넥스트폼의 조선해양분야 개발 사례

2019. 09. 27

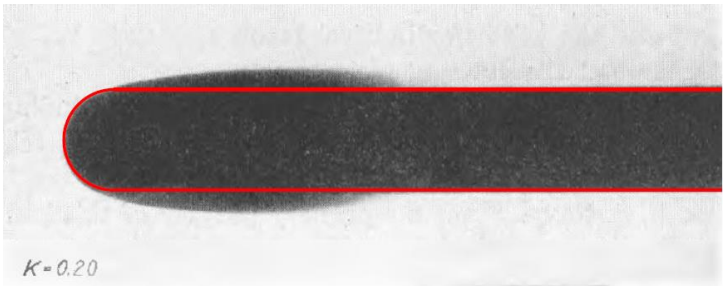
(주) 넥스트폼
김현식 선임연구원

목차

관련실적

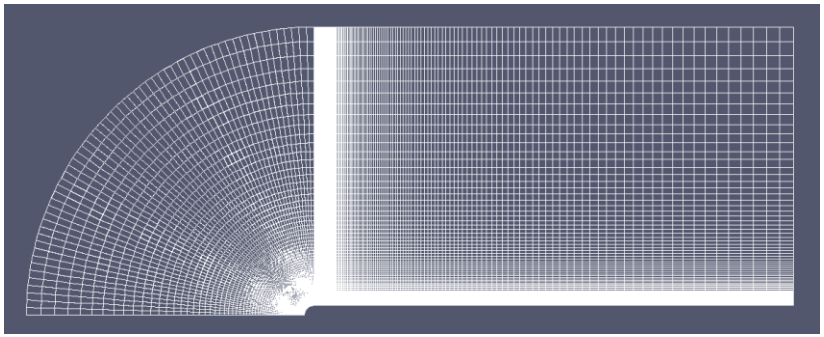
관련실적-1

- Rouse and McNown(1948) experiment
  - Cavitation on head shape geometry
    - Hemispherical head
  - Re=2.1e^5



Liquid density	998.16 kg/m3
Vapor density	0.0173 kg/m3
Liquid viscosity	1.003 m2/s
Vapor viscosity	5.619 m2/s
Saturation pressure	2339 Pa

- Calculation conditions
  - 2D axisymmetric grid
    - Number of grid : 21000



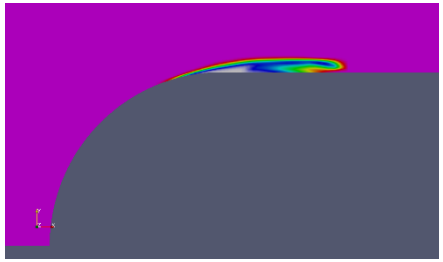
  - Boundary conditions

Inlet velocity	8.2966 m/s	
Outlet pressure	19516 Pa	12645 Pa
Cavitation number	0.5	0.3

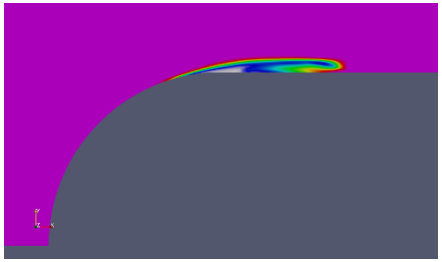
- Time increment (unsteady)
  - 1e-5 seconds

- Calculation results (σ = 0.5, unsteady)

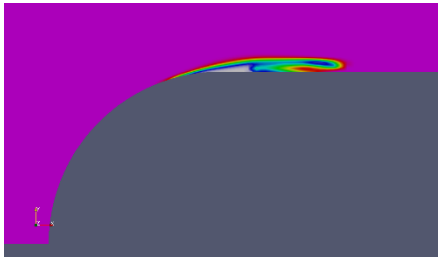
Kunz



Merkle

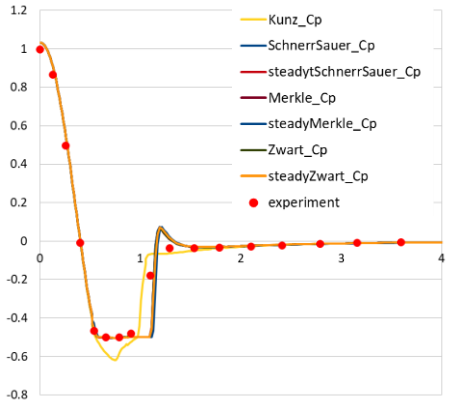


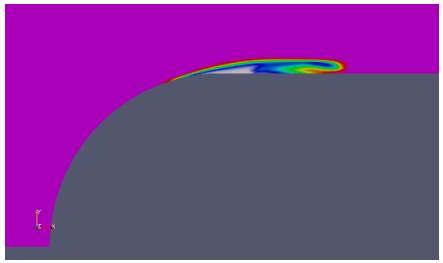
SchnerrSauer



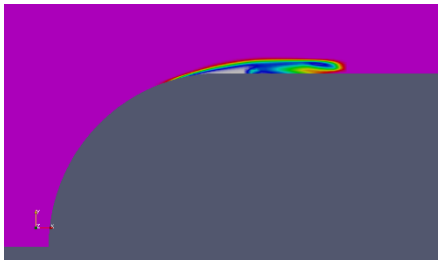
Zwart

- Calculation results (σ = 0.5, steady)

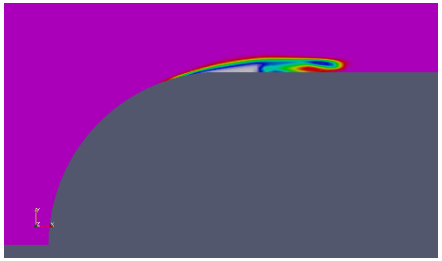




Merkle



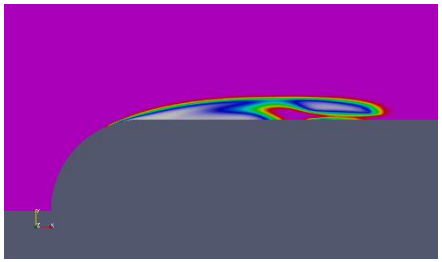
SchnerrSauer



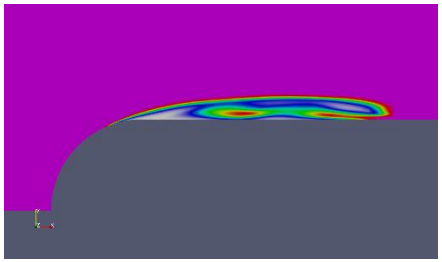
Zwart

- Calculation results (σ = 0.3, unsteady)

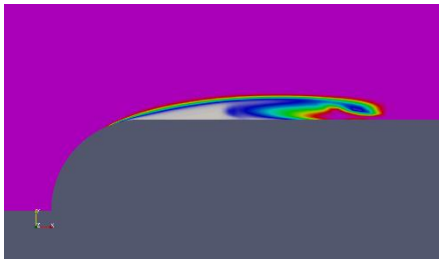
Kunz



Merkle

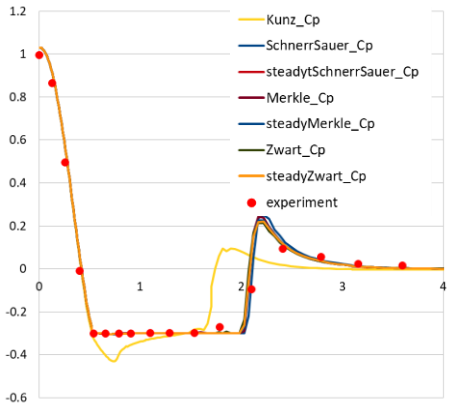


SchnerrSauer



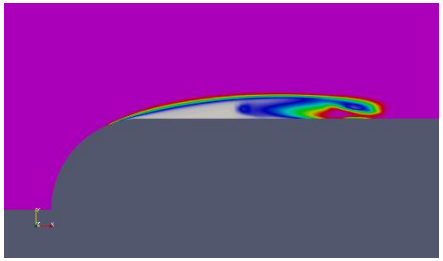
Zwart

- Calculation results (σ = 0.3, steady)



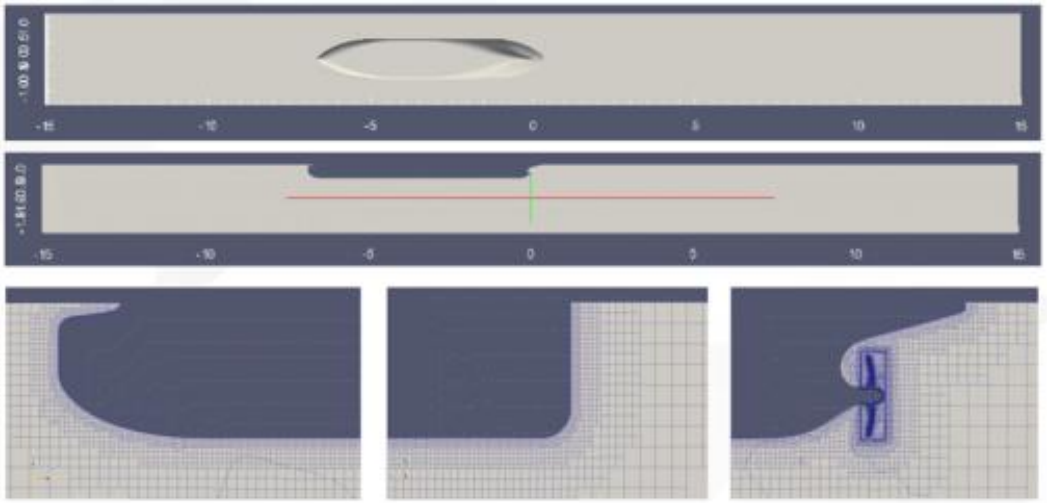
Merkle

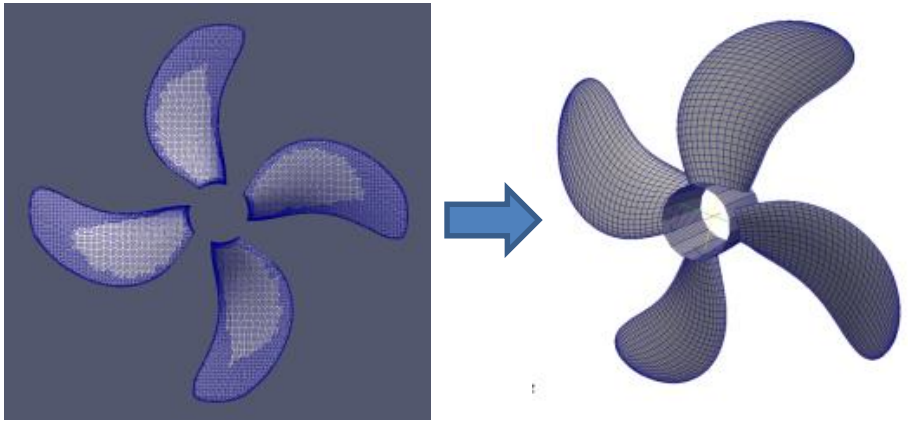
SchnerrSauer



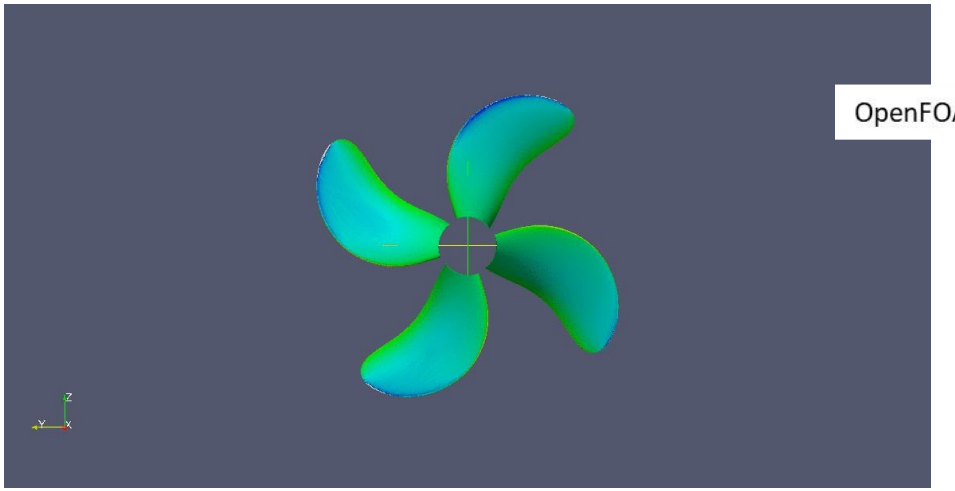
Zwart

- 선박 Cavitation
  - snappyHexMesh
  - Sliding mesh
  - Cavitation model
    - Schnerr-Sauer
  - KRISO 실험 및 계산 결과와 비교
  - **소음 해석 코드와 연동**
    - CFD 결과 BEM code input으로 mapping
    - 소음 계산

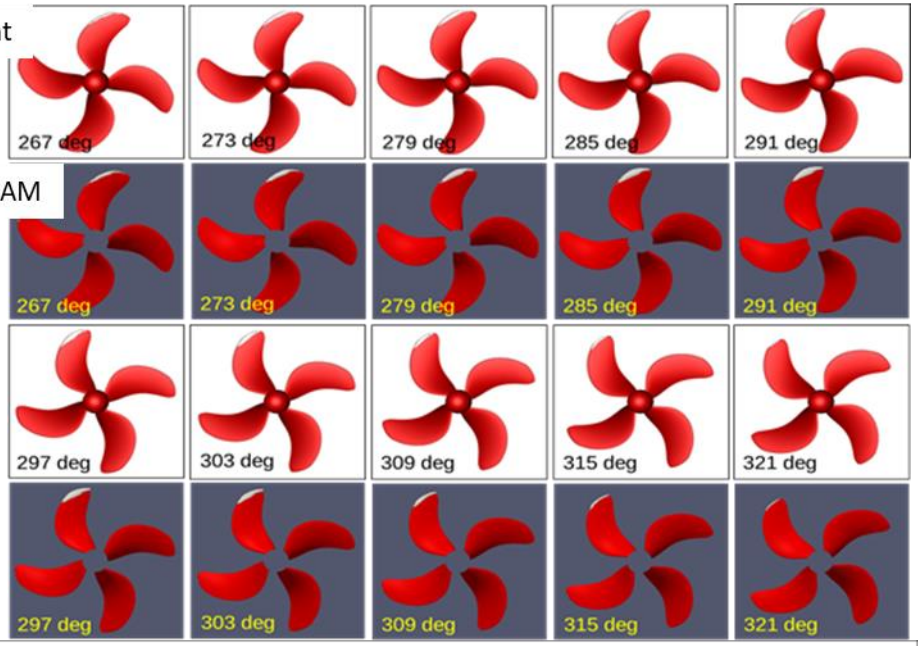


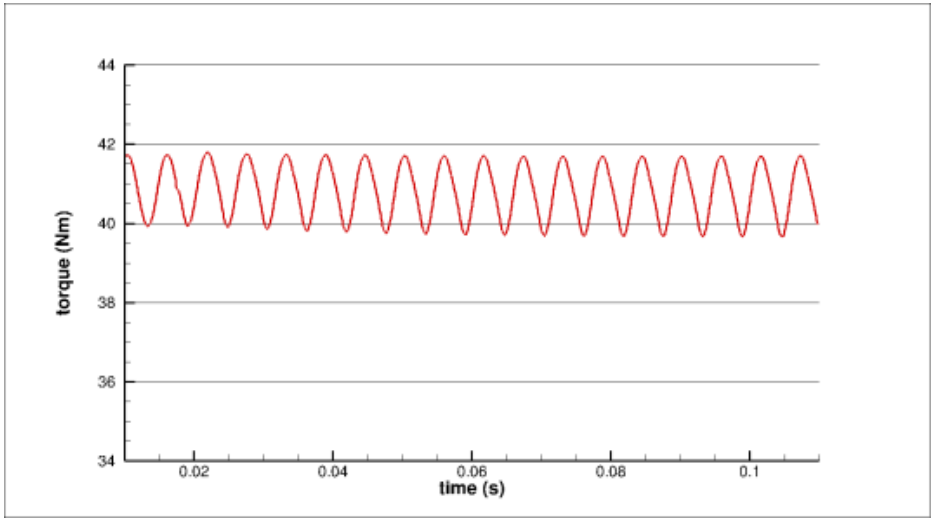


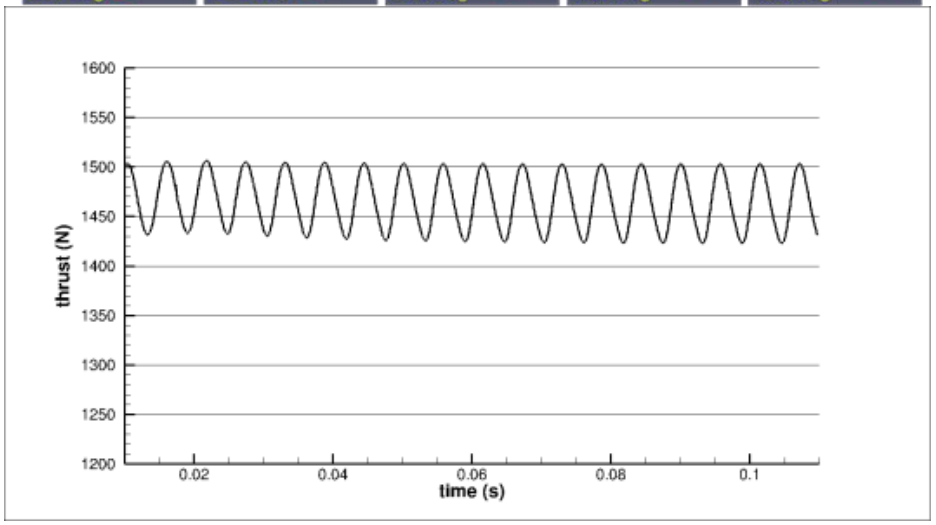
Fluent



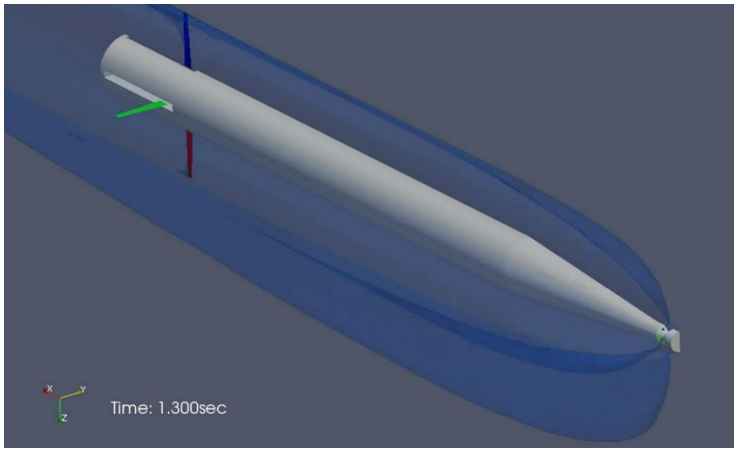
OpenFOAM



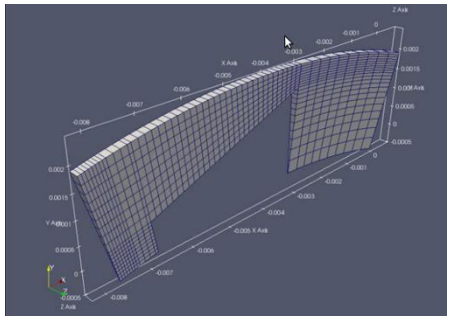




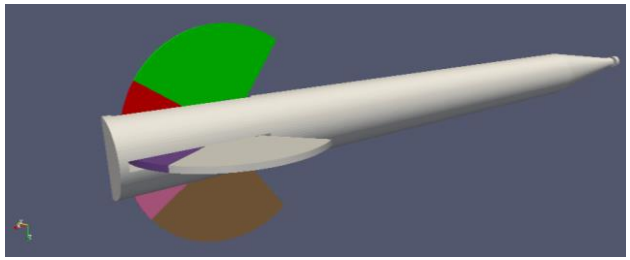
- 초공동 수중체의 제어판 전개 해석
  - interPhaseChangeDyMFoam 기반(OpenFOAM 2.4.0)
  - Multiphase Model
    - VOF(non-condensible gas 포함)
    - Cavitation Model : Kunz Model



