STATE MARINE TECHNICAL UNIVERSITY

OF SAINT PETERSBURG

High-performance computing in solving specific problems of ship hydromechanics

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- Influence of the sea conditions on hydrodynamics of marine objects

Introduction

State Marine Technical University of St. Petersburg (SMTU)

- *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;

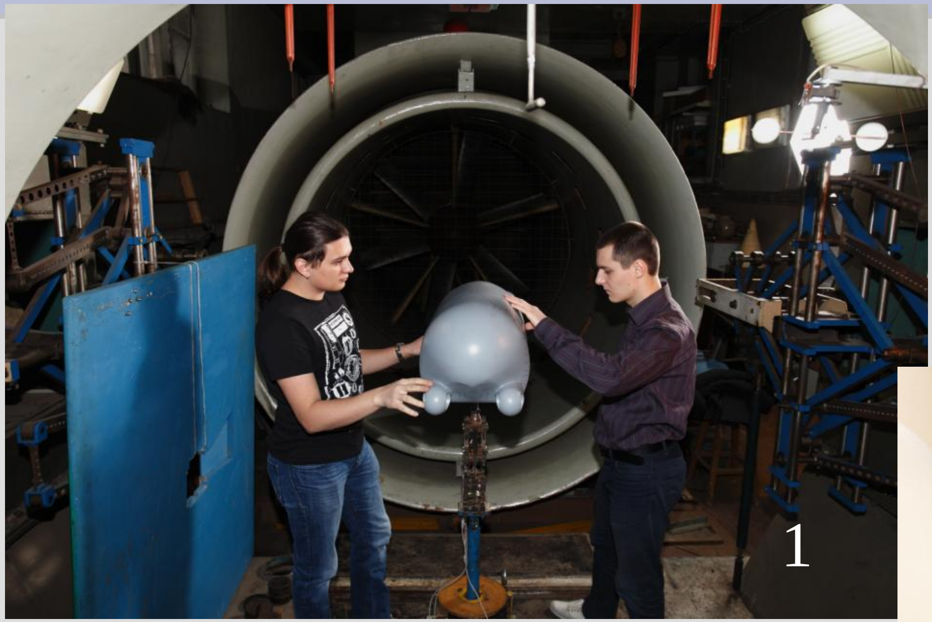
Research Institutes – 1;

Research Educational Centers – 1.

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

Introduction

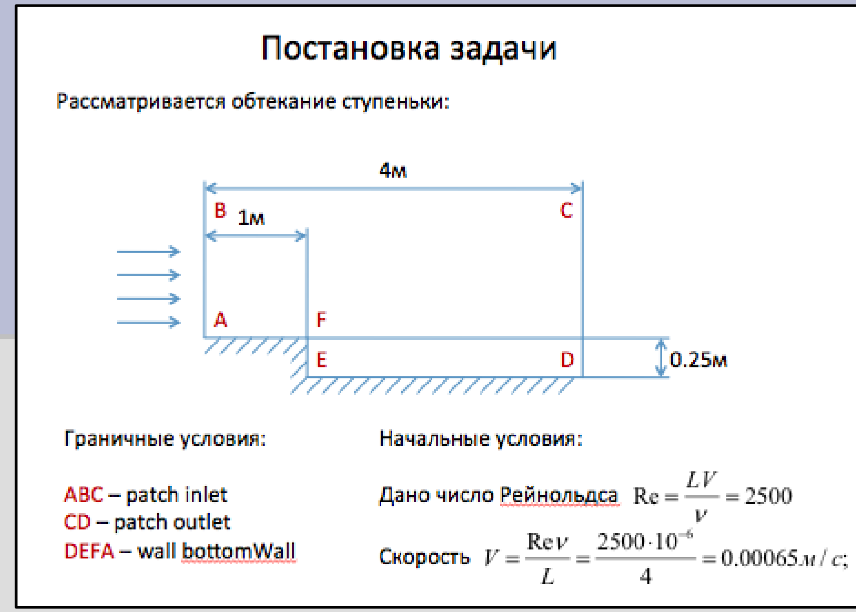
Facilities and equipment of SMTU

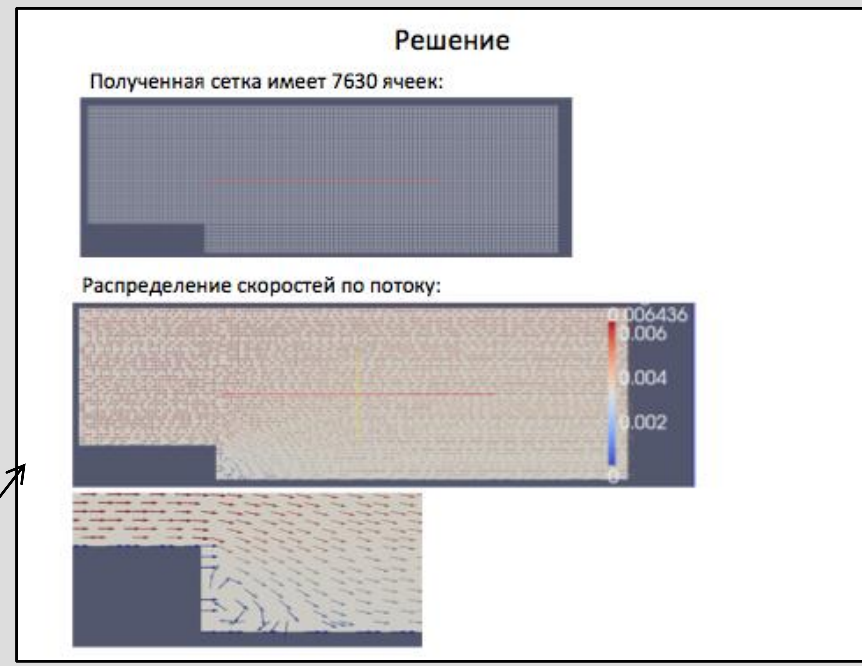


① Big wind tunnel (D=2.0 m, 50 m/sec);
② Small wind tunnel (D=0.4 m, 30 m/sec);
③ Training aerodynamic laboratory;
④ Acoustic laboratory;
⑤ Center of High Performance Computations.

CFD, HPC 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.



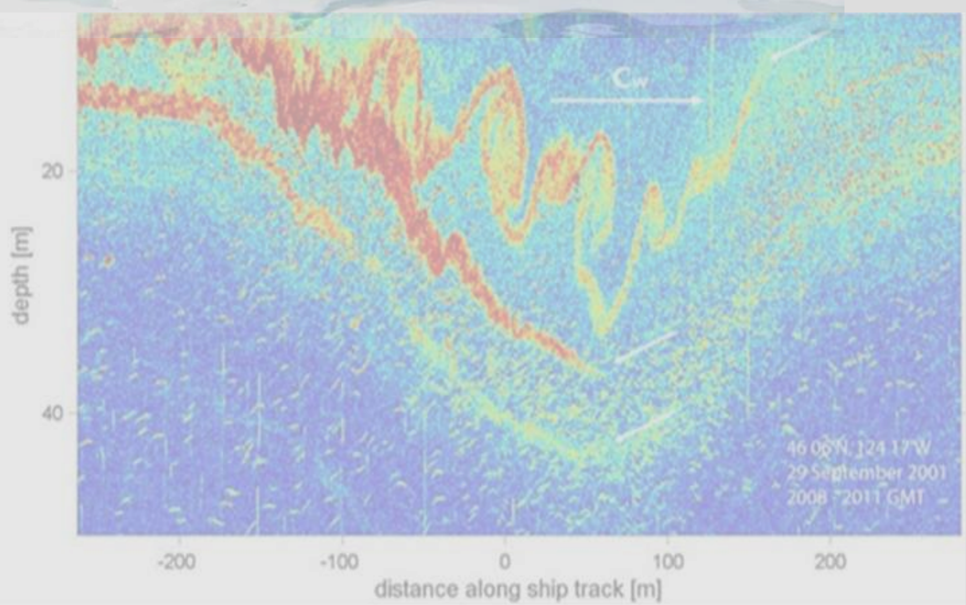


Flow past step

Example of laboratory work

Specific problems of ship hydromechanics

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



Features of simulation of flows past marine objects in natural conditions

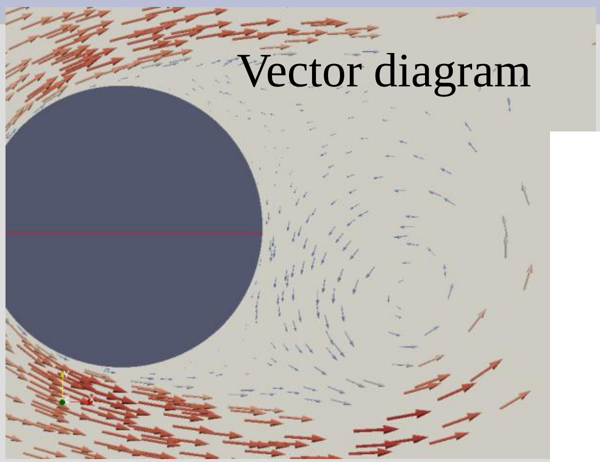
- High Reynolds number ($Re>10^7$); => Turbulence modeling, grid resolution > 10^7
- Gas-liquid interface => Wave motion, cavitation
- Stratification => Mixing, internal waves
- Interaction with ice => Ice model

Mathematical models, hardware and services

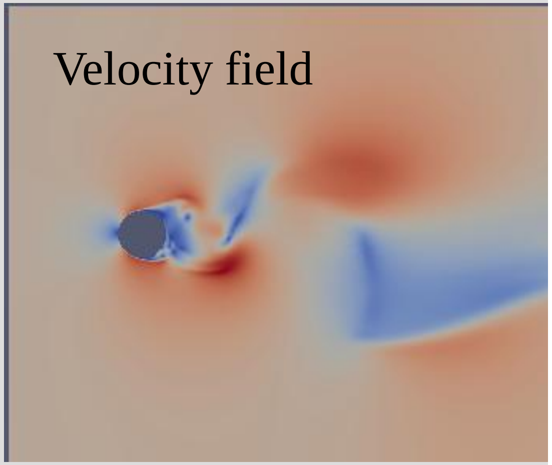
- ***Mathematical model:***
  - Unsteady Reynolds Averaged Navier-Stokes equations (URANS), Large Eddy Simulations (LES) equations;
  - URANS models (k-eps, k-omega, SST), LES models (Smagorinsky, DSM, DMM);
  - Volume of Fluid (VoF) and mixture fraction methods.
- ***Hardware***:
  - University cluster 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

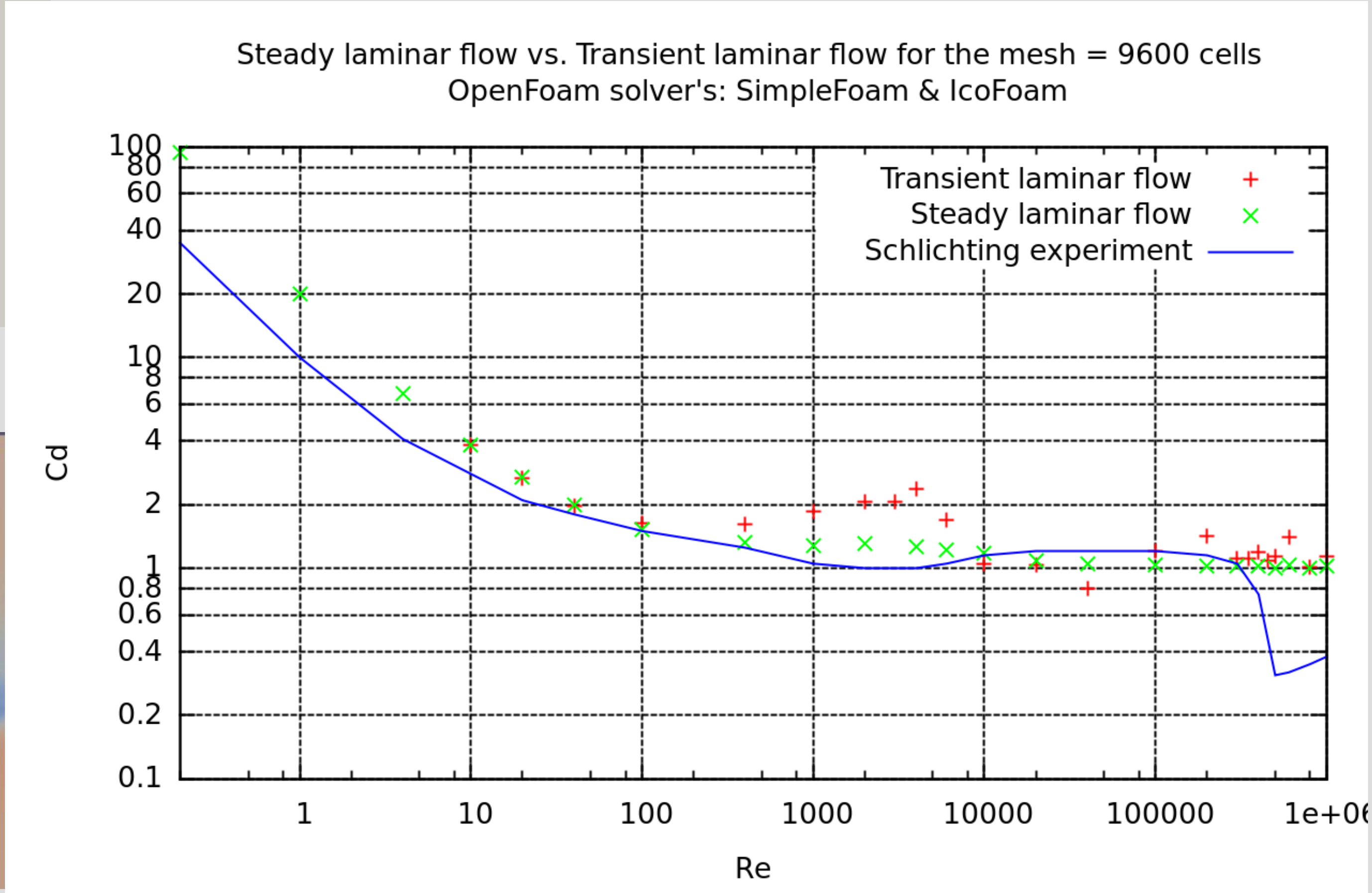
Homogeneous flow past the cylinder



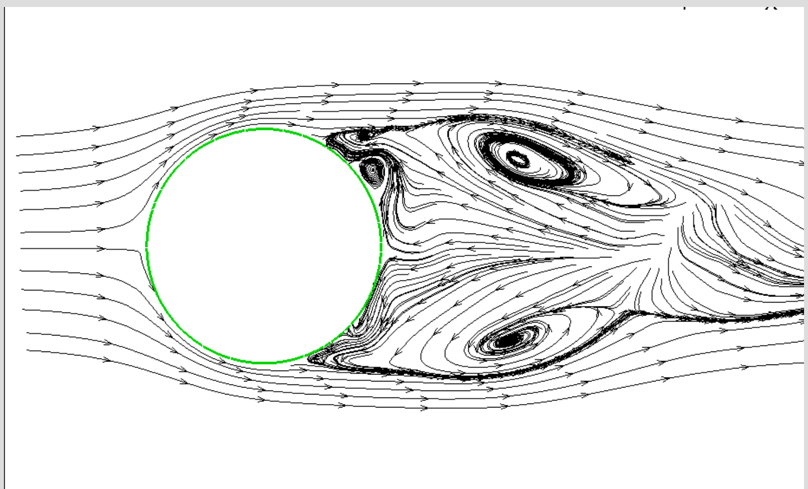
Re=4000



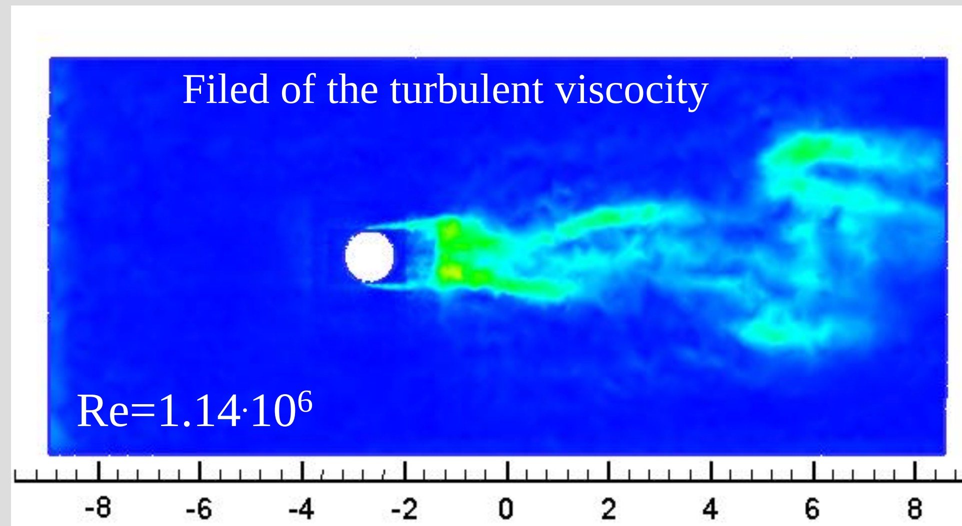
OpenFOAM, laminar flow, 2D, cylinder

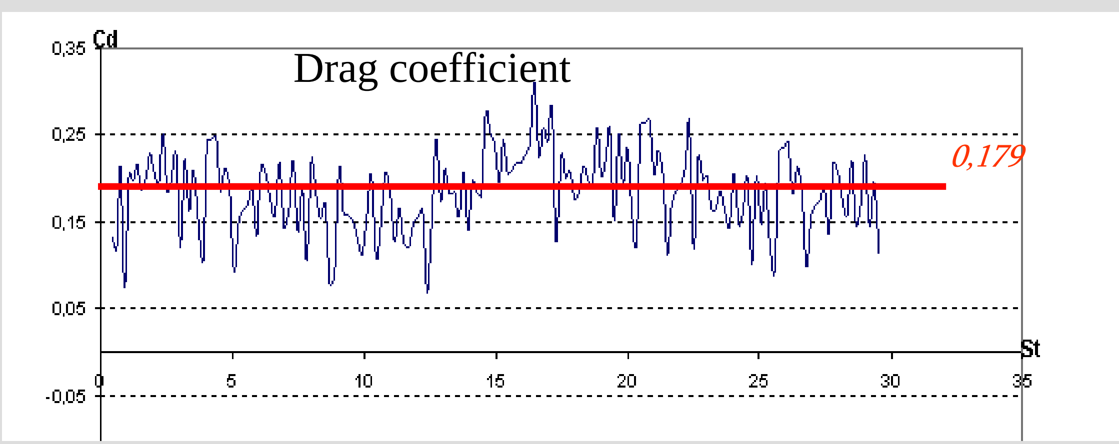


Homogeneous flow past the sphere



Re=14062





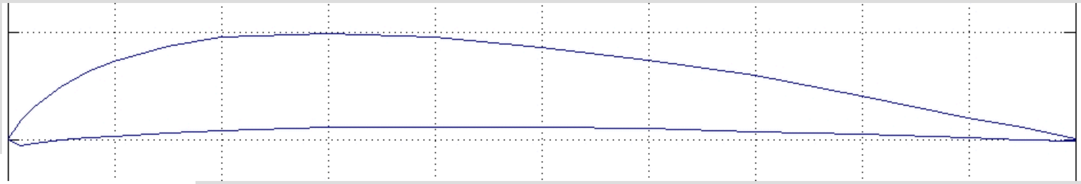
Re	$C_D^{calc.}$	C_D^{exp}
14062	0.36	0.4
1140000	0.179	0.12-0.18

