STATE MARINE TECHNICAL UNIVERSITY

OF SAINT PETERSBURG

The experience of the applying the open-source software in ship hydrodynamics

Dr. Igor. V. Tkachenko, Nikita V. Tryaskin, Sergey I. Chepurko

Contents

Introduction

State Marine Technical University of St. Petersburg

- *Faculty of Naval Architecture and Ocean Engineering*
- Faculty of Natural and Social Sciences and Humanities
- Faculty of Marine Engineering
- Faculty of Marine Electronics and Control Systems
- Faculty of Business and Management

Faculty of Naval Architecture and Ocean Engineering:

Departments - 10;

Laboratories – 9;

Research Institutes – 1;

Research Educational Centers – 1.

The value of scientific financing - 3d place in Saint-Petersburg

Introduction

Department of Hydrodynamics and Marine Acoustics (DHMA)

Facilities:

① Big wind tunnel (D=2.0 m, 50 m/sec);

② Small wind tunnel (D=0.4 m, 30 m/sec);

③ Training aerodynamic laboratory;

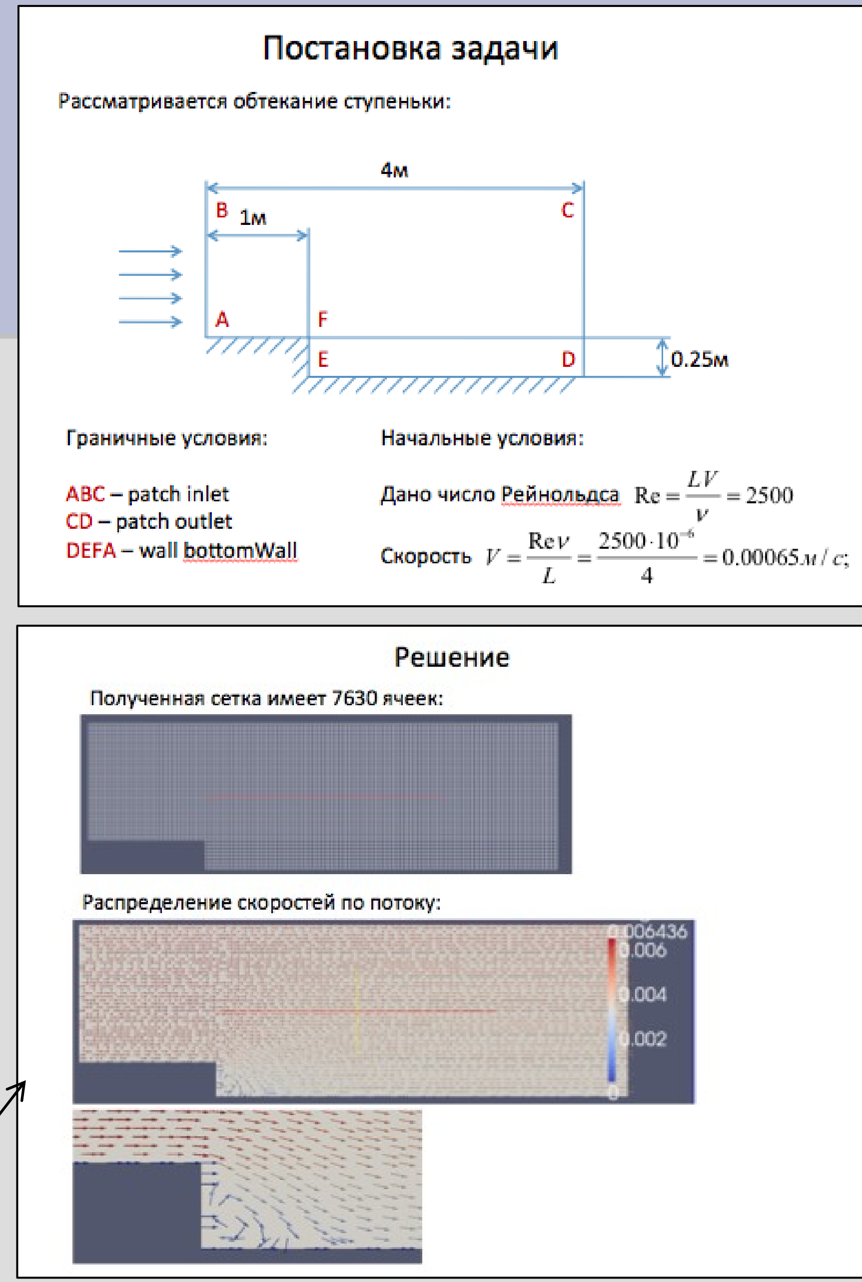
④ Acoustic laboratory;

⑤ Center of High Performance Computations.

CFD and Education

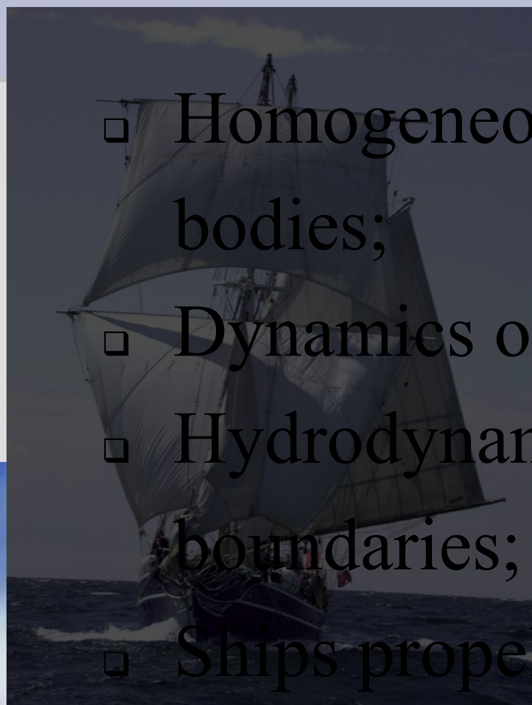
- Disciplines:
  - Boundary and layer theory;
  - Modern turbulent models;
  - Numerical Methods in fluid dynamics;
  - High Performance Computations in ship hydrodynamics.
- Software:
  - Ansys CFX, Fluent;
  - OpenFOAM.
- Students works:
  - Lab works;
  - Project works;
  - Diploma works.

Flow past step

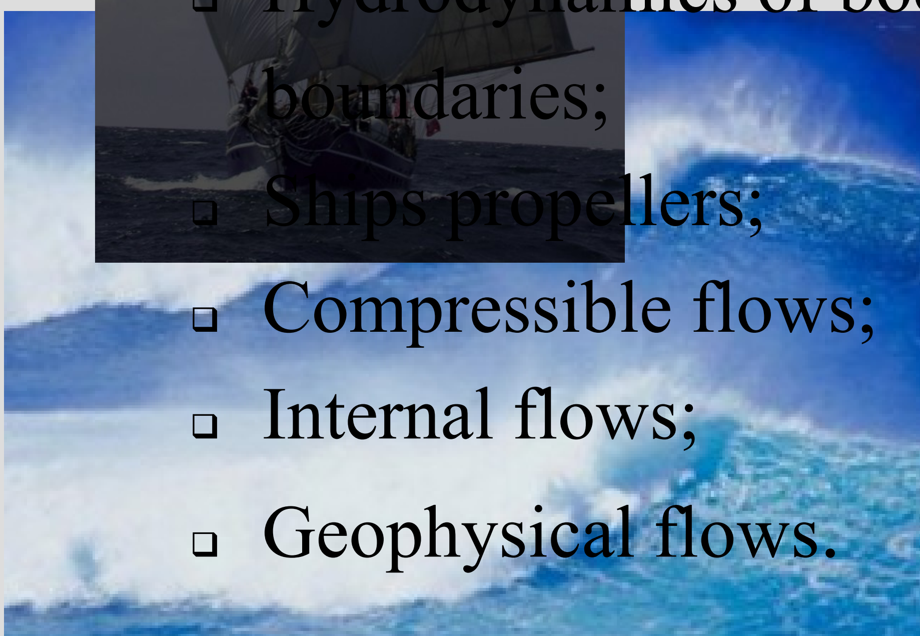


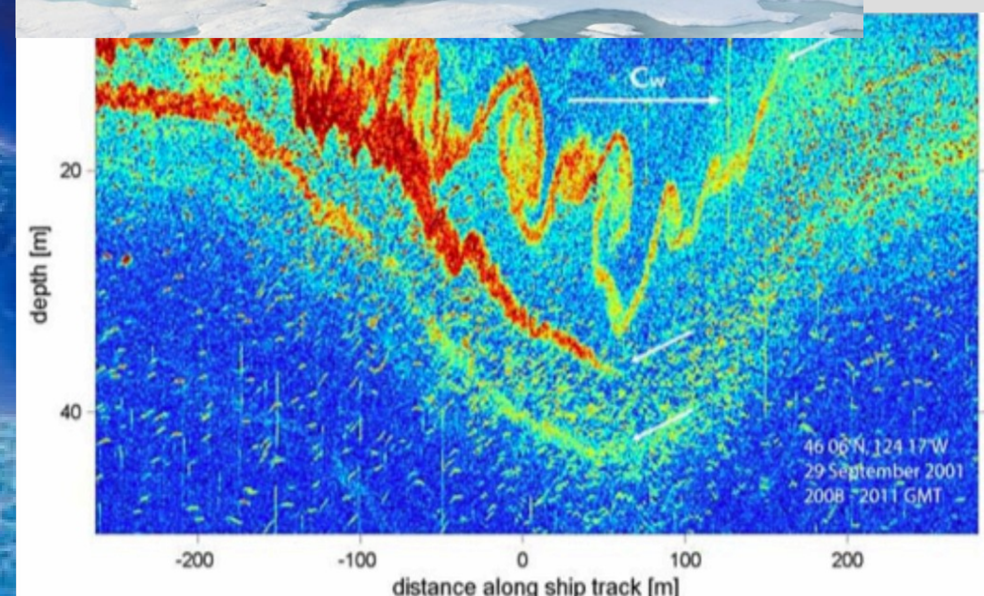
Example of laboratory work

Numerical investigations



- Homogeneous and heterogeneous flows past an bodies;
- Dynamics of bodies;
- Hydrodynamics of bodies near the solid and liquid boundaries;
- Ships propellers;
- Compressible flows;
- Internal flows;
- Geophysical flows.





Features of simulation of flows past marine objects in natural conditions

High Reynolds number ($Re>10^7$);	=> Turbulence modeling, grid resolution > 10^7
Gas-liquid interface	=> Wave motion, cavitation
Stratification	=> Mixing, internal waves
Interaction with ice	=> Ice model

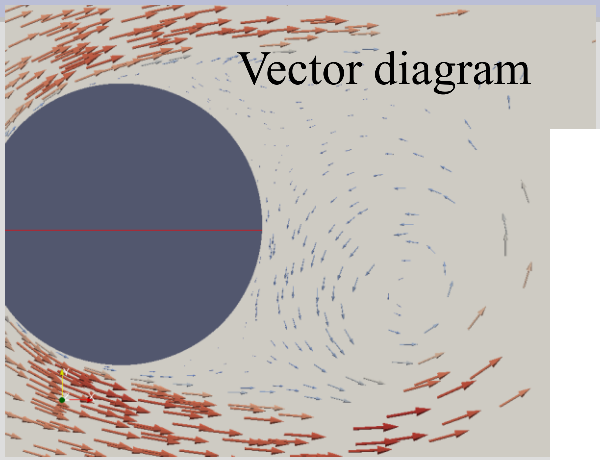
Mathematical models, hardware and services

- ***Mathematical model:***
  - Unsteady Reynolds Averaged Navier-Stokes equations (URANS), Large Eddy Simulations (LES) equations, Hybrid Methods (DES);
  - URANS models (k-eps, k-omega, SST), LES models (Smagorinsky, DSM, DMM);
  - Volume of Fluid (VoF) and mixture fraction methods.
- ***Hardware***:
  - University cluster of the SMTU (64 cores, 96 Gb RAM);
  - UniHub (Clusters of the ISP RAS, JSCC RAS, HP, 512-1024 cores).
- ***Services***:
  - Open source SALOME - CAD;
  - Open source OpenFOAM + ParaFOAM (FVM, SIMPLE, PISO, unstructured grids, MPI, CUDA) + Cloud Services;
  - Inhouse code FlowFES + Paraview (FEM, projection method, unstructured grids, MPI).

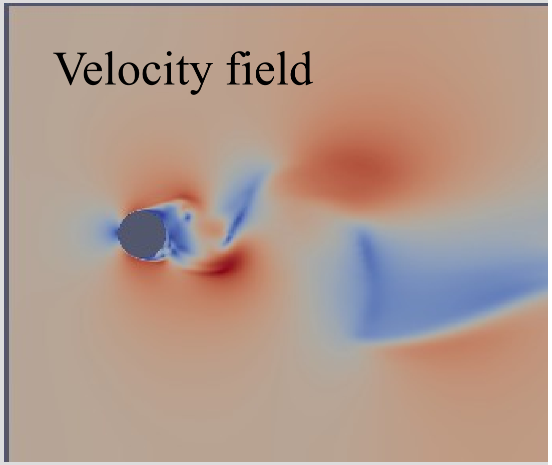
Simulation of homogeneous flows past an bodies