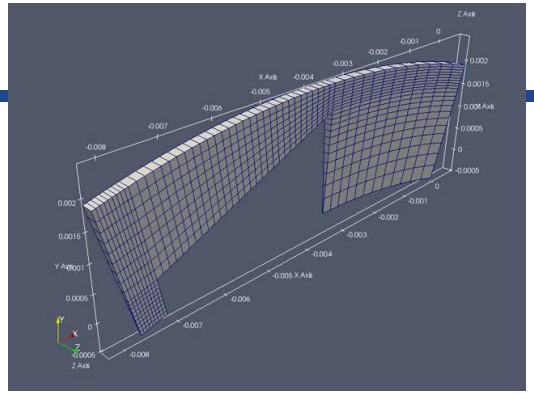
- dynamicMesh
  - Layering 기법 적용
  - foam-extend-3.2 version의 multiTopoBodyFvMesh library 활용

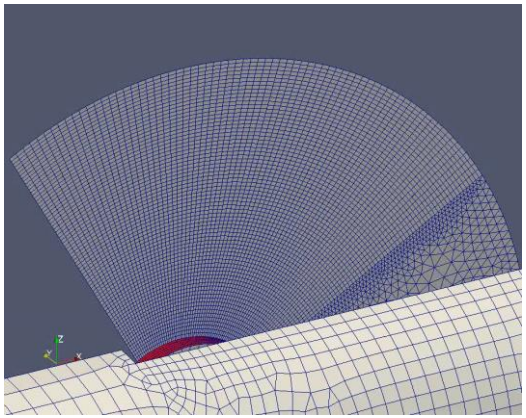


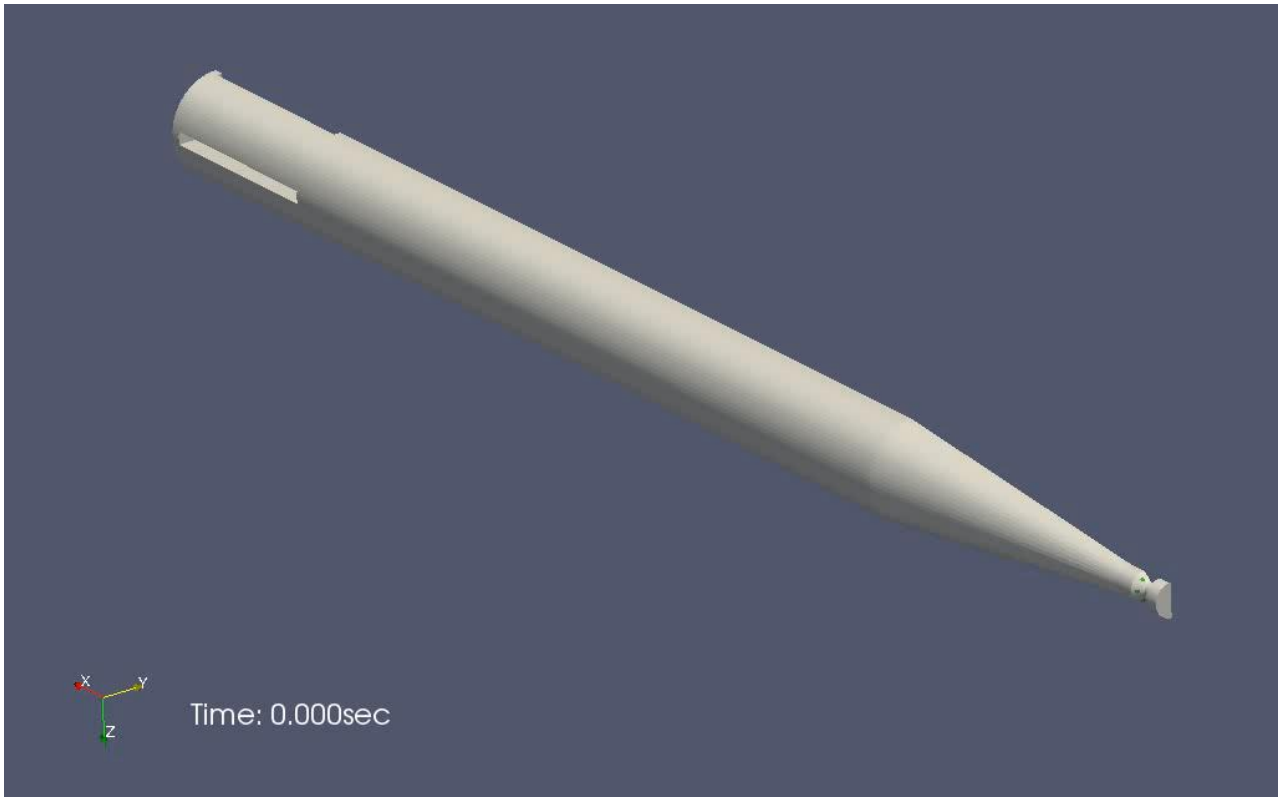
  - AMI interface 설정

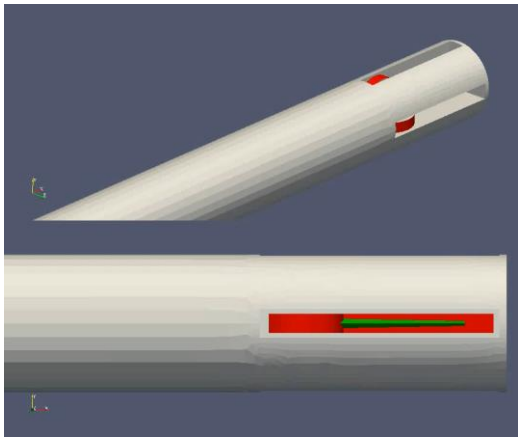


- 초공동 수중체의 제어판 전개 해석 결과



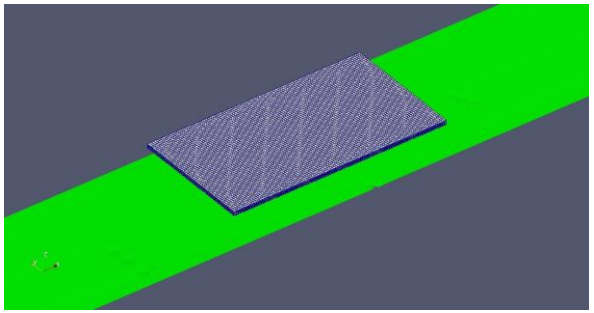
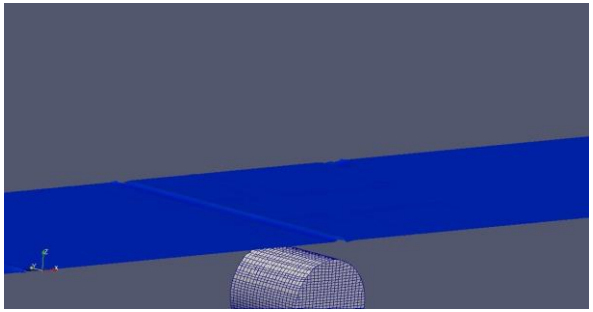
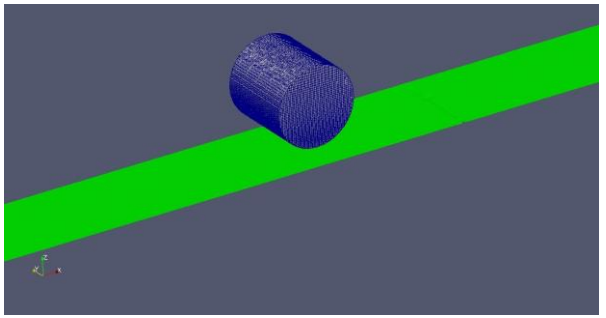
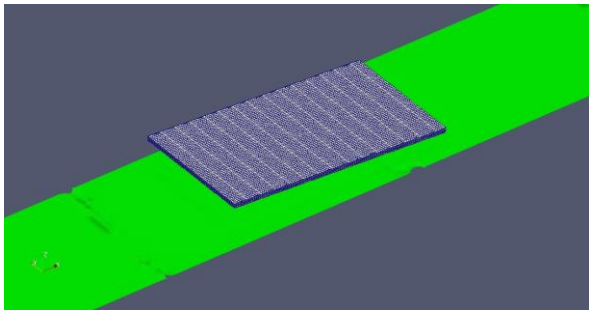
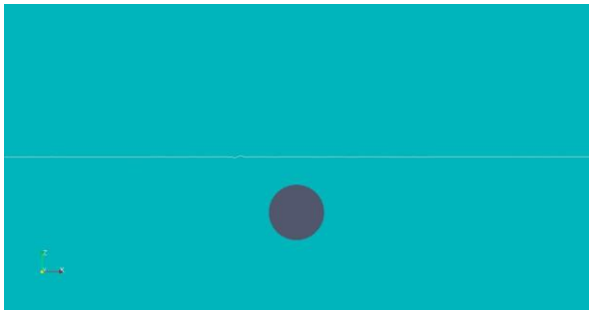
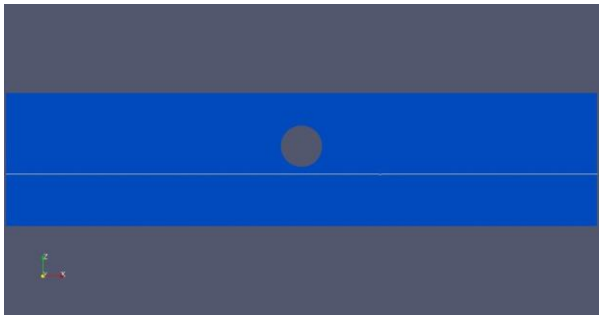






