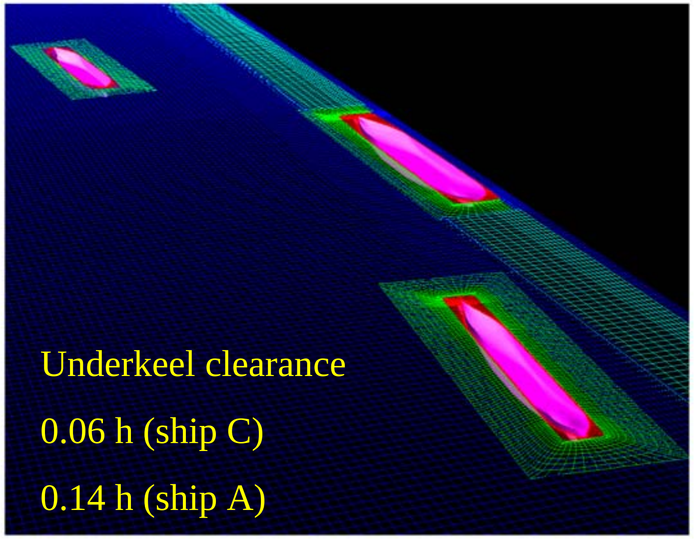


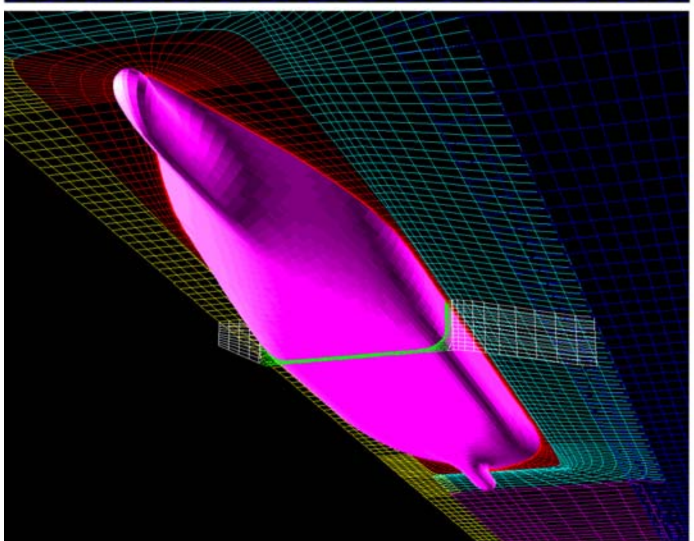
Yaw Moment

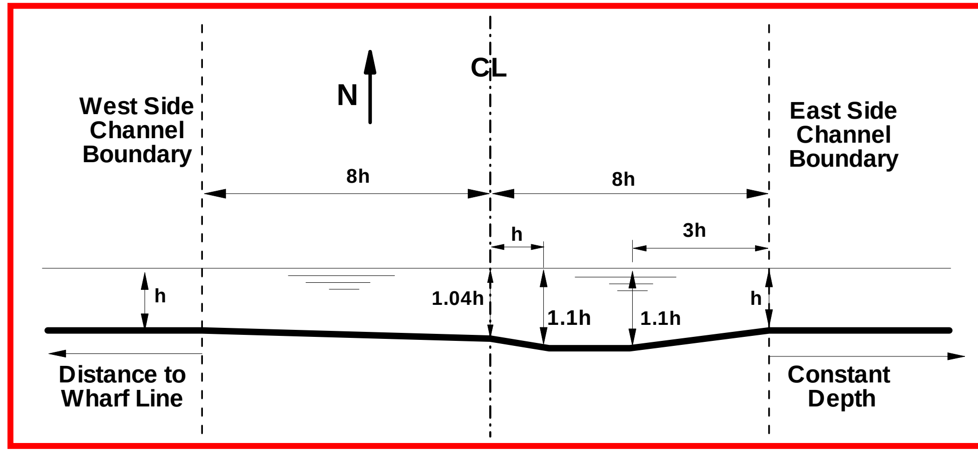




Related Application - Ships in A Channel







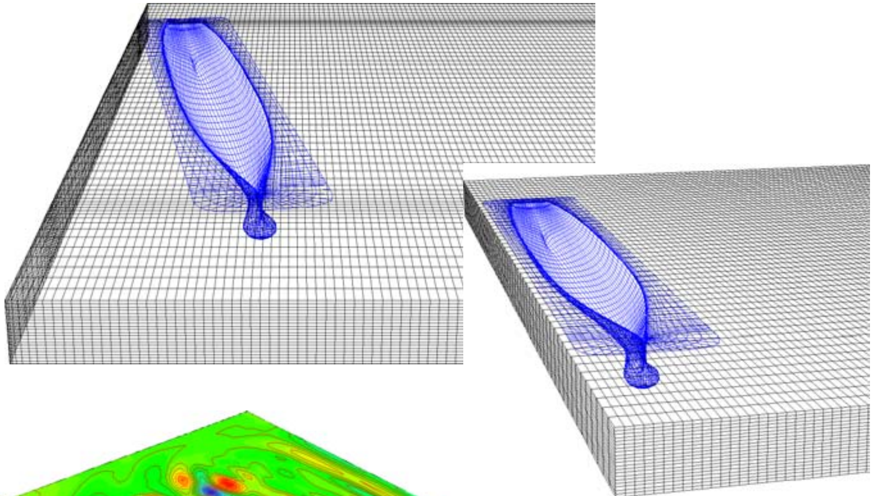
Parametric Study of:

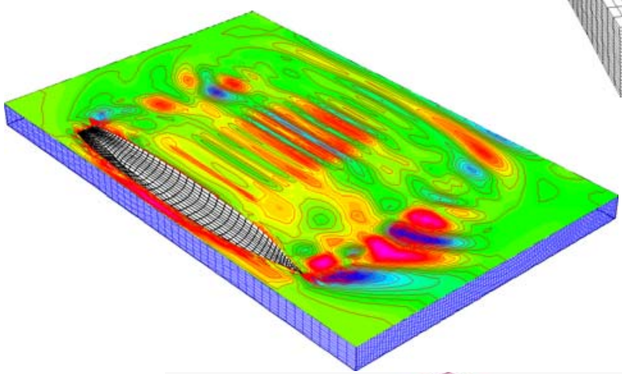
- Bank distance and slope – design issue
- Shallow water with bottom topology – dredging issue
- Own and passing ship speed, ship size, and wind conditions – operation issue
- Mooring line for the moored ship – design issue

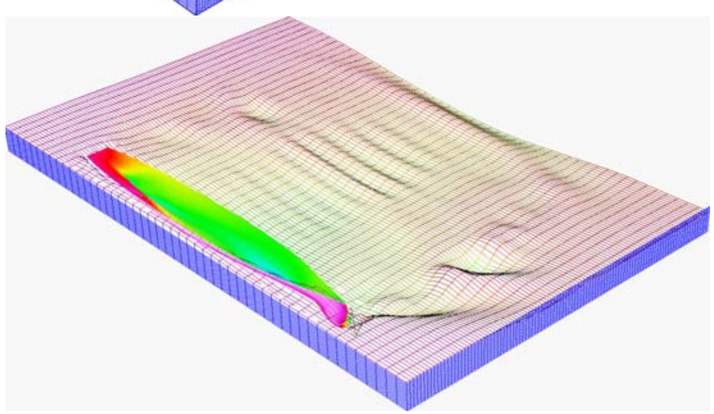
Passing Ship Effects on a Moored Vessel

- The passing ship effects on a moored vessel is not a simple function of speed squared
- Bernoulli effect contribution to ship-ship interactions declines rapidly as lateral separation distance increases, but other long-reaching mechanisms maintain significant passing ship effects
- Linear superposition of several 1-on-1 passing ship effects on a moored vessel does not represent closely to the integrated effects of multiple passing vessels
- On parallel course, if the passing vessel has a crab angle, the passing ship effects on a moored vessel can increase, contrary to the modeling of many simulators

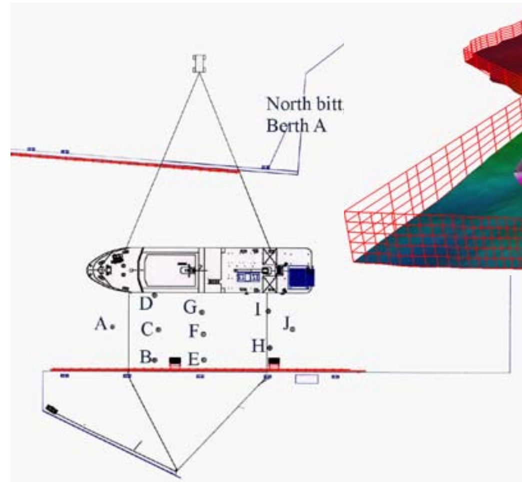
Related Application – Berthing Operations