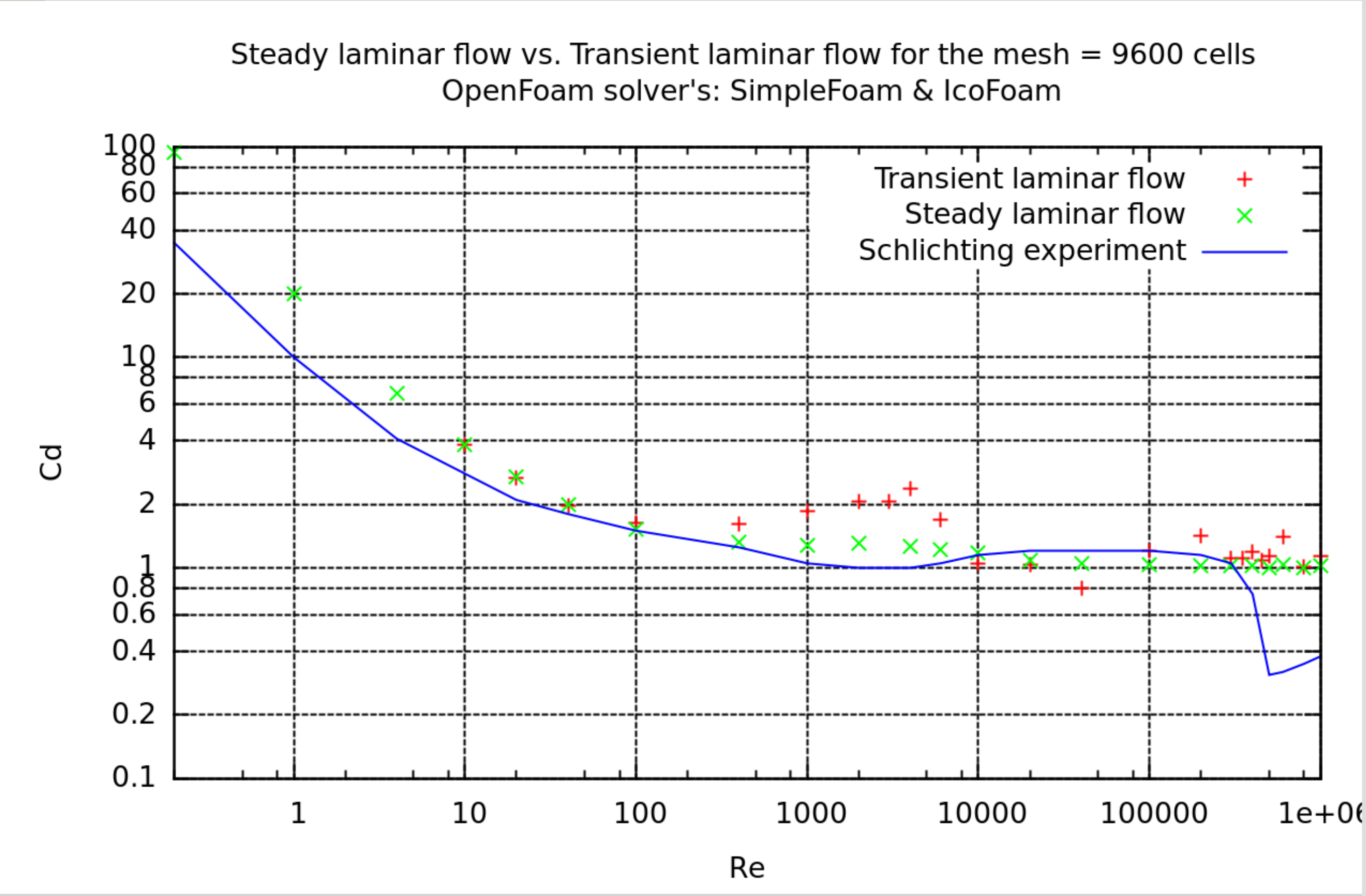
Homogeneous flow past the cylinder

OpenFOAM, laminar flow, 2D, cylinder

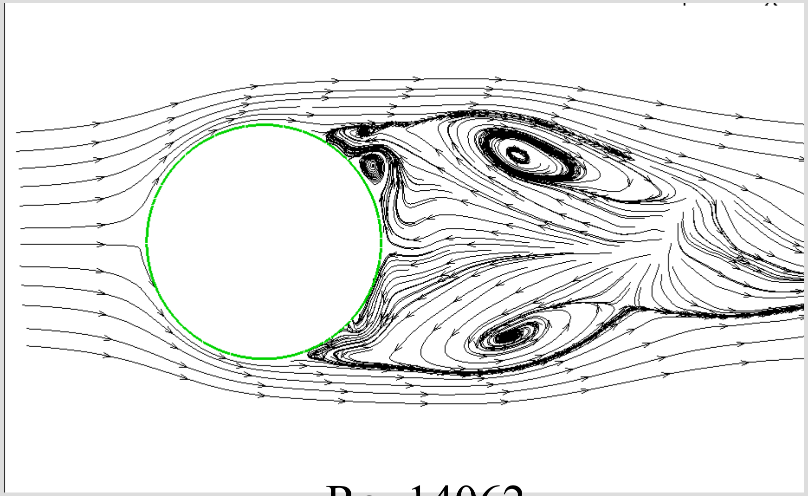


Re=4000

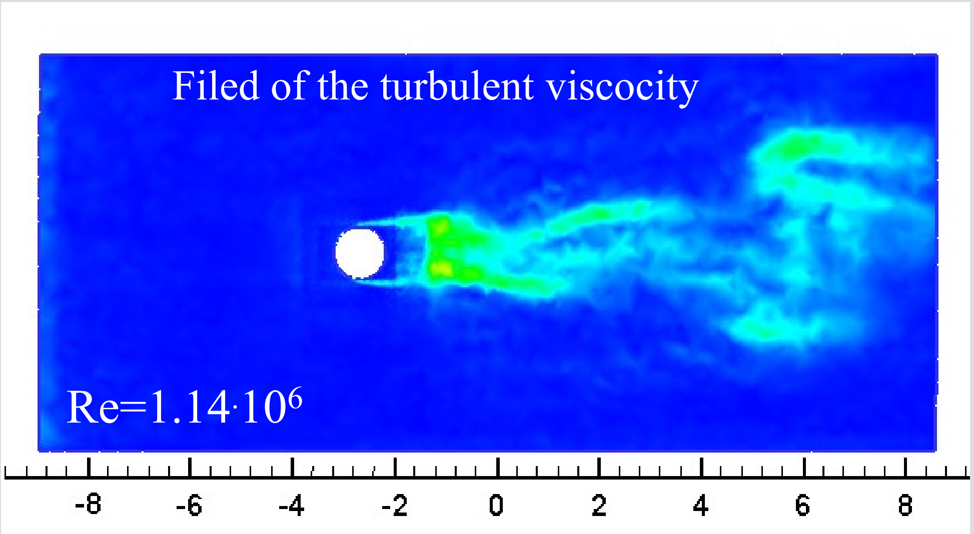


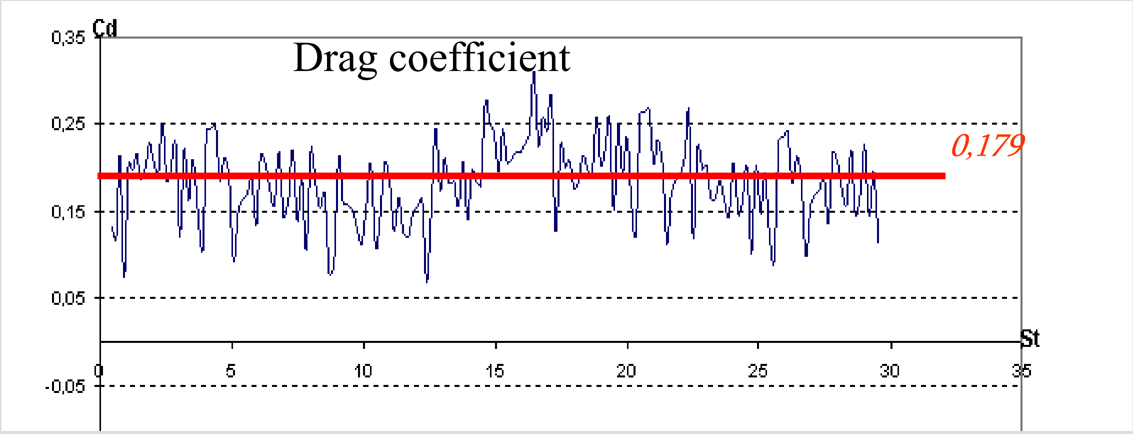


Homogeneous flow past the sphere



Re=14062



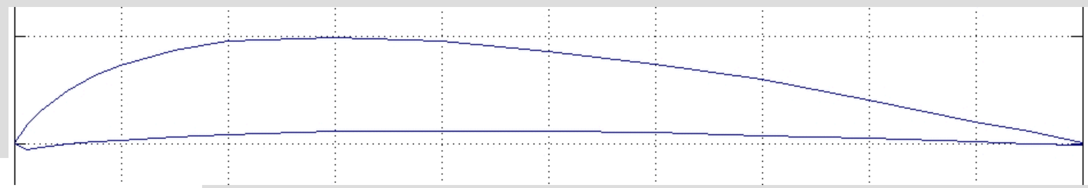


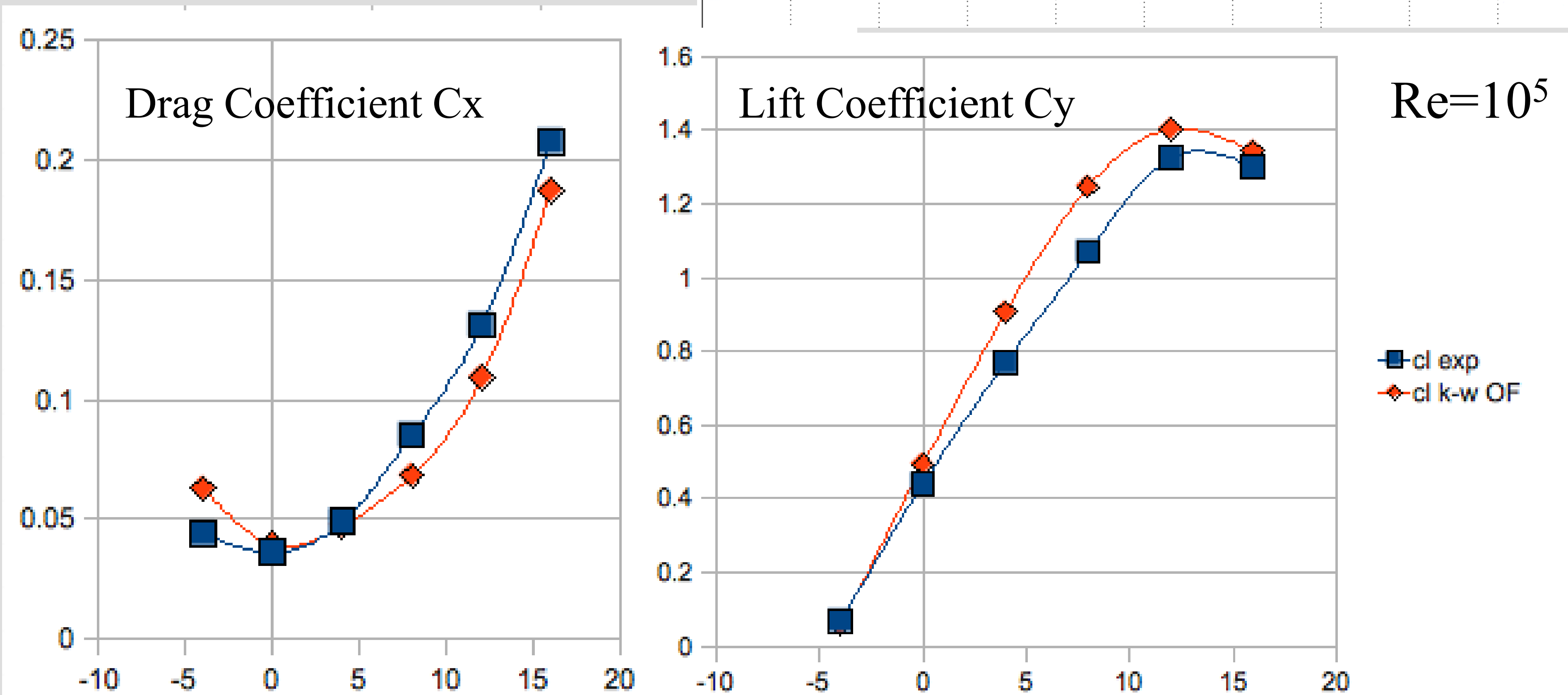
Re	$C_D^{calc.}$	C_D^{exp}
14062	0.36	0.4
1140000	0.179	0.12-0.18

FlowFES, LES-Smagorinsky, 3D, sphere

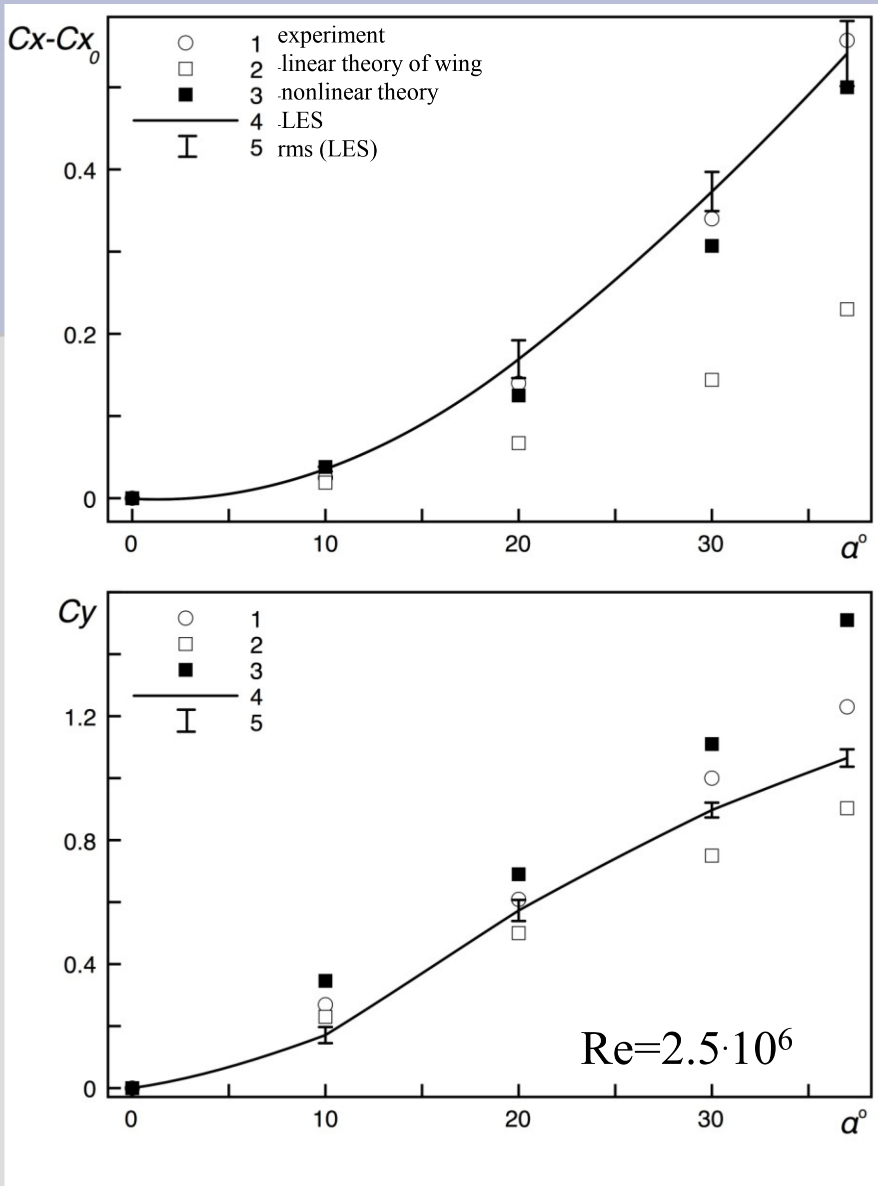
Homogeneous flow past the airfoil

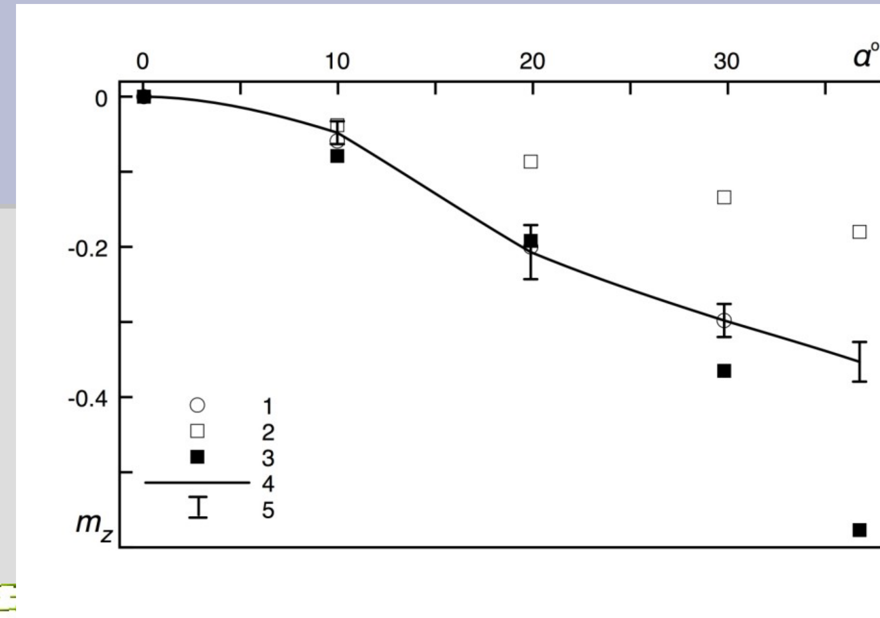
OpenFOAM, RANS, 2D, Airfoil
Göttingen 92

