Computational Fluid Dynamics in Offshore Applications

Jer-Fang Wu, Ph.D.

Singapore Offshore Technology Center
American Bureau of Shipping
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Offshore Hydrodynamics

- Design challenges - MODU and FPU
  - Constantly challenged by the need to estimate the environmental loads more accurately and comprehensively
- Why environmental load estimate is a challenge?
  - Wide variety of load types
    - Wind, current, waves (nonlinear and random)
  - Complex physics
    - Turbulence, highly nonlinear/breaking waves and their interaction with offshore structures
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Complexity of environment – Violent free surface

- Spray due to wave impact
- Run-up and wave breaking
- Green water / wave on deck
- Sloshing
Complexity of environment – Extreme Waves

Monster waves

- Freak waves (also known as rogue waves or monster waves) - relatively large ocean waves with $H > 2H_s$

25 m above the mean sea level
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Analysis Difficulty due to Violent Waves

- Offshore platform design concerns
  - In structure strength design, wave loads is obviously important
  - Wave induced motions are also important to operation problems
- Determination of the wave loads and floater system response are difficult
  - Under violent (extreme) waves, hydrodynamic load and its induced structure motion are highly nonlinear
  - Floater system includes floater, risers, mooring system. The interaction among them is strong and they should be considered as a whole.
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Complexity of environment – Turbulent Current

Current with varied magnitude and direction

The Campos Basin, off the southeastern coast of Brazil near Rio de Janeiro.
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Complex physics behind the turbulent current

- VIV (Vortex Induced Vibration)
  - 2D geometry and inflow condition generates 3D flow structure downstream
  - Steady inflow associated with unsteady vortex shedding
  - Multi-risers cases: large motions (sometimes collision occurs) and strong interaction among risers
Fluid Flow Models

- Viscous flow model:
  - Navier - Stokes Equations

- Inviscid-rotational flow model:
  - Euler Equations

- Potential flow model – inviscid & irrotational:
  - Laplace Equations
Potential flow based simulation

- Potential flow theory
  - Inviscid fluid under irrotational motion
  - No capability for viscous effect dominated problems (VIV, VIM, FPSO roll motions)

- Commercial softwares
  - WAMIT, AWQA, MOSES, MLTSIM, LAMP
  - BEM based software
  - Weakly non-linear waves (2nd to 5th order Stokes’ waves)

- Limitations:
  - Highly nonlinear waves (breaking waves simulation is beyond the potential flow capability)
  - Large amplitude motions
  - Turbulent and viscous flow
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- Potential flow based simulation (WAMIT) vs. measurement
Emerging CFD Based Analysis

- CFD simulations
  - Navier-Stokes equations based model
    - NS eqs. include all the physics for real fluid flows
    - Viscosity, turbulence, vortex motion
  - Capabilities to overcome the previous three handicaps in potential flow simulation
    - RANS model for turbulent flow
    - Free surface capturing method for violent waves
    - Overset grid for large motion
Free surface capturing method – level-set method

**Equations:**

- Navier-Stokes equations
- Continuity equation
- Energy equation

**Boundary Conditions:**

- Wall boundary
- Inlet boundary
- Outlet boundary

**Initial Conditions:**

- Initial velocity
- Initial pressure

**Numerical Methods:**

- Finite volume method
- Finite element method

**Software Tools:**

- ANSYS CFX
- Fluent
- OpenFOAM

**Applications:**

- Offshore engineering
- Marine structures
- Renewable energy (wind, wave)
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Time domain simulation – sloshing

Transverse Motion, FLVL = 30%
Time Step = 0, Time = 0 sec

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Time Step = 0, Time = 0 sec
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- Multi-risers VIV – large motion + multi-body interaction

VIV of four circular cylinders in a square array configuration, L/D=4, Re = 1 \times 10^3, m^* = 1.0, m^*\zeta^* = 0.005, U^* = 6.055

Vorticity ($\omega_z$) contours
Viscous-inviscid coupling method

- Although CFD is powerful, the computation price is high, especially for time domain simulation (nonlinear problem) for large domain

- To enhance the computation efficiency, for the areas viscous effect is not important, simplified potential flow model should be used instead of the expansive RANS CFD computations
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Applications of viscous-inviscid coupling method

Surface Effect Ship – $C_b = 0.6$
ABS – IHPC Collaborations

- IHPC - Institute of High Performance Computing, the leading high performance computing research institute in Singapore
- IHPC has up-to-date computing resources
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ABS – IHPC Collaborations

• Full collaboration effort between ABS & IHPC since 2006

• Three Phases are planned for CFD in Offshore Application capability development:
  - Phase I – Infrastructure set-up for subsequent CFD R&D and offshore applications, 2006-2008
  - Phase II – Software development and validation of key modules, 2009-2011
  - Phase III – Provide engineering services for CFD related offshore applications, 2011 -
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Closing Remarks

- Driven by offshore structure design for deeper water and harsher environment, prediction methods for hydrodynamic loading require capabilities for
  - violent free surface waves
  - large motion, and
  - turbulent simulation

- Most of off-the-shelf engineering tools for hydrodynamic analysis are
  - Potential flow theory based, BEM type software
    - WAMIT, AWQA, MOSES, MLTSIM, LAMP
  - Handicap to violent waves, large motion and turbulent flows
Closing Remarks

● The CFD capabilities may be enhanced by integrating the following features:
  ■ interface capturing methods - VOF, Level-Set
    • To account for violent free surface effects
  ■ Overset grid technique
    • To deal with violent floater motions and multi-body interactions
  ■ Viscous-inviscid coupling method
    • To reduce CFD computation cost

● ABS Singapore Offshore Technology Center (SOTC) is making considerable effort in promoting CFD in Singapore since 2006
Thank You!

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