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CMHL COMPUTATIONAL MARINE HYDRODYNAMICS LAB
SHANGHAI JIAO TONG UNIVERSITY

Virtual Test for Vortex Induced Vibration Based on Database (viv-FAST-SJTU)

Virtual Test for Vortex-Induced Vibration Based on CFD (viv-FOAM-SJTU)

Virtual Test for Vortex Induced Motion of Platforms in the Sea (vim-FOAM-SJTU)

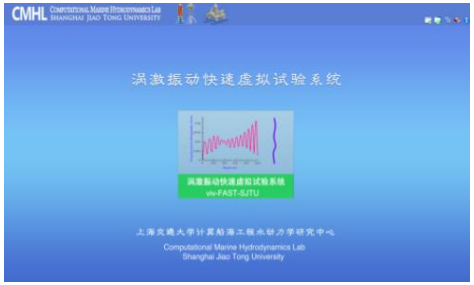
http://dcwan.sjtu.edu.cn

Shanghai Jiao Tong University
Dec. 2017

Virtual Test for Vortex Induced Vibration Based on Database (viv-FAST-SJTU)

The Virtual Test for Vortex Induced Vibration Based on Database (viv-FAST-SJTU) is designed for marine riser, anchor chain and other riser-type structure of the vortex-induced vibration problem. It is developed based on building fluid forces database system and Structure Finite Element Dynamics model to obtain Vortex-induced dynamic response of marine risers rapidly.

The viv-FAST-SJTU includes the standalone version and the web version. You can run on the computer and get the results within 10 minutes. The system can carry out the modal analysis of the large aspect ratio riser and output the natural frequency and mode shapes. It can calculate the vortex-induced dynamic response of RMS displacement, velocity and stress. Results of data and curve can automatically generated rapidly.

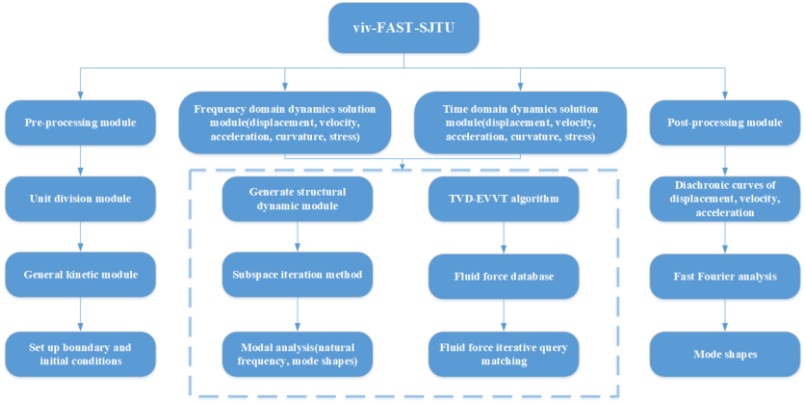


Standalone version

Web version

Composition & Module

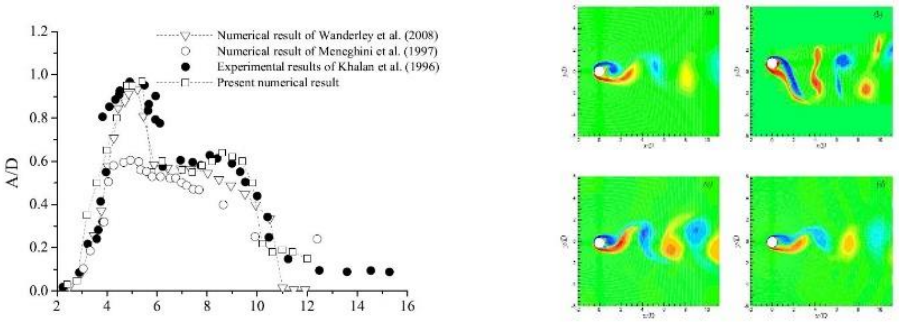
The System has a clear structure and a good scalability with three modules (pre-processing, solver and post-processing), consisting of more than 10 sub-modules.



Module framework of viv-FAST-SJTU

Performance & Characteristics

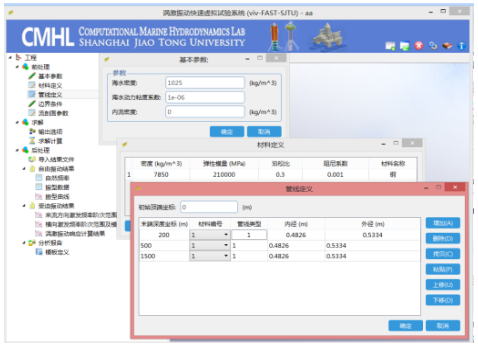
The viv-FAST-SJTU uses Subspace iteration method to calculate structural dynamic response and fluid force iterative query matching according to high accuracy algorithm TVD-EVVT to obtain Vortex-induced dynamic response of marine risers rapidly.