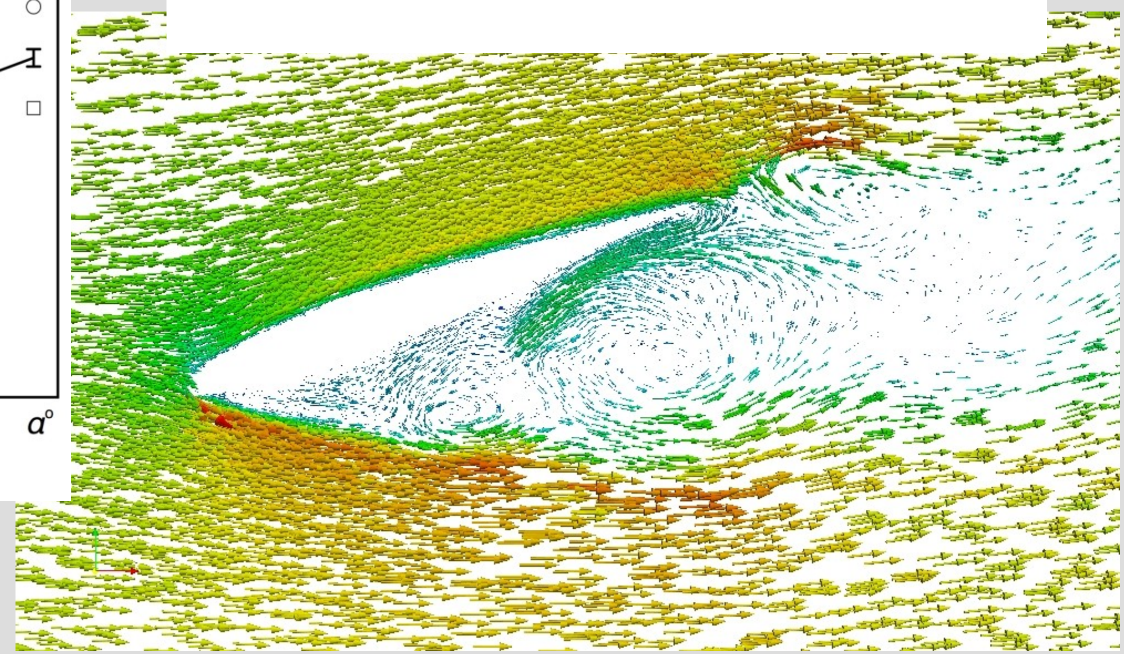




Homogeneous flow past the wing

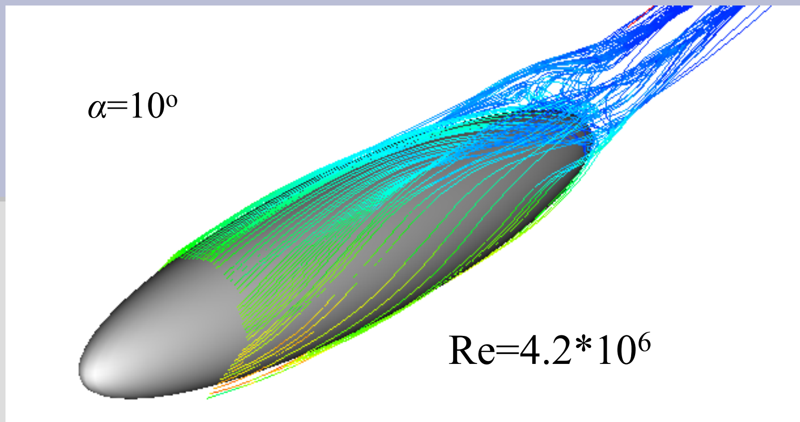




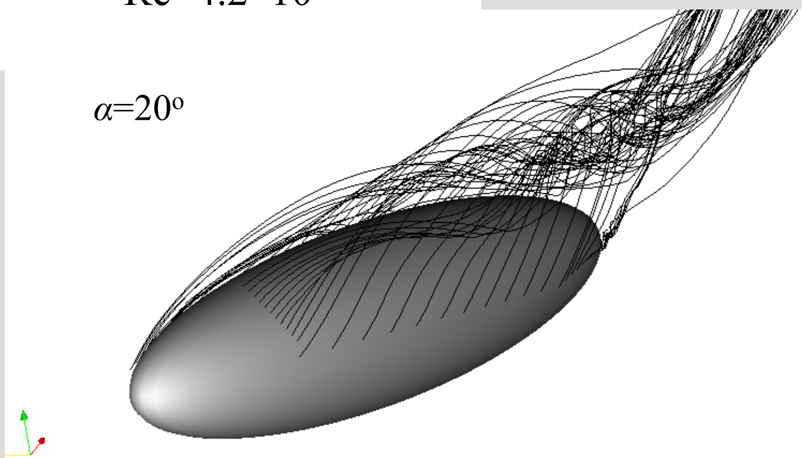


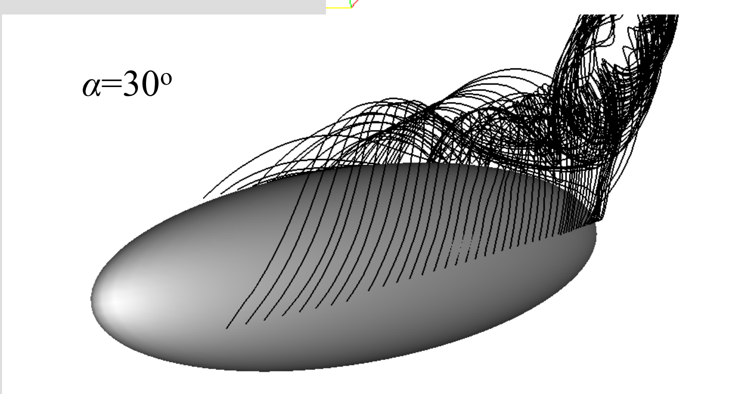
FlowFES, LES, 3D, NACA 0018, Ratio 1

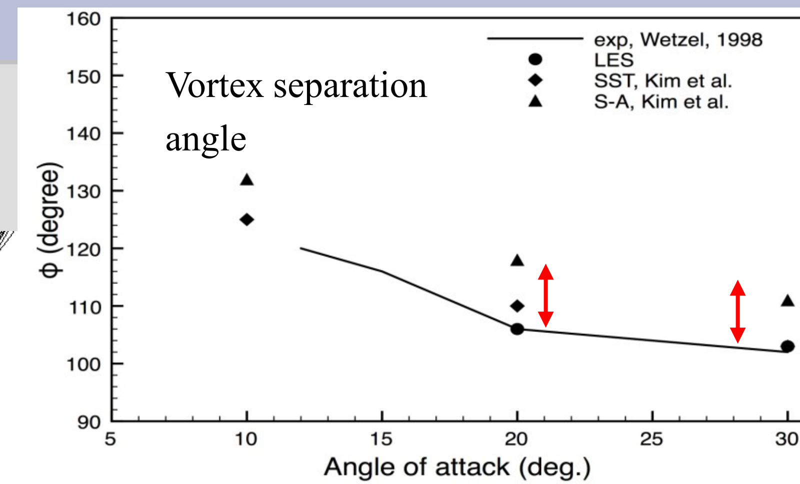
Homogeneous flow past the spheroid

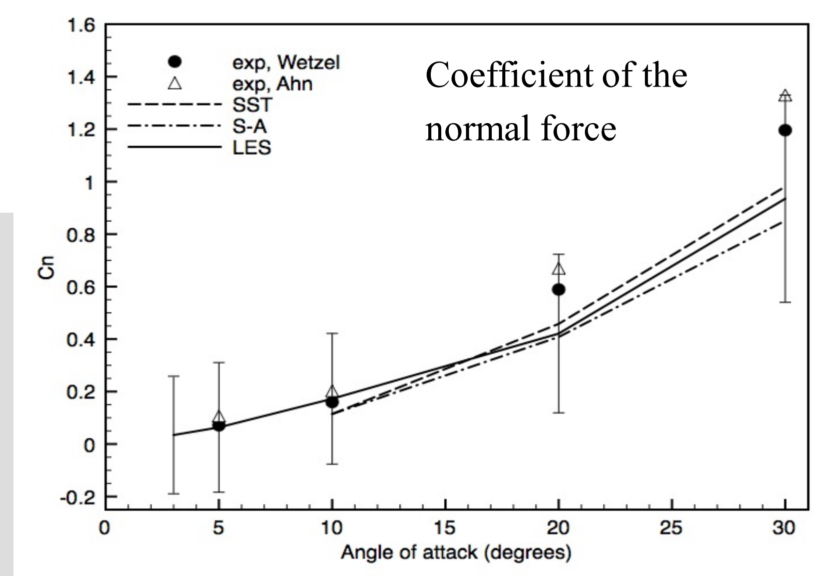


FlowFES,
LES, 3D,
spheroid 6:1



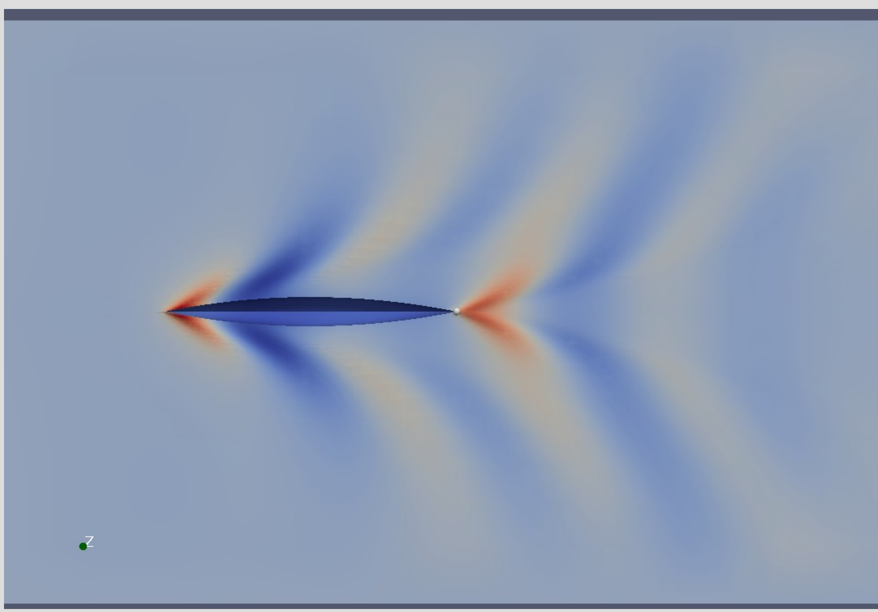


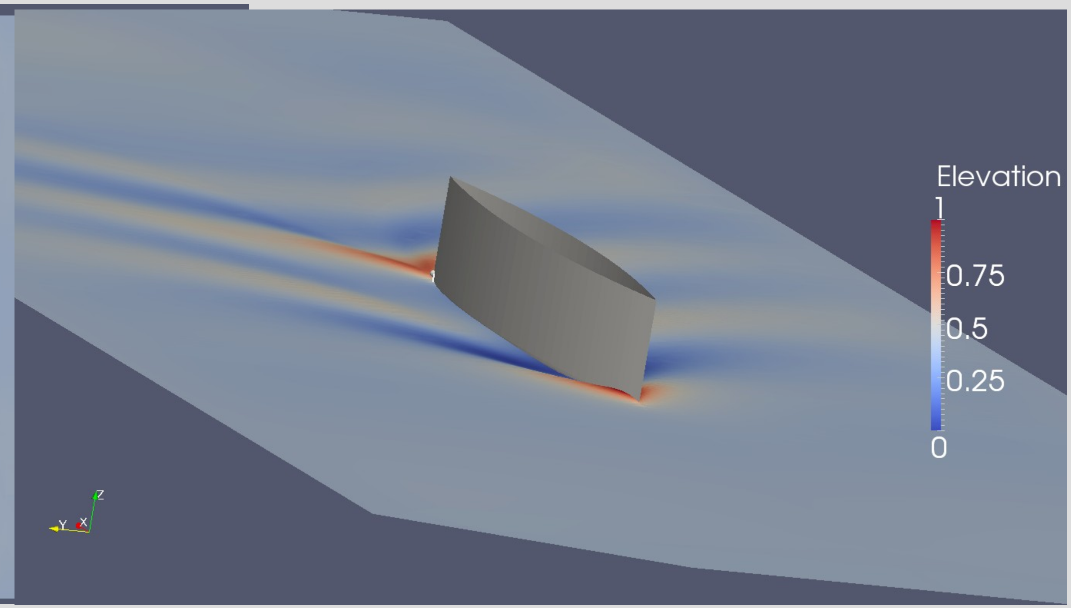




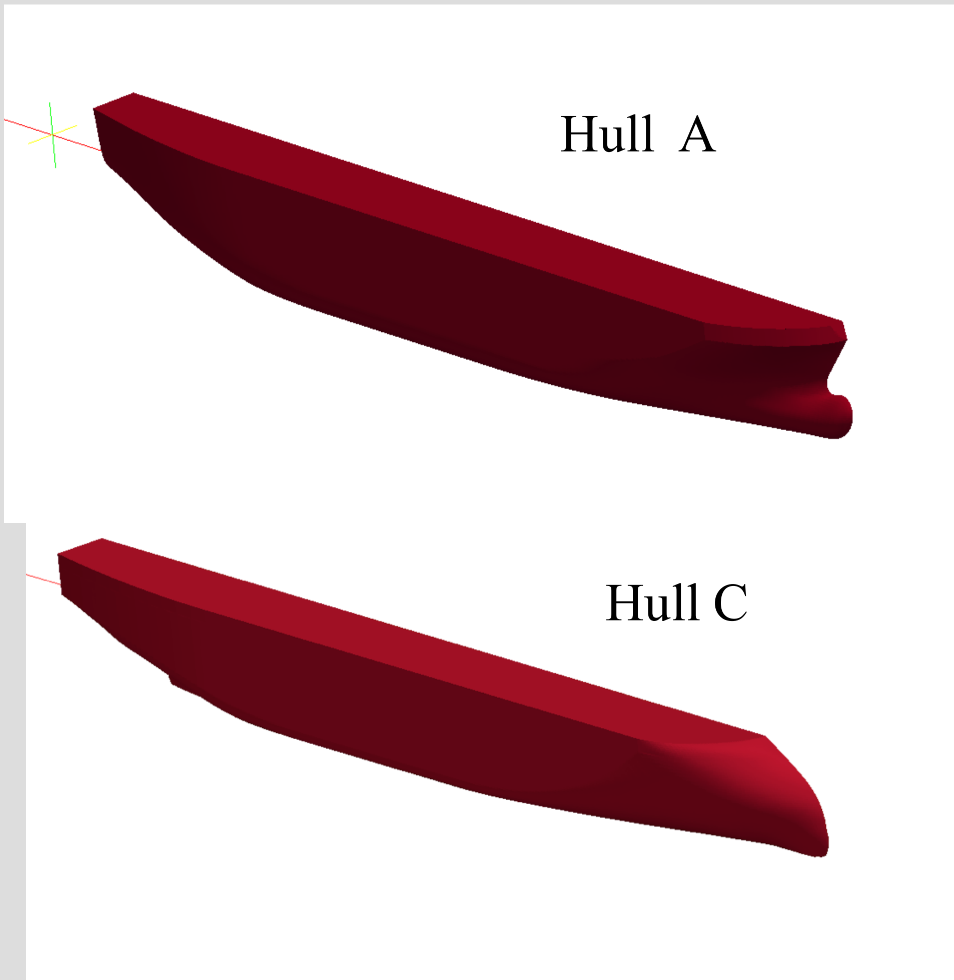
The motion of Wigley body on free surface

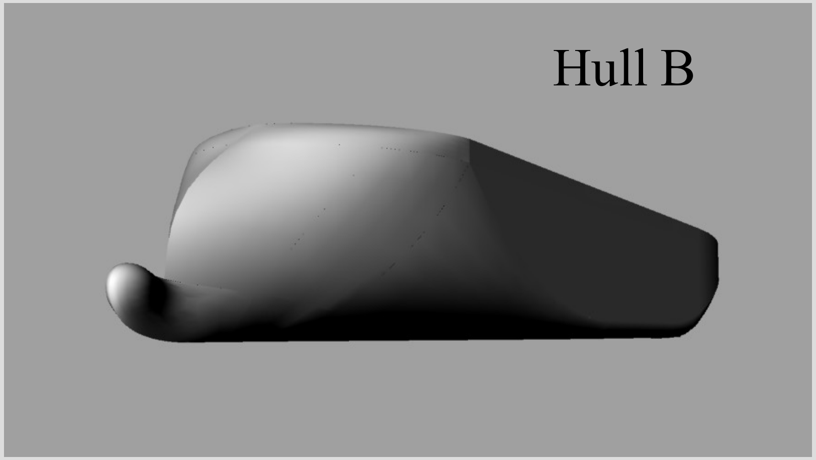
C_T^{calc}	$C_T^{\exp}$ [Maki K. Ship Resistance Simulations with OpenFOAM // 6th OpenFOAM Workshop. 13-16 June. Pensylvania. USA]
0,0046	0,0048





The motion of LNG tanker on free surface



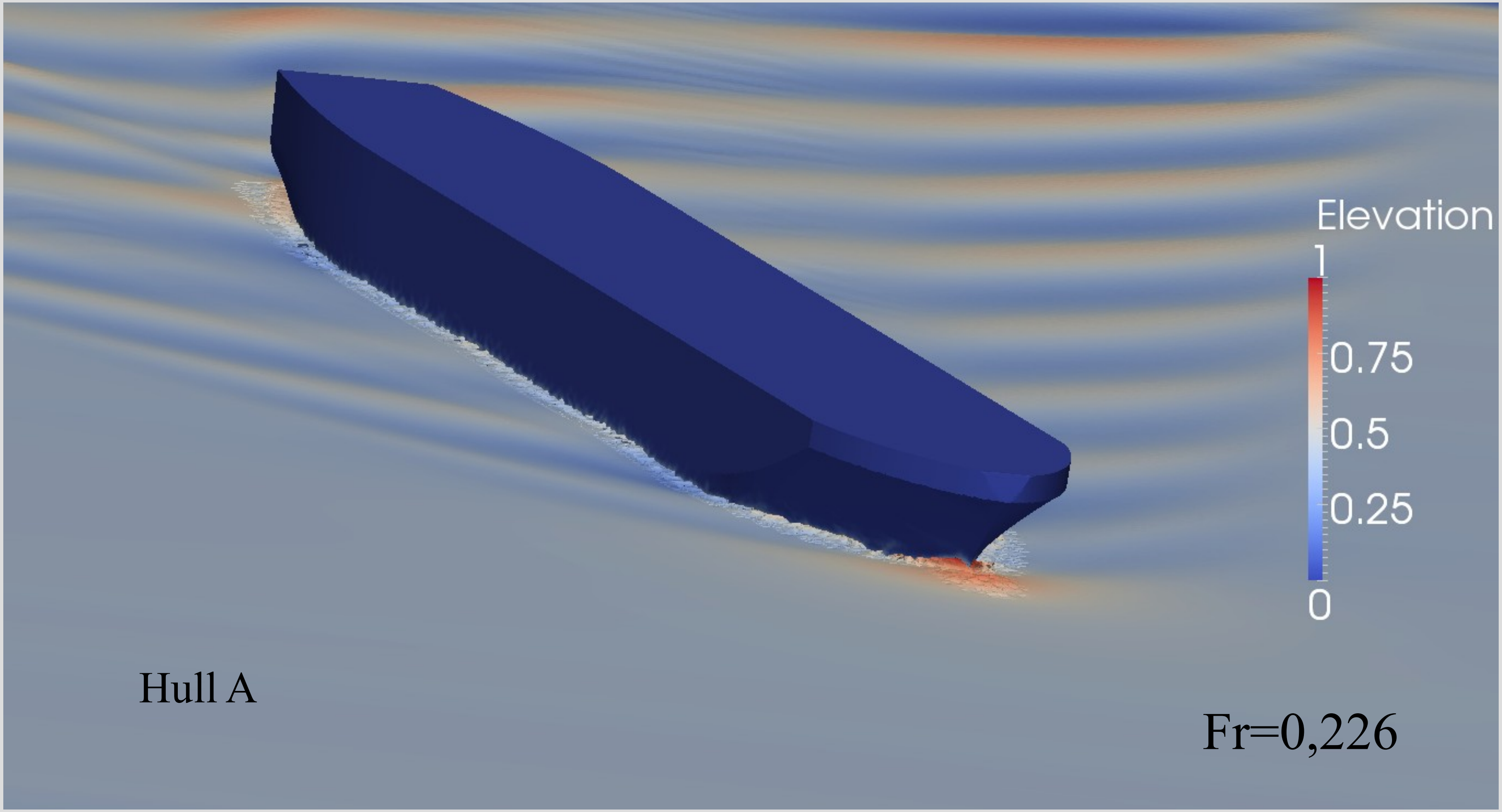


A – traditional ship bow;

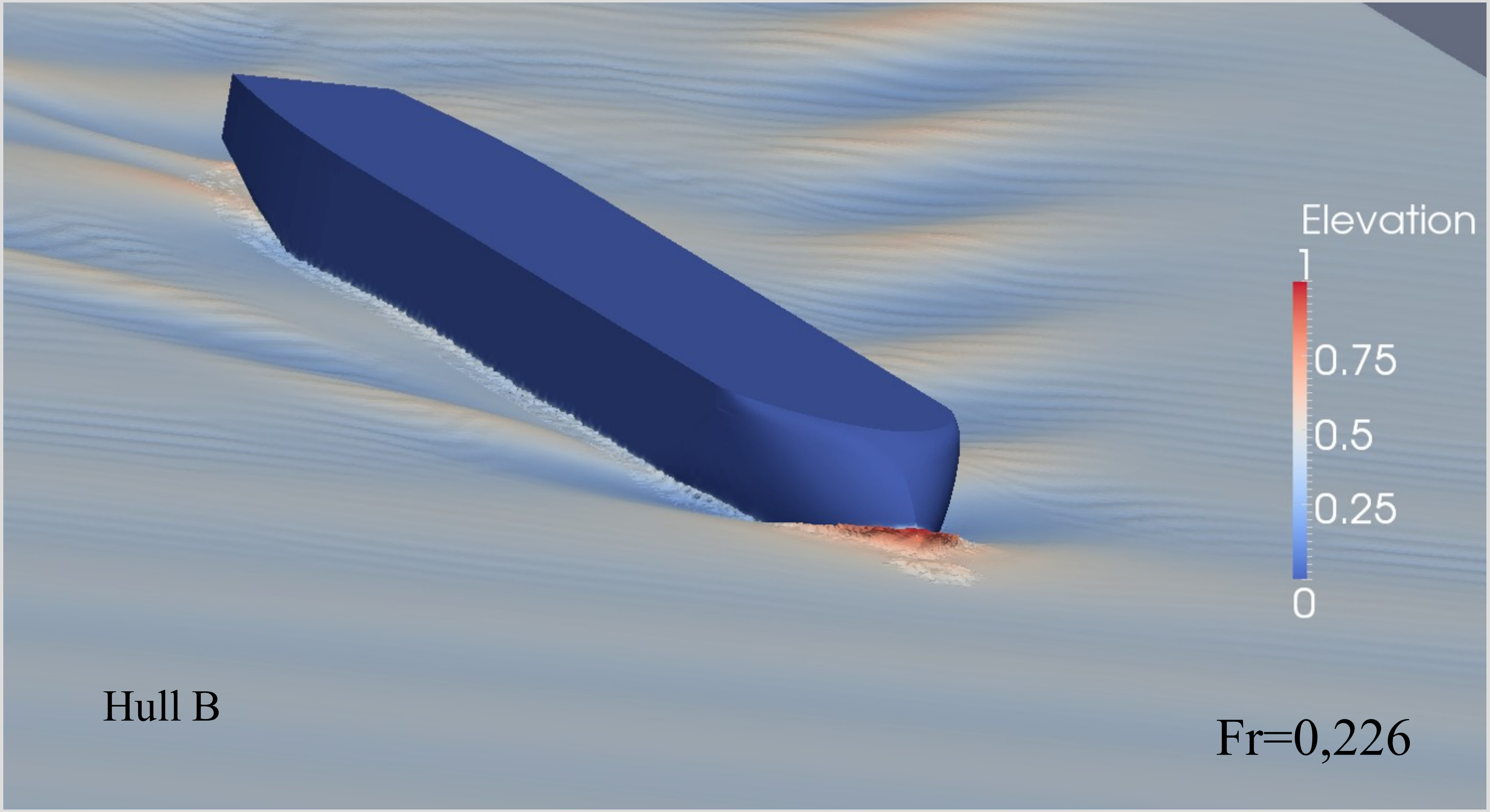
B – lightweight hull;

C – ice-class lightweight hull.