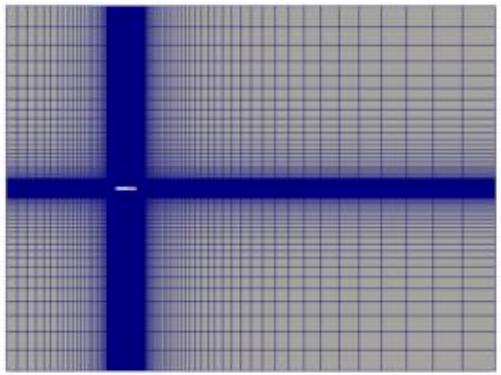
관련실적-2

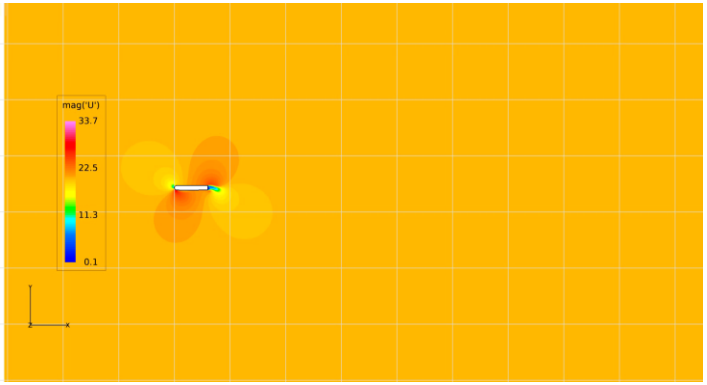
- Water Entry / Exit loading 추정

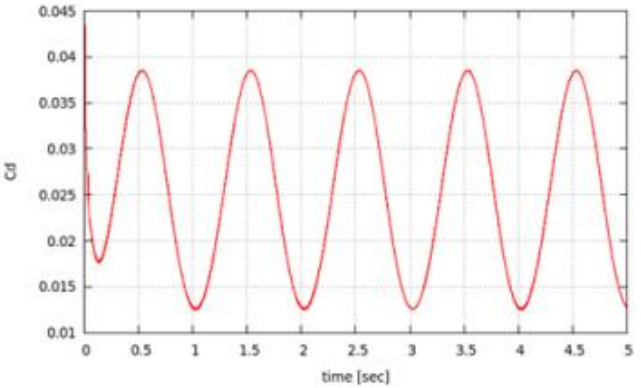







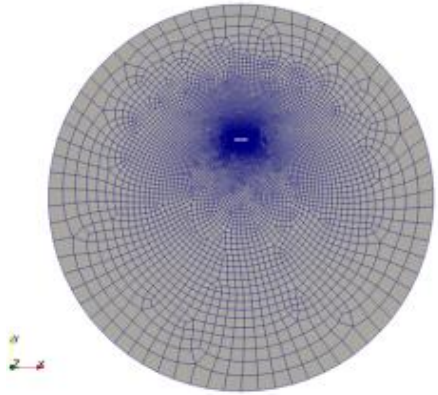
관련실적-3

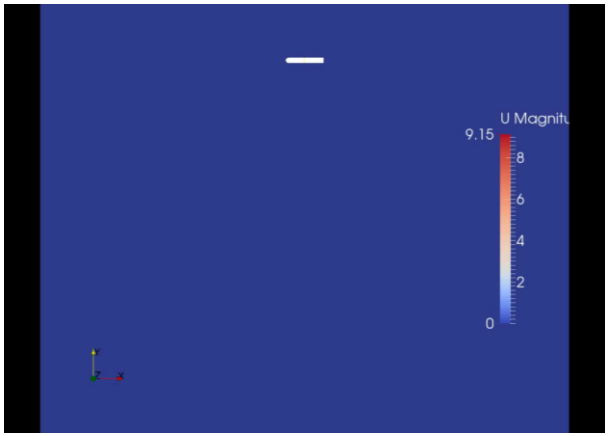
- 2D-PMM
  - Pure-sway / Rotating arm

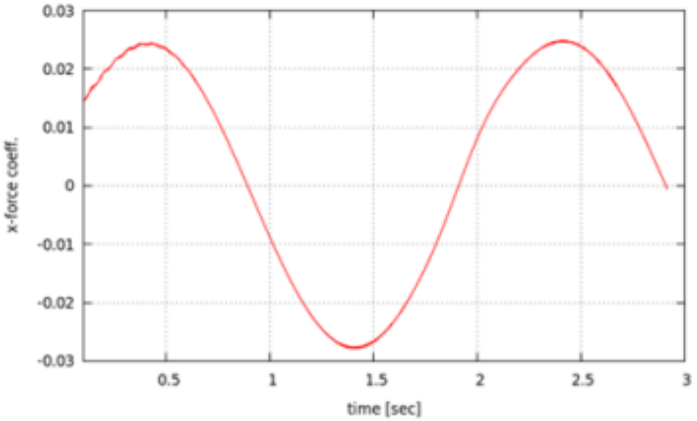






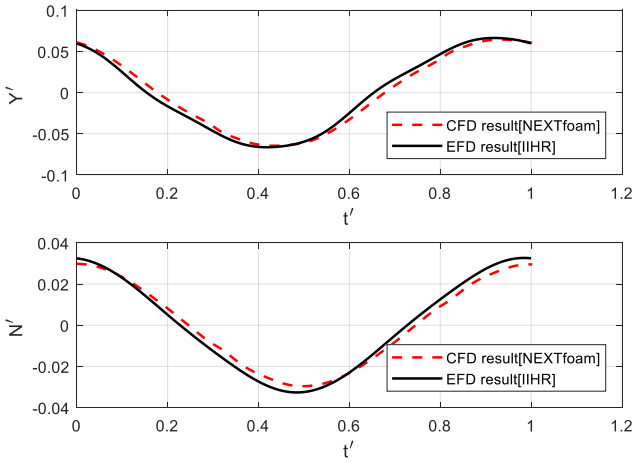




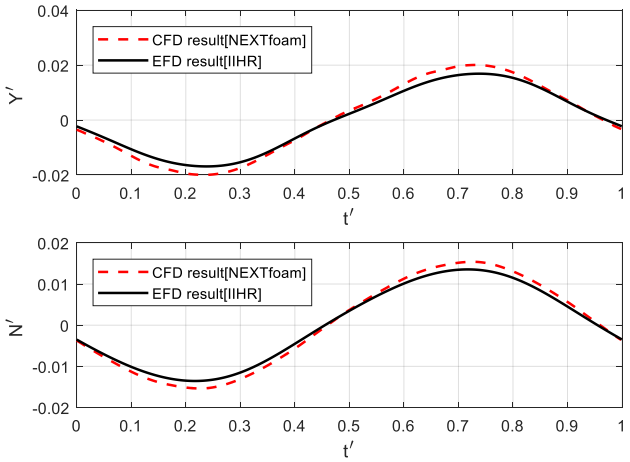


- 3D-PMM

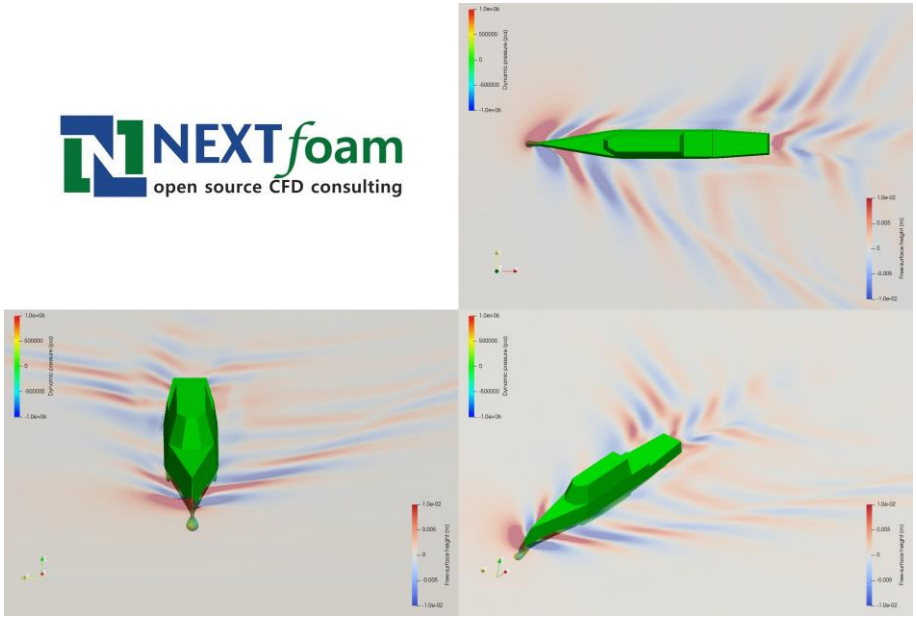
Pure sway result



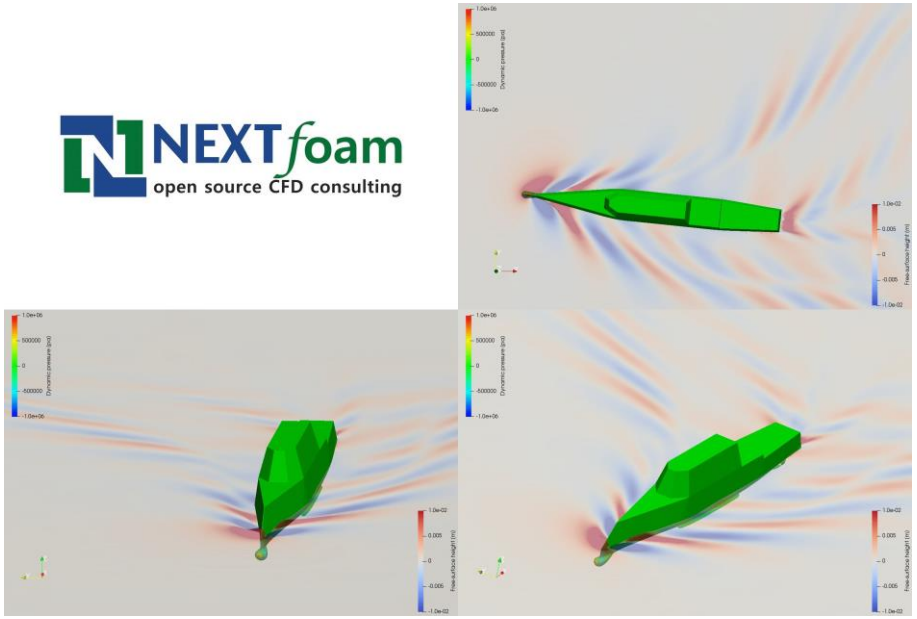
Pure yaw result



NEXTfoam open source CFD consulting

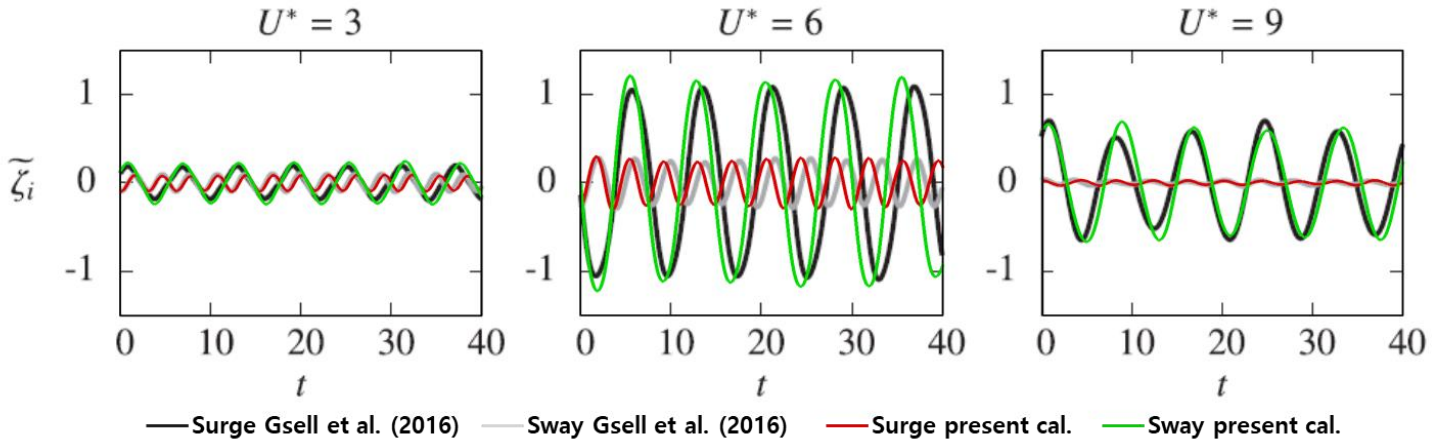


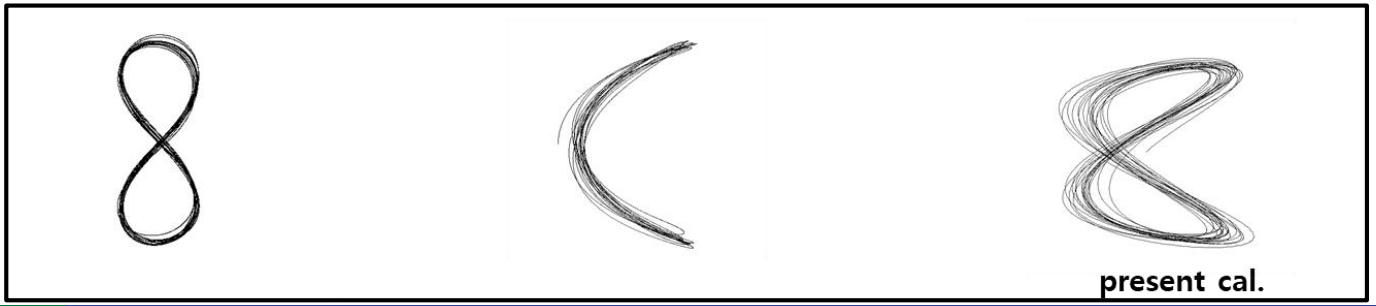
NEXTfoam open source CFD consulting

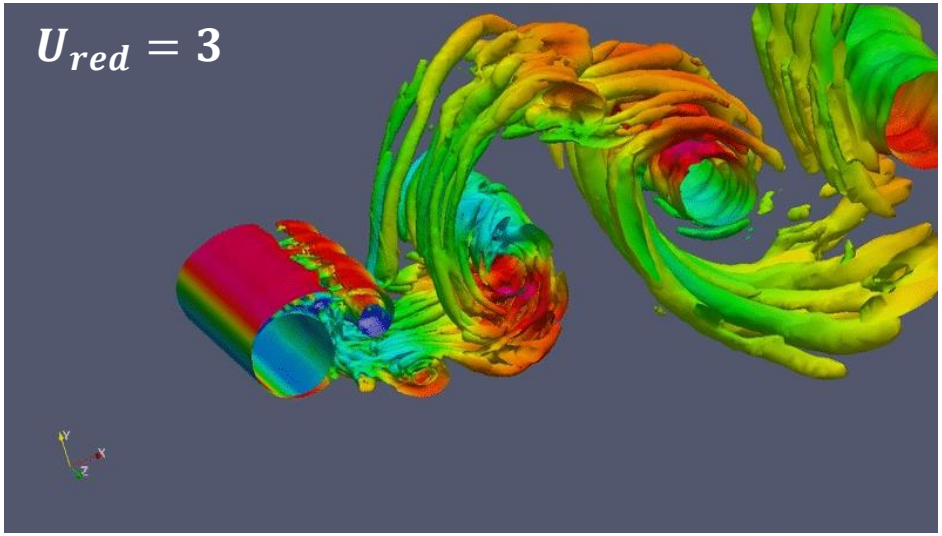


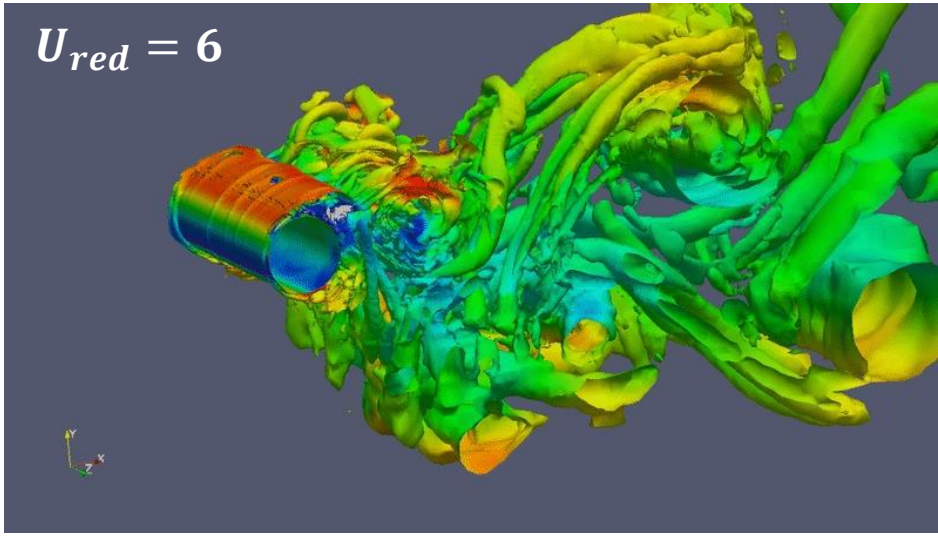
관련실적-4

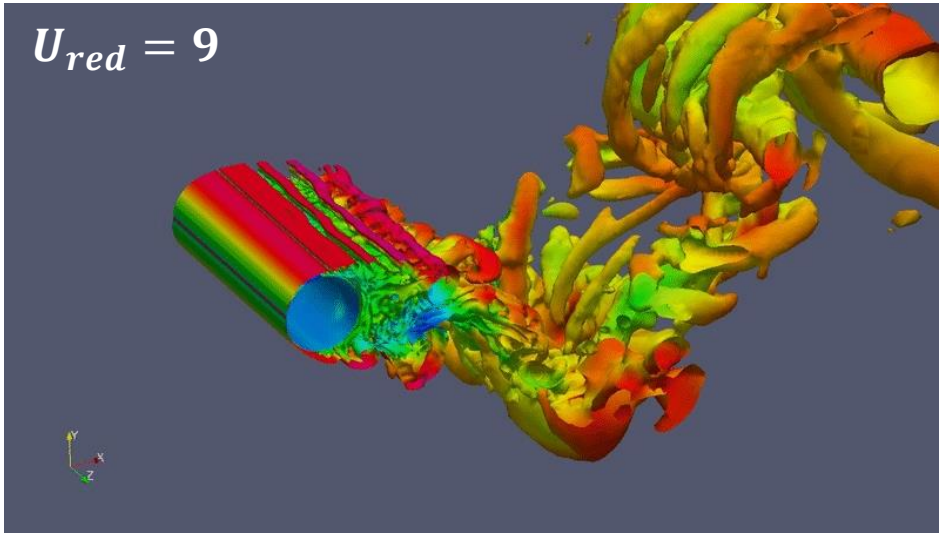
- 라이저 와유기 진동: 2자유도 라이저 (Re=3900)