Comparison betweenTVD-EVVT calculation results ,experimental results, and the other numerical simulation results

System Features

The system uses a clear and simple process with friendly and flexible interface. Engineers can easily predict the vortex-induced vibration response of marine risers under different tensions and structural parameters.Therefore the system provides strong support for the design and use of marine engineering.

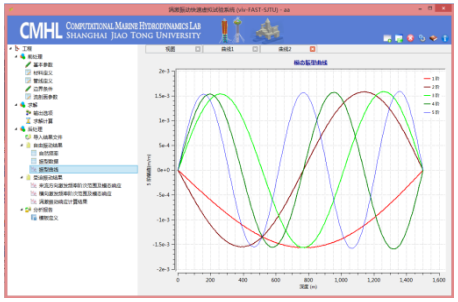


User interface (Standalone version)

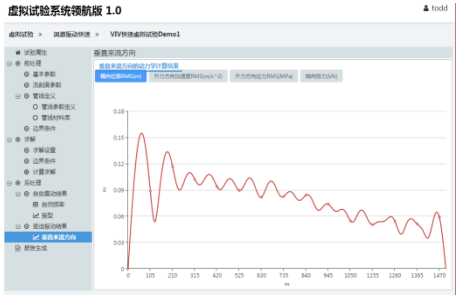
User interface (Web version)

Typical test

Experimental parameter: Riser length: 1500m; Outer diameter: 0.5334m; Inside diameter: 0.4826m; Internal density: 1438 kg/m3; Elastic Modulus: 210GPa; Density: 7850 kg/m3; Top tension: 7766.2kN (1.5 times of wet weight); Current speed: 0.5m/s-1.5m/s gradient flow.



The 1-5th mode shape curve of riser (Standalone version)



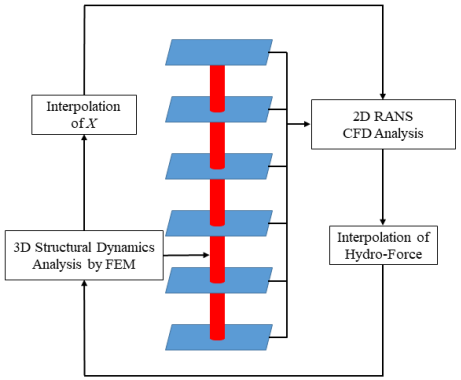
RMS of displacement results (Web version)

Virtual Test for Vortex-Induced Vibration Based on CFD (viv-FOAM-SJTU)

Different from viv-FAST-SJTU, Virtual Test for Vortex-Induced Vibration Based on CFD (viv-FOAM-SJTU) employs the method of coupling the strip theory based CFD model with structural dynamical model to calculate the flexible riser VIV response as well as detailed flow field analysis. The system includes two set of VIV solvers: viv-FOAM-SJTU based on OpenFOAM platform and TVD-FVM-VIV using high-resolution discretization approach.

The system realizes the function of grid generation, parameters definition, calculation and visualization of results in the user-friendly interface. Based on the tools of time-domain, frequency-domain and modal analysis, the system can provide multiple forms of data visualization.

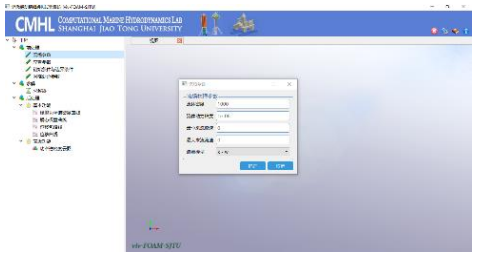
Main interface of viv-FOAM-SJTU



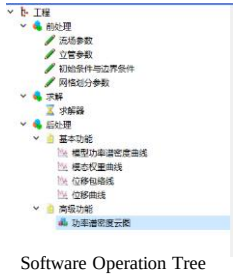
Principle diagram of strip theory

Performance & Characteristics

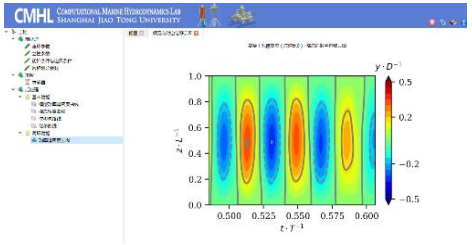
The system realizes the function of grid generation, parameters definition, calculation and visualization of results in the user-friendly interface. Based on the tools of time-domain, frequency-domain and modal analysis, the system can provide multiple forms of data visualization.