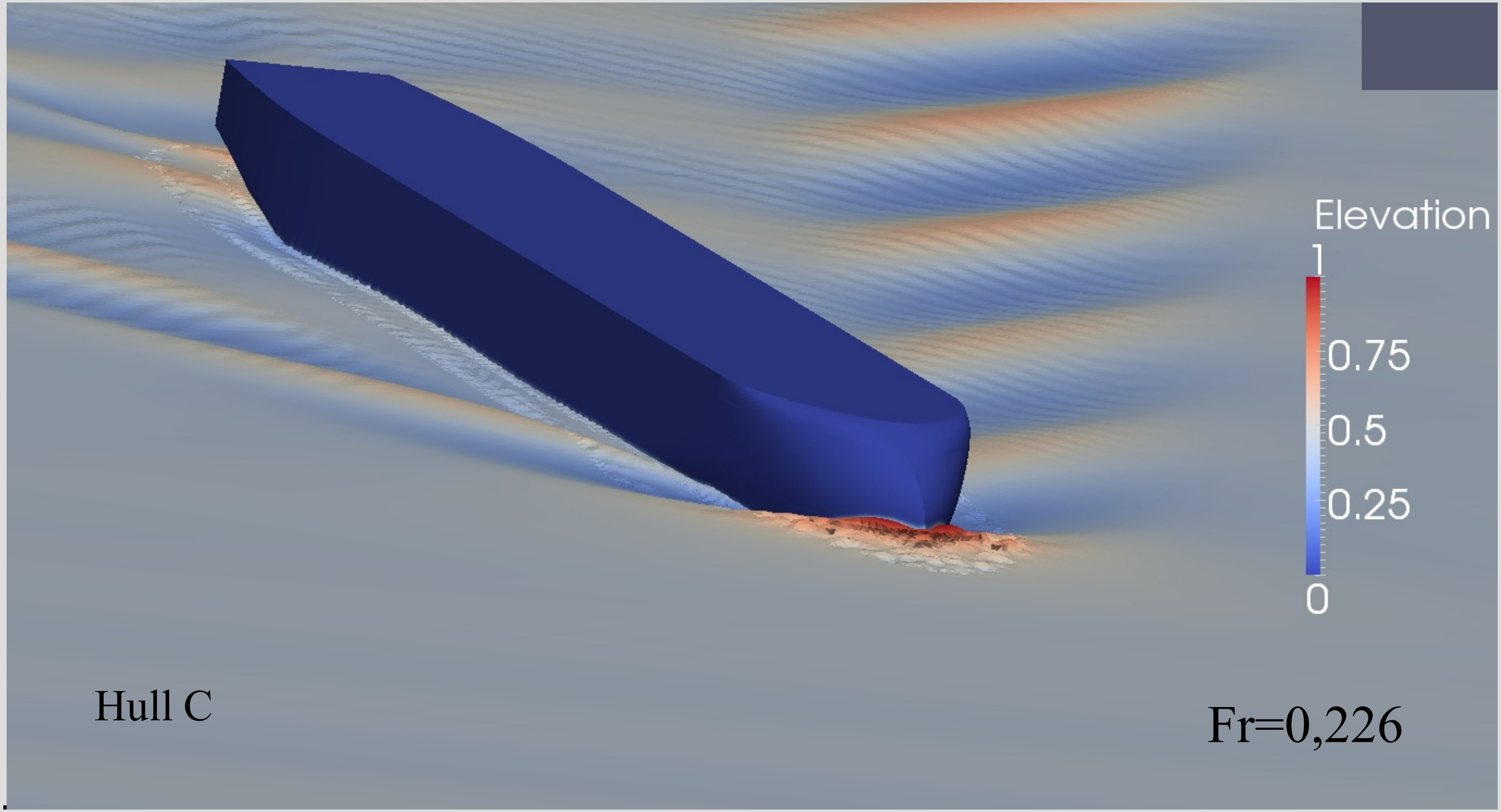
Optimization of a bow of LNG tanker



Optimization of a bow of LNG tanker



Optimization of a bow of LNG tanker

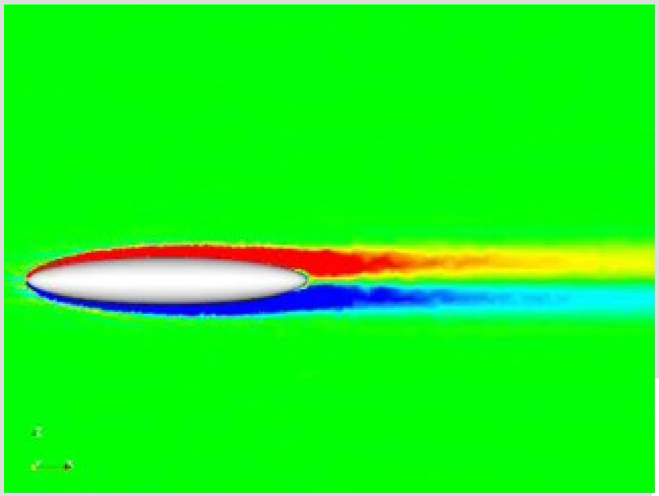


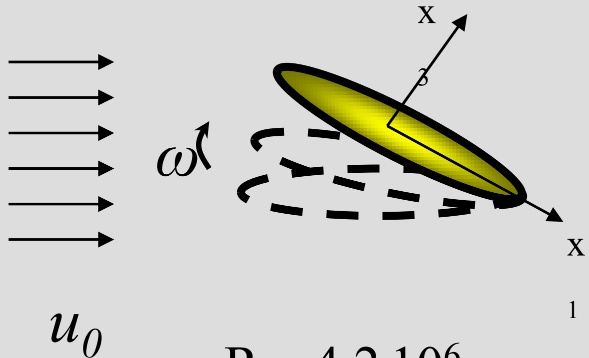
Optimization of a bow of LNG tanker

Simulation of the dynamics of marine vehicles

Pitch up maneuver of the spheroid

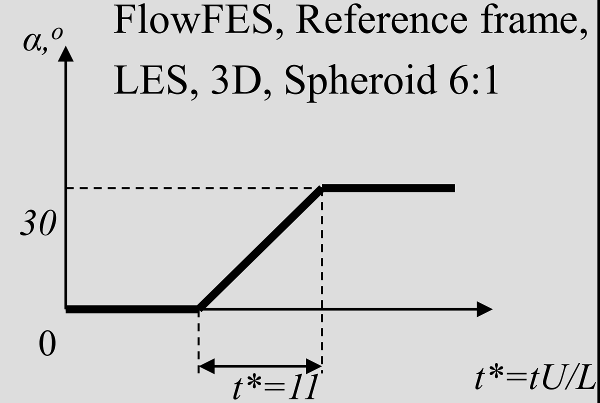
Vorticity

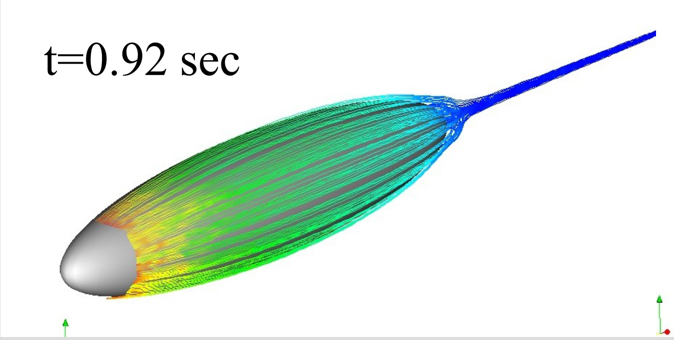


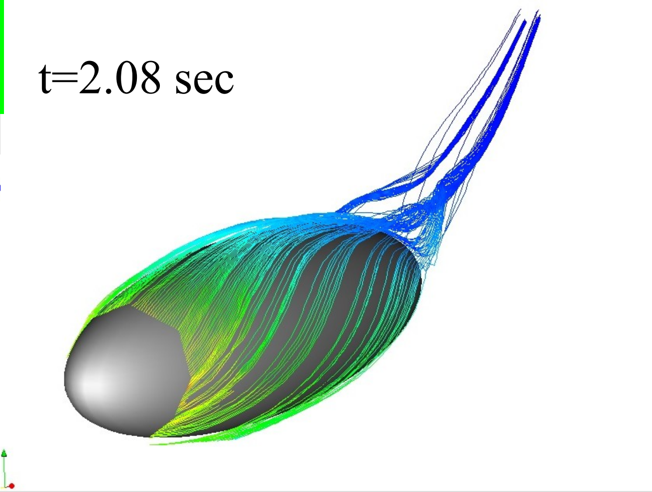


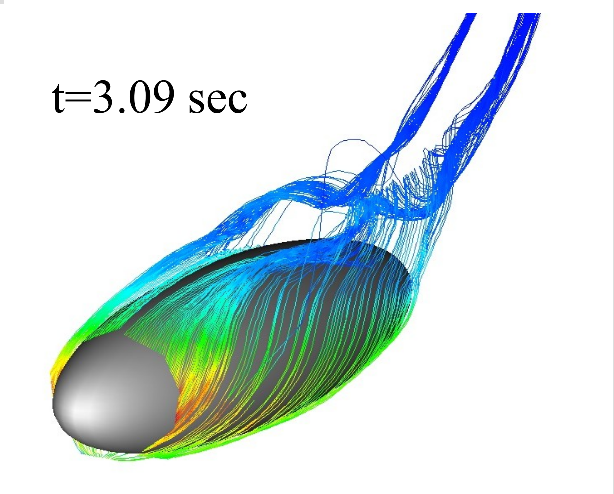
Re=$4.2 \cdot 10^6$

FlowFES, Reference frame, LES, 3D, Spheroid 6:1





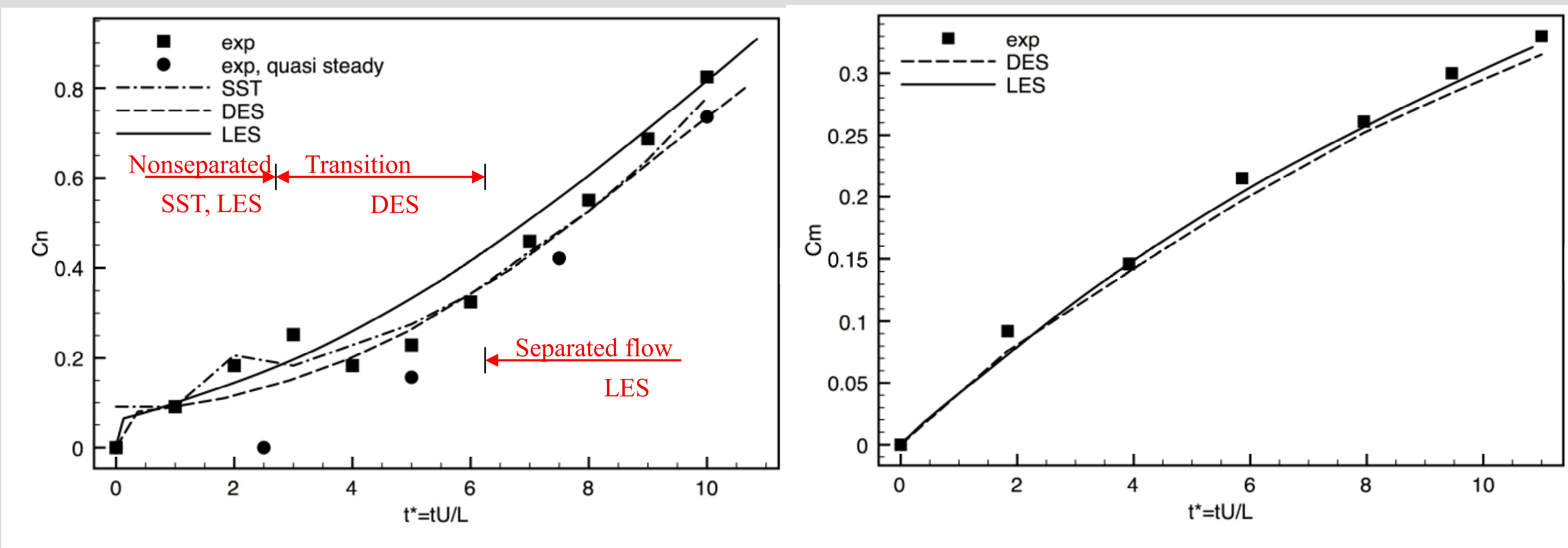




Tracers

Pitch up maneuver of the spheroid

$\alpha(t) = 0 \Box 30^0$ LES, Smagorinsky

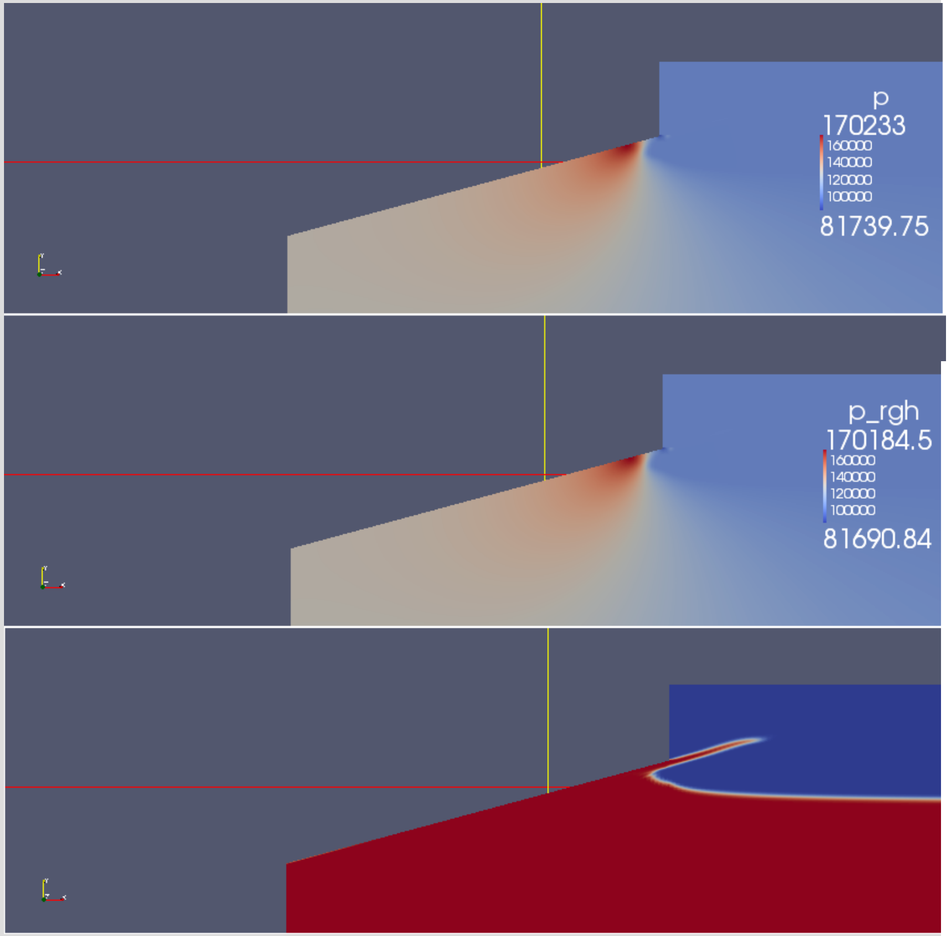


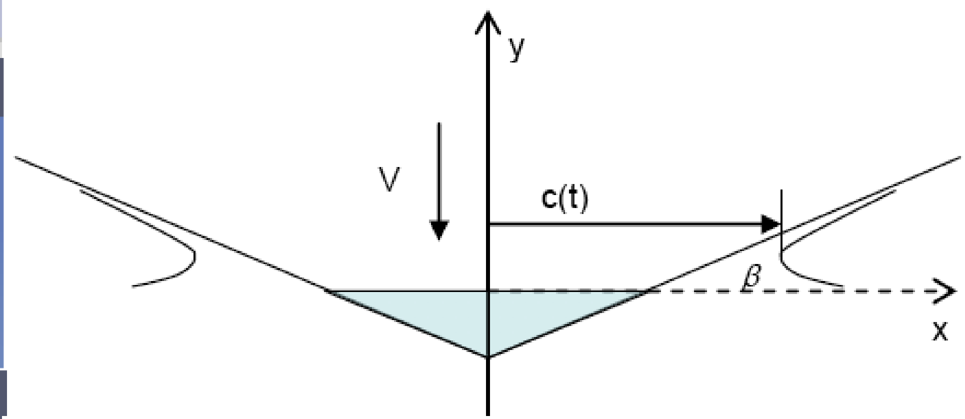
Evolution of the coefficients of normal force Cn and pitch-up moment Cm.

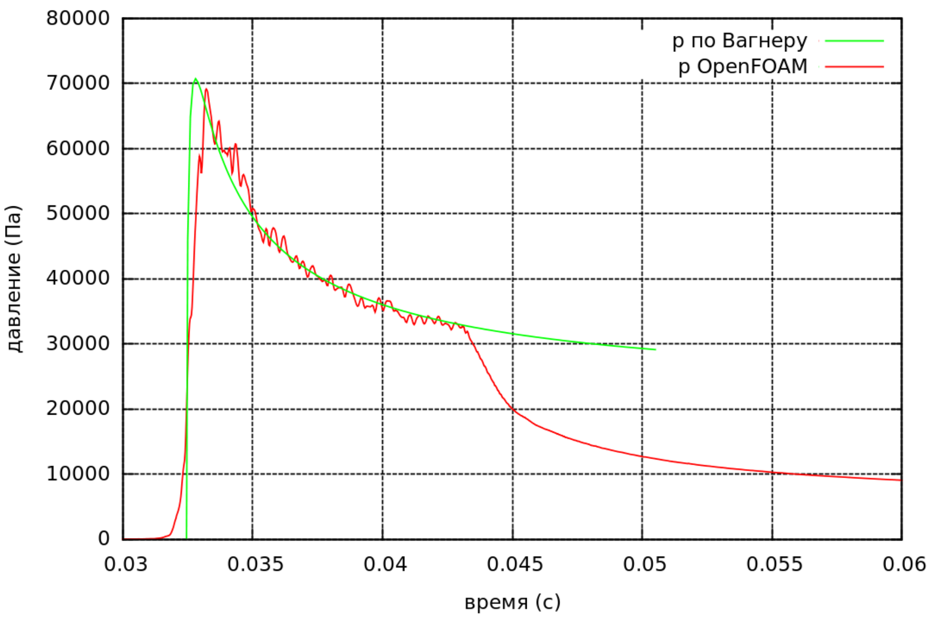
Exp - Wetzel, 1997, SST - Kim et al., 2003, DES - Kotatpati-Apparao et al., 2003

Impact the wedge into compressible liquid (slamming)

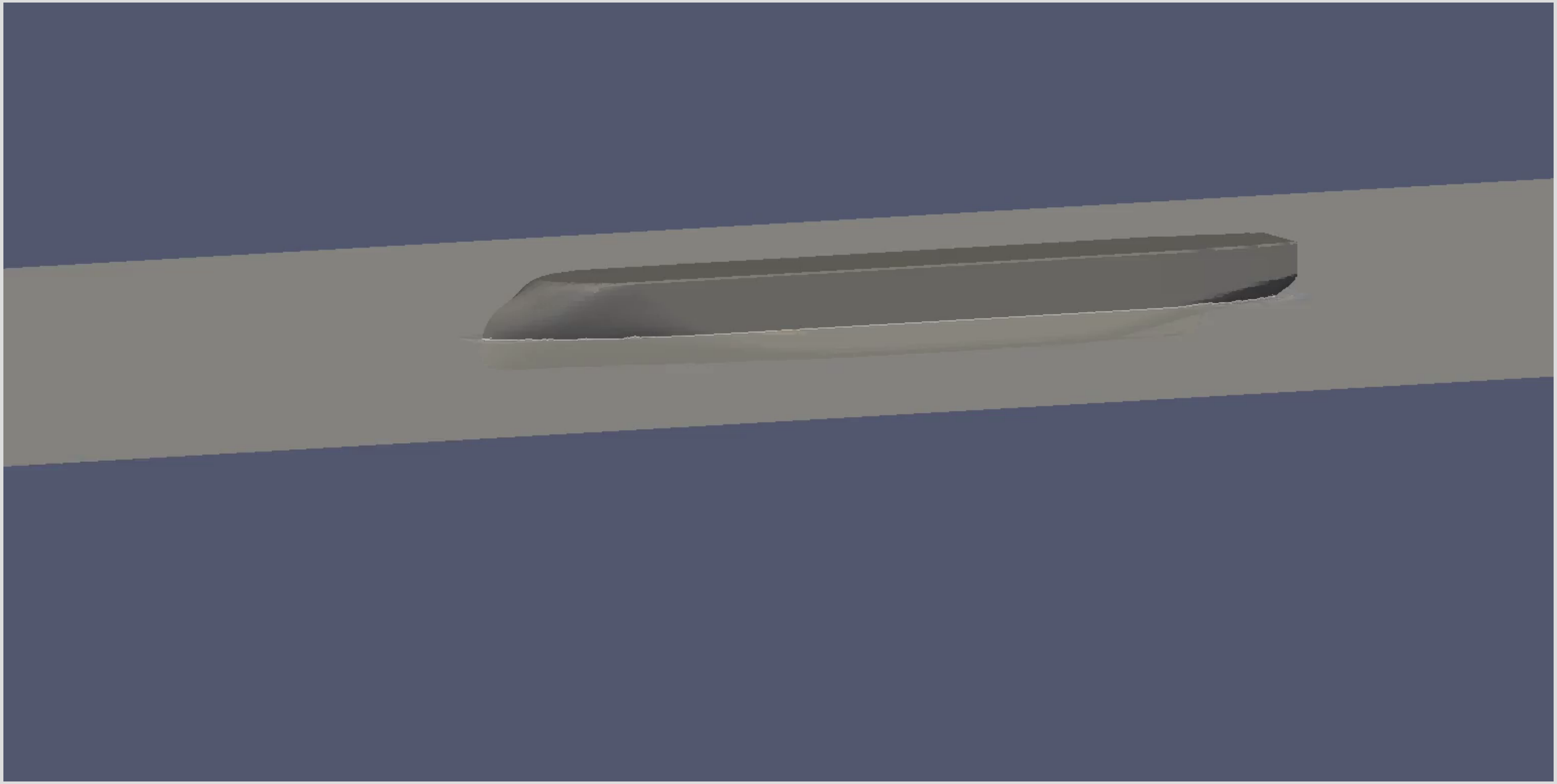
OpenFOAM, URANS, VoF, 2D



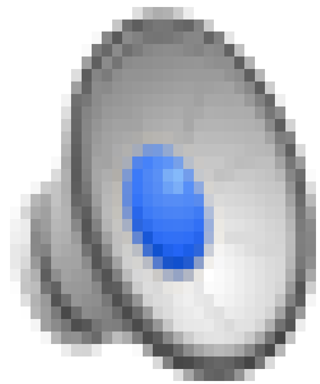




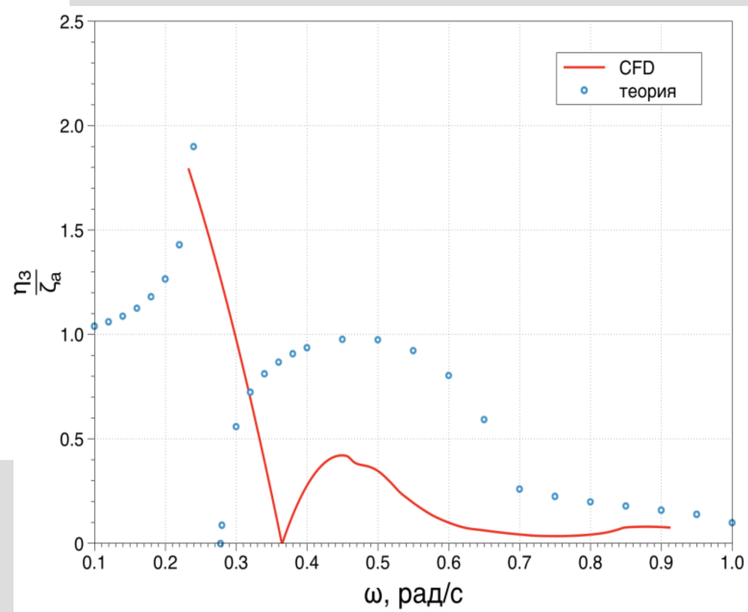
Heave and pitch motions of gas-tanker on regular waves



Heave and pitch motions of semi-submersible platform on regular waves

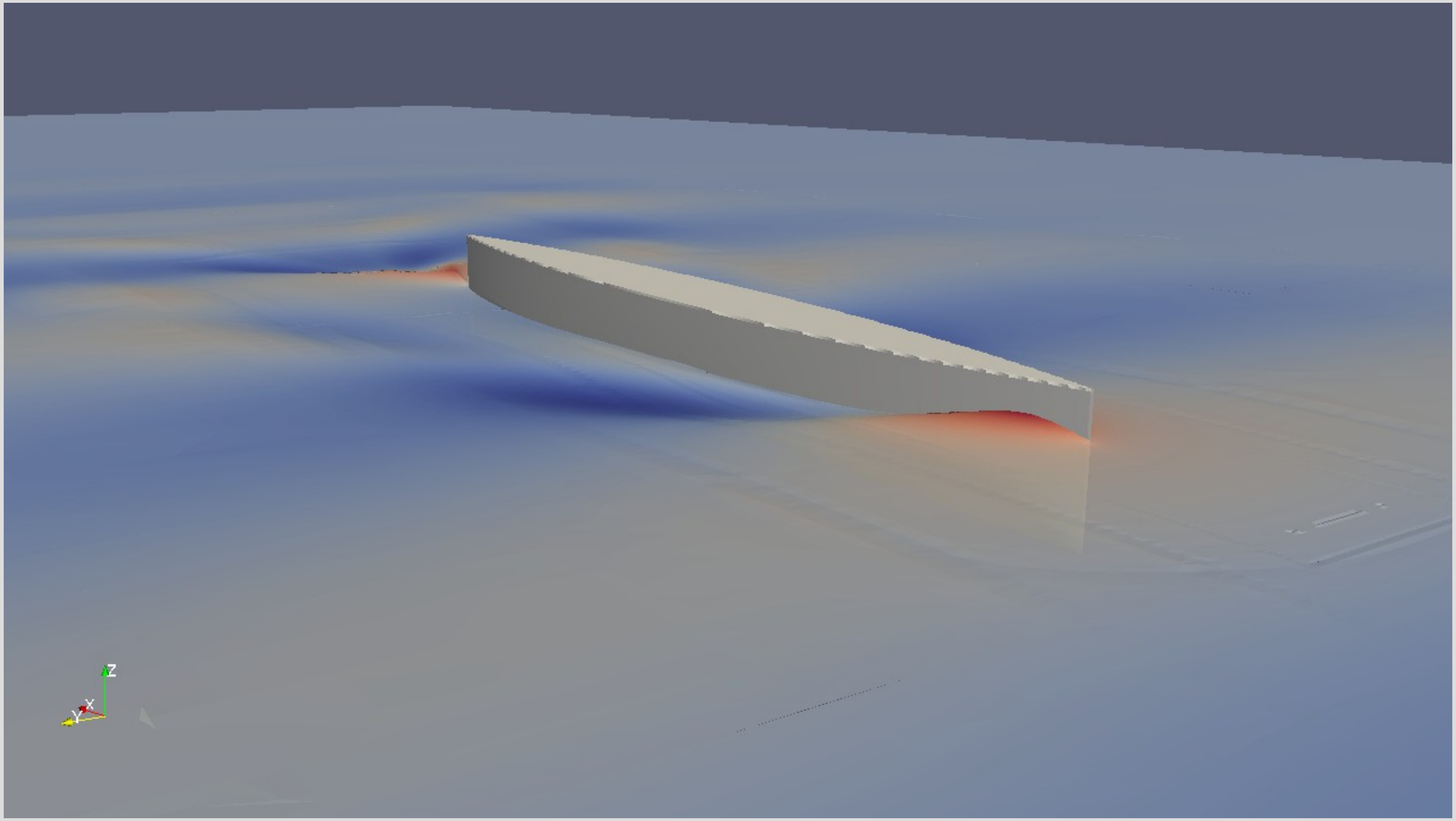


ROA of heave motion



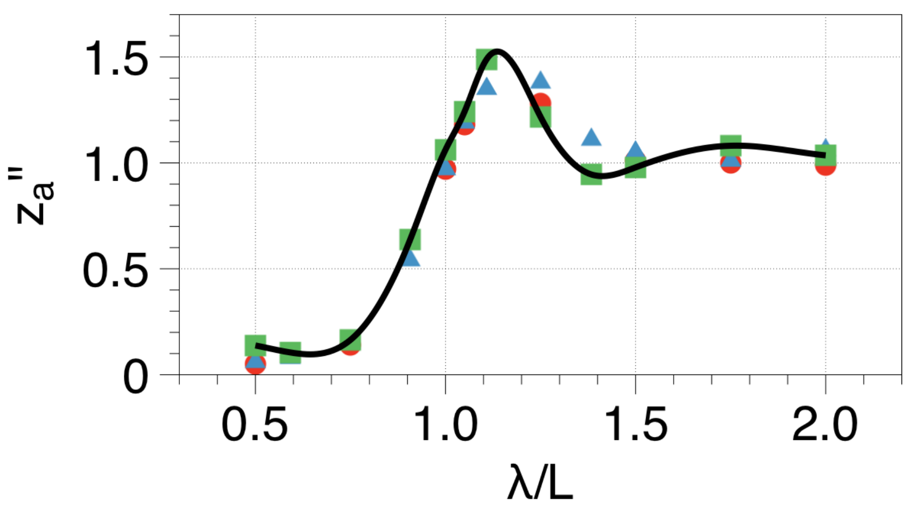
Heave and pitch motions of Wigley body on regular waves