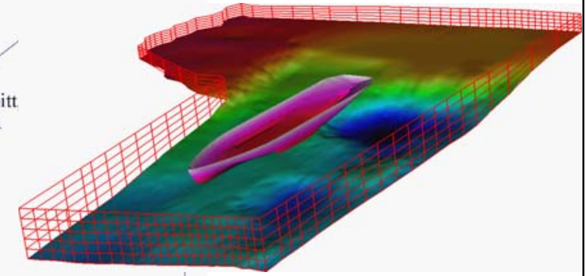




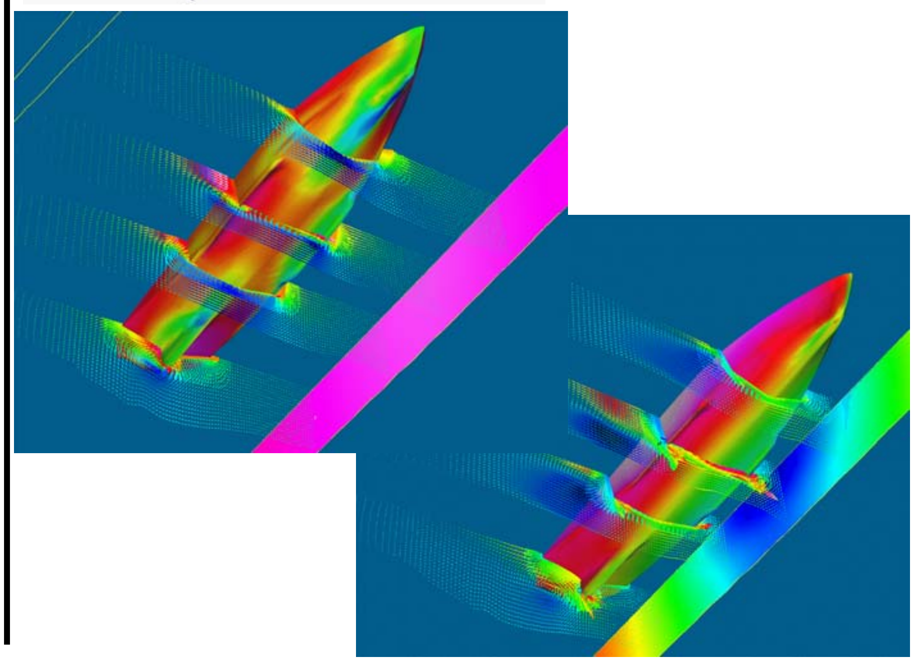


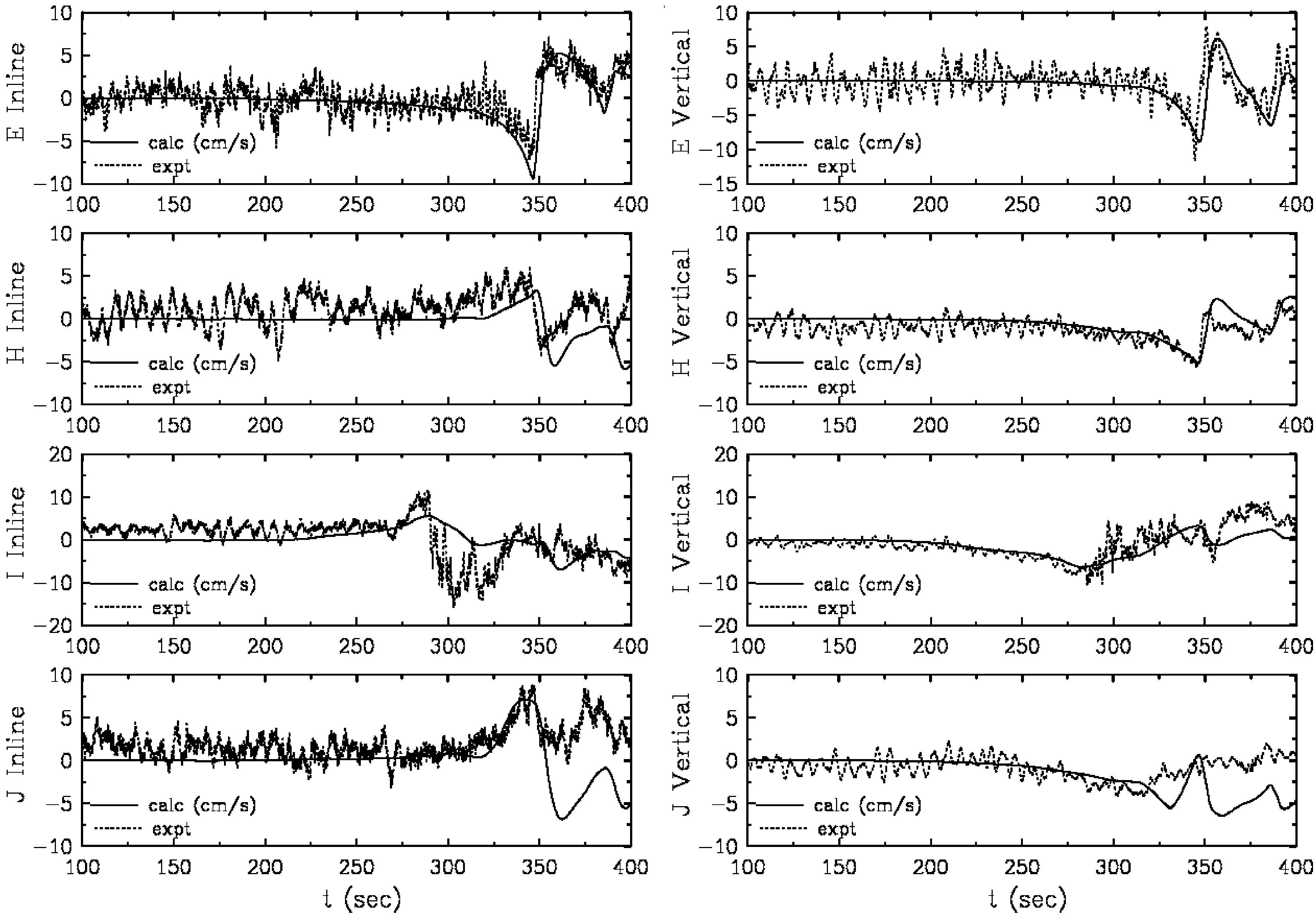
DDG-51



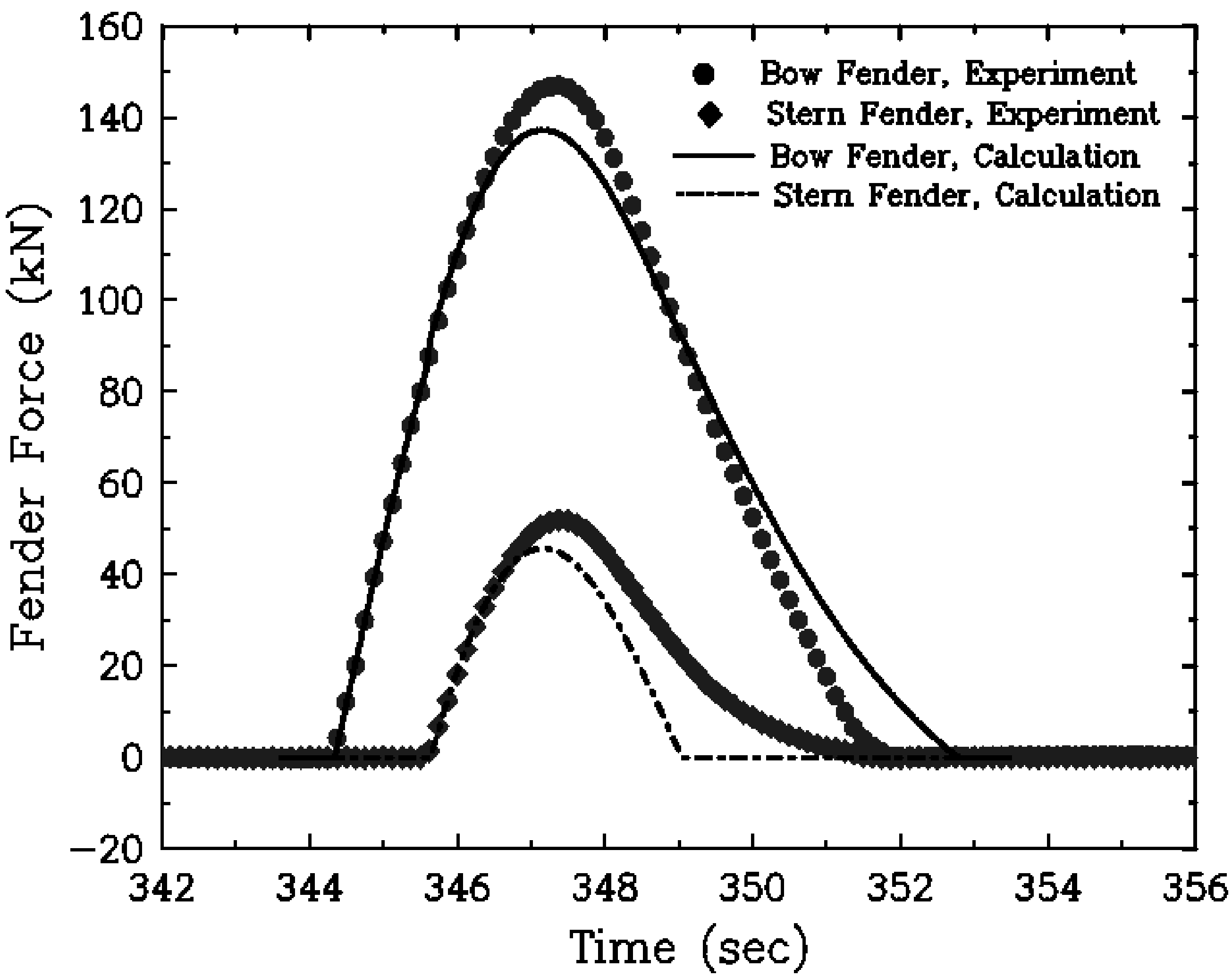


**Port Hueneme
California**



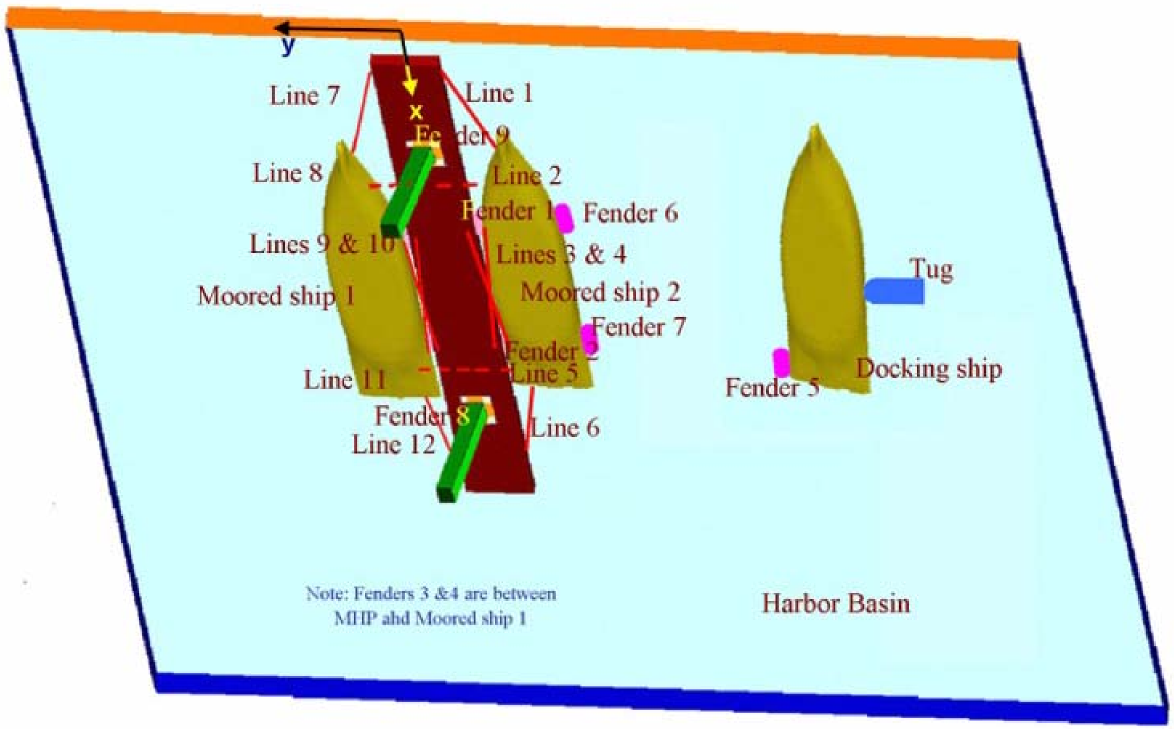

E Inline
calc (cm/s)
expt
E Vertical
calc (cm/s)
expt
H Inline
calc (cm/s)
expt
H Vertical
calc (cm/s)
expt
I Inline
calc (cm/s)
expt
I Vertical
calc (cm/s)
expt
J Inline
calc (cm/s)
expt
J Vertical
calc (cm/s)
expt
t (sec)
t (sec)

Fender Force Comparisons



An Employee-Owned Company

Floating Pier & Multiple-Vessel Interactions



Simulation Scenario

- MHP (Modular Hybrid Pier) secured by two mooring dolphins, fender stiffness = 806 tons/m
- Two LHD ships moored to the starboard and port sides of MHP with 12 mooring lines (3” O.D.)
- The third LHD ship docking from starboard side at 182.9 m (600 ft, center-to-center) away
- Tug applies a thrust of 21.85 tons
- Seven foam fenders hang on outside edges of MHP and moored ships, fender stiffness = 96 tons/m
- Water depth = 8.53 m
- Ship drafts = 8.23 m (3.7% underkeel clearance)
- MHP draft = 4.36 m