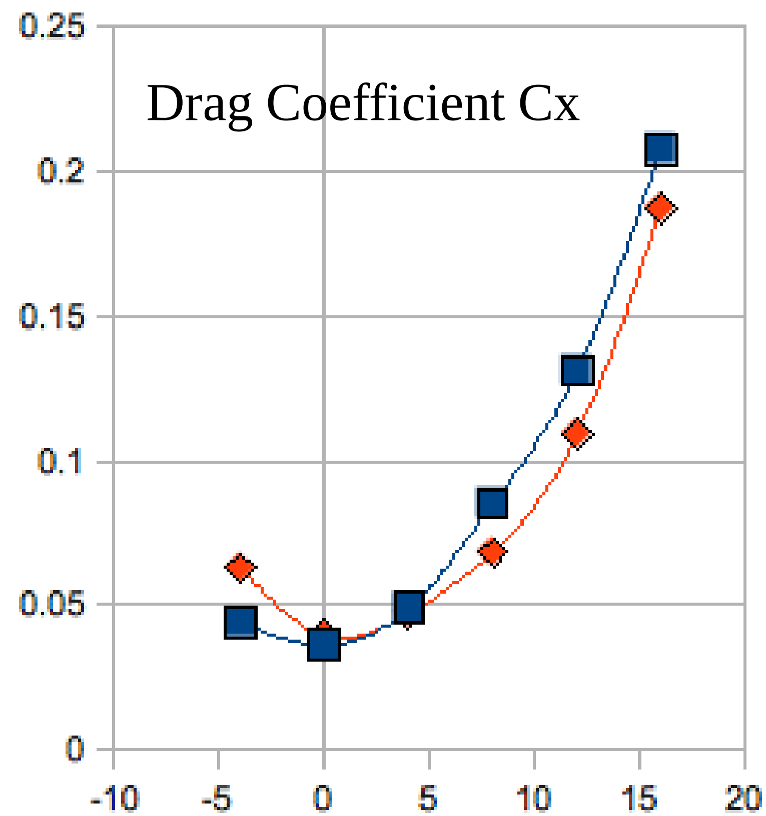
FlowFES, LES-Smagorinsky, 3D, sphere

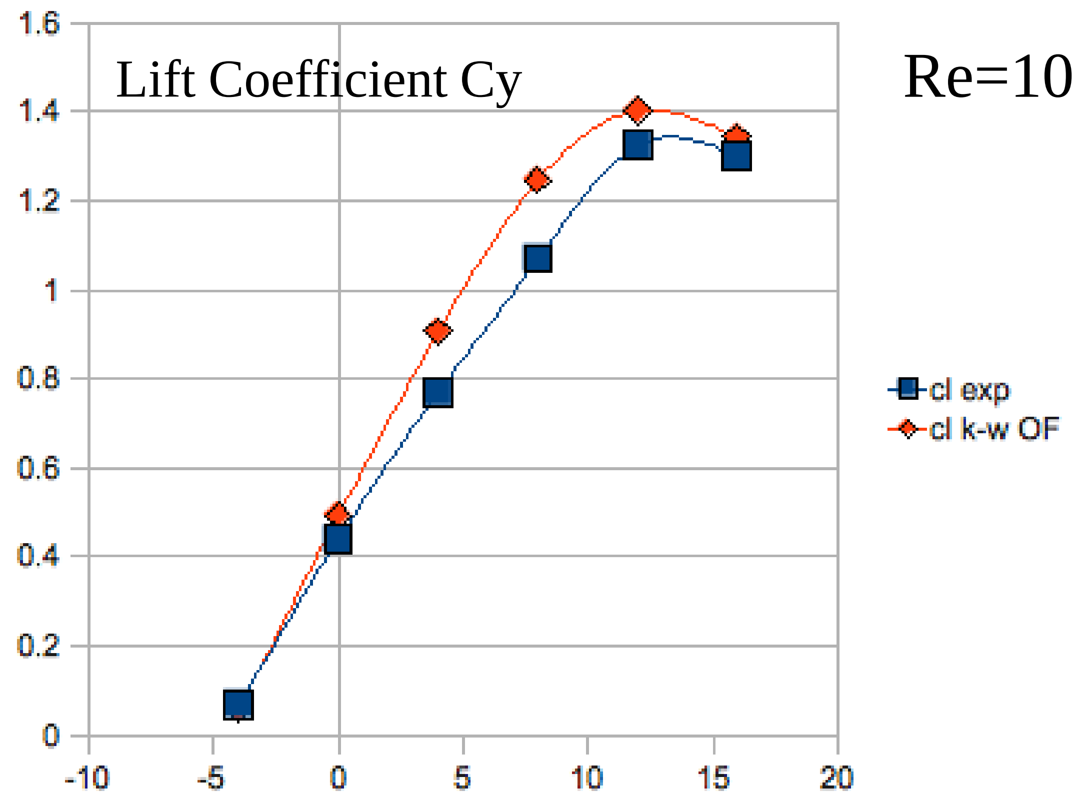
Homogeneous flow past the airfoil

OpenFOAM, RANS, 2D, Airfoil

Göttingen 92

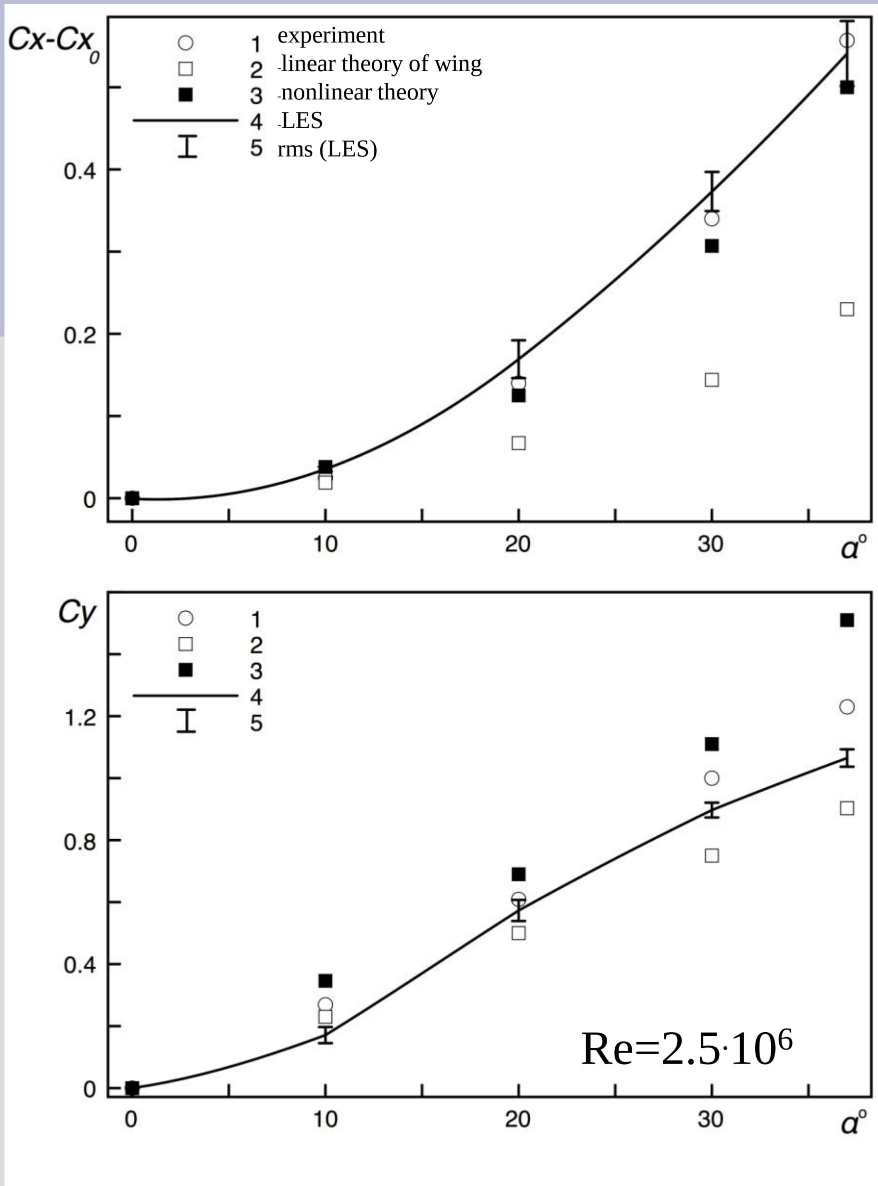


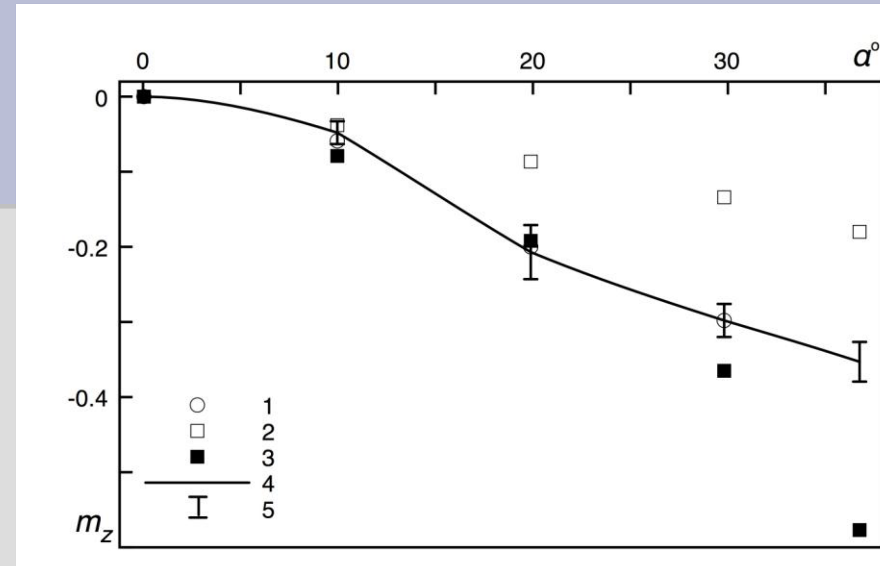


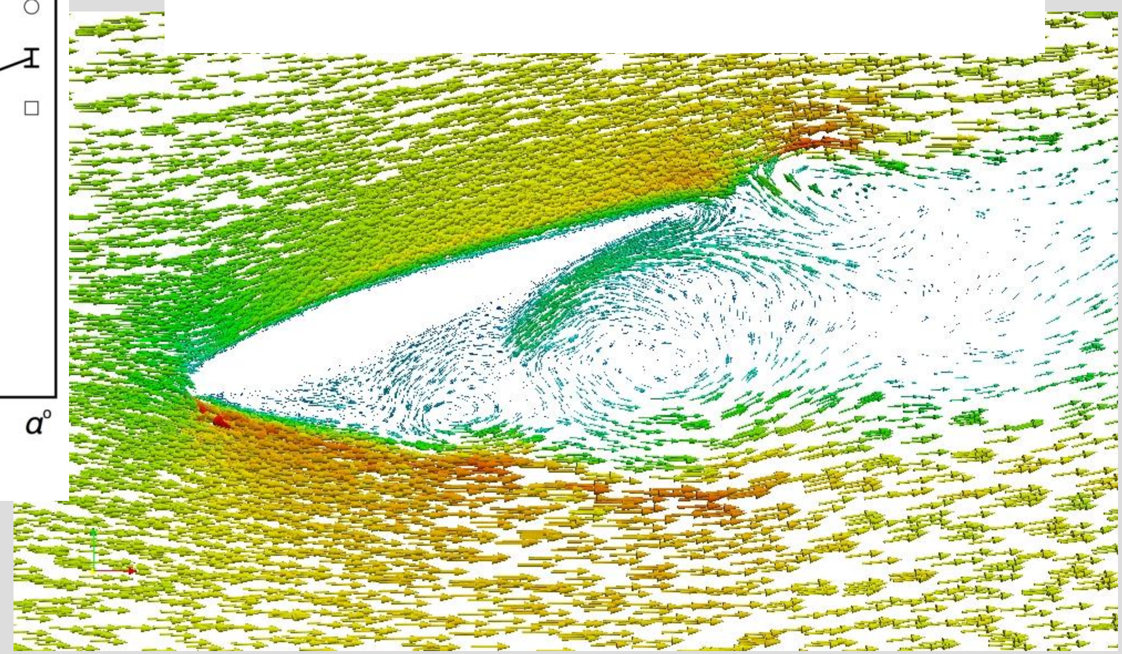


$Re=10^5$

Homogeneous flow past the wing



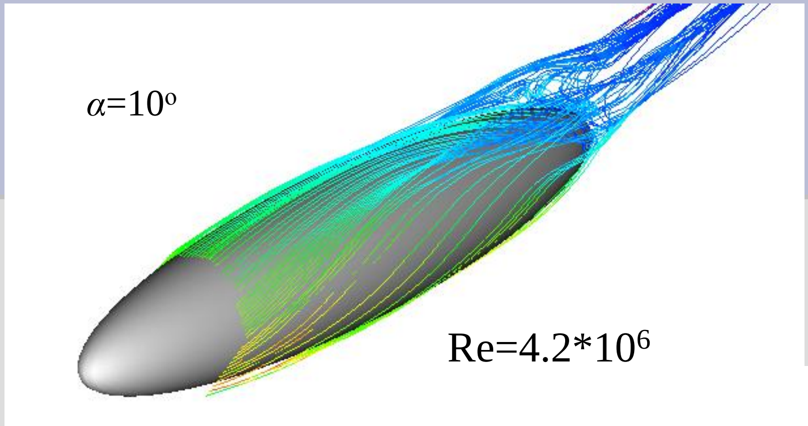




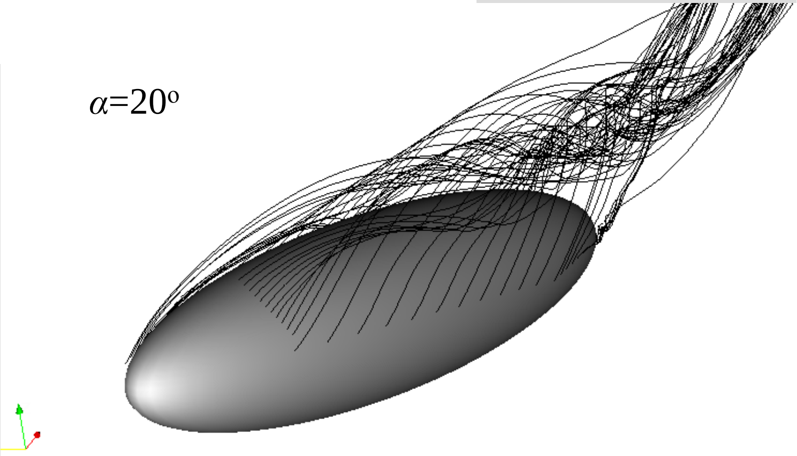
FlowFES, LES, 3D, NACA 0018,

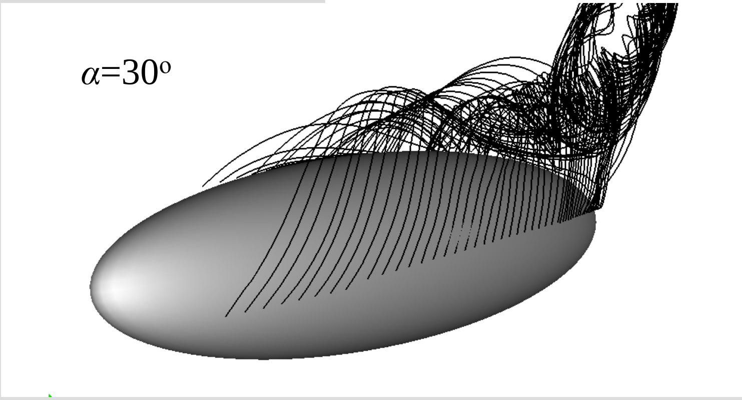
Ratio 1

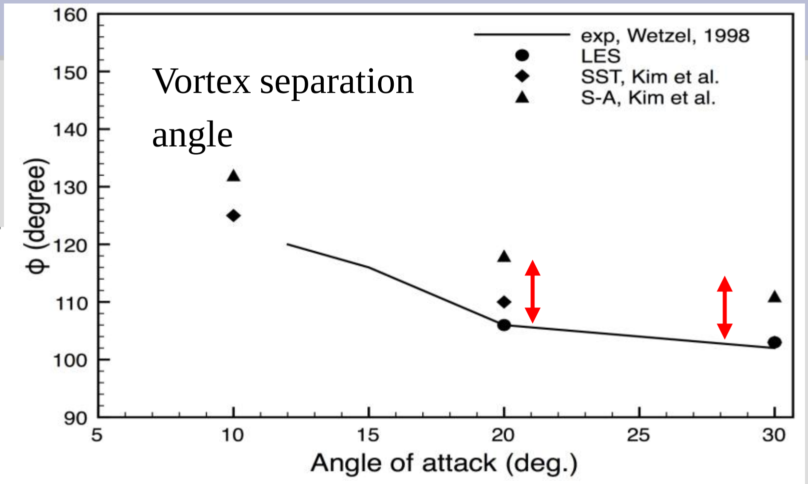
Homogeneous flow past the spheroid

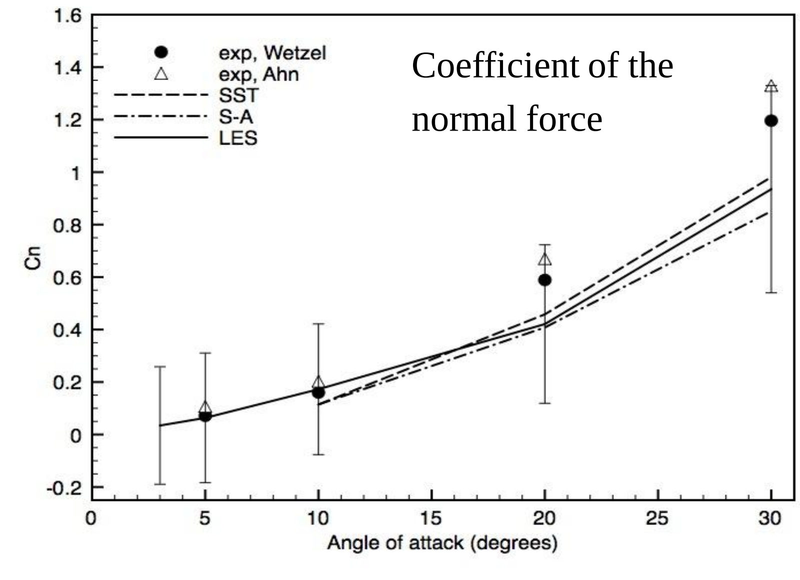


FlowFES,
LES, 3D,
spheroid 6:1



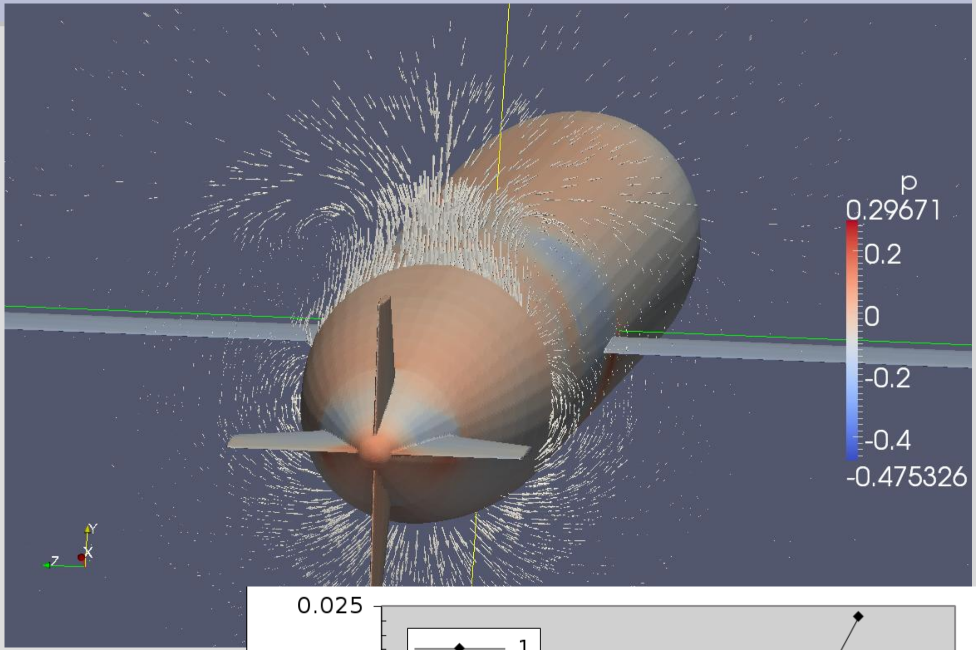


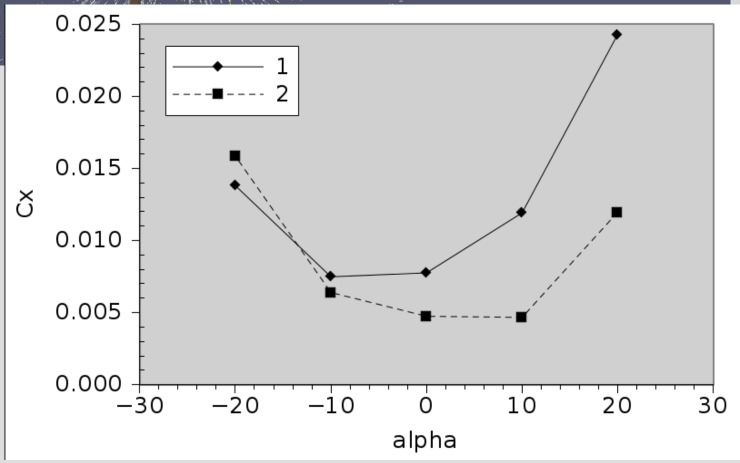


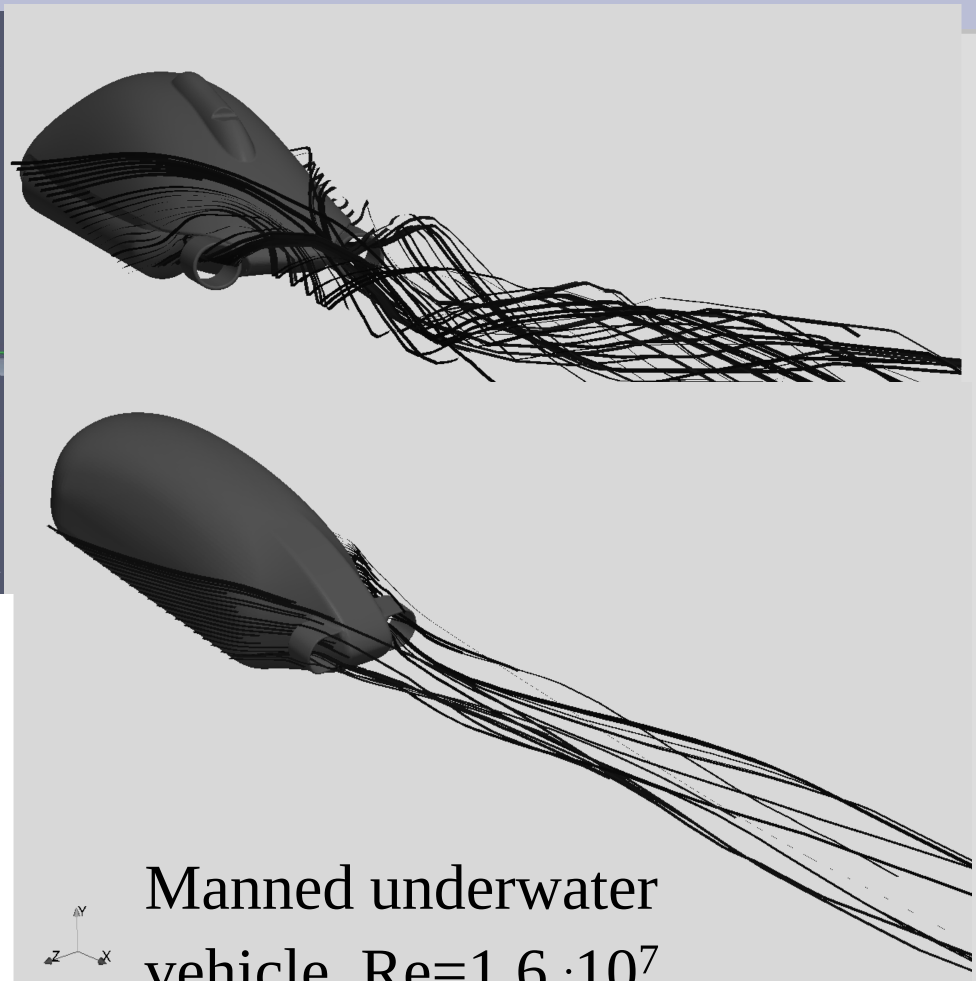


Homogeneous flow past the underwater objects

Glider, Re=2 $\cdot 10^6$





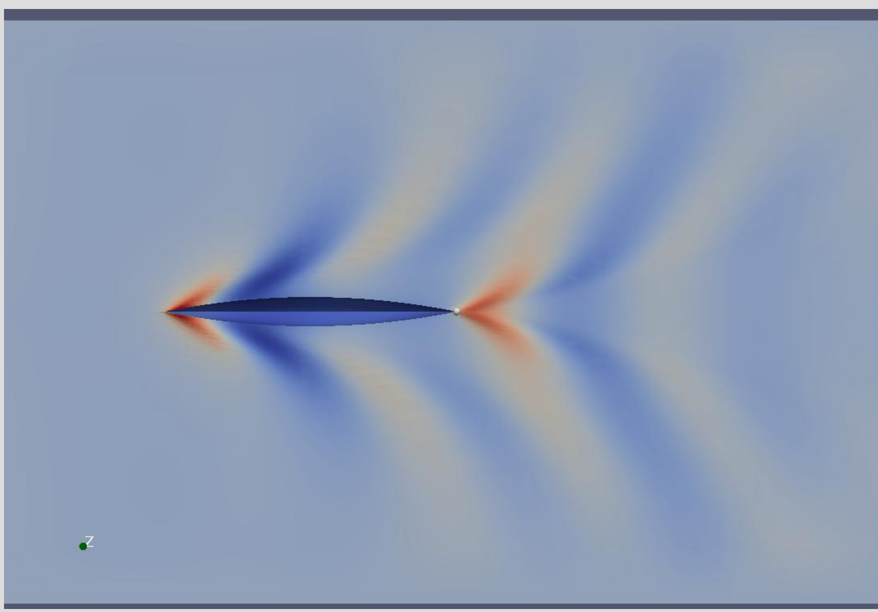


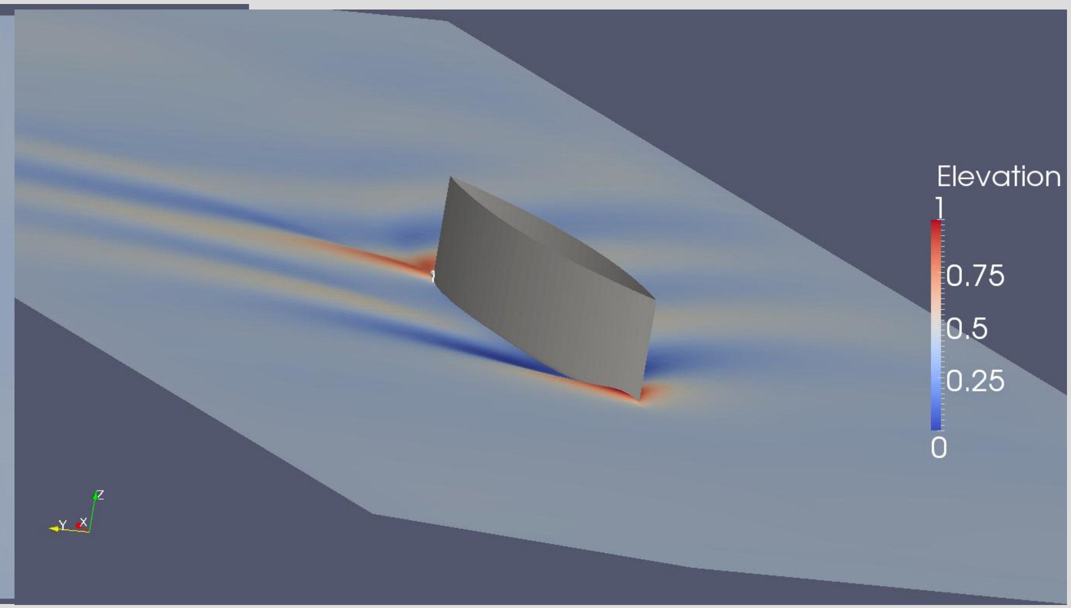
Manned underwater vehicle, Re=1.6 $\cdot 10^7$