Heave and pitch motions at Fr = 0.3

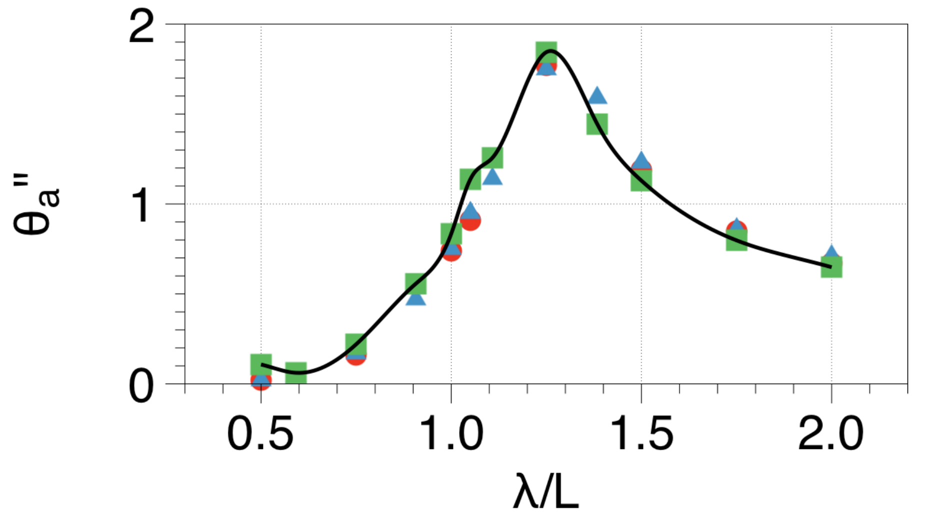


Heave and pitch motions of Wigley body on regular waves: response amplitude operator (RAO)

ROA of heave motion



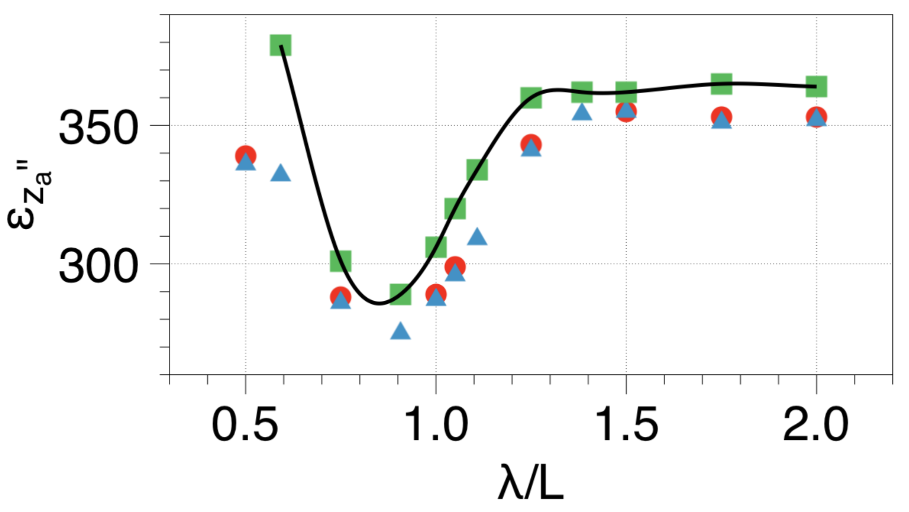
ROA of pitch motion



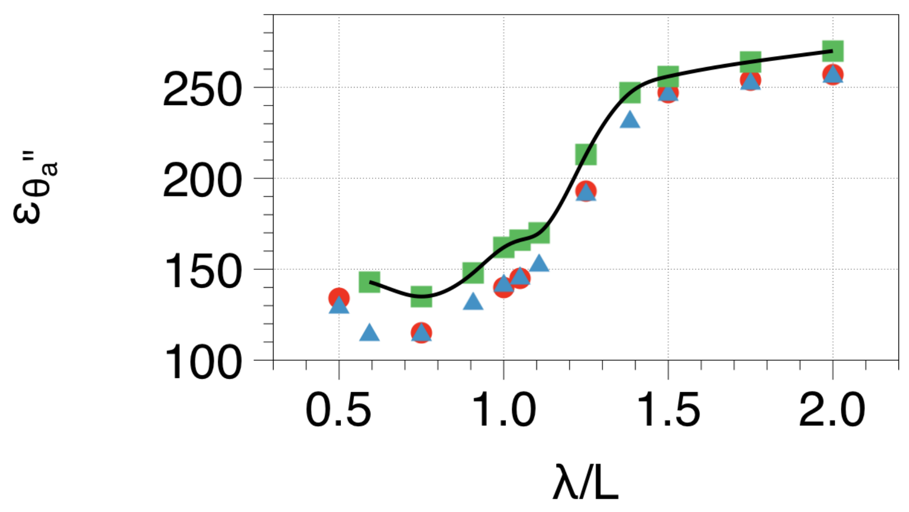
Fr = 0.3

Heave and pitch motions of Wigley body on regular waves: phase shift

Phase shift of heave motion



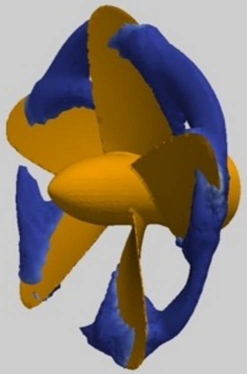
Phase shift of pitch motion



Fr = 0.3

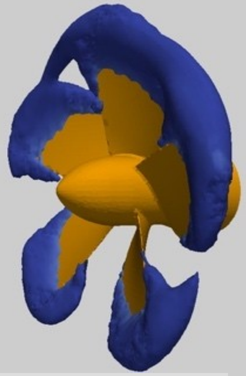
Simulation of the flow past ship propellers

Ship propeller in uniform flow



a

TKE: $a - J = 0.1$, $k/U^2 = 2$; $b - J = 0.3$, $k/U^2 = 0.08$; $c - J = 0.5$, $k/U^2 = 0.01$



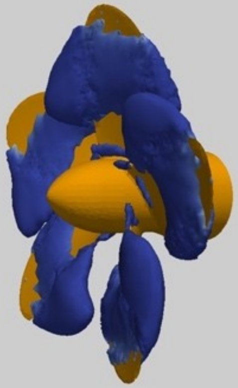
b

Propeller Series B:

Blades - 5,

Expanded BAR - 0.6,

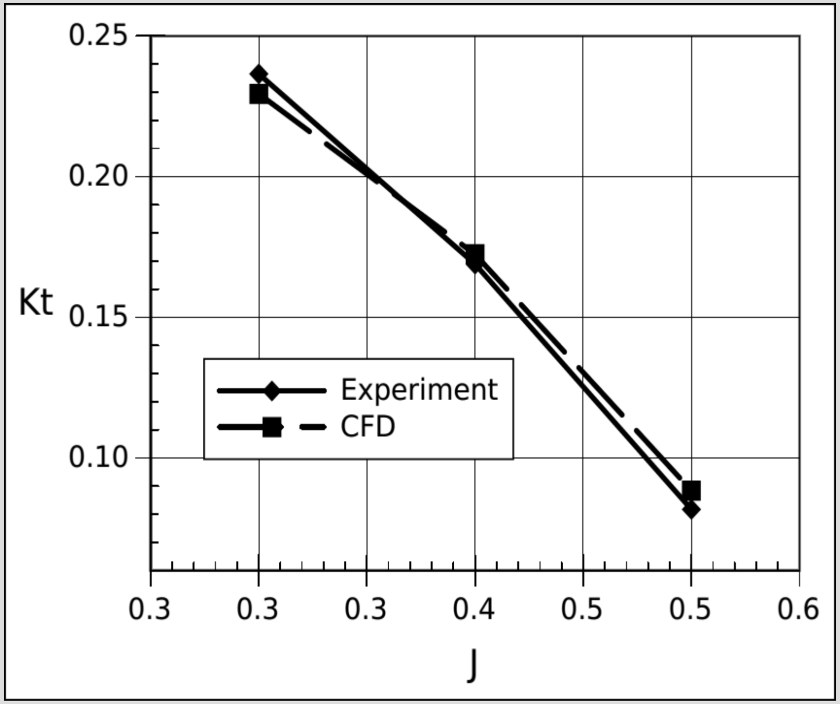
Nominal pitch - 0.6

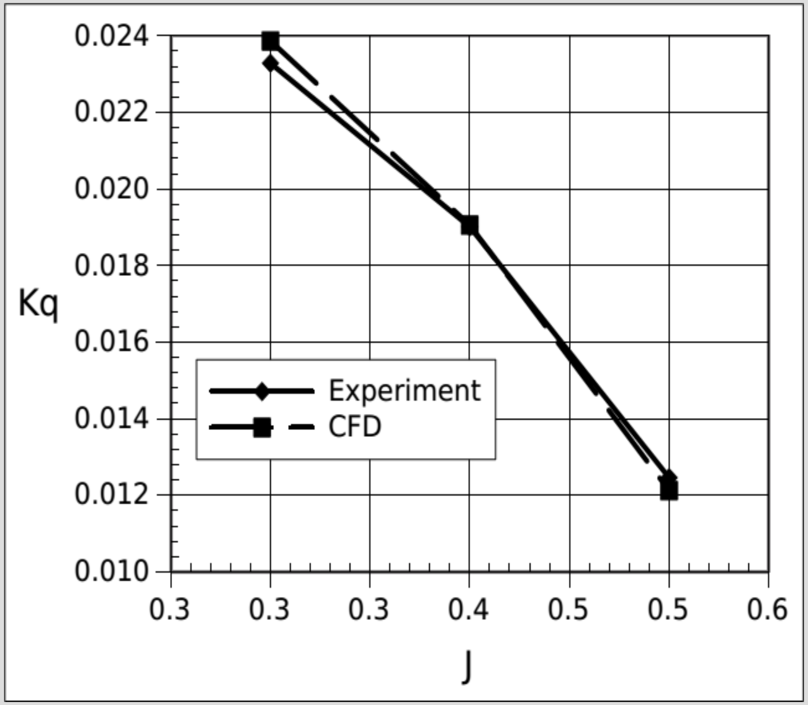


c

Ship propeller in uniform flow

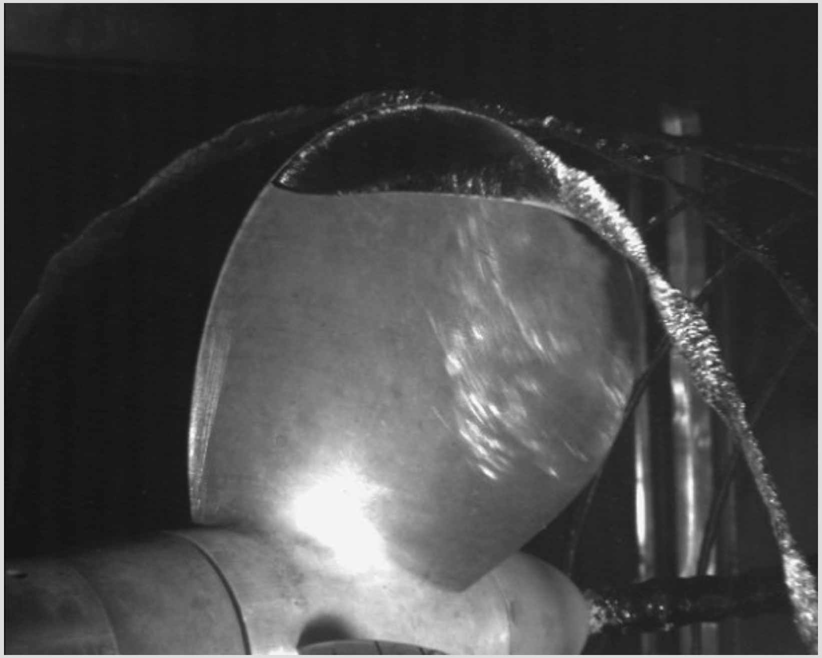
Thrust and torque coefficients



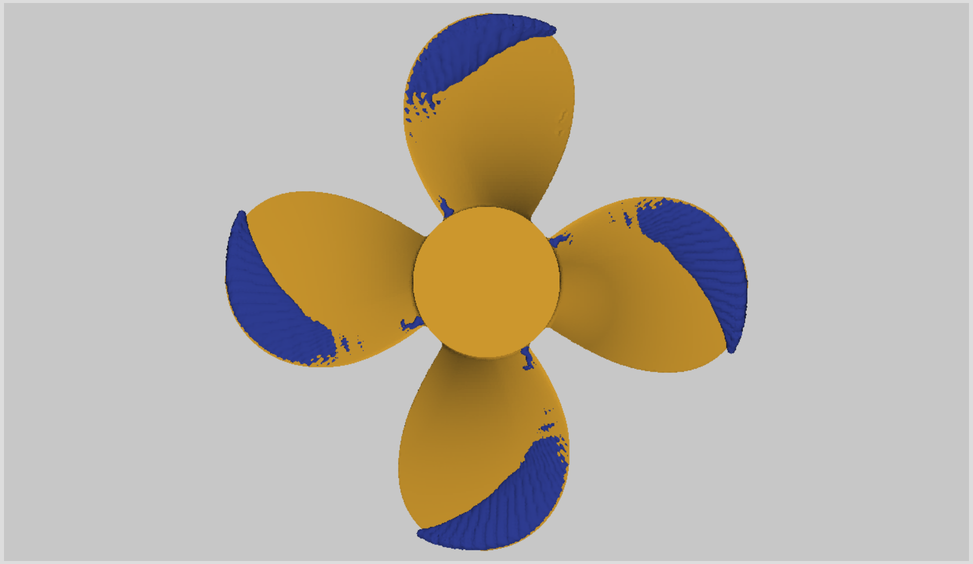


Cavitation on ship propeller

Propeller Series E779



Experiment

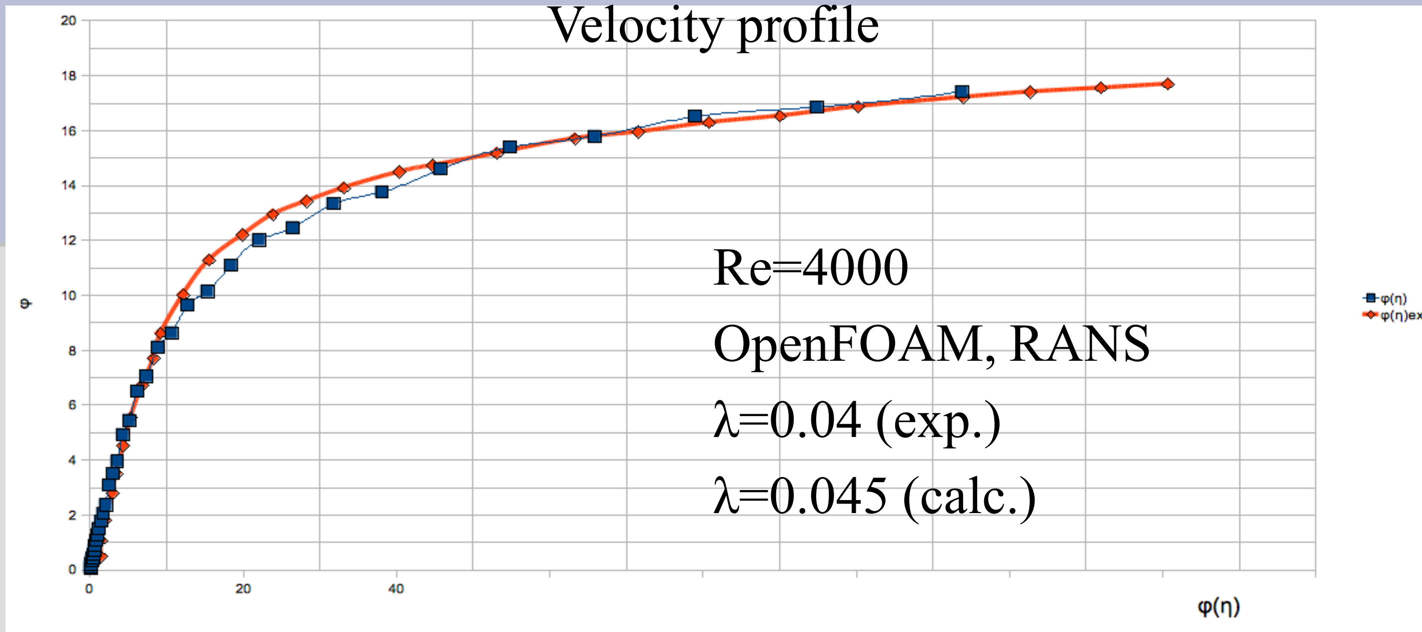


CFD

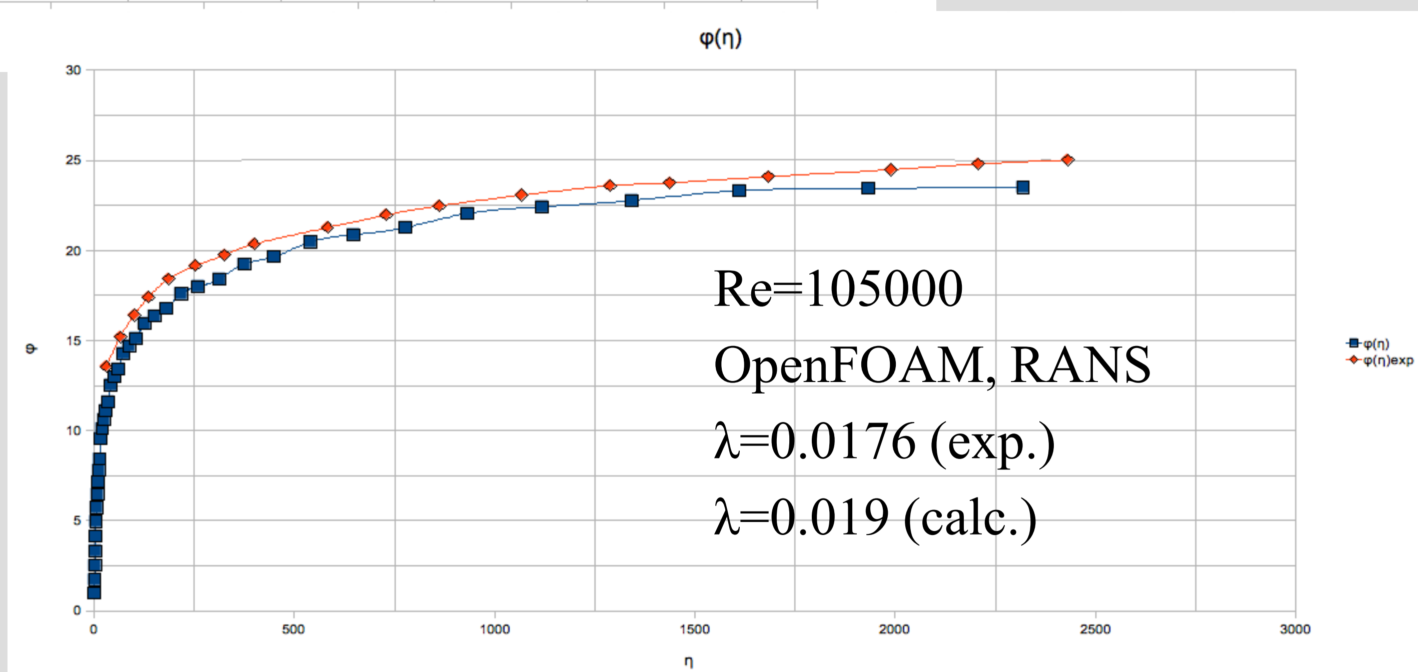
Simulation of the internal flows

The pipe flow

Velocity profile



Re=4000
OpenFOAM, RANS
λ=0.04 (exp.)
λ=0.045 (calc.)