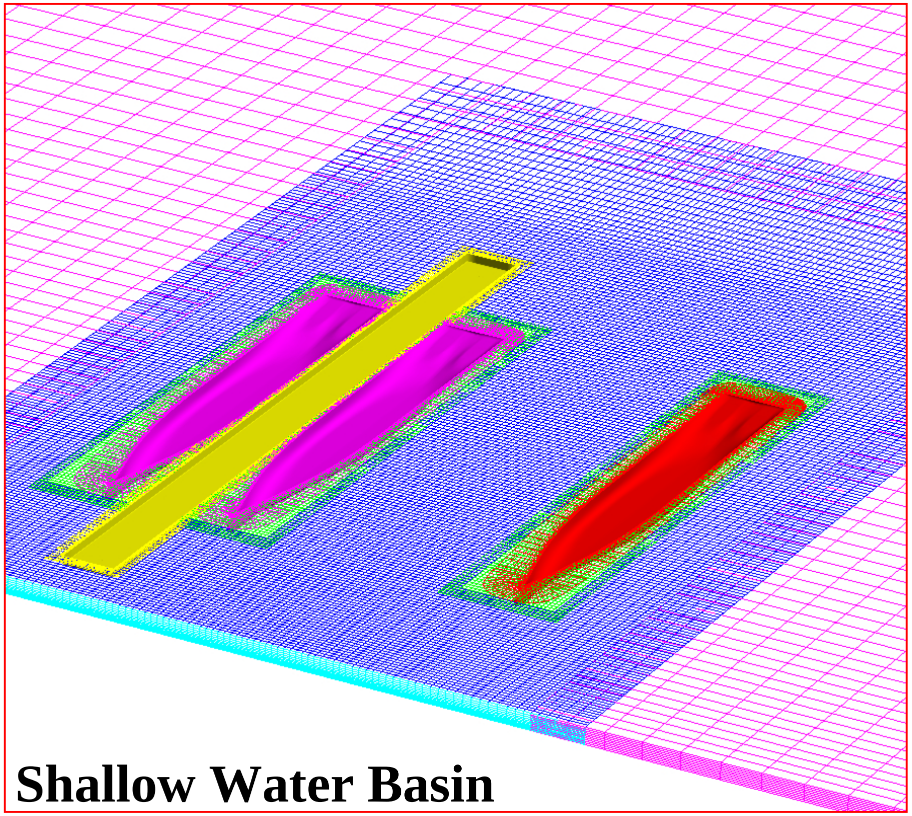
Particulars of the Floating Pier and Vessels

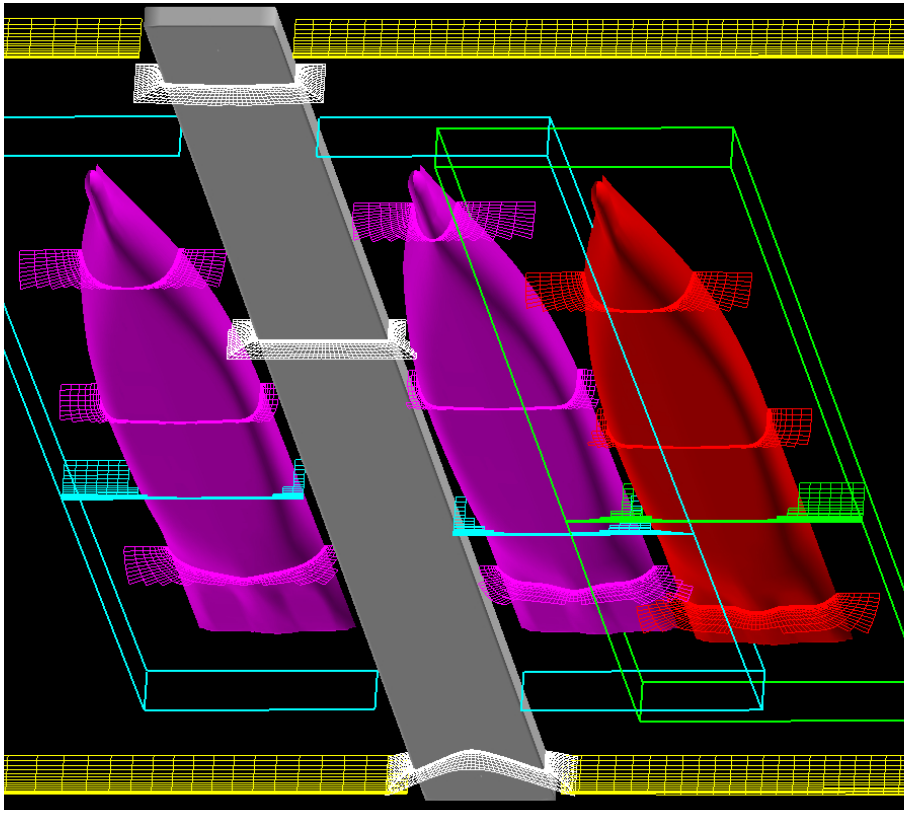
	Pier	Ship
Displacement (tons)	42550	41150
Overall length (m)	396.25	237.14
Beam (m)	26.82	32.31
Draft (m)	4.36	8.23
Xcg from bow (m)	198.12	113.08
Ycg from centerline (m)	0	0
Zcg from waterline (m)	0	0

Dynamic Characteristics of the Coupling members

Item	Characteristics
Foam fender (outer)	Diameter: 8 feet OD (2.44 m) Stiffness: 96 tons per meter
Trellex fender (inner)	Model: Trellex MX 1450 Stiffness = 806 tons per meter Maximum reaction: 807 tons
Mooring lines	Diameter: 3 inches (7.6 cm) Maximum tension: 13 tons