Simulation of the ship motion on free surface

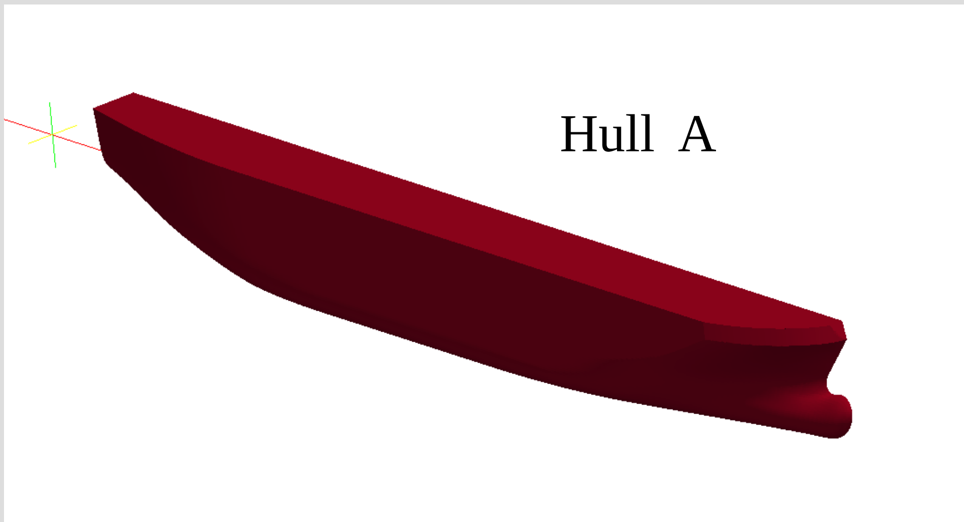
The motion of Wigley body on free surface

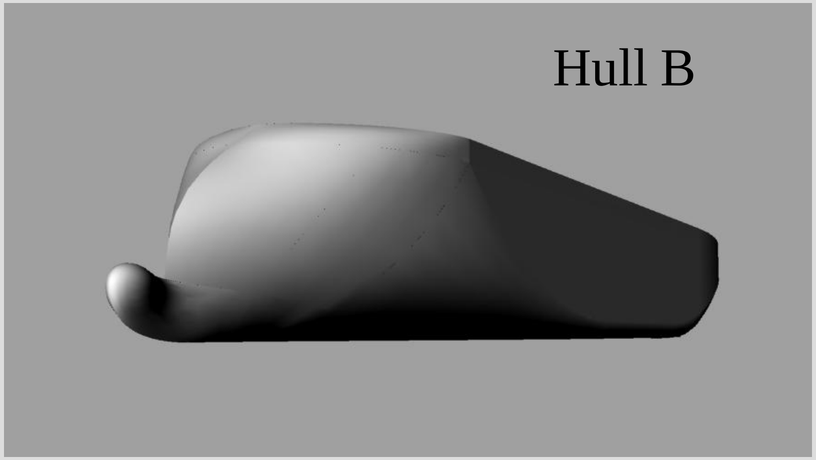
C_T^{calc}	C_T^{exp} [Maki K. Ship Resistance Simulations with OpenFOAM // 6th OpenFOAM Workshop. 13-16 June. Pensylvania. USA]
0,0046	0,0048





The motion of LNG tanker on free surface



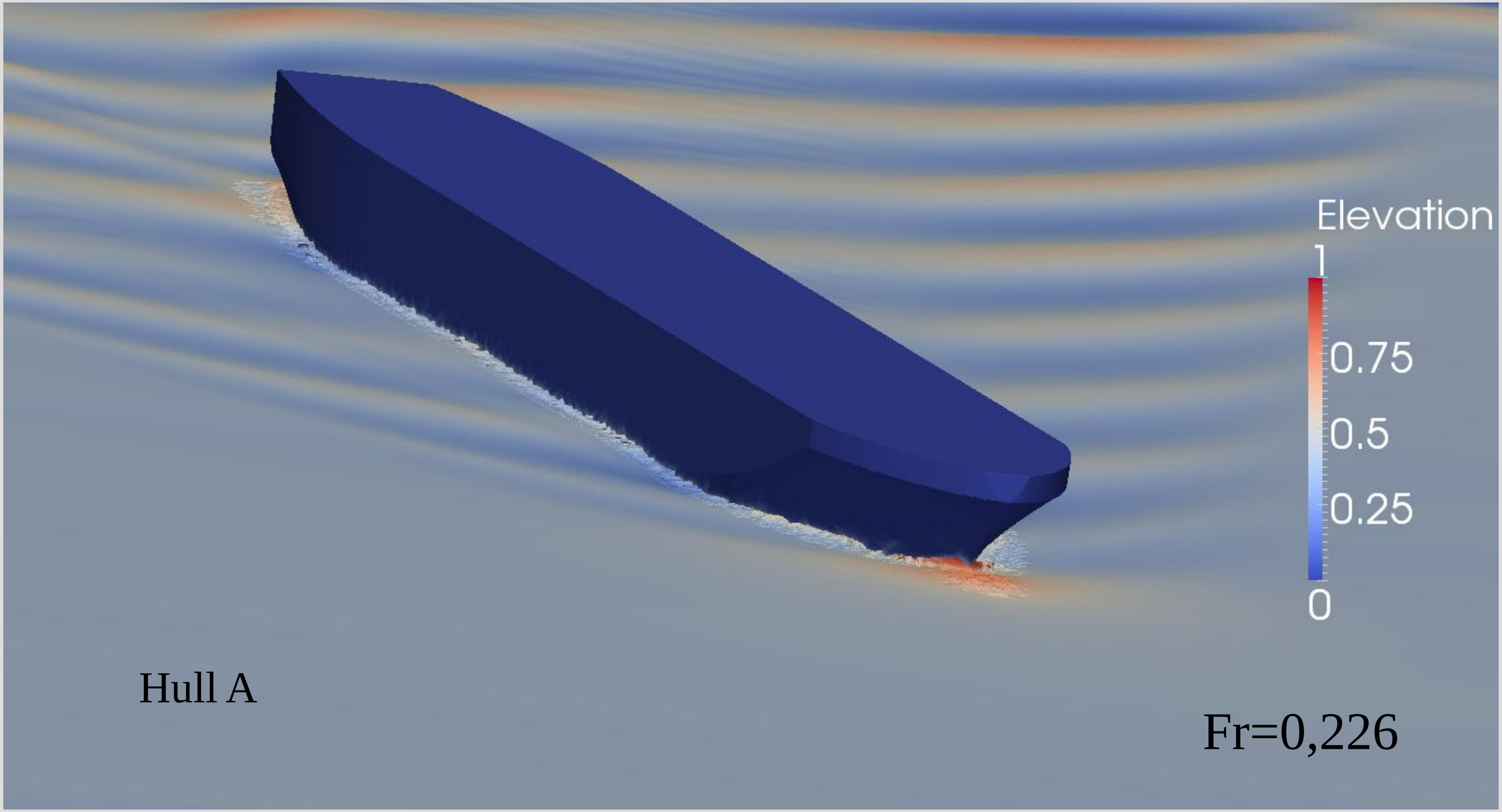


A – traditional ship bow;

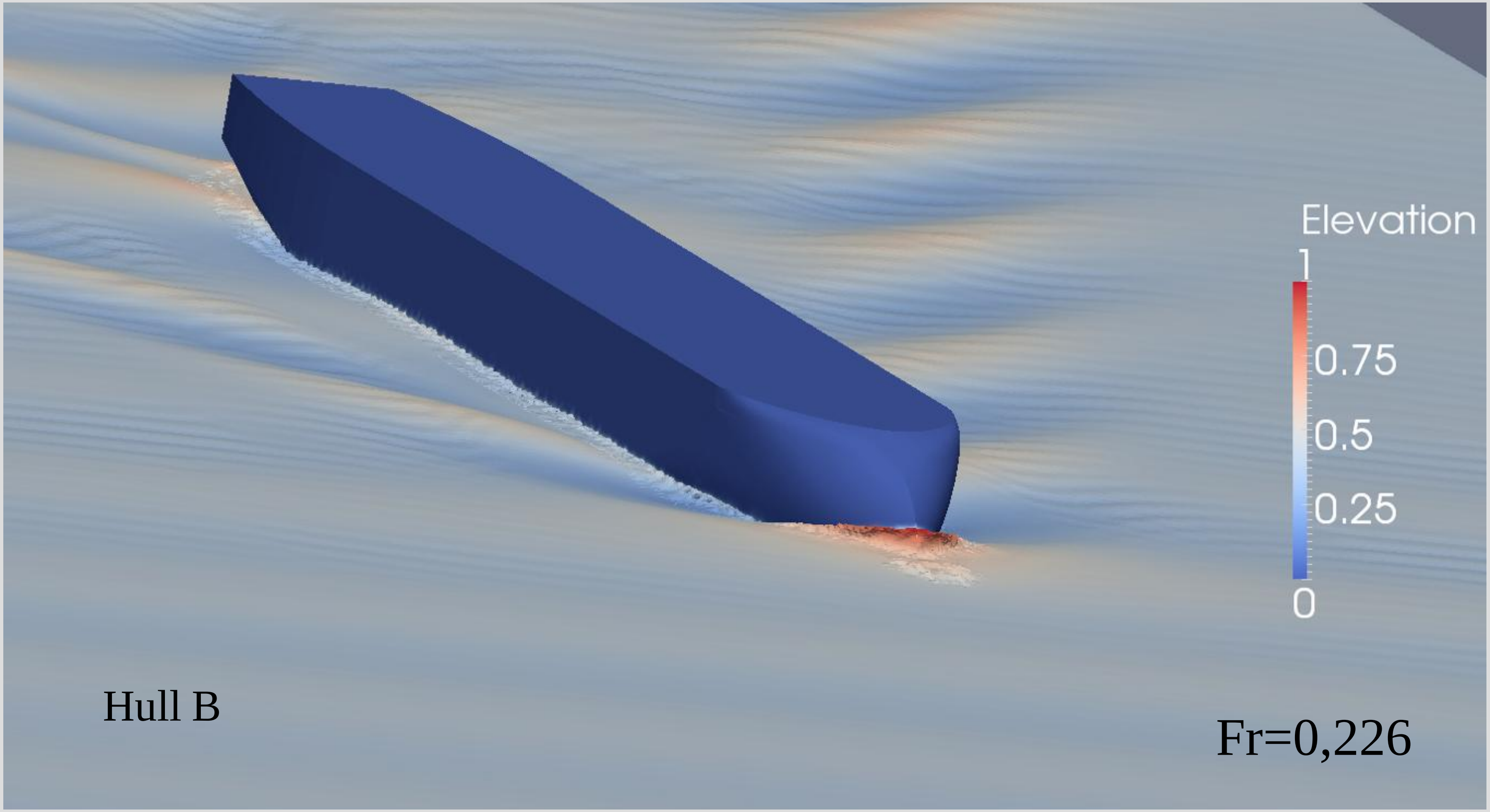
B – lightweight hull;

C – ice-class lightweight hull.

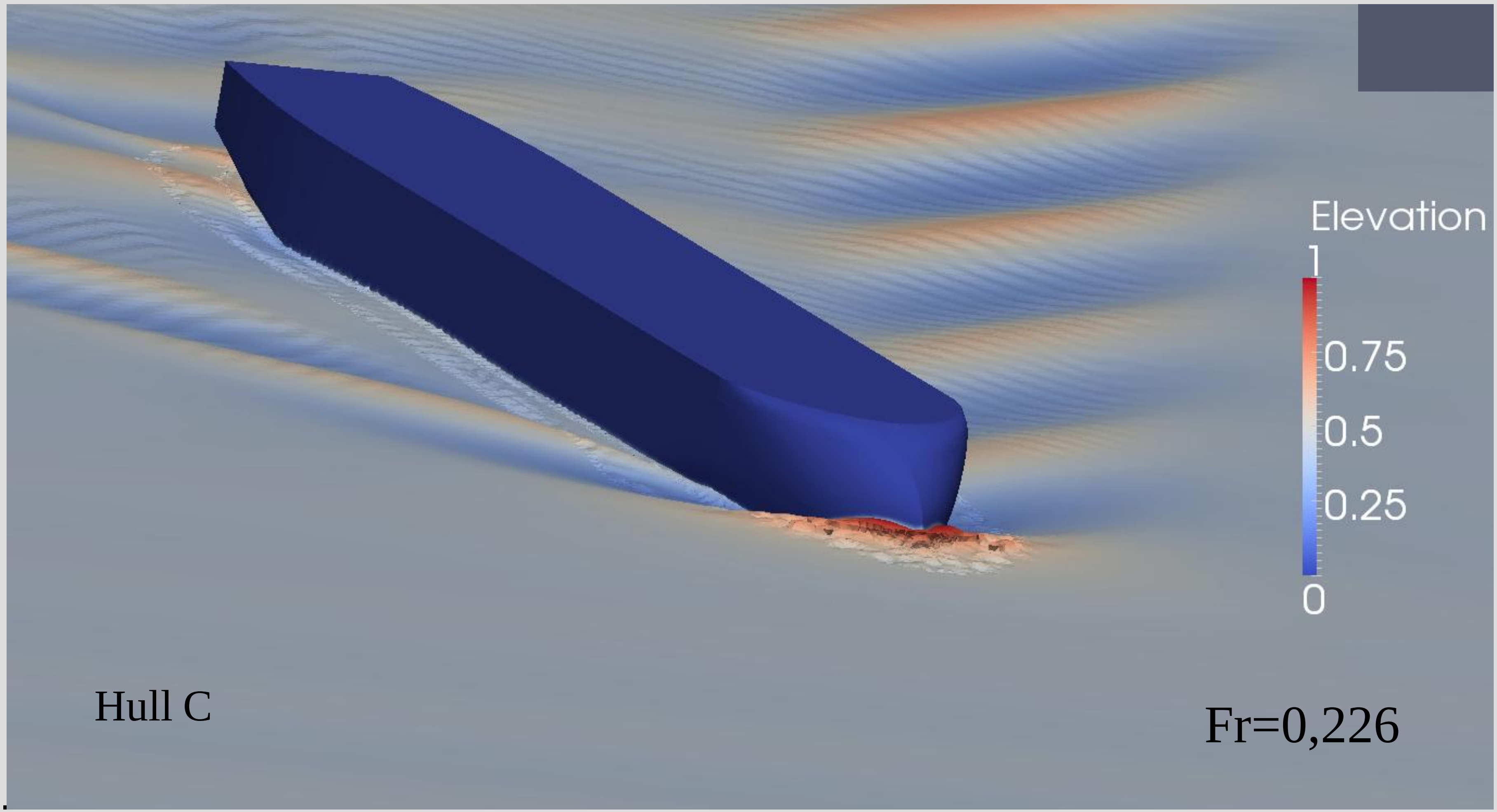
Optimization of a bow of LNG tanker



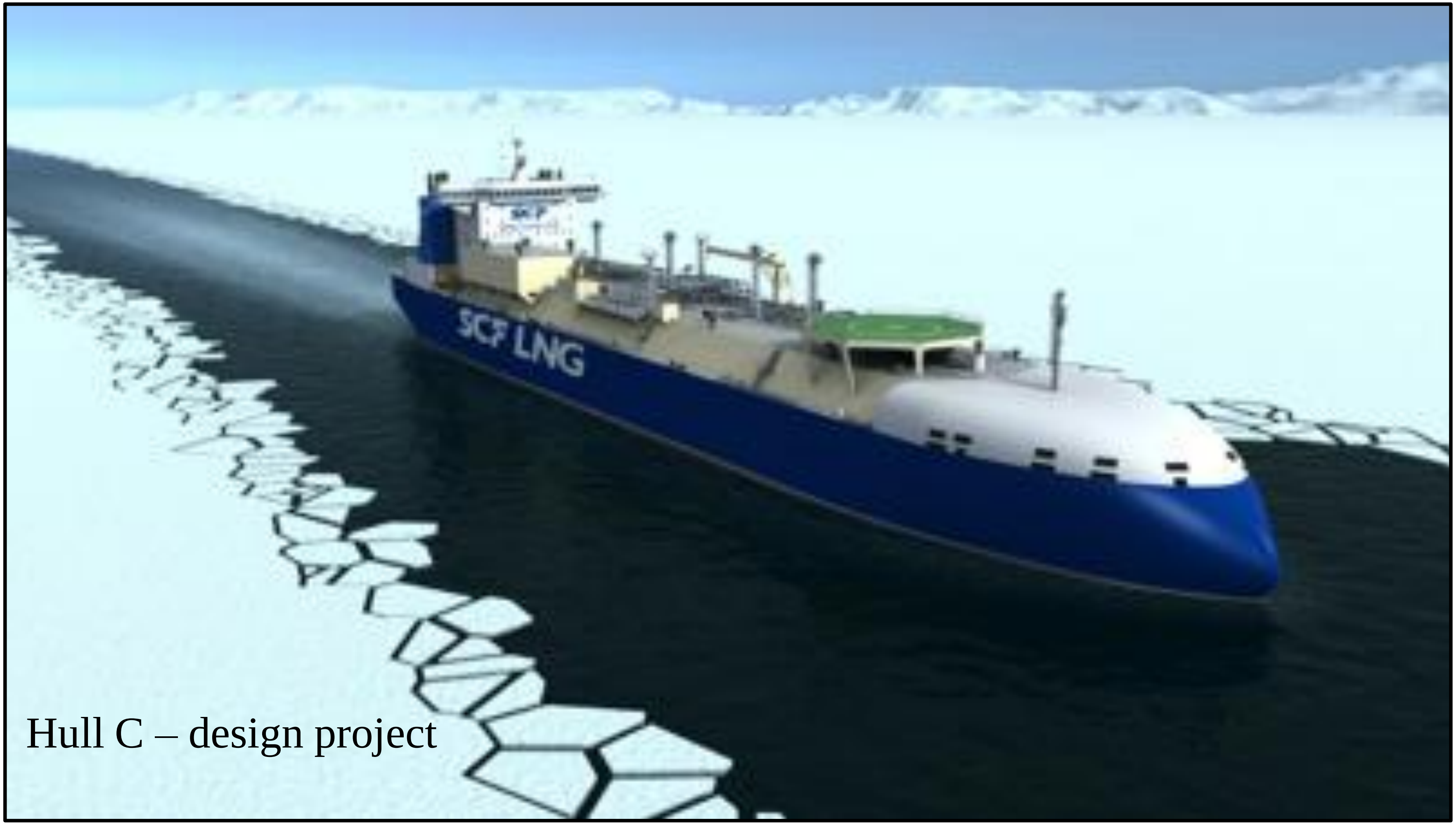
Optimization of a bow of LNG tanker



Optimization of a bow of LNG tanker



Optimization of a bow of LNG tanker

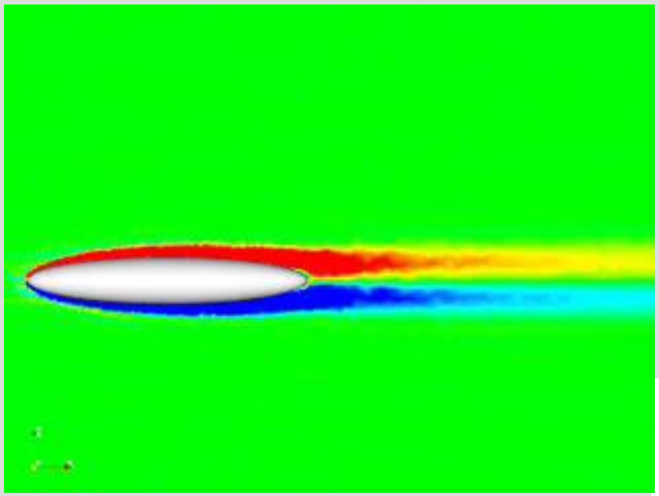


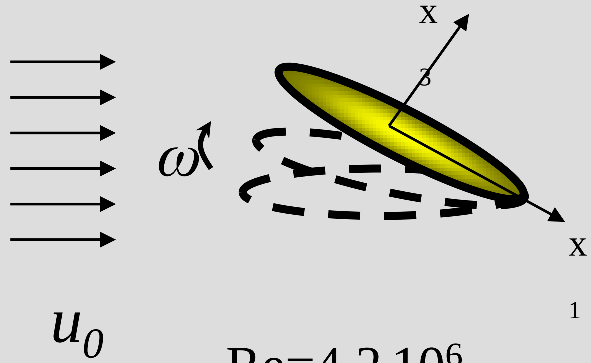
Hull C – design project

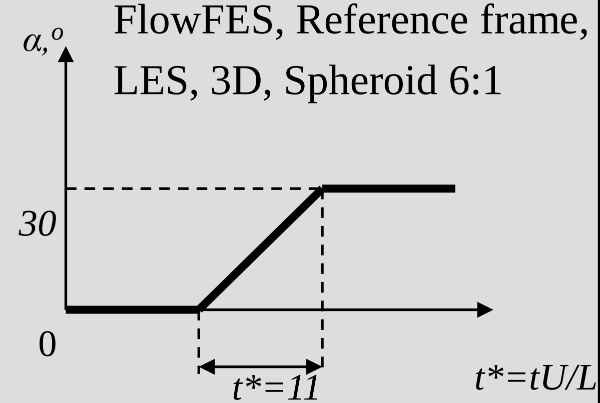
Simulation of the dynamics of marine vehicles