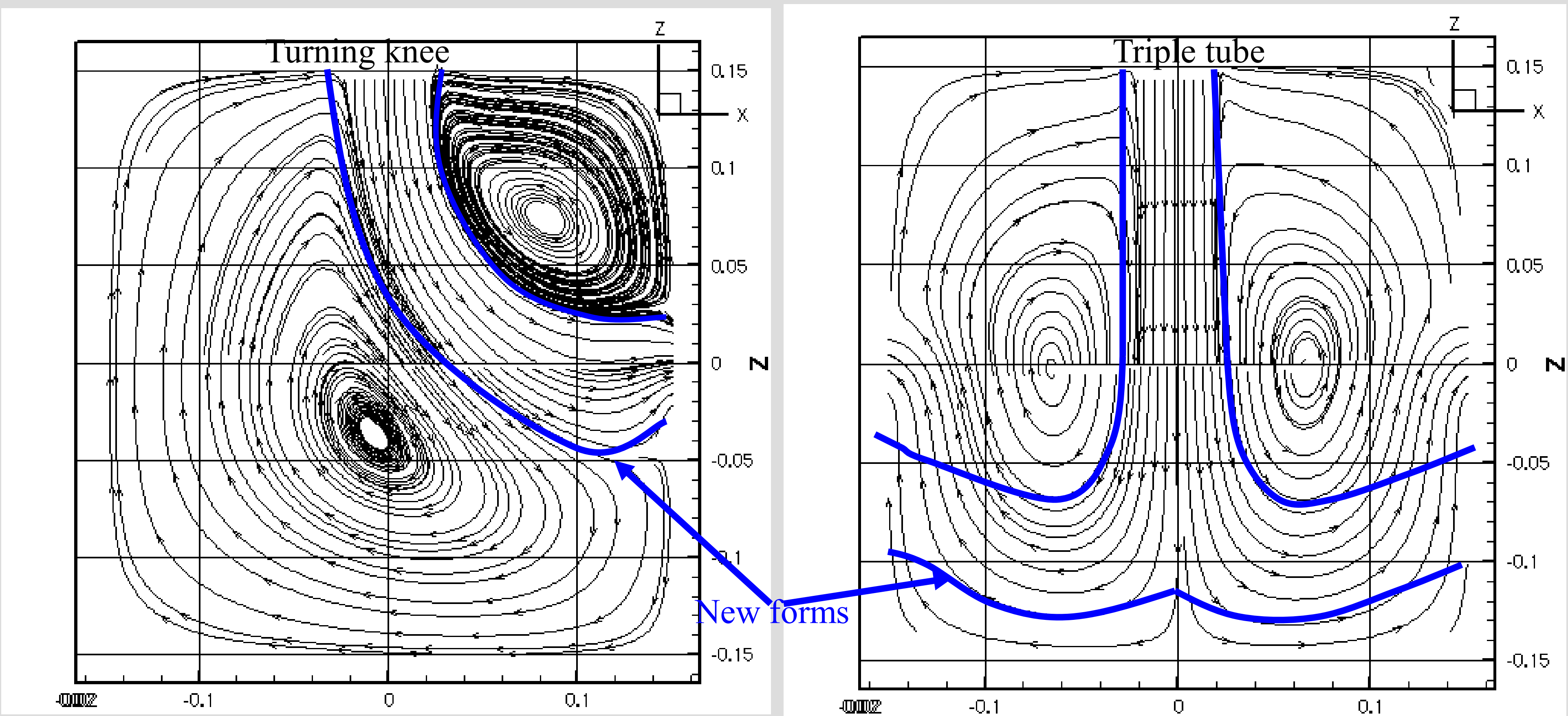


Re=105000
OpenFOAM, RANS
λ=0.0176 (exp.)
λ=0.019 (calc.)

Flows in profiled elements of ship pipe systems

Turning knee and triple flows

FlowFES, LES, 3D

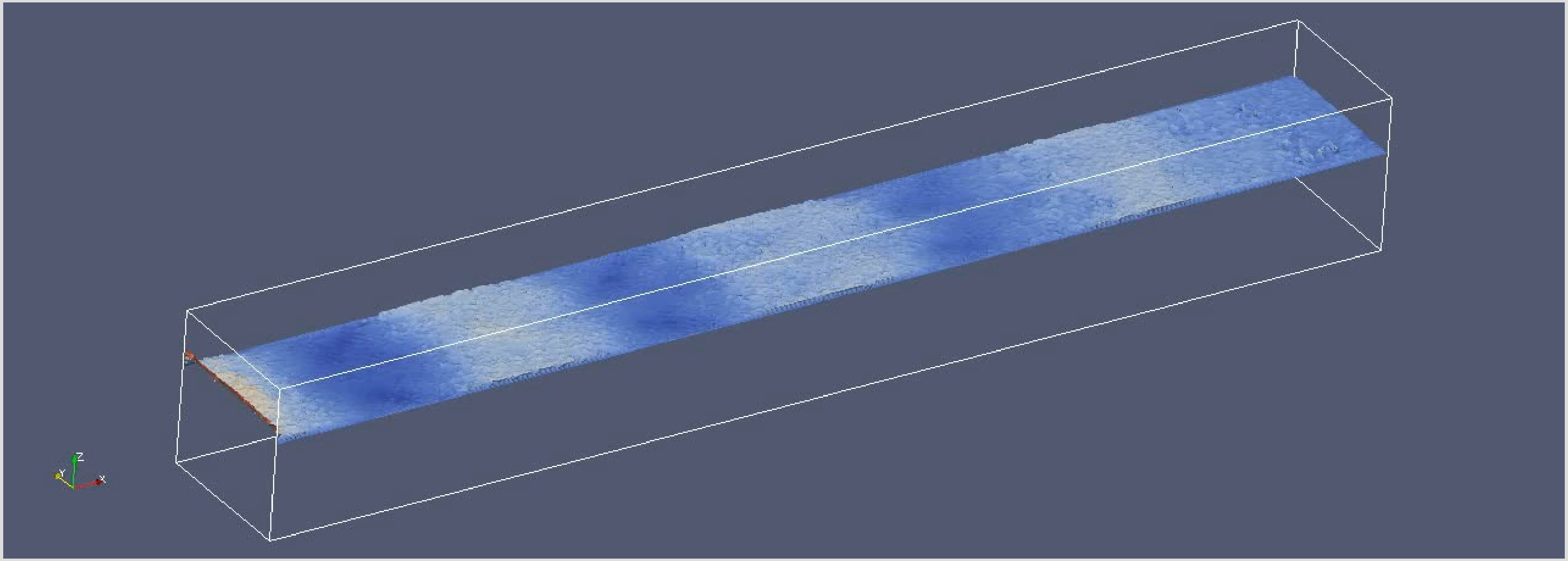


Choosing of the optimal configuration of the pipe corners

Simulation of the coastal dynamics

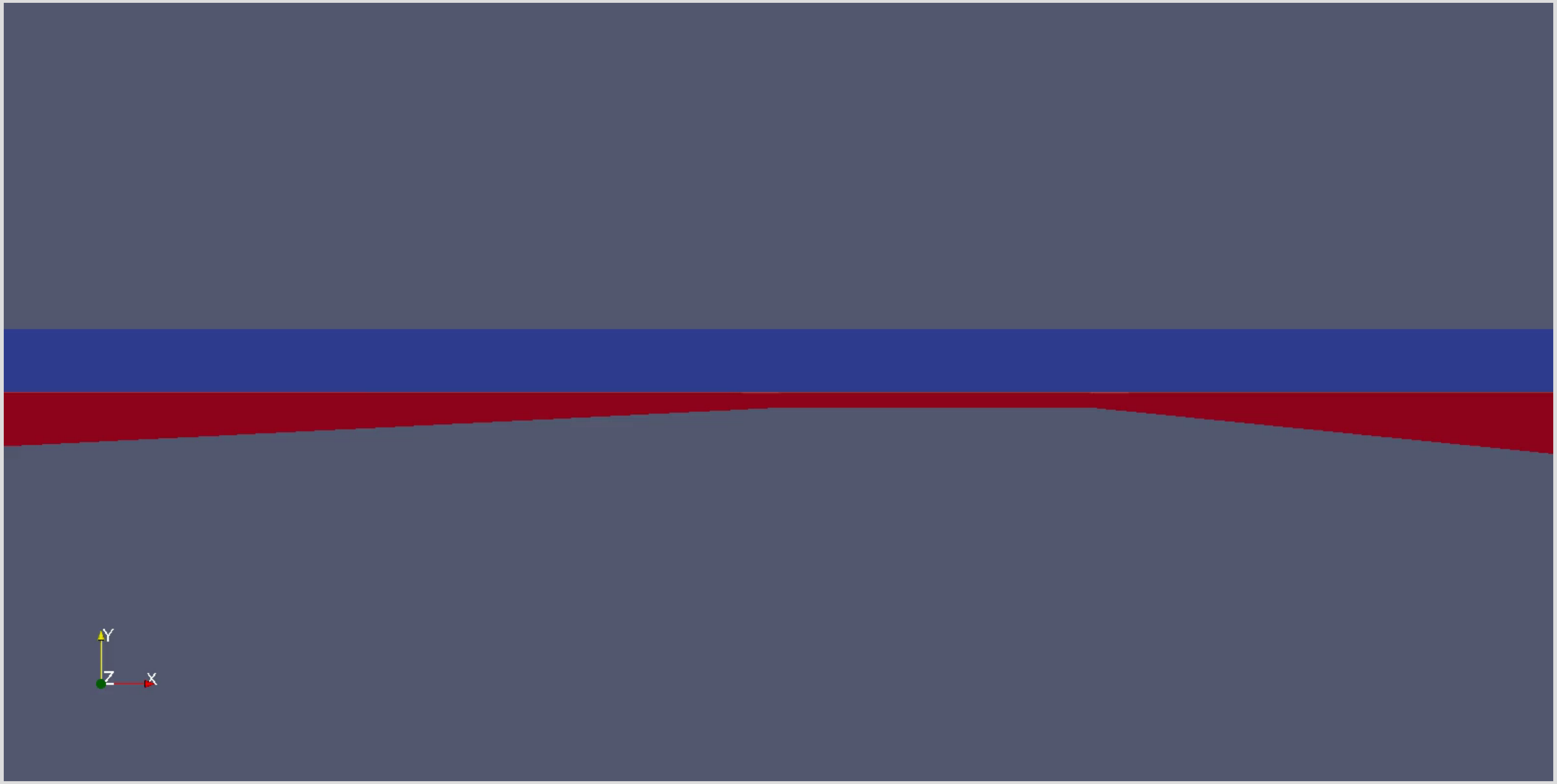
Simulation of regular surface waves

- Stokes 2nd order waves:
  - InterFoam, WaveFoam, FlowFES.

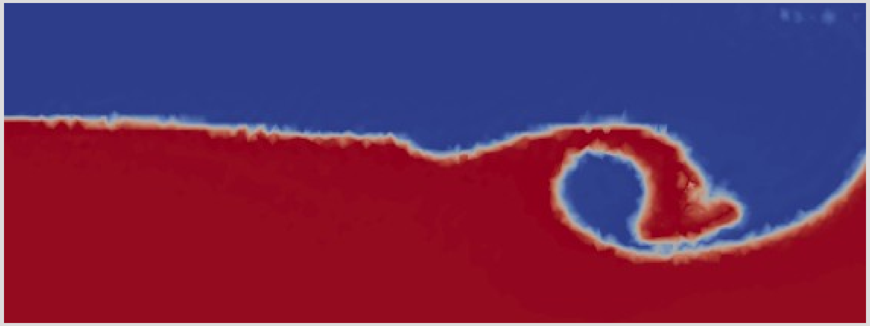


Interaction of regular surface waves with obstacles

- Stokes waves:
  - InterFoam, WaveFoam.



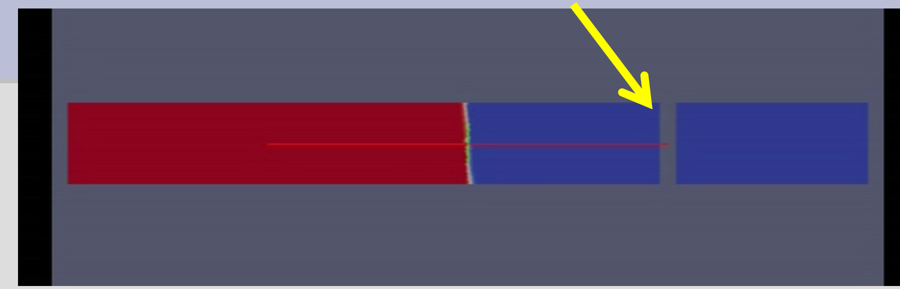
Wind-wave interaction



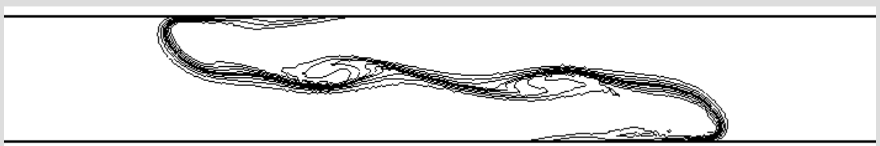
The breaking wave at wind speed 10 м/с: surface elevation (left) and subgrid turbulence energy (right).

The gravity current flow

Bearing of the platform

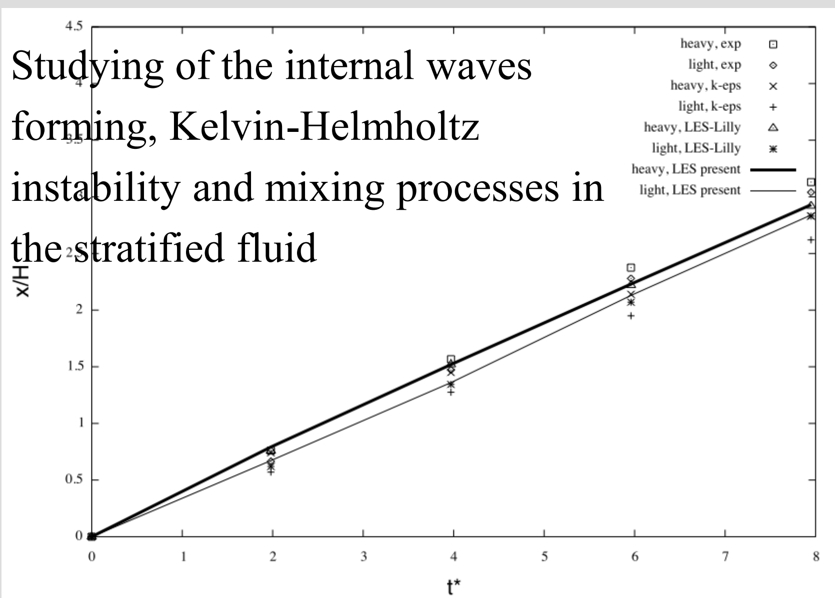


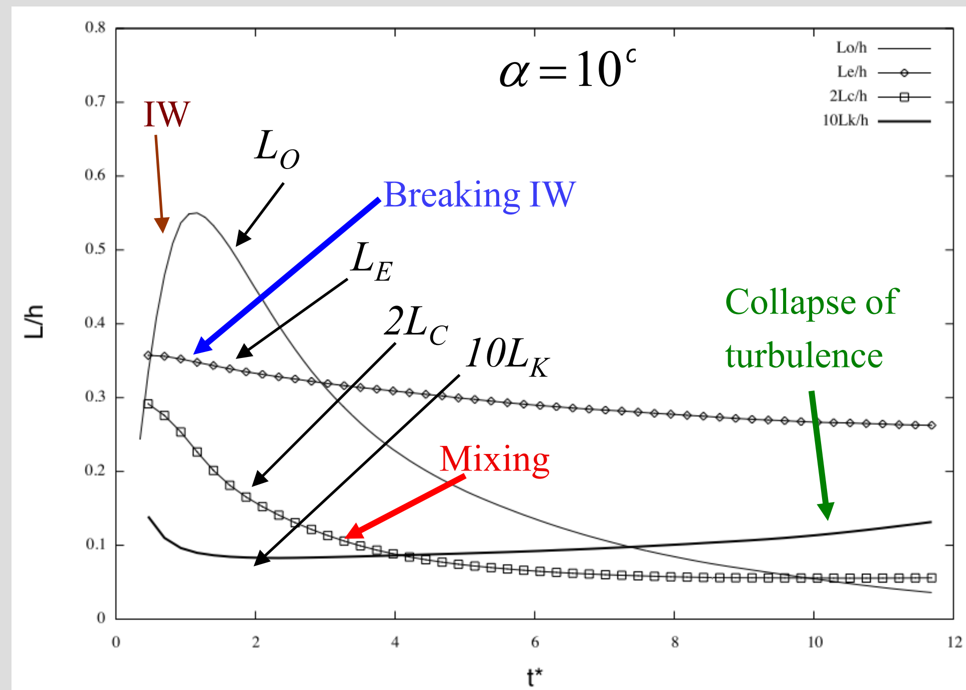
Experiment Lowe et. al., 2005



FlowFES, LES, MF, 3D

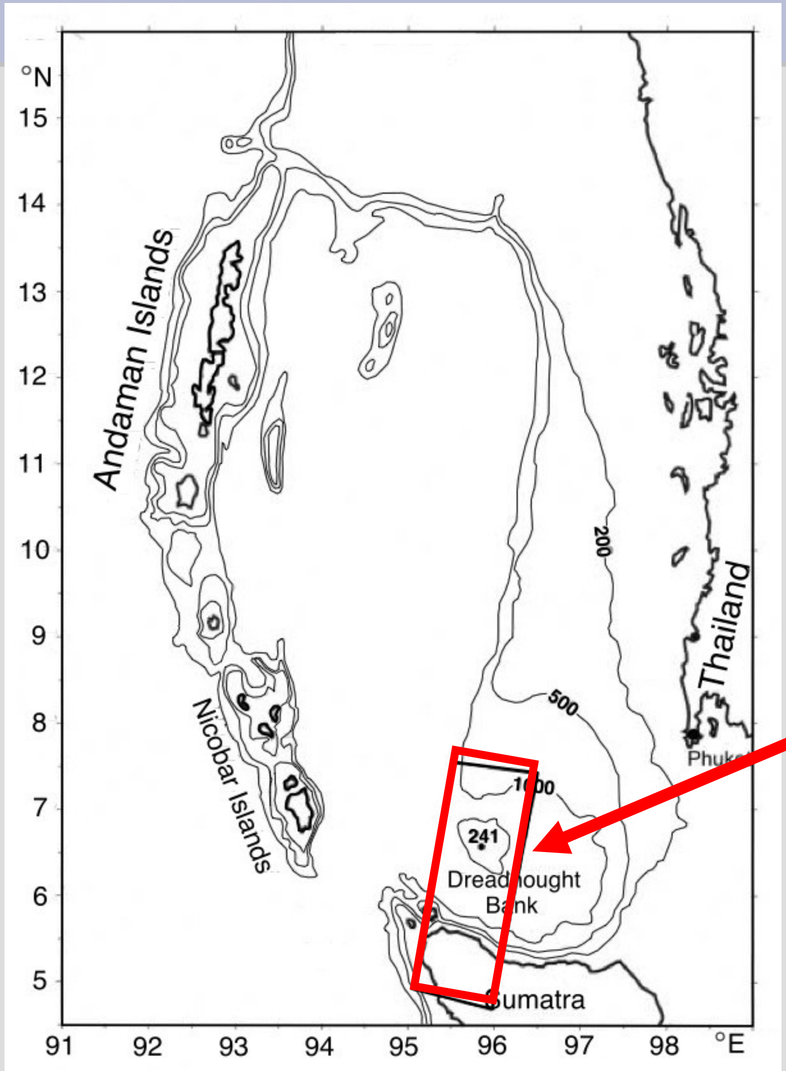
Studying of the internal waves forming, Kelvin-Helmholtz instability and mixing processes in the stratified fluid