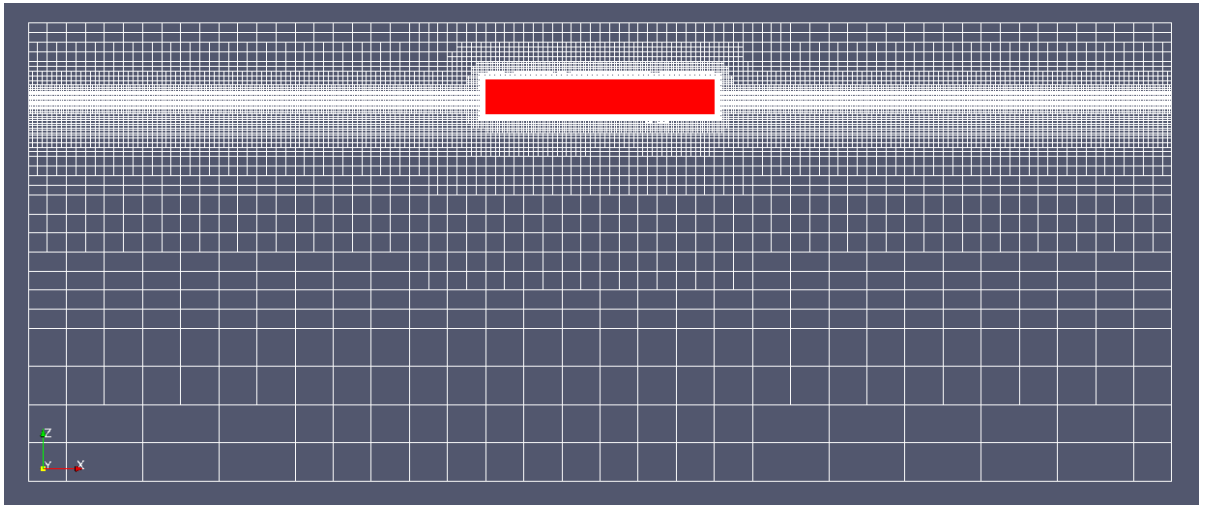

$U_{red} = 3$

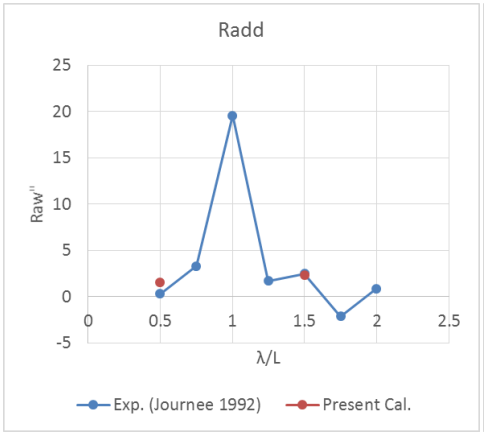

$U_{red} = 6$


$U_{red} = 9$

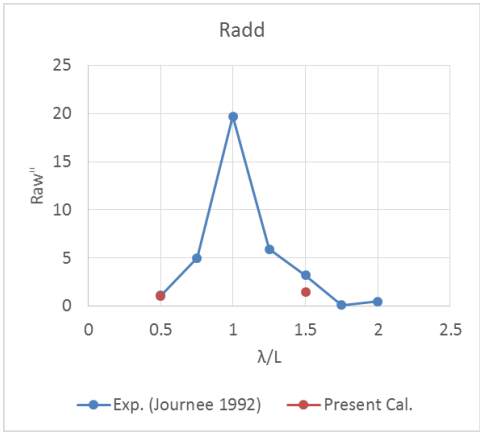
관련실적-5

- 부가저항
  - Wigley-III hull

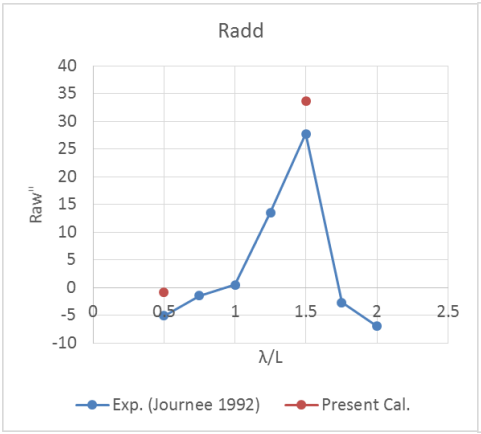




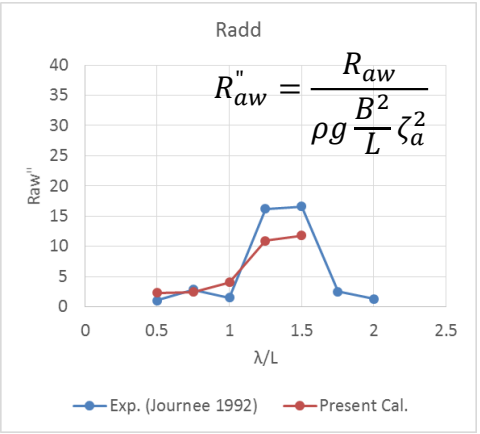
$Fn = 0.2, H = 0.02$



$Fn = 0.2, H = 0.04$



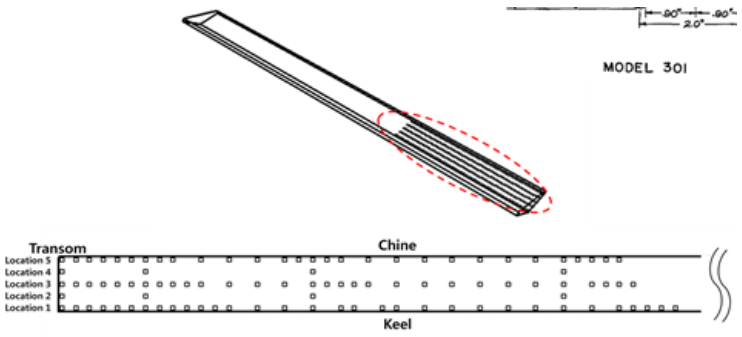
$Fn = 0.4, H = 0.02$

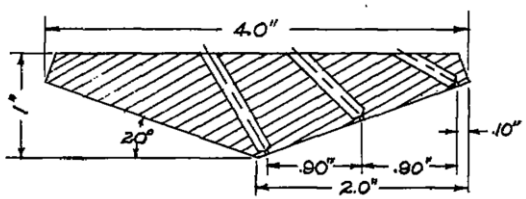


$Fn = 0.4, H = 0.04$

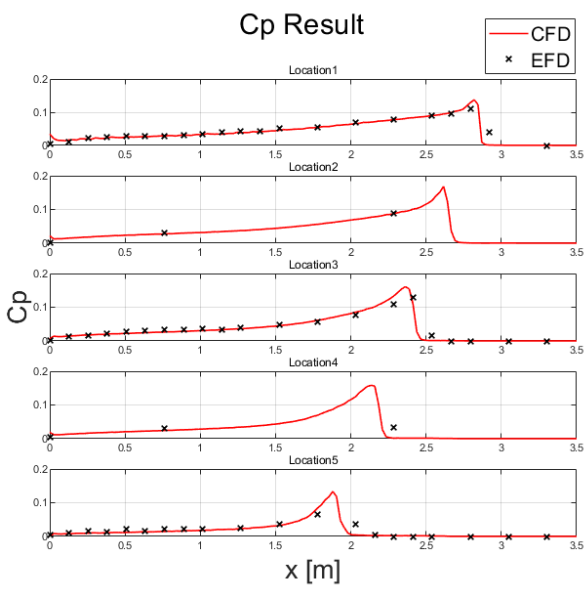
관련실적-6

- 고속 활주하는 주상체의 선저압력 추정
  - Model 301

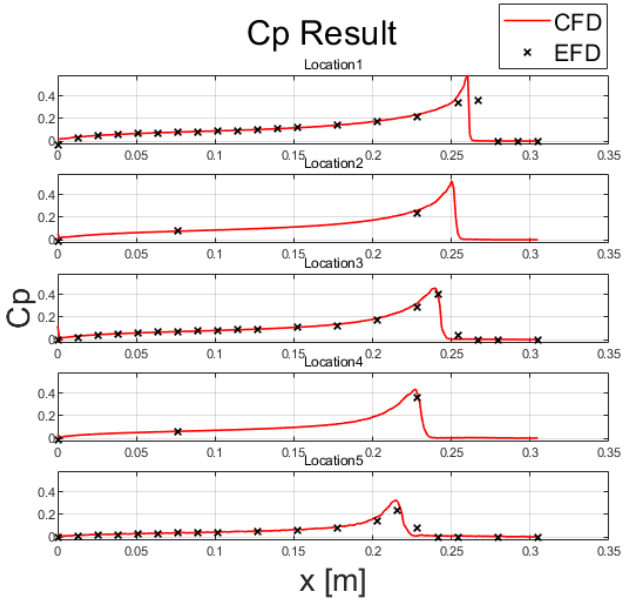




MODEL 301



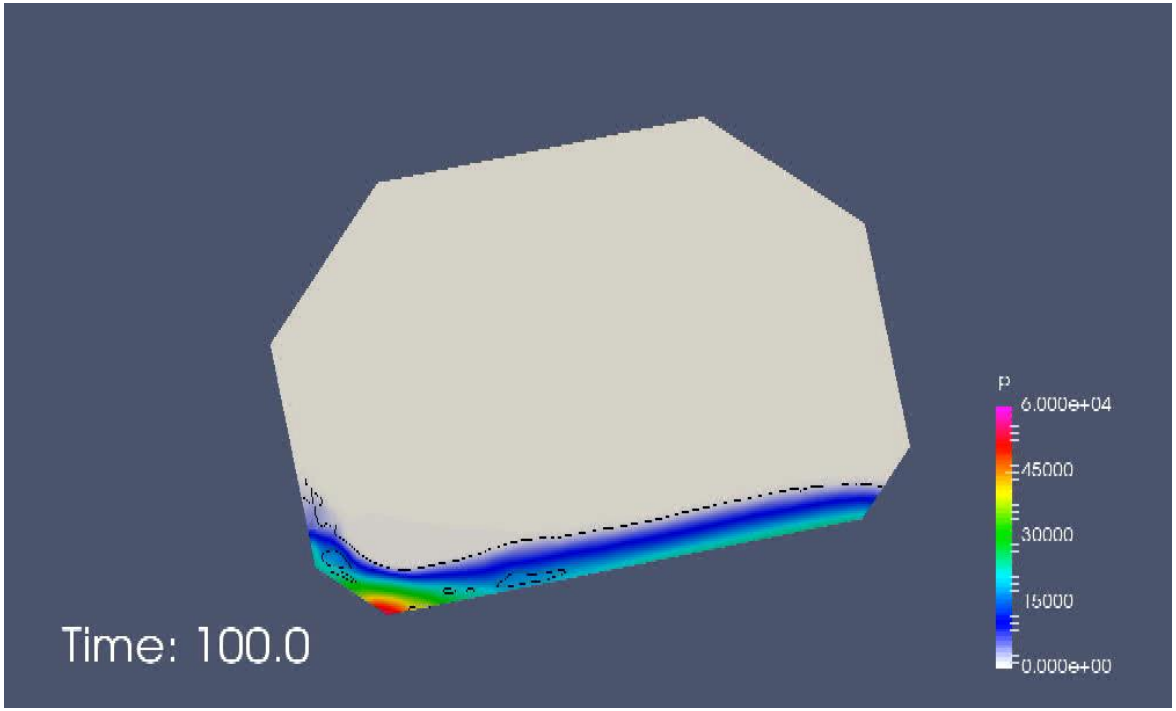
<Result of trim angle 6 deg>



<Result of trim angle 12 deg>

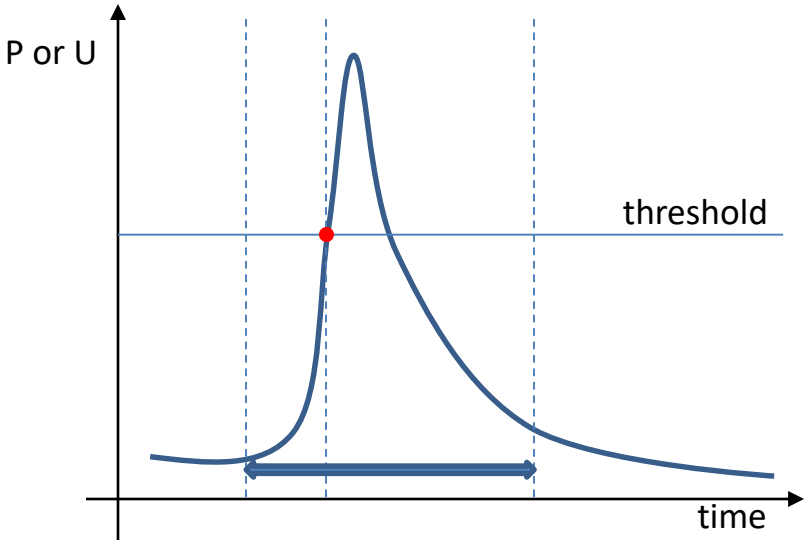
관련실적-7

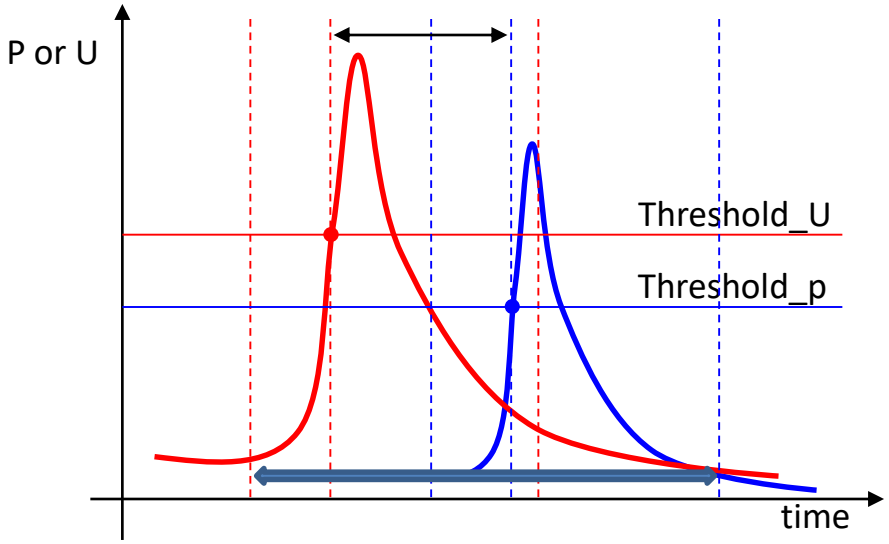
- 슬로싱 유동 해석
- interDyMFoam
  - OpenFOAM의 표준 솔버 (버전 : 2.4)
  - 동적격자를 포함하는 비압축성 2상 유동 해석



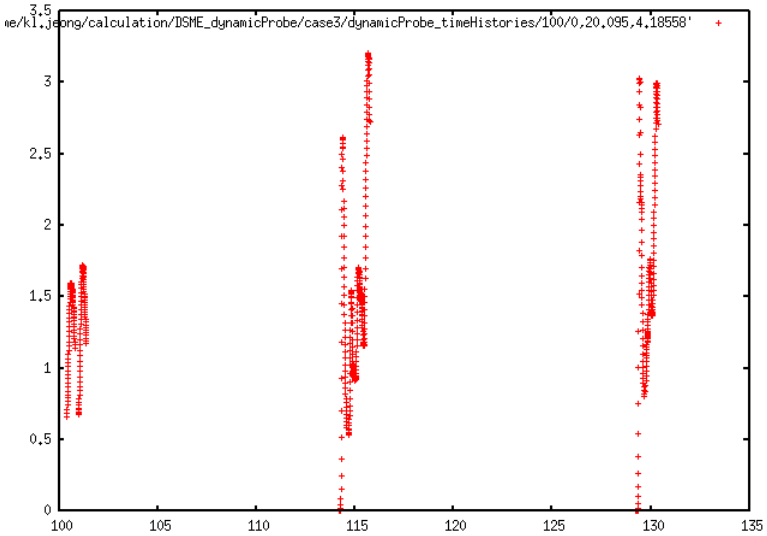
결과파일출력 조건

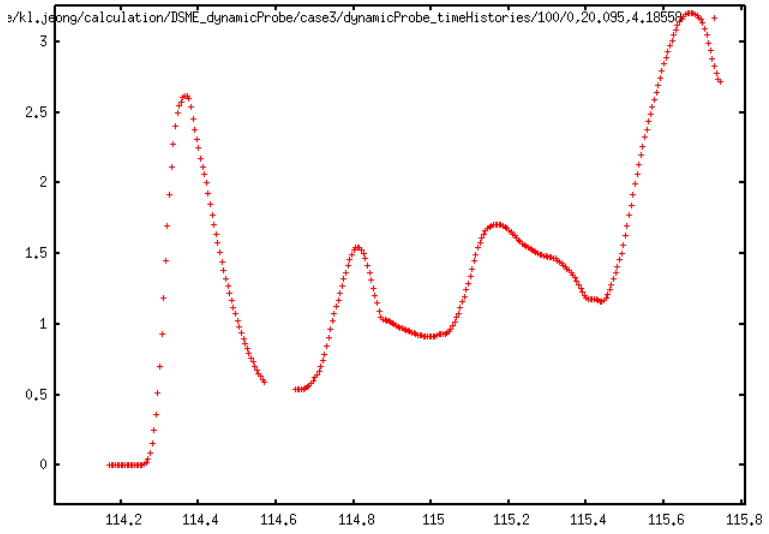
- 위치 : 벽면에서 수직방향으로 일정거리 떨어진 위치
- 대상 : 압력과 벽면에 수직한 물의 속도
- 조건 :
  - 특정압력을 넘어가는 시간을 기준으로 전후 몇 초간 (p)

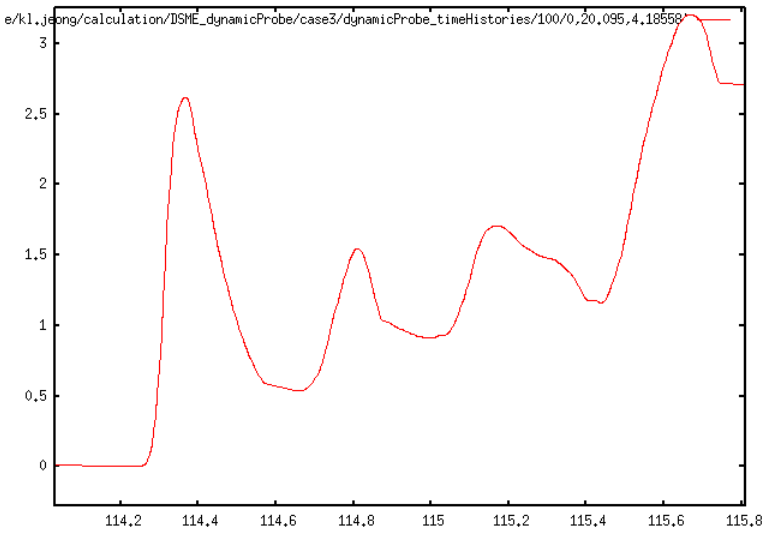




- 출력파일 가시화


ne/kl.jeong/calculation/DSME_dynamicProbe/case3/dynamicProbe_timeHistories/100/0,20.095,4.18558'
3.5
3
2.5
2
1.5
1
0.5
0
100
105
110
115
120
125
130
135


e/kl.jeong/calculation/DSME_dynamicProbe/case3/dynamicProbe_timeHistories/100/0,20.095,4.18558'
3
2.5
2
1.5
1
0.5
0
114.2
114.4
114.6
114.8
115
115.2
115.4
115.6
115.8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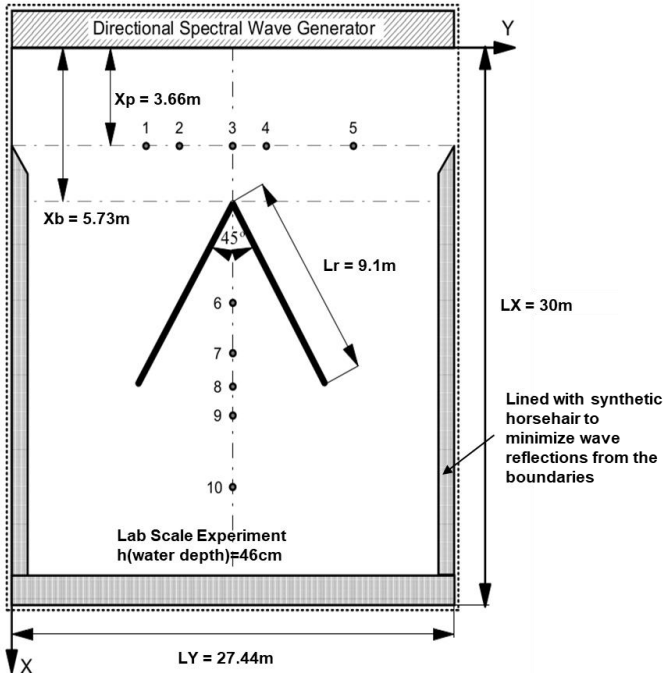
3
2.5
2
1.5
1
0.5
0
114.2
114.4
114.6
114.8
115
115.2
115.4
115.6
115.8

관련실적-8

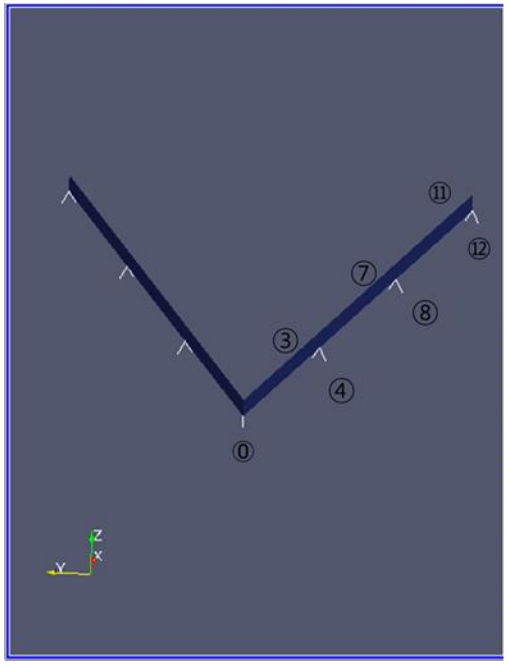
- RIBS 해석 프로그램 개발
  - RIBS 구조물의 운동해석
  - 구조물의 6DoF 운동해석
  - 해석 조건 :
    - Regular wave, Irregular wave

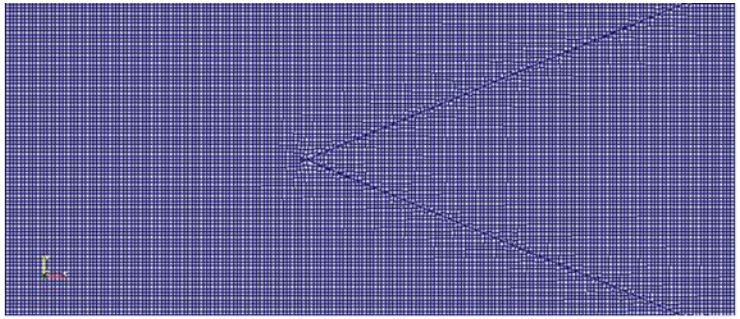
Rapidly Installed Breakwater System

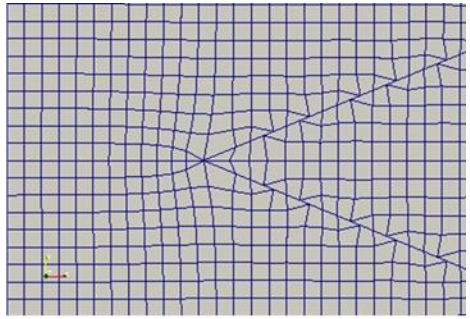
Figure 1. Rapidly Installed Breakwater System (RIBS) concept.