Pitch up maneuver of the spheroid

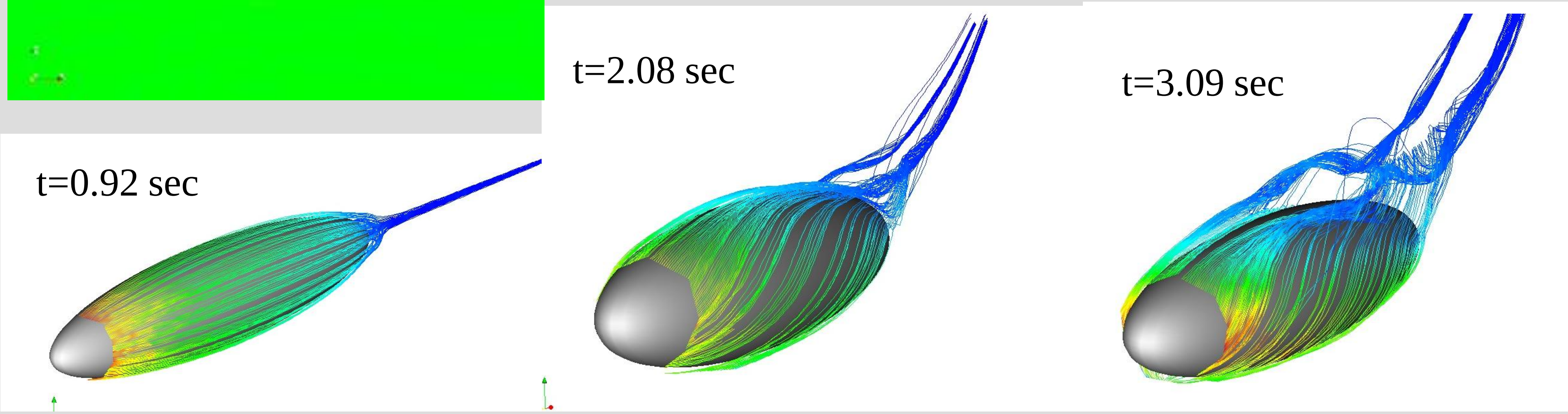
Vorticity







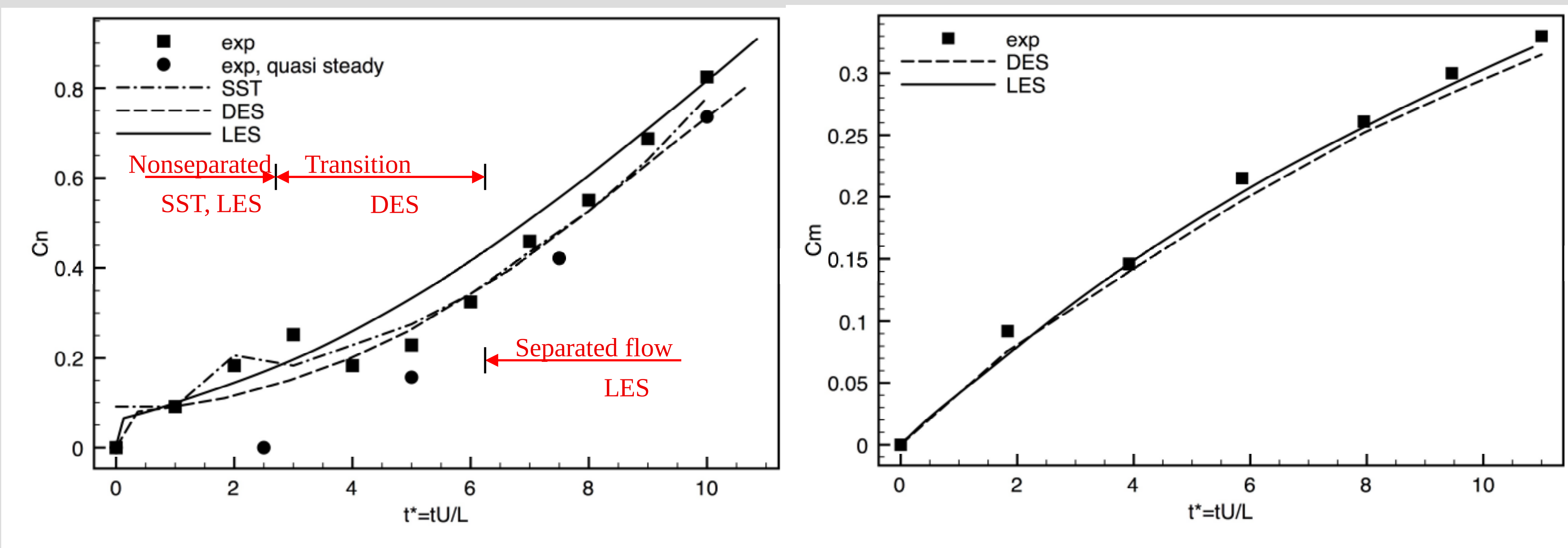
FlowFES, Reference frame, LES, 3D, Spheroid 6:1



Tracers

Pitch up maneuver of the spheroid

$a(t) = 0$ ¸ 30^{0} LES, Smagorinsky

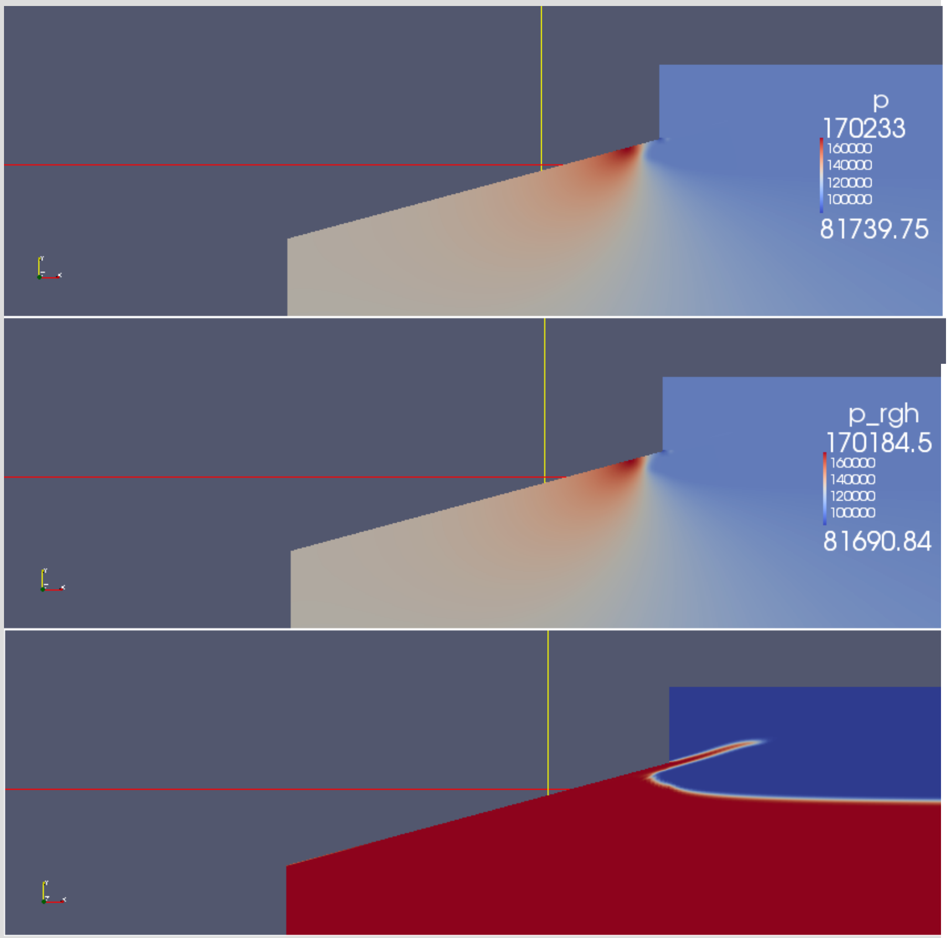


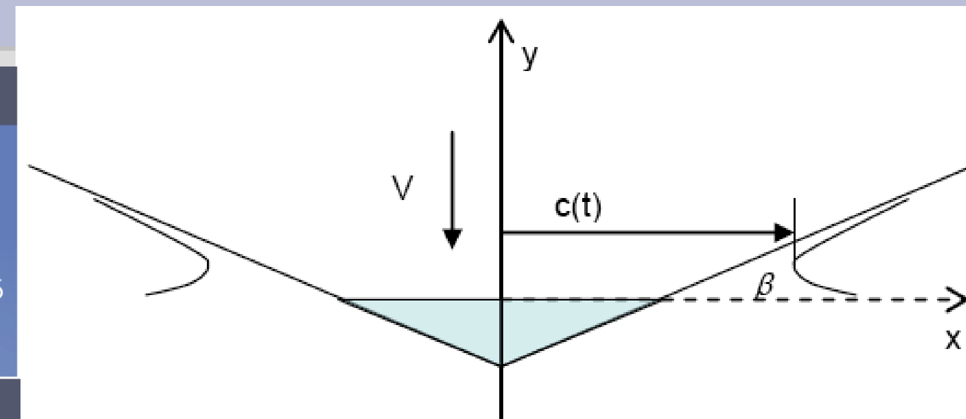
Evolution of the coefficients of normal force Cn and pitch-up moment Cm.

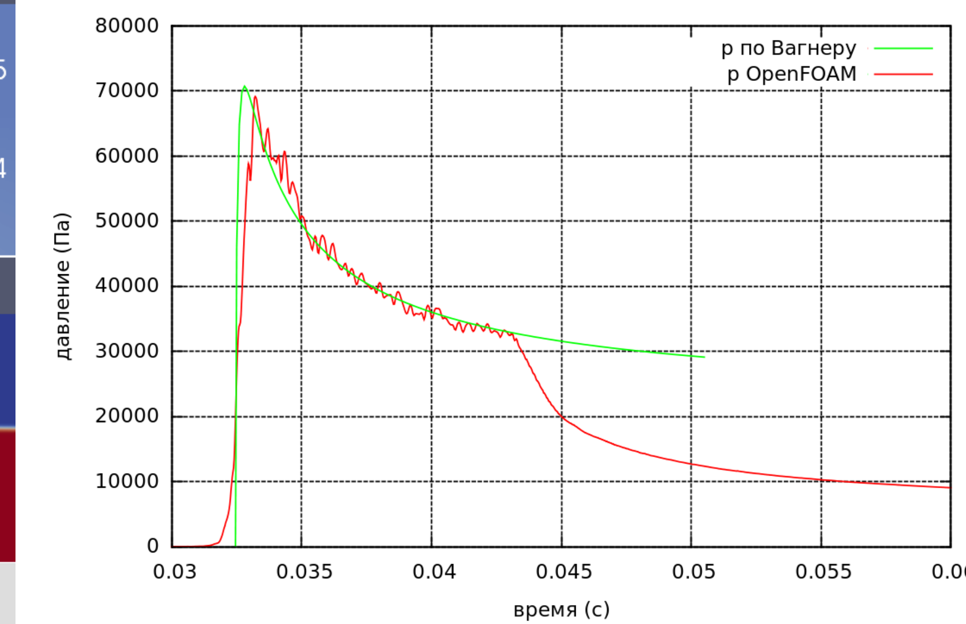
Exp - Wetzel, 1997, SST - Kim et al., 2003, DES - Kotatpati-Apparao et al., 2003

Impact the wedge into compressible liquid (slamming)

OpenFOAM, URANS, VoF, 2D

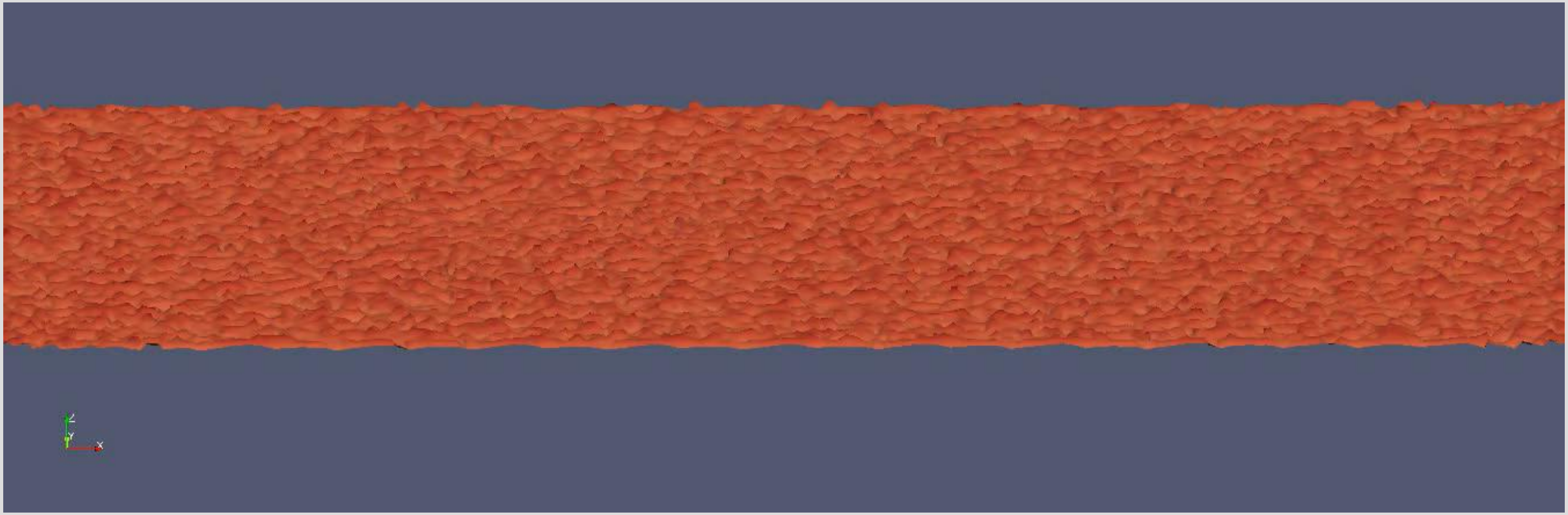






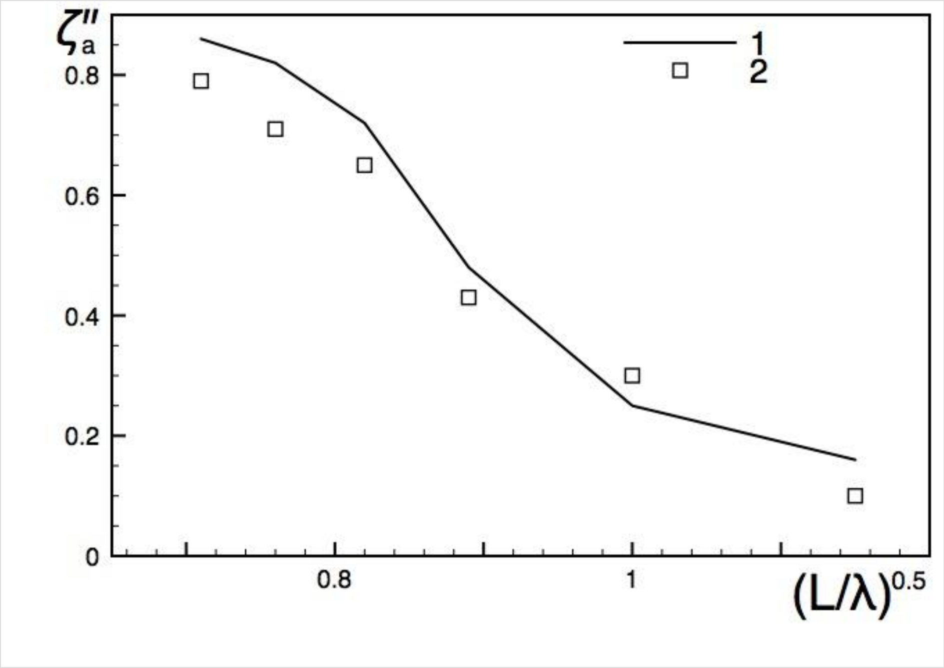
Emersion of body

- 1DOF (pontoon, vertical motion, MRF), Fr=0.6, Re=$2 \cdot 10^7$.

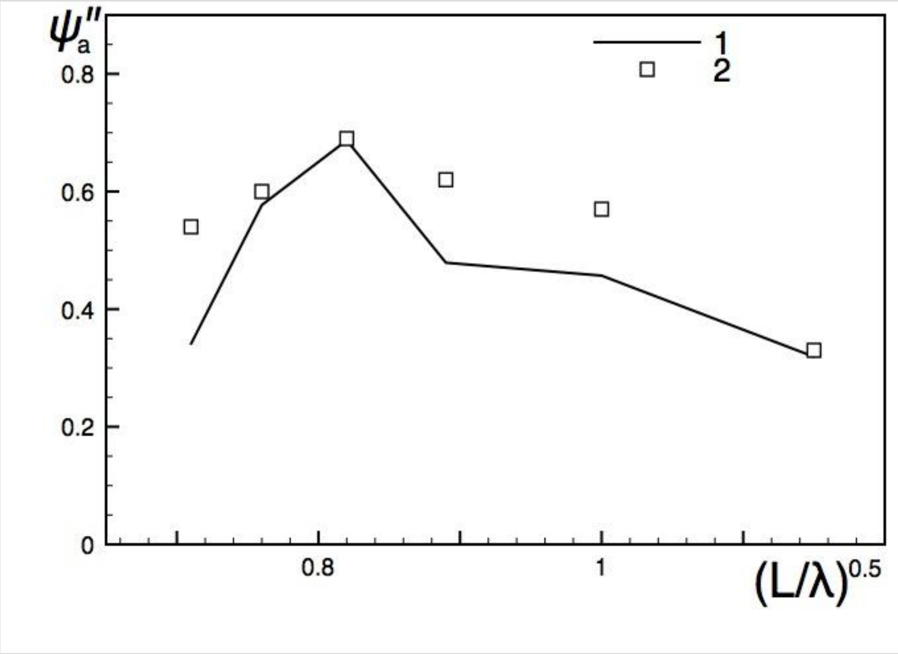


Heave and pitch motions of Wigley body on regular waves: response amplitude operator (RAO)

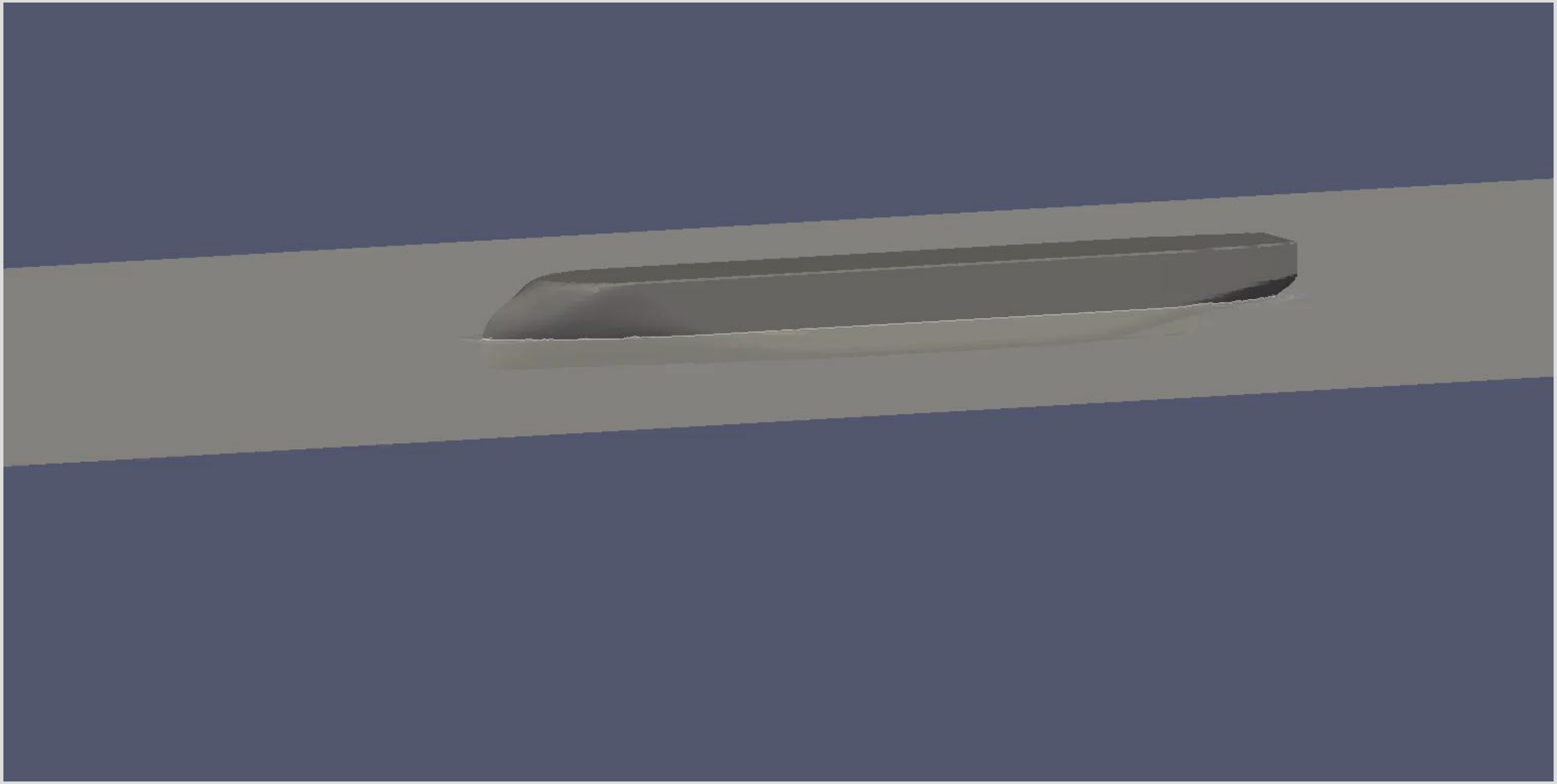
ROA of heave motion



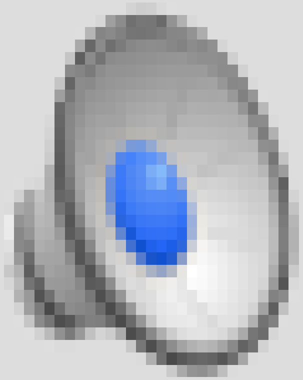
ROA of heave motion



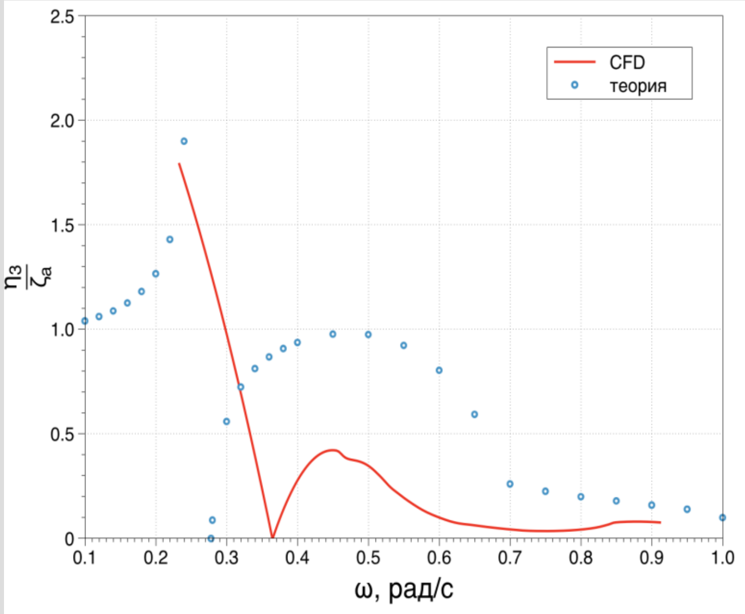
Heave and pitch motions of gas-tanker on regular waves