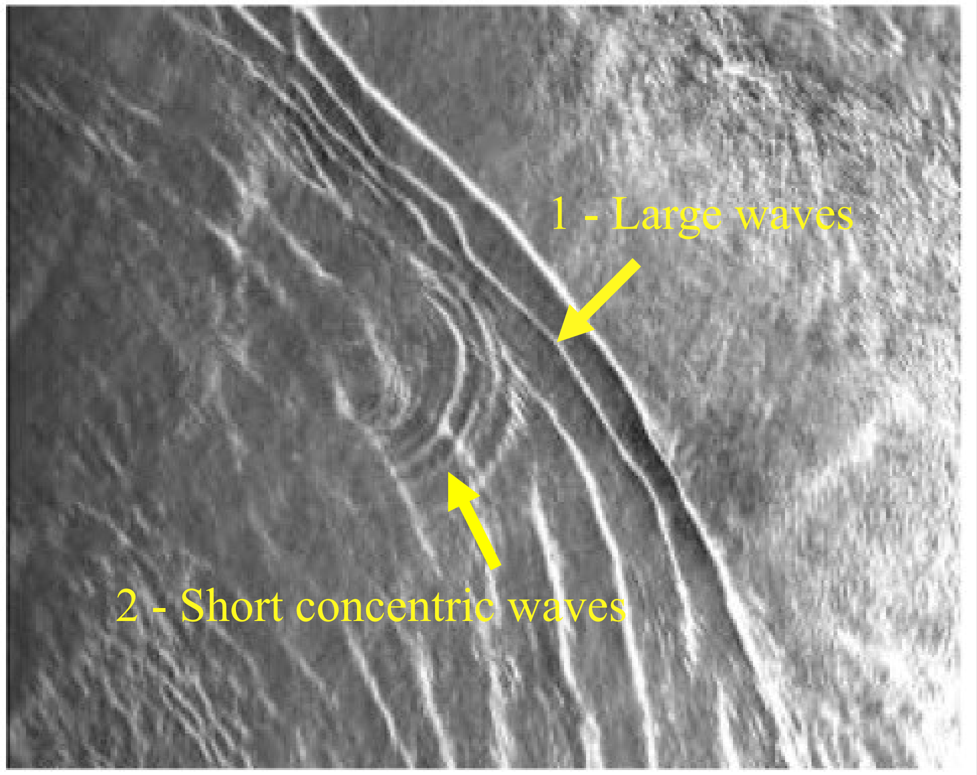




Flow parameters: $\gamma = \rho_1/\rho_2 = 0.998$

Internal tidal waves

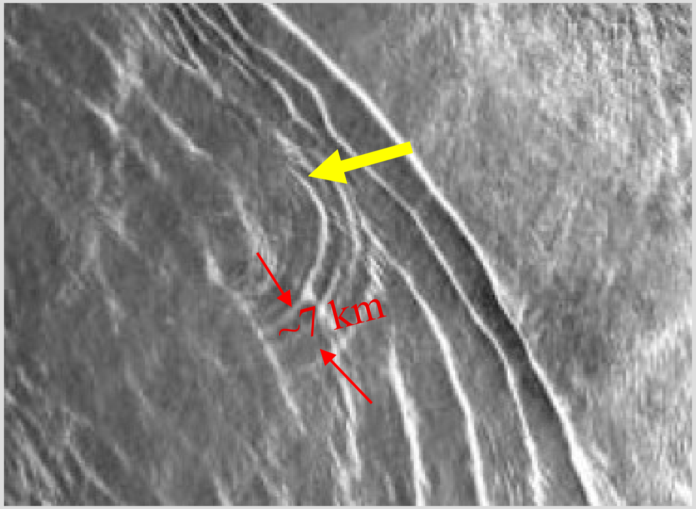




SAR image. 11.02.1997 0360 UTC.
Andaman Sea. Dreadnought Bank

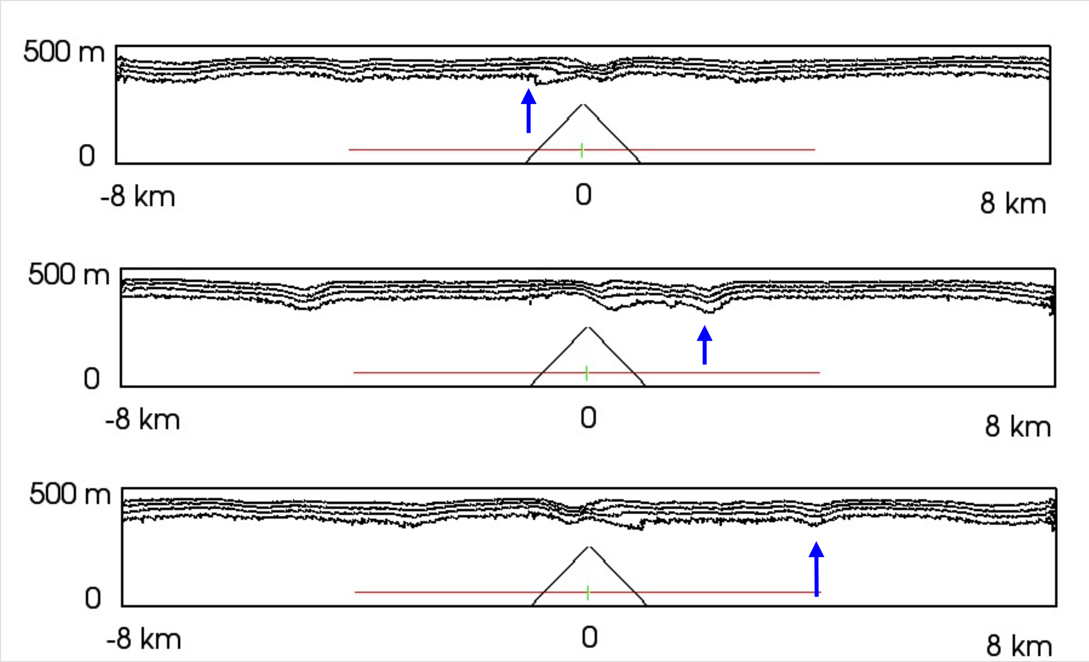
Internal tidal waves

SAR image. 11.02.1997 0360 UTC. Andaman Sea. Dreadnought Bank. Internal tidal wave

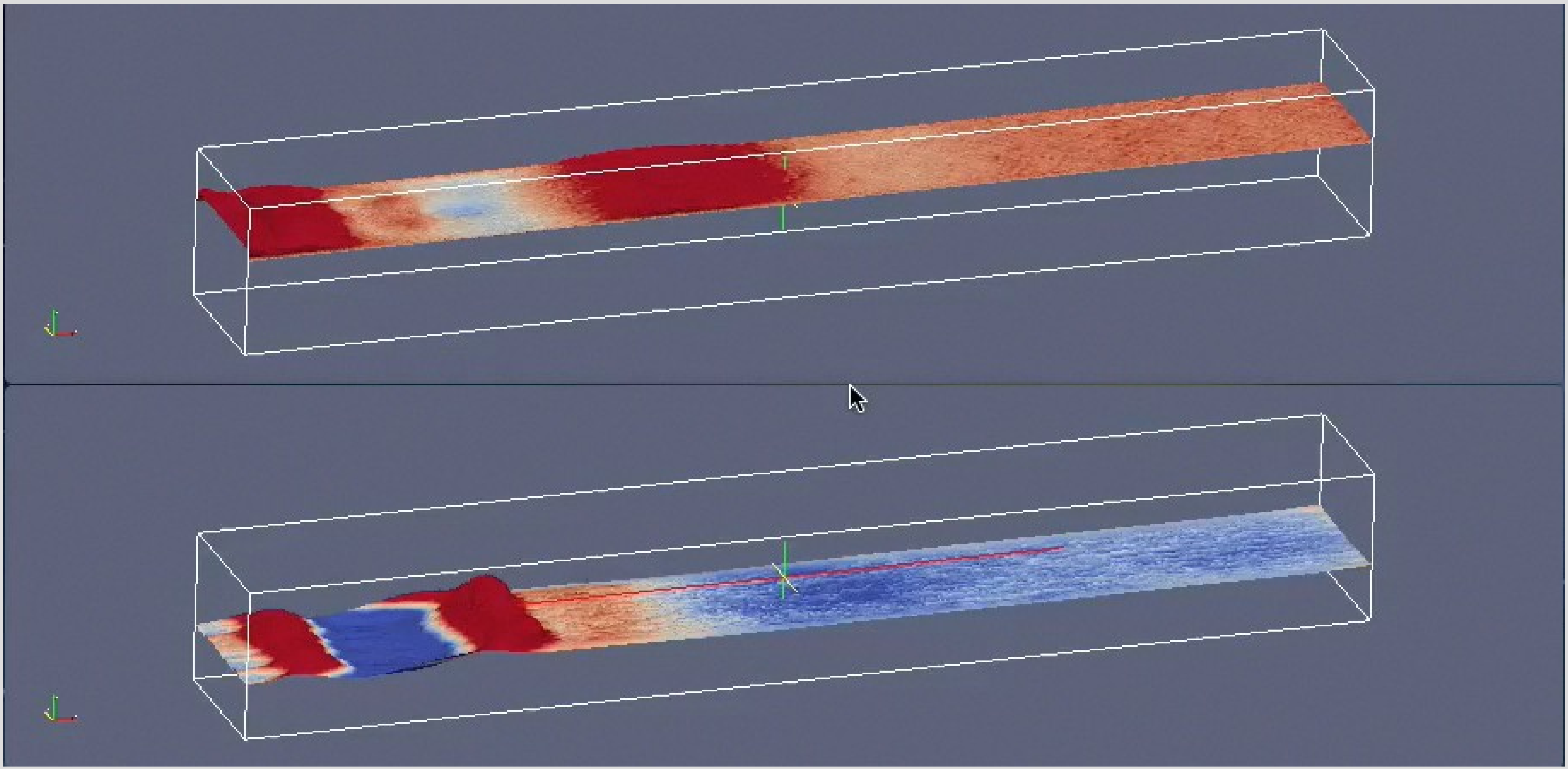


FlowFES, LES, MF, 3D

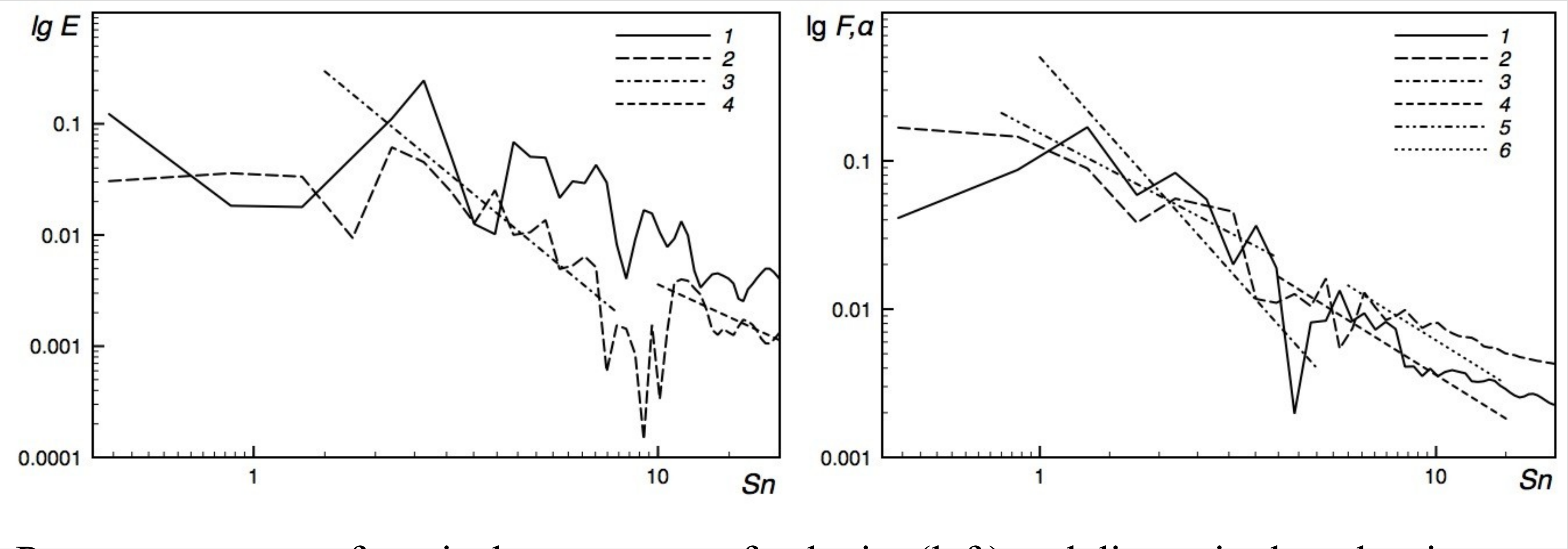
Isopycnals



Interaction of internal and surface waves



Interaction of internal and surface waves



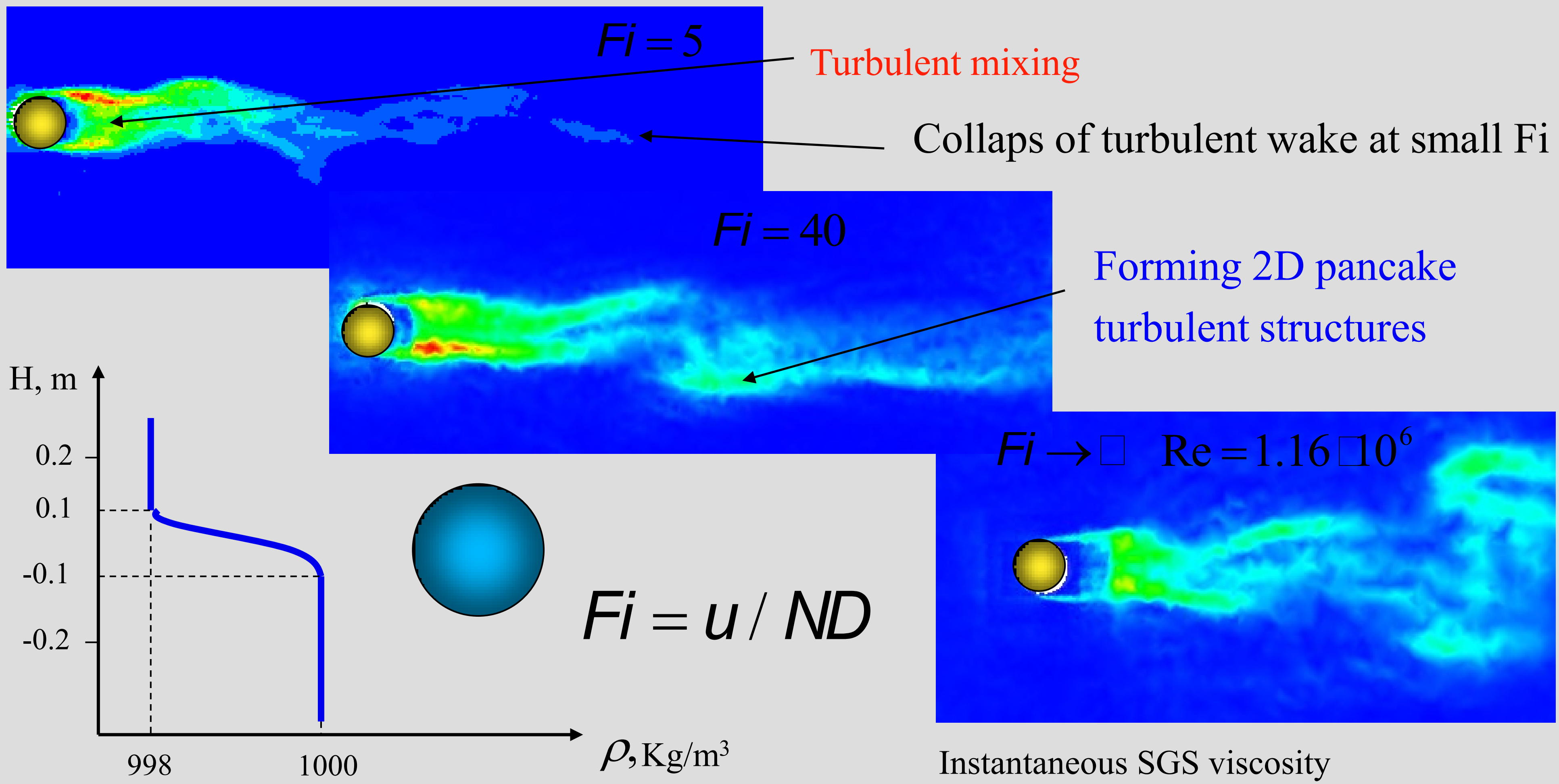
Power spectrums of vertical component of velocity (left) and dimensionless density, volume fraction (right) on free surface and on pycnocline СП и пикноклина: 1 – spectrum of free surface waves (SW), 2 – spectrum of internal waves (IW), 3 - ~Sn^{-3}, 4 - ~$Sn^{-5/3}$, 5 - ~ $Sn^{-7/5}$, 6 - ~$Sn^{-5/3}$. Modes SW: Sn=2.6, 4.4, 7; modes IW: 2.2, 4, 5.3, 6.6