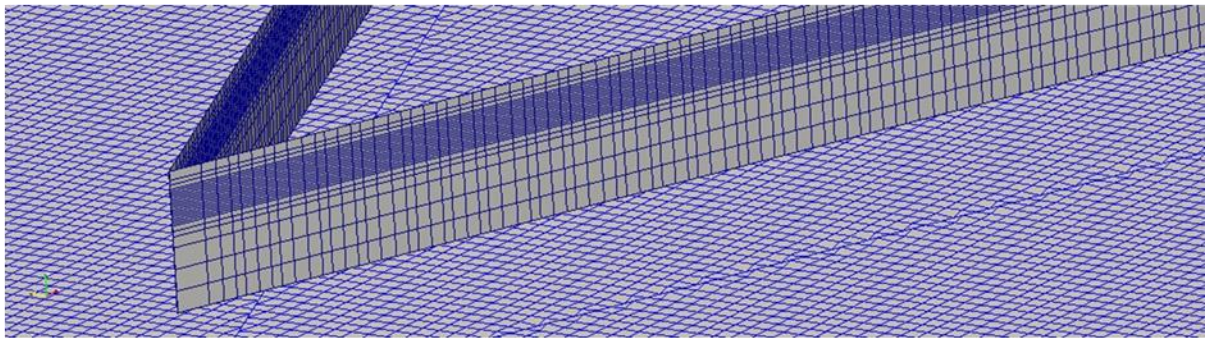


- Mooring 및 격자 구성

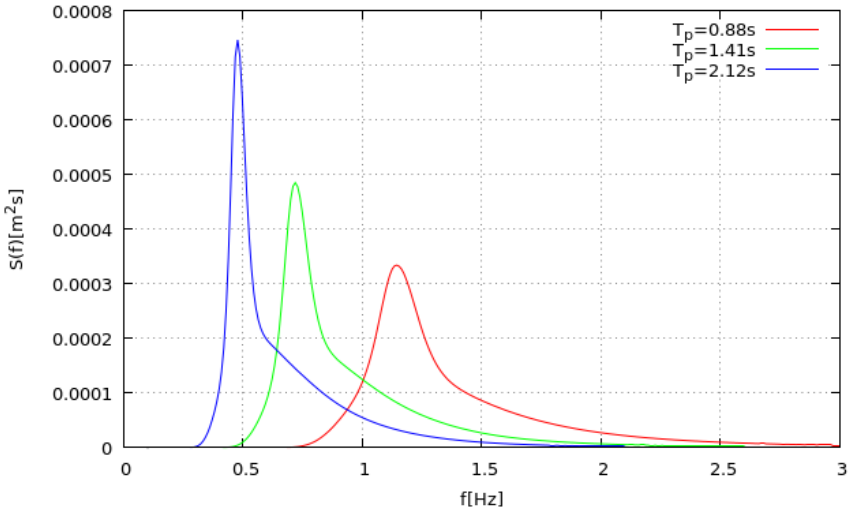


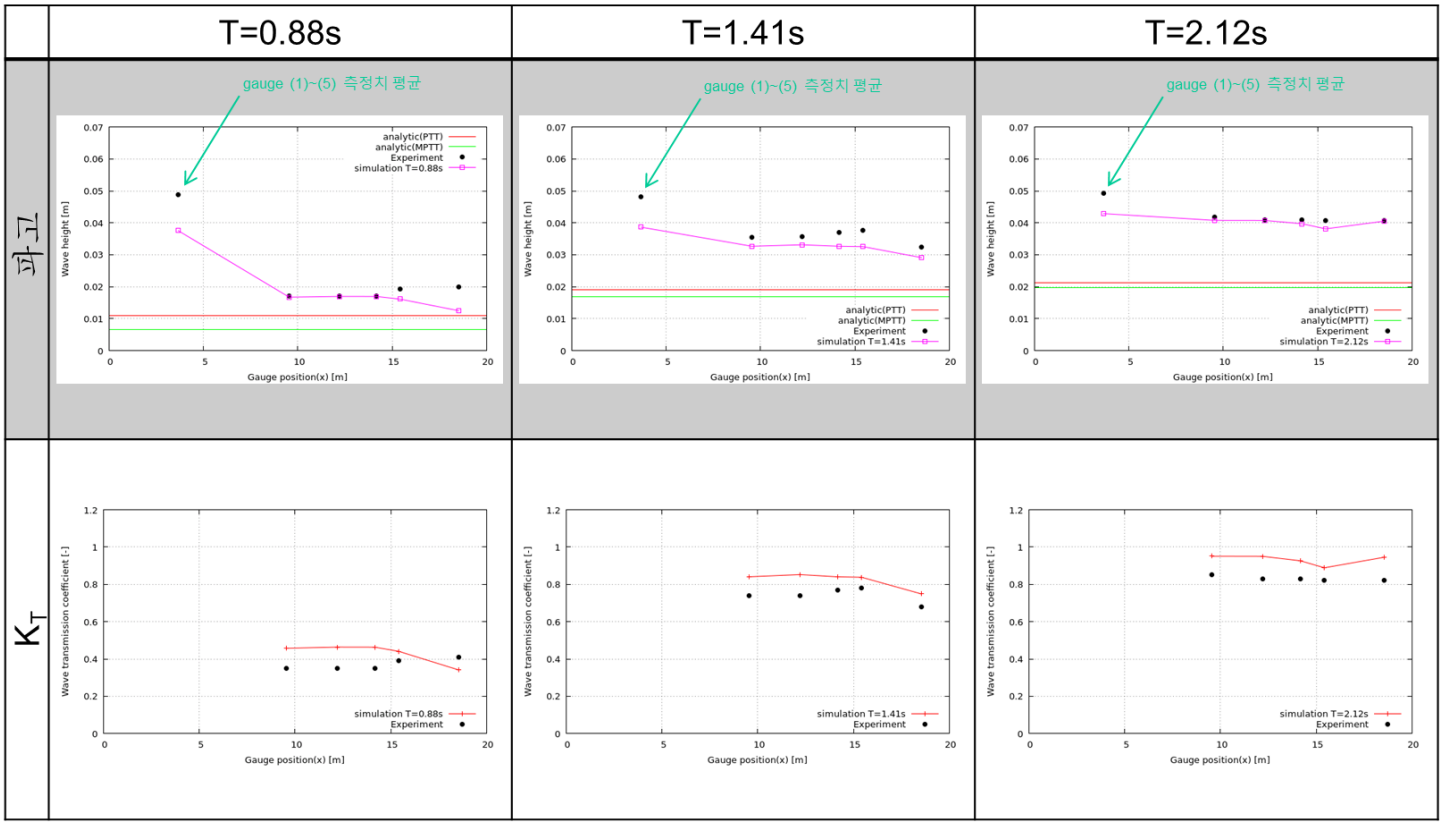




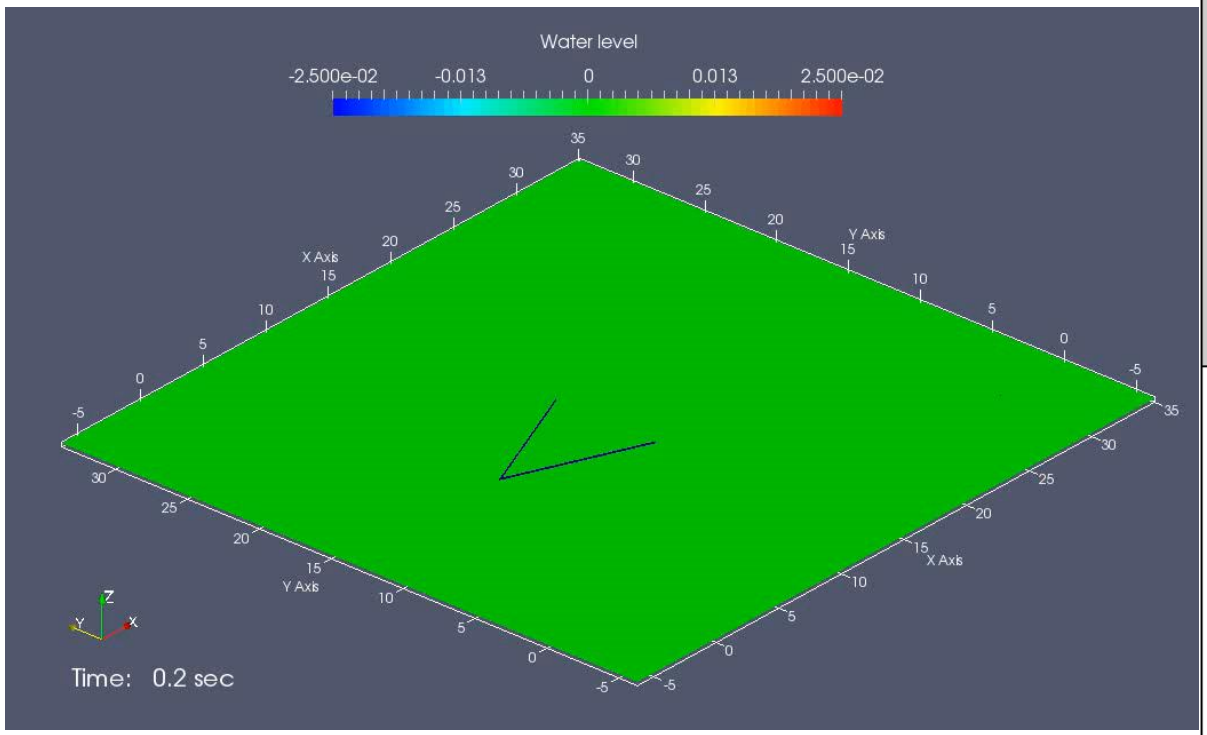


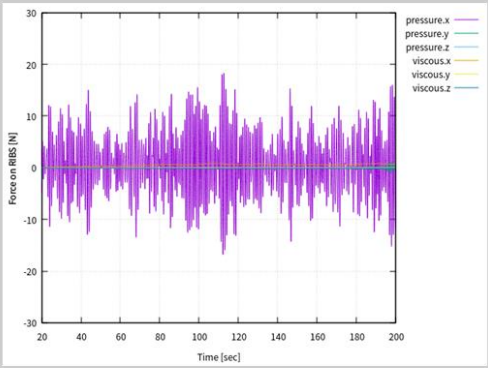
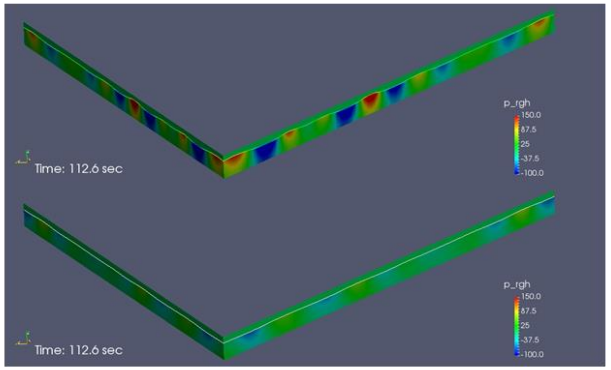
- TMA spectrum



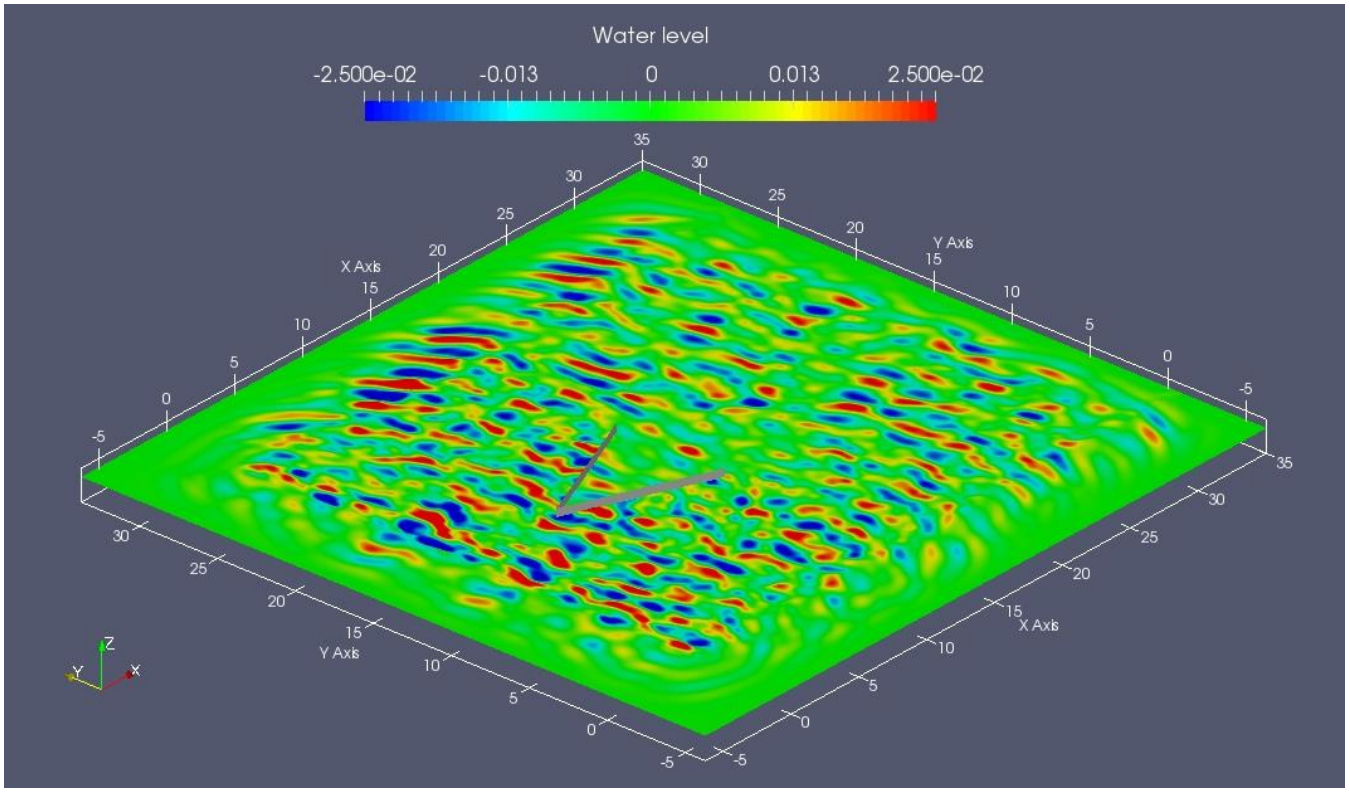


- Water level (T : 0.88s)



	Spectral(TMA)
Force on RIBS	
Pressure contour @ 112.6 sec	

- 다방향 불규칙파 해석
  - Water depth(h) : 46cm
  - Wave height(H) : 4.8cm
  - Period(T) : 1.41s
  - TMA spectrum
  - Frequency division : N_f = 300 (0.1 ~ 3.0Hz)
  - Direction division : M_θ = 40 (-90° ~ 90°)
  - Mean direction : θ_m = 0°
  - σ_m = 30°



ESPER
Estimating Ship PERformance

ESPER 구성

- 2 solvers
  - Single phase incompressible steady solver
  - Two phase incompressible unsteady solver
- 3 libraries
  - Dynamic mesh library for running attitude
  - Dynamic mesh library for rotating propeller
  - Actuator disk library

Problem	Free surface treatment	Time dependency	Propulsion	Solver	Library
POW	-	Steady	MRF	Single phase	-
Resistance	Double body	Steady	-	Single phase	-
	Free surface	Unsteady	-	Two phase	Running attitude
Propulsion	Double body	Steady	Actuator disk	Single phase	Actuator disk library
		Unsteady	Sliding mesh	Single phase	Running attitude + rotating propeller
	Free surface	Unsteady	Actuator disk	Two phase	Actuator disk library
		Unsteady	Sliding mesh	Two phase	Running attitude + rotating propeller

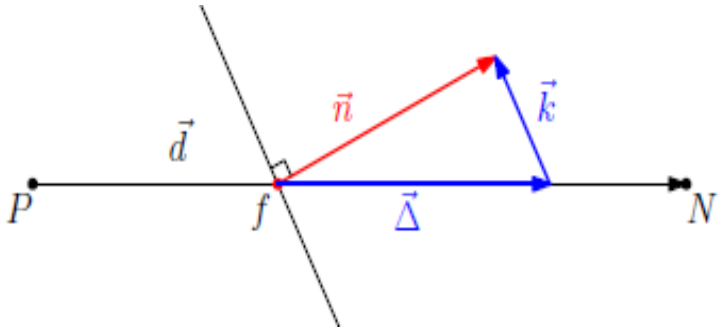
CFD solver 안정화

- Pressure correction
  - Poisson equation

$$\nabla^2 p = s$$

  - Explicit treatment of pressure gradient

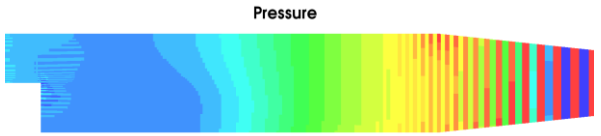
$$\nabla^2 p = \nabla \cdot \left(\vec{n} \cdot (\nabla p)_f\right)$$



$$\sum S\left(\vec{n} \cdot (\nabla p)_f\right) = \sum S\left(|\vec{\Delta}| \frac{p_N - p_P}{|\vec{d}|} + \vec{k} \cdot (\nabla p)\right)$$

$$\sum S\left(\vec{n} \cdot (\nabla p)_f\right) = \sum S\left(|\vec{\Delta}| \frac{p_N - p_P}{|\vec{d}|} + \vec{k} \cdot (\nabla p)_{old} + \alpha\{\vec{k} \cdot (\nabla p)_{new} - \vec{k} \cdot (\nabla p)_{old}\}\right)$$

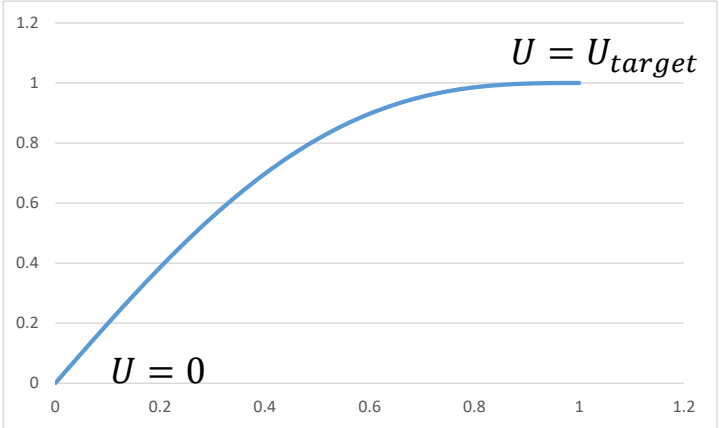
- Rhie-Chow interpolation
  - Collocated grid에서 checker boarding을 제거하기 위한 기법
  - OpenFoam 표준 솔버 : delayed pressure discretization method
  - 본 과제 개발 솔버 : Rhie-Chow interpolation method