Chimera Moving Grids

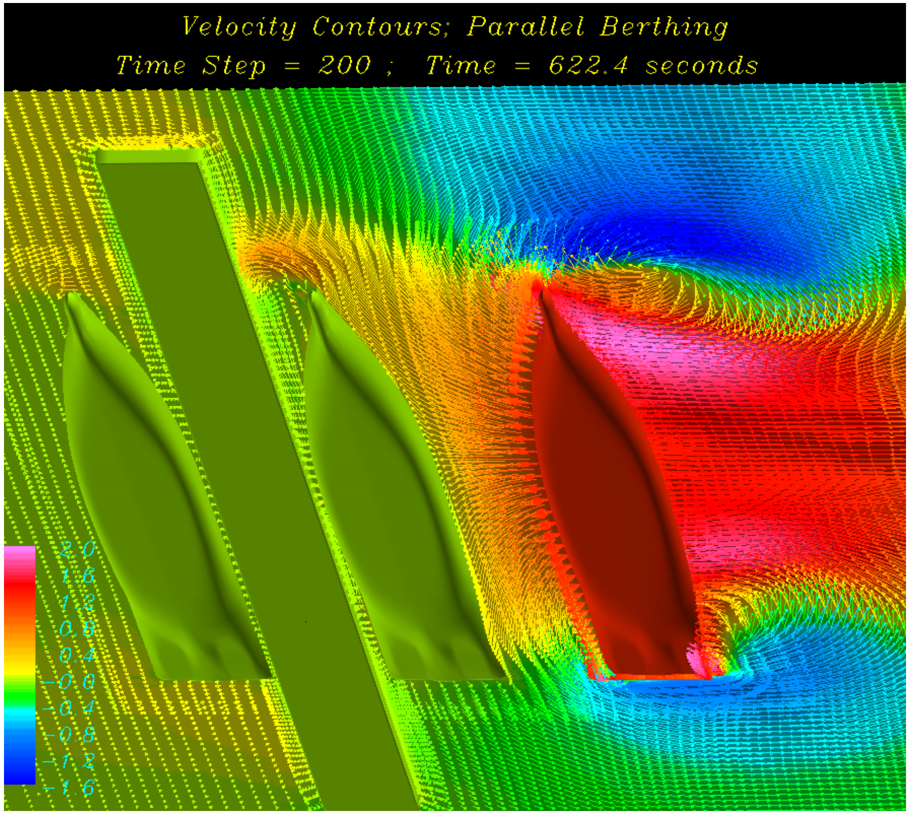


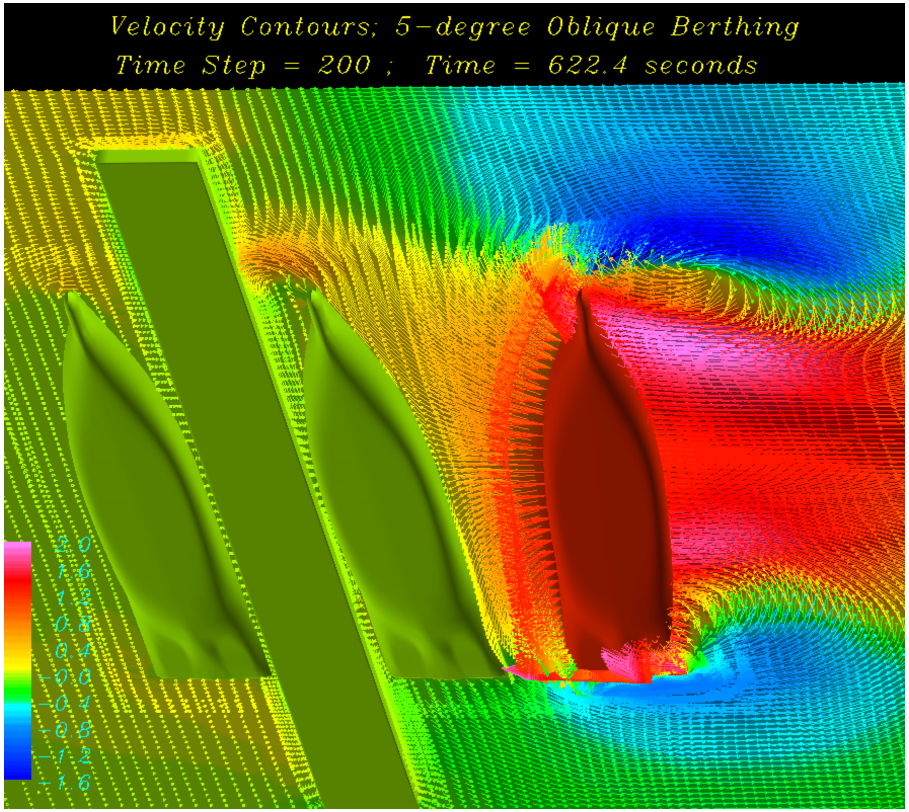


Chimera Domain Decomposition

Overlapping and Embedding Grids