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

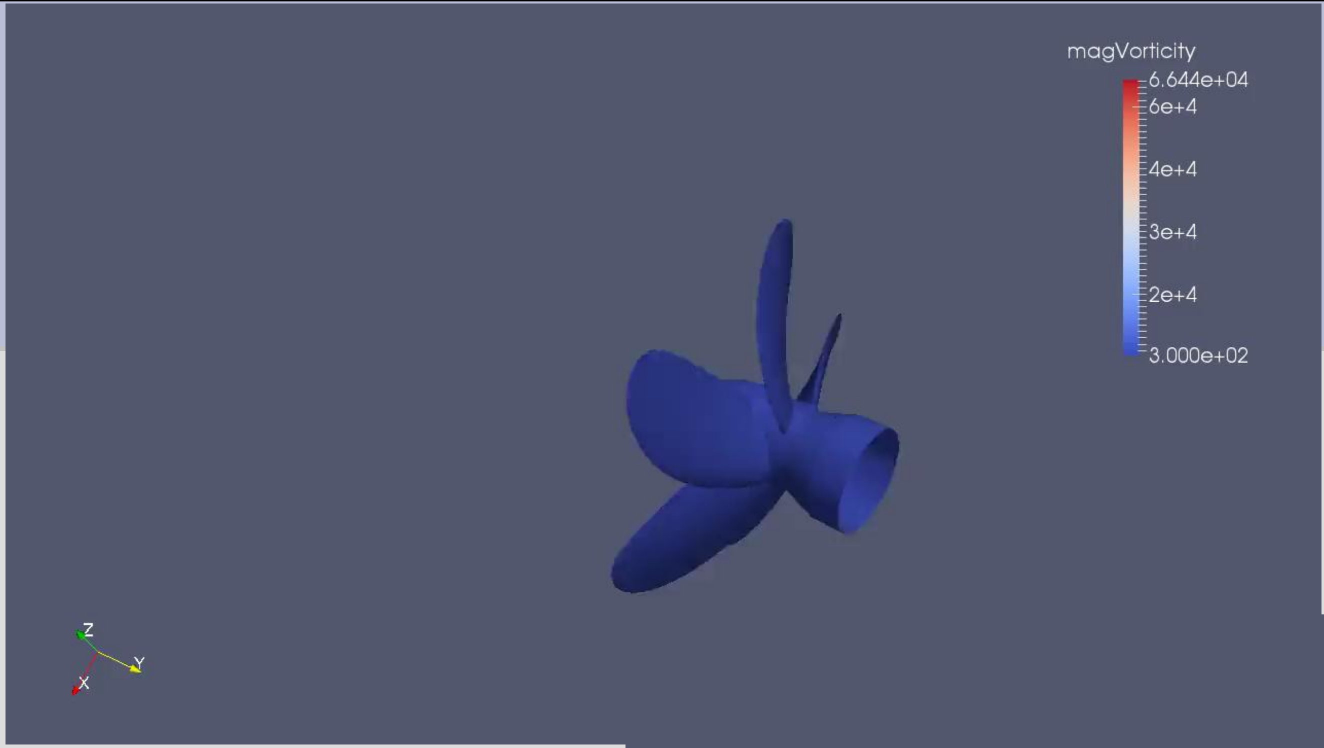


ROA of heave motion



Simulation of the flow past ship propellers

Ship propeller in uniform flow

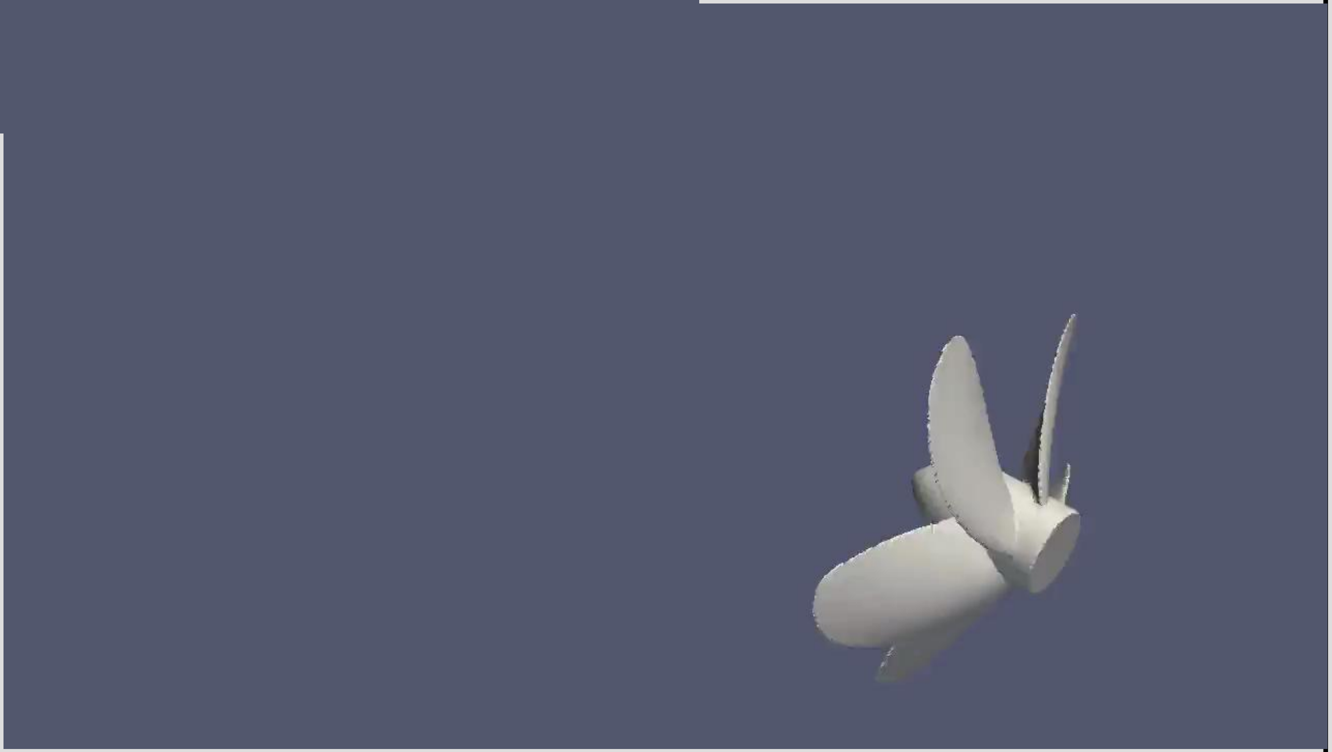


Propeller Series B:

Blades - 5,

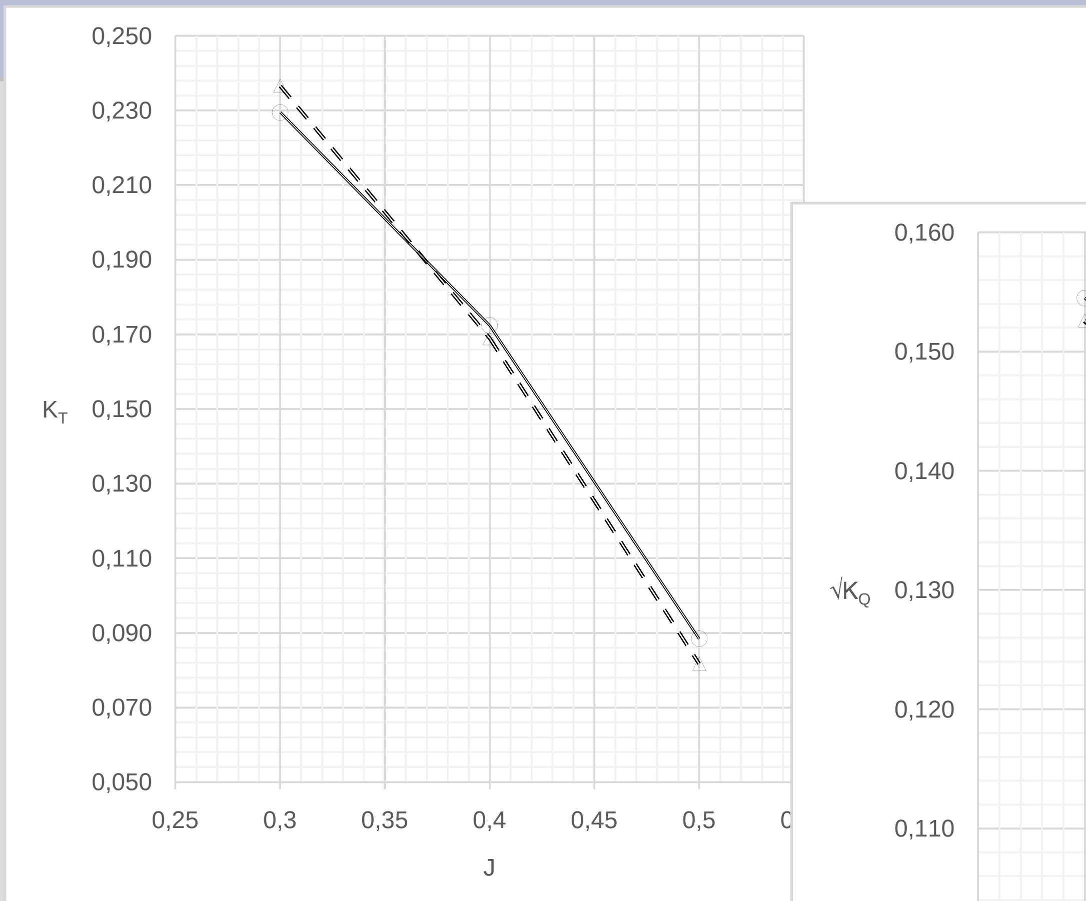
Expanded BAR - 0.6,

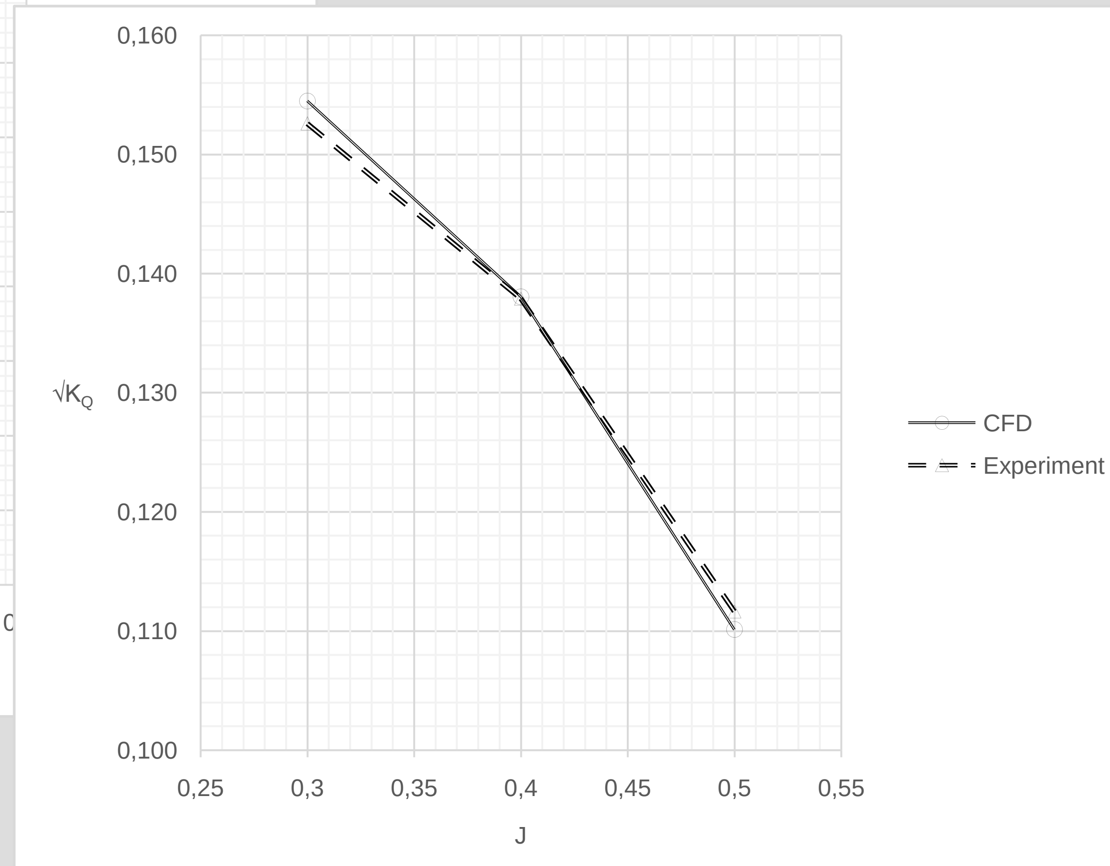
Nominal pitch - 0.6



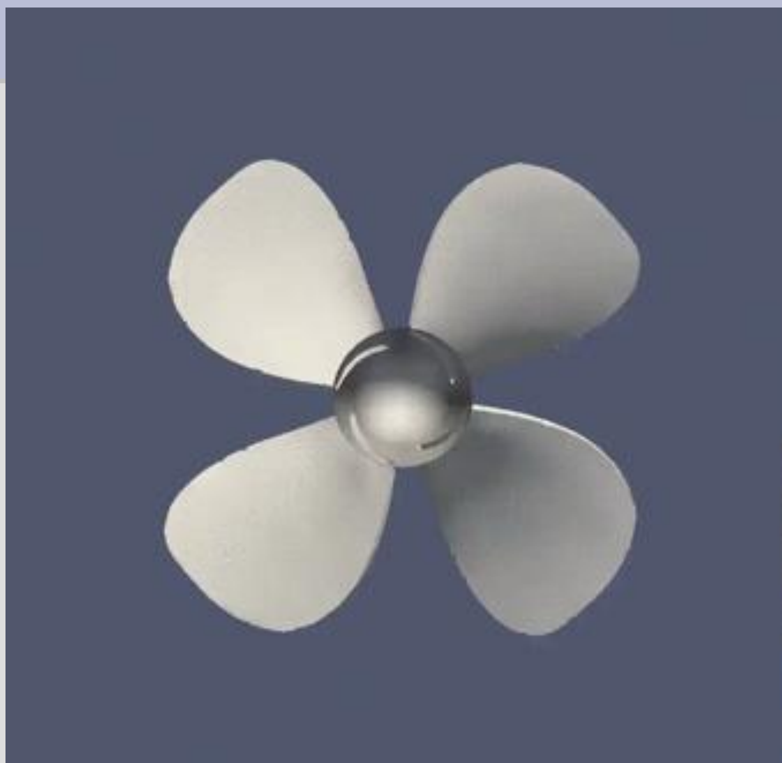
Ship propeller in uniform flow

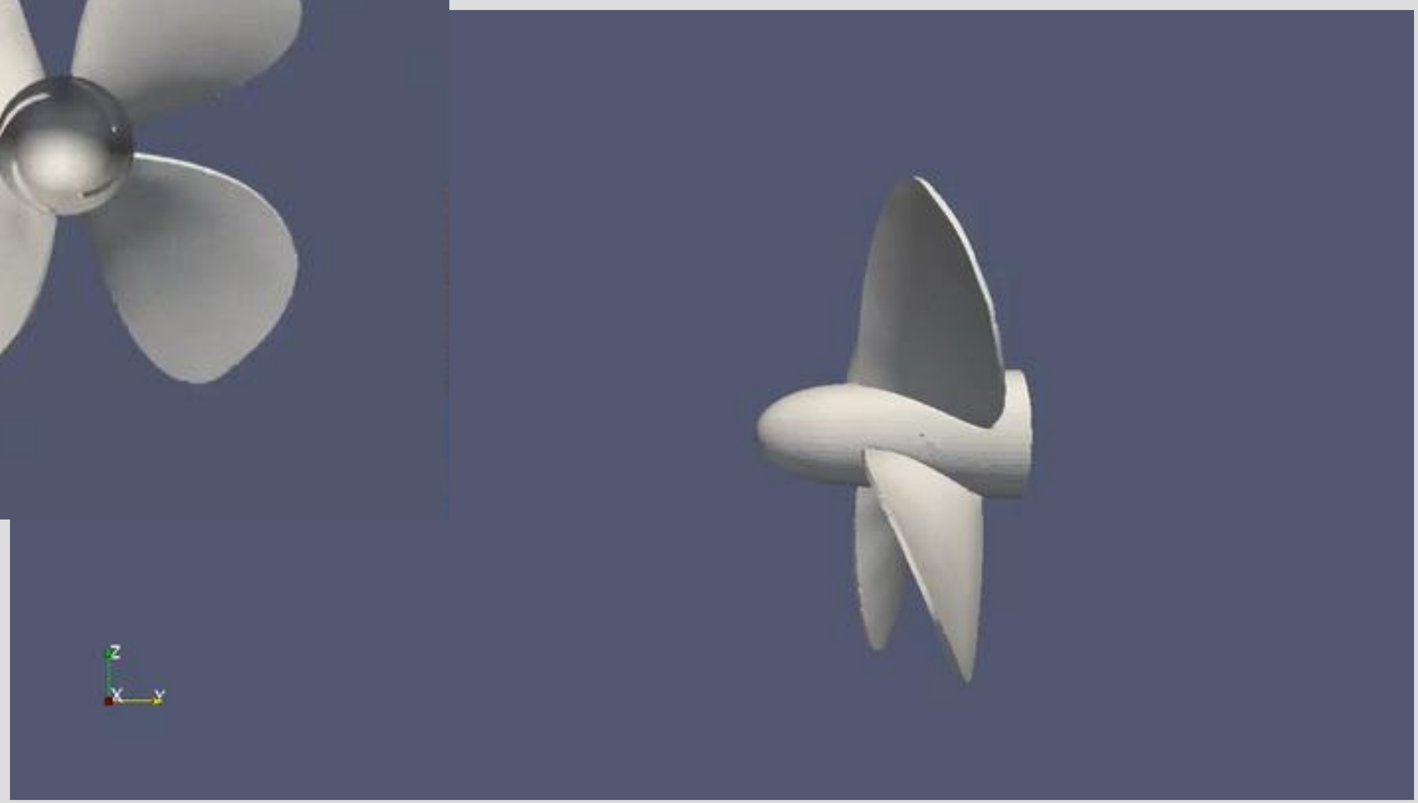
Thrust and torque coefficients





Cavitation on ship propeller

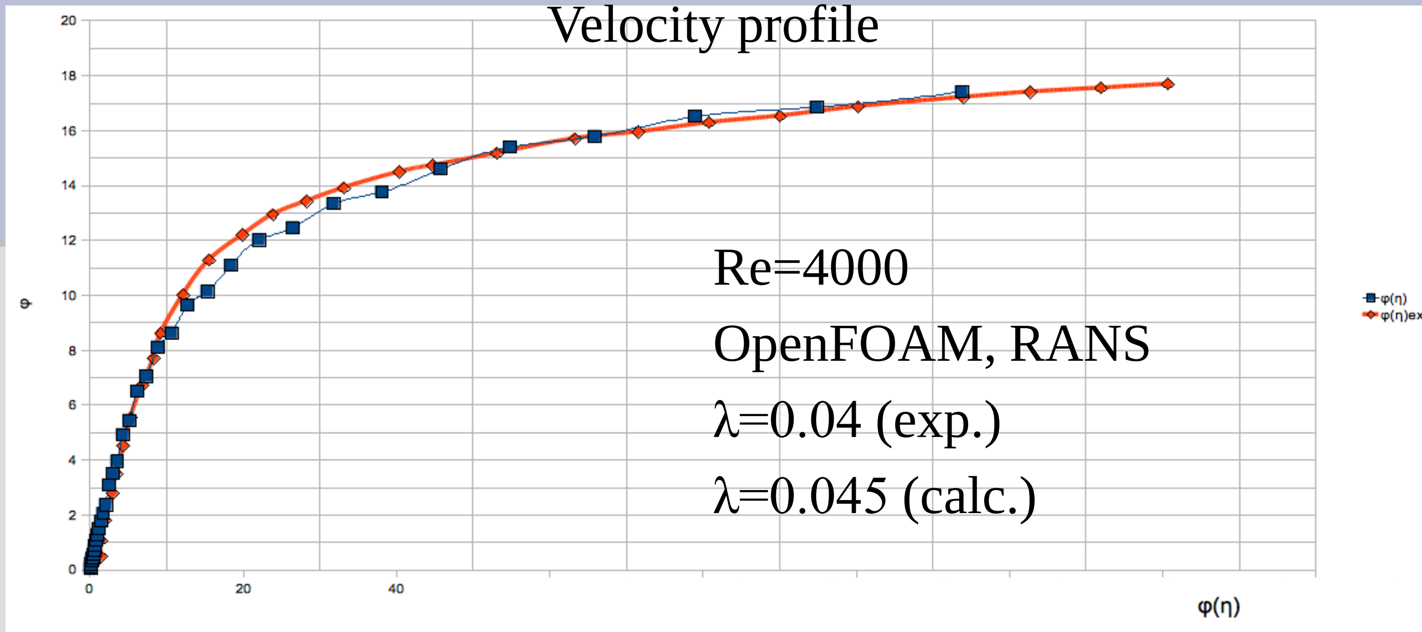




Simulation of the internal flows

The pipe flow

Velocity profile

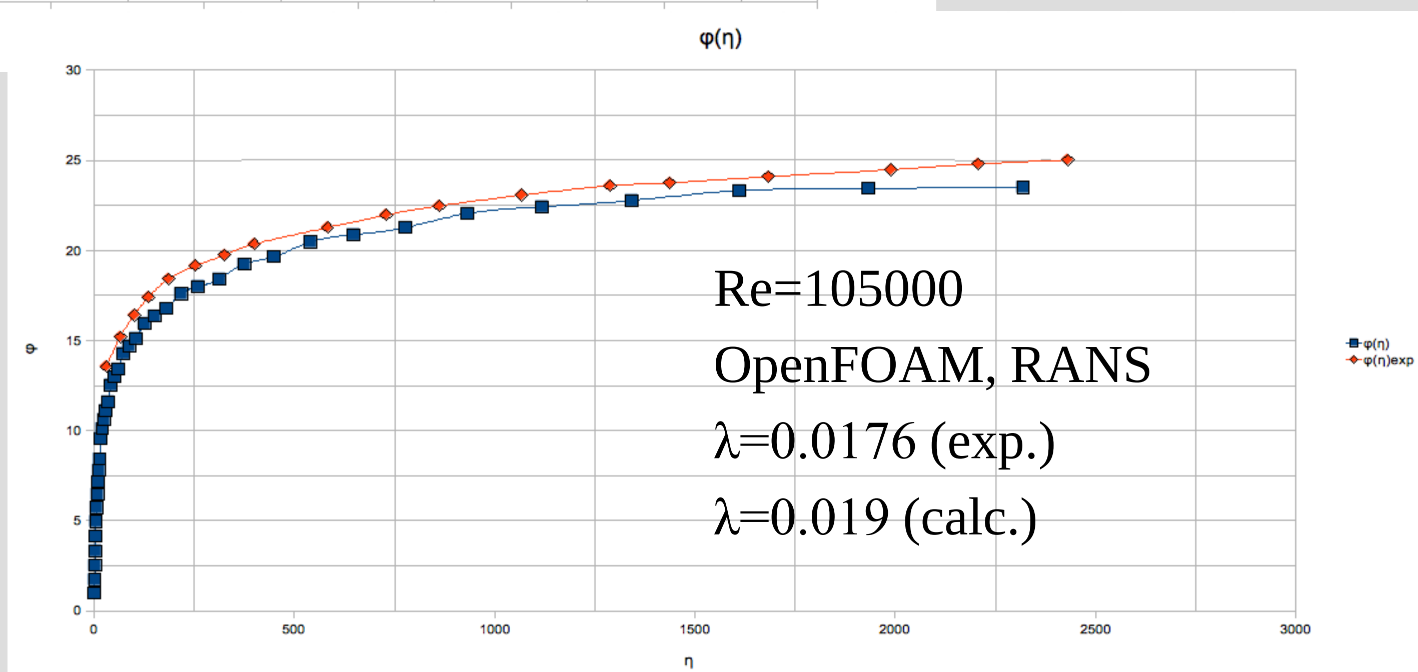


Re=4000

OpenFOAM, RANS

λ=0.04 (exp.)

λ=0.045 (calc.)