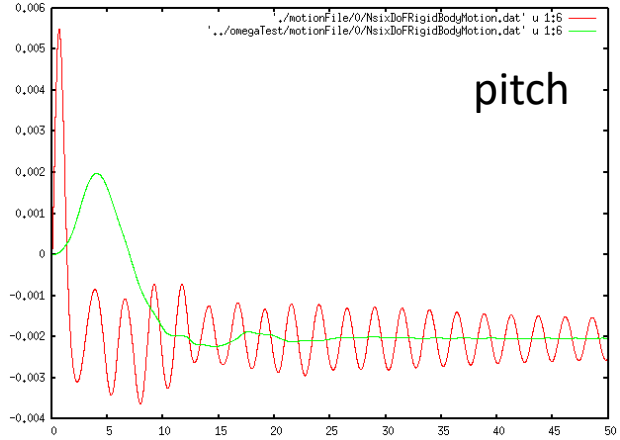


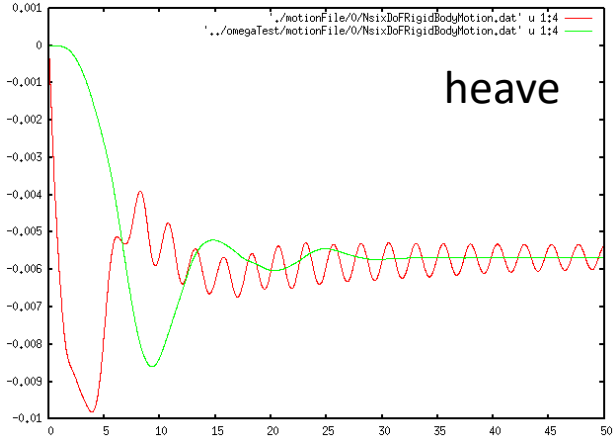
	original	modified
1. solve momentum equation and get $\vec{U}^*$	$a_P\vec{U}_P = H(\vec{U}) - V_P(\nabla p)_P$	$a_P\vec{U}_P = H(\vec{U}) - V_P(\nabla p)_P$
2. interpolate pseudo-velocity to get mass flow rate	$F^* = \left\{\frac{H(\vec{U}^*)}{a}\right\}_f \cdot \vec{S}_f$	$F^* = \left\{\vec{U}^* + \frac{V_P}{a_P}(\nabla p)_P\right\}_f \cdot \vec{S}_f$
3. solve pressure equation and get p^*	$\nabla \cdot \left(\frac{V}{a}\nabla p\right) = \sum_f F^*$	$\nabla \cdot \left(\frac{V}{a}\nabla p\right) = \sum_f F^*$
4. correct mass flow rate	$F^{new} = F^* - \left(\frac{V}{a}\right)_f \lvert\vec{S}_f\rvert\vec{n} \cdot (\nabla p^*)_f$	$F^{new} = F^* - \left(\frac{V}{a}\right)_f \lvert\vec{S}_f\rvert\vec{n} \cdot (\nabla p^*)_f$
5. original: under-relax pressure modified: correct velocity	$p^{new} = p^{old} + \alpha_p(p^* - p^{old})$	$\vec{U}_P^{new} = \vec{U}_P^* - \frac{V_P}{a_P}(\nabla p')_P$
6. original: correct velocity modified: under-relax pressure	$\vec{U}_P^{new} = \frac{H(\vec{U}^*)}{a_P} - \frac{V_P}{a_P}(\nabla p^{new})_P$	$p^{new} = p^{old} + \alpha_p(p^* - p^{old})$

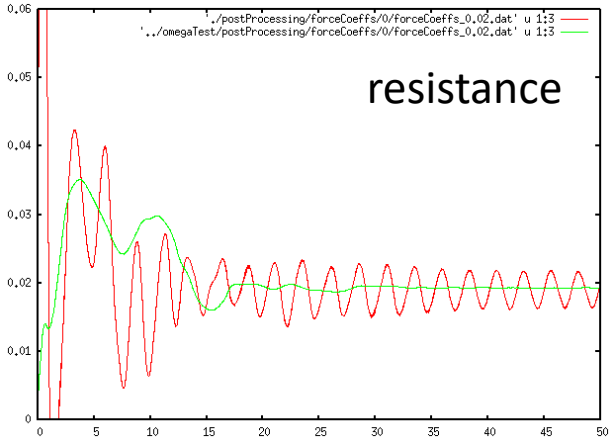
저항/자항 해석시간 단축

- Impulsive start VS. slow start
  - Impulsive start : 유속 초기 값을 선속으로 설정
  - Slow start : 유속 초기값을 '0'으로 설정, 점진적 가속
- 계산초기 선체운동의 처리
  - 특정 시간 이전의 운동을 구속
    - 운동을 자유롭게 하면 초기에 운동이 과도하게 계산
  - Ramp time을 지정하여 초기 가속도를 감쇠
    - 항주자세 계산속도가 향상됨





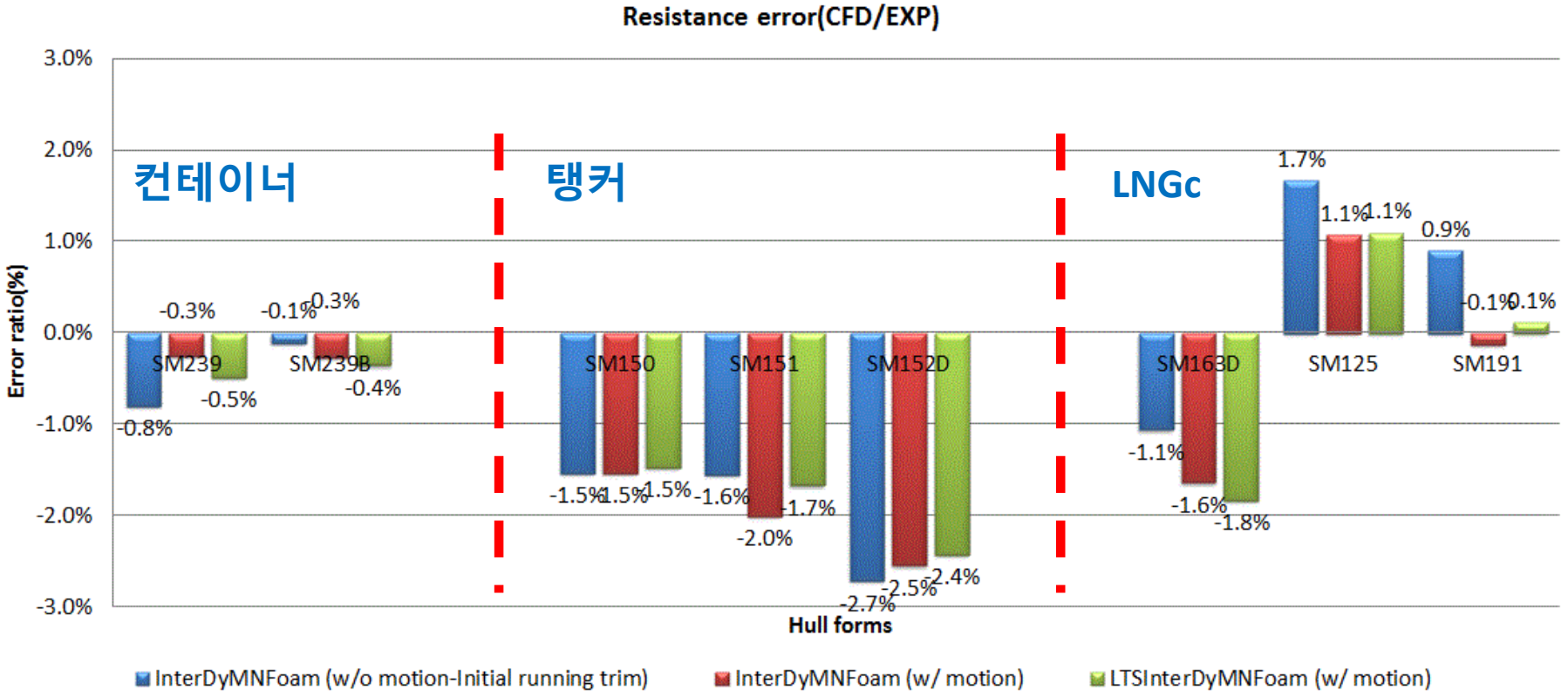




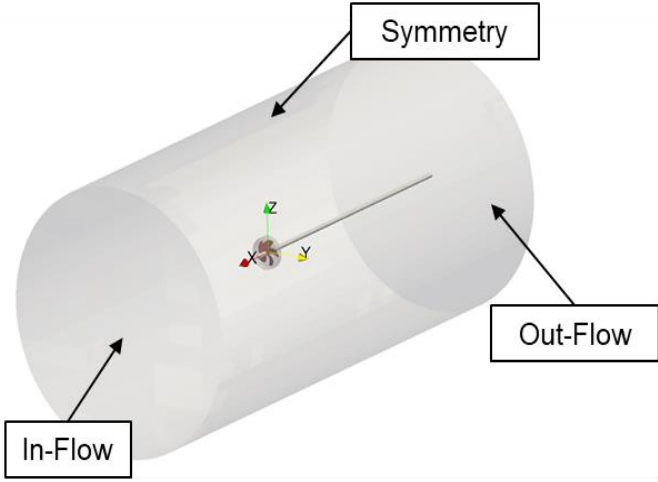
KVLCC2를 이용한 비교 :가속시간 : 10초

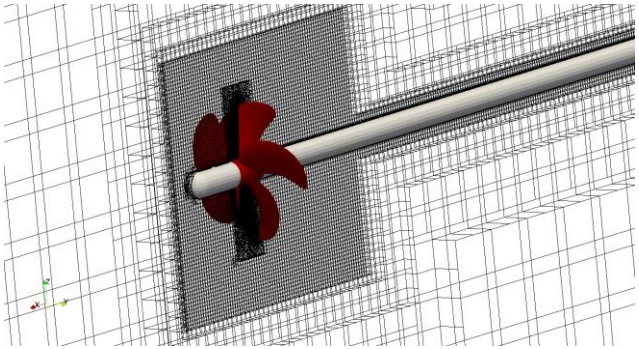
삼성중공업 저항해석 적용사례

- 총 8척
  - 컨테이너 2척, 탱커 3척, LNGc 3척

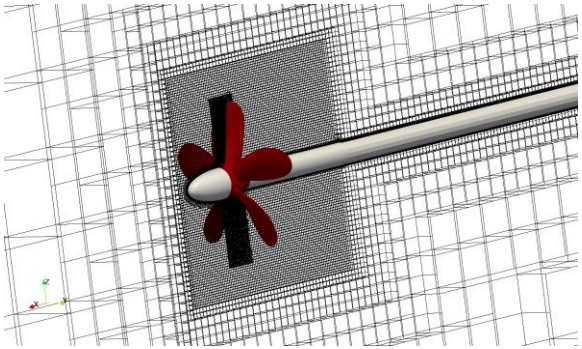


POW 해석

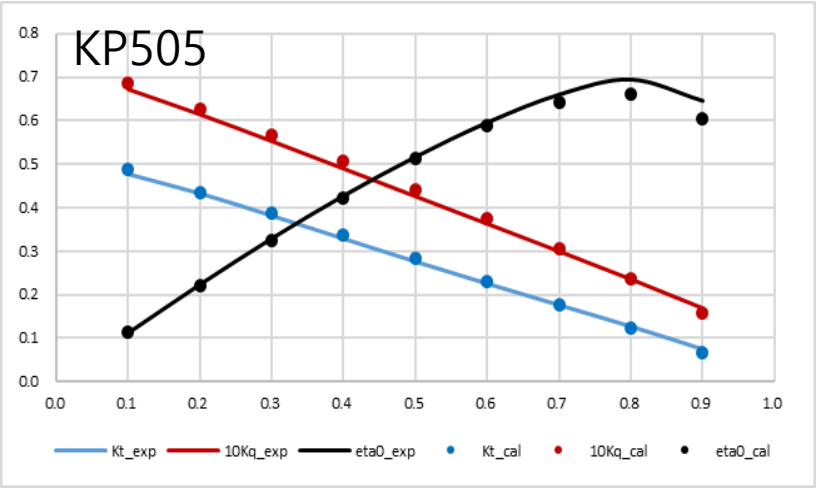


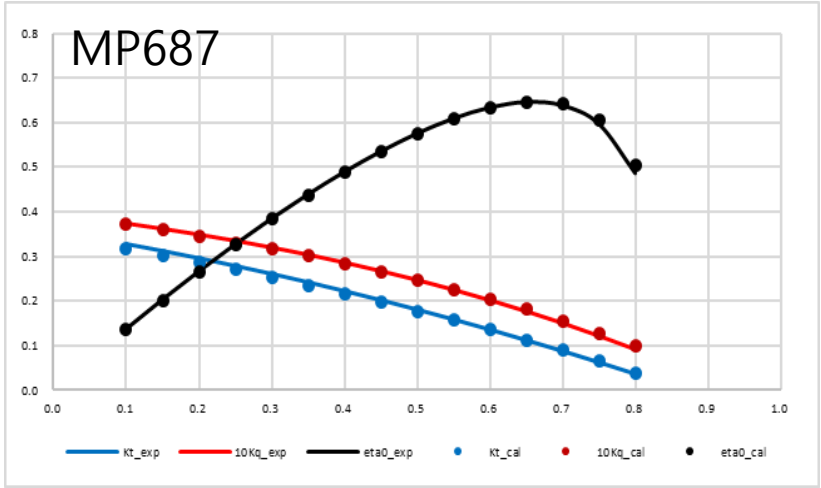


KP505



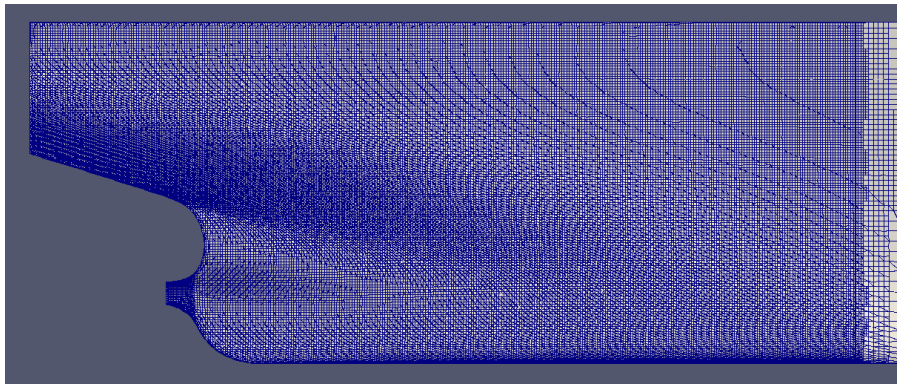
MP687

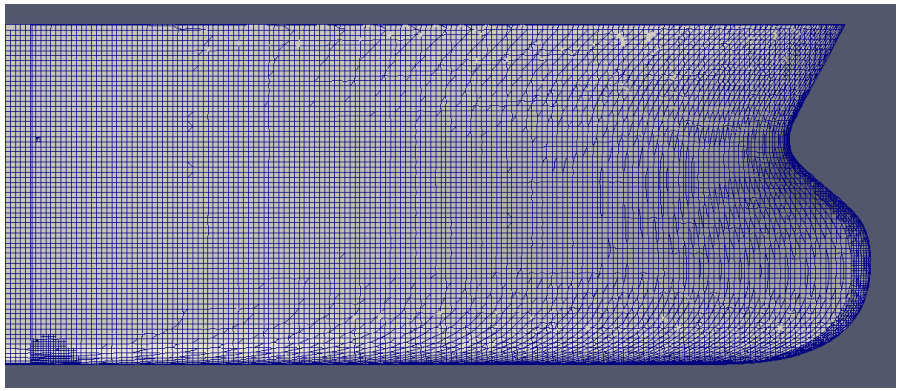


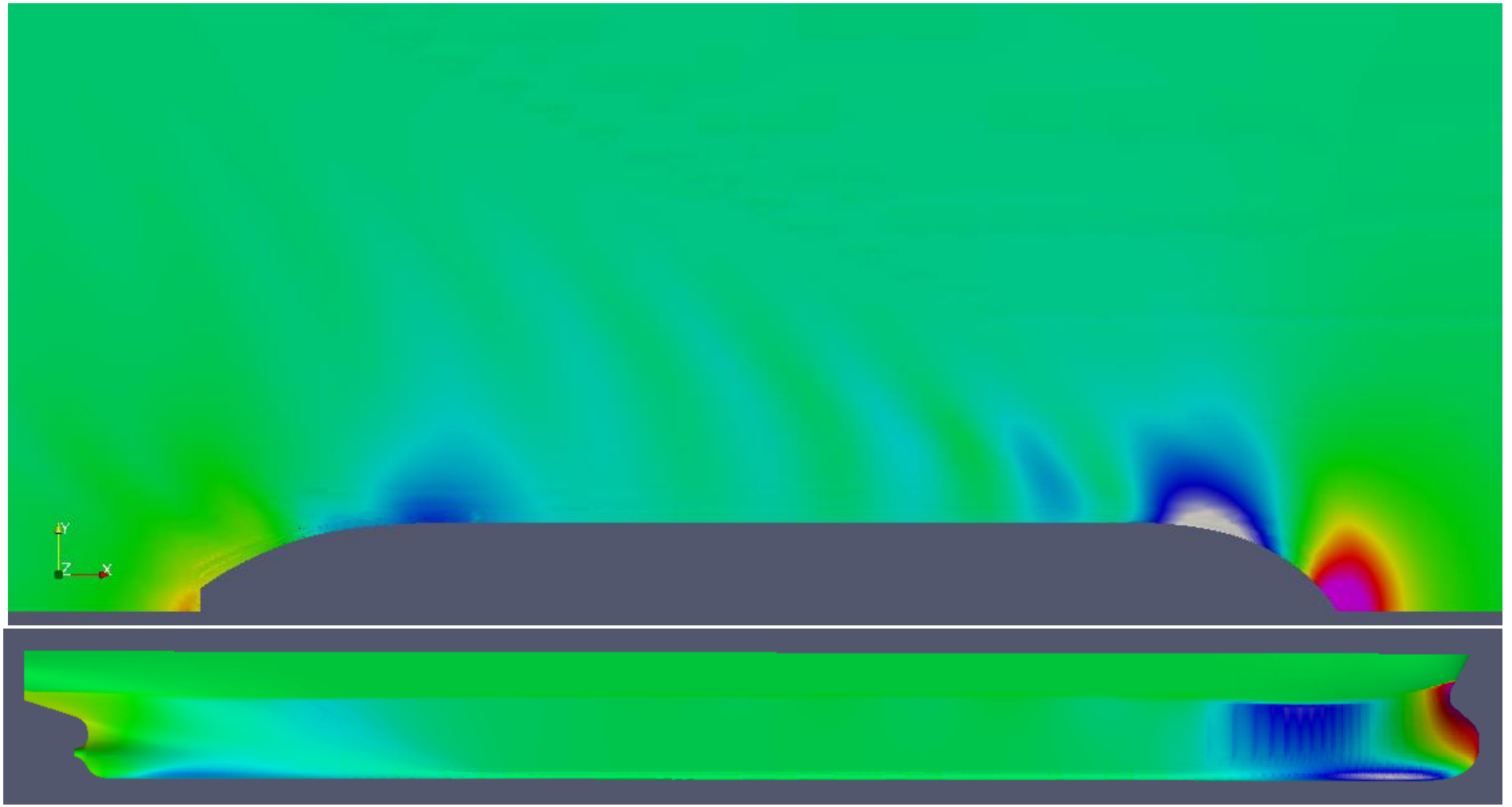


저항해석 – JBC 선형

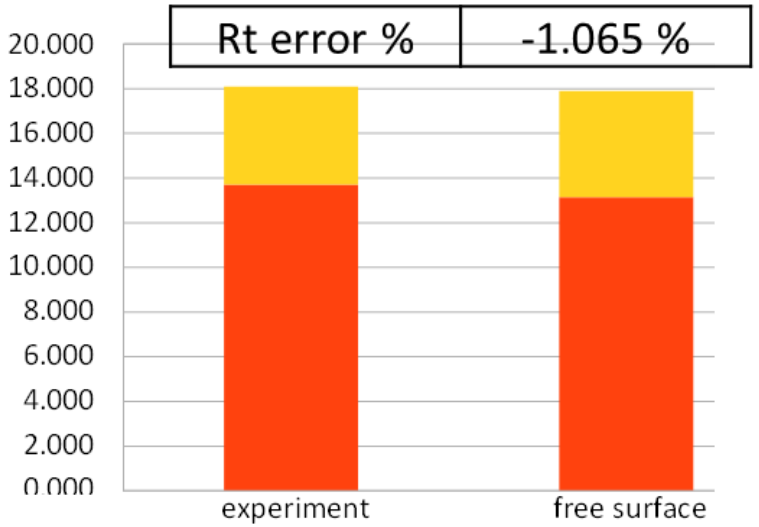
- 유동 해석 : With free surface, free running attitude
  - Re=6.5E+6
  - 시간간격 0.025sec