Floating Pier & Multiple-Vessel Interactions



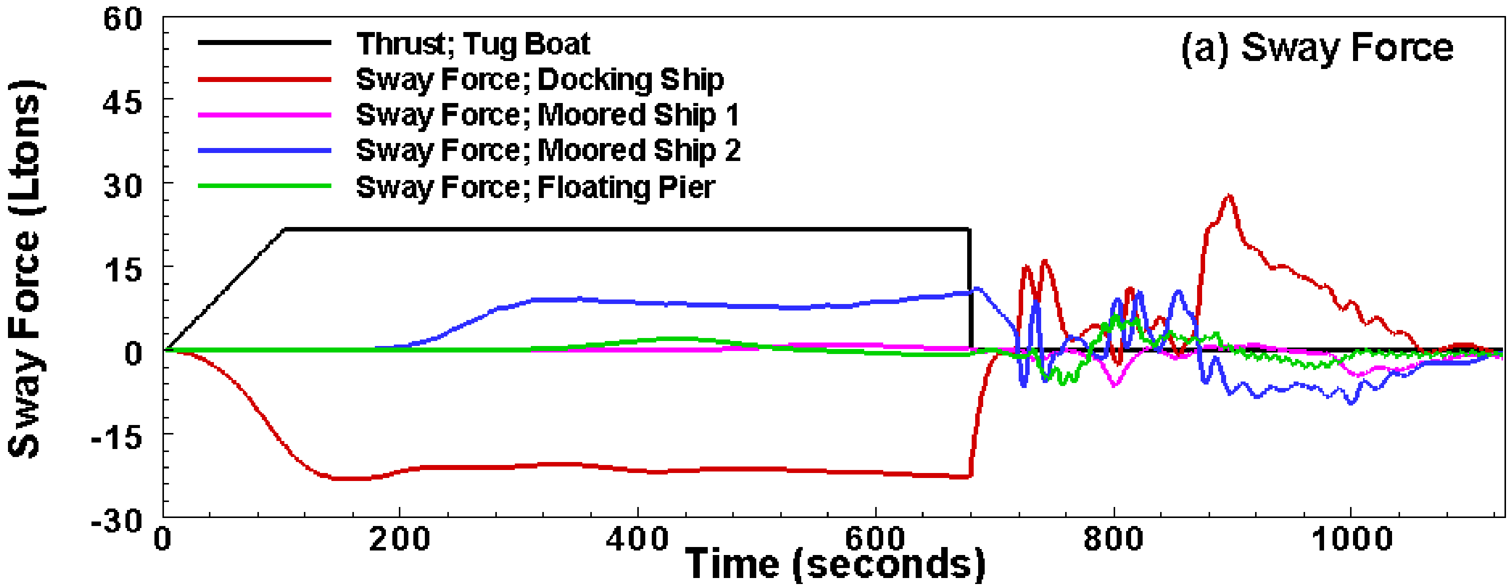


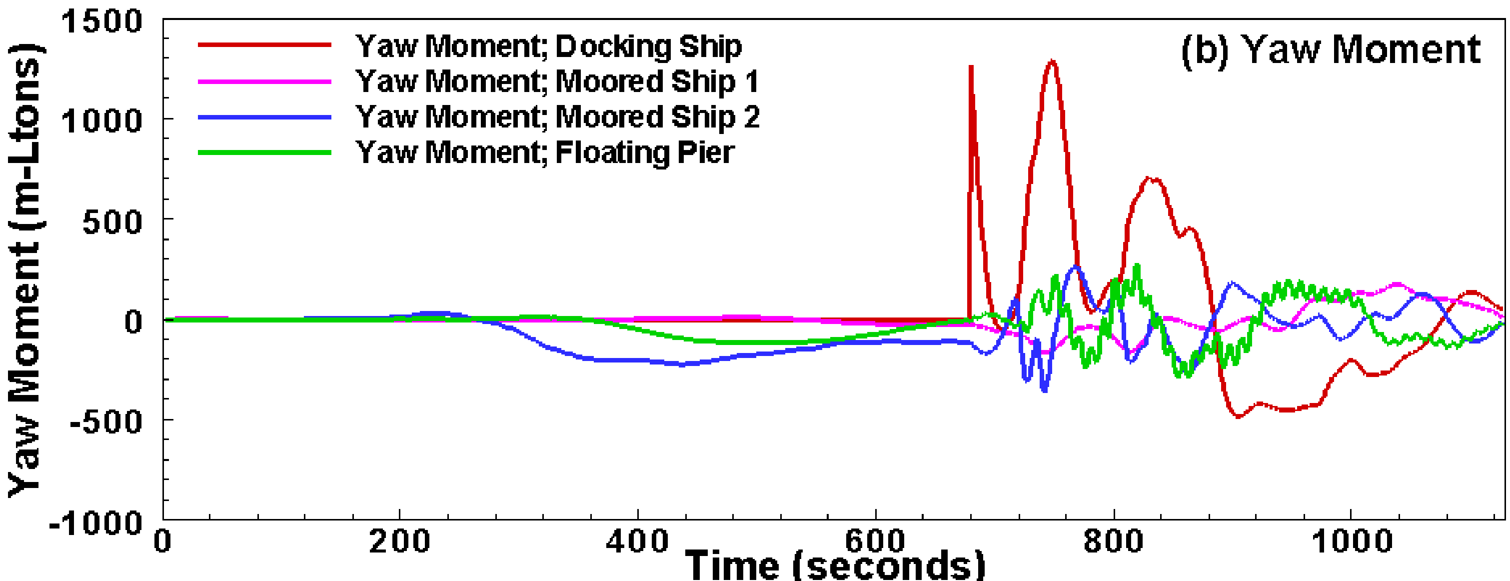
(a) Parallel Berthing **(b) 5° Oblique Angle**