Re=105000

OpenFOAM, RANS

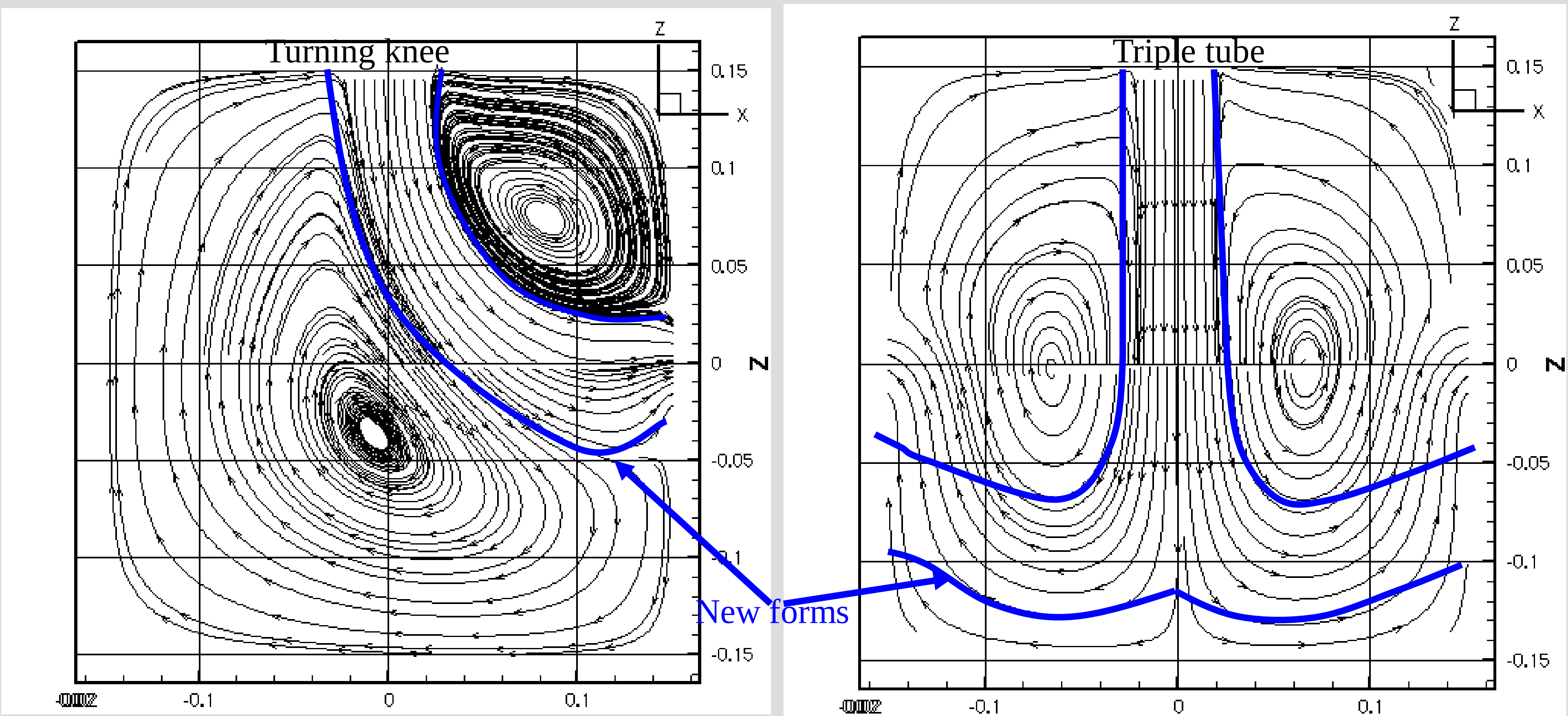
λ=0.0176 (exp.)

λ=0.019 (calc.)

Flows in profiled elements of ship pipe systems

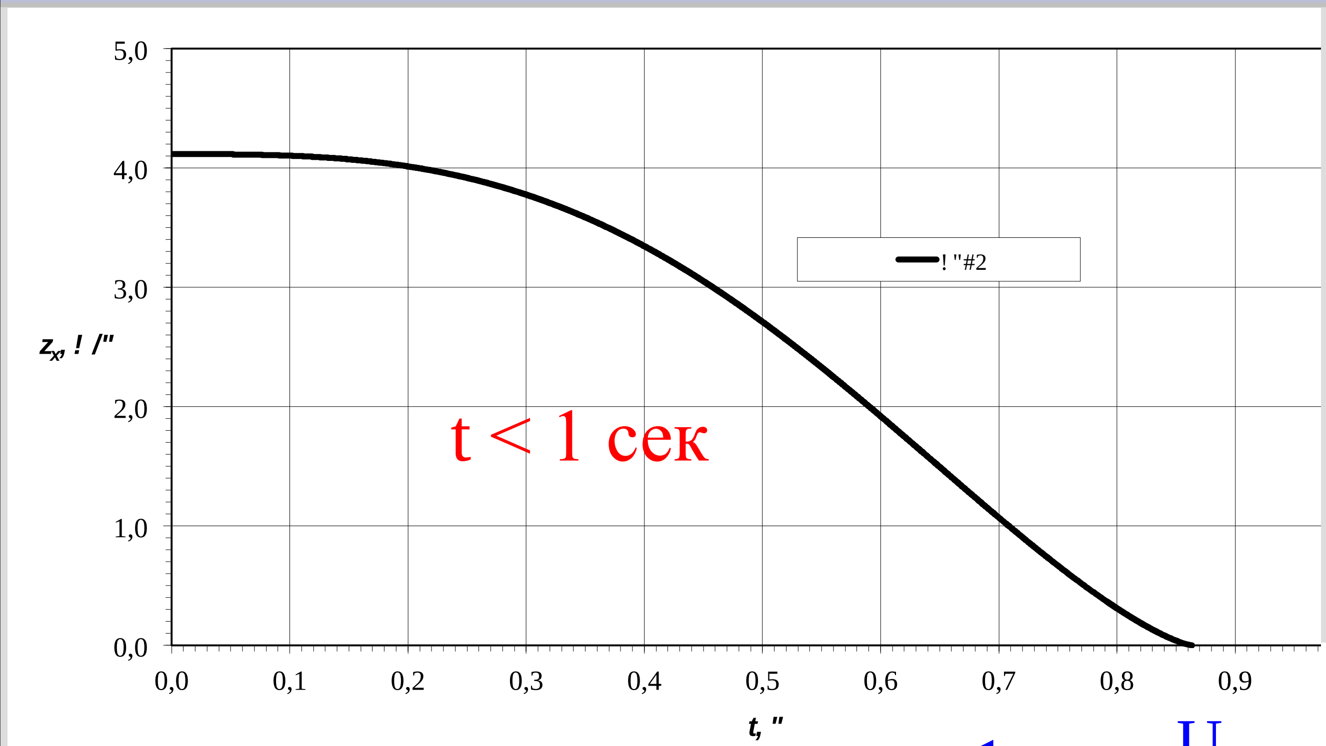
Turning knee and triple flows

FlowFES, LES, 3D

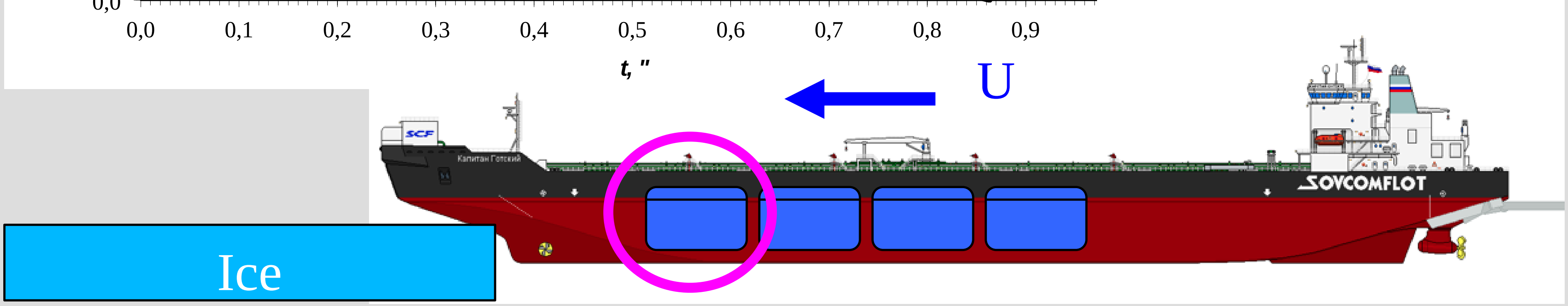


Choosing of the optimal configuration of the pipe corners

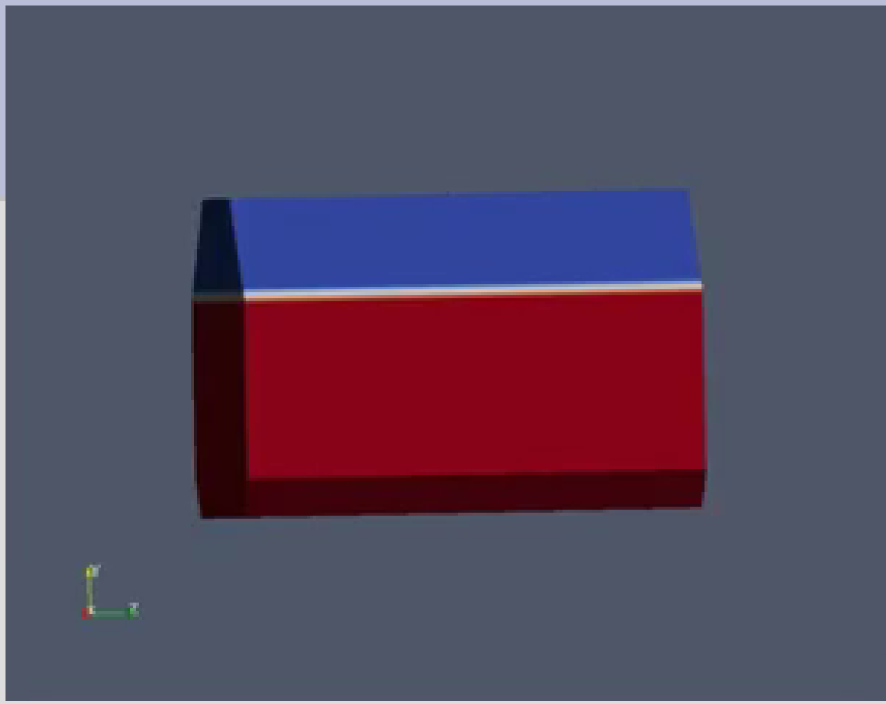
The sloshing in tank after impact interaction of the ship with ice



Speed of the ship after impact with ice

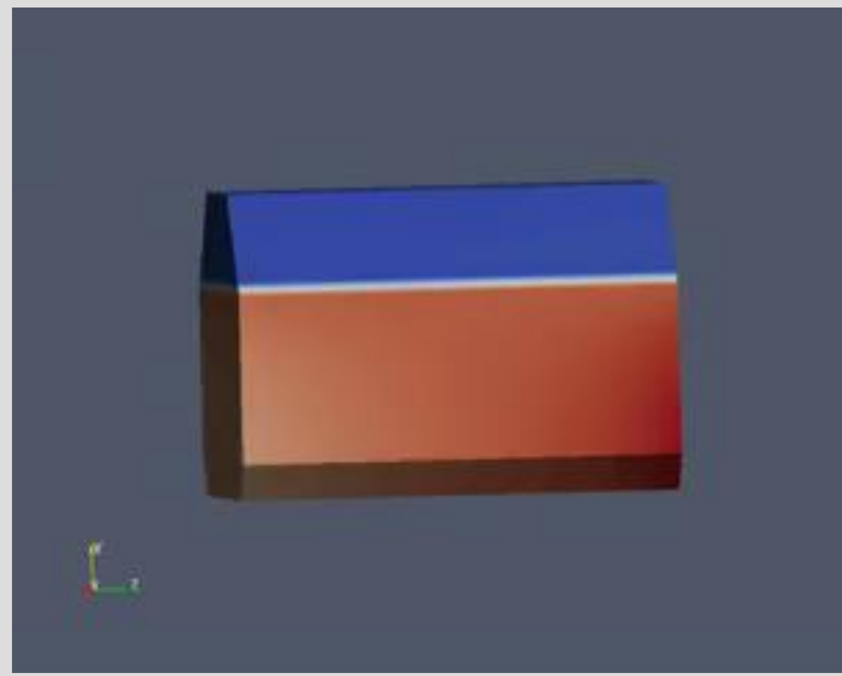


The sloshing



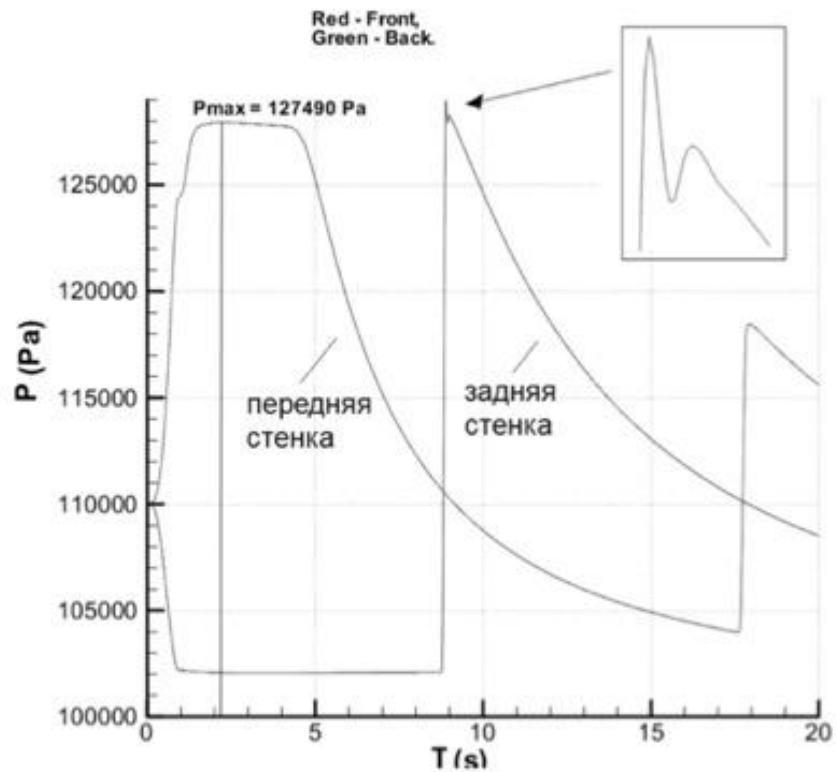
Evolution of the pressure field in the tank after impact of tanker with ice

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



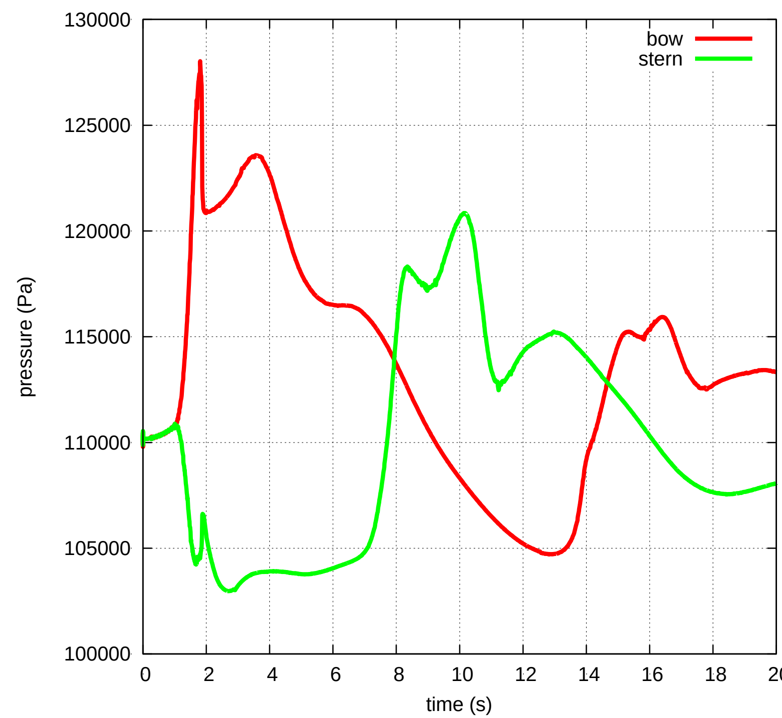
OpenFOAM, URANS,
VoF, 3D

The sloshing



Shallow water equations

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



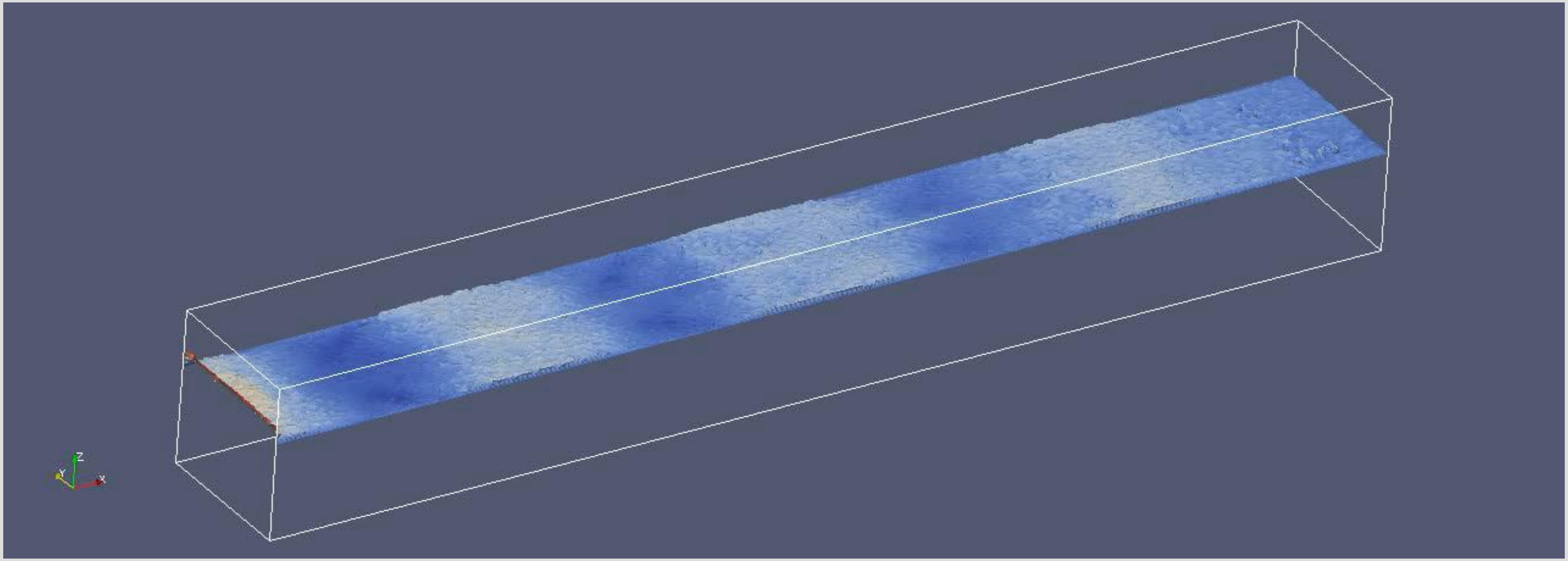
Navier-Stokes equations

Tryaskin N., Tkachenko I. [3]

Simulation of the coastal dynamics

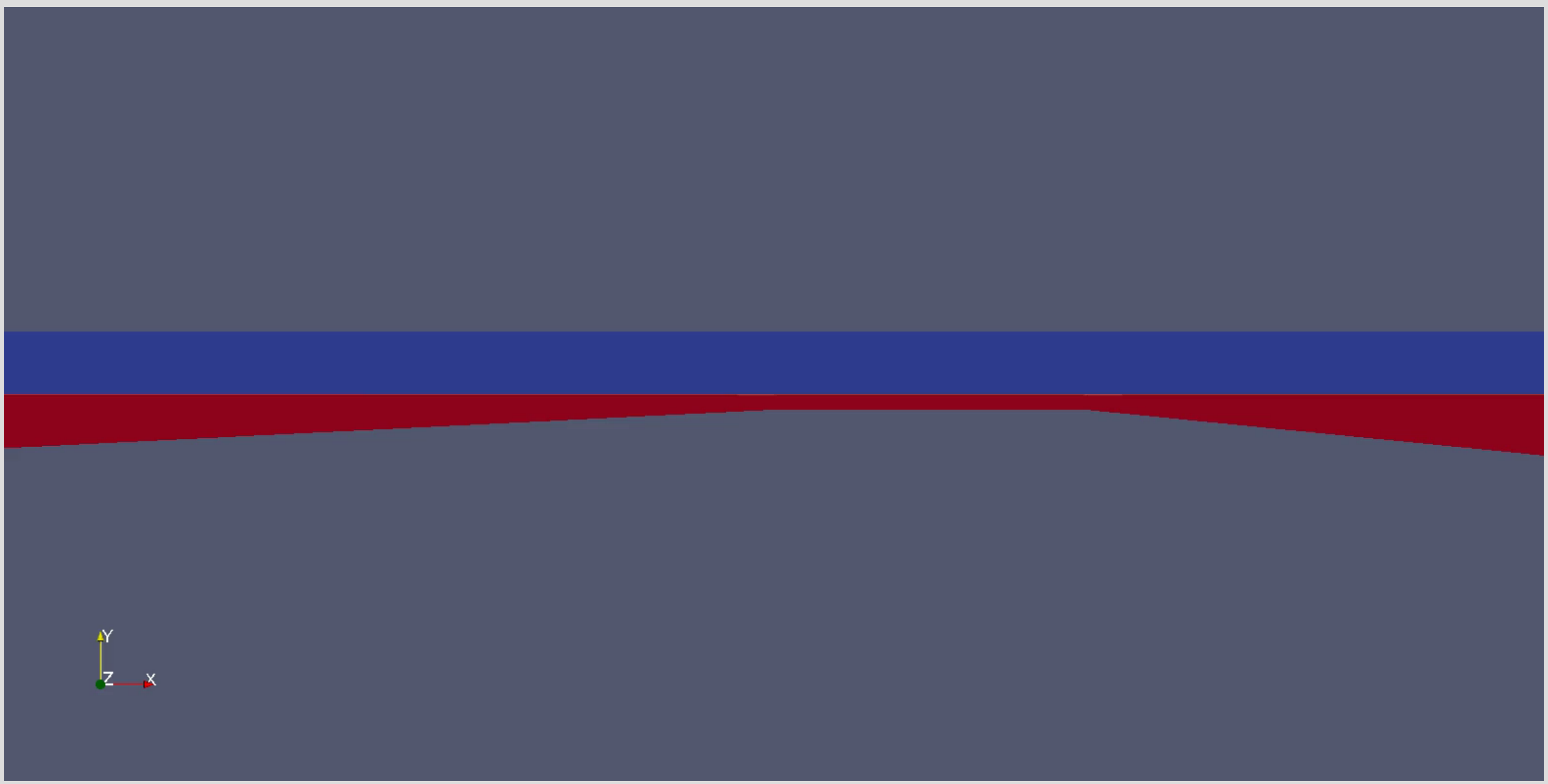
Simulation of regular surface waves

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

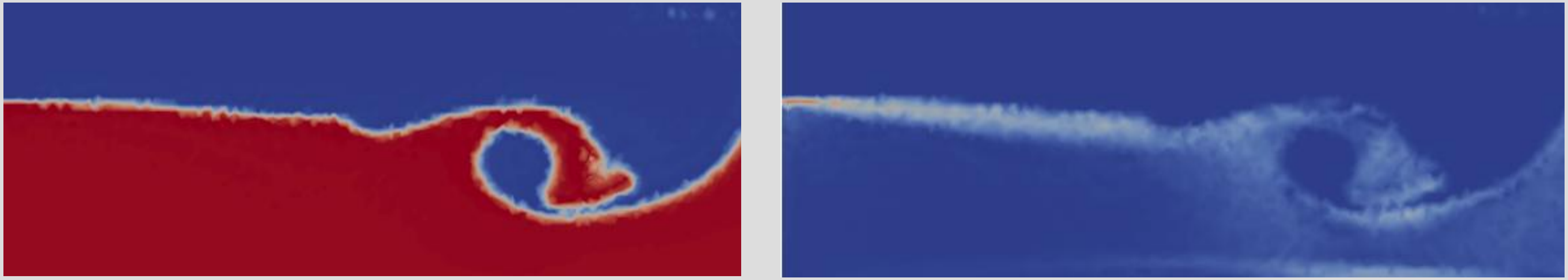


Interaction of regular surface waves with obstacles

- Stokes waves:
  - InterFoam, WaveFoam.