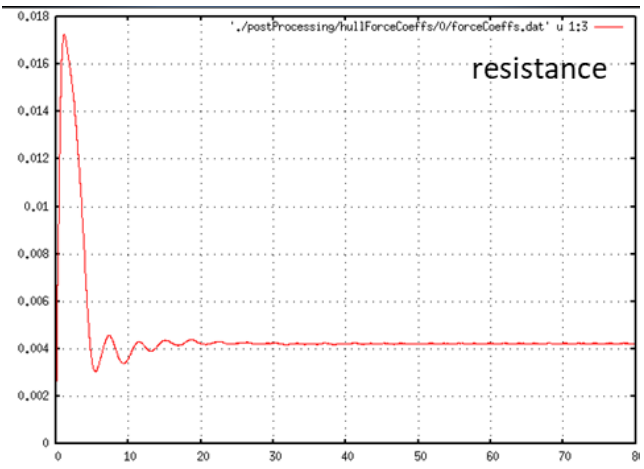


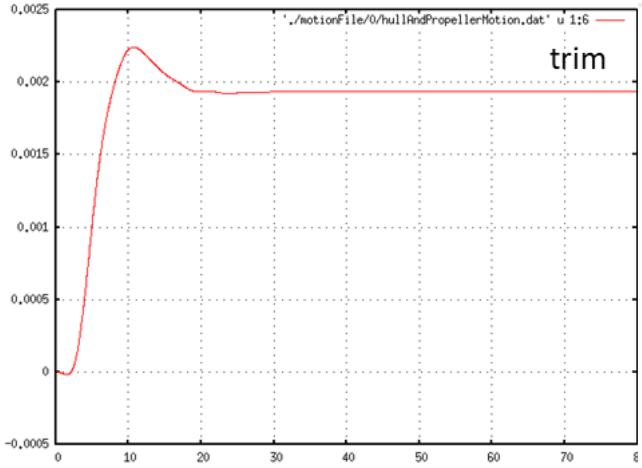


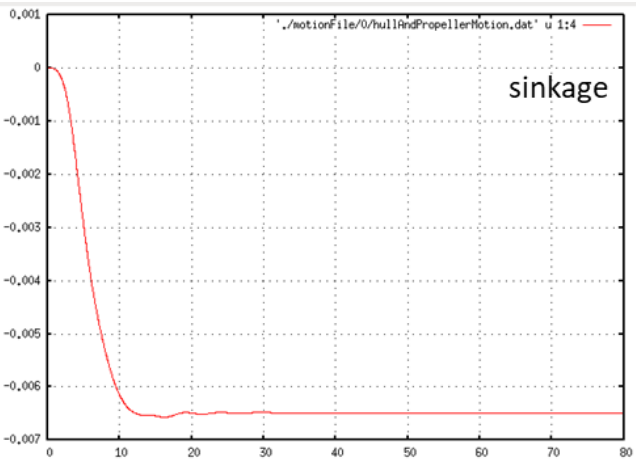

Y
Z
X

– 실험과의 저항값 비교 : 1.065% 오차
– 저항 값이 약 1.5% 진동함
  • 시간간격이 크기 때문에 수렴에 한계가 있음
    – dt=0.025초, CFL number = 약 95



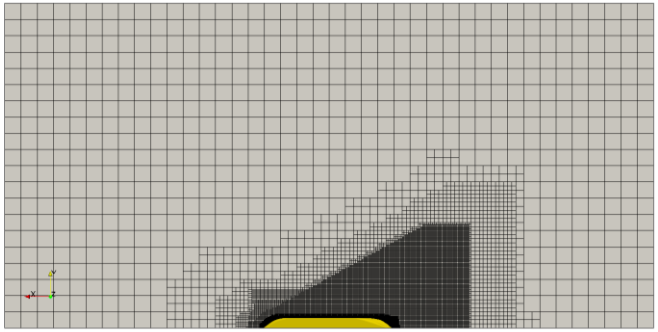


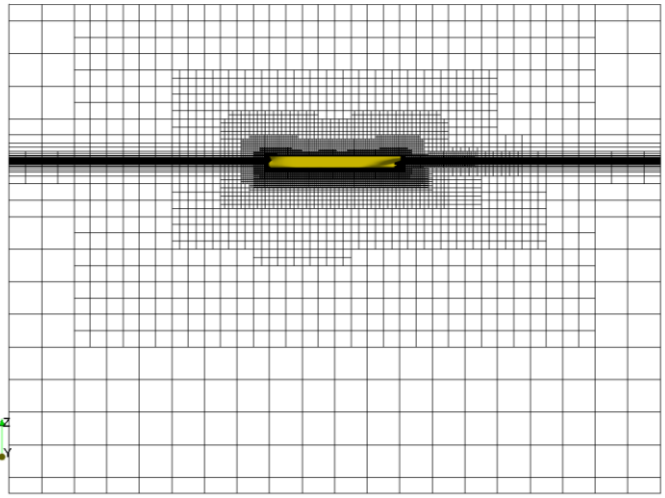




자항해석 – JBC 선형

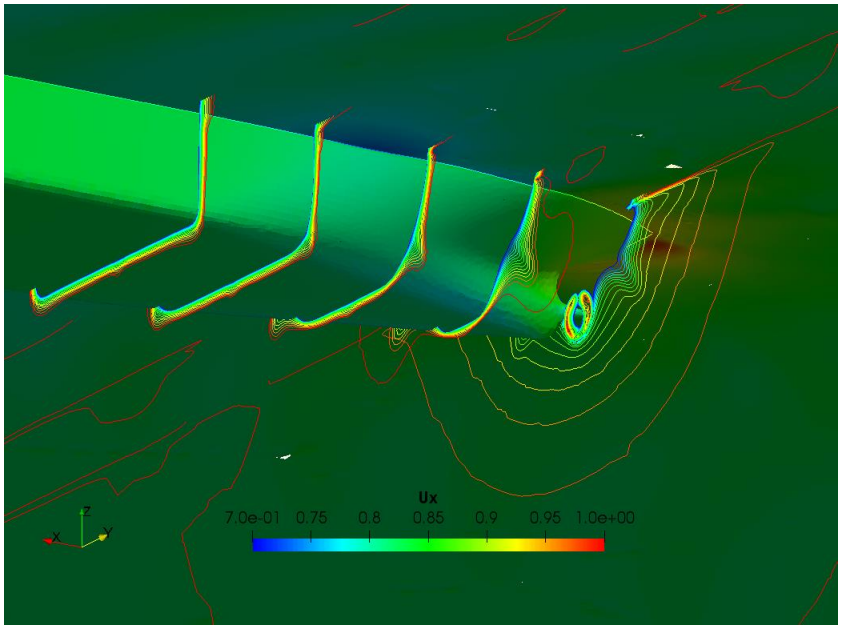
- 유동 해석 : With free surface, actuator disc
- 저항해석과 동일한 조건에서 자항해석
  - 동일한 격자, 수치기법, 시간간격



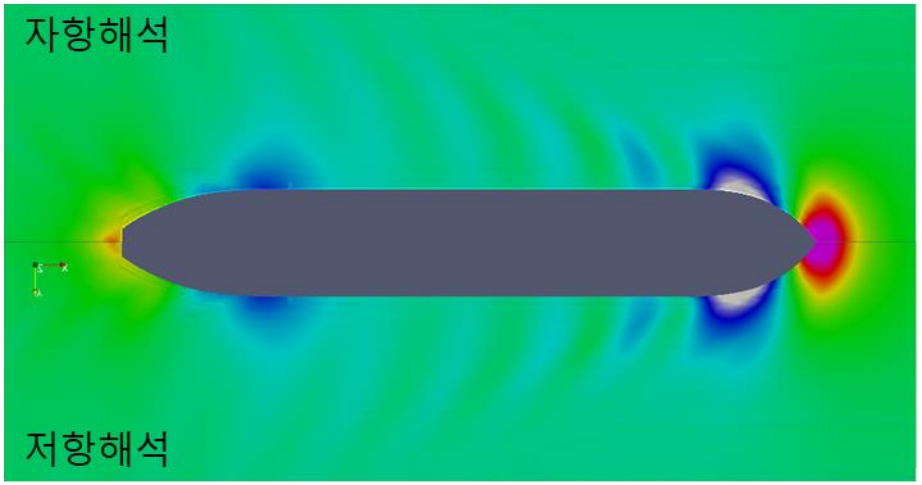


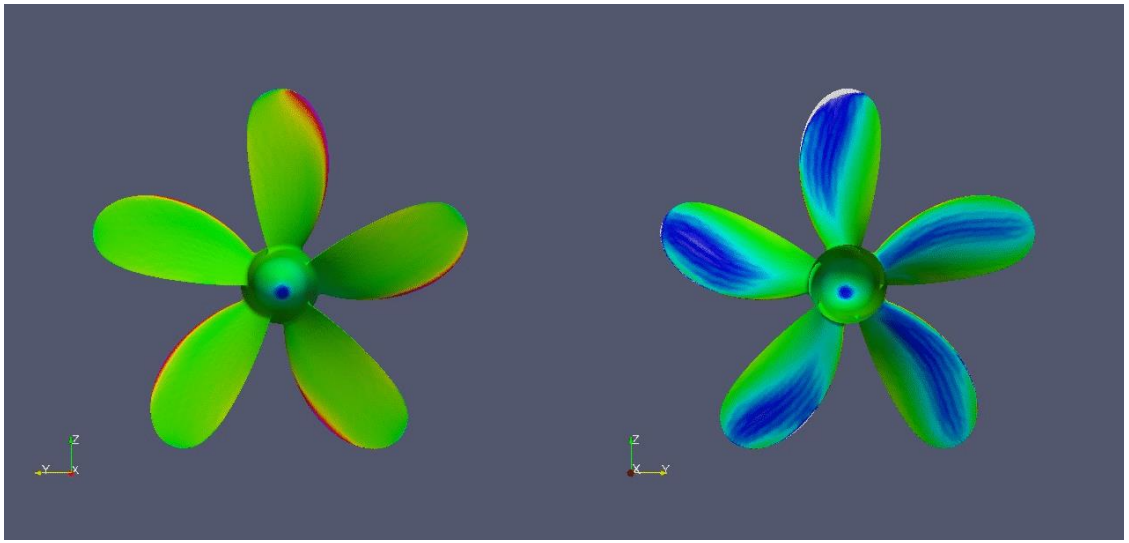
```
/*--------------------------------*- C++ -*----------------------------------*\
| =========                 |                                                 |
| \\      /  F ield         | OpenFOAM: The Open Source CFD Toolbox           |
|  \\    /   O peration     | Version:  2.4.x                                 |
|   \\  /    A nd           | Web:      www.OpenFOAM.org                      |
|    \\/     M anipulation  |                                                 |
\*---------------------------------------------------------------------------*/
FoamFile
{
    version     2.0;
    format      ascii;
    class       dictionary;
    object      virtualPropellerProperties;
}
// * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * //

        axisP1          (.12000000000000000000 0 .12955000000000000000);
        axisP2          (.08000000000000000000  0  .12955000000000000000);
        outerRadius     .10150000000000000000;
        innerRadius     .01750000000000000000;
        inflowDistance  .06400000000000000000;
        inflowRadius    .10353000000000000000;

        propellerRPS    7.0;

        Kt              polynomial ((0.2902 0) (-0.2641 1) (-0.1183 2) (-0.1217 3) (0.1153 4));
        Kq              polynomial ((0.0284 0) (-0.0246 1) (0.0146 2) (-0.0058 3) (0.0324 4));

        relaxFactor     1.05;
        UName           U;

// ************************************************************************* //
```

	Exp.	Present	Error
Total resistance (N)	40.844	41.344	1.22%
Frictional resistance (N)	26.818	26.783	-
Pressure resistance (N)	14.025	14.561	-
Thrust Coefficient, K_T	0.217	0.216	-0.24%
Torque Coefficient, K_Q	0.0279	0.0282	1.23%
Skin Friction Correction (N)	18.2	19.0	4.24%



- 유동 해석 : With free surface, rotating propeller
  - MRF 해석 후 Sliding mesh 해석



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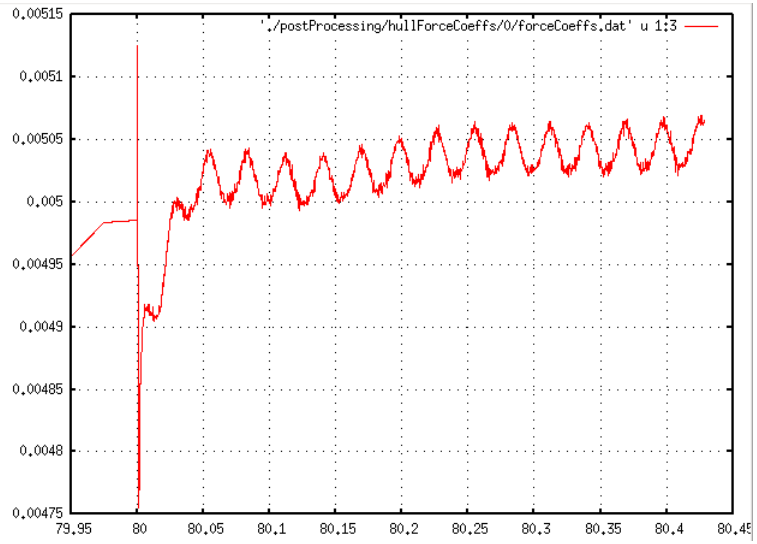
Hull resistance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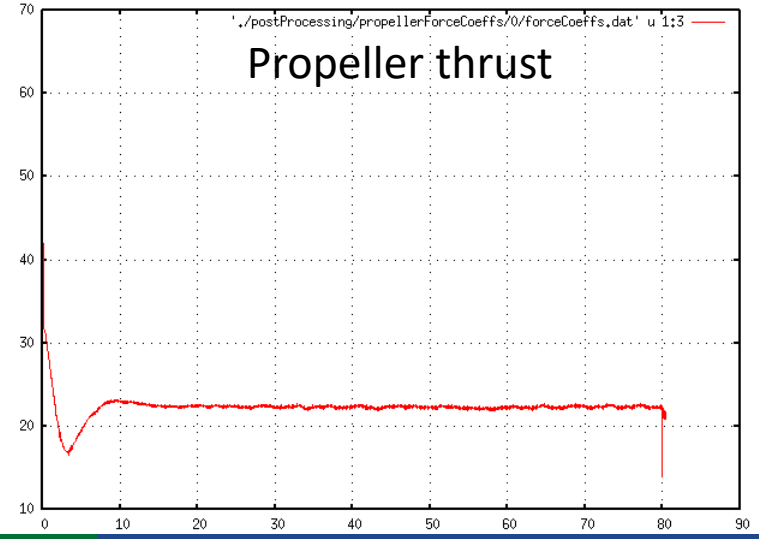
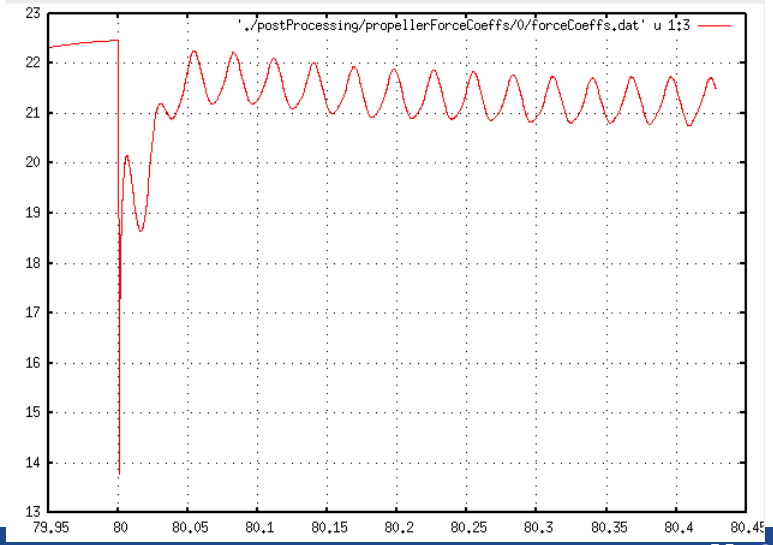

'./postProcessing/propellerForceCoeffs/0/forceCoeffs.dat' u 1:3
Propeller thrust


'./postProcessing/propellerForceCoeffs/0/forceCoeffs.dat' u 1:3

– 실험결과와 비교

- JBC
- Ship speed : 1.1793 m/s, propeller RPS : 7.8

	Exp.	Present	Error
Total resistance (N)	40.844	42.95	5.18%
Frictional resistance (N)	26.818	26.43	-
Pressure resistance (N)	14.025	16.52	-
Thrust Coefficient, K_T	0.217	0.229	5.43%
Torque Coefficient, K_Q	0.0279	0.0290	4.08%
Skin Friction Correction (N)	18.2	19.3	6.27%