Movie

An Employee-Owned Company

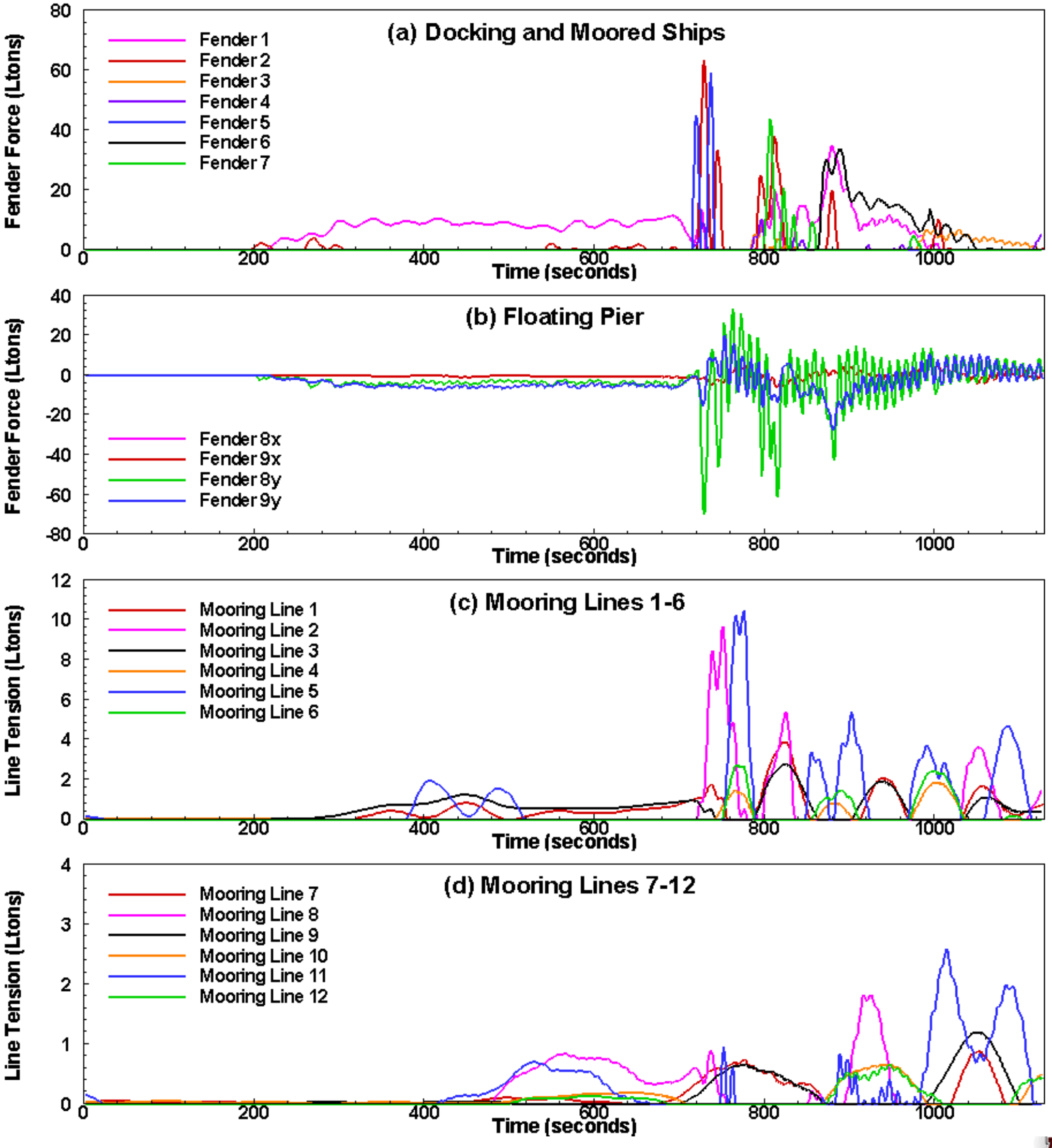
Hydrodynamic Forces





An Employee-Owned Company

Fender Forces and Mooring Line Tensions



Concluding Remarks - Results

- Unsteady Chimera RANS Method is used to study ship-ship interaction problems
- The time-domain computation results in general track the experimental measurement reasonably well even though there are some differences in the settings
- Study of detailed flow field may allow us to gain some insights of the ship-ship interaction phenomena
- The method was successfully applied to:
  - Passing ship effects on a moored vessel
  - Berthing operations
  - Floating pier and multiple-vessel interactions including mooring and fender effects
- Numerical method is suitable for practical applications:
  - Chimera gridding technique
  - Run on PC or workstations

Concluding Remarks – CFD Method

- The use of Unsteady Chimera RANS Method to study ship-ship interactions, ships operating in a channel, and berthing have been quite successful and revealing
  - Use of Chimera Domain Decomposition Method greatly simplifies the complexity of grid generation and make it practical for the current study – parametric study is possible
  - Advances in solution techniques and computer hardware make it more affordable to use CFD for these types of study
  - Results in general track the experimental measurements reasonably well – further validations can be very valuable
  - The RANS Solutions contain detailed flow information (velocity, pressure, turbulence, vorticities, waves, etc.) at every location in the computational domain. That allows us to understand the physics of the problem at a level not previously possible
  - Use CFD for ship maneuvering forces is possible and can be expanded to include rudder & propulsor effects
  - Combination of CFD & FEM can address issues of a complex system composed of ship, fenders, mooring lines

Concluding Remarks – General Thoughts

- There are tremendous amount of domain knowledge, expertise, and test data available in the study of ship-ship interactions, ships operating in a channel, ship maneuvering, and berthing operations in general
- Advanced flow computational method (so called CFD) can be very useful for studying in “these” areas – it offers new possibilities that are difficult to achieve before
- CFD alone is not enough for solving all the problems – our understanding of flow physics is still limited
- Continuing validation of CFD can help to improve the reliability and accuracy of CFD results
- The most desirable and effective approach is to use CFD together with theories, expert domain knowledge, database, model-scale tests, and full-scale measurements

Concluding Remarks – Coordinated Systematic Research

- Calibrate CFD Tools for bare hull, effects of shallow water, bank, and passing ships
  - Use existing towing tank test data of aggregated force & moment
  - Model tests measuring the hull pressure distributions
- Use validated CFD tools to check assumptions/algorithms commonly adopted by simulator math modeling community
- Use validated CFD tools to quantify scale effects
- Feed full size ship maneuvering data & survey into CFD tools to calculate pressure distribution, forces & moments on the hull. Dissect contributions of bank, shallow water and passing ships.
- Improve simulation model and verify with real voyages using recorded engine & rudder activities

For Further Information Please Contact

Prof. Hamn-Ching Chen
Department of Civil Engineering, Texas A&M University
(979) 847-9468; hcchen@civilmail.tamu.edu

Dr. Woei-Min Lin
Ship Technology Division, Science Applications International Corporation
(410) 266-0990; linw@saic.com

Dr. Wei-Yuan Hwang
Computer Aided Operations Research Facility, U.S. Merchant Marine Academy
(516) 773-5605; hwangw@usmma.edu

Dr. Erick T. Huang
Code ESC31, Naval Facilities Engineering Service Center, Port Hueneme
(805) 982-1256; huangt@nfesc.navy.mil