Wind-wave interaction

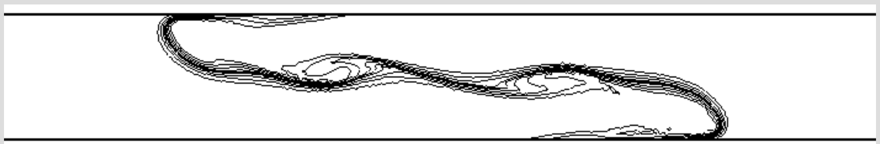


The breaking wave at wind speed 10 м/с: surface elevation (left) and subgrid turbulence energy (right).

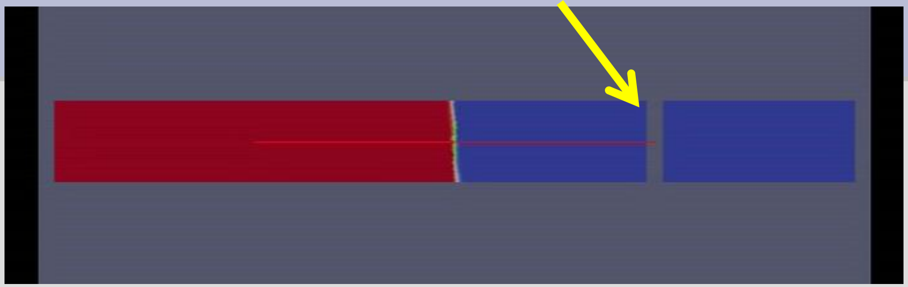
The gravity current flow

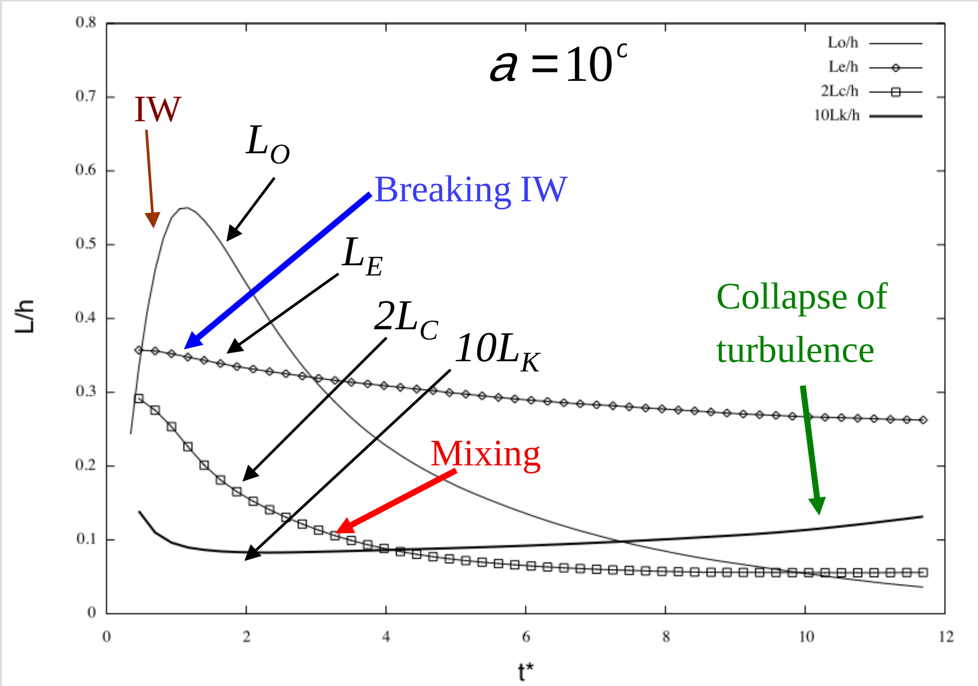
Bearing of the platform

Experiment Lowe et. al., 2005

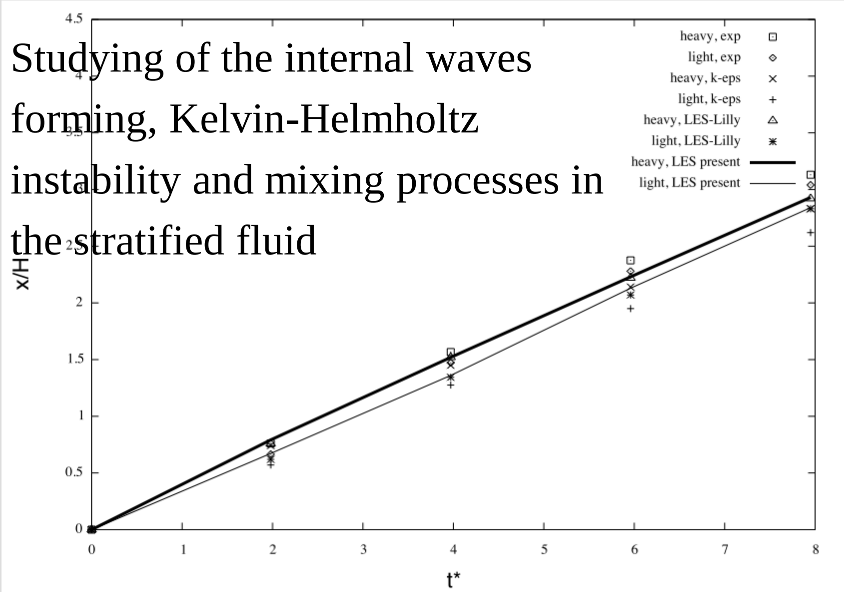


FlowFES, LES, MF, 3D



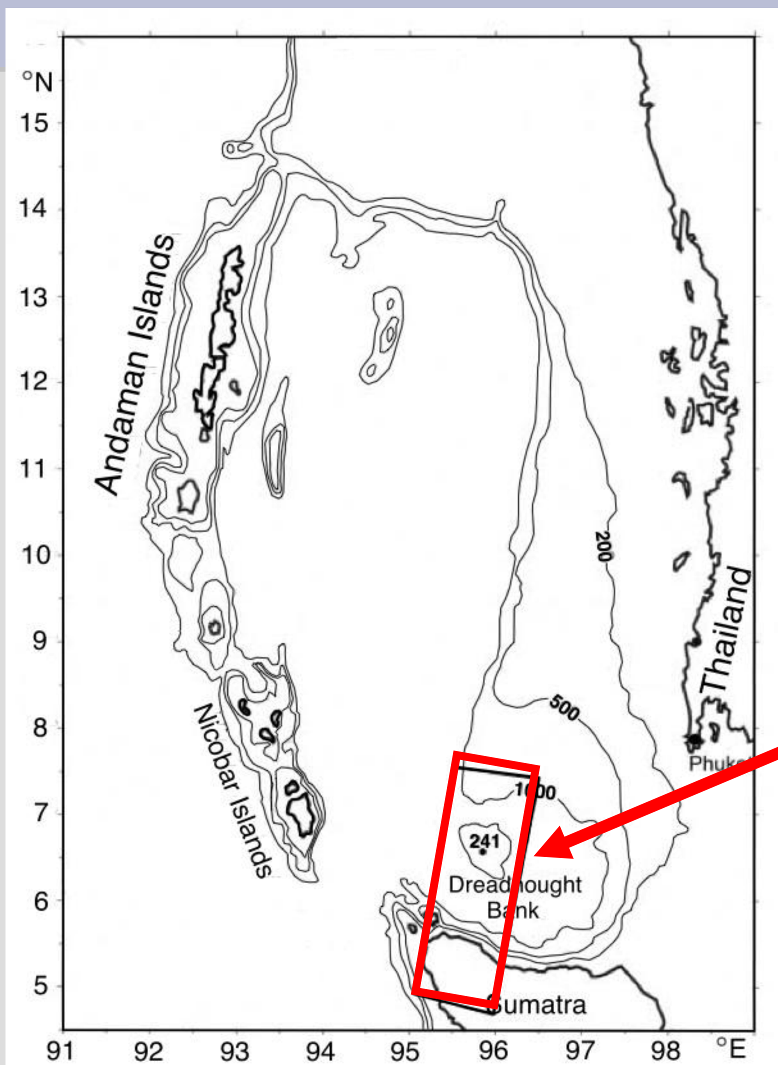


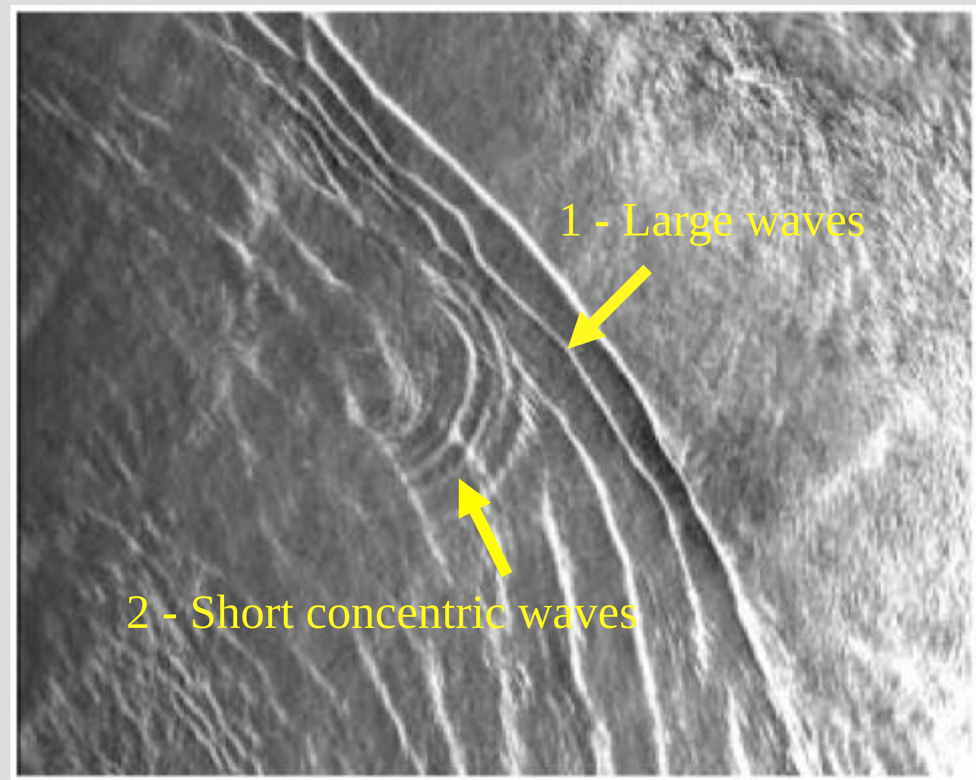
Studying of the internal waves forming, Kelvin-Helmholtz instability and mixing processes in the stratified fluid



Flow parameters: $g = r_1 / r_2 = 0.998$

Internal tidal waves

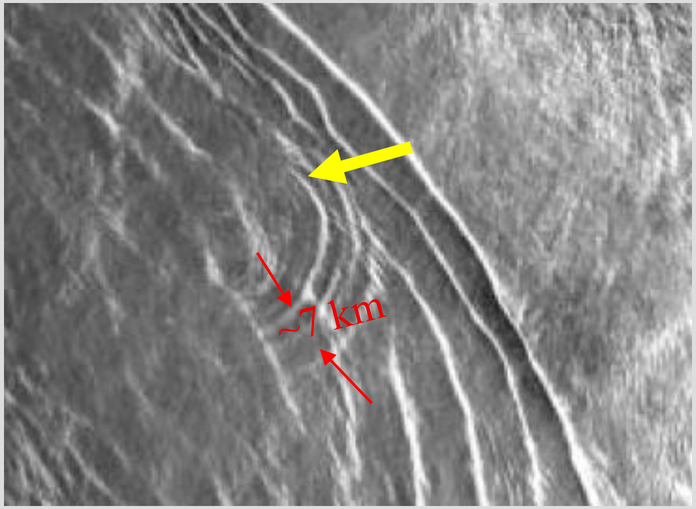




SAR image. 11.02.1997 0360 UTC.
Andaman Sea. Dreadnought Bank

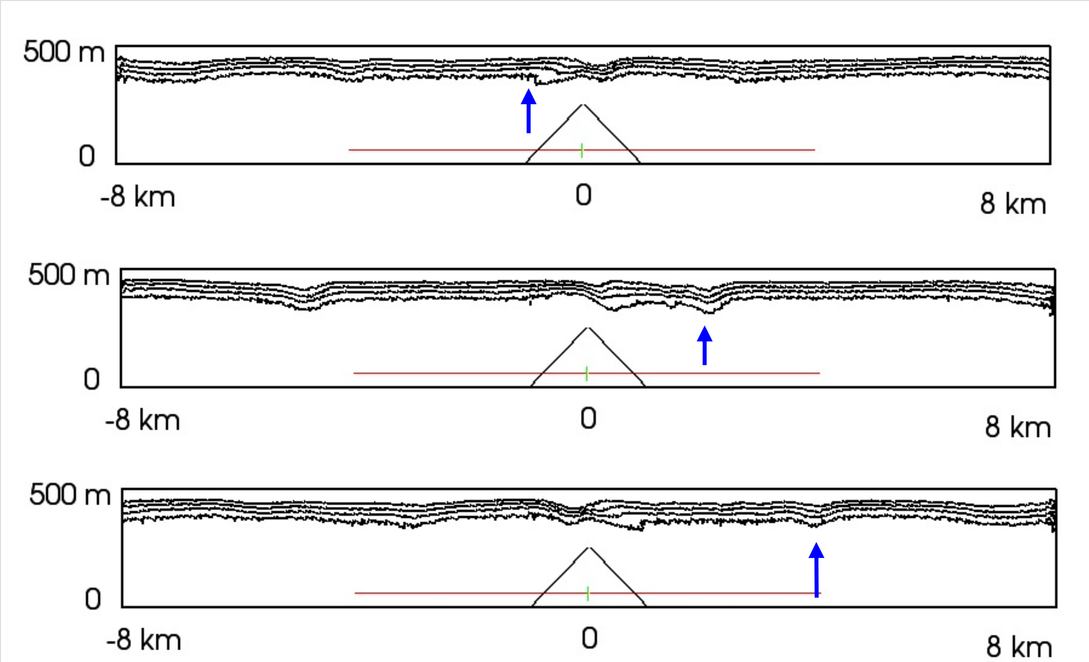
Internal tidal waves

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

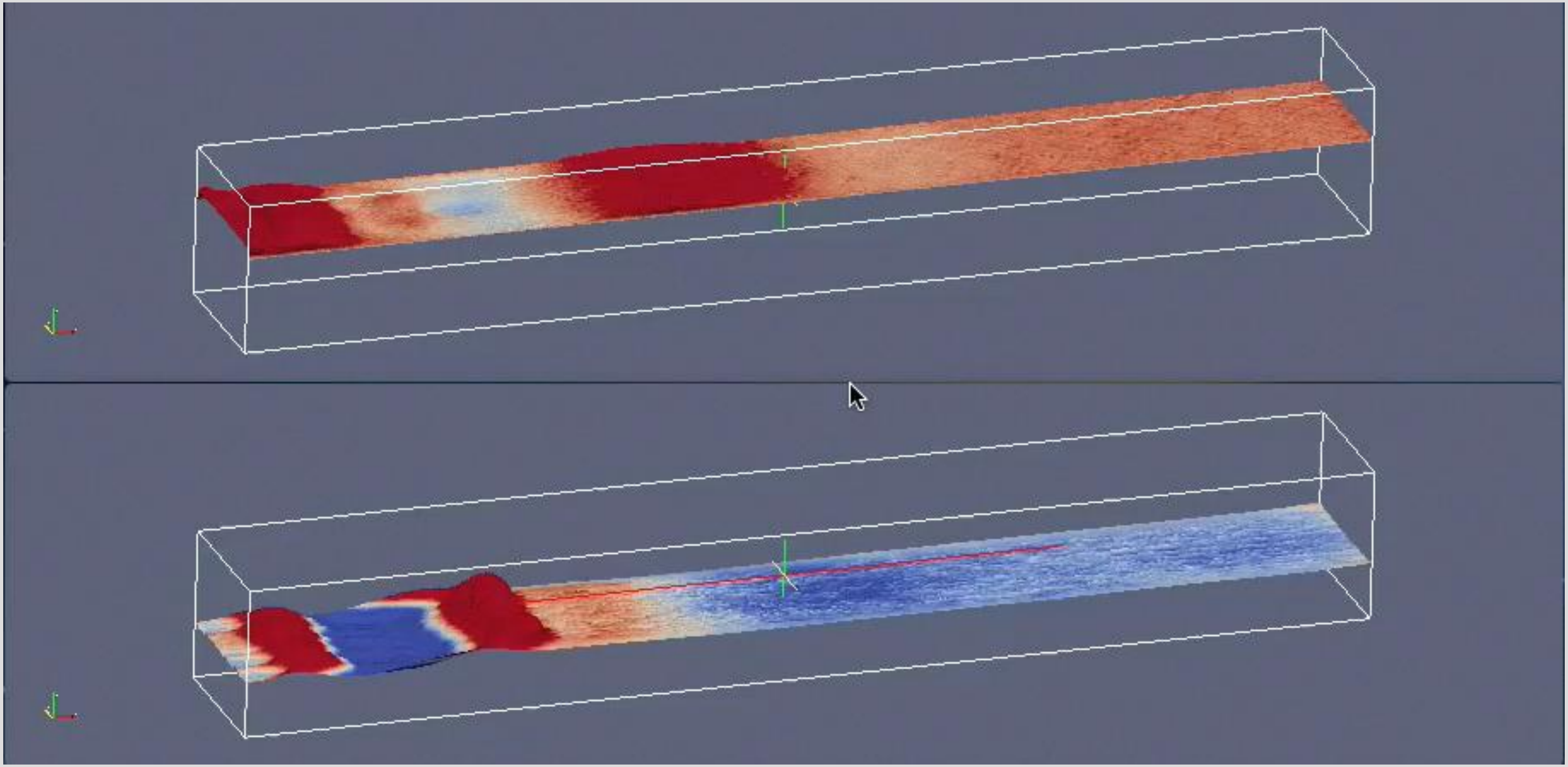


FlowFES, LES, MF, 3D

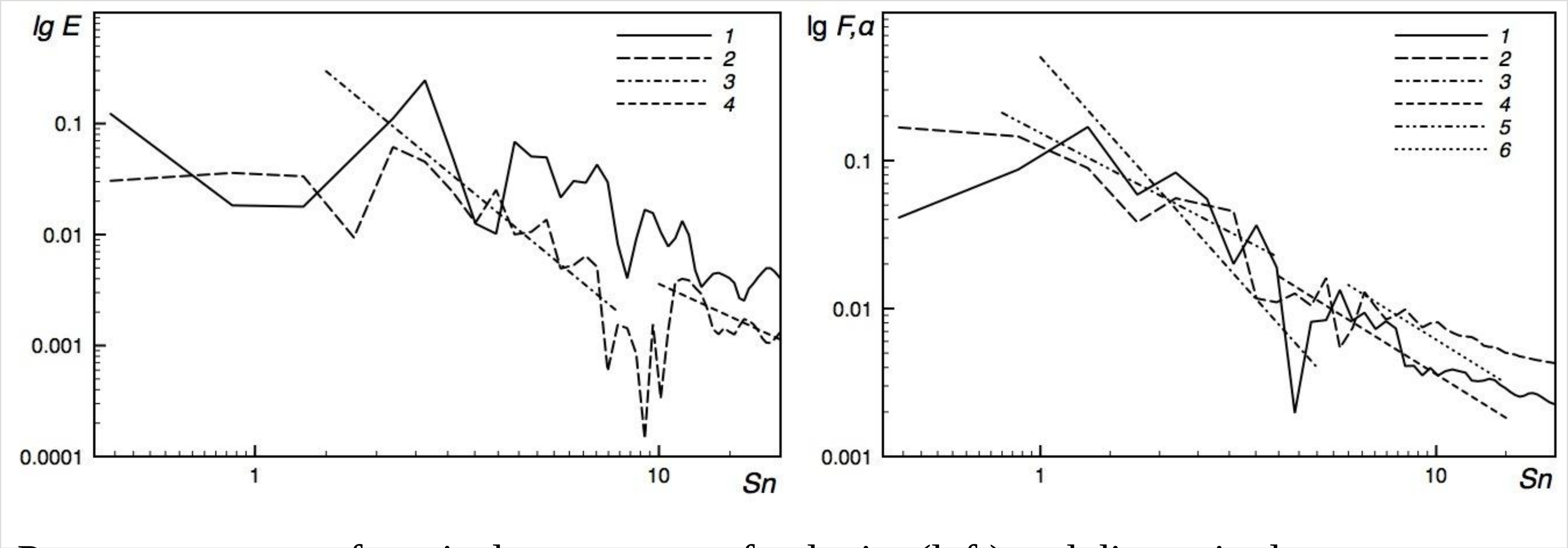
Isopycnals



Interaction of internal and surface waves



Interaction of internal and surface waves

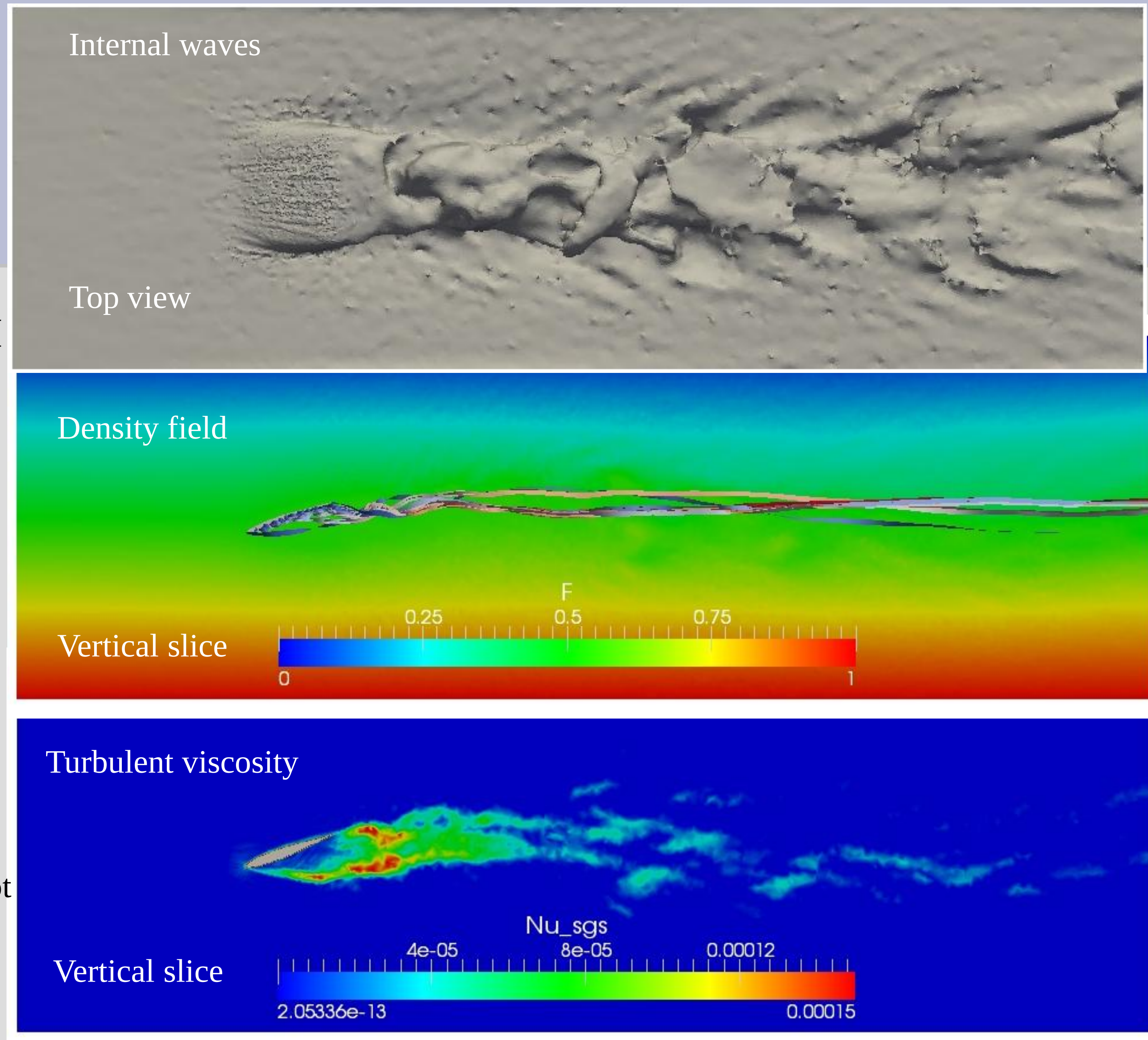


Power spectrums of vertical component of velocity (left) and dimensionless density, volume fraction (right) on free surface and on pycnocline СП и пикноклина: 1 – spectrum of free surface waves (SW), 2 – spectrum of internal waves (IW), 3 - ~Sn^{-3}, 4 - ~$Sn^{-5/3}$, 5 - ~ $Sn^{-7/5}$, 6 - ~$Sn^{-5/3}$.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