고속선 – 계산조건

- 저항해석
  - 축척비 : 1/12 (모형크기)
  - 속도 : 3.712 m/s (모형), 25 knots (실선)
  - 2가지 조건에서 계산 : even keel, trim -0.369 m (heave, pitch 자유)

- POW 해석
  - 축척비 : 1:1 (실선크기)
  - 전진비 : 0.65~1.00

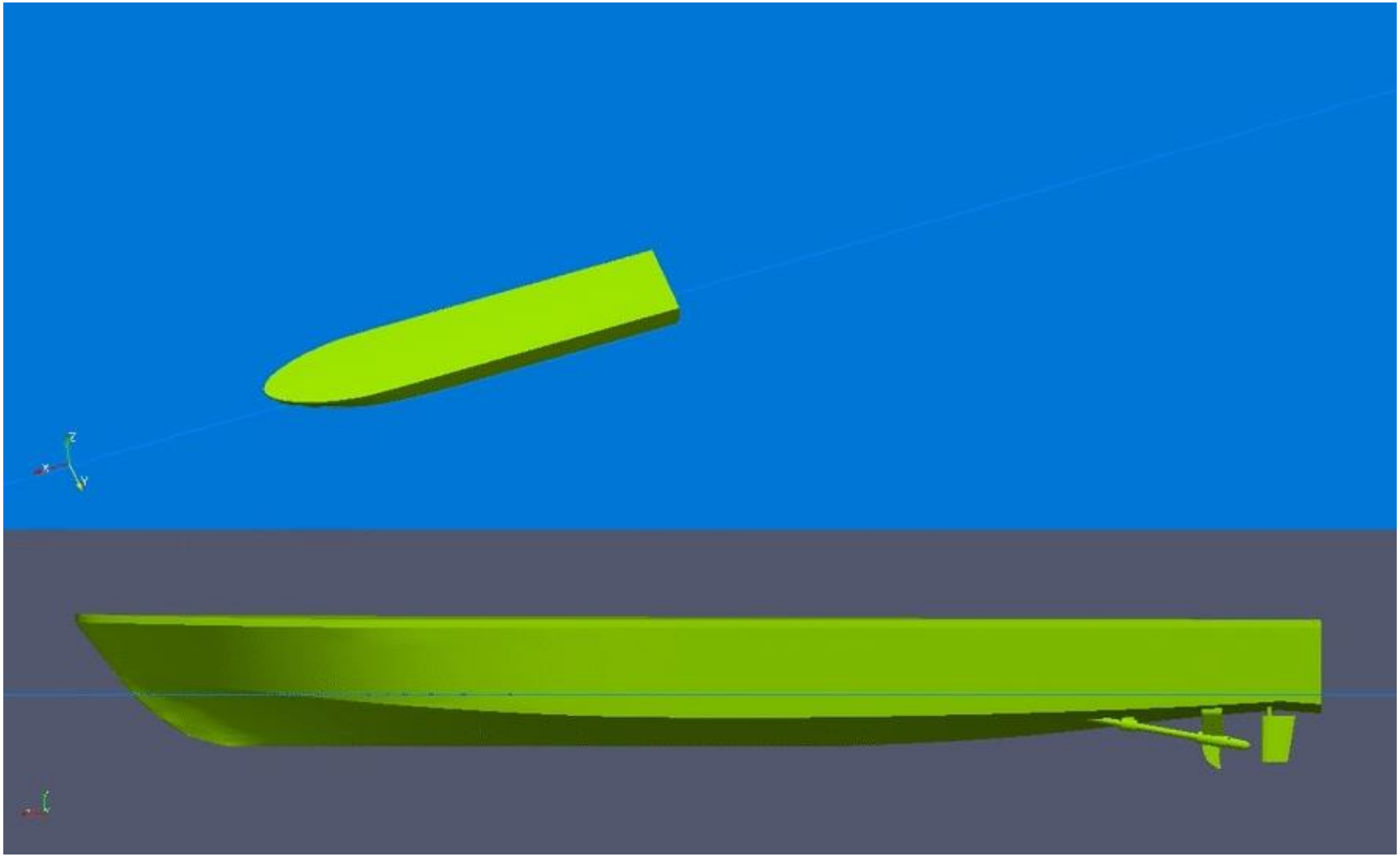
- 자항해석
  - 축척비 : 1:1 (실선크기
  - 속도 : 25 knots
  - 2가지 조건에서 계산 : even keel, trim -0.369 m (heave, pitch 자유)
    - Even keel : 1000 RPM, 1030 RPM
    - Trim -0.369 m : 990 RPM, 1010 RPM

고속선 – 해석 결과(저항)

	Even keel		Trim -0.369m	
	Experiment	Calculation	Experiment	Calculation
R_{TM} (N)	47.7	47.6	44.4	43.6
R_{FM} (N)	17.3	21.4	17.4	19.7
R_{PM} (N)	30.4	26.2	27.0	23.8
$C_{TS\ (Ca=0.4e-3)}$	8.01	8.00	7.43	7.27
R_{TS} (N)	74.4	74.3	68.5	67.1
Trim (deg)	1.43	1.20	2.89	4.70
Sinkage (m)	0.27	0.06	-0.014	-0.003

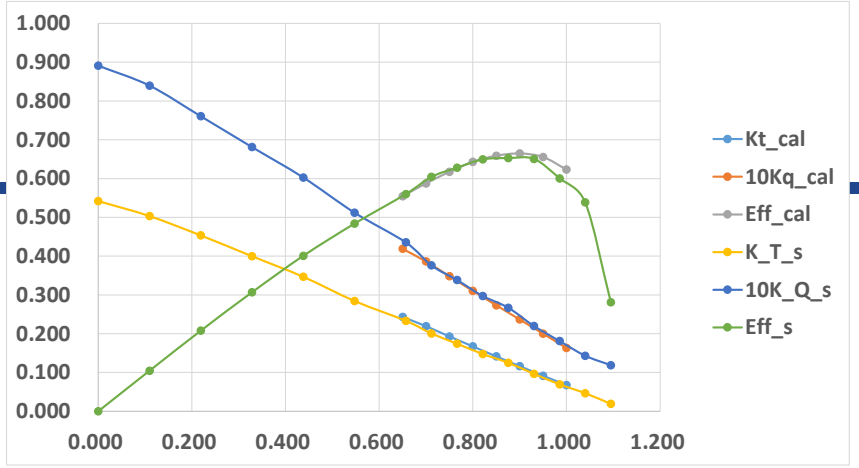
- 저항해석 오차
  - 저항 : 1.8 %
  - Trim : 1.8 deg
  - Sinkage : 0.21 m

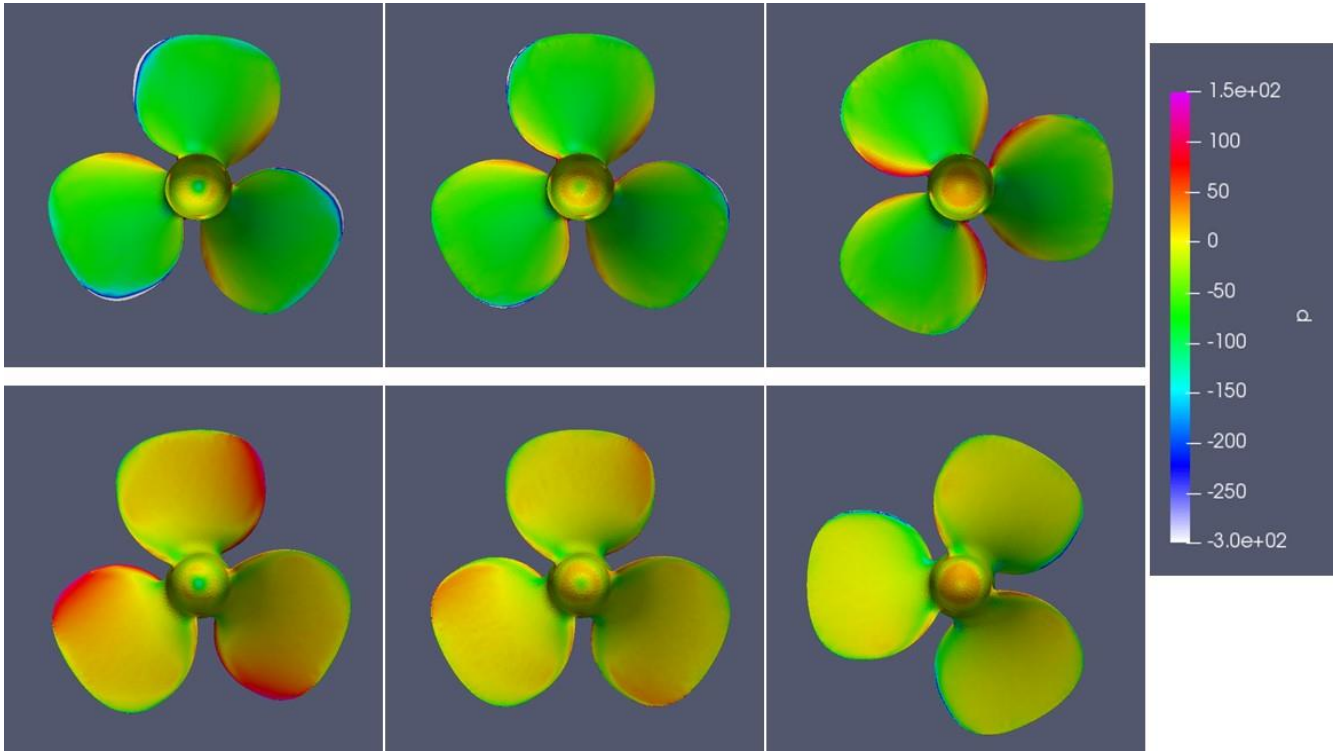
- Even keel



고속선 – 해석결과(POW)

- 수치해석 결과
  - POW 해석 오차 : 약 5%





J=0.75 J=0.85 J=0.95

고속선 – 해석결과(자항)

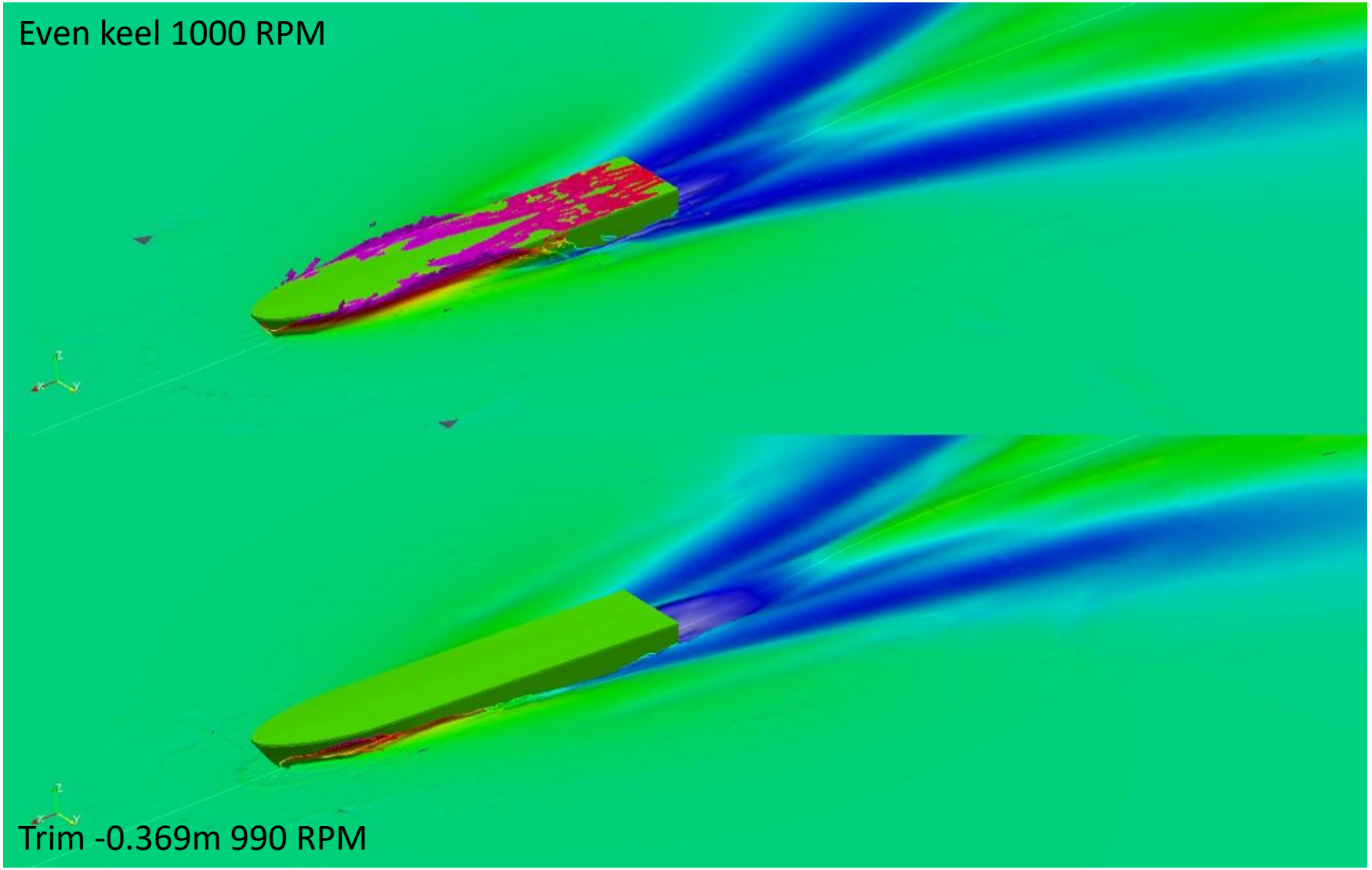
– 자항성분

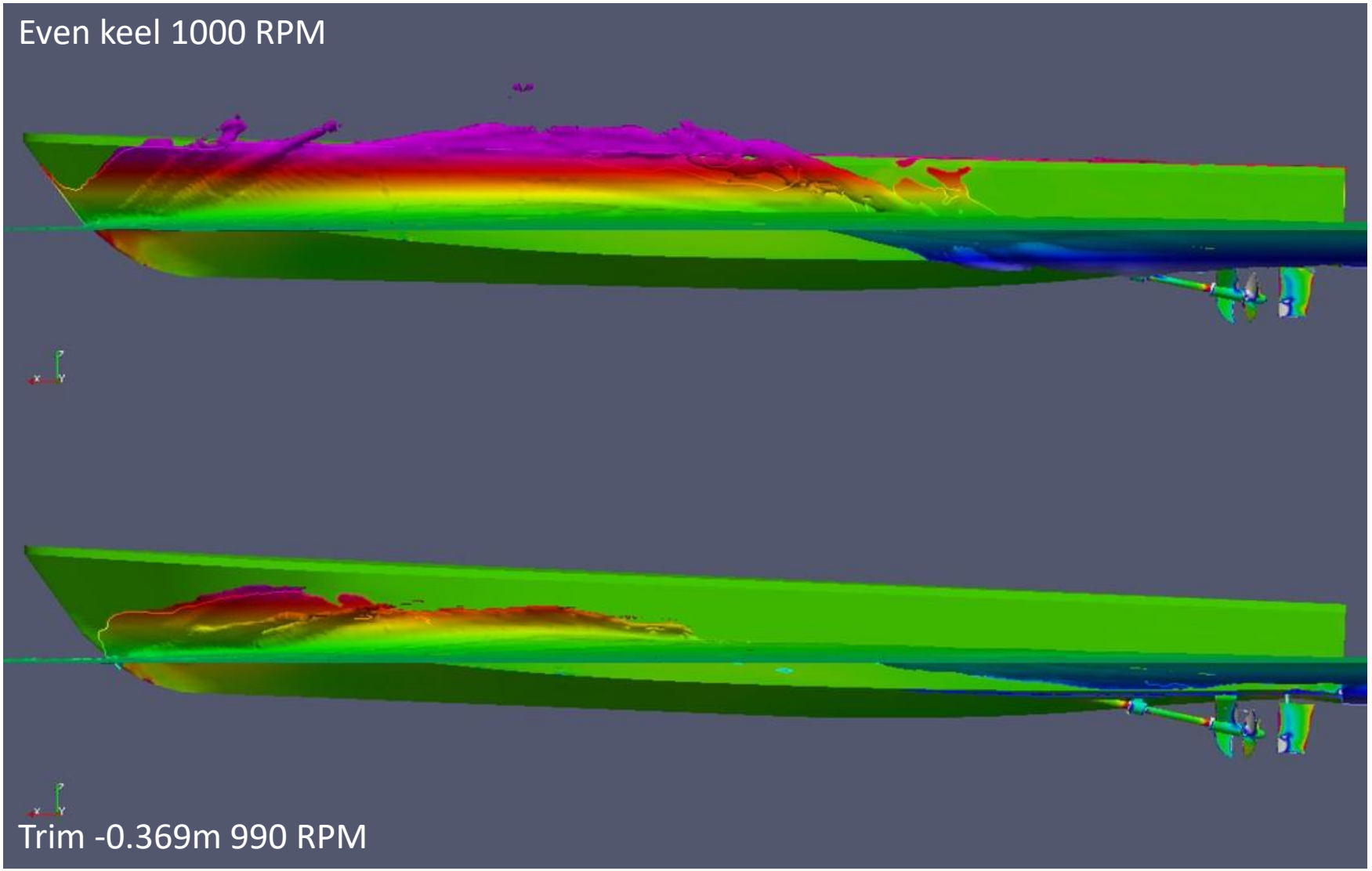
	η_H	η_R	η_0	η_D
Even keel	0.947	0.991	0.644	0.604
Trim -0.369m	0.946	0.983	0.647	0.602

$$\eta_D = \eta_H \times \eta_R \times \eta_0$$

$$\eta_H = \frac{1-t}{1-w} \qquad \eta_R = \frac{Q_0}{Q} \qquad \eta_0 \text{ from POW test}$$

	J_v	J_a	w	t	$Q_0(\mathrm{Nm})$	$Q\ (\mathrm{Nm})$
Even keel	0.795	0.789	0.0076	0.0605	7135	7200
Trim -0.369m	0.817	0.806	0.0135	0.0666	6400	6509


Even keel 1000 RPM
Trim -0.369m 990 RPM


Even keel 1000 RPM
Trim -0.369m 990 RPM

- 1000 RPM even keel condition