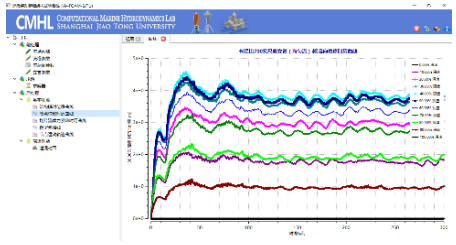
Interface of viv-FOAM-SJTU



Software Operation Tree



Cross-flow (CF) displacement time histories at selected spanwise location.

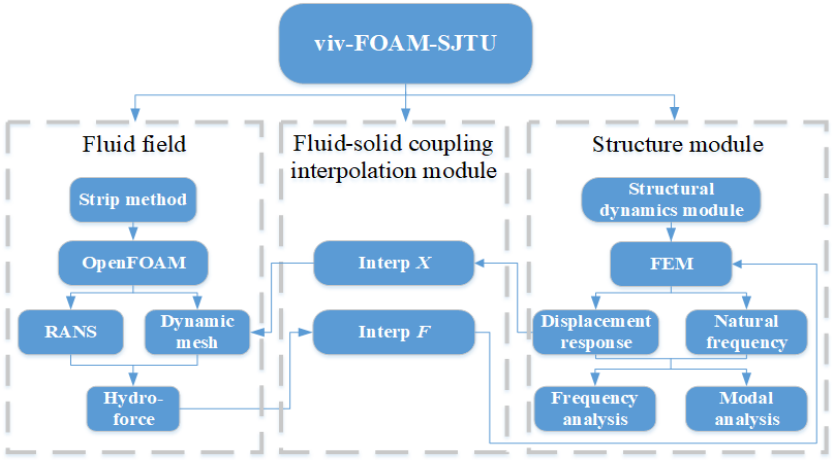


Time-averaged in-line (IL) displacement along the cylinder span.

viv-FOAM-SJTU Solver

Composition & Module

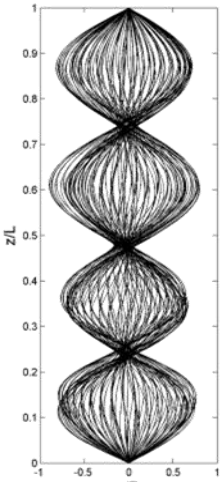
The viv-FOAM-SJTU solver was developed based on the OpenFOAM platform and strip method. The flow field around the riser are simulated by finite volume method and RANS turbulence model acquiring the riser stresses and flow field characteristics. The Euler-Bernoulli beam model and the three-dimensional finite element method are used for modeling. The information is transferred through the interpolation module to realize the coupling calculation of the mesh deformation and the structural dynamic response.



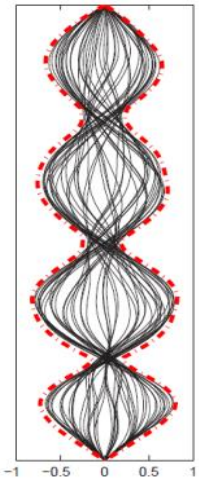
Module Framework of viv-FOAM-SJTU

VIV of a single riser under the stepped flow

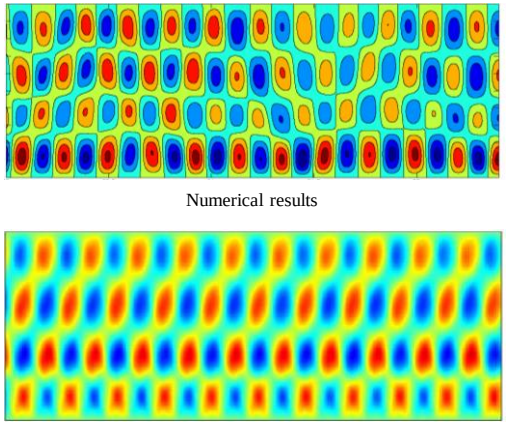
The viv-FOAM-SJTU solver can simulate the vortex-induced vibration of in-line and cross-flow coupling of risers under uniform flow, shear flow, oscillatory flow and platform motions. In the standard numerical simulation of the viv-FOAM-SJTU solver, the error of the displacement of the in-line and the cross-flow vibration is within 10%, which verifies the validity and reliability of the solver.



Numerical results of cross-flow vibration



Experimental results of cross-flow vibration

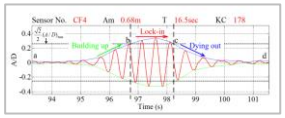


Spatial-temporal image of cross-flow displacement

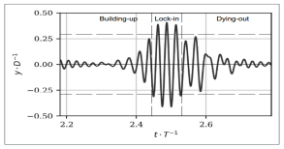
Vortex-induced vibrations of the riser under platform motions

The viv-FOAM-SJTU solver can simulate the "build-up-lock-in-die-out" process of vortex-induced vibration of flexible riser under oscillatory flow. The results are in good agreement with the experimental results. The solver can simulate vortex-induced vibration of risers under the platform surge, sway and heave motions.

VIV of the riser under oscillatory flow

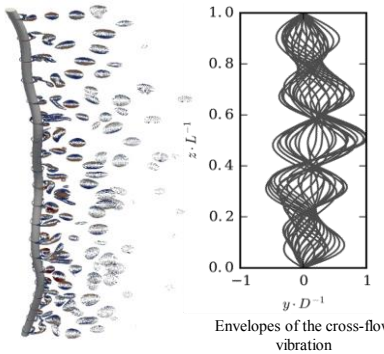


Experimental results



Numerical results

Time history curve of cross-flow vibration



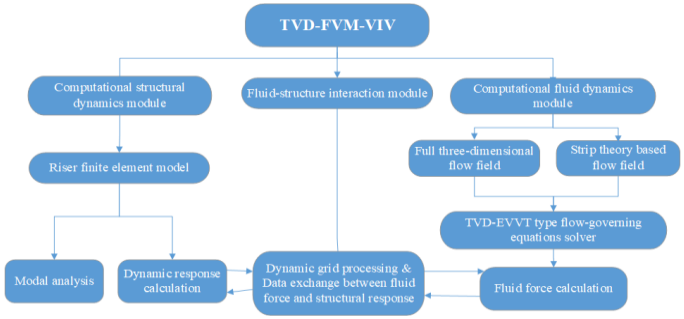
Envelopes of the cross-flow vibration

VIV of the riser under platform motions

TVD-FVM-VIV solver

TVD-FVM-VIV solver is developed by using the finite volume method based upon the total variation diminishing (TVD) scheme and elemental velocity vector transformation (EVVT) method from several-year-study achievements of Professor Jiasong Wang and his study group. The solver is implemented by the fluid governing equation of Navier-Stokes equations, coupling with the structural dynamical equation using the finite element method and the fluid-structure interaction module. It can reliably model the VIV problem of actual size of flexible riser under the real ocean environmental conditions.

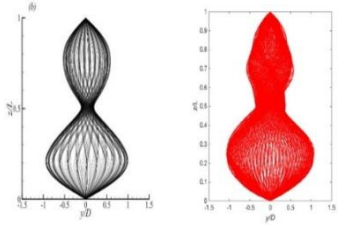
TVD-FVM-VIV solver can select the strip theory of 2D CFD method or the full 3D CFD method to carry out the fluid flow around risers. The fluid moving boundary was achieved through the arbitrary Euler Lagrange (ALE) method. The structural dynamical model was constructed by using 3D beam-element coupling with the fluid dynamical computation under the moving mesh condition through the fluid-structure interaction module.



Module framework of TVD-FVM-VIV

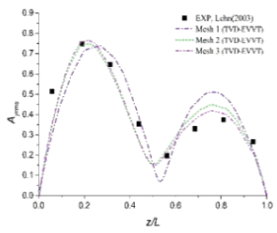
VIV simulation of riser with L/D=481 under uniform flow

The solver was validated by a standard experimental model of uniform flow with an incoming velocity of 0.42 m/s for a riser of 9.63m in length and 481 in ratio of length to diameter. The response envelope and RMS amplitude agree well with the experimental results. In the same computational conditions, the computational time of this solver reduces over 30% comparing with the commercial CFD software. It can simulate the practical engineering conditions, such as up to 106 of Reynolds number and 1000 of length to diameter ratio.

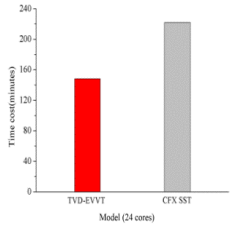


Structural CF response envelopes of simulation

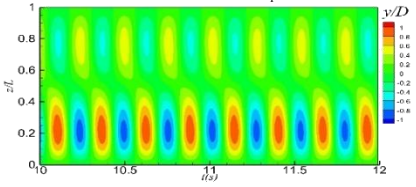
Structural CF response envelopes of experiment



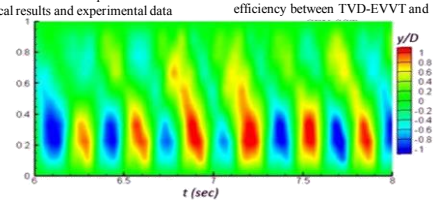
Comparison of the RMS amplitudes between numerical results and experimental data