Influence of the sea conditions on hydrodynamics of marine objects

Stratified flow past the wing

FlowFES, LES, M F, 3D, Wing : BQM 34, ratio 1.2, linear stratification



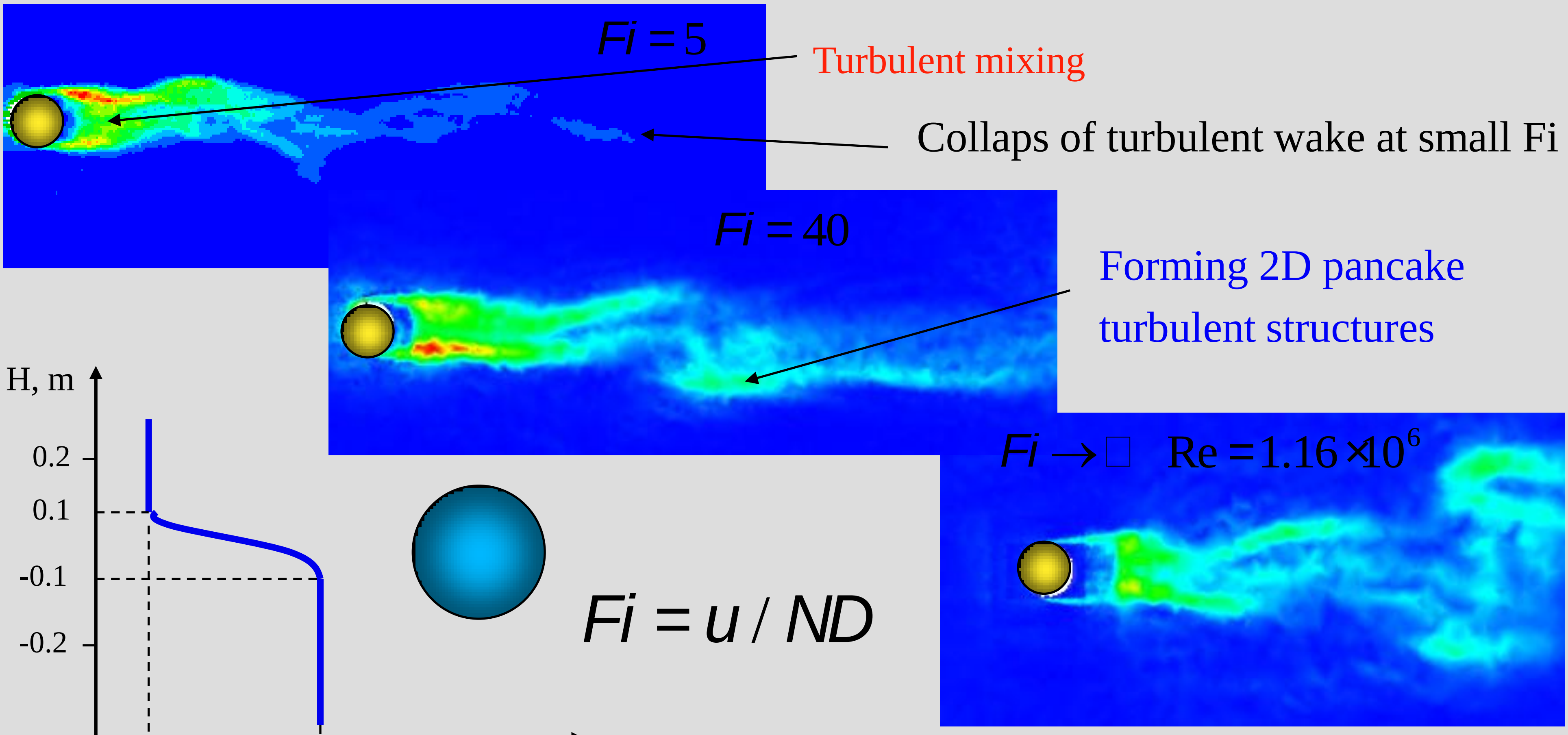
Re=*ub/v*=313000, Fi=u/Nb=1.42

Wingtip vortices do not go up, collapse of the turbulent wake.

Stratified flow past the sphere

The turbulent wake

FlowFES, LES, MF, 3D, shpere

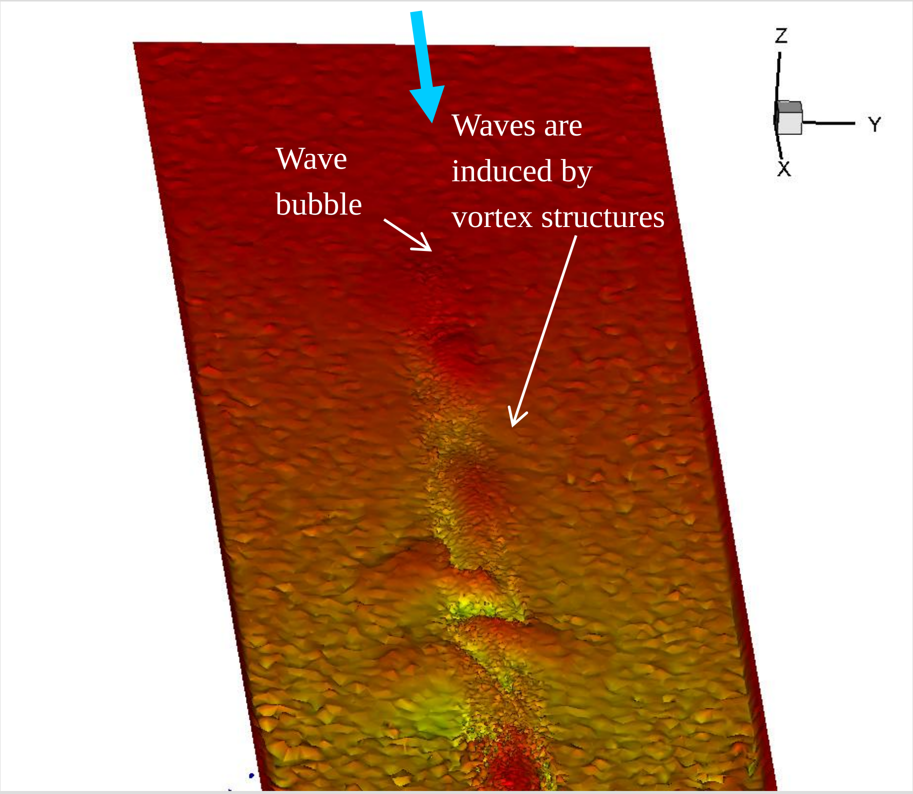


Instantaneous SGS viscosity

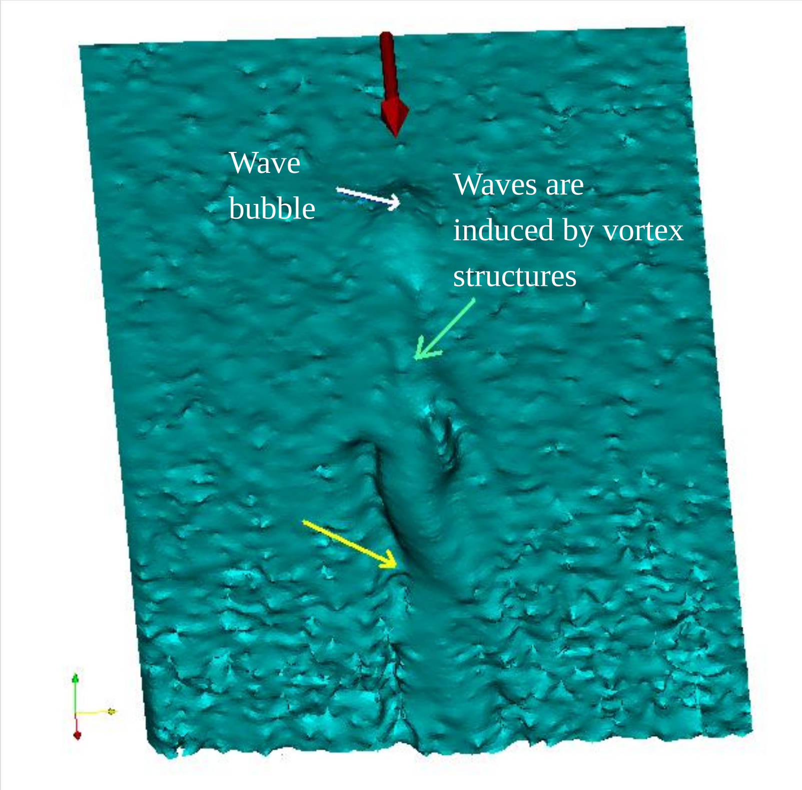
Stratified flow past the sphere

Internal waves past sphere at different Froude numbers

Isopycnal surfaces



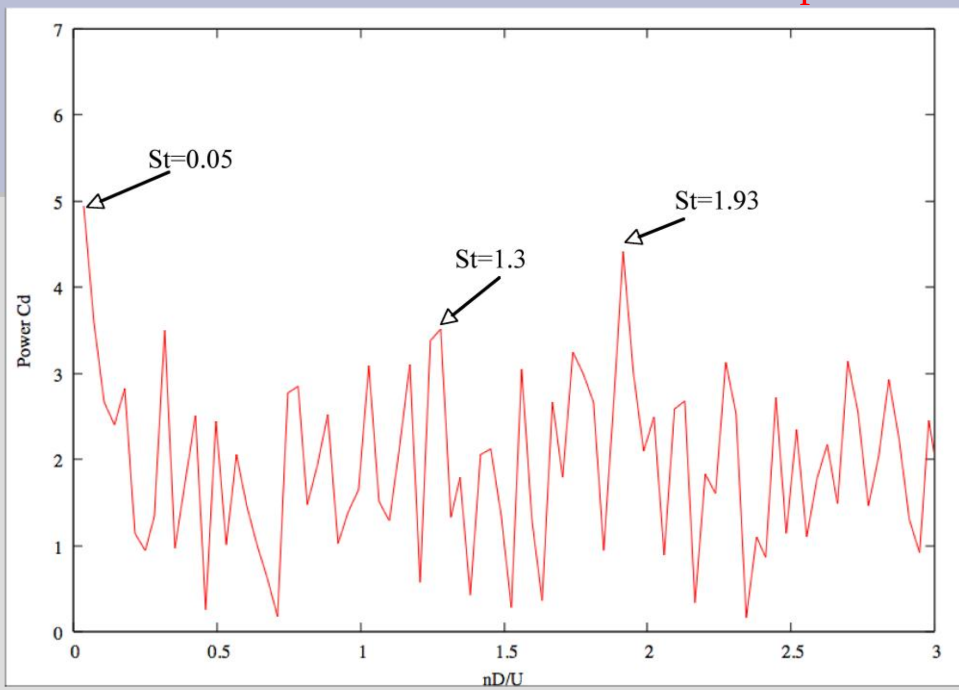
Fi = 5



Fi = 40

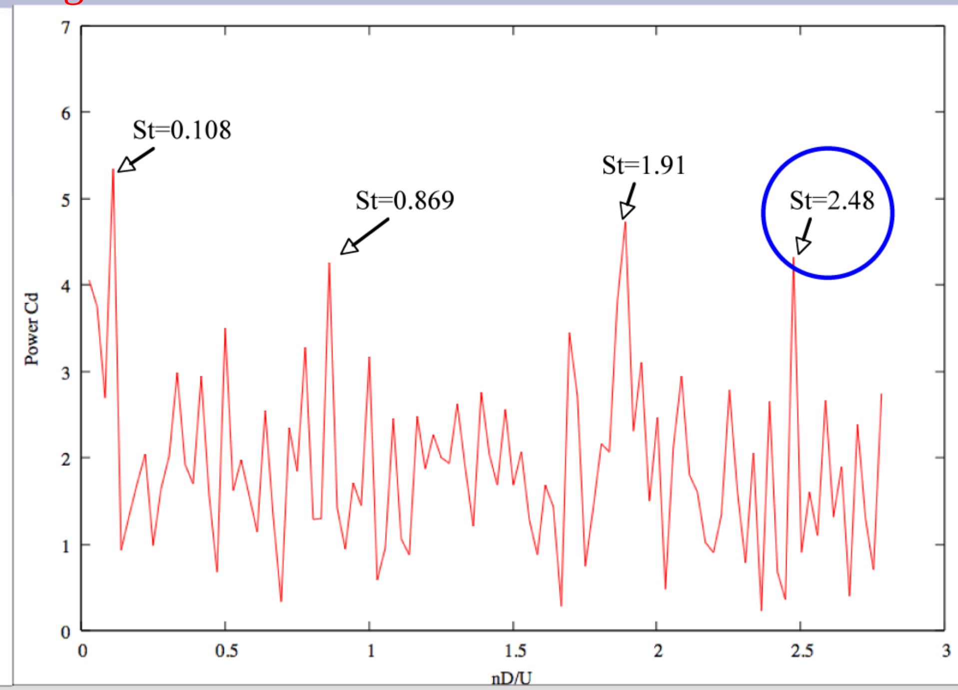
Stratified flow past the shere

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



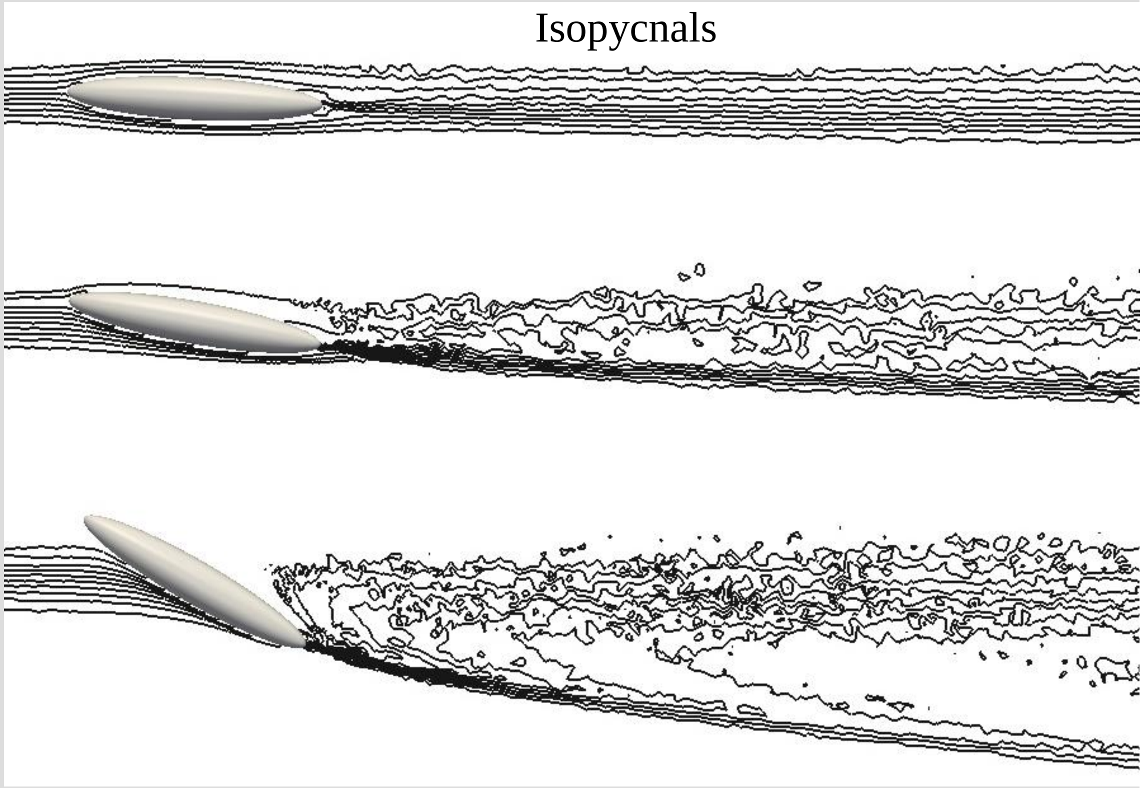
Spectra of coefficient of drag force in stratified flow Fi=5.

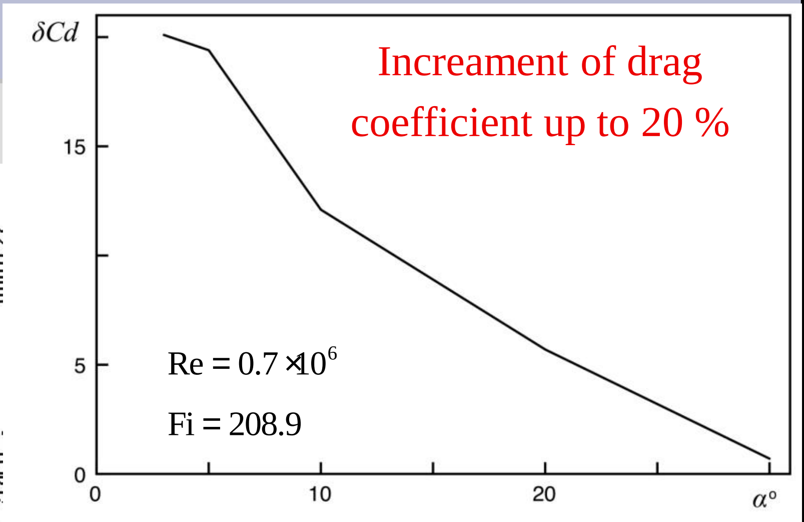
Additional mode – St=2.48

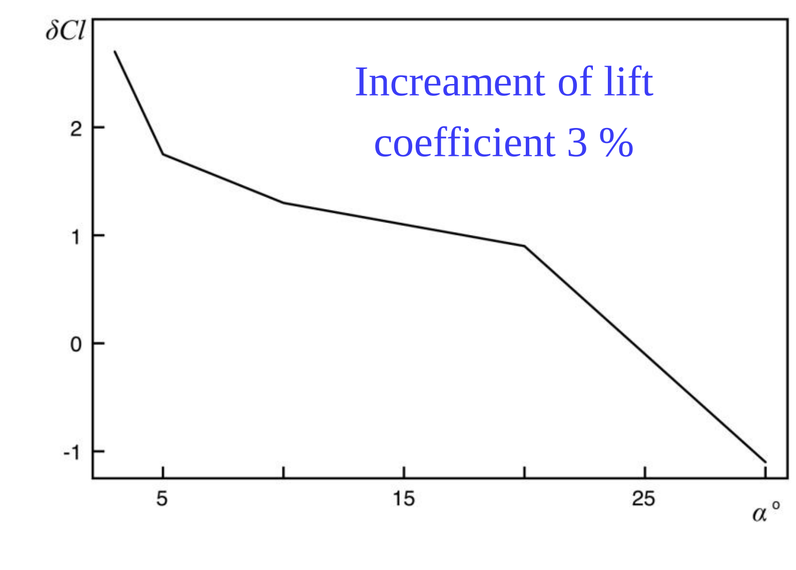
	C_D^{calc}	C_D^{exp}
Fi=5, Re=14062	0.34	0.377

Stratified flow past the spheroid placed into pycnocline

Body locates into pycnocline

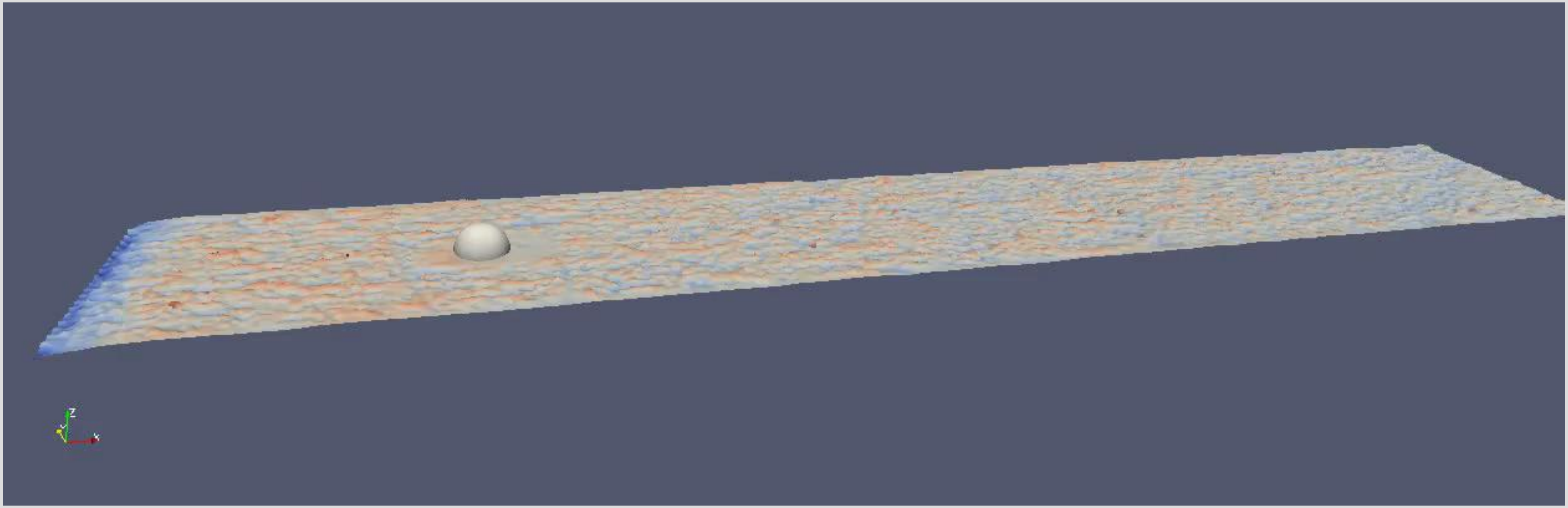






Interaction of internal waves with moving sphere in stratified liquid

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



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):

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

- 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