The sea conditions and maritime technical objects: waves, stratification, ice

Stratified flow past the sphere

The turbulent wake

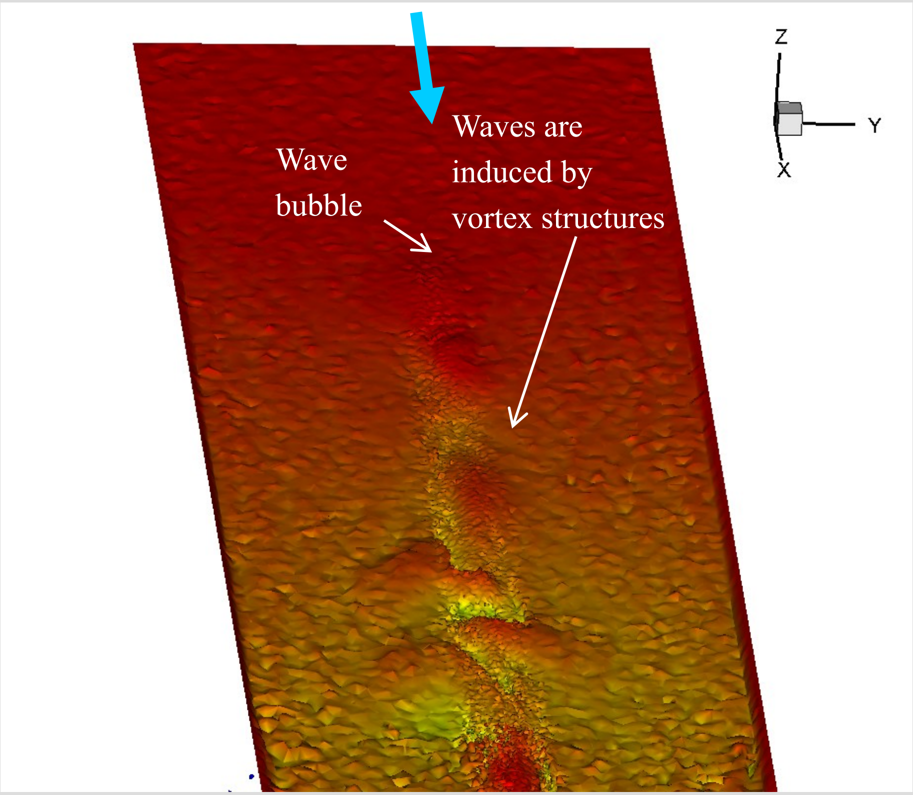
FlowFES, LES, MF, 3D, shpere



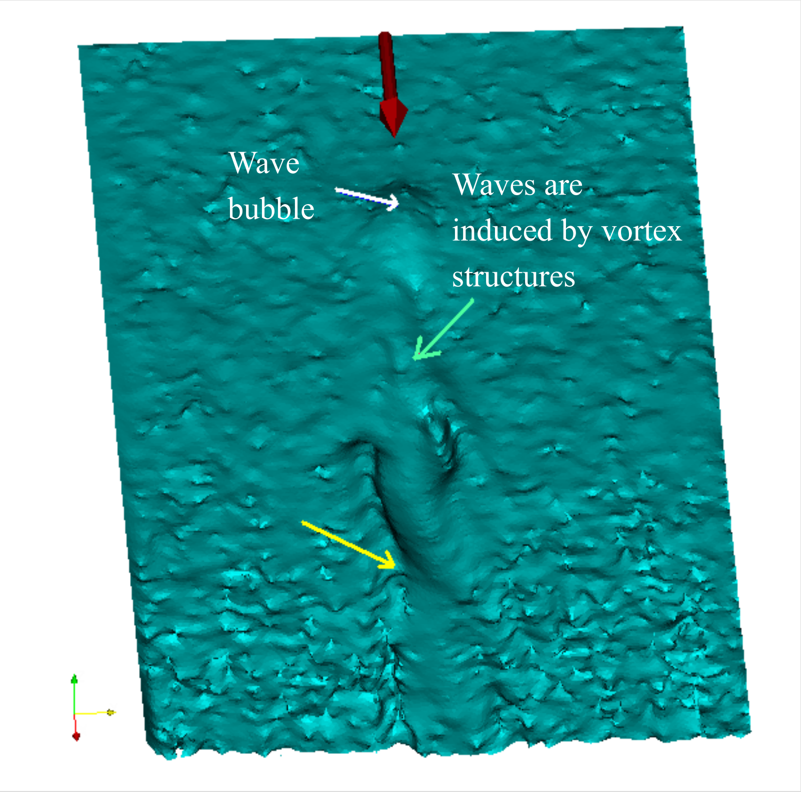
Stratified flow past the sphere

Internal waves past sphere at different Froude numbers

Isopycnal surfaces



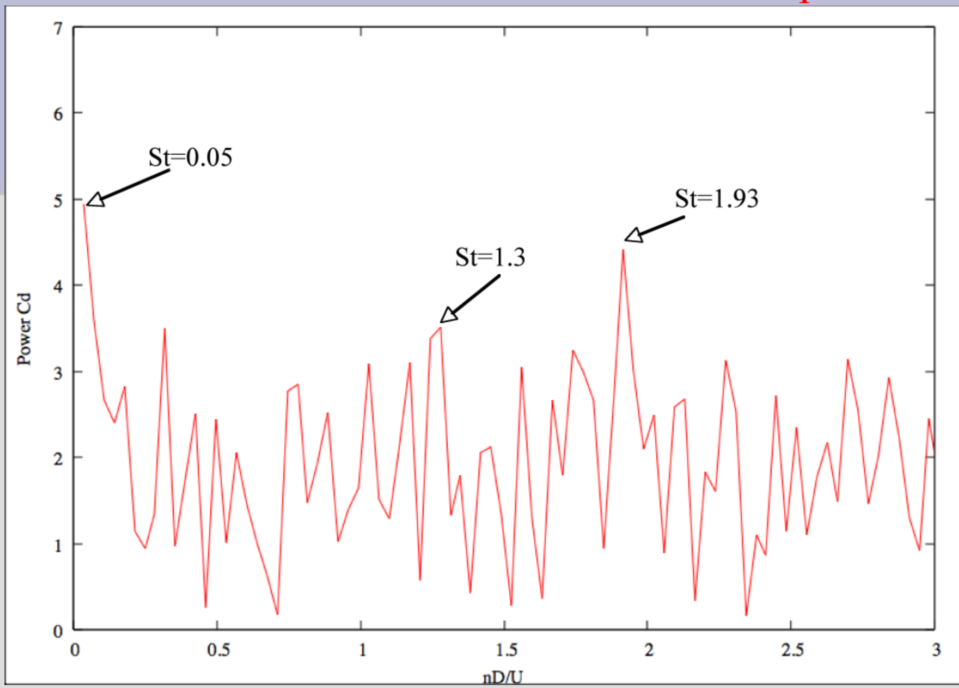
$Fi = 5$



$Fi = 40$

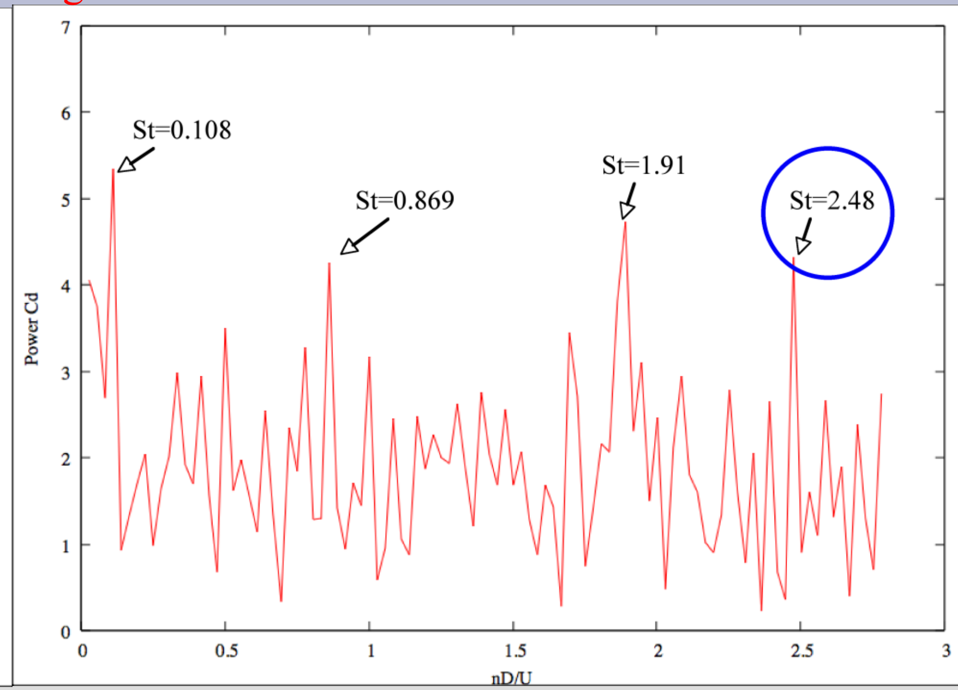
Stratified flow past the shere

Spectra of drag coefficient



Spectra of coefficient of drag force in homogeneous flow.

Experimental values of main frequence modes: 1st mode - St=0.05-0.2; high mode 2 - St=1.1-1.3 and mode 3 - St=1.8-2.0



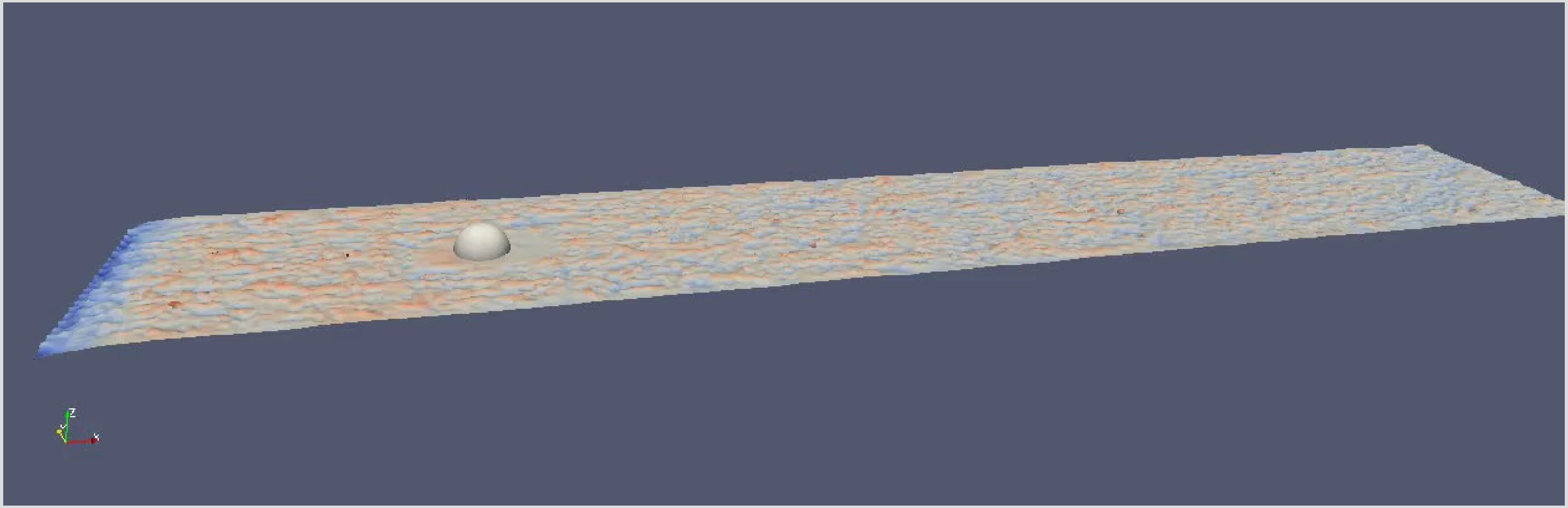
Spectra of coefficient of drag force in stratified flow Fi=5.

Additional mode – St=2.48

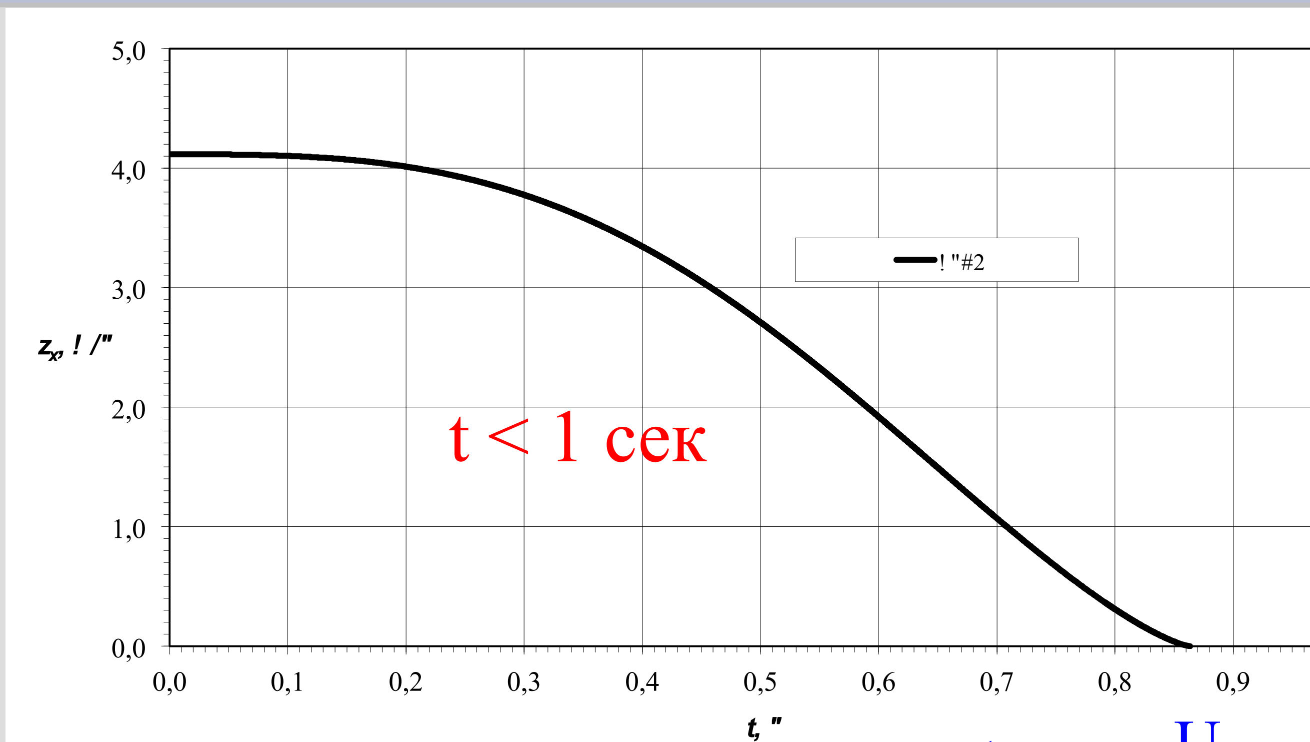
	C_D^{calc}	C_D^{exp}
Fi=5, Re=14062	0.34	0.377

Interaction of internal waves with moving sphere in stratified liquid

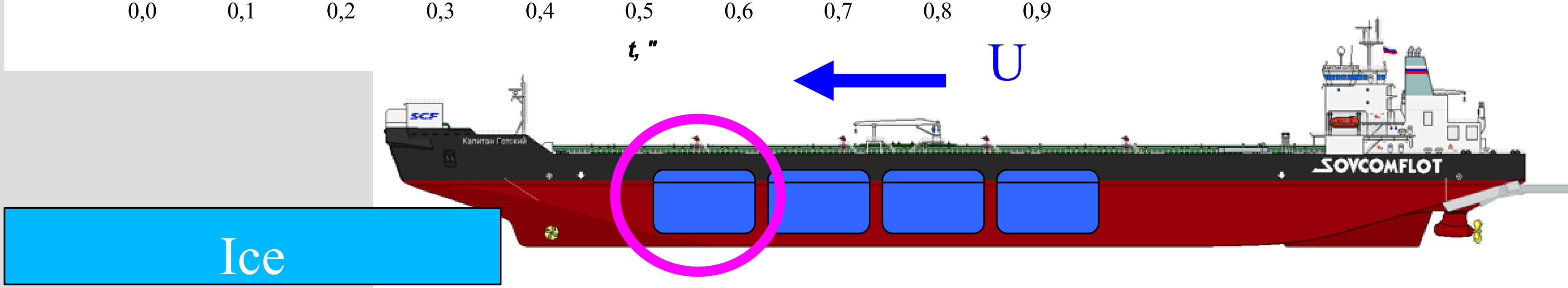
$Fr = U/(gD)^{0.5} = 0.6$, $\omega = 0.628$ rad/sec



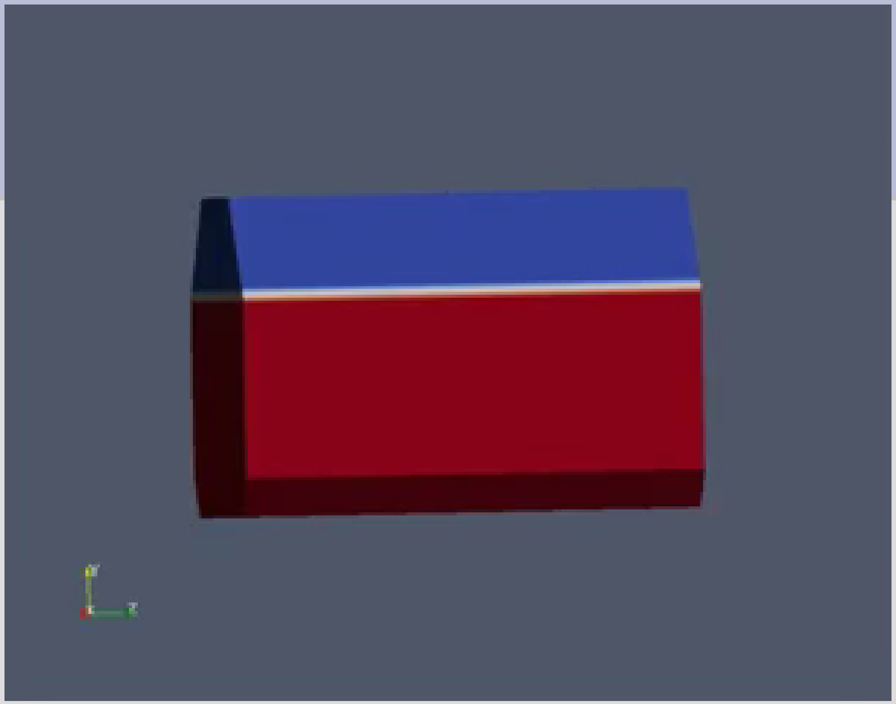
The sloshing in tank after impact interaction of the ship with ice



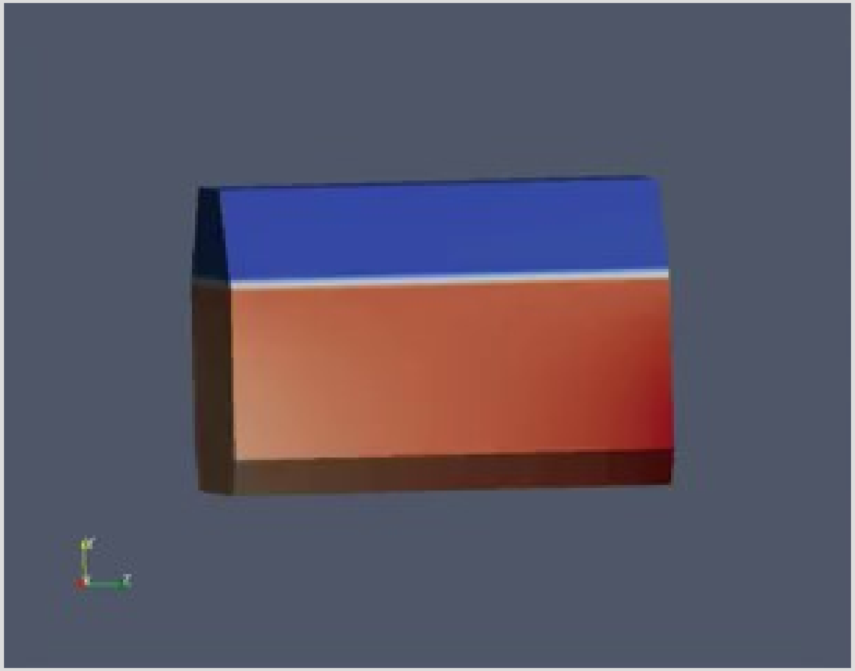
Speed of the ship after impact with ice



The sloshing



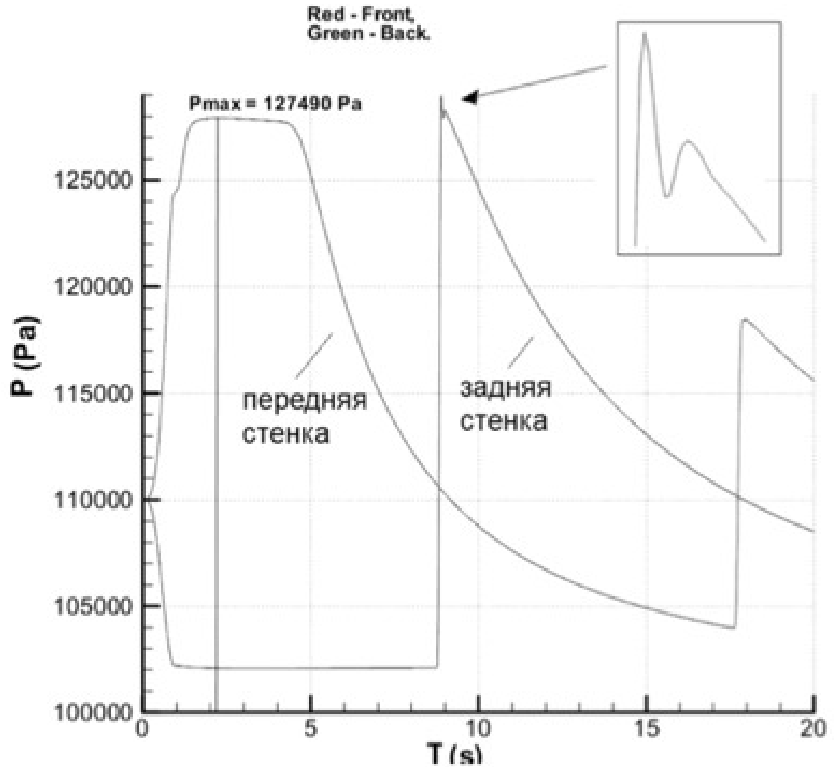
Evolution of the pressure field in the tank after impact of tanker with ice



Evolution of the liquid gas level in the tank after impact of tanker with ice

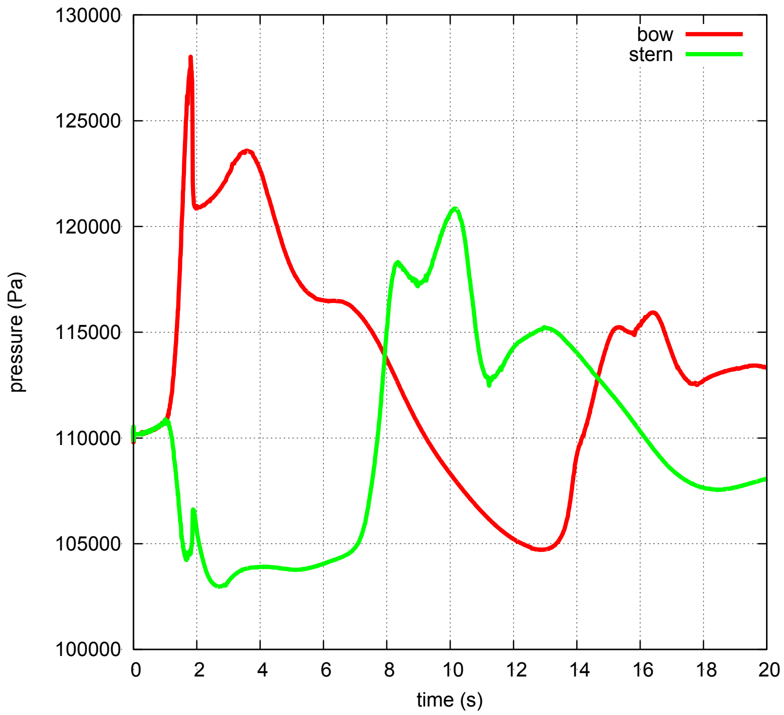
OpenFOAM, URANS,
VoF, 3D

The sloshing



Shallow water equations

Elizarova T.G. [1], Saburin D.S. [2]



Navier-Stokes equations

Tryaskin N., Tkachenko I. [3]

Thank you for attention!

Математическая модель

Reynolds averaging (URANS):

$$\bar{\varphi}(\vec{x},t) = \frac{1}{T}\int_T \varphi(\vec{x},t)\,dt$$

Space filtering (LES):

$$\bar{\varphi}(\vec{x},t) = \int \varphi(\vec{x}-\vec{s},t)\,F(\vec{s})\,d\vec{s}$$

- Уравнение неразрывности

$$\frac{\partial \bar{u}_i}{\partial x_i} = 0$$

- Уравнения Навье-Стокса

$$\frac{\partial \bar{u}_i}{\partial t} + \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\nu\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right) - \tau_{ij}^{SGS}\right] - \frac{1}{\rho_a}\frac{\partial \bar{p}}{\partial x_i} + g_i \frac{(\rho - \rho_0)}{\rho_a}$$

- Уравнение переноса скаляра (объемной фракции жидкости VOF)

$$\frac{\partial \bar{f}}{\partial t} + \bar{u}_j \frac{\partial \bar{f}}{\partial x_j} = \frac{\partial}{\partial x_j}\left[D\left(\frac{\partial \bar{f}}{\partial x_j}\right) - J_j^{SGS}\right] \qquad \frac{\partial \bar{f}}{\partial t} + \bar{u}_j \frac{\partial \bar{f}}{\partial x_j} = 0$$

- Модели турбулентности
  - URANS: *k-ε*, SST, RSM, …
  - LES: Smagorinsky, Dynamic Smagorinsky, Dynamic Mixed