Comparison of CFD computational efficiency between TVD-EVVT and



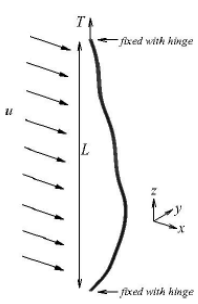
Temporal evolution of CF displacement along the cylinder span in simulation

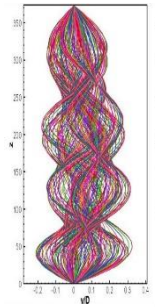


Temporal evolution of CF displacement along the cylinder span in experiment

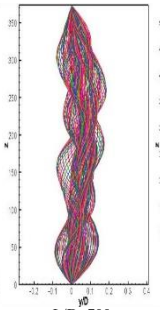
VIV simulation of riser at real scale

Using TVD-FVM-VIV solver, the VIV simulation is carried out on the practical size of riser. The examples of risers, having aspect ratios of 700, 100 and 1500 with a 0.6 m/s uniform and 0.1-1.0 m/s linearly sheared flow, are considered respectively, which is hinge connected at both ends with a top tension equivalent of 1.5 unit of wet gravity. TVD-FVM-VIV solver can effectively capture the multi-modes and high wavenumbers of structural response for the large length to diameter ratio of practical risers using in engineering.

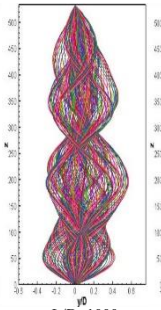




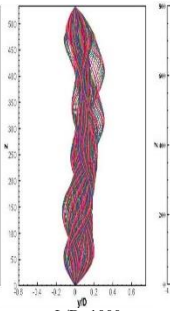
L/D=700 uniform flow



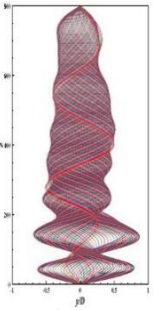
L/D=700 sheared flow



L/D=1000 uniform flow

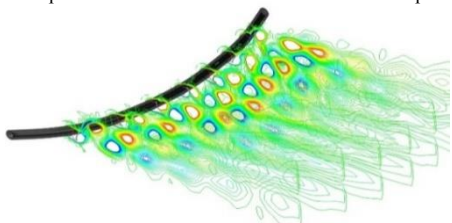


L/D=1000 sheared flow

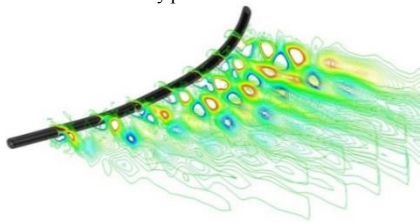


L/D=1500 uniform flow

TVD-FVM-VIV solver effectively predicts the travelling wave patterns of VIV response of long flexible riser at high Reynold number, which is hard to be captured in experimental tank. The flow field around the flexible riser can be accurately simulated, with the governing equations of full three-dimensional flow. The vortex shedding pattern at different spanwise locations and three-dimensional transport of wake can be distinctly presented.



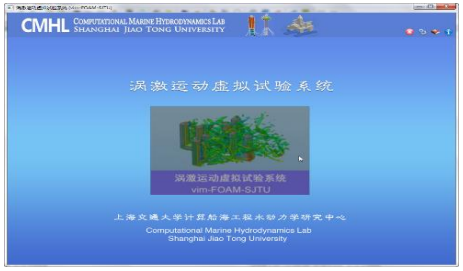
Instantaneous iso-contours of spanwise vorticity (L/D=1000, uniform flow)



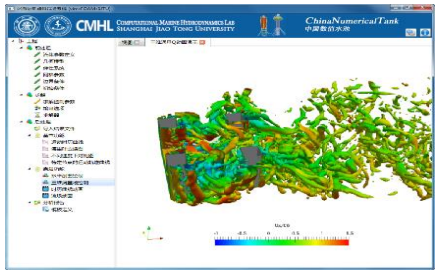
Instantaneous iso-contours of spanwise vorticity (L/D=1000, linearly sheared flow)

Virtual Test for Vortex Induced Motion of Platforms in the Sea (vim-FOAM-SJTU)

The Virtual Test for Vortex Induced Motion of Platforms in the Sea (vim-FOAM-SJTU) is developed for predicting and analyzing the vortex-induced-motion of offshore platforms. It applies the Detached Eddy Simulation (DES) method to simulate the three-dimensional flow separation at high Reynolds numbers, and solves the vortex-induced motions coupled with the six-degree-of-freedom motion theory and the moving-boundary spring mesh technique. The core of this system is a vim-FOAM-SJTU solver developed on the basis of OpenFOAM.



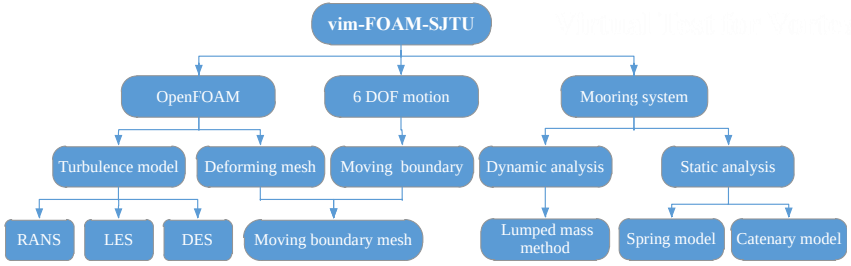
Interface of VIM Virtual Experimental System



Snapshot of VIM simulation results

Composition & Module

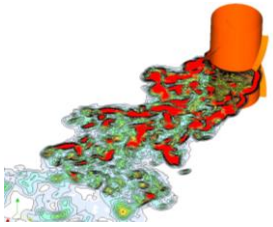
The vim-FOAM-SJTU solver uses the Finite Volume Method (FVM) and the Detached Eddy Simulation (DES) method to solve the flow field around the platform, and applies the six-degree-of-freedom motion theory to deal with the motion of platform. Meanwhile, it uses the moving boundary spring mesh technique to solve the moving boundary problem caused by the motion, and adopts different static analysis model to simulate the mooring system.



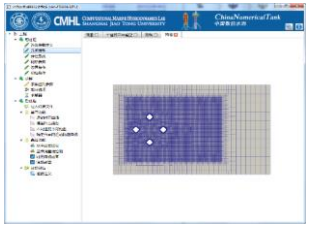
Module framework of VIM Virtual Experimental System

Performance & Characteristics

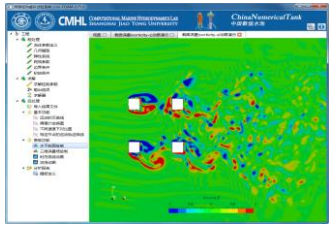
The system uses the DES method to capture precise details of the three-dimensional flow field at high Reynolds numbers. The coupling motions of the platform with multi degrees of freedom can be realized, the velocity ranges of "lock-in" phenomena can be accurately predicted. The system is capable of flexible grid generation, parameters definition, simulation and result visualization in the user-friendly interface.



Precise flow field at high Reynolds numbers



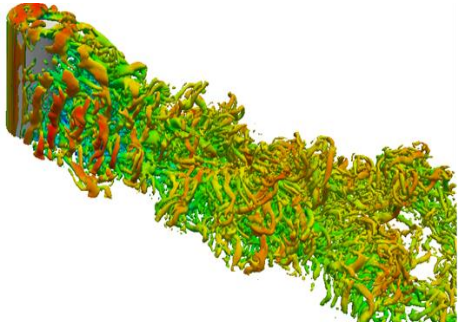
Interface of grid generation



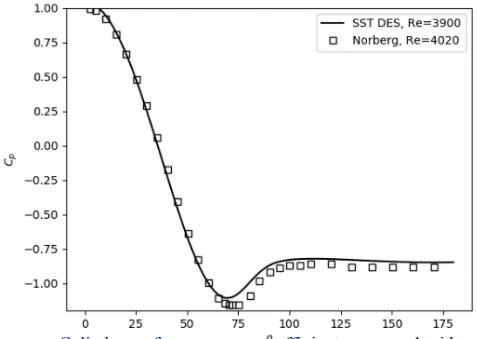
Visualization of VIM numerical results

The flow around a cylinder

For simulating the flow around a cylinder, the vim-FOAM-SJTU solver can capture finer vortex structure and more accurate three-dimensional vortex-shedding effects than the time-averaged method. The error of pressure coefficients on the surface is within 5%.



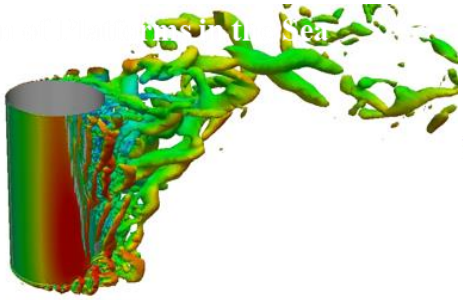
DES simulation of flow past a circular cylinder



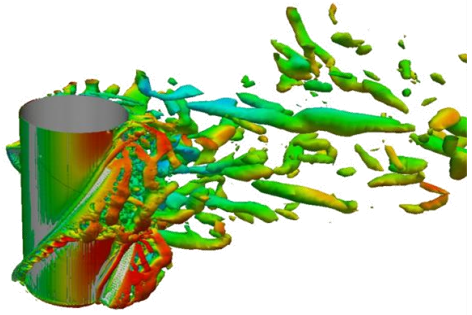
Cylinder surface pressure coefficient compared with the experimental data

VIM of a Spar platform

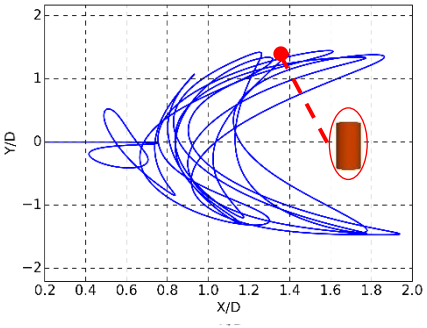
The vim-FOAM-SJTU solver can be used to predict the VIM of the Spar platform, to analyze the vortex-induced-motion response of the platform under different conditions and the vortex reduction effects of the helical side plate on the cylinder surface. The helical strakes can significantly reduce the motion responses in the flow and lateral directions.



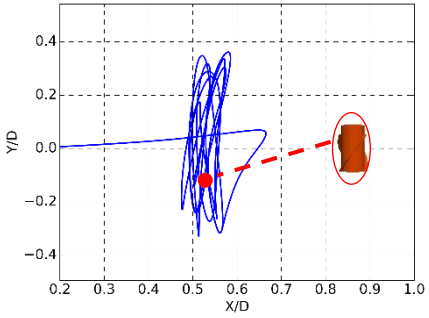
Vortical structures of VIM around a Spar platform without helical strakes



Vortical structures of VIM around a Spar platform with helical strakes



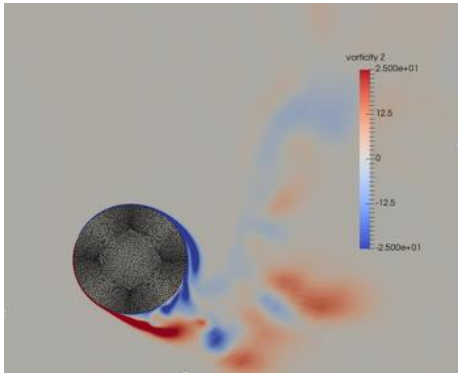
Trajectory of VIM around a Spar platform without helical strakes



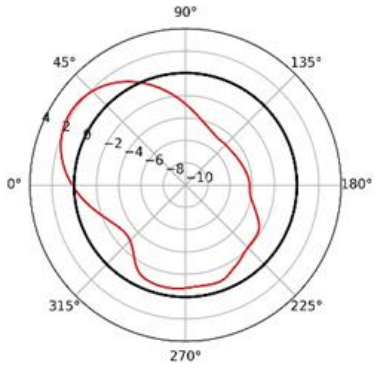
Trajectory of VIM around a Spar platform with helical strakes

VIM of a rotating buoy

The vim-FOAM-SJTU solver can simulate the vortex-induced motion of a cylindrical buoy with rotating motion.



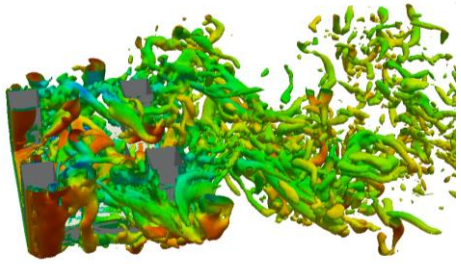
VIM around a rotating buoy



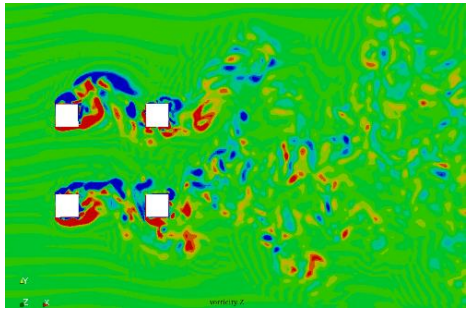
Circumferential distributions of pressure coefficient C_p

VIM of a semi-submersible platform

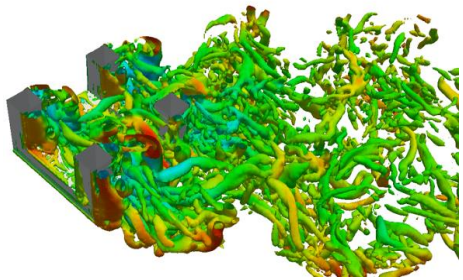
The vim-FOAM-SJTU solver can also simulate the vortex induced motion of a multi-column semi-submersible platform under different incoming flow conditions, and provide the analyses on the characteristics of platform motion and vortex-shedding past the platform.



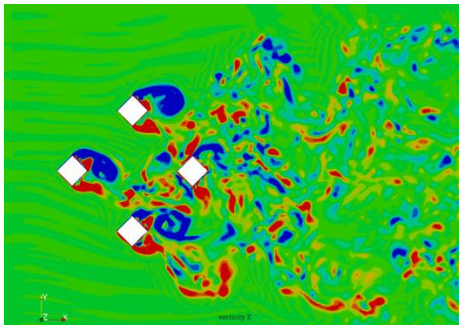
Tail vortex structure of a semi-submersible platform with a 0-degree flow angle



Vortex structure on a horizontal plane with a 0-degree flow angle

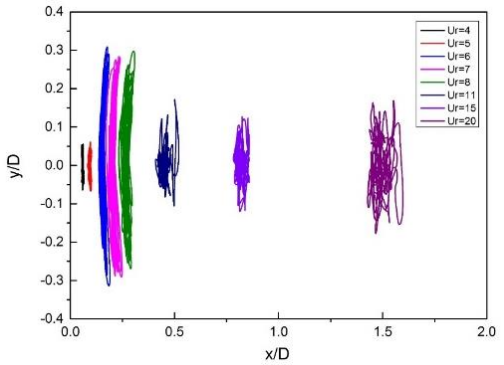


Tail vortex structure of a semi-submersible platform with a 45-degree flow angle

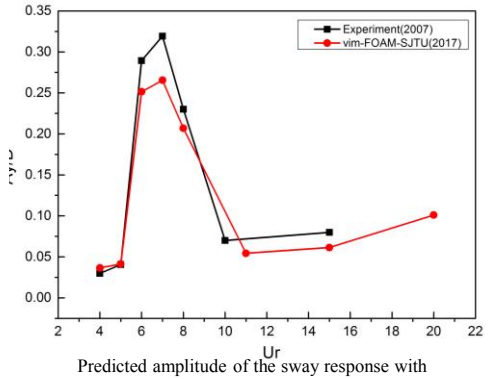


Vortex structure on a horizontal plane with a 45-degree flow angle

vim-FOAM-SJTU can also accurately predict the “lock-in" phenomena, and the prediction error of drag force is about 6%, and as for vortex-induced motions response, the error is less than 10%.



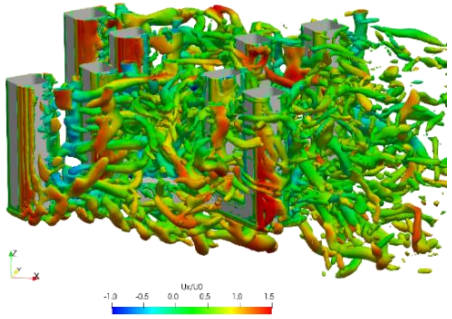
Accurate prediction of “lock-in” phenomena



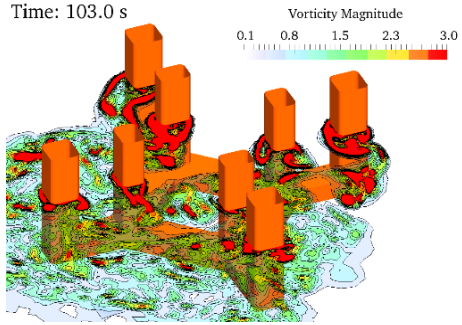
Predicted amplitude of the sway response with varying reduced velocity

VIM of a paired-column semi-submersible platform

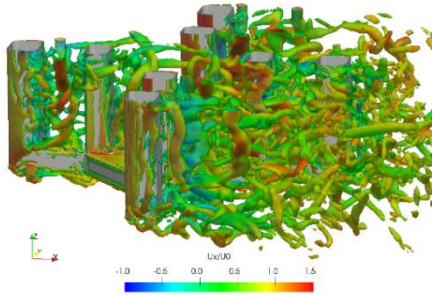
vim-FOAM-SJTU solver can simulate the vortex induced motion for new-type platforms, such as the paired-column semi-submersible platform, and predict the VIM features under different conditions.



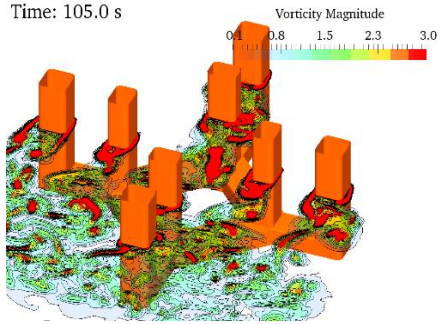
Tail vortex structure of a paired-column semi-submersible platform with a 0-degree flow angle



Vortex structure on the z/L=0.5 plane with a 0-degree flow angle



Tail vortex structure of a paired-column semi-submersible platform with a 45-degree flow angle



Vortex structure on the z/L=0.5 plane with a 45-degree